E.3 Space Planes and Space Shuttles

[In addition to the winged A-9 rocket, an even larger winged manned space vehicle capable of reaching New York was the Silbervogel (Silver Bird) prototype space shuttle designed by Dr. Eugen Sänger and Dr. Irene Bredt (who later married). A rocket-powered catapult sled on a 3 km long earthbound track would essentially serve as the first stage, and the rocket-powered Silbervogel would effectively be the second stage. The Silbervogel is relatively well known in the published literature [e.g., Griehl 2005 Vol. 2 and Myhra 2002], which tends to describe it as purely a paper design project that never found political and financial support for actual development and testing. For example, aerospace historian Manfred Griehl stated: "Since creation of such a dreadful project was pure fantasy in the 1940s, theoretical research work was halted and Professor Sänger himself was reassigned..." [Griehl 2005 Vol. 2 p. 329].

In contrast, several pieces of evidence suggest that major parts of the Silbervogel system were actually built and even tested; evidence also demonstrates the extensive influence of German-speaking scientists on the development of postwar space planes and space shuttles:

- Eugen Sänger and Irene Bredt completed and submitted a 900-page proposal giving details of the Silbervogel design and development program to the German government in 1941 [Myhra 2002].

- Wind tunnel models of Silbervogel are known to have been constructed and tested (p. 5138).

- At least one photograph exists of a full-sized Silbervogel engine that had been constructed for testing no later than 1944 (p. 5139).

- In January 1946, five Canadian aerospace experts reported that while visiting a German research station, they viewed "a rocket motor 10 times larger than those used on V-2s." That description could match either the Silbervogel motor or the A-10 booster rocket motor (p. 5015).

- Detailed orbital calculations were performed in 1944 to find the best trajectory for the Sänger-Bredt vehicle to reach New York (pp. 5140–5142).

- An article published in the 30 October 1944 *Daily Mail* reported that the Germans in occupied France had been constructing a "huge ramp" that was "intended as a launching place for flying bombs, which... would wreck New York." The size of the ramp, the reference to flying bombs, and the claimed target of New York seem consistent with the Silbervogel launch catapult (p. 5143).

- U.S. Army Air Forces Colonel Donald Putt, in charge of overseeing all German rocket scientists and related equipment and information rounded up at the end of the war, reported in March 1946: "Test model was made that carried one man and had landing gear, although it is not known if this model ever flew; it is known, however, that test runs were made on its engine."

Thus according to an authority with arguably the best access to the available information, the Silbervogel engine was constructed and tested, a Silbervogel vehicle complete with cockpit and landing gear was constructed, its engine was operational, and postwar U.S. officials were left wondering if flight tests of the Silbervogel may have even been conducted (p. 5144). What German witnesses and documents was this information based on? What became of the prototype Silbervogel vehicle—was it destroyed by the Germans, removed by the Americans, or removed by the Soviets?

- A lengthy and detailed October 1946 article in *Harper's Magazine* stated that the Silbervogel system "was never completed merely because of the war's quick ending" (p. 5035).

- A 1957 U.S. Air Force report stated: "The boost-glide concept was... partially tested by the Germans in the early 1940's" (p. 5146).

- Wernher von Braun and other German-speaking engineers published detailed descriptions and illustrations of a space plane in 1952 in *Collier's* magazine, in order to try to excite U.S. public interest and government funding for such a project [*Collier's* 1952-03-22].

- In 1946, Walter Dornberger began work on the Bell Aerospace GAM-63 RASCAL air-launched cruise missile, a large liquid propellant rocket with wings designed for long-range horizontal flight (p. 1847). In 1952, Dornberger led the Bell Aerospace team that proposed the Bomi (Bomber Missile) space plane, which was heavily based on the wartime Silbervogel designs—see p. 1925. In 1954, Dornberger's team designed the X-15 rocket plane, which had many similarities to the wartime manned A-9 designs [Käsmann 2013, p. 105]. After the Bomi proposal was rejected, Dornberger was instrumental in recycling the Bomi and Silbervogel designs to create the X-20 Dyna-Soar space plane; a prototype was built but the program was cancelled in 1963 [Robert Godwin 2003].

- Hans Multhopp (German, 1913–1972) designed the Martin Marietta X-24 lifting body, which first flew in 1969 [R. Dale Reed 1997, pp. 129–130, 136]; see pp. 1926 and 5155.

- In 1965, Walter Dornberger named the newest U.S. space plane program the "Space Shuttle" [Dornberger 1965a, 1965b].

- The U.S. Space Shuttle (Fig. 9.224) incorporated design features, experience, and personnel from the earlier A-9, Silbervogel, Bomi, Dyna-Soar, and X-24 space plane programs [Winter 1990, pp. 42–44, 113–122]; see pp. 5151 and 5153.

- Adolf Busemann (German, 1901–1986) suggested ceramic tiles for thermal insulation on the Space Shuttle, and also contributed his detailed knowledge of hypersonic aerodynamics and heating for the design and reentry [NYT 1986-11-05]; see p. 5154.

- Krafft Ehricke (German, 1917–1984) was deeply involved in space plane projects from Bomi to the Space Shuttle [Freeman 2008].

- The Space Shuttle Main Engines (SSMEs) were directly derived from engine designs with especially high combustion chamber pressures that were developed during and after the war (such as the MBB P111 engine and the Rocketdyne HG-3 engine) by Klaus von Riedel, Karl Stöckel, Hans Georg Paul, Dieter Huzel, and other German-speaking engineers (see pp. 5156–5160).

- The Space Shuttle Solid Rocket Boosters (SRBs) were based on enormous German-speaking contributions to solid propellant rockets (see Sections 9.8 and E.4).

Thus the Silbervogel and the manned winged A-9, as well as the German-speaking scientists who worked on them, led directly to postwar space plane programs such as the X-20 Dyna-Soar, the U.S. Space Shuttle (first launched in 1981, Fig. 9.224), the Soviet Buran (first launched in 1988, Fig. 9.226), and other space planes such as Dream Chaser (Fig. 9.227) [Chertok 2005–2012, Vol. 1, pp. 262–265; Winter 1990, pp. 42–44, 113–122].

Much more archival research on the wartime and postwar development of space planes by German-speaking scientists is necessary.]

Eugen Sänger and Irene Bredt. 1944. *Über einen Raketenantrieb für Fernbomber.* UM 3538. Ainring: Deutsche Luftfahrtforschung. English translation 1952. *A Rocket Drive for Long Range Bombers.* CGD-32, C-84296. Technical Information Branch, Buaer Navy Department. pp. 148, 152.

As an example of area attack with single propulsion and full turn, we use the attack on New York at a range of 6500 km. For c=4000 m/sec, the bomb load is 6 tons, and the detailed attack runs as follows: the motor starts to work 36 seconds after the take-off at 12 km. distance from the take-off point, and consumes the total fuel supply of 84 tons in the next 336 sec. At the end of the climb process, the aircraft reaches a velocity of 6370 m/sec, an altitude of 91 km, a distance of 736 km. from the point of take-off, and a weight of 16 tons. Using only its store of potential and kinetic energy, the bomber flies on to the point of bomb release, 5550 km. from the take-off point, and 950 km. in front of the target. At this point, which is reached 1150 sec. after take-off, the velocity has decreased to 6000 m/sec, and the stationary altitude to 50 km. After the bomb release the weight is 10 tons. Then the aircraft goes into a turn and in 330 sec. goes through a turn-spiral 1000 km. in diameter until it has reached the direction for the return flight to the home base. During turning, the altitude is greatly decreased in order to develop the aerodynamic forces necessary for the turn. At the end of the turn path, the velocity is still 3700 m/sec. and the corresponding stationary altitude is 38 km. The supersonic glide-path in the direction of the home base goes over 5450 km. in 2600 sec. and ends 100 km. before the home base at an altitude of 20 km. and velocity 300 m/sec. Subsonic glide and landing are completed in customary fashion. The whole flight lasts 4755 sec.

Figure E.170: Dr. Irene Bredt and Dr. Eugen Sänger (circa 1945).

TRANSLATION CGD-32

A ROCKET DRIVE FOR LONG RANGE BOMBERS

(Über einen Raketenantrieb für Fernbomber)

by

E. Sänger and J. Bredt

Ainring, August 1944

Deutsche Luftfahrtforschung

UM 3538

Translated by M. HAMERMESH
RADIO RESEARCH LABORATORY

Reproduced by
TECHNICAL INFORMATION BRANCH
BUAER NAVY DEPARTMENT

C– 84296

Figure E.171: English translation of Eugen Sänger and Irene Bredt. 1944. *Über einen Raketenantrieb für Fernbomber.* UM 3538. Ainring: Deutsche Luftfahrtforschung [Saenger and Bredt 1944, English translation].

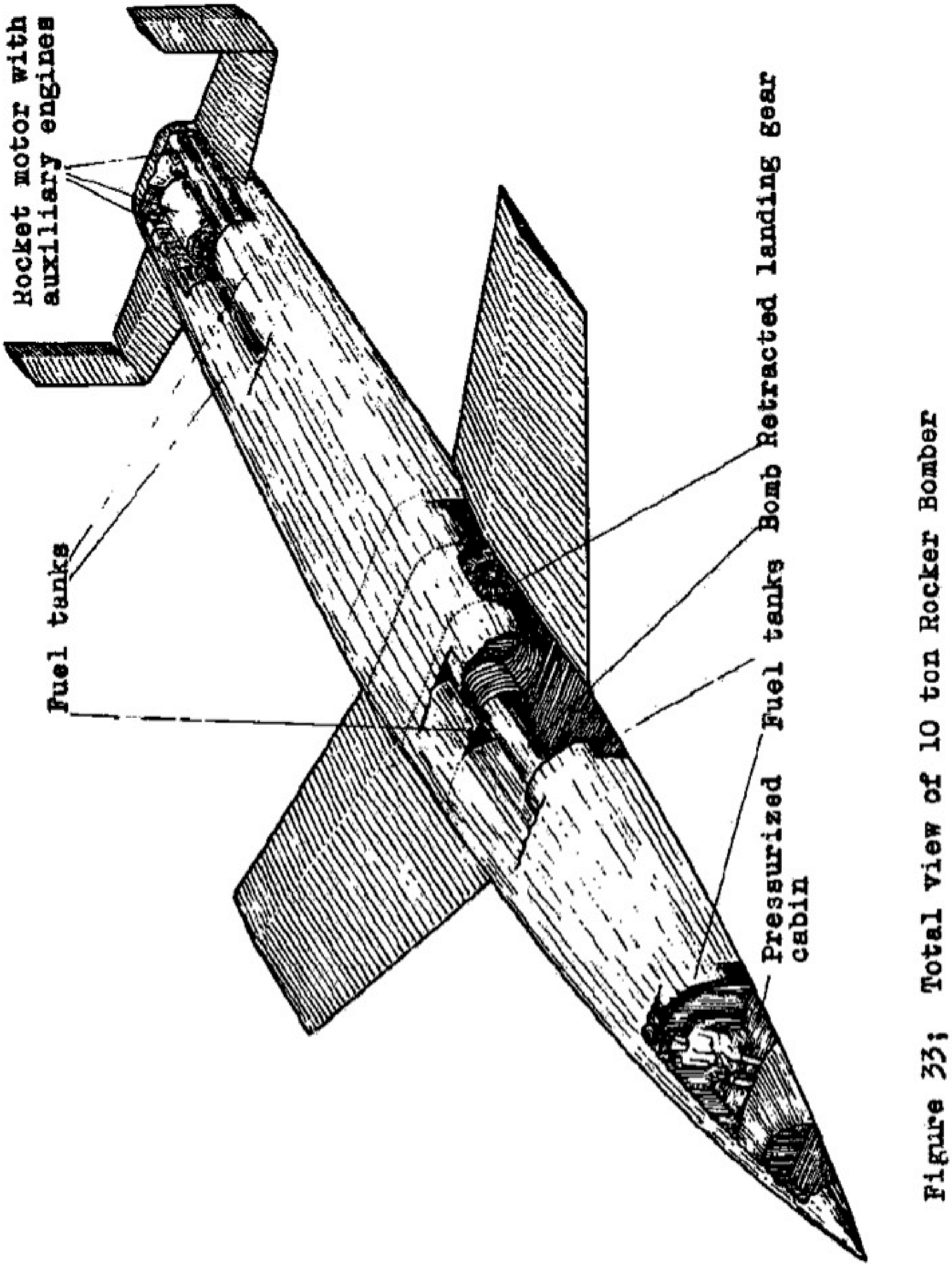


Figure E.172: Silbervogel space plane: design of the vehicle [Saenger and Bredt 1944, English translation].

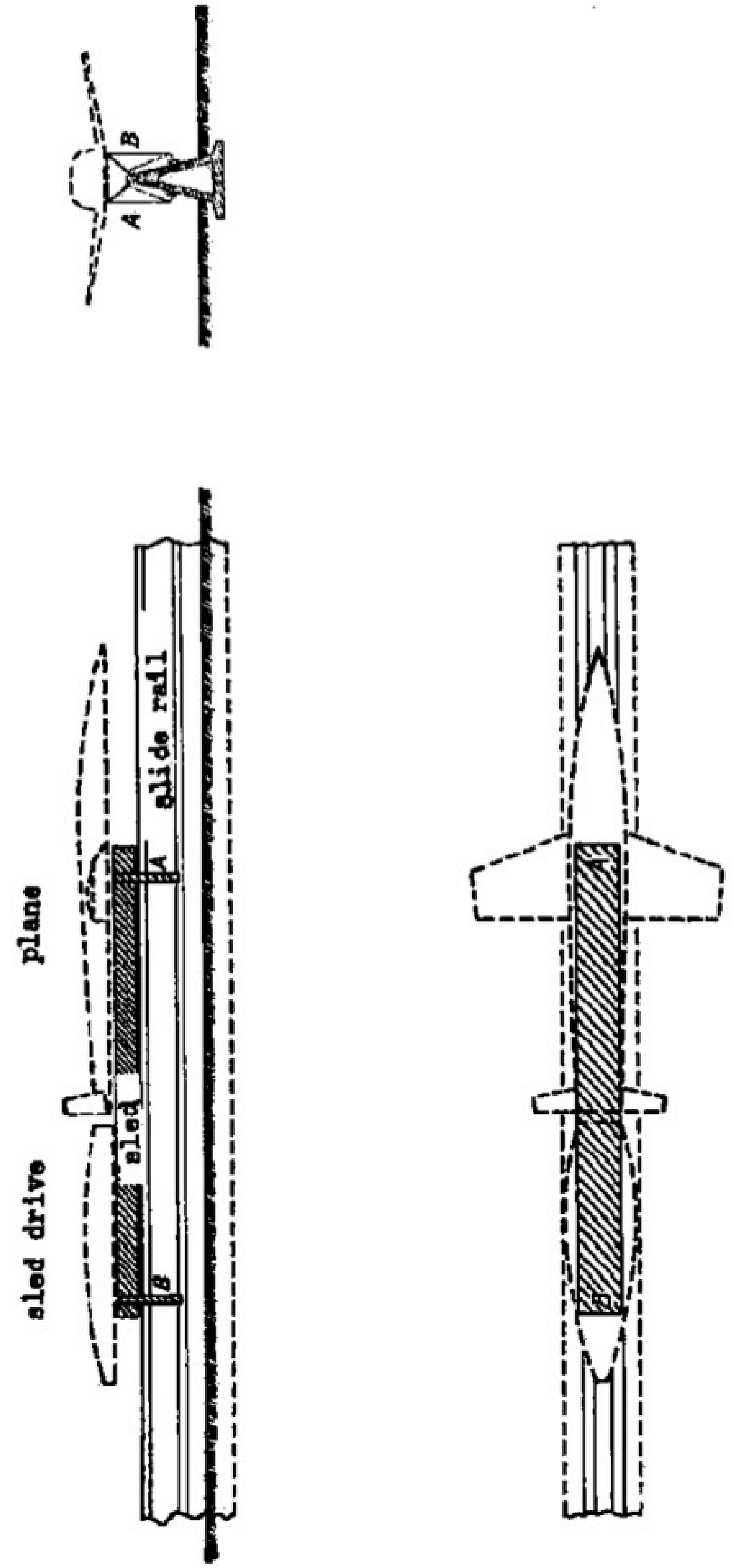


Figure E.173: Silbervogel space plane: design of the booster sled and track [Saenger and Bredt 1944, English translation].

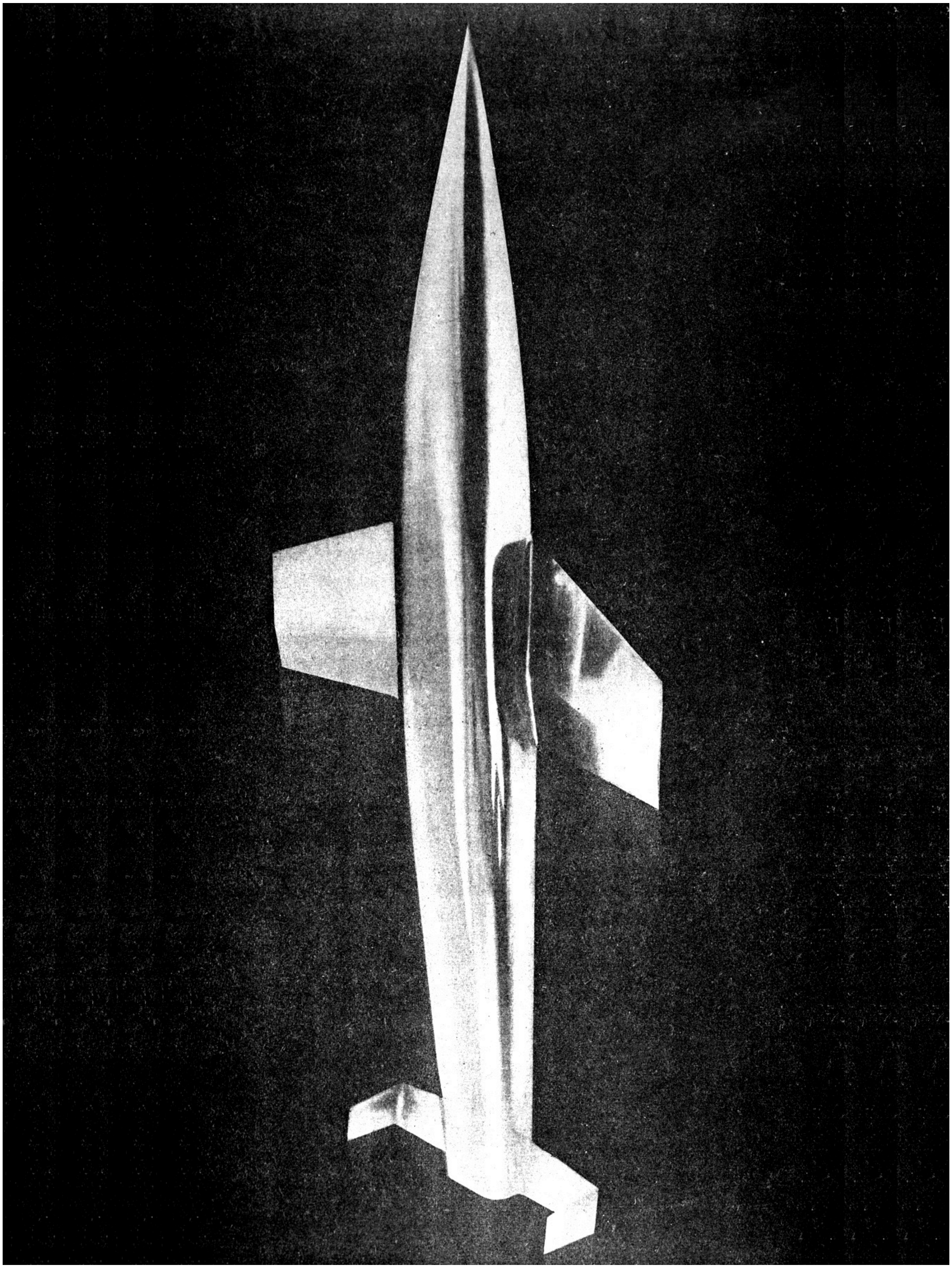


Figure E.174: Silbervogel space plane: wind tunnel model [Deutsches Museum Archive, photo 30394].

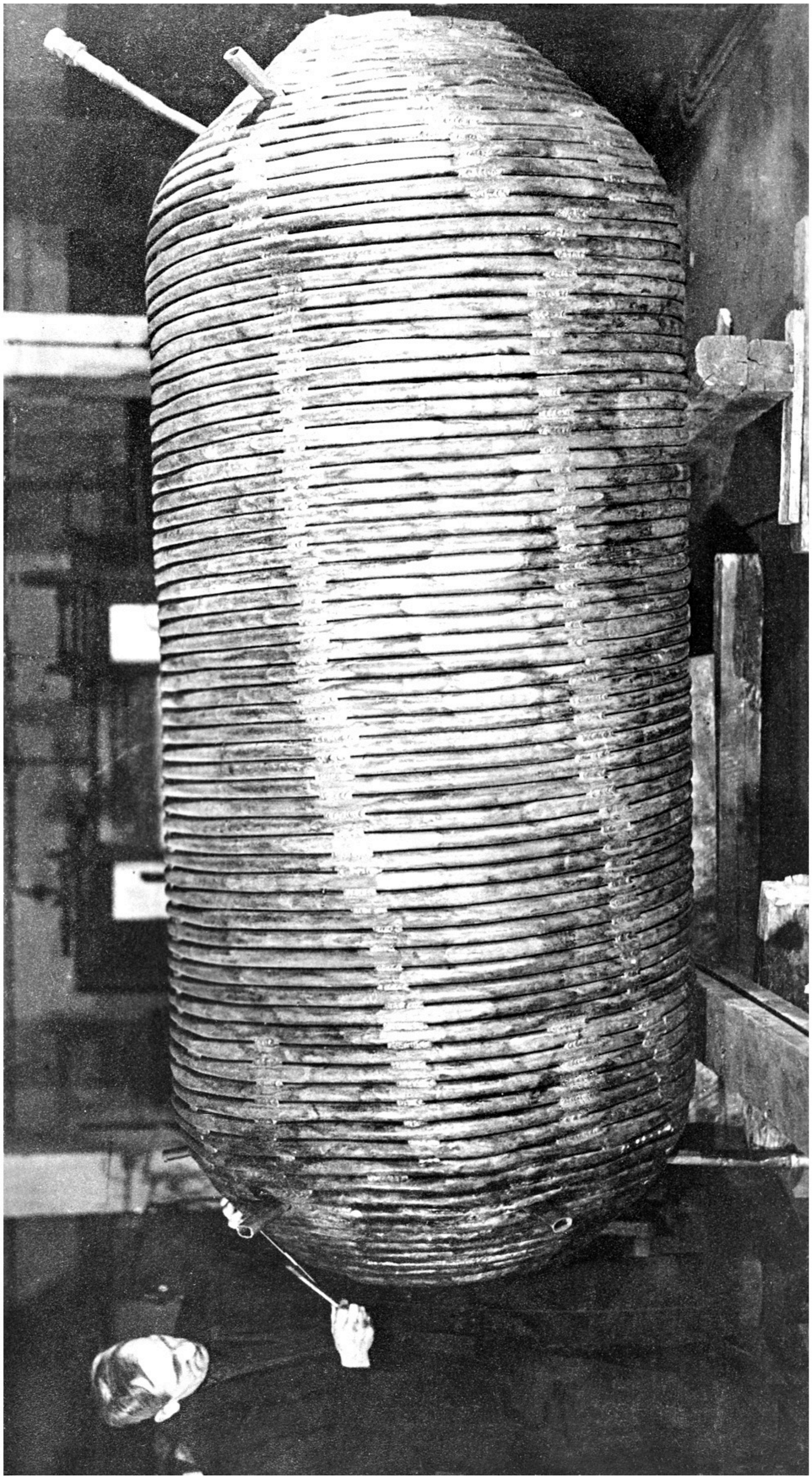


Figure E.175: Silbervogel space plane: construction of prototype 100-ton rocket engine in 1941 [Deutsches Museum Archive, photo 30391].

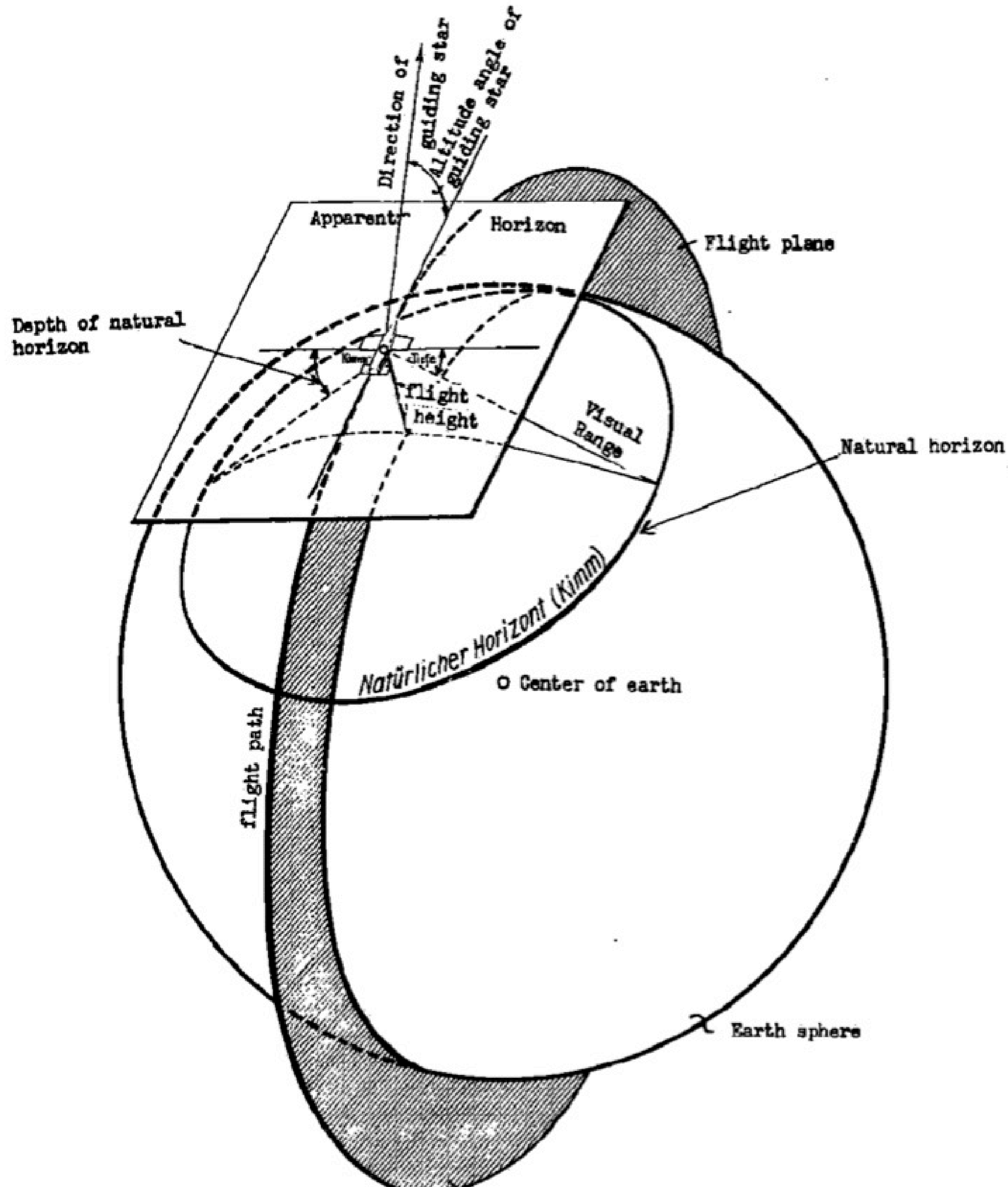


Figure E.176: Silbervogel space plane: calculated orbital trajectory of the vehicle [Saenger and Bredt 1944, English translation].

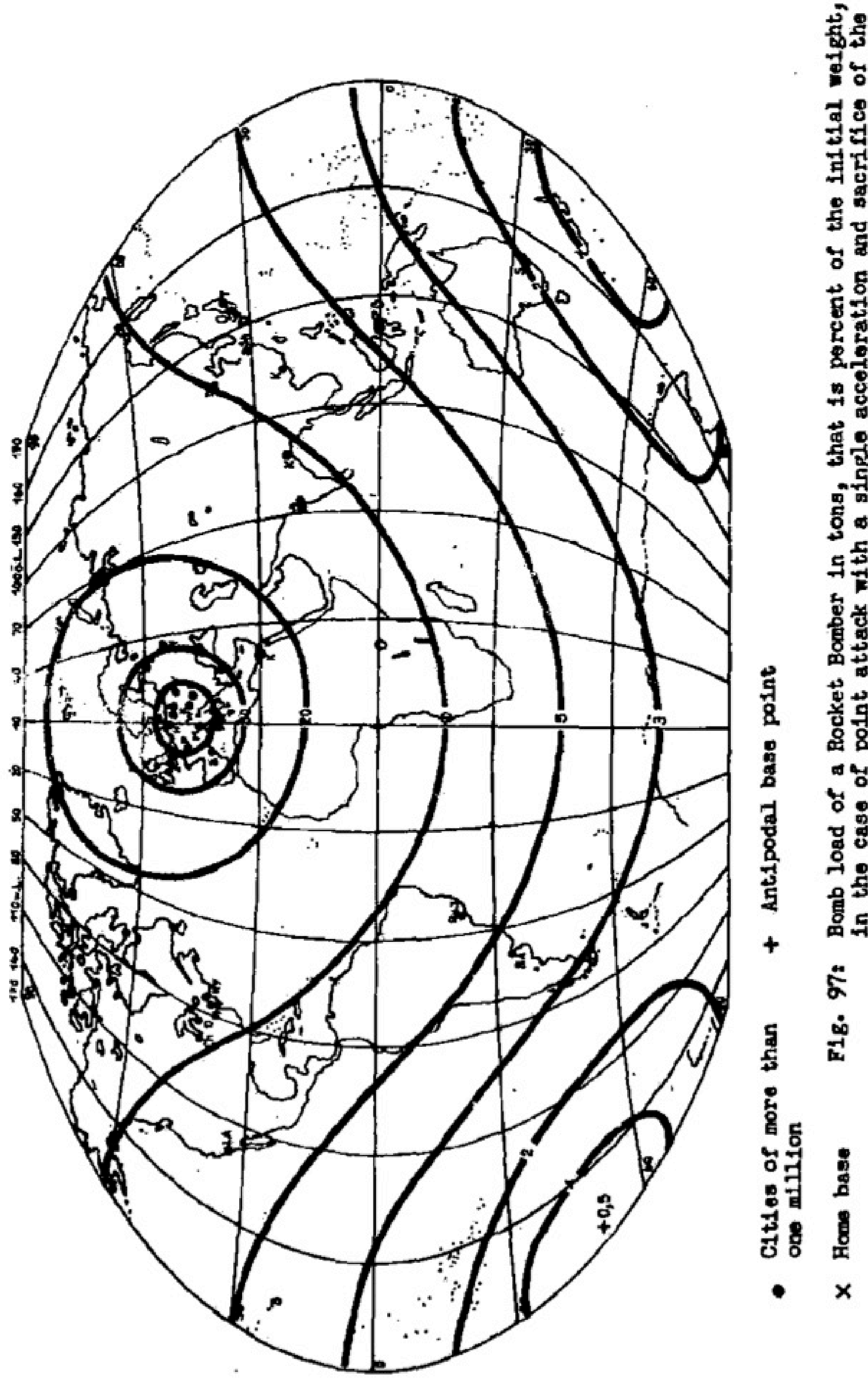


Figure E.177: Silbervogel space plane: global targets within range of vehicle [Saenger and Bredt 1944, English translation].

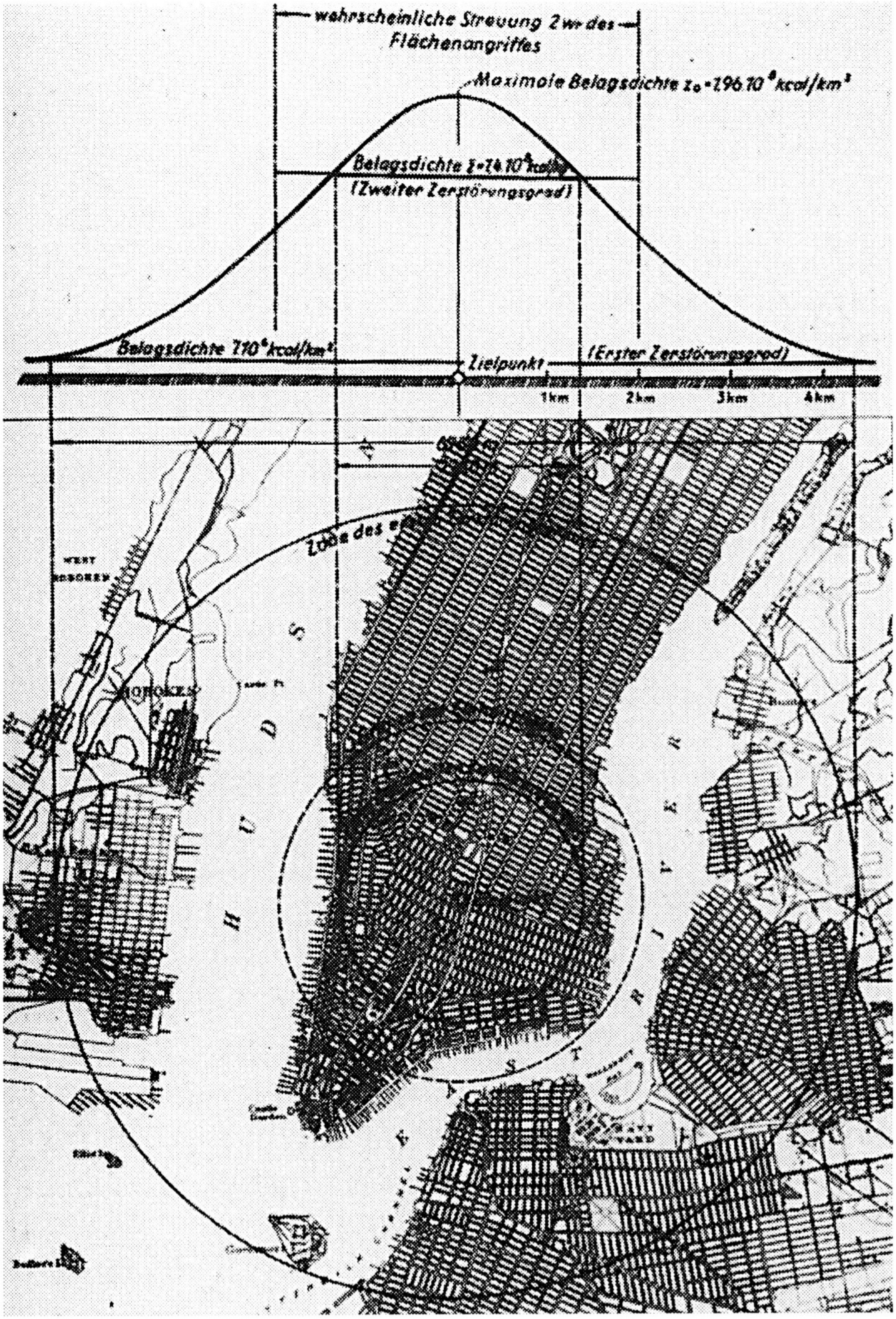


Figure E.178: Silbervogel space plane: projected bomb impact on New York [Deutsches Museum Archive, photo CD56143]. Also published in: Map Showing N.Y. City As Target For German Rocket [NYT 1946-04-02 p. 12.]

G. Ward Price, Fly-bombs Were Meant for U.S.: Huge Ramp Found. *Daily Mail.* 30 October 1944.

Immense concrete works on top of a hill in Artois, near Saint Omer, were intended as a launching place for flying bombs, which, the Germans boasted, would wreck New York.

Thousands of workmen were employed in tunnelling and building a cylindrical cupola on top of the hill, 250ft. in diameter.

Lorries, and even trains, could drive right into the heart of the hill.

German engineers told local French people that when the vast machinery was installed and ready to fire, the district would have to be evacuated for six miles around.

Frequent attacks by the R.A.F. kept on delaying work until the Allied advance from Normandy obliged all the enemy engaged on it to pack up hurriedly.

Footnote.—A German U-boat commander recently told naval cadets at Esjberg, Denmark, that Germany was preparing a new secret weapon for use against America. He said that U-boat crews would play a decisive part in the use of the weapon.

[This sounds like a launching sled track for Silbervogel, or possibly a slightly smaller launching track for the winged A-9 rocket.

The six-mile radius suggests that it would have been carrying a weapon of mass destruction. A 6-mile or 10-km blast radius would correspond to a ~1.6 megaton bomb, which would suggest a hydrogen bomb and not a simple fission bomb.

Also see article on p. 4571 mentioning development of a catapult-launched atomic bomb delivery system in Norway. Could that have been a rocket-powered sled track for a Silbervogel or winged A-9?

Donald L. Putt. 1946. German Developments in the Field of Guided Missiles. *Society of Automotive Engineering (SAE) Journal (Transactions)* 54:8:404–411. [Putt 1946b]

One of the Germans' most fascinating projects was their long-range bomber. (See Fig. 14.) This was a liquid fuel supersonic pilot-controlled aircraft intended to fly from Germany to New York in 40 min at an altitude of approximately 154 miles. The motor was to weigh 2 1/2 tons and to deliver a thrust of 100 tons. This bomber was never finished, but it is believed that time was the only obstacle against its completion.

This bomber was to be catapult-launched at 500 mph and rise to altitude in 4–8 min, during which time the fuel would be exhausted. It was then to glide and skip along the outer atmosphere with decreasing oscillations. The Germans hoped to be able to destroy any large city on the earth with a fleet of 100 of these bombers within the space of a few days' operations.

Fig. 14—Rocket bomber designed to fly from Berlin to New York in 40 min at an altitude of 154 miles—engine burned liquid oxygen and alcohol—rocket nozzle was cooled by water, condenser being used to form water from products of combustion—other side of condenser could be used to vaporize the alcohol. Test model was made that carried one man and had landing gear, although it is not known if this model ever flew; it is known, however, that test runs were made on its engine

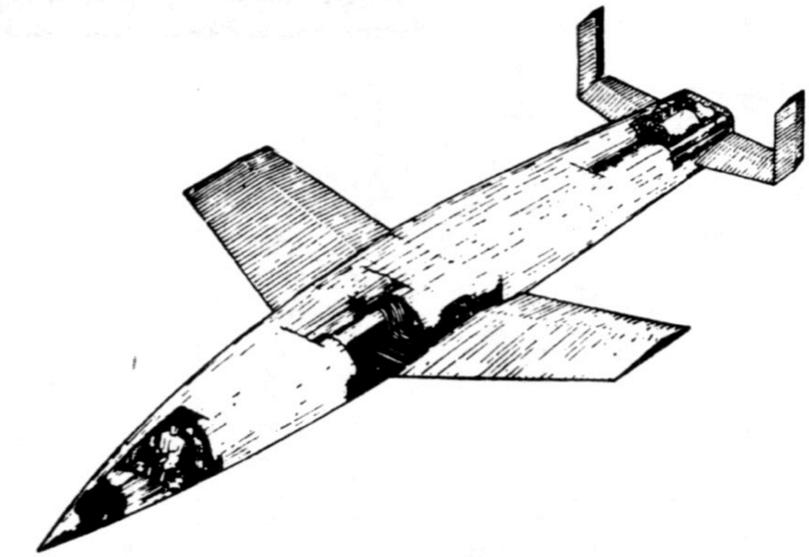
[Donald Putt was the U.S. Army Air Forces Colonel (later General) in charge of rounding up most of the German aerospace engineers in Europe at the end of the war, and funding them to continue their work in the United States for many years after the war. From that very well-informed position, he stated in this 7 March 1946 presentation to the Society of Automotive Engineers that the Silbervogel space plane was actually built, complete with cockpit, landing gear, and a functioning engine, and that it was possible that it was even test-flown.

Interestingly, his statement that the Silbervogel was actually built and might have been test flown (as well as some of his other statements about German rocket developments) vanished without explanation from later versions of this speech, such as the 27 June 1946 version written at Wright Field, possibly due to censorship:

- Donald L. Putt. 1946. German Developments in the Field of Guided Missiles: An Address Before the SAE in New York, 7 March 1946. Summary Report. Report No. F-SU-1122-ND. 27 June 1946. Headquarters, Air Materiel Command, Wright Field, Dayton, Ohio. Library of Congress, Washington, DC. Call number MLCM 95/01648 (T) FT-MEADE.

- Donald L. Putt. 1946. World's Cities Threatened by Nazi Supersonic Bomber. *Society of Automotive Engineering (SAE) Journal* 54:7:9.]

THE AUTHOR: COL. D. L. PUTT, USAFF, has since August, 1945, been assigned as deputy commanding general, Intelligence (T-2), in charge of all technical intelligence activities of the Air Materiel Command at Wright Field. He joined the Air Forces as a flying cadet in 1928, and after completing his flying training was assigned to Wright Field. In January, 1945, he was made director of technical services of the ATSC in Europe. His service awards include the Legon of Merit for work on the B-29, Bronze Star with Oak-Leaf Cluster, and the Croix de Guerre.



■ Fig. 14 – Rocket bomber designed to fly from Berlin to New York in 40 min at an altitude of 154 miles – engine burned liquid oxygen and alcohol – rocket nozzle was cooled by water, condenser being used to form water from products of combustion – other side of condenser could be used to vaporize the alcohol. Test model was made that carried one man and had landing gear, although it is not known if this model ever flew; it is known, however, that test runs were made on its engine

finished, but it is believed that time was the only obstacle against its completion.

This bomber was to be catapult-launched at 500 mph and rise to altitude in 4-8 min, during which time the fuel would be exhausted. It was then to glide and skip along the outer atmosphere with decreasing oscillations. The Germans hoped to be able to destroy any large city on the earth with a fleet of 100 of these bombers within the space of a few days' operations.

August, 1946 411

Figure E.179: Donald Putt, who was in charge of collecting all technical intelligence from Europe for the U.S. Army Air Forces, published a written statement confirming that a manned Silbervogel complete with landing gear and a working engine was actually built during the war [Donald L. Putt. 1946. German Developments in the Field of Guided Missiles. *Society of Automotive Engineering (SAE) Journal (Transactions)* 54:8:404–411].

U.S. Air Force Air Research and Development Command. 1957. *Weapon Sys 464L Abbreviated Development Plan.* [Reproduced in Robert Godwin 2003, pp. 38–51]

[...] Briefly, this concept is characterized by a manned, winged vehicle, rocket-boosted to hypersonic speeds and altitudes above 100,000 feet, whereupon the vehicles operates in an unpowered gliding mode, trading kinetic and potential energy for ranges on the order of 5,000 nautical miles to 22,000 nautical miles depending upon the mission and time period.

The hypersonic boost-glide concept offers a major technological breakthrough in performance and mission capability which should be exploited in future reconnaissance and bombardment aircraft weapon systems. [...]

The boost-glide concept is not new. In the early Forties, Dr. Sänger, German rocket scientist, proposed a skip-glide vehicle to bomb New York from a launch site in Germany. Serious consideration was given this proposal by the Germans. A program known to the Germans as the A9/A10 development was designed to use a winged V-2 rocket as the second stage of a two-stage system. This vehicle was under development and test by the Germans when the war ended. At the close of the war Dr. Walter Dornberger, ex-German general and head of the Peenemunde Rocket Research Institute in Germany went to work for Bell Aircraft Corporation in this country. It is not surprising then that Bell approached the USAF in 1952 with an unsolicited proposal for a Manned, Hypersonic Boost-Glide Bomber/Reconnaissance Weapon System. Rand conducted investigations of this concept in 1948 and NACA published work on the subject in 1954. Since 1954, the ARDC has sponsored a considerable amount of work in the boost-glide field. The following table summarizes this effort. [Programs BOMI, Brass Bell, ROBO, HYWARDS, and now Dyna-Soar.]

[However far the development of Silbervogel actually got during the war, it led to many German-speaking engineers to develop additional space planes after the war.

After the war this approach was also championed by Walter Dornberger and other German-speaking scientists, ultimately leading to several vehicles: the U.S. X-20 Dyna-Soar that was built but not flown, the U.S. Space Shuttle, the Soviet Buran, and assorted other space planes that have been designed and in some cases flown.

Wernher von Braun and other German-speaking engineers published detailed descriptions and illustrations of a space plane in 1952 in *Collier's* magazine, in order to try to excite U.S. public interest and government funding for such a project [*Collier's* 1952-03-22].

In 1946, Walter Dornberger began work on the Bell Aerospace GAM-63 RASCAL air-launched cruise missile, a large liquid propellant rocket with wings designed for long-range horizontal flight (p. 1847). In 1952, Dornberger led the Bell Aerospace team that proposed the Bomi (Bomber Missile) space plane, which was heavily based on the wartime Silbervogel designs—see p. 1925. In 1954, Dornberger's team designed the X-15 rocket plane, which had many similarities to the wartime manned A-9 designs [Käsmann 2013, p. 105]. After the Bomi proposal was rejected, Dornberger was instrumental in recycling the Bomi and Silbervogel designs to create the X-20 Dyna-Soar space plane; a prototype was built but the program was cancelled in 1963 [Robert Godwin 2003].

Ultimately the work of these and other German-speaking engineers led to several space planes that were actually launched, including the U.S. Space Shuttle and the Soviet Buran.]

R&D PROJECT CARD

TYPE OF REPORT: Proposed Weapon System

REPORT CONTROL SYMBOL: DD-R&D/A/119

1. PROJECT TITLE: (Conf) Hypersonic Glide Rocket Weapon System
(Uncl) Hypersonic Strategic Weapon System

2. SECURITY OF PROJECT: Secret

3. PROJECT NO.: System 464L

4. INDEX NUMBER: N/A

5. REPORT DATE: 23 August 57

6. BASIC FIELD OR SUBJECT: Supporting Systems

7. SUB FIELD OR SUBJECT SUB GROUP: SS

7A. TECH. OBJ.: SS-1

8. COGNIZANT AGENCY: Hq ARDC

9. DIRECTING AGENCY: Hq ARDC, RDZP

10. REQUESTING AGENCY: Hq USAF

12. CONTRACTOR AND/OR LABORATORY: To be determined

CONTRACT/W. O. NO.:

11. PARTICIPATION AND/OR COORDINATION:
NACA (P)
AMC (P)
SAC (I)
U. S. NAVY (I)
U. S. ARMY (I)

13. RELATED PROJECTS:
Project 7990
Task 89774

14. DATE APPROVED:

15. PRIORITY: 1A

16. MAJOR CATEGORY: A

17. EST. COMPLETION DATES

RES.	"Cont."
DEV.	"Cont."
TEST	"Cont."
OP. EVAL.	

18. FY	FISCAL ESTIMATES
58	3,000
59	5,000
60	8,000

19. REPLACED PROJECT CARD AND PROJECT STATUS: This report supercedes DD Form 613 dated 31 Dec 56, System 459L (Brass Bell); DD Form 613 dated 28 Dec 56 System 610A (HYWARDS): and Task No. 89774 (ROBO) of DD Form 613 dated 8 Jan 57, Project 7990.

20. Requirement and/or Justification

This system is proposed to satisfy System Requirement 131, dated 14 November 1956, title:(U) Hypersonic Weapons Research and Development Supporting Systems; GOR No, 92 (TA-4e-1-59), dated 12 May 1955, title:(U) GOR For A Piloted Very High Altitude Reconnaissance Weapon System; and SR No. 126, dated 12 June 1956, title classified, Unclassified short titles ROBO.

The logical development of weapon systems utilizing the boost-glide concept encompasses the above requirements in the order mentioned.In keeping with the philosophy of "more Air Force per dollar" and the desirability of obtaining operational weapon systems of this type as early as practicable, it is essential that. weapon systems using the boost-glide concept be developed under a completely integrated program. This program consolidates the DD Form 613's previously submitted on projects. HYWARDS and Brass Bell (see Item 21e); the ARDC Form 111's dated 29 March 1957 and 10 May 1957 on Project 7990, Task 89774 (ROBO); and the Evaluation Report of the Ad Hoc Committee for ARDC System Requirement No. 126 ROBO dated 1 August 1957. This program is identified as Weapon System: 464L and given the nickname Dyna Soar, which stands for Dynamic Soarer.(Confidential)

22. OASD (R&D)	SN.	CN.	C.	X.	I.	C.

DD FORM 1 APR 55 613 REPLACES DD FORM 613, 1 JAN 52, WHICH MAY BE USED.

SECRET

C7-115361 PAGE 1 OF 10 PAGES

Figure E.180: U.S. Air Force Air Research and Development Command. 1957. *Weapon Sys 464L Abbreviated Development Plan.* [Robert Godwin 2003, pp. 38–51].

R/D PROJECT CARD
CONTINUATION SHEET

SECRET
SECURITY CLASSIFICATION

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NUMBER
(Conf) Hypersonic Glide Rocket Weapon System	Secret	System 464L
(Uncl) Hypersonic Strategic Weapon System	4.	5. REPORT DATE 23 August 57

21. Brief of Project and Objective

a. Brief and Military Characteristics

It is proposed that a development program for advanced weapon systems utilizing the boost-glide concept be initiated to take advantage of the tremendous capability and potential this concept offers in the accomplishment of Air Force missions of the 1967 through 1980 time period and beyond.Briefly, this concept is characterized by a manned, winged vehicle, rocket-boosted to hypersonic speeds and altitudes above 100,000 feet, whereupon the vehicle operates in an unpowered gliding mode, trading kinetic and potential energy for ranges on the order of 5,000 nautical miles to 22,000 nautical miles depending upon the mission and time period.

The hypersonic boost-glide concept offers a major technological breakthrough in performance and mission capability which should be exploited in. future reconnaissance and bombardment aircraft weapon systems.The tremendous improvements in speed, altitude, and range capabilities attainable simultaneously with such a system, warrant immediate initiation of a concerted development program to provide solutions to the technical problems involved in this concept.

Knowledge of the flight characteristics and equipment operation problems for the boost-glide flight regime is very limited.Ground based facilities such as wind tunnels, shock tubes, ballistic ranges and small scale flight models can provide an important portion of the required information.However, the inability of these ground facilities to simulate simultaneously the parameters encountered in actual flight requires design and development decisions to be made in many areas on the basis of unsubstantiated theory, inference, and extrapolation, unless actual flight data are available.The final critical evaluation of systems and components can only be accomplished with a full scale vehicle flying at the proper altitudes and speeds,

The development program, described herein, is designed to introduce boost-glide weapon systems into the USAF inventory in an appropriate time period compatible with weapon systems existing at that time and as a follow-on to the weapon systems becoming obsolete at that time. Considerable care has been taken in laying out the development schedule to avoid the necessity of a crash program in the development of boost-glide weapon systems.

(1) Dyna Soar I

(a) General

The first flight article proposed under the program is a

DD FORM 613-1, 1 FEB 55 — PREVIOUS EDITIONS OF THIS FORM MAY BE USED. SECURITY CLASSIFICATION C7-115361 PAGE 2 OF 10 PAGES

SECRET

Figure E.181: U.S. Air Force Air Research and Development Command. 1957. *Weapon Sys 464L Abbreviated Development Plan.* [Robert Godwin 2003, pp. 38–51].

R&D PROJECT CARD
CONTINUATION SHEET

SECRET
SECURITY CLASSIFICATION

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NUMBER
(Conf) Hypersonic Glide Rocket Weapon System (Uncl) Hypersonic Strategic Weapon System	Secret	System 464L
	4.	5. REPORT DATE 23 August 57

(2) Administrative Approach

It is planned that management responsibility for this program will be assigned to the Directorate of Systems Management, Headquarters ARDC. A supporting team of technical personnel from WADC Laboratories and other appropriate ARDC Centers will be established to provide effective utilization of personnel and facilities available within ARDC. Support by the NACA in the form of over-all technical guidance and participation in the testing phases of this program is considered essential to the successful development of the proposed systems. Arrangements for NACA support and participation already initiated in this area will be expanded and finalized. A single contractor will be selected to accomplish the exploratory research part of the Pre-Phase I investigation program giving due consideration to all capable contractors in the field. This work must be non-proprietary in nature and must be accomplished under paid Air Force contract. The second part of the Pre-Phase I program, that of design studies and systems analysis, will be carried out on a competitive basis under paid and/or voluntary studies and the data generated will be proprietary. Two or more contractors will be selected for competition under this part of the Pre-Phase I program. It will be made clear at the outset that all of the contractors involved in the Pre-Phase I program will have an equal opportunity to compete for the Phase I of the conceptual test vehicle. This philosophy is applied throughout the development schedule for all Dyna Soar vehicles. Proprietary rights of contractors competing in the design study and system analysis phase will be protected as necessary to maintain their competitive position. Technical data from WS 107A has been and will be utilized to the maximum during this program. In addition, studies of the designs and concepts of the Dyna Soar program will show cognizance of the facilities, support equipments, concepts, etc. being developed for the WS 107A.

A more thorough treatment of the Dyna Soar program, including justification for the weapon systems proposed and the test vehicle required, the development philosophy, and a thorough discussion of the development schedule is contained in Attachment 3.

c. Background History

The boost-glide concept is not new. In the early Forties, Dr. Sanger, German rocket scientist, proposed a skip-glide vehicle to bomb New York from a launch site in Germany. Serious consideration was given this proposal by the Germans. A program known to the Germans as the A9/A10 development was designed to use a winged V-2 rocket as the second stage of a two-stage system. This vehicle was under development and test by the Germans when the war ended. At the close of the war Dr. Walter Dornberger, ex-German general and head of the Peenemunde Rocket Research Institute in Germany went to work for Bell Aircraft

DD FORM 1 FEB 53 613-1 PREVIOUS EDITIONS OF THIS FORM MAY BE USED. SECURITY CLASSIFICATION SECRET C7-115361 PAGE 8 OF 10 PAGES

Figure E.182: U.S. Air Force Air Research and Development Command. 1957. *Weapon Sys 464L Abbreviated Development Plan.* [Robert Godwin 2003, pp. 38–51].

R&D PROJECT CARD
CONTINUATION SHEET

SECRET
SECURITY CLASSIFICATION

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NUMBER
(Conf) Hypersonic Glide Rocket Weapon System	Secret	System 464L
(Uncl) Hypersonic Strategic Weapon System	4.	5. REPORT DATE 23 August 57

Corporation in this country. It is not surprising then that Bell approached the USAF in 1952 with an unsolicited proposal for a Manned, Hypersonic Boost-Glide Bomber/Reconnaissance Weapon System. Rand conducted investigations of this concept in 1948 and the NACA published work on the subject in 1954. Since 1954, the ARDC has sponsored a considerable amount of work in the boost-glide field. The following table summarizes this effort.

Contractors	Program	Effort	Year	P-600 Funds	Contractor Funds
Bell	BOMI	Feasibility	Apr 54-Apr 55	$246,000	$200,000
Bell	BOMI	Design Study	Sep 55-Dec 55	174,000	400,000
Bell	Brass Bell	" "	May 56-Aug 57	1,736,000	
Bell	ROBO	Feasibility & Design	1956 - Jun 57	None	Total for ROBO voluntary studies by all contractors $3,200,000
Boeing	ROBO	" "	Jan 56-Jun 57	None	
Convair	ROBO	" "	Jun 56-Dec 56 Jan 57-Present	245,000 None	
Douglas	ROBO	" "	Jun 56-Jan 57 Jan 57-Present	374,000 None	
Martin	ROBO	" "	Jan 57-Present	None	
North American	ROBO	" "	Jun 56-Dec 56 Jan 57-Present	240,000 None	
Republic	ROBO	" "	Jun 56-Jun 57	None	
Lockheed	ROBO	" "	Jul 57-Present	None	
			TOTALS:	$3,015,000	$3,800,000

d. Future Plans

Upon receipt of Headquarters USAF Development Directive together with necessary funds and other essential resources, ARDC and AMC will select a contractor for the exploratory research part and two or more contractors to

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Figure E.183: U.S. Air Force Air Research and Development Command. 1957. *Weapon Sys 464L Abbreviated Development Plan.* [Robert Godwin 2003, pp. 38–51].

Boris Chertok. 2005–2012. *Rockets and People*. 4 vols. Washington, DC: U.S. Government Printing Office.
[**https://www.nasa.gov/connect/ebooks/rockets_people_vol1_detail.html**]

[Vol. 1, pp. 262–265:] The collective panel of experts that was set up there on the spot determined that this document was the design for a rocket-powered bomber. [...]

As far as I was able to understand later, this was not the design of theA-9/A-10 missile, which was designed for a range of 800 kilometers. The report discussed the ranges required to strike New York. From today's standpoint, we can say that the layout of the vehicle described in the report—found in the woodpile in Peenemünde in May 1945—anticipated the structure of the American Space Shuttle and our Energiya-Buran system. [...]

The report had been issued in Germany in 1944. Its authors were the Austrian rocket engine researcher E. Sänger, who was already well known before the war, and I. Bredt, who was unknown to us and was later identified as Irene Bredt, a gas aerodynamics specialist.

Eugen Sänger was known for his book *Raketen-flugtechnik* (The Technology of Rockets and Aviation), which he published in 1933. It had been translated and published in the Soviet Union. Back when he was a 25-year-old engineer, Sänger was captivated by the problems of rocket technology. He was one of the first serious researchers of gas dynamic and thermodynamic processes in rocket engines.

You can imagine how Bolkhovitinov and other NII-1 specialists felt as they leafed through the top-secret report, one of 100 printed copies. Judging by the distribution list, it had been sent to the leaders of the *Wehrmacht* main command, the ministry of aviation, to all institutes and organizations working in military aviation, and to all German specialists and leaders who were involved in rocket technology, including General Dornberger in the army department of armaments, who also served as chief of the Peenemünde center.

The title of the report was "Über einen Raketenantrieb für Fernbomber" (On a Rocket Engine for a Long-Range Bomber). This paper analyzed in great detail the technical capabilities for creating a manned winged rocket weighing many tons. The authors convincingly showed by constructing nomograms and graphics that with the proposed liquid-propellant rocket engine with a thrust of 100 metric tons it was possible to fly at altitudes of 50–300 kilometers at speeds of 20,000–30,000 kilometers/hour, with a flight range of 20,000–40,000 kilometers. The physical and chemical processes of high-pressure and high-temperature propellant combustion were studied in great detail, along with the energetic properties of propellants, including emulsions of light metals in hydrocarbons. The work proposed a closed, direct-flow, steam power plant both as a cooling system for the combustion chamber and as a means to activate the turbopump assembly.

The problems of aerodynamics for an aircraft with a speed ten to twenty times greater than the speed of sound were new for our aerodynamics specialists.The report went on to describe the launch, takeoff, and landing dynamics. In an apparent attempt to interest the military, the report included a highly detailed examination of bombing issues, considering the enormous speed of a bomb dropped from such an aircraft before it approached the target.

It is interesting that Sänger had already shown by the early 1940s that launching space aircraft without auxiliary means was unacceptable. He proposed launching space aircraft using a catapult with a horizontal track that would enable the aircraft to reach a speed greater than the speed of sound. [...]

The total takeoff weight of the bomber was 100 metric tons, of which 10 metric tons was the weight of the bombs.The landing weight was assumed to be 10 metric tons. If the flight range were reduced, the weight of the bombs could be increased to 30 metric tons.They proposed that the subsequent work to implement the design of the rocket-propelled bomber be divided into twelve stages, in which the bulk of the time would be devoted to firing rig optimization of the engine, rig testing of the interaction of the engine and aircraft, launcher testing, and finally, all phases of flight tests.

In 1945, the work of Sänger and Bredt was translated, and in 1946 it was published under the title "Survey of Captured Technology" by the Military Publishing House of the USSR Armed Forces Ministry, under the editorship of Major General of the Aviation Engineer Service V. F. Bolkhovitinov; a large number of copies were printed.

Being in Germany at the time, Isayev and I had no idea that this report had caused quite a stir after its delivery to NII-1 in May 1945.We could only imagine the feelings experienced by our patron, who was considered a dreamer in higher aviation circles, but who was respected for his enthusiasm in the face of extremely bold proposals, a quality that was very unusual for a chief designer.Together with the engine specialists from RNII, we had only obtained a reliable liquid-propellant rocket engine with a thrust of 1.5 metric tons in 1943. Isayev dreamed of bringing the engine up to a thrust of 2–3 metric tons in a year or two. But then, in 1944, a V-2 engine with a thrust of almost 30 metric tons was recovered in Poland. Added to this now was Sänger's report, which outlined the design for an aircraft with engine thrust of 100 metric tons!

When Bolkhovitinov's deputy, MAI professor Genrikh Naumovich Abramovich, flew into Berlin from Moscow in June, he was already familiar with Sänger's work. Being a very erudite theoretician, he said that such an abundance of gas-kinetic, aerodynamic, and gas-plasma problems required a profound scientific analysis. He believed it would take ten years—God willing—before it came down to the business of designers."It's easier to make rockets than that airplane."

Yes, that proposal was at least twenty-five years ahead of its time. The first space aircraft in the form of the Space Shuttle flew in 1981. But it launched vertically as the second stage of a rocket. To this day there is no authentic aerospace vehicle with a horizontal launch.

Frank Winter, U.S. National Air and Space Museum Curator [Winter 1990, pp. 42–44, 113–119, 122]

The Space Shuttle concept also originated in the 1920s and 1930s. [...]

Eugen Sänger of Austria, who held a doctorate in aeronautical engineering from Vienna's Technische Hochschule, focused on the rocket-propelled stratospheric plane. [...]

From the start [1920s], Sänger favored the reusable rocket plane over "ballistic" systems[...]

After the war, as leader of the newly formed International Astronautical Federation, Sänger became a tireless advocate of the spaceplane. He died in 1964, before he could see his Silver Bird take flight, greatly modified in the form of the Space Shuttle. [...]

Two early postwar designs based on his work, as well as on the winged V-2s, were by von Braun and Dornberger. Von Braun's idea, the more famous, was introduced in the March 22, 1952, issue of *Collier's* magazine as part of a marvelously illustrated series on manned spaceflight. [...]

At about the same time von Braun was drafting these concepts (1951–1955), Walter Dornberger and Krafft Ehricke were working at Bell Aircraft on the highly classified Bomi (Bomber-Missile) study for the Air Force. [...T]he Bomi owed much to the Antipodal Bomber. [...]

Meanwhile, the Air Force was developing three projects similar to the Bomi. [...] In October 1957 the three were consolidated into the Air Force's X-20, known as the Dyna-Soar (Dynamic Soaring) vehicle, so called because it combined ballistic missile lift with the soaring and precise flight control of an airplane. For the same reasons, it was also called a boost-glider. In its brief, controversial carrier, the Dyna-Soar nearly became the very first Space Shuttle. [...]

The PRIME project (Precision Recovery Including Maneuvering Entry) was the second phase of START. Three PRIME vehicles, flown between 1966 and 1967 and boosted into space by Atlas launchers, were likewise small unmanned gliders but were true lifting bodies. [...]

The X-24B made especially valuable contributions toward the Shuttle, not only by gathering data on aerodynamics and handling but also by test-flying components later incorporated in the Shuttle's orbiter (the manned spaceplane which orbits the Earth). In addition, the X-24B showed that a spaceplane did not need any cumbersome auxiliary turbojet or other powerplant to land, as some designs of the time required. [...]

The years 1969 to 1972 thus represented an intense period of evolution, during which the Shuttle design was refined on the basis of many proposals. [...]

One remarkable feature of the Shuttle is its reusable thermal protection system. This consists of four types of insulation, which are used on various parts of the ship according to the heat protection required. The most critical areas are the underside and the leading edges of the wings and body, which reach a searing 1,200–2,300 degrees Fahrenheit during reentry. Here are glued 30,922 individually contoured tiles made of silicon carbide and carbon cloth.

[High-temperature ceramics for the Space Shuttle trace back to wartime German work on high-temperature ceramic components for turbojet engines.

Suitable shapes for hypersonic reentry and the suggestion to use ceramic tiles both came from Adolf Busemann at Langley–see the obituary for Adolf Busemann below.

In 1965, Walter Dornberger named the newest U.S. space plane program the "Space Shuttle" [Dornberger 1965a, 1965b].

Krafft Ehricke (German, 1917–1984) was deeply involved in space plane projects from Bomi to the Space Shuttle [Freeman 2008].

The X-24 lifting body design came from Hans Multhopp [R. Dale Reed 1997, pp. 129–130, 136]; see pp. 1926 and 5155.

The Space Shuttle Main Engines (SSMEs) were directly derived from engine designs with especially high combustion chamber pressures that were developed during and after the war (such as the MBB P111 engine and the Rocketdyne HG-3 engine) by Klaus von Riedel, Karl Stöckel, Hans Georg Paul, Dieter Huzel, and other German-speaking engineers (see pp. 5156–5160).

The Space Shuttle Solid Rocket Boosters (SRBs) were based on enormous German-speaking contributions to solid propellant rockets (see Sections 9.8 and E.4).]

Adolf Busemann, 85, Dead; Designer of the Swept Wing [NYT 1986-11-05]

Adolf Busemann, whose design of the swept wing for aircraft helped make supersonic flight possible, died Monday at the Fraiser Meadows Manor Health Care Center here. He was 85 years old.

Mr. Busemann, a native of Luebeck, Germany, presented his discovery at the Volta Congress in Rome in 1935. After World War II, he carried on his research in the United States.

The swept-wing design was used in American F-86 and Soviet MIG-15 jet fighters in the Korean War.

He had held a professorship in aerospace engineering at the University of Colorado since 1963. Research in wind tunnels led him to advise the National Aeronautics and Space Administration on the use of ceramic tiles, which could withstand high temperatures better than aluminum, on the space shuttle.

R. Dale Reed, retired NASA engineer who worked on the lifting body reentry tests that paved the way for the U.S. Space Shuttle [R. Dale Reed 1997, pp. 129–130, 136].

A high-volume lifting body, the SV-5 was the brain child of Hans Multhopp, an aerodynamicist at the Martin Aircraft Company. The SV-5 quickly became the centerpiece of a new Air Force program known as START (Spacecraft Technology and Advanced Reentry Tests). Established in January 1964, START consisted of dual programs—the unpiloted PRIME (Precision Recovery Including Maneuvering Entry) and the piloted PILOT (Piloted Lowspeed Tests).

In early 1964, I visited the Martin Aircraft Company to gather information on the SV-5 and possibly gain some support from Martin and the Air Force in convincing NASA management to fund a supersonic lifting-body flight-test program. I met Hans Multhopp, introduced to me as Martin's chief scientist and the designer of the SV-5. A soft-spoken man with a heavy German accent, Multhopp seemed to be highly respected and admired by others in Martin engineering. After a conversation with him about the SV-5, I could understand why he was so highly respected, for his knowledge of aerodynamics and aircraft design was impressive.

A former aeronautical engineer, Multhopp had worked during World War II for the Focke-Wulf Flugzeugbau in Bremen, Germany, first as head of the aerodynamics department and then as chief of the advanced design bureau. One of his projects at Focke-Wulf was designing, in conjunction with Kurt Tank, the Ta-183. Information on the Ta-183 design obtained by the Russians at the end of World War II greatly influenced the design of the Russian MIG-15 jet fighter. The Pulqui-II, a derivation of the Ta-183 design flown in Argentina after World War II, had been built by former Focke-Wulf employees who had fled to Argentina.

Whisked out of Germany at the end of World War II, Multhopp went to work for the British at Farnborough. There, he designed the swept-wing British Lightning fighter, using calculation techniques he had developed. After four years, however, the British found his arrogance intolerable and he was sacked. He then became the chief scientist for the company that eventually became the giant American aviation and space contractor, Martin Marietta.

Multhopp was able to convince Martin management as well as the Air Force that the SV-5 shape was superior to NASA's M2-F3 and HL-10 shapes on the basis of six features. First, the SV-5 was a maneuverable lifting body with no essential surface components that would be destroyed on reentry from orbit. Second, the vehicle had a hypersonic lift-to-drag ratio of 1.2 or better, permitting a lateral range of 1,000 miles. This feature would enable a recall to any preselected site at least once a day as well as emergency recall to a suitable location from every orbit.

Third, the low-speed aerodynamics of the SV-5 were suitable for making a tangential landing without resort to automatic controls. Fourth, volumetric efficiency was as high as possible, the shape giving as much volume forward as possible for center-of-gravity control. The resulting configuration gave more room up front for the pilot and equipment. The center-of-gravity could then be positioned sufficiently forward to provide adequate vehicle control without resorting to an unstable vehicle with a negative static margin. Fifth, positive camber was included in the body, allowing trimmed lift conditions at lower angles of attack as well as a high subsonic lift-to-drag ratio of about 4.0. Sixth, in regards to pilot visibility, the SV-5 cockpit canopy design was superior to that of the M2-F3 and the HL-10.

My first meeting with Hans Multhopp at Martin in early 1964 also turned out to be my last. After that visit, he seemed simply to disappear from public view. Later, when the X-24A was being flown at Edwards Air Force Base as the final stage of the PILOT portion of the SV-5 program, I was surprised to learn that my Air Force colleagues at Edwards had never even heard of Hans Multhopp. At that time, there was still considerable resentment in this country about using German engineers in American aerospace projects. Consequently, it became the usual practice to keep German engineers at low profile. However, this was not always true. A good example of an exception to this practice was Wernher von Braun, who rose to high rank in NASA in full public view and made a significant contribution to our space program. [...]

By combining much larger fuel tanks with a lighter-weight structure in the X-24A, Hans Multhopp and the other Martin designers theoretically achieved the potential for the X-24A to attain much higher speed and altitude than either the M2-F3 or the HL-10.

Dan Sharp. 2016. *Luftwaffe Secret Bombers of the Third Reich.* Horncastle, U.K.: Mortons. pp. 127–129.

KARL STÖCKEL ROCKETS AND RAMMERS

Another DVL employee who dreamed up unusual concepts with advanced features was Karl Stöckel. During 1944, when the effects of Allied bombing were becoming increasingly significant for Germany, he began thinking of specialised aircraft that might be able to tackle the incoming enemy bombers. It was noted in Luftwaffe: Secret Jets of the Third Reich that what was frequently referred to as the Blohm & Voss MGRP 'Manually Guided Rocket Projectile' might well be one of a series of 'rammer', ramjet and rocket concepts drafted by Stöckel—and this can now be conclusively verified.

A drawing showing a 'Manuell gesteuertes Raketenprojektil' has been discovered, signed by Stöckel and dated August 23, 1944. It shows a large missile, similar in size to a V2, with a very small parasite aircraft attached at its base—barely large enough for one man. The missile would weight five tonnes, the aircraft 0.5 tonnes and the remaining 4.5 tonnes of the combination's all-up weight would be rocket fuel. A diagram and notes on the same sheet indicate how the MGRP was intended to operate. [...]

After the war, Stöckel seems to have gone on to work for Bölkow, designing and patenting a series of rocket engine chambers during the 1950s and 1960s.

[Karl Stöckel began his career by designing rocket planes that would be carried aloft by riding piggyback on the side of a larger rocket booster, essentially a miniature version of what the U.S. Space Shuttle was when it finally launched nearly four decades later.

To power such vehicles, Stöckel spent most of the rest of his career designing and building ever more sophisticated rocket engines capable of operating with especially high combustion chamber pressures (in order to maximize the thrust-to-weight ratio of the engines). The best known of Stöckel's own engines was the Bölkow/MBB P111, which caught the eye of other German engineers at Rocketdyne and NASA and directly led first to the Rocketdyne HG-3 engine and ultimately to the Space Shuttle Main Engines (SSMEs).]

Karl Stoeckel. 1985. History of Development of Staged Combustion Rocket Engine in Germany. [https://www.researchgate.net/publication/293622179_History_of_Development_of_Staged_Combustion_Rocket_Engine_in_Germany]

The development history of the staged combustion engine begins with preliminary studies for interceptors at DVL Berlin during the war, continues with the first test runs using small LOX-regeneratively cooled copper combustion chambers at Boelkow KG in Stuttgart in 1957 and culminates in the 50 kN-LOX/Kerosine staged combustion engine P 111 at MBB in Ottobrunn in 1965. This particular high pressure engine was the first of its kind in the history of rocketry and influenced the development of the space shuttle main engine (SSME) with the H 13 combustion chamber. Subsequent development work continued until 1975 at MBB with the planned 200 kN-LH_2/LO_2 high pressure stage engine H 20 for ELDO III, the combustion tests up to a pressure of 200 bar with the N_2O_4/UDMH-copper chamber M 1 in Ottobrunn and finally the development and manufacture of the LH_2/LO_2 combustion chamber HM 7 for the third stage of Ariane. Past work shows that continued development of high-pressure engine for future applications still has potential.

Christophe Rothmund, Helmut Hopmann, and Erich Kirner. 1992. The early days of LOX/LH2 engines at SEP and MBB. IAF, 43rd International Astronautical Congress, Washington, D.C. Aug. 28–Sept. 5, 1992. [https://www.researchgate.net/publication/234528704_The_early_days_of_LOXLH2_engines_at_SEP_and_MBB]

The development of cryogenic LOX and LH2 rocket engines is reviewed for two European manufacturers. Of note are: (1) the HM4 early turbopump LOX/LH2 engine; (2) the P111 engine with a staged combustion cycle and oxygen-rich preburner; (3) a thrust-chamber program; and (4) the development of LOX-cooled bearings, dynamic LOX seals, and LOX inducers. Launchers were developed by these manufacturers that incorporated LOX and H2O technologies, and the Europa is emphasized. These developments led to collaboration on the Ariane series of Vulcain rocket motors which relied heavily on the technologies established for the HM7 engine. The correction of ignition delays and bearing instabilities in these engines led to a class of rocket engines with a wide range of applications.

Frank-E. Rietz. 2006. EADS Expertise on the Space Shuttle: An Idea Catches On. *Planet AeroSpace* 2006:2:76–78.

Which is where EADS technology comes into play, for the space shuttle main engines work on a principle that originated south of Munich. The design of these innovative engines was conceived 50 years ago—in 1956—at Bölkow GmbH, a predecessor of EADS.

The historical roots of this engine design actually go back even further, to an original idea dating from 1942. Karl Stöckel, an aeronautical engineering graduate who later worked for Bölkow, devoted his research to ultra-high velocity aircraft and possible means of propelling them. He was particularly interested in the concept of combined rocket and turbojet propulsion. Stöckel believed it was crucial to raise the pressure in the combustion chamber to a point where it would meet flightworthiness requirements in terms of compact architecture, low weight and low fuel consumption. The pressure in standard combustion chambers could not be raised above the level of 15 bars, which is why conventional rocket engines work on what is known as the bypass flow principle. This means that the gas generator with the turbine driving the fuel pumps is installed parallel to the thrust chamber. Inevitably, this technique results in loss of momentum and a significant drop in efficiency. The new concept involved 'staged combustion', with combustion taking place in two successive stages. In the first stage of this arrangement, a certain amount of the fuel is burnt up at high pressure in a pre-burner to generate the gas that drives the turbines for the fuel pumps. In the second stage, the gas is mixed with fuel and burns up completely in the combustion chamber. At the same time, a means of cooling the combustion chamber was discovered: the liquid oxygen flowing round the combustion chamber through an arrangement of channels, cooling the chamber and being itself heated in readiness for the combustion process.

Practical testing of this type of engine began on 1 September 1956. The following year, the German ministry of defence awarded Bölkow a contract to develop the full-flow engine. Development of the P111 test engine began in 1958 as soon as the company had relocated from Stuttgart to Ottobrunn. In the months and years that followed, the Bölkow engineers learned important lessons on the structure and function of high-pressure engines. They conducted research into ignition and combustion processes, cooling requirements and heat transfer ratios and paved the way for copper combustion chambers with axial cooling channels. This made it possible to increase chamber pressure to 100 bars. In 1963, only five years after the start of development, the full-flow engine underwent its first test run. And finally, the innovative rocket engine was presented to experts at the 1966 Hanover air show.

NASA began to take an interest in the full-flow engine during its preliminary studies for the space shuttle. Working in conjunction with the U.S. company Rocketdyne, specialists at Ottobrunn developed an engine based on the full-flow principle. During their test runs they achieved a chamber pressure of 282 bars—a world record even today. NASA decided to adopt full-flow engine technology for the shuttle, and this in turn brought licence fees for the German company. Ever since the first flight of Columbia 25 years ago, the technology from Ottobrunn has proved its worth in the entire shuttle fleet.

Roland Kindermann, Steffen Beyer, Peter Bichler, Wolfgang Keinath, Torsten Sebald. Advanced Production Technologies for Thrust Chambers of Liquid Rocket Engines. AAAF Paper 16_96_P, 6th International Symposium for Space Propulsion.

The forebear of today's rocket combustion chamber was tested in Berlin under the leadership of Klaus von Riedel. This was the first time that new, good heat-conducting materials such as aluminum and copper, were used for a thin-walled combustion-chamber liner instead of the steel that was commonly used at the time. Technologies for forced cooling under high pressure were also being used, as was fuel injection through jets. The years to follow saw ever-increasing requirements for higher pressures combined with efforts to arrive at a compact construction, low weight and minimized fuel consumption. There was therefore a move towards main flow engines with the aim of achieving the desired cooling for an increase in power. Development of the P111 (Figure 1) commenced at Astrium, the space subsidiary of EADS (European Aeronautic Defense and Space Company) and ushered in a 40-year tradition of liquid engines.

Processes such as cool-channel milling, waxing the channels and electronickeling were used in the manufacture of the support liner. A successful test was carried out in 1963 using a LOX/kerosene fuel mixture, achieving a thrust of 49 kN at a pressure of 85 bar. The first engine powered by LH2/LOX, the RL10, was successfully produced in the USA over the same period. At the close of the 1960s, the experience thus obtained led to a transatlantic joint venture between Astrium and Rocketdyne. A heat test performed during the course of this cooperation produced a world record that is still in place today: chamber pressure of 282 bar. The construction and operation of the P111 was patented by MBB. It later formed the basis for developing the high-energy SSME by NASA. The 1970s saw the commencement of the long period of technological cooperation between France and Germany. The two countries were working on the joint development of their own cryogenic engines. The HM7 engine for the Ariane 4 was the first LOX/LH2 to be developed outside the USA. The fast expanding market for satellites placed increasingly large demands on launcher payloads and it was essential to develop Ariane 5. Requirements of 100 bar or more for chamber pressures and exceptional heat flux entailed a new combustion chamber material with the relevant physical and mechanical properties.

Successful development of the Narloy-Z copper-based alloy for the combustion chamber of the Space Shuttle Main Engine (SSME) constituted the foundation stone for the development and introduction of the European variant CuAgZr as the combustion chamber material used in the Vulcain engine powering Ariane 5. The principle of construction based on HM7 production technology was transferred to the low-energy upper stage rocket of Ariane 5, the Aestus engine. The corrosion fuel combination used with Aestus (MMH/N2O4) and the low thermal load involved selecting an austenitic chromium-nickel steel (1.4546) for the combustion chamber.

Mike Wright. 1995. MSFC Propulsion Center of Excellence is Built on Solid Foundation [https://web.archive.org/web/20150427090253/http://history.msfc.nasa.gov/saturn_apollo/propulsion_center.html].

Space Shuttle Main Engine

The last Saturn F-1's that NASA employed helped lift Skylab into orbit in 1973. By then, NASA engineers were already deep into the design for the space shuttle main engine, a concept that broke with the past, according to shuttle historian Dennis R. Jenkins. The challenge, Jenkins said, was "not to build a larger, more powerful engine, but to build a small, compact engine that could be throttled during ascent to provide some measure of control over the maximum dynamic pressure and speed of the vehicle." MSFC engineers who have traced the technology projects leading to the development of the space shuttle main engine have pointed to an "aggressive technology program in high-pressure tubomachinery initiated in the 1960's." They point out that much of the work was done by Pratt & Whitney under MSFC's sponsorship, with outgrowth known in-house as the concept for the HG-3, a 350,000-pound-thrust engine named after Hans G. Paul, the long-time chief of the Propulsion Division. In essence, the HG-3 concept eventually became the space shuttle main engine. [...]

Mark Wade. 2019. HG-3. [http://www.astronautix.com/h/hg-3.html].

HG-3.

Rocketdyne LOx/LH2 rocket engine. Study 1967. High-performance high-pressure chamber engine developed from J-2. Considered for upgrades to Saturn V launch vehicle upper stages. Technology led to Space Shuttle Main Engines. [...]

E.4 Submarine-Launched and Solid Propellant Rockets

[This section concerns submarine-launched missiles that were developed or were under development during the war, including submarine-launched versions of small rockets, V-1, V-2, and other missiles, as well as the postwar influence of such projects and German-speaking scientific experts. This section also presents numerous sources about the wartime and postwar development of solid propellant rockets. Not all submarine-launched missiles used solid propellant, and not all solid propellant rockets were designed to be launched from submarines, but the two histories are so deeply intertwined (because solid propellant is especially desirable for submarine-launched rockets) that they are presented here in the same section.

Official histories claim that the major innovations underlying modern solid propellant rockets and submarine-launched ballistic missiles (SLBMs) were invented primarily in the United States, and primarily after World War II. For example, Vaclav Smil, a prolific science historian at the University of Manitoba, wrote [Smil 2006, p. 84]:

> In 1942 John W. Parsons, an explosives expert at California Institute of Technology, formulated the first castable composite solid propellant by combining asphalt (fuel and binder) with potassium perchlorate (an oxidizer).
>
> Key improvements in the preparation of these propellants were made during the late 1940s and the early 1950s. In 1945 Caltech's Charles Bartley and his coworkers replaced asphalt with Thiokol (synthetic rubber). This polysulfide polymer was synthesized for the first time in 1926 by Joseph C. Patrick, and the eponymous corporation was formed in 1928. In 1947 Thiokol Corporation began the systematic, and still continuing (now as Morton-Thiokol), development of solid propellant rockets. The second key innovation was the replacement of potassium perchlorate by ammonium perchlorate (AP) as an oxidizer. Another critical discovery was made at the Atlantic Research Corporation by Keith Rumbel and Charles B. Henderson, who found that adding large amounts of aluminum (Al) greatly increased the specific impulse of composite propellants: they used 21% Al, 59% AP, and 20% plasticized polyvinyl chloride (PVC).
>
> Solid propellants, configured inside the casings mostly in five- to twelve-pointed stars, were used in America's first SLBMs (*Polaris* in 1960, with AP/Al/polyurethane propellant) and ICBMs.

However, evidence demonstrates that these innovations were imported from earlier German-speaking scientists and engineers:

- During the war, German-speaking scientists developed and demonstrated solid propellant rockets that used ammonium perchlorate oxidizer (pp. 5227, 5233).
- The same German-speaking scientists also developed and demonstrated solid propellant rockets that used polybutadiene "buna" synthetic rubber in the propellant to act as both fuel and binder (pp. 5227, 5233).

- The same German-speaking scientists also added plasticizers to enable the propellant to be molded into any desired shape, to adhere tightly to metal walls, and not to be prone to crumbling or brittleness (pp. 5227, 5233).

- During the war, German-speaking scientists added powdered aluminum to rocket propellants and closely related solid explosives in order to improve performance (pp. 5235–5238).

- During the war, German-speaking scientists used a wide variety of grain designs for the geometrical shape of the combustion surface inside the propellant to give the desired variation of thrust with time (pp. 5211–5212, 5233, 5238).

- The Rochen ammonium perchlorate/polybutadiene short-range missile was first fired in 1944 (p. 1904).

- The Rheintochter two-stage solid-propellant surface-to-air missile was first launched in 1943 (p. 1905).

- The Rheinbote four-stage solid-propellant long-range rocket was first launched in 1943 (p. 1906).

- The V-101, an ammonium perchlorate/polybutadiene propelled, 140-ton, 30-meter-tall, long-range ballistic missile, was under development when the war ended 1907).

- Submarine-launched small ballistic rockets were successfully demonstrated during the war (pp. 5171–5188).

- Submarine-launched V-1 cruise missiles were developed, tested, and possibly even deployed (pp. 5161–5170).

- Methods of firing large ballistic missiles from deeply submerged submarines were perfected by the end of the war (p. 5289).

- Towed submarine carriers for A-4 or V-2 rockets were designed and possibly developed during the war (pp. 5171–5203).

- Rockets with dimensions suitable for submarine launch were developed by wartime laboratories under contract with the German navy (p. 5077).

- An August 1945 U.S. report stated that the Germans had developed a wide variety of guided missiles including "underwater launched to air," "surface," and "underwater targets" (p. 4974).

- German-speaking scientists were directly involved in developing Jupiter, a postwar U.S. ballistic missile designed to be launched from submarines (but ultimately only deployed on land; see p. 5046).

- German-speaking scientists were deeply involved in the development of the U.S. Polaris, Pershing, and Minuteman solid propellant ballistic missiles in ways that have never been fully disclosed to the public (pp. 5243–5278).

The wartime and postwar German technologies and the associated scientists were directly responsible for the development of large solid propellant rockets for modern ballistic missiles, strap-on rocket boosters, and some satellite launch vehicles.

The German-derived technologies and scientists led directly to the postwar development of submarine-launched nuclear missiles, the third component of the nuclear triad. (Thus the entire modern nuclear triad was a wartime German creation.) The wartime programs included both submarine-launched ballistic missiles—direct ancestors of postwar SLBMs such as Polaris, Poseidon, and Trident—and submarine-launched V-1 cruise missiles—direct ancestors of modern versions such as the U.S. Tomahawk and Russian Kalibr.]

Neal Stanford. Must Be Last War. *Wilmington Star* (North Carolina), 31 October 1944, p. 4. [**https://chroniclingamerica.loc.gov/lccn/sn78002169/1944-10-31/ed-1/seq-4**]

Five times, one day, this week, Washington correspondents lived through buzz-bomb raids. Vicariously, to be sure, and the raids were only nine minutes each.

But that was more than enough for most. It was more than enough to persuade all that in these robot bombs, these rocket bombs, rumors of atomic bombs, the world had something which, if not controlled, would destroy it. Truly the world has a bear by the tail and can't let go. Its only choice is to tame it.

Buzz-bombs have such tremendous destructive potentialities that despite Britain's suffering from this menace that has killed over 5,000, injured 16,000 more, destroyed 23,000 homes, churches, hospitals, stores, schools in London, and damaged 1,000,000 more, we have only begun to feel its power of devastation.

That lesson was shouted from every foot of the film—with appropriate sound effects—that the British Information Service showed, for the first time either in Britain or the United States, to the Washington press corps. We saw these bombs hurtling through Britain's skies, morning, noon, and night. We heard them zooming overhead as rescue crews dug out hapless victims of V-1. We watched them in fascination plummet to earth and explode in a blast of smoke. And we gloried in Britain's defenses, ack-ack gun crews, Spitfires, barrage balloons that caught over half of the 8,000 mechanical buzzards in flight. But thousands out-sped defenses. We realized only too well why buzz-bombs were not a peculiarly British problem—why they were our problem as well.

This nine-minute capsule of buzz-bomb terror, it is expected, will shortly be shown widespread over the United States. Its purpose is to educate, to awaken, to arouse—not to entertain or cause fear. For while 50,000,000 Britons know that the buzz-bomb, the rocket bomb, the automatic bomb have made this war civilization's last hope, there is no similar assurance that 135,000 Americans are irrevocably committed to working to make this the last war. It may be their aim, but is it their determination?

The V-1, or buzz-bomb, is still hitting England from time to time. Capture of the Calais coast has not ended the danger. Launching platforms with shortened German lines can still speed robots over England. Planes also can launch these robots, and have. So for Britain, the Battle of the Robomb is still not over.

Theoretically, America is not immune from the possibility of robot bombings. German U-boats still prowl up and down the Atlantic coast. If a plane can be launched from a submarine, why not robot bombs? They might have to be modified versions, since submarines aren't long enough for serving as launching platforms for the present buzz-bomb. They could certainly not come over any American seacoast area one a minute as they have over London. They might be able to launch two or three or four.

But they would only be vengeance shots involving all the inaccuracies of such bombings. The whole thing, to use a favorite word of President Roosevelt, is very "iffy." If the Nazis have adapted buzz-bombs to U-boat use, and if they are persuaded even the weakest token bombing of America would have psychological benefits, they might spend valuable manpower and resources that way. But the chances seem slight. Some authoritative sources here believe it impossible.

There is no doubt, though, that Germany is experimenting with new types of rocket bombs of larger and deadlier variety. A Stockholm report that the Nazis have some super-rocket bomb is common gossip here. Sometimes it's a 40-foot robot with "atomic explosive features." Other times it's a 40-ton projectile that can, theoretically at least, be hurled 3,000 miles. It is rumored to be as large as a Sherman tank and the destructive possibilities of having a tank full of high explosives crash in your backyard after a 3,000-mile rocket ride through space is best left to your imagination. If V-2 comes up to certain rumors, it is possible that some day one or two might come hurtling across the Atlantic. Of course, they might fall 500 to 1,000 miles off their objective.

As an Army Air Forces officer commented, "Most things are possible technically, of course, but there do seem to be immense technical difficulties involved." Germany, he explained, was no doubt working to develop rocket bombs with atomic explosive features. They'd be foolish if they didn't, he added.

These buzz-bombs or rocket bombs are the best argument that has come out of this war why, from purely selfish reasons, this country, any country, must consecrate itself to preventing another world war.—Christian Science Monitor.

Clayton Bissell and Hewlett Thebaud to the Joint Chiefs of Staff. 9 December 1944. Subject: Agreed Joint Evaluation of the Possible Existence of the V-3 Rocket and Probability of Attack against the U.S. [Franklin Delano Roosevelt Library, Hyde Park, New York. Map Room Files, Box 164, Folder Naval Aides. Files: A/16—General Correspondence]

1. The cable from Lieutenant Commander Earle, Naval Attaché, Turkey is probably propaganda and represents a plant by the Germans. There is no reliable information available of German development of a long range rocket other than the V-2.

2. The V-3 may possibly be a rocket of smaller dimensions than the V-2 with a shorter range. It would be possible to launch such a missile from specially designed or modified submarines. Attached is a sketch of a German submarine based in a southern Norwegian port showing a pair of rails extending from conning tower to the bow and terminating at a flat, rectangular surface. The purpose of this is unknown.

3. German attack from Europe of United States cities by long range rockets is deemed impossible now. Small rocket or flying bomb attacks from specially constructed submarines are considered possible. Any such action would be made with propaganda effect rather than material damage as the primary objective.

[The sketch mentioned in this document is on p. 5166. The sketch was based on photographs taken on 19 September 1944.]

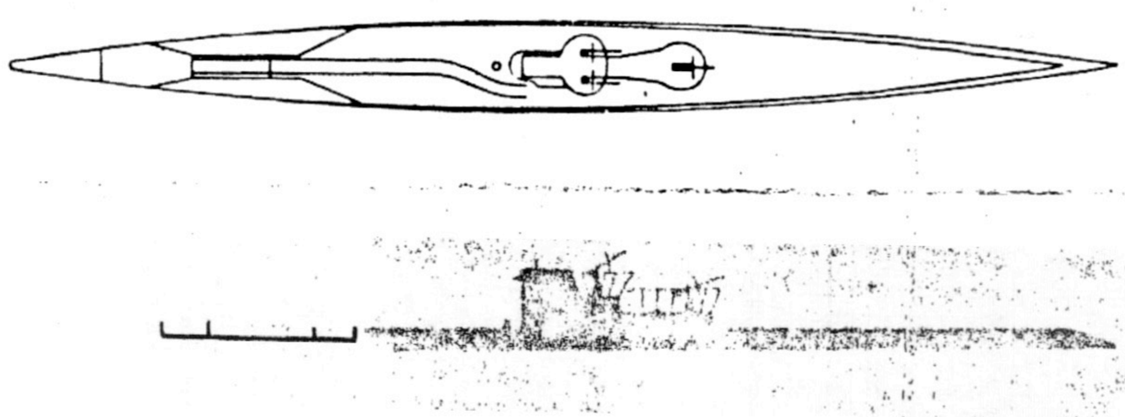
FDR Library, Map Room Files, Box 164,
Folder Naval Aides. Files: A/16—General Correspondence

INTERPRETATION REPORT Nº S 103

Appendix A

German 740 ton U boat with modified deck forward.

Scale 1" - 50ft.



Dimensions :-

Length 244'
Beam 21'

Armament :-

Probably 1-37mm gun
" 4-20mm guns

Special features :-

(1) Narrowing of deck forward
(2) "Rails" on deck running from the port side of the Conning Tower forward to the narrow neck of the deck

Drawn from photographs taken by Coastal Command aircraft on 19th Sept '44
(H.Q.C.C. Ref A.2201-MIL-19th Sept 44//Q.224-Nº11)

Neg Nº 42946

Figure E.184: Allied drawing of a German submarine that was apparently modified to launch V-1 cruise missiles, based on photographs taken on 19 September 1944 [FDR Library, Map Room Files, Box 164, Folder Naval Aides. Files: A/16—General Correspondence].

Dwight Eisenhower to AGWAR. 1 November 1944. Outgoing Cable. [TNA WO 219/298; Henshall 2000, p. 165]

Following passed for what it is worth.

Special Force report quoting Danish source states U-boat will be leaving European waters shortly to launch V-1s against NEW YORK.

Date of report 30 October.

Clayton Bissell to Stockholm Military Attaché. 3 November 1944. Outgoing Cable WAR 56799. [Franklin Delano Roosevelt Library, Hyde Park, New York. Map Room Files, Box 49, Folder Rocket Bombs 1944]

Have been advised through OSS that Tykander their representative in Stockholm has received reliable information that German U boats are equipped with bomb launching platforms. Investigate and keep us fully informed.

Dwight Eisenhower to SFHQ, London. 7 November 1944. Outgoing Cable 8-65824. [TNA WO 219/298; Georg and Mehner 2004, p. 209.]

War Department G-2 have requested further evidence and any other confirmation of Special Force report of 30 October quoting Danish source who stated U boat would be leaving European waters shortly to launch V 13 [sic: V-1s] against NEW YORK. Most grateful your assistance including re evaluation source and report if possible.

Dwight Eisenhower to AGWAR. 13 November 1944. Outgoing Cable S-66672. [TNA WO 219/298; Henshall 2000, p. 164]

Special Force Headquarters reports same source reported 7 November that he believed 4 U-Boats were to be used in operation against NEW YORK operating from BERGEN but course and rate unknown. Special Force Headquarters grades source as (usually reliable) but comments that no other confirmation to possibility of such action received from BERGEN or elsewhere.

U-Boat Aimed V-Bomb Here, Army Paper Says. *New York Times.* 15 May 1945 p. 10.

A German submarine tried to V-bomb New York last election day, presumably with a jet-propelled or rocket-propelled weapon, the Army newspaper Stars and Stripes reported tonight, quoting "sources considered reliable."

It was reported that the bomb was launched from the deck of a U-boat lying off the coast and that it fell short or was knocked down by fighter planes patrolling as a screen against any such projectiles. The Stars and Stripes said that "operators" at Mitchel Field were quoted as having said that it was determined that the bomb fell into the sea.

The paper recalled that last Nov. 8, the day after the Presidential election, the Army and Navy in a joint statement said that a V-bomb attack on the United States was entirely possible.

A Navy spokesman in Washington said that the report of the submarine attack was without foundation, The United Press reported.

An official of the bomb squad of New York's Police Department said last night that the squad had no knowledge of an attempted bombing of New York last Nov. 7 by the Germans.

"Undoubtedly, if a robot bomb had been launched at New York from a U-boat, as reported, and had neared its objective, we would have been informed," the spokesman said.

[The original version of this story appeared as: U-Boat Aimed V-Bomb at New York, *Stars and Stripes*, 14 May 1945. Considering that the report came from the U.S. Army's own newspaper and sources that they considered reliable, the subsequent denials by the U.S. Navy spokesman and New York bomb squad do not seem very convincing.

If the incident actually occurred, can it be clarified if the weapon was a sub-launched V-1 cruise missile or something else? If the weapon fell into the sea, was it ever located?

Was the warhead a conventional explosive, or a chemical, biological, or nuclear weapon? A V-1 strike on a U.S. city with only a conventional warhead would have done relatively little damage and would have had no strategic military value. For evidence of modified V-1 missiles that could have delivered weapons of mass destruction, see pp. 1835 and 4466–4467, as well as Henshall 2000, pp. 129–130.

U.S. fears of a submarine-launched missile strike on East Coast cities continued in spring 1945. From April to the end of the war in Europe, the U.S. Navy conducted Operation Teardrop to intercept a number of German submarines approaching the United States. Were any of those submarines armed with something more than has been acknowledged in the official history books? All relevant archival files need to be located and declassified.]

S. McClintic, Headquarters U.S. Strategic Air Forces in Europe, Office of the Director of Intelligence, to George C. McDonald. 6 January 1945. Big Ben (Rockets). [AFHRA A5734 electronic version pp. 1093]

[...] Again we receive reports of ships being constructed for the launching of flying bombs, this one a 6000 ton boat at Hamburg, and another report that the shipyards, DEUTSCHE WERFT BETRIEB FINKENWERDER are putting ramps on the decks. [...]

J. Edgar Hoover to Harry Hopkins. 8 January 1945. [Franklin Delano Roosevelt Library, Hyde Park, New York. Official File 10b. Box 20. Folder OF 10-b, Justice Department, FBI Reports 1944–45. 2597–2618]

During the interrogation of William Curtis Colepaugh, the enemy agent who was landed by German submarine off the coast of Frenchman's Bay, Maine, on the night of November 29, 1944, several interesting features have arisen concerning his submarine trip to the United States. [...]

Upon arrival at Kristianson, Norway, on the U-1230 he learned that the U-1231 and the U-1233, both submarines of the same type as the U-1230, had just completed some sort of test at Kristianson, Norway.

Colepaugh has said that members of the crew of the U-1230 indicated in conversation that they had observed at one of the submarine ports near Danzig some members of other submarine crews practicing in groups with equipment of a rocket or gun type on the deck and these crew members presumed this equipment would be used against the United States. He said the crew members he talked with were pretty definite about this stating that the submarines would proceed to within 100 or 200 miles of the United States and then fire these rockets. Colepaugh pointed out, however, that the crew members on the U-1230 had no knowledge of the use of this rocket and based their presumption only on what they had observed at the submarine port near Danzig.

Robot Bomb Attacks Here Held 'Probable' by Admiral. *New York Times*, 9 January 1945, pp. 1, 6.

AN EAST COAST PORT, Jan. 8—A strategically futile attack on New York or Washington by robot bombs within thirty to sixty days was described today as not only "possible but probable" by Admiral Jonas H. Ingram, new Commander in Chief of the Atlantic Fleet, whose command stretches from the Arctic to the Falkland Islands. [...]

"And we know very definitely that there are three ways in which he might get robot bombs within range of either city. He might sneak a half dozen submarines off the coast. He might launch robots from the long-range planes we know he has. Or he might sneak a surface ship, disguised as a neutral, within range." [...]

[See also: Officials Silent on Robot Threat/London Paper Predicts Attack. *New York Times*, 10 January 1945, p. 7.]

H. H. Smith, N. W. Dickson, V. P. Kovac, and E. H. Bennett. German Developments in the Guided Missile Field. 10 January 1946. Project 2874. [NARA RG 319, Entry NM3-82, Box 2879, Folder Project 2784]

Two further developments of the V-1 program were an attempt to launch the missile from a ramp on the deck of a submarine and a project for a piloted V-1. In the first case a ramp was constructed though never used; it is believed that this was intended for attacks against coastal towns and defenses on the Eastern seaboard of the U.S.A. In the second instance, several models were constructed though, as far as is known, none were ever used. It was intended that the pilot should fly the missile to within a short range of the target, set the controls and then jump out.

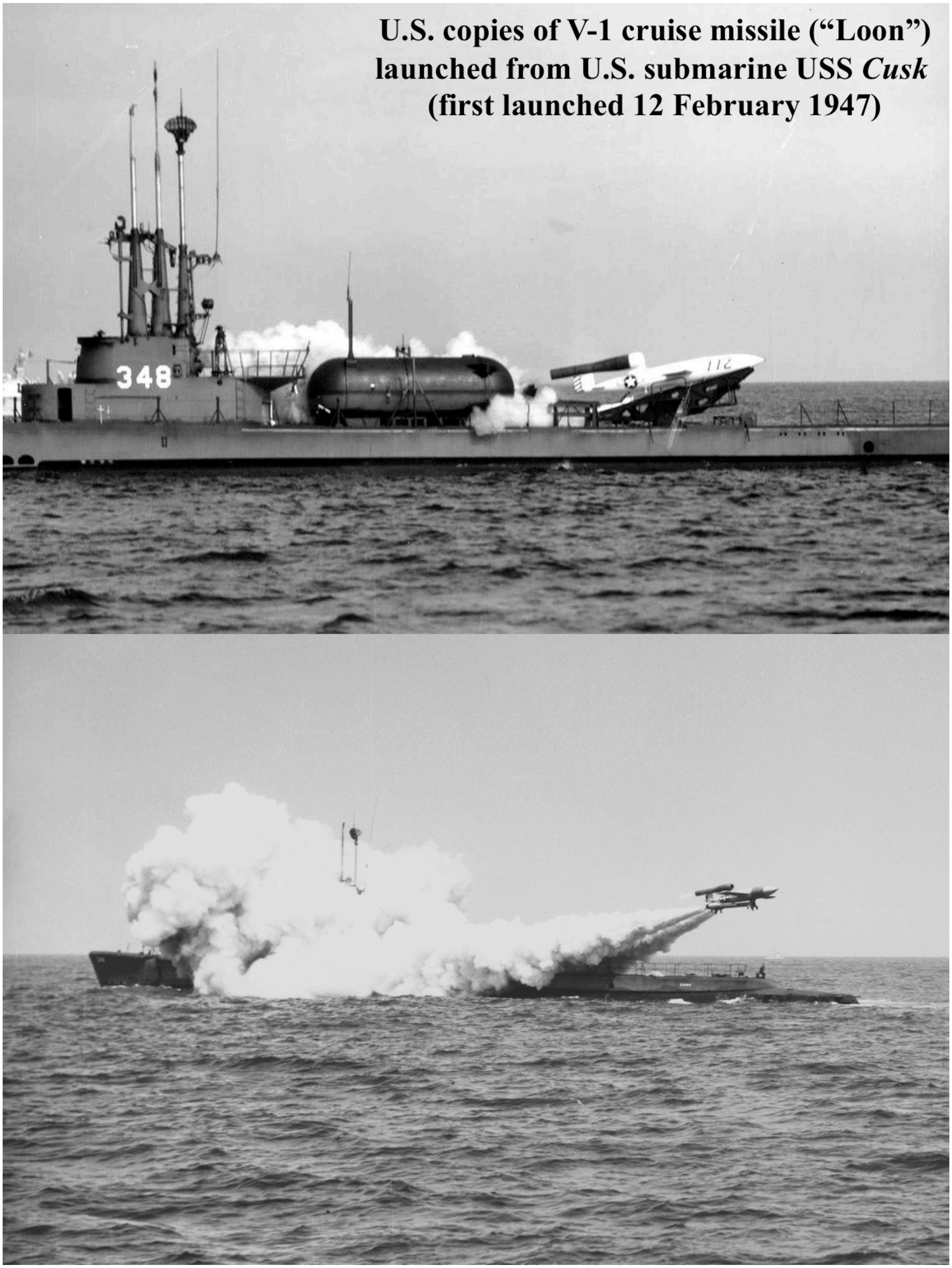


Figure E.185: Loon, a U.S. copy of the V-1 cruise missile, was launched from the USS *Cusk* submarine, based on wartime German developments and implemented by German-speaking scientists at Point Mugu Naval Air Missile Test Center.

Walter Dornberger. 1958. *V-2: The Nazi Rocket Weapon.* New York: Viking. pp. 231–237.

In the autumn of 1943 Lafferenz, of the German Labour Front, paid me a visit and told me that he had proved by practical experiment that, contrary to predictions by the Navy, a submarine could take in tow as many as three cigar-shaped, submersible containers 100 feet long. He urged us to examine the possibility of launching our A4 from these floats. It it could be done we should be able to bombard big military objectives overseas across hundreds of miles of water.

The problem interested us. In the summer of 1942 we had already experimented near the Greifswald Oie with launching solid-propellant rockets from a submarine. It had been Steinhoff's idea at the time. He had noticed the heavy projectiles developed by my department, the solid rockets for the *Nebelwerfer*[1] detachments. His brother was a submarine commander and had a long voyage to make very shortly. We were talking about it and suddenly had an idea. Rockets worked under water; how would it be if we could accommodate 20 or 30 of them, with a charge of inflammable oil or high explosive and ready for launching, aboard a submarine? The submarine could then submerge, approach to within 2 miles of the shore and discharge the rockets under water against oil tank installations on the coast. The petrol and oil tanks would certainly be set on fire by the oil which would ignite on impact.

[1]The *Nebelwerfer* was a weapon roughly equivalent to a trench mortar, in which rocket-propelled shells (originally intended to lay smoke-screens, etc.) were fired from a multi-barrelled launcher.

At Swinemünde improvised launching frames were erected on the deck of the submarine by workmen from Peenemünde and a few days later several salvos were launched from a depth of 30–50 feet. Nothing whatever could be felt of the launchings in the submerged submarine. The trajectory was capital, in fact dispersion was reduced and range slightly increased by the improved initial motion of the missiles through the water. A staggering sight it was when those 20 heavy solid rockets suddenly rose, with a rush and roar, from the calm waters of the Baltic. This improvisation could have been put to immediate and successful use against the enemy, but the Naval Weapons Department, the competent authority for all naval weapon development, would not approve it, though it had served its purpose perfectly. The Navy itself insisted on doing the designing. Months, a whole year went by. [...]

Peenemünde made a thorough study of the problem set by Lafferenz. A submarine could tow three floats weighing about 500 tons for 30 days at an average speed of 12 knots. Their submerging and surfacing could be controlled from the submarine. An A4 and the necessary quantities of propellants could be accommodated without difficulty.

On arrival at the launching point the floats could be partially flooded so that they stood upright in the water. The top hatch could then be opened and the A4, erect upon its gyro-stabilized platform, after being fueled, prepared for launching and laterally adjusted, could be discharged.

We did not expect any construction difficulties that could not be overcome, but work on the subject had been temporarily suspended because of the A4 troubles. Now, at the end of 1944, it was resumed. By the middle of December a full memorandum was being prepared on the preliminary experiments, and we were getting to work on the first draft designs. The evacuation of Peenemünde put paid once for all to a not unpromising project.

[Dornberger mentioned several wartime projects that are illustrated on the following pages:

- In May 1942, there was a series of successful tests to launch small Nebelwerfer rockets from a submerged submarine (U-511). Those tests were documented in a June 1942 report [Bundesarchiv Militärarchiv Freiburg RH 8/369]. See pp. 5174–5182.

- Based on those successful initial tests, during 1942–1945, the German Navy sponsored the development of a whole series of increasingly sophisticated short-range rockets that could be launched from a submerged submarine. Those rockets were successfully demonstrated at Toplitz See, Austria. The rockets and testing equipment were all destroyed at the end of the war as American forces approached. After the war, though, U.S. Navy investigators interrogated several of the engineers who were involved in the project and wrote a report about their work [NavTecMisEu 500-45]. See pp. 5183–5188.

- Also based on the 1942 tests and the proposal by Lafferenz, engineers from Peenemünde began working on the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines. For examples from a large collection of 1944 design drawings [Bundesarchiv Militärarchiv Freiburg RH 8/4067K], see pp. 5189–5197. Although in Dornberger's postwar public statements he said that nothing ever came of the project, it is unclear how far the project may have actually progressed. There were reports that at least one Prüfstand XII unit may have been constructed and tested before the end of the war.

- As described in earlier documents (pp. 5161–5170), there were also wartime programs to launch modified V-1 cruise missiles from German submarines.

These and other wartime German projects were continued in other countries after the war, with the aid of German-speaking scientists and captured German hardware and plans:

- Beginning in February 1947, Loon missiles, U.S. copies of German V-1 cruise missiles [Quigg 2014], were launched from the USS *Cusk* submarine, based on wartime German developments and implemented by German-speaking scientists at Point Mugu Naval Air Missile Test Center. See p. 5170.

- As part of Operation Sandy, the U.S. Navy launched an A-4 (V-2) rocket from the deck of the USS Midway on 6 September 1947, demonstrating that an A-4 rocket could indeed be transported and launched at sea (p. 5204).

- German-speaking scientists and technologies were used to develop a series of more advanced U.S. cruise missiles beginning in the late 1940s (pp. 1843–1847).

- Wernher von Braun's team was directly involved in developing Jupiter, a liquid propellant ballistic missile designed to be launched from submarines (but ultimately only deployed on land; see p. 1890).

- German-speaking scientists were deeply involved in the development of U.S. solid propellant submarine-launched ballistic missiles (SLBMs) in ways that have never been fully disclosed to the public (pp. 1895–1897 and 5243–5278).

- In 1962, Robert Truax at Aerojet proposed to greatly scale up the "Prüfstand XII" approach to create the Sea Dragon, a sea-launched rocket that would have been larger than even a Saturn V (p. 5198).

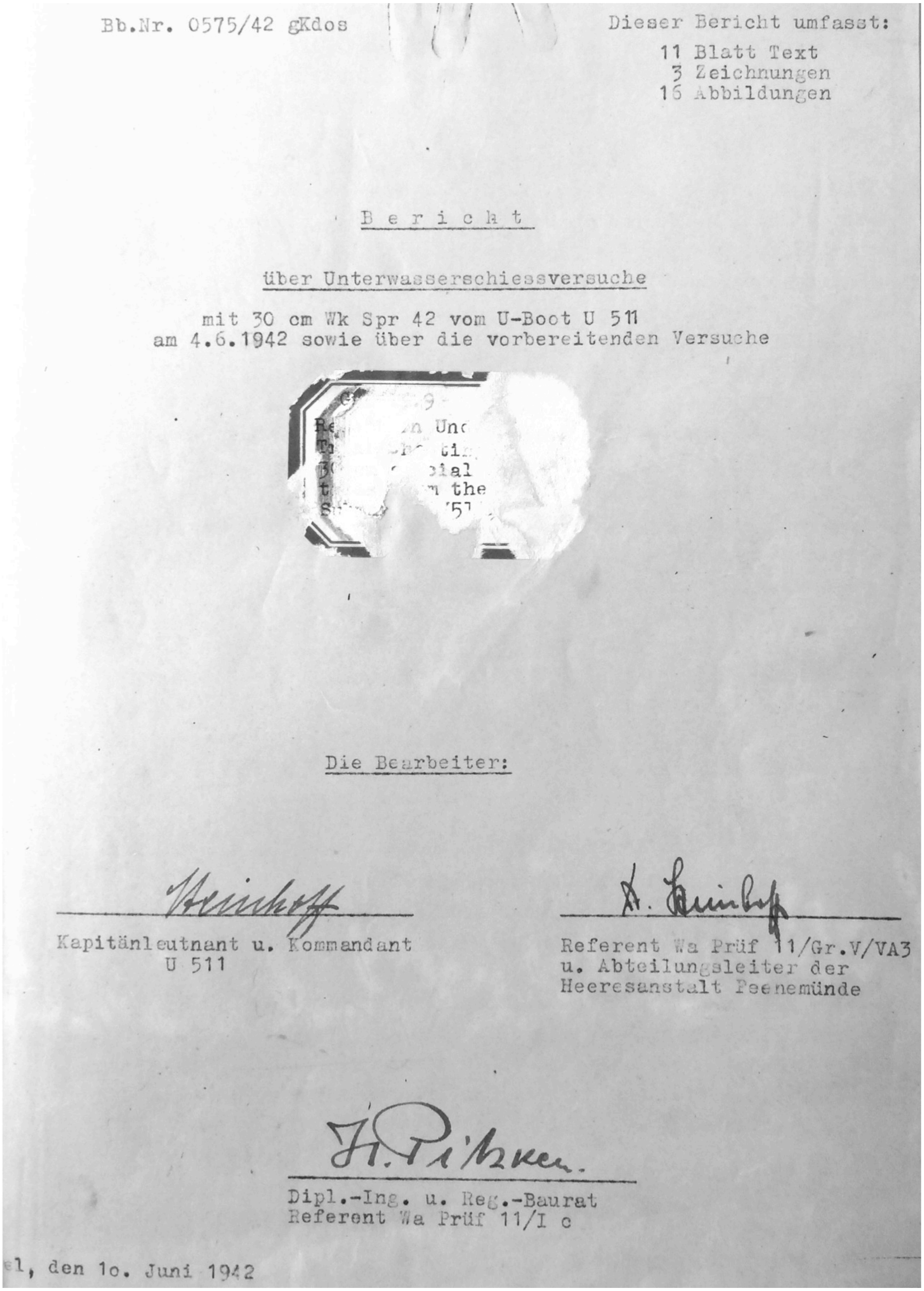
- The Soviet Union also investigated versions of the "Prüfstand XII" approach as part of its postwar Golem program to develop SLBMs.[7]

- The first deployed Soviet SLBM, the R-11FM Zemlya (SS-1B SCUD-A), was directly based on the German Wasserfall (first launched in 1944). Like the Wasserfall, it used storable liquid propellants. The R-11FM was first launched from a submarine on 16 September 1955. See pp. 1891–1892.

- Later generations of Soviet SLBMs, such as the R-13 (SS-N-4, first launched in 1959) and R-21 (SS-N-5, first launched in 1962) were scaled up from the R-11FM and again were directly based on German-developed technologies and propellants (p. 1893).

- German-speaking scientists and technologies likely also had a great impact on the postwar submarine-launched missile programs of other countries (e.g., p. 5203).]

[7] https://www.globalsecurity.org/wmd/world/russia/golem.htm



Bb.Nr. 0575/42 gKdos

Dieser Bericht umfasst:
11 Blatt Text
3 Zeichnungen
16 Abbildungen

B e r i c h t

über Unterwasserschiessversuche

mit 30 cm Wk Spr 42 vom U-Boot U 511
am 4.6.1942 sowie über die vorbereitenden Versuche

Die Bearbeiter:

Kapitänleutnant u. Kommandant
U 511

Referent Wa Prüf 11/Gr.V/VA3
u. Abteilungsleiter der
Heeresanstalt Peenemünde

Dipl.-Ing. u. Reg.-Baurat
Referent Wa Prüf 11/I c

...el, den 1o. Juni 1942

Figure E.186: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Bb.Nr.0575/42 gKdos. Seite 5

Kapt.Ltn. Mäckel
beim BDU

und Oberleutnant Grundke
Nachrichtenreferent beim 2.Admiral der U-Boote.

Ausserdem waren

vom OKH Wa Prüf 11/Ic
Reg.Baurat Dipl.-Ing. Pietzken
und Ing. Gronwald, OKH Wa Prüf 11/III

von der Heeresanstalt Peenemünde

Oberst Dipl.-Ing. Zannsen
Oberstleutnant Dipl.-Ing. Stegmaier
Hauptmann Stölzel
Dr. v. Braun
und Dr. Steinhoff

zugegen.

Im Anschluss an dieses Schiessen wurde zwischen dem 2. Admiral der U-Boote und der HAP abgesprochen, dass die nächsten Schiessversuche von U-Boot U 511 stattfinden sollen und dieses U-Boot nach Abschluss der praktischen Übung und Erledigung des Abhorchens der Sondereinbauten bei dem U-Bootstützpunkt Stettin durchgeführt werden sollen. Diese Einbauten wurden in der Zeit vom 31.5. - 4.6. in Stettin durchgeführt. Es wurden 4 Abschussgestelle für insgesamt 16 30 cm Wk Spr 42 hinter dem Turm des U- Bootes so angebracht, dass die Schussrichtung der an Backbord auf den Torpedotransportschienen montierten Gestelle nach Steuerbord und die auf den Transportschienen steuerbordseitig angebrachten Abschussgestelle eine unter 90° zur Bootslängsachse ausgerichtete Schussrichtung nach Backbord ergab. Die Zündanlage wurde im Turm des U- Bootes angebracht und durch die vorhandene wasserdichte Durchführung zunächst am Turm herunter und dann unter Deck bis zu den Abschussgestellen geführt. An den Durchführungen am Turm befindet sich jeweils ein Verteilerkasten, ausserdem wurden durch die Oderwerft Stettin jeweils in der Höhe des Geschosses druckwasserdichte doppelpolige Steckdosen verlegt.

Figure E.187: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

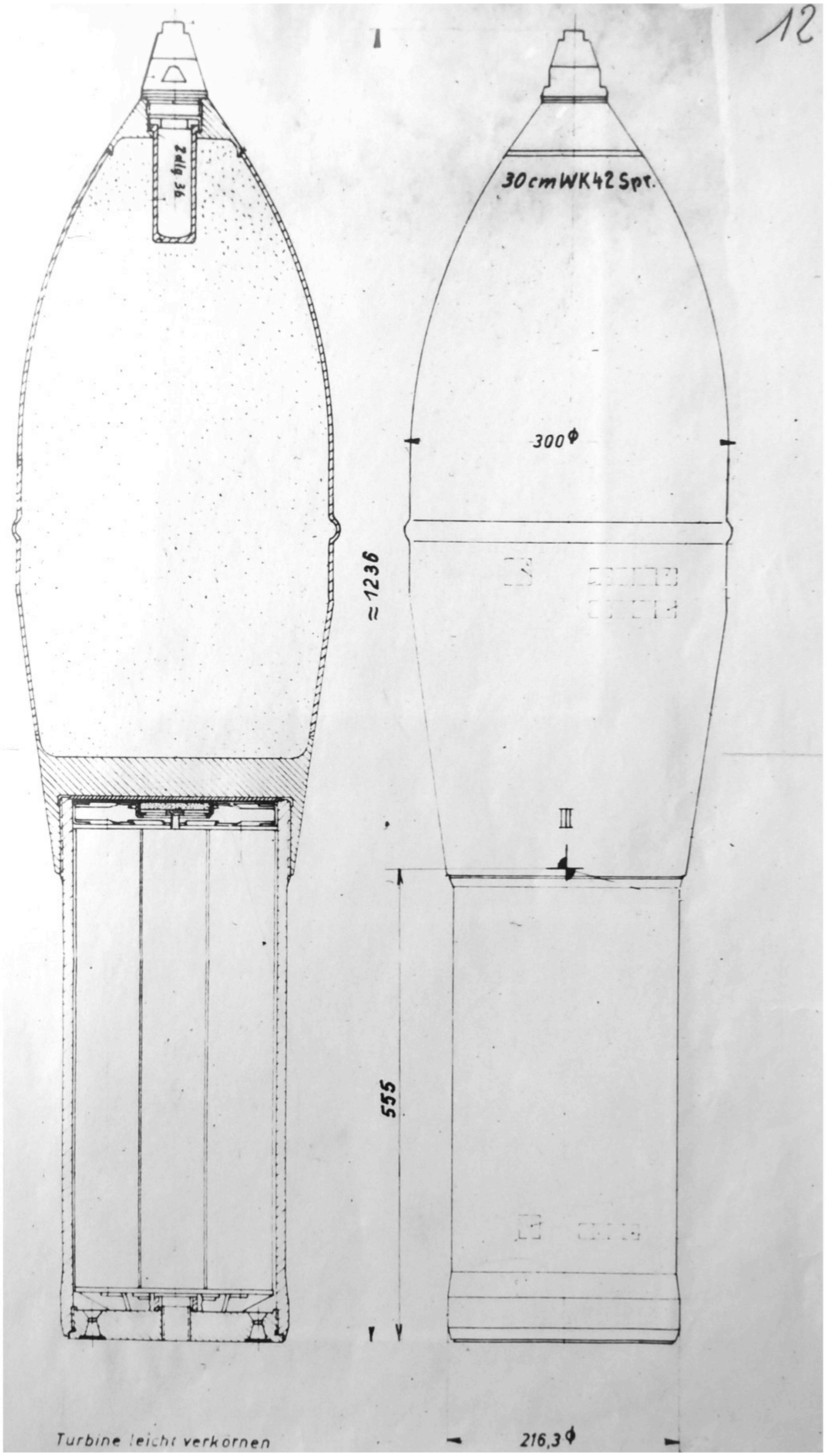


Figure E.188: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Abb. 2: 30 cm WK Spr. 42 im Packgefäss auf dem Wurfrahmen montiert.

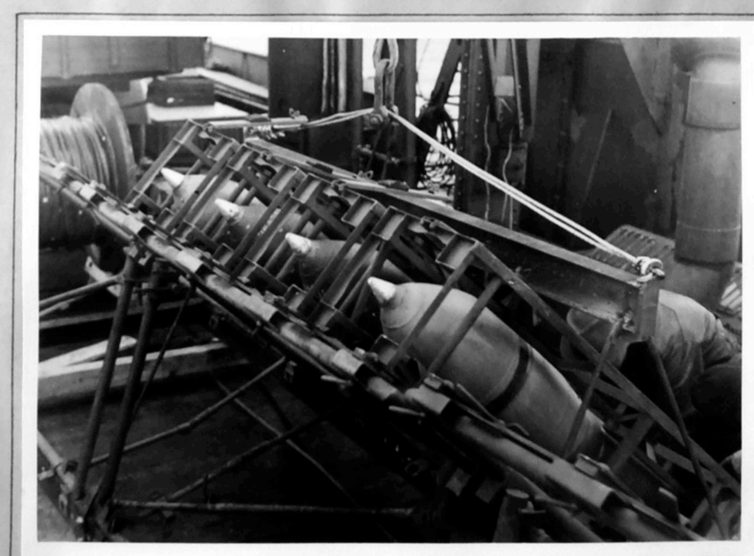


Abb. 3: Wurfrahmen mit 4 Packgefässen mit 30 cm WK Spr. 42 beladen.

Figure E.189: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

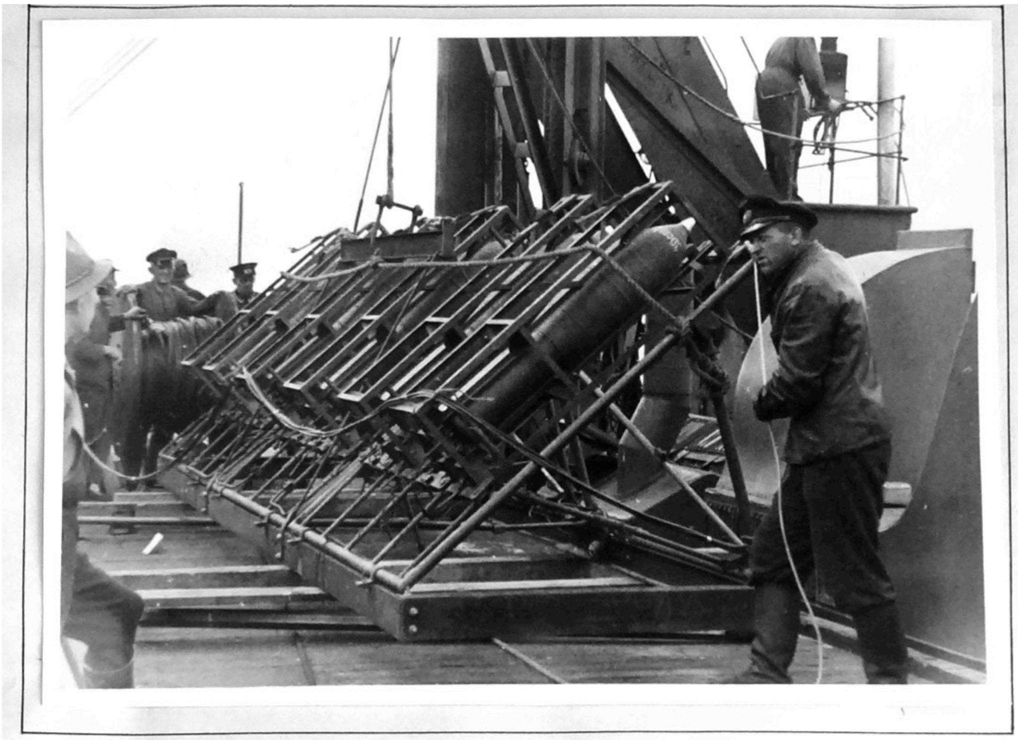


Abb. 4

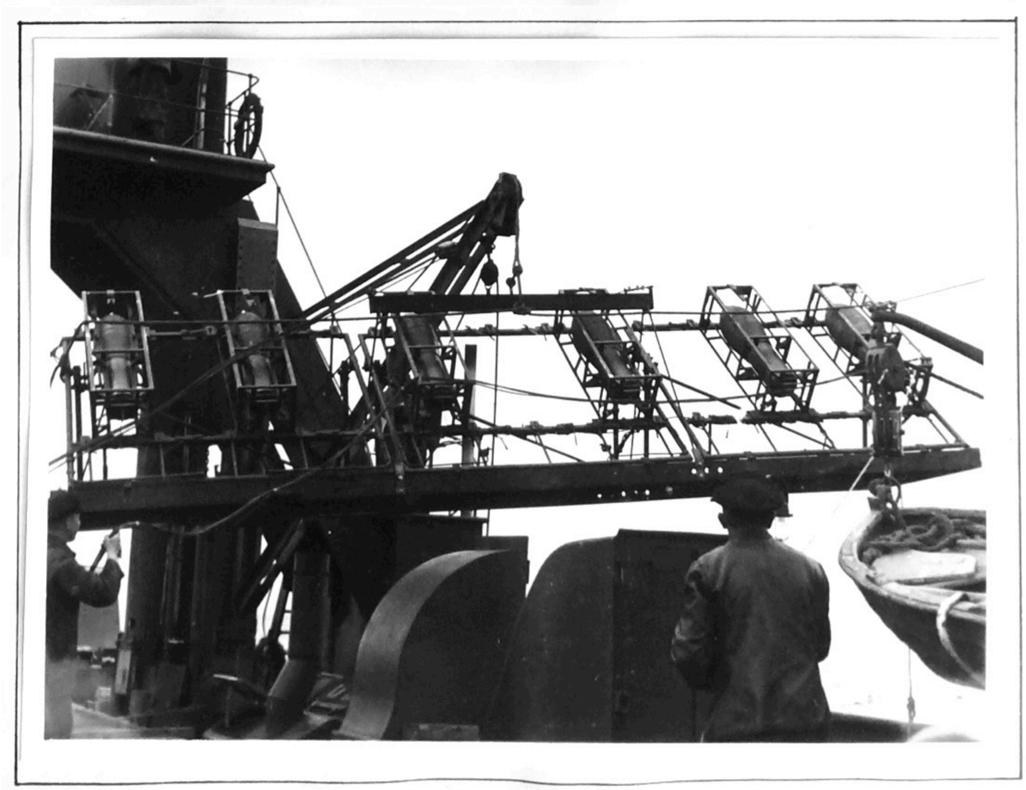


Abb. 5

Figure E.190: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Abb. 6: Vorbereitung der Unterwasserschiessversuche am 14.5.42

Abb.7: Anbringung der Abschussgestelle auf U 511 am 4.6.1942.

Figure E.191: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

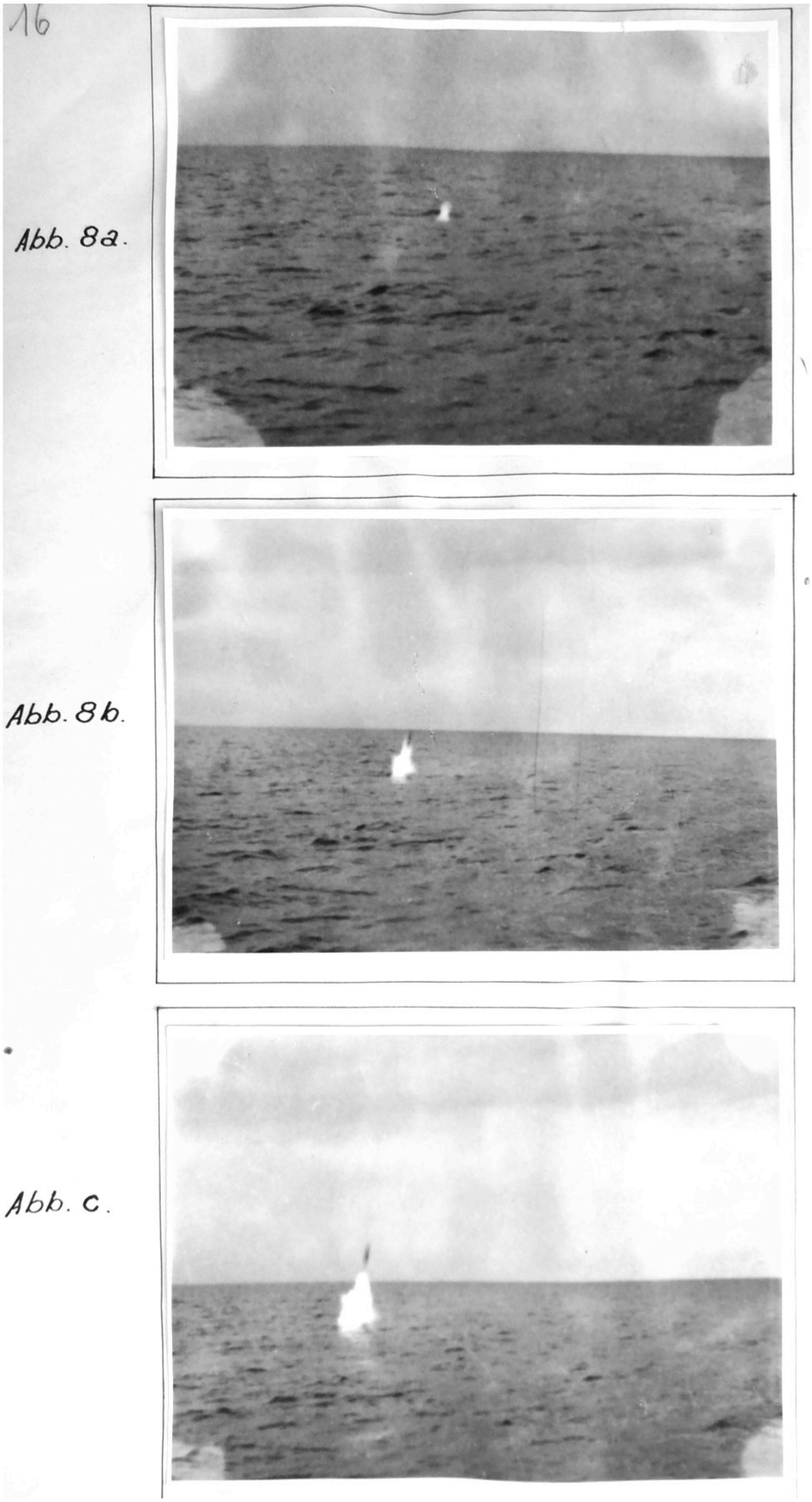


Figure E.192: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

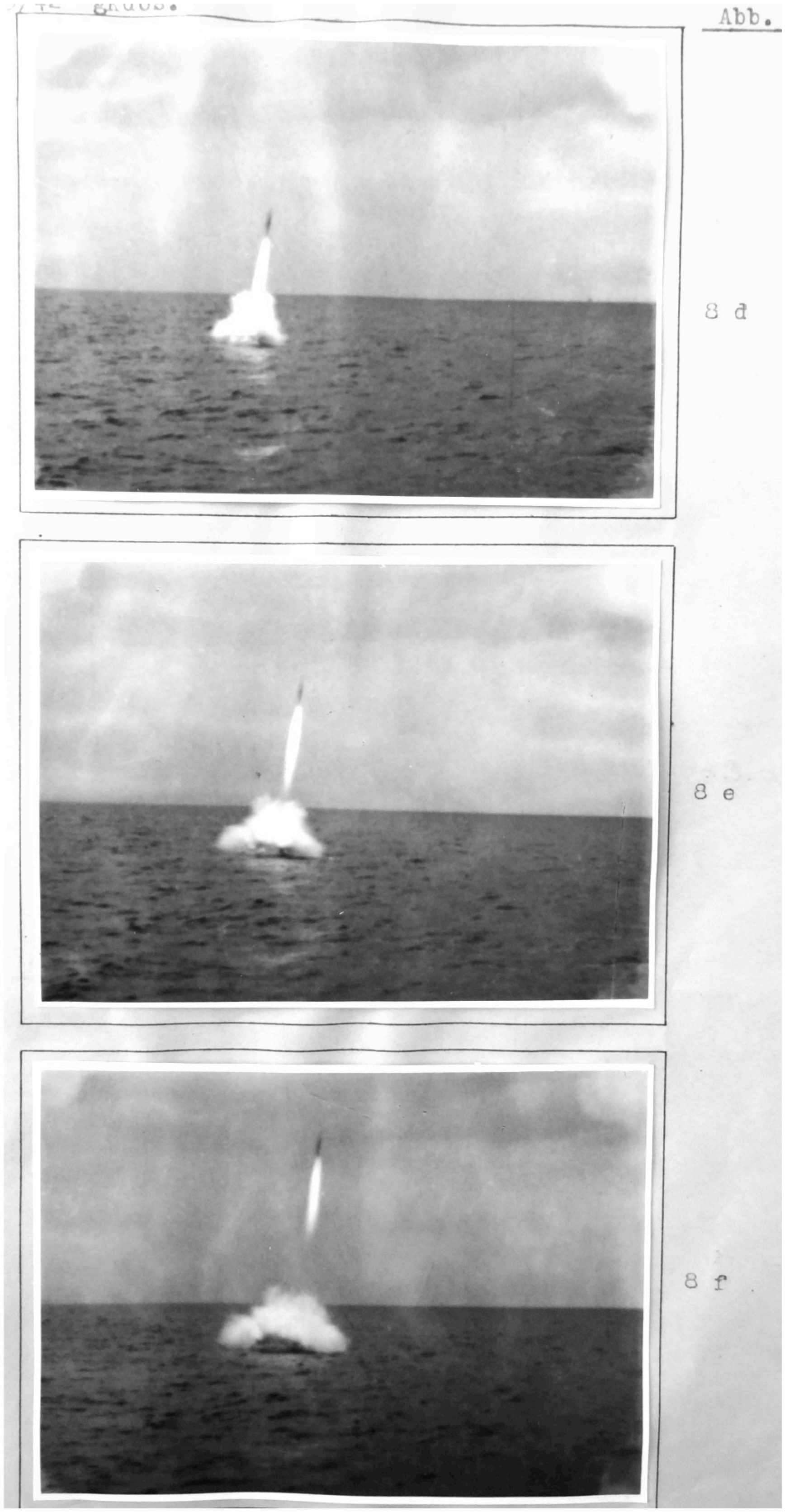


Figure E.193: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

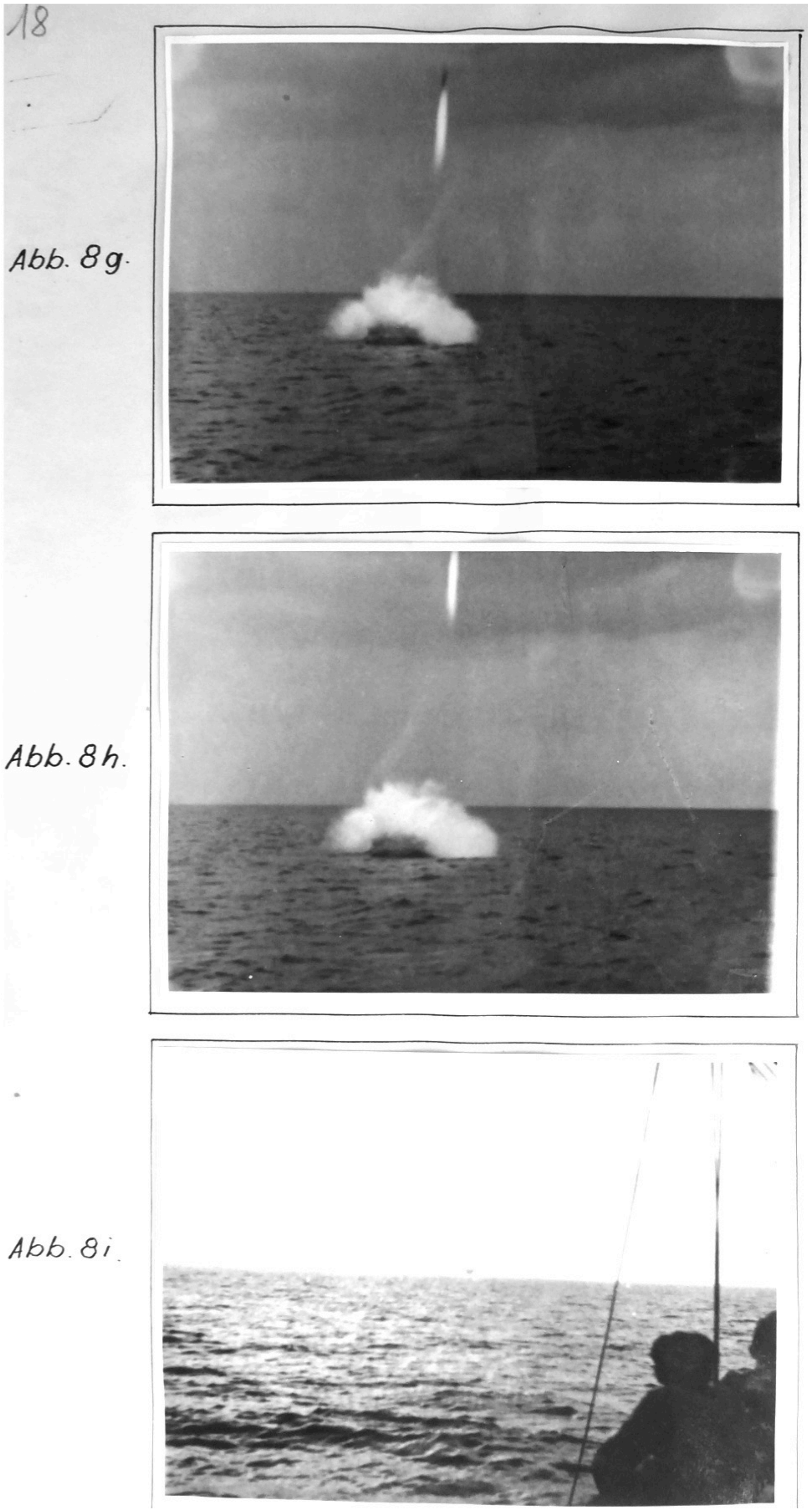


Figure E.194: Selected pages from a June 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

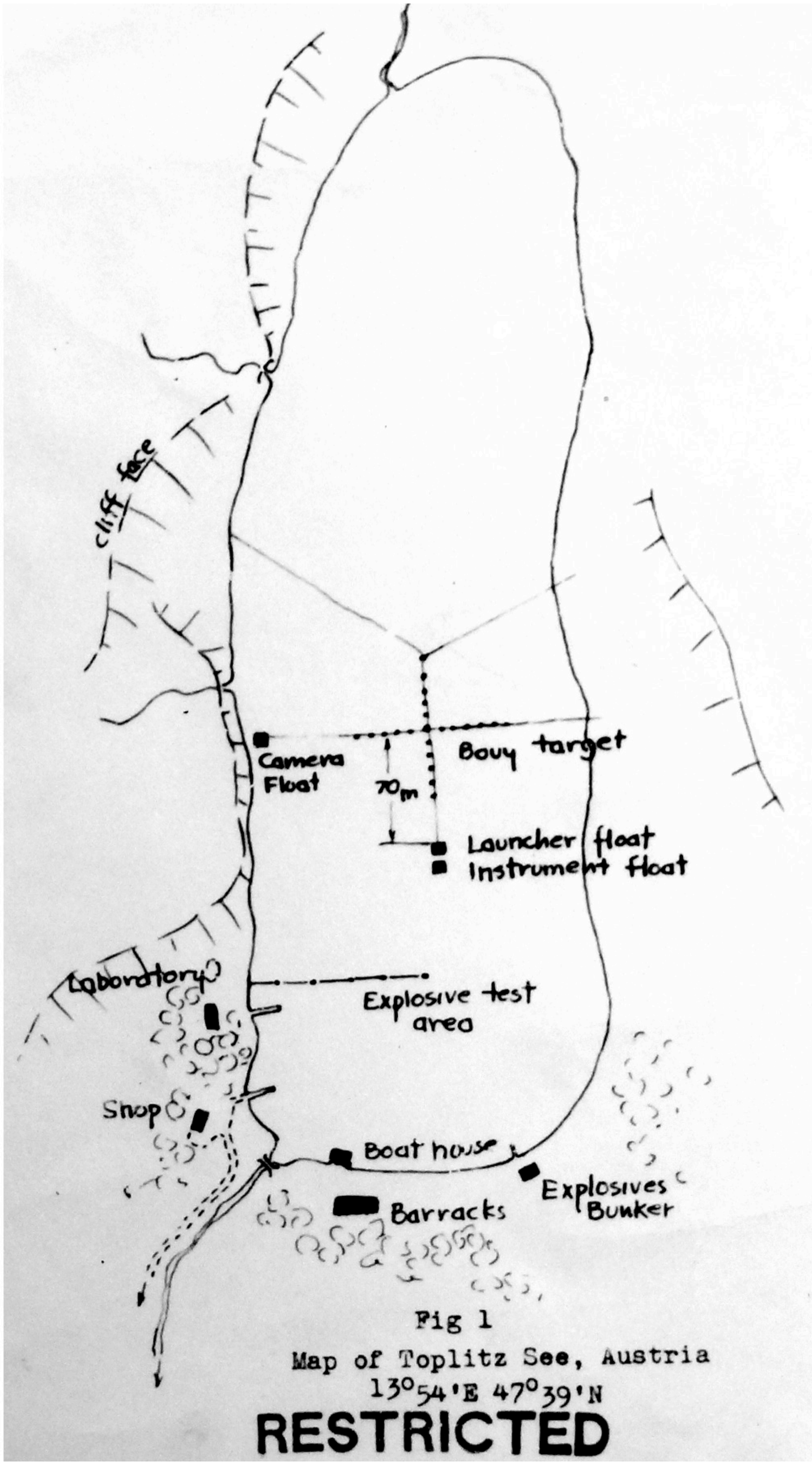


Figure E.195: Drawings from a postwar report on a long series of increasingly sophisticated submarine-launched rockets that were developed 1942–1945 and successfully demonstrated at Toplitz See, Austria [NavTecMisEu 500-45].

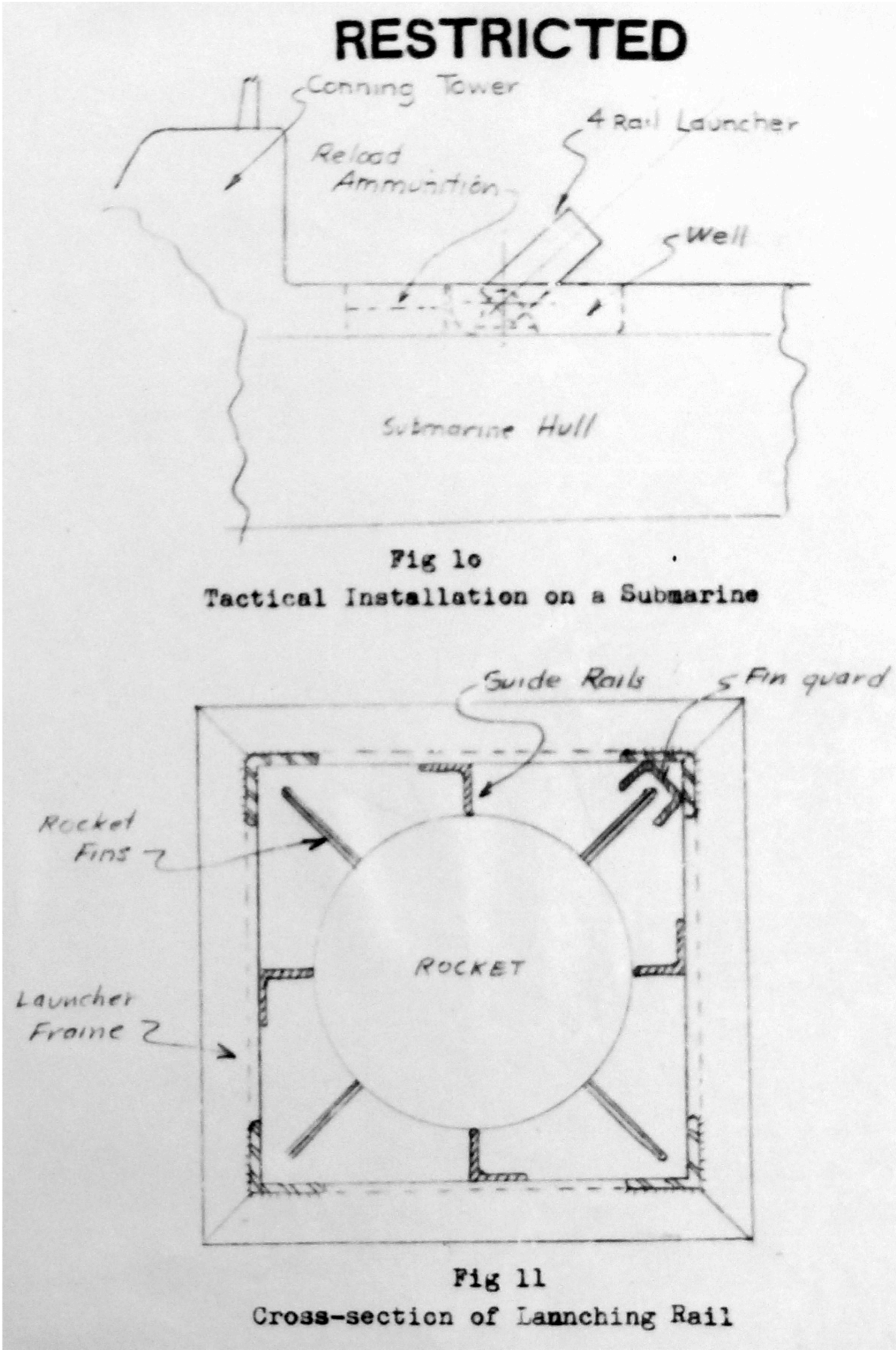


Figure E.196: Drawings from a postwar report on a long series of increasingly sophisticated submarine-launched rockets that were developed 1942–1945 and successfully demonstrated at Toplitz See, Austria [NavTecMisEu 500-45].

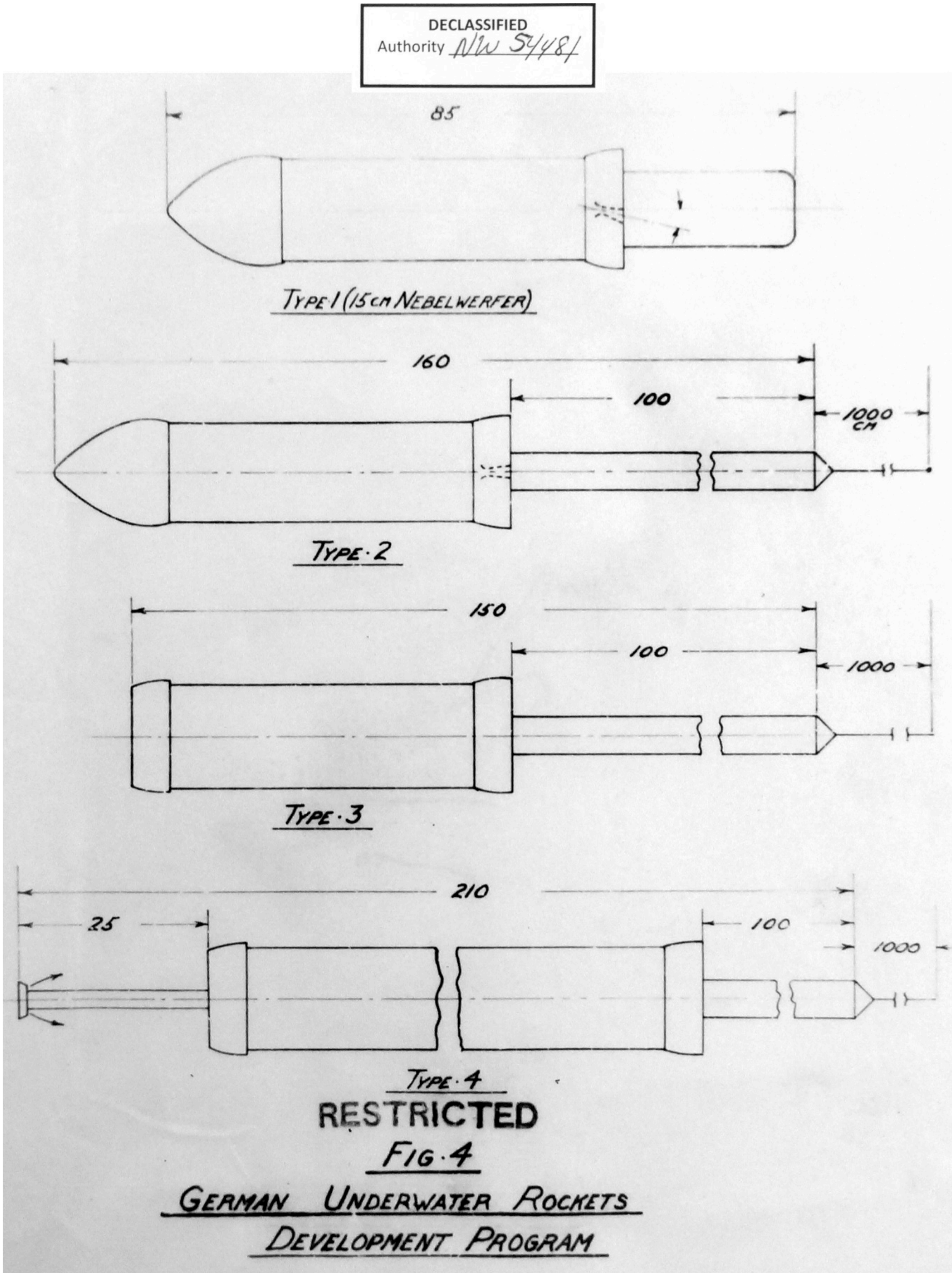


Figure E.197: Drawings from a postwar report on a long series of increasingly sophisticated submarine-launched rockets that were developed 1942–1945 and successfully demonstrated at Toplitz See, Austria [NavTecMisEu 500-45].

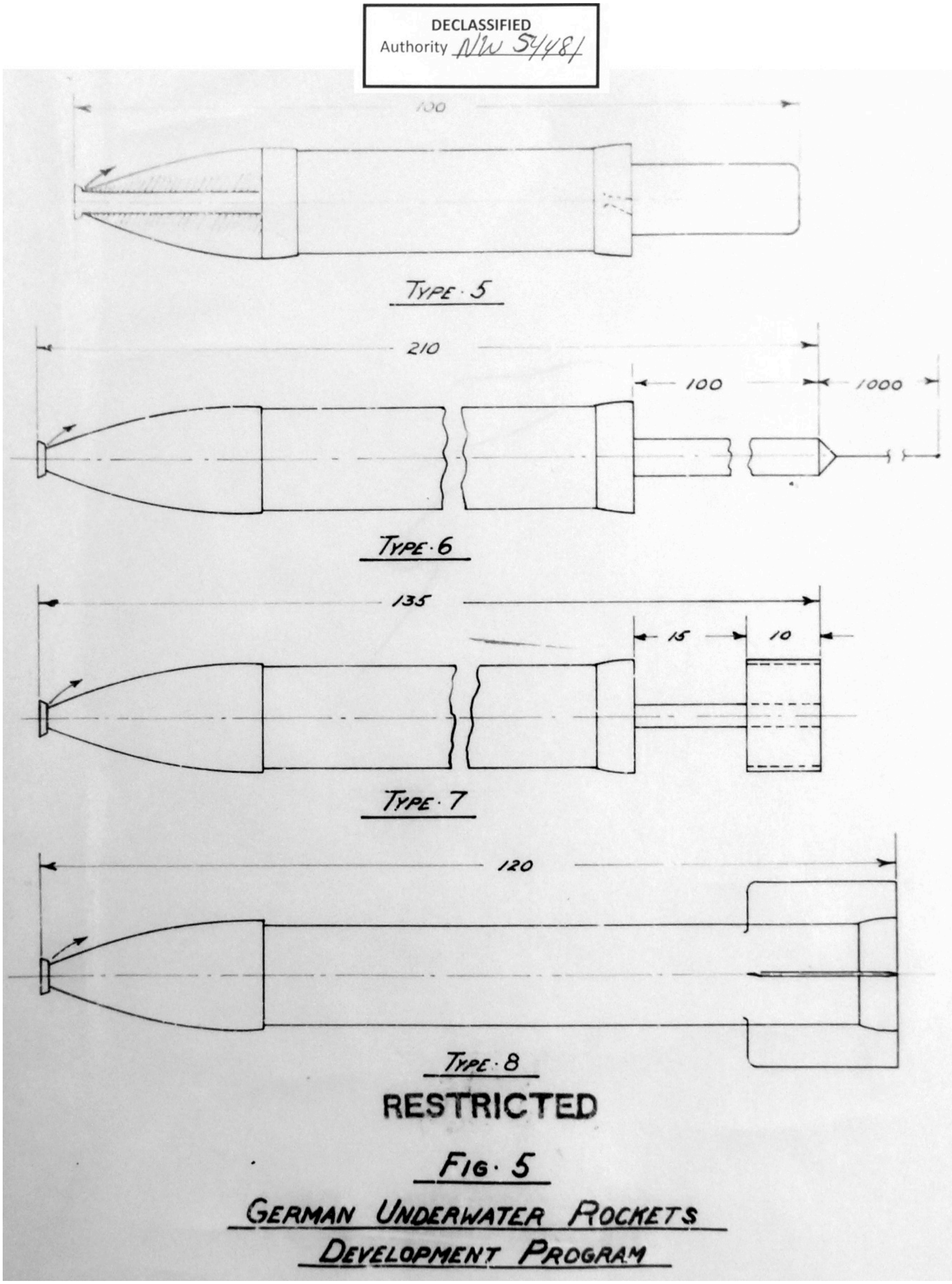


Figure E.198: Drawings from a postwar report on a long series of increasingly sophisticated submarine-launched rockets that were developed 1942–1945 and successfully demonstrated at Toplitz See, Austria [NavTecMisEu 500-45].

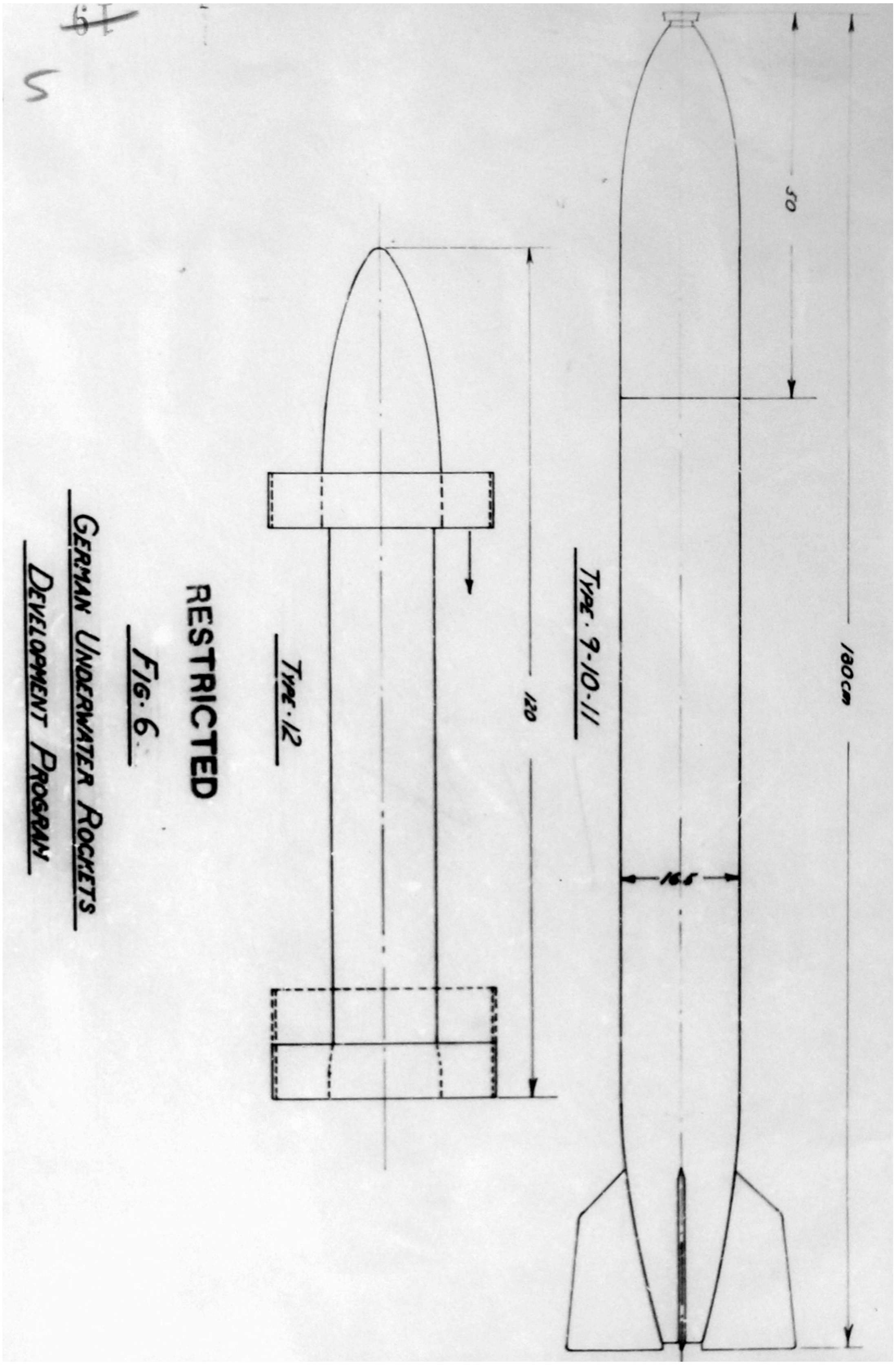


Figure E.199: Drawings from a postwar report on a long series of increasingly sophisticated submarine-launched rockets that were developed 1942–1945 and successfully demonstrated at Toplitz See, Austria [NavTecMisEu 500-45].

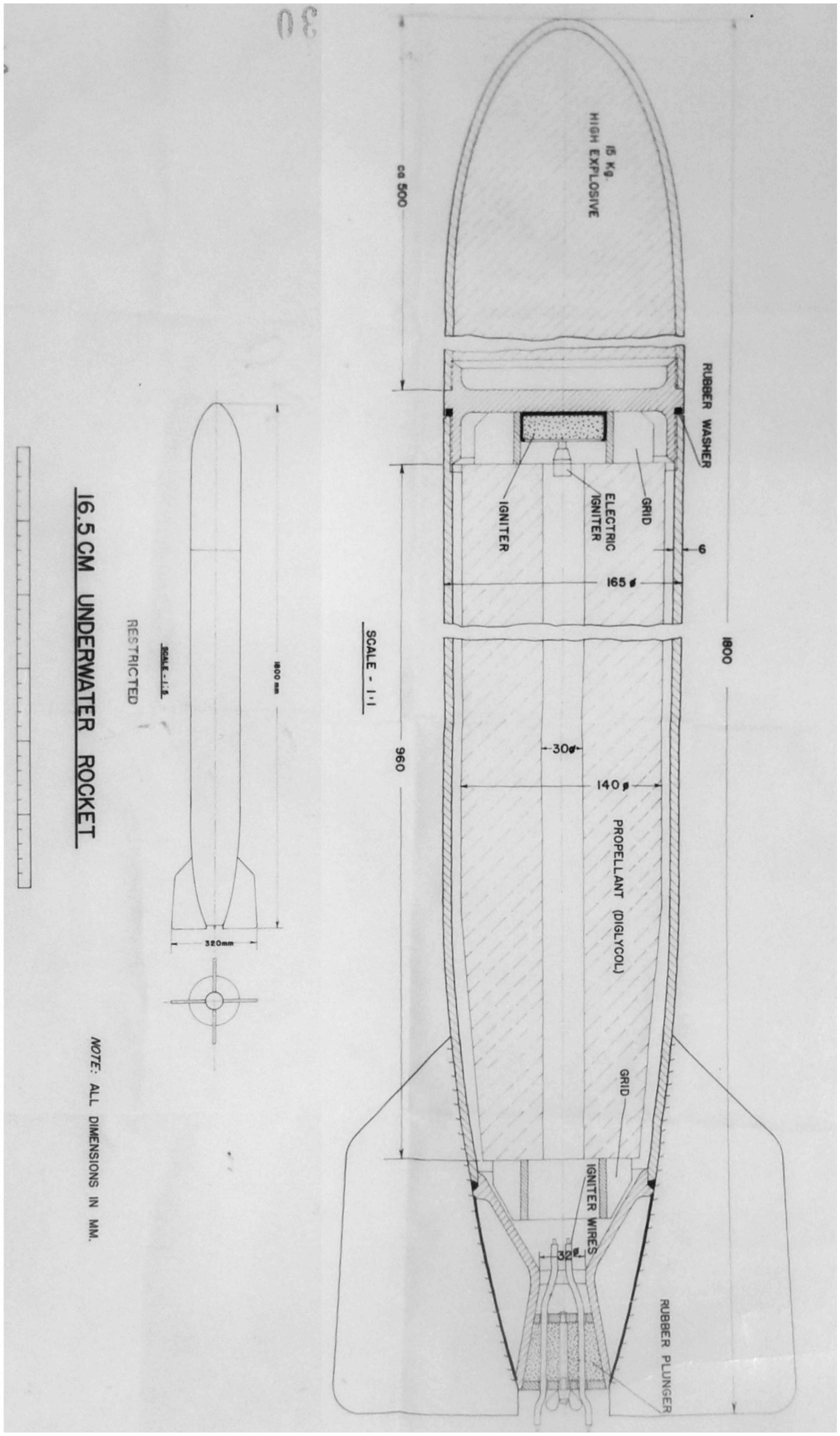


Figure E.200: Drawings from a postwar report on a long series of increasingly sophisticated submarine-launched rockets that were developed 1942–1945 and successfully demonstrated at Toplitz See, Austria [NavTecMisEu 500-45].

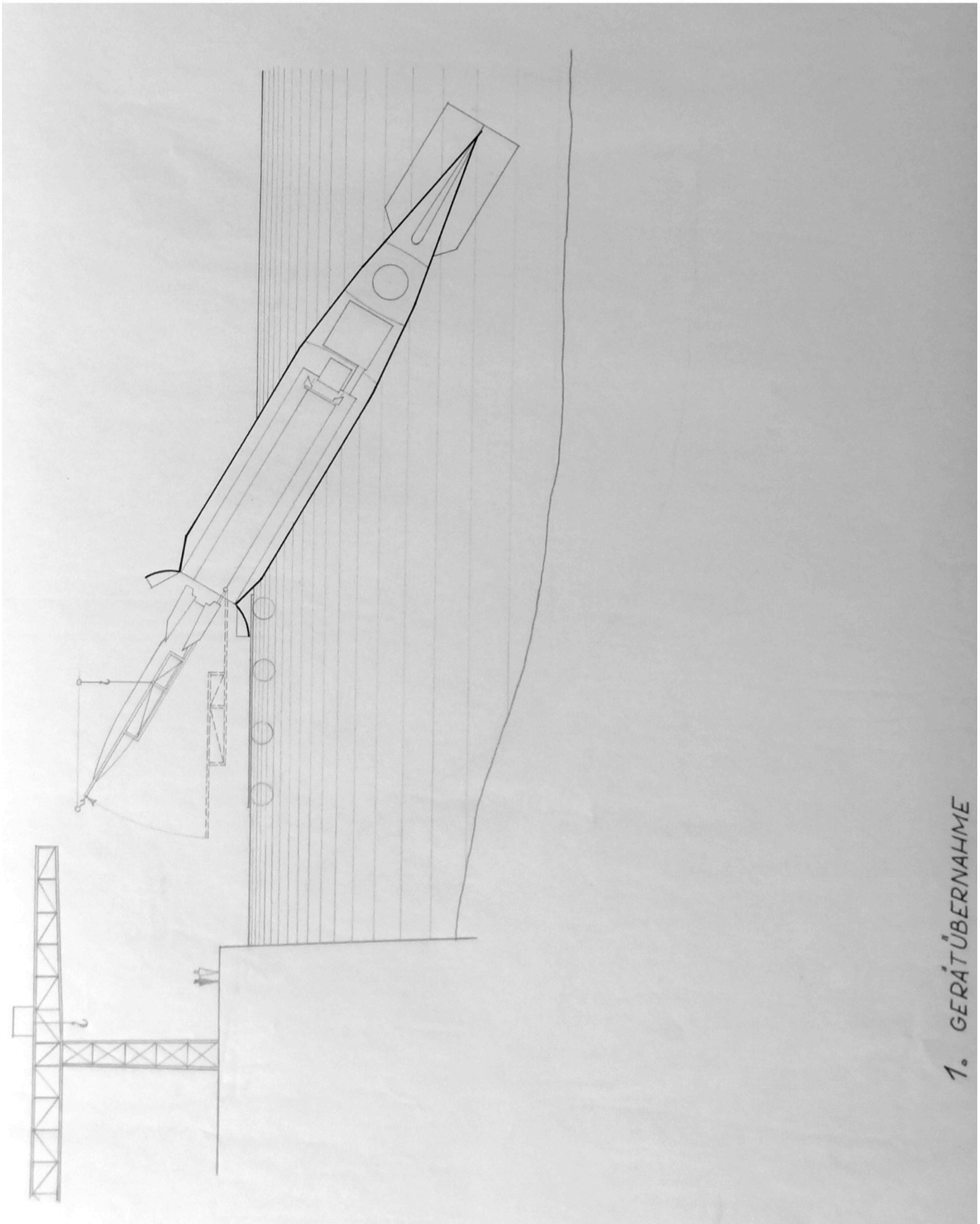


Figure E.201: 1944 drawings from the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

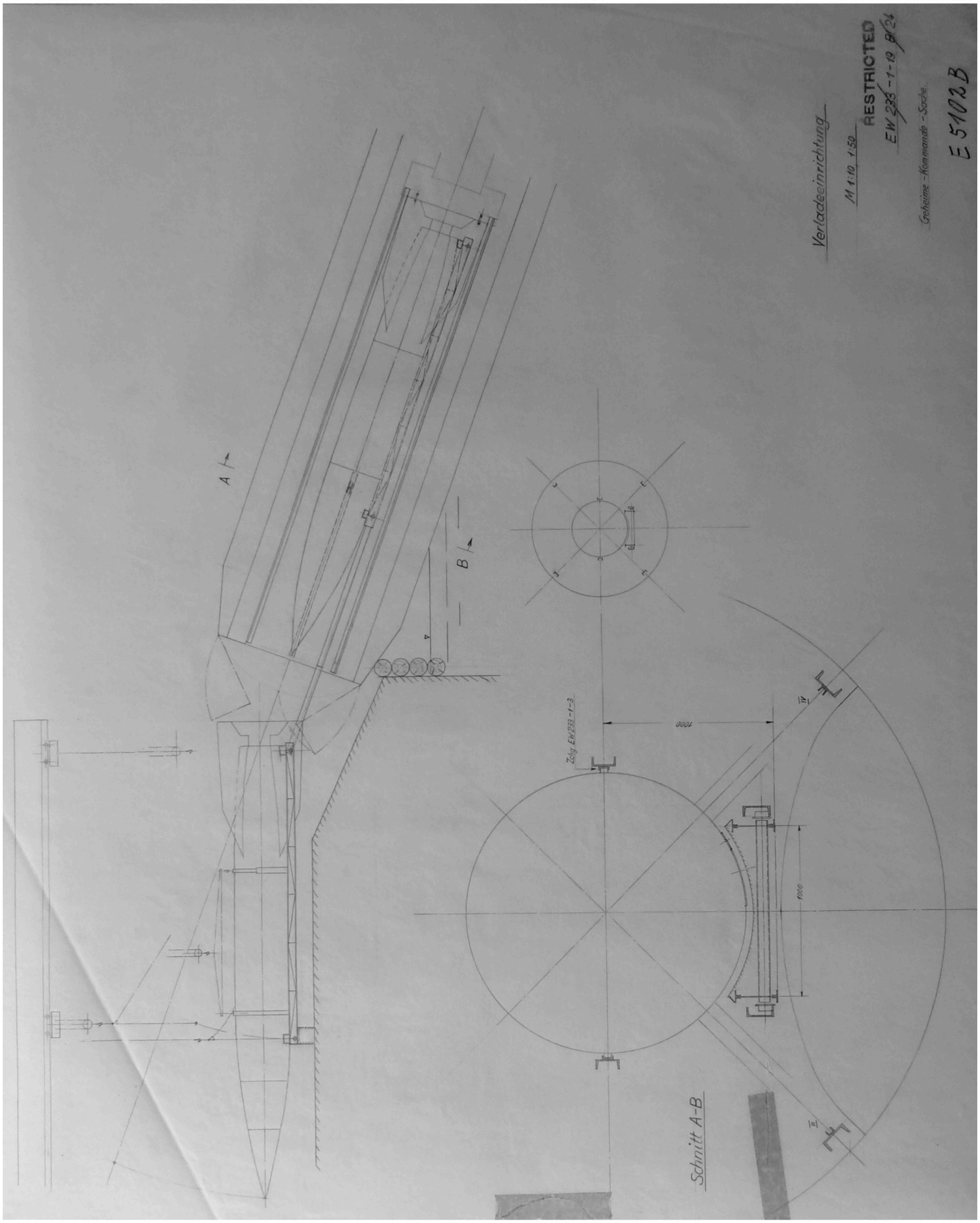


Figure E.202: 1944 drawings from the “Prüfstand XII” project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

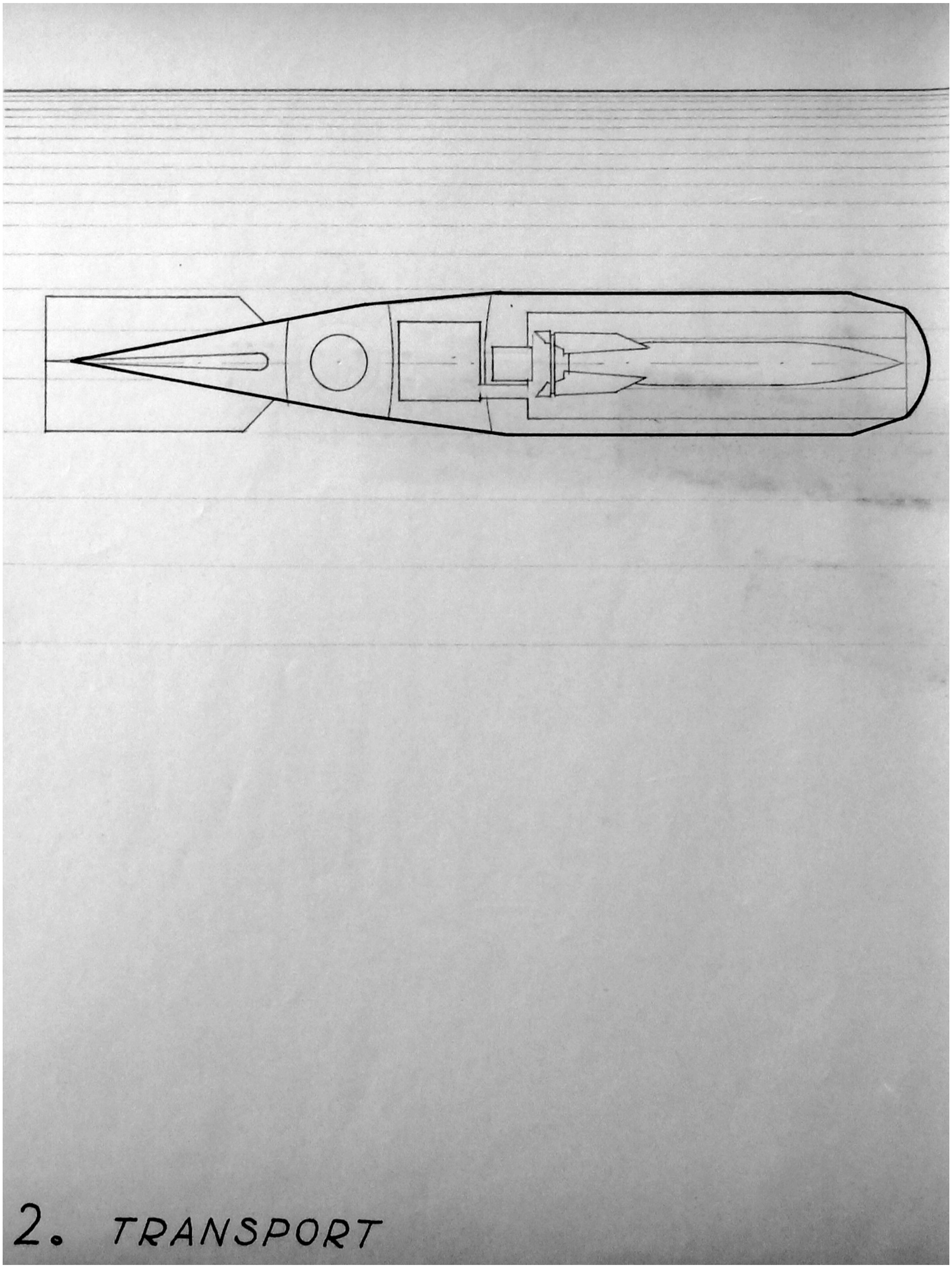


Figure E.203: 1944 drawings from the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

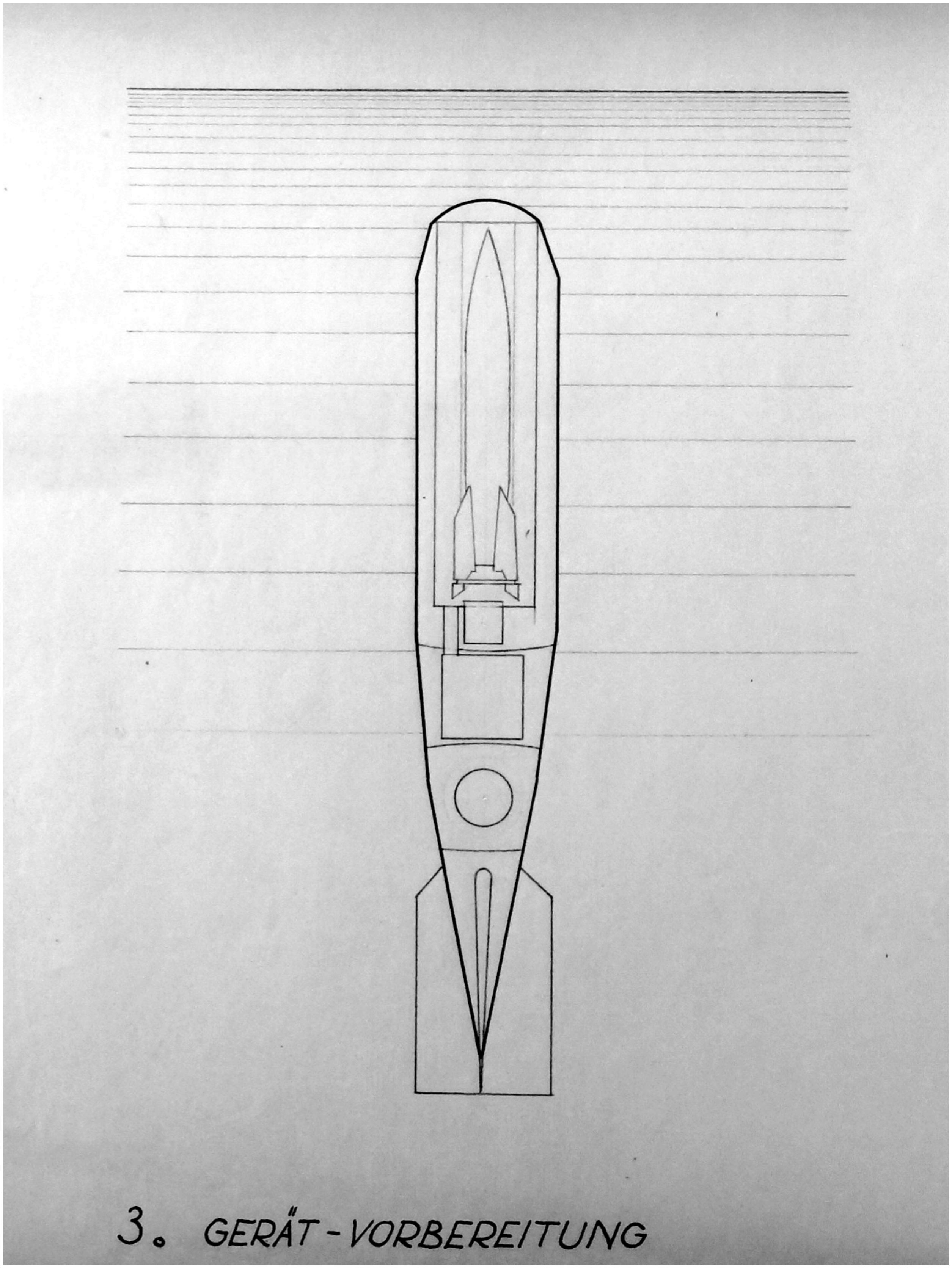


Figure E.204: 1944 drawings from the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

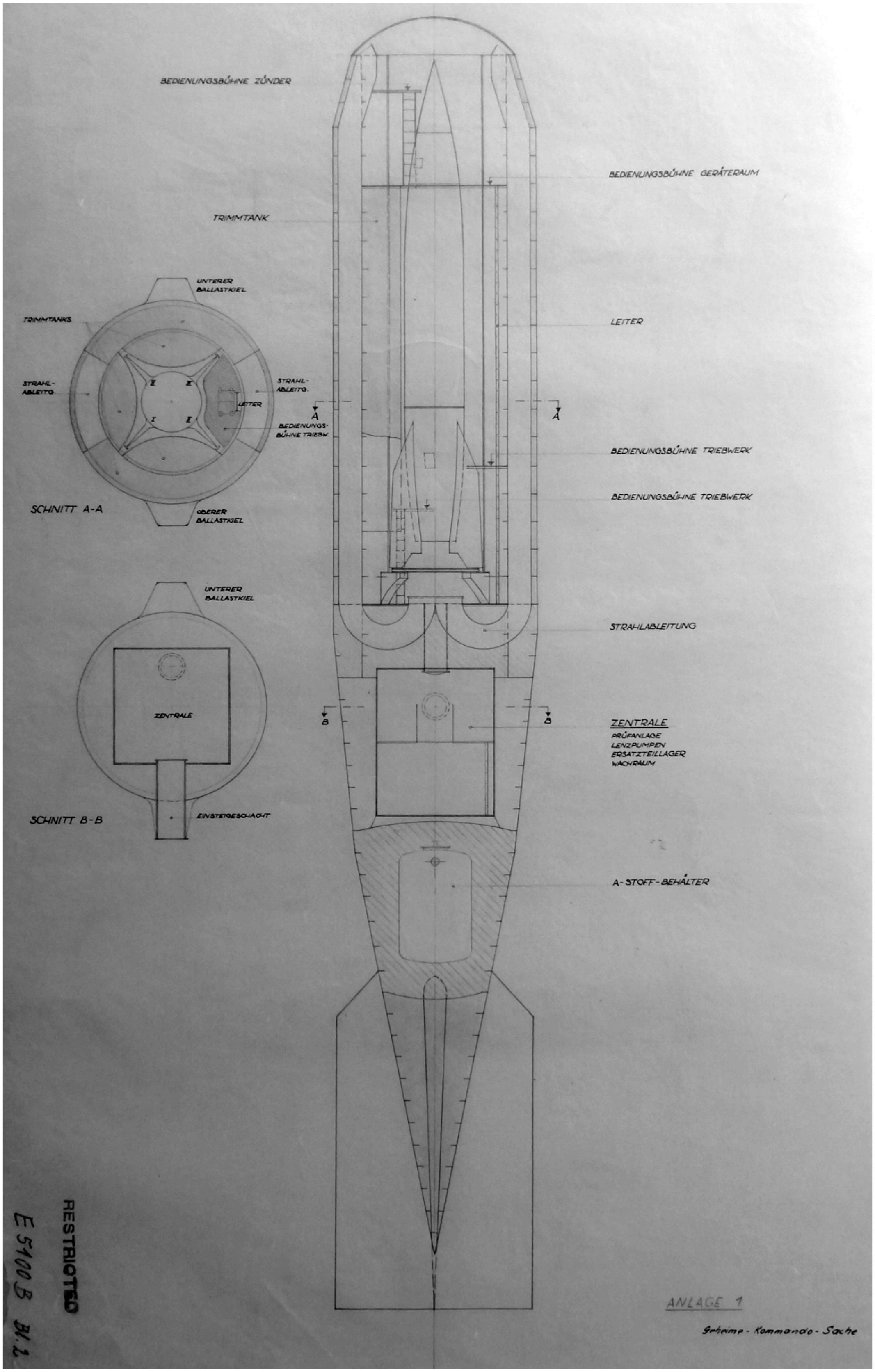


Figure E.205: 1944 drawings from the “Prüfstand XII” project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

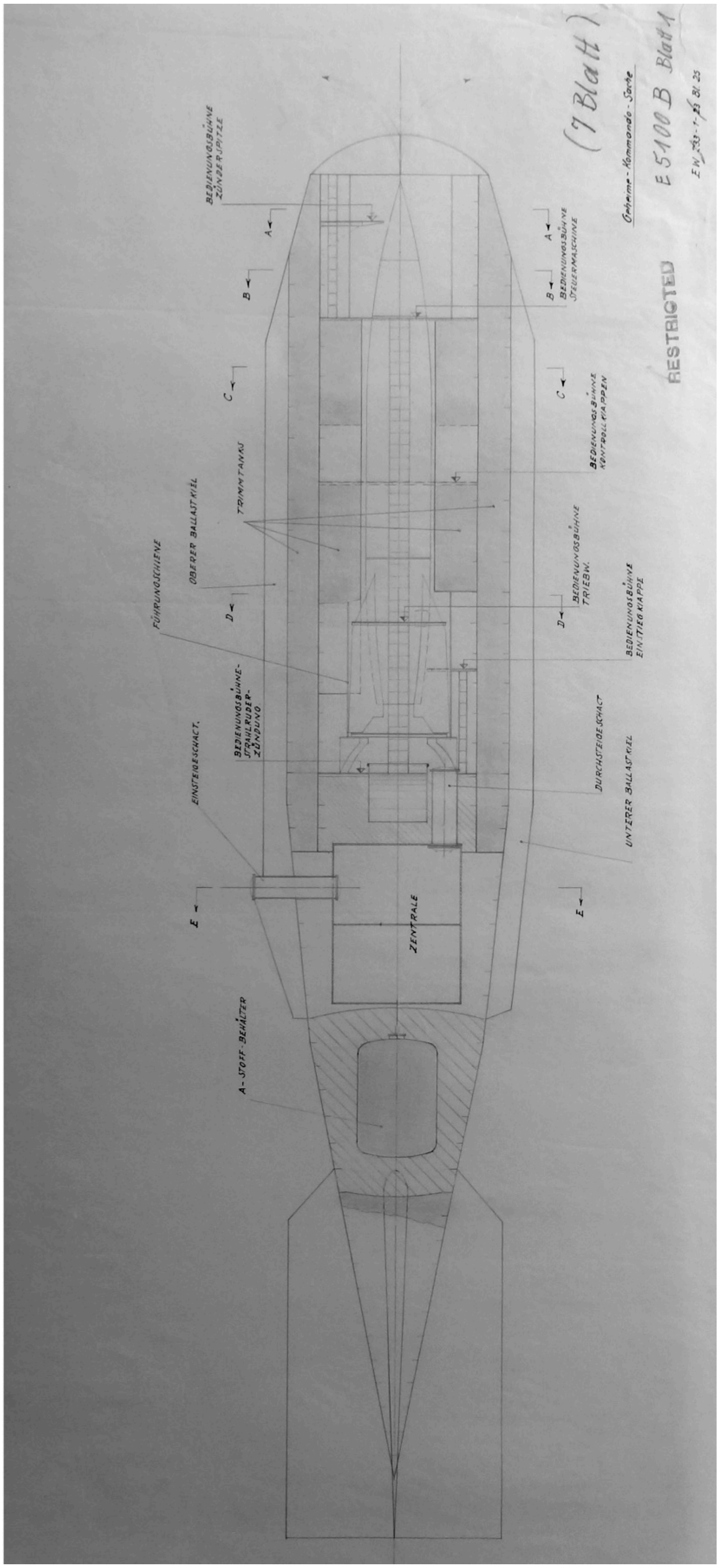


Figure E.206: 1944 drawings from the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

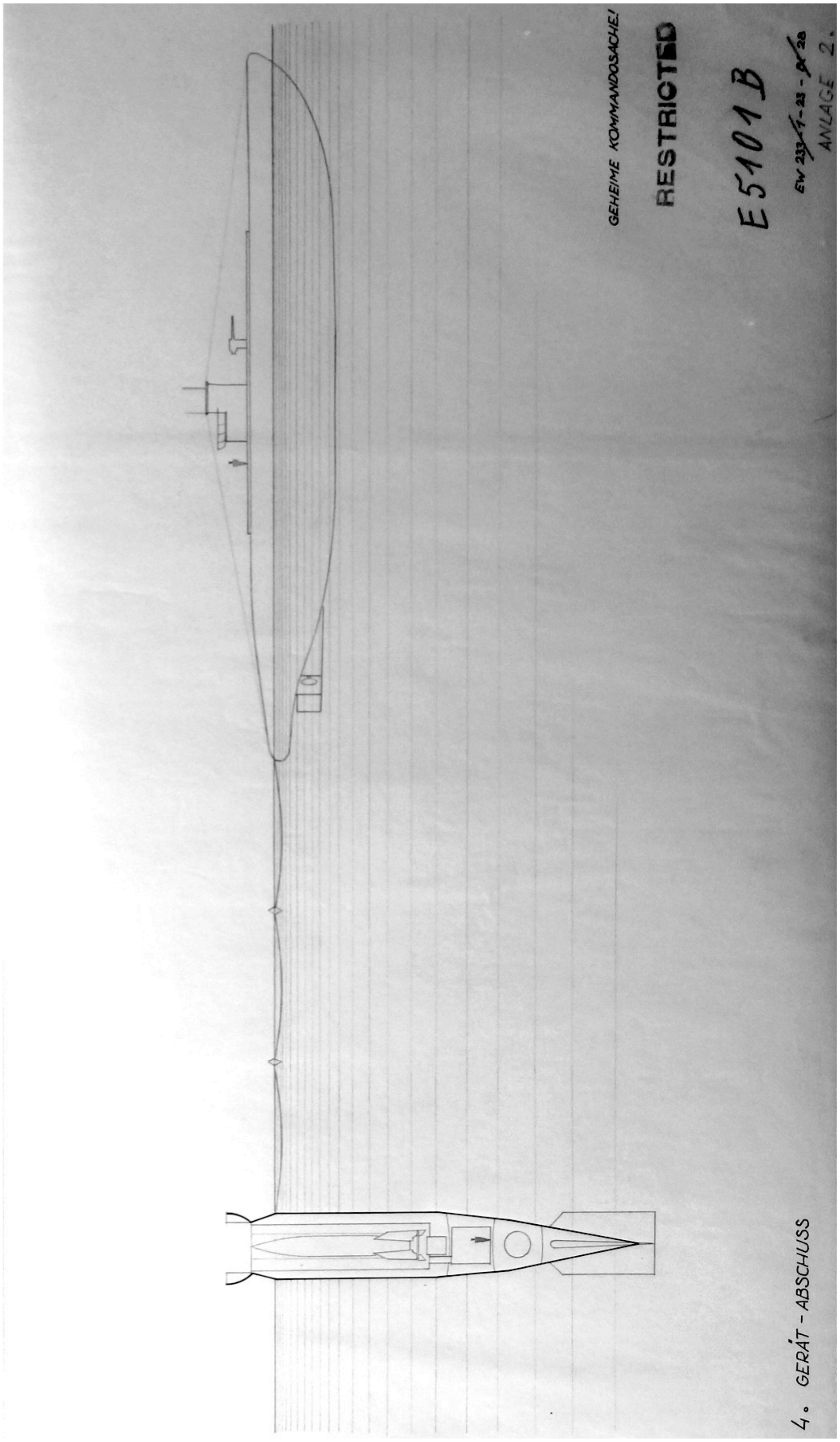


Figure E.207: 1944 drawings from the “Prüfstand XII” project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

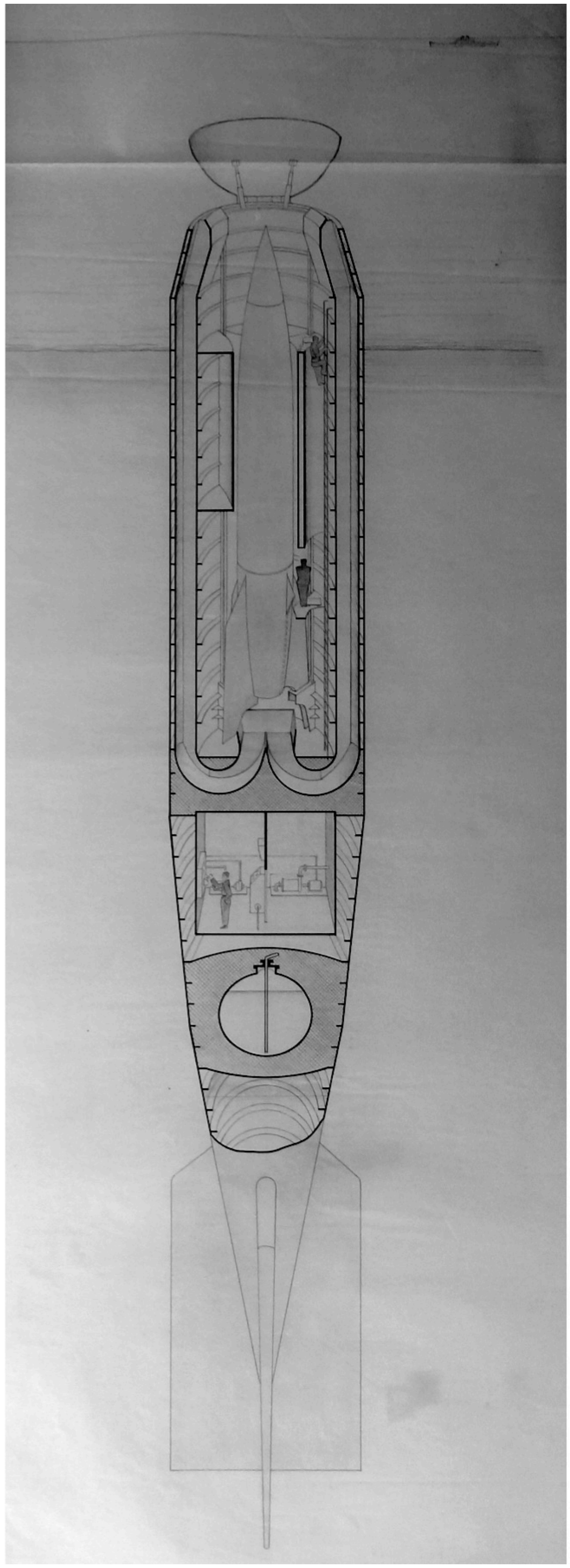


Figure E.208: 1944 drawings from the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

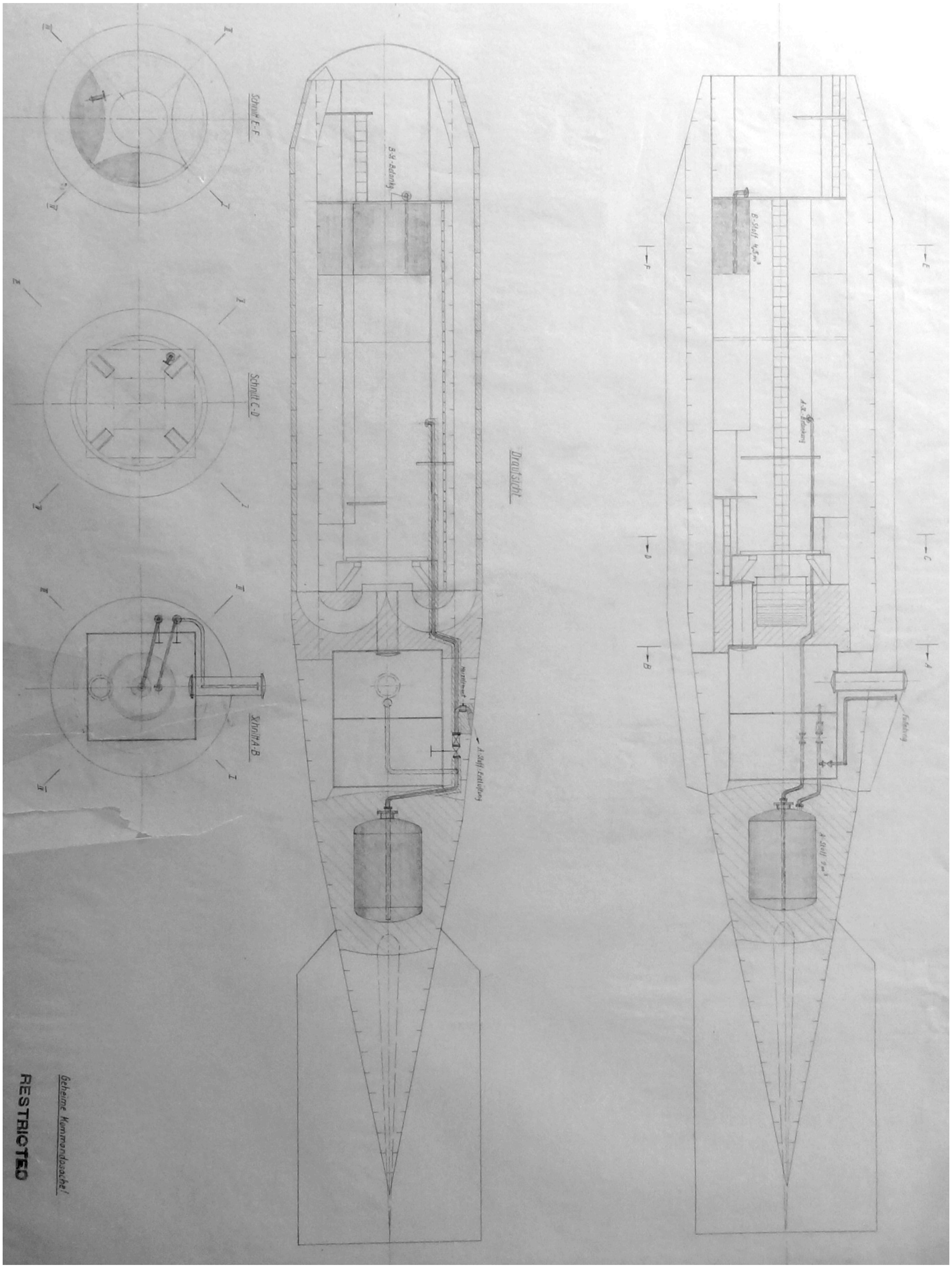


Figure E.209: 1944 drawings from the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

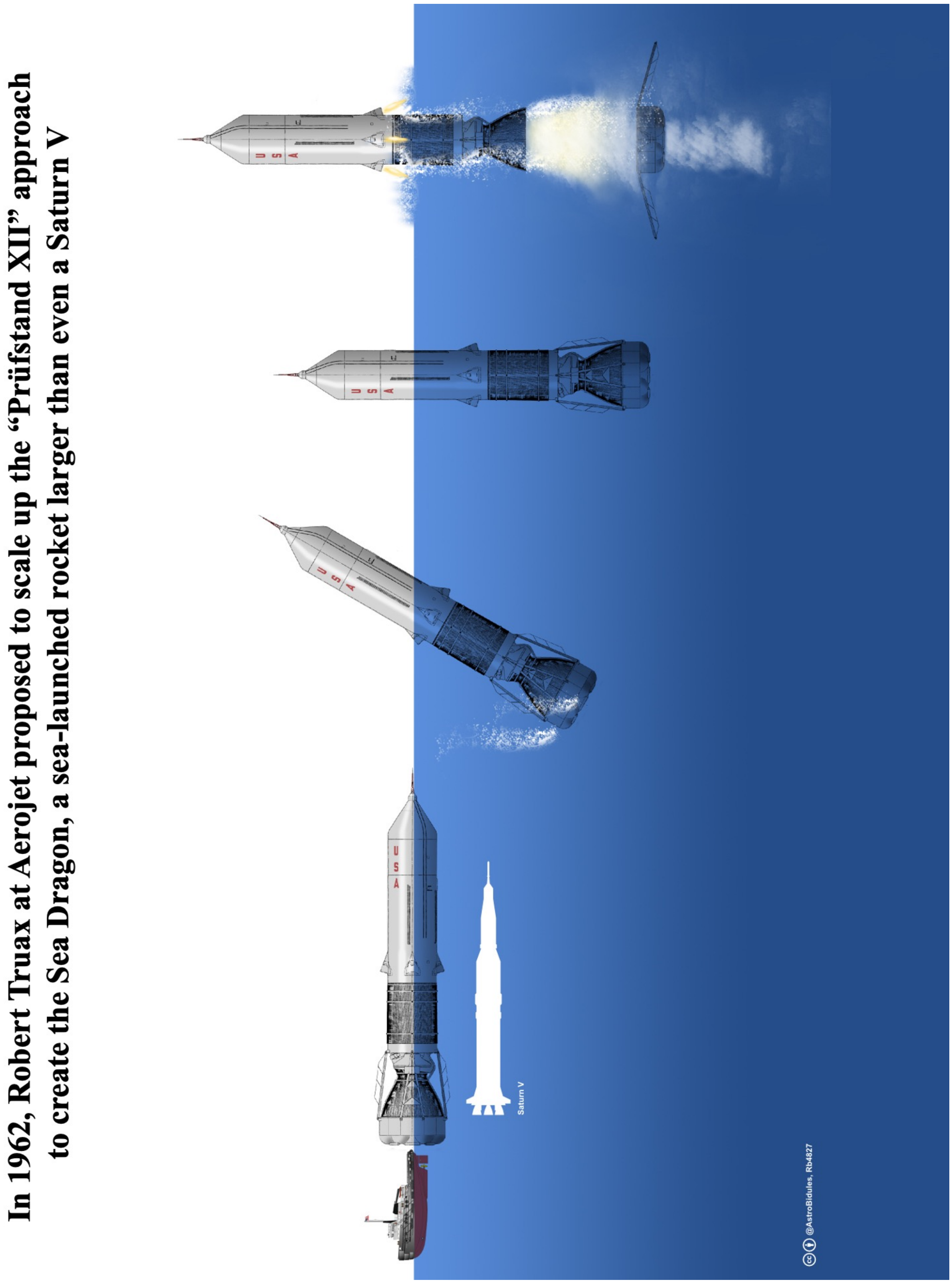


Figure E.210: In 1962, Robert Truax at Aerojet proposed to greatly scale up the “Prüfstand XII” approach to create the Sea Dragon, a sea-launched rocket that would have been larger than even a Saturn V.

Fritz Hahn. 1998. *Waffen und Geheimwaffen des deutschen Heeres 1933-1945.* 3rd ed. Bonn: Bernard & Graefe. p. 172

Das System konnte natürlich nicht für die große A 4-Fernrakete angewendet werden. Aber auch für einen derartigen, zum Beschuß der amerikanischen Küste geplanten Einsatz fand man eine Lösung. U-Boote sollten die Rakete in einem 500 t großen Behälter von 32 170 mm Länge und 5500 mm Durchmesser in die Nähe der gegnerischen Küste schleppen. Dort wollte man das Heck dieses Behälters so weit fluten, daß er, nun senkrecht stehend, etwa 5 m aus dem Wasser herausstand. Mit den im Behälter vorhandenen Treibstoffen wollte man dann die Rakete auftanken. Kreiselstabilisiert hätte das sicherlich eine ausreichende Platform für den vom U-Boot durch Funk ausgelösten Abschuß ergeben. Ein Problem wäre der Verlust an Sauerstoff durch die Verdunstung geworden, denn das U-Boot wäre bei 12 sm etwa 30 Tage unterwegs gewesen.

Der Unterwasserschlepp wurde mit U 1063 erprobt und zeigte kaum Probleme. Für den Einsatz waren die Elektro-Boote vom Typ XXI vorgesehen. Die ersten Besprechungen zur Lösung der technischen Fragen führte Dr. Dickmann von der mit dem Bau beauftragten *Stettiner Vulkan-Werft* am 9. Dezember 1944—die drei begonnen Muster sind aber nicht mehr fertig geworden.

Of course, this system [small sub-launched rockets] could not be used for the large A-4 long-range rocket. But a solution was also found for such an operation planned for the American coast. Submarines were to tow the rocket in a 500 ton container of 32.17 m length and 5.5 m diameter near the enemy coast. There they wanted to flood the stern of this container so far that it, then standing vertically, protruded about 5 m out of the water. They wanted to fuel the rocket with the propellant contained in tanks. Stabilized by gyroscopes, this would surely have provided a sufficient platform for the launch controlled by radio from the submarine. A problem would have been the loss of oxygen by the evaporation, because the submarine would have required 12 sm or about 30 days for the voyage.

The underwater towing was tested with U-1063 and showed hardly any problems. The electric boats of type XXI were intended for use. The first discussions for the solution of the technical questions were held by Dr. Dickmann of the *Stettiner Vulkan-Werft* on 9 December 1944—the three started samples were not finished anymore.

[Fritz Hahn did not cite sources for the information in his books, but he was very closely connected to people who were involved in advanced military projects.

It is true that cryogenic liquid oxygen, the usual oxidizer for A-4 rockets, would have been difficult to keep from evaporating during a long sea voyage. However, wartime Germany developed storable, noncryogenic oxidizers such as nitrogen tetroxide (N_2O_4) and inhibited red fuming nitric acid (IRFNA) that could have been used instead of liquid oxygen in an A-4 rocket.]

Deutsches U-Boot-Museum. U 511 and Missiles: U 511, U 1063 and plans for U-boats armed with seabased missiles. [**https://dubm.de/u-511-and-missiles/?lang=en**]

Also, the vision, born after the US entered the war, to fire at the US an advanced multiple stage version of the V-2 (the project A-9/A-10 with ranges of more than 5,000 km) gained some momentum following a proposal brought forward by a director of the "Deutsch Arbeitsfront" (= German Labor Front, a sort of national socialistic controlled trade union), Otto Lafferenz. After a visit of the facilities at Peenemünde and a meeting with the Military Commander, Major General Walter Dornberger, in the Autumn of 1943, he proposed to develop floating containers to accommodate V-2s and to tow them by U-boats before the US Eastern coast, to fire at New York and other area targets utilizing on their range up to 300 km. This arms project now called "Lafferenz-Project" (somewhat irritating, various authors in historic writing use other project names such as "Schwimmweste" = "Life Vest", "Apparat F", or "Prüfstand XII" = "Test Stand XII") was consequently developed further, and as a first step a floating container was invented able to transport and launch, to be towed by U-boats. The end status of the concept envisaged an operation, where up to three containers were towed simultaneously by U-boats across the Atlantic Ocean, to be erected in some distance before the coasts into a vertical firing position by partial flooding—and to launch the V-2s.

For that the Weapons Test Command No. 10 at Stetting developed a container with a length of about 32 meters, a diameter of about 5.5 meters and a displacement of some 300 tons, to be constructed at the Vulcan shipyard at Stettin. At the turn of 1944 to 1945 successful towing trials were actually executed using the type VII C/41 U-boat U 1063, which went through its basic and combat readiness training with the 5th U-boat (Training) Flotilla at Stetting at that time, after it had been commissioned on 08 July 1944 at the end of its construction by the Germania shipyard at Kiel. Following its training period until the end of February 1945 the U-boats came frontal unit as of 01 May 1945 at Bergen, Norway.

[Most books say that the Prüfstand XII project was only a paper design that was briefly considered and never progressed further. However, from the above and similar reports, it sounds as if at least one Prüfstand XII unit may have actually been constructed and tested. It is unclear how far the project may have actually progressed by the end of the war].

Joseph Mark Scalia. 2000. ***Germany's Last Mission to Japan: The Failed Voyage of U-234.*** **Annapolis, Maryland: Naval Institute Press. p. 84.**

American naval intelligence officials were determined to press Kessler for as much information as possible on the state of Germany's U-boat capability. While the Wehrmacht and the Luftwaffe had been virtually destroyed by the time of Germany's capitulation, Dönitz's submarine corps, rejuvenated by the potential of the revolutionary electric U-boats, remained a considerable threat. As a result, the export of German submarine technology to Japan constituted an immediate threat to the U.S. Navy. A major area of concern was Germany's alleged development of submarine ballistic-missile technology. Reports of the submerged launching of missiles prompted the ONI to question Kessler regarding the rumor of U-boats, stationed in Norway, that were able to launch a V-2 rocket while submerged.

Albert Ducrocq. 1947. *Les Armes Secrètes Allemandes.* Paris: Berger-Levrault. pp. 161–163.

D'ailleurs, outre le bombardement par A-9, les Allemands voulaient entreprendre le bombardement direct des côtes américaines au moyen de V-2 lancées par des sous-marins. C'était leur deuxième arme nouvelle contre l'Amérique. Elle devait entrer en action en même temps que la A-9, c'est-à-dire au début de l'été 1945...

What is more, in addition to A-9 bombing, the Germans wanted to undertake direct bombing of the American coastline using submarine-launched V-2s. This was their second new weapon against America. It was to come into action at the same time as the A-9, i.e. in early summer 1945...

Les V-2 amphibies

Amphibious V-2s

L'idée d'utiliser les sous-marins pour transporter des V-2 remonte à 1942. Au moment où la fabrication industrielle des V-2 était entreprise, l'entourage d'Hitler avait porté beaucoup d'attention au projet de V-2 amphibies que venait d'élaborer l'équipe de von Braun. Mais les travaux d'aménagement pratiques furent longs et fastidieux et ne purent être menés à bonne fin qu'en 1944, date à laquelle le premier sous-marin capable de lancer des V-2 fut effectivement construit. [...]

The idea of using submarines to transport V-2s dates back to 1942. At the same time as industrial production of the V-2s was being undertaken, Hitler's entourage had paid close attention to the amphibious V-2 project that von Braun's team had just drawn up. But the practical development work was long and tedious, and was not completed until 1944, when the first submarine capable of launching V-2s was actually built. [...]

Il apparait que les mises au point devaient être complètement terminées au moment de l'effondrement allemand de mail 1945 et que les Allemands s'apprêtaient à continuer les essais sur l'Amérique elle-même. Quelle aurait été la zone menacée? Il semble que la portée de la V-2 amphibie, du moins dans l'état où les recherches expérimentales du lac Toplitz ont laissé la question, était très nettement inférieure à celle de la V-2 ordinaire, de l'ordre de 150 à 200 kilomètres seulement. Inutile d'ajouter que c'eût quand même été largement suffisant pour le bombardement des port américains: Boston, New-York, Philadelphie, Baltimore, Charleston, etc. Évidemment plus la profondeur à laquelle opéraient les sous-marins était grande, plus la portée était réduite. Nous avons vu que les derniers sous-marins allemands pouvaient voguer à 300 mètres de profondeur; il ne semble toutefois pas qu'un lancer de V-2 amphibies ait pu être envisagé à partir d'une telle profondeur.

It transpires that the tests were to be completed by the time of the German collapse in 1945, and that the Germans were preparing to continue the tests on America itself. What area would have been threatened? It seems that the range of the amphibious V-2, at least in the state left by the experimental research at Lake Toplitz, was considerably less than that of the ordinary V-2, of the order of only 150 to 200 kilometers. Needless to say, this would still have been more than sufficient for bombing American ports such as Boston, New York, Philadelphia, Baltimore, and Charleston. Obviously, the greater the depth at which the submarines operated, the shorter their range. We have seen that the latest German submarines could operate at a depth of 300 meters; however, it doesn't seem that an amphibious V-2 launch could have been envisaged from such a depth.

Quoi qu'il en soit, la menace eût été extrêmement sérieuse pour la côte américaine puisque, d'une part, une fois la V-2 lancée, il a jusqu'ici été impossible de se défendre contre elle, et que, d'autre part, la détection et la lutte contre les nouveaux sous-marins allemands n'eût pas été une petite affaire, indépendamment de l'auto-guidage de la V-2 par détection de rayons infra-rouges ou autres. [...]

C'est vraisemblablement à partir du mois de juin 1945 que l'Allemagne pensait attaquer le territoire américain. Notons-le: alors que la mise en action d'autres armes secrètes, comme les bombes volantes et les nouveaux avions-fusées, était littéralement imminente, cette menace contre les États-Unis doit être située à six semaines ou deux mois après la date qui marqua l'effondrement du Reich. On nous permettra de la trouver pratiquement tout aussi dangereuse, d'autant plus que les V-2 amphibies, elles aussi, auraient très bien pu transporter des bombes atomiques.

In any case, the threat would have been extremely serious for the American coast, since, on the one hand, once the V-2 had been launched, it has so far been impossible to defend against it, and, on the other hand, detecting and combating the new German submarines would have been no small matter, independently of the V-2's self-guidance by infra-red ray detection or other means. [...]

Germany was probably thinking of attacking American territory beginning in June 1945. It should be noted that while the use of other secret weapons, such as flying bombs and new rocket planes, was literally imminent, this threat to the United States must be located six weeks or two months after the date of the collapse of the Reich. We are allowed to consider it almost as dangerous, especially since the amphibious V-2s, too, could very well have carried atomic bombs.

[Albert Ducrocq (1921–2001) was a French scientist and science writer who was involved in the French investigations of German science and German scientists near the end of the war and after the war. He would have had enormous insight into German scientific plans and capabilities.

Based on his personal experience and his sources, Ducrocq stated that Germany possessed atomic bombs and planned to deliver them via submarine-launched missiles and other means, with a massive, nearly simultaneous attack on many Allied targets to be carried out within a matter of weeks if the war in Europe had not ended when it did. For independent confirmation, see pp. 4241–4242, 4272, 4299, 4305–4315, 4325–4327, 4373, 4598, 4999–5011.

For more information from Ducrocq, see pp. 4768, 4925, 5209.]

Raketen aus dem Ozean: Roboterhände helfen starten: Neue U-Boot-Kampfmittel. *Abendpost* (Frankfurt) 14 April 1950 p. 2.

In der für die Zivilluftschifffahrt gesperrten Morecambe-Bucht an der Westküste Englands arbeiten englische und deutsche Fachleute an der Entwicklung der Waffen des zukünftigen Seekrieges. Ihr Ziel: schnelle, weitreichende, fast unbegrenzt tauchfähige U-Kreuzer, die zur Abwehr feindlicher U-Boote, vor allem aber als Abschluß-Basen für ferngelenkte Raketen eingesetzt werden können.

Was es für die Techniker schon eine schwierige Aufgabe, auf den fischförmigen schmalen Rumpf eines U-Bootes die breite Plattform für den Abschuß einer V 2 zu montieren, so schien es zunächst fast unmöglich, das Problem des Abschusses von Raketen unter Wasser zu lösen. Deutsche Pläne, die nach der Kapitulation von englischen Truppen gefunden wurden, gaben der britischen Admiralität die entscheidenden Anregungen für die nun in der Morecambe-Bucht erprobten Geschosse.

Die neuen Raketen werden in zwei Phasen abgeschossen. Wie ein Torpedo gelangt das riesige Geschoß von der Plattform des beliebig tief getauchten U-Bootes mit Hilfe von Preßluft an die Wasseroberfläche. Hier geschieht das Wunder: im Augenblick des Auftauchens treten von Präzisions-Uhrwerken angetriebene Roboterhände in Tätigkeit. Sie bauen aus einem Gitterwerk von Leichtmetallplatten, die aus dem Schwanzteil der Rakete herausgeschleudert werden, eine Art schwimmende Abschußbasis. Auf die Sekunde genau mit der Fertigstellung der Plattform beginnen die Rückstoßkammern der Rakete zu arbeiten. Mit einem feurigen Schweif steigt der unheimliche, wassergeborene Komet in die Höhe. Zugleich mit der Rakete wird eine Tele-Boje mit kompletter Radareinrichtung an die Oberfläche geschickt, die nun als Zwischenstation die Richtungsbefehle des getauchten U-Bootes an die Rakete weitergibt. [...]

In Morecambe Bay on the west coast of England, which is closed to civil aviation, English and German experts are working on the development of weapons for the future naval war. Their goal: fast, long-range, almost unlimited submersible U-cruisers, which can be used to defend against enemy submarines, but above all as bases for remote-controlled missiles.

What was already a difficult task for the technicians to mount the wide platform for launching a V-2 on the fish-shaped narrow hull of a submarine, at first it seemed almost impossible to solve the problem of launching rockets under water. German plans, which were found after the surrender of English troops, gave the British admiralty the decisive suggestions for the projectiles now tested in Morecambe Bay.

The new missiles will be launched in two phases. Like a torpedo, the huge projectile is launched from the platform of the submarine submerged to any depth with the aid of compressed air to the surface of the water. This is where the miracle happens: at the moment of emergence, robotic hands driven by precision clockworks start working. They build a kind of floating launch base from a lattice of light metal plates which are ejected from the tail of the rocket. The recoil chambers of the rocket start to work exactly to the second when the platform is completed. With a fiery tail, the eerie, water-born comet rises. At the same time as the rocket, a tele-buoy with complete radar equipment is sent to the surface, which now transmits the directional commands of the submerged submarine to the rocket as an intermediate station. [...]

[This article describes a wartime alternative to the Prüfstand XII approach, and also serves as an example of how German plans and German-speaking scientists played critical roles in other countries' postwar programs to develop submarine-launched missiles.]

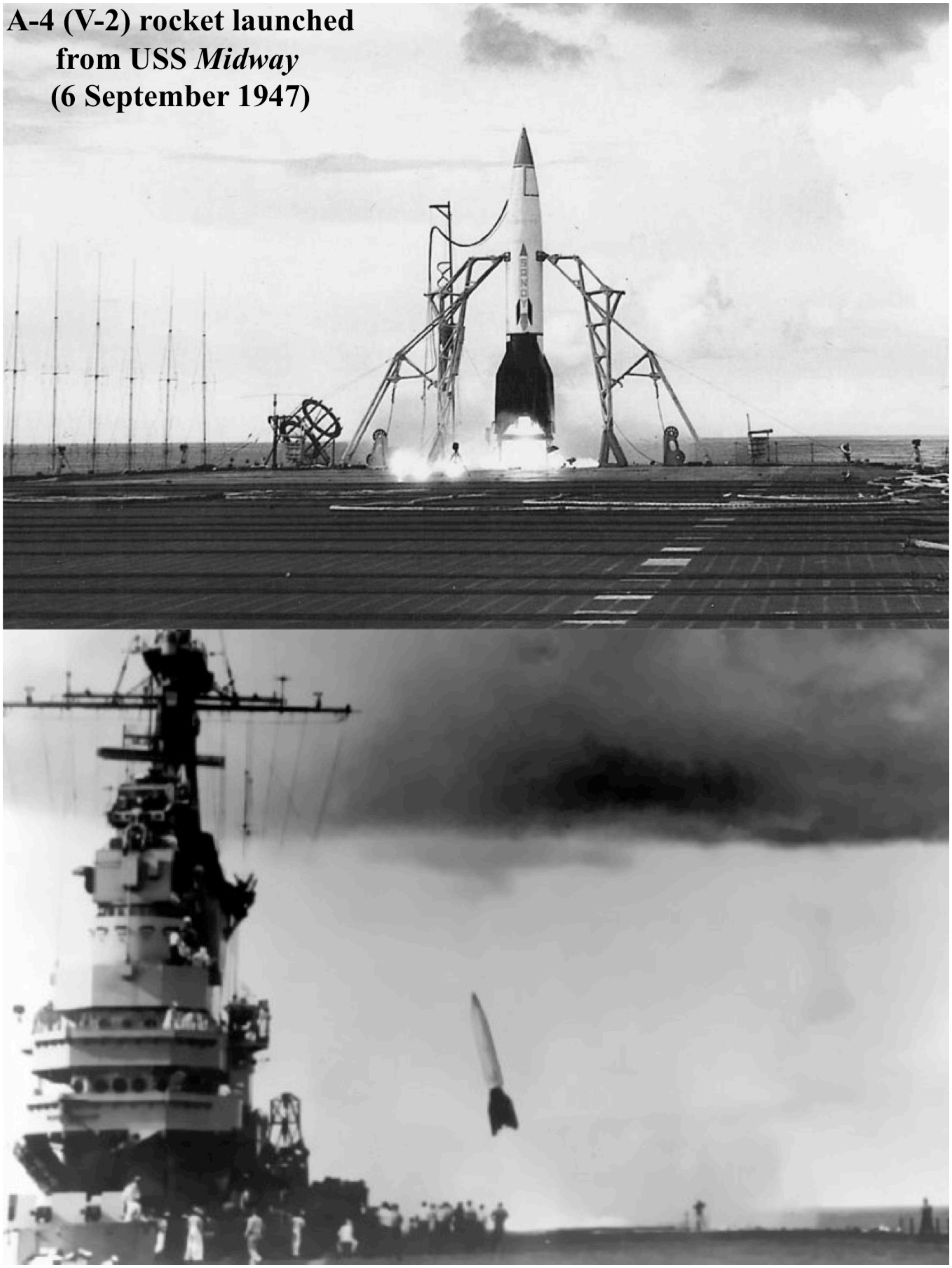


Figure E.211: As part of Operation Sandy, the U.S. Navy launched an A-4 (V-2) rocket from the deck of the USS Midway on 6 September 1947 [http://www.cv41.org/photos/gallery/main.php?g2_itemId=17451].

[Although solid propellant rockets have lower exhaust velocities than liquid propellant rockets, they can generally be stored for years without degradation. Therefore, they are primarily used for military rockets and "off-the-shelf" boosters that can be strapped to the side of the first stage of a spacecraft launch vehicle. For submarine-launched rockets, where it is necessary to be able to store the rockets stably and safely for years and yet fire them on very short notice, solid propellants are highly preferable to liquid propellants.

In a solid propellant rocket, the propellant burns along its exposed surfaces, releasing hot exhaust gases through the nozzle unless the thrust termination port is opened (see p. 1898). Different solid propellant grain designs have different cross-sectional patterns of exposed surfaces such that the exposed surface area and hence the thrust changes in some desired way (increasing, remaining constant, or decreasing) as the rocket burns.

During World War II, a number of nearly forgotten German-speaking chemists and engineers (such as those shown on pp. 1899–1903), successfully developed and demonstrated advanced solid propellant rockets, including for example:

- The Rochen ammonium perchlorate/polybutadiene short-range missile, first fired in 1944 (p. 1904).
- The Rheintochter two-stage surface-to-air missile, first launched in 1943 (pp. 1905 and 5206).
- The Rheinbote four-stage long-range rocket, first launched in 1943 (pp. 1906 and 5206).
- The V-101, an ammonium perchlorate/polybutadiene propelled, 140-ton, 30-meter-tall, long-range ballistic missile that was under development when the war ended (p. 1907).

Key German innovations of that solid propellant rocket technology included:

1. Ammonium perchlorate oxidizer [BIOS 31; BIOS 571].
2. Polybutadiene "buna" synthetic rubber in the propellant to act as both fuel and binder [BIOS 31; BIOS 571].
3. Plasticizers to enable the propellant to be molded into any desired shape, to adhere tightly to metal walls, and not to be prone to crumbling or brittleness [BIOS 31; BIOS 571].
4. Powdered aluminum as a fuel additive to improve performance [BIOS 27; BIOS 31; BIOS 100; BIOS 477; BIOS 1261; FIAT 1035; HEC 2434; HEC 2485; HEC 2487; NavTecMisEu 327-45].
5. Various grain designs for the combustion surface inside the propellant to give the desired variation of thrust with time [Benecke and Quick 1957, pp. 253–255; Klein 1977; BIOS 31; BIOS 1110; NavTecMisEu 327-45].

This wartime German technology became the basis for large postwar solid propellant rockets, including satellite launch vehicles such as the U.S. Scout; strap-on solid rocket boosters such as those used with the U.S. Space Shuttle, Titan, and Delta rockets; submarine-launched ballistic missiles such as the U.S. Polaris, Poseidon, and Trident; and solid propellant land-based ballistic missiles such as the U.S. Minuteman and MX.]

Figure E.212: Rheintochter R1 two-stage solid propellant rocket (left), partial Rheintochter R3 strap-on solid propellant booster (horizontal, center), and Rheinbote four-stage solid propellant rocket (right).

Nazis Use 'AA' Rockets in Italy. *New York Times*, 16 January 1945, p. 12.

ROME, Jan. 15 (Reuter)—The Germans are using anti-aircraft rockets for the first time in northern Italy, it was reported today. Havoc pilots of the Mediterranean Allied Air Force said on returning to bases that two volleys of twenty-five rockets each were fired at them when they were attacking enemy motor transport and communications in the Genoa area.

Carl Spaatz. 19 June 1945. [**AFHRA A5729 frame 1570**]

GEORGE C. McDONALD
Brigadier General, USA
Asst. Chief of Staff A-2

19 June 1945

COMMANDING OFFICER, 2ND TAF (RAF)

FOR WING COMMANDER WHEELER. INFORMATION HERE THAT RHEINTOCHTER HAS SEVEN EACH NEW TYPE ROCKETS. ANTI AIRCRAFT ROCKETS SUPPOSED TO USE PROXIMITY FUZE. SIGNAL ALLSTONT [?] AND LOCATION FOR AIR LIFT BY OUR AIRCRAFT.

SPAATZ

NavTecMisEu 373-45. ***German War Research vs Air Superiority.***

In the Me 262 the Germans had years of development behind both the turbo-jet engine and the high speed airplane. The latter was achieved through their supersonic wind tunnel research. Their experience with this airplane was rapidly leading them toward the supersonic airplane speed we hope to achieve in the future. In our own development, the advent of our jet engines has created a situation in which we do not have airplane designs capable of efficiently utilizing the high speeds they make possible.

Guided missels were not in the original research and development program of 1933. They did not receive important consideration until after the German research reorganization. However, the strong foundation of basic research and development laid for other aeronautical purposes was immediately available. The magnitude of this work was such as to provide the rapid expansion and development of some two hundred different designs and studies of guided missels. One of the best developed at war's end was a ground-to-air rocket projected by a ground director into the rear of its target. There, an infra red homing device picked up the heat from the engines and directed it into the rear of its target. It was claimed that 70 four-engine bombers were brought down with 75 of these guided missels.

Various naval devices were being used in their accelerated science to expedite aeronautical developments. In Hamburg the high speed towing basin was being used for the underwater towing of airplane components to determine their air load carrying capacity at very high air speeds. A complete airplane, the Heinkel He 162 was towed underwater in the experiment. In Goettingen, a water tunnel was being used to determine airfoil cavitation, translatable into air cavitation at high speeds.

Completely synthesized aircraft engine oils and other lubricants were in use. Precise control had been developed for each individual hydrocarbon molecule. Thus, there was achieved in war reality, a dream of our organic chemists for many years.

[By 1945, German-speaking scientists and engineers had been developing approximately 200 different types of missiles, many of which were actually fielded, ranging from the A-4 (V-2) to heat-seeking anti-aircraft missiles that were successfully demonstrated according to this report.

The Allied investigators did not even know how to spell the word "missile."

But the Allied investigators were very excited to take the German-developed missiles and other technologies.]

Albert Ducrocq. 1947. *Les Armes Secrètes Allemandes.* Paris: Berger-Levrault. pp. 96–98.

La Rheintochter était la R-1; la R-2 ne fut jamais construite industriellement, et an mai 1945, les usines allemandes auraient sorti la R-3.

Ces bombes volantes, série “R”, étaient toutes destinées à la lutte contre l'aviation alliée et elles devaient littéralement révolutionner la D. C. A. [Défense Contre Avions] [...]

Quant à la fusée auxiliaire pour le départ, elle possédait sa propre voilure cruciforme, les quatre ailes étant reliées par un système de haubans. A l'extrémité, se trouvaient cinq réacteurs. En général, cette fusée auxiliaire était abandonnée au bout de 2 kilomètres de vol et alors la R-1 prenait presque instantanément une vitesse de l'ordre de 1.500 kilomètres/heure. C'était donc bien un appareil supersonique!

La précision, déjà bonne dans la R-1, s'annonçait excellente avec les R-3, car les Allemands mettaient au point leur fameux dispositif de radar interconnecté. Il s'agissait en somme d'une carte du ciel, en l'occurrence l'écran d'un oscillographe, où apparaissait la zone balayée par l'aviation anglo-américaine; on y voyait la trajectoire des avions alliés, et la trajectoire des bombes R lancées sur eux; les servants de R-1 et de R-3 auraient ainsi pu suivre le chemin de leur engin, et, au fur et à mesure, corriger les trajectoires par radio-guidage en regardant sur le *Reichshimmel* les déplacements relatifs des avions et des bombes, cette opération, bien entendu, s'effectuant à plusieurs mètres sous terre dans un confortable abri.

C'est en se penchant sur ces réalisations que l'on peut seulement comprendre l'immense espoir de gagner la guerre qui, jusqu'à la dernière seconde, put animer certains Allemands...

The Rheintochter was the R-1; the R-2 was never built industrially, and by May 1945, German factories would have produced the R-3.

These flying bombs, the “R” series, were all intended for use against Allied aircraft, and were literally to revolutionize anti-aircraft defenses. [...].

As for the auxiliary rocket for departure, it had its own cruciform canopy, with the four wings connected by a system of stays. At the end were five jet engines. This auxiliary rocket was usually abandoned after 2 kilometers of flight, at which point the R-1 reached speeds of around 1,500 km/h almost instantaneously. A supersonic aircraft indeed!

Accuracy, already good in the R-1, was to become excellent with the R-3, as the Germans developed their famous interconnected radar system. This was basically a map of the sky, in this case the screen of an oscillograph, showing the area swept by Anglo-American aircraft; it showed the trajectory of Allied planes, and the trajectory of the R-rockets fired at them; R-1 and R-3 servicemen could thus follow the path of their vehicles, and, as they went along, correct trajectories by radio guidance, watching the relative movements of the planes and rockets on the *Reichshimmel*, this operation, of course, being carried out several meters underground in a comfortable shelter.

It is only by looking at these achievements that one can understand the immense hope of winning the war that, right up to the last second, could animate certain Germans...

[For more information from Ducrocq, see pp. 4768, 4925, 5201–5202.]

John Christopher. 2013. *The Race for Hitler's X-Planes: Britain's 1945 Mission to Capture Secret Luftwaffe Technology.* The Mill, Gloucestershire: History Press. pp. 131–132, 136–137.

Rheintochter, named after Richard Wagner's Rhine Maidens, was a multi-stage solid-fuel surface-to-air missile developed by Rheinmetall-Borsig for the German Army. [...] It was 20ft 8in (6.3m) long overall including the booster stage, and the body had a diameter of 1ft 9.25in (54cm). [...]

After eighty-two test launches, further development of the *Rheintochter* R-I, and the proposed operational version R-II, was abandoned in December 1944 because it was only attaining the same altitude as the other missile systems. A third version of the *Rheintochter*, the R-III, was to have been a far sleeker affair with a liquid-propellant rocket motor for the main stage, and it did away with the second stage in favour of solid-fuelled boosters mounted to the side of the missile. Only six test firings were made. [...]

Rheinbote ('Rhine messenger') was developed by the Rheinmetall-Borsig company in 1943. Strictly speaking this slender four-stage rocket cannot be classified as a smart bomb as it was aimed solely by the positioning of the launcher and possessed no internal or external guidance systems. Apart from the V-2 (A4) this was the only other long-range ballistic missile to enter service during the Second World War. [...]

In appearance *Rheinbote* was a slender spike 37ft (11.4m) long, with stabilising fins at the rear and three sets of smaller fins arranged at the end of each of the four stages. The rockets were fuelled by diglycol-dinitrate solid-fuel propellant and in tests achieved a blistering Mach 5.5, or 4,224mph (6,800km/h), the fastest speed of any missile at the time. *Rheinbote* was transported and launched from a modified V-2 (A4) rocket trailer which had an elevating launch gantry. The missile was aimed by orientating the trailer itself and elevating the gantry, although the accuracy of this method of aiming is highly questionable.

In tests the *Rheinbote* carried an 88lb (40kg) warhead, only 6.5 per cent of the missile's total mass, up to 48 miles (78km) into the atmosphere to a range of up to 135 miles (220km), but for shorter ranges some of the stages could be removed. Over 200 were produced and they were used in the bombardment of Antwerp from November 1944 into early 1945. After the war ended the Soviets helped themselves to the designs at Rheinmetall-Borsig's Berlin-Marienfelde headquarters, but in general the *Rheinbote* was considered to be lacking accuracy, thanks partly to the effect of the stage separations, and lacking punch as the payload was too small and the almost vertical high-speed delivery tended to bury it deep into the ground.

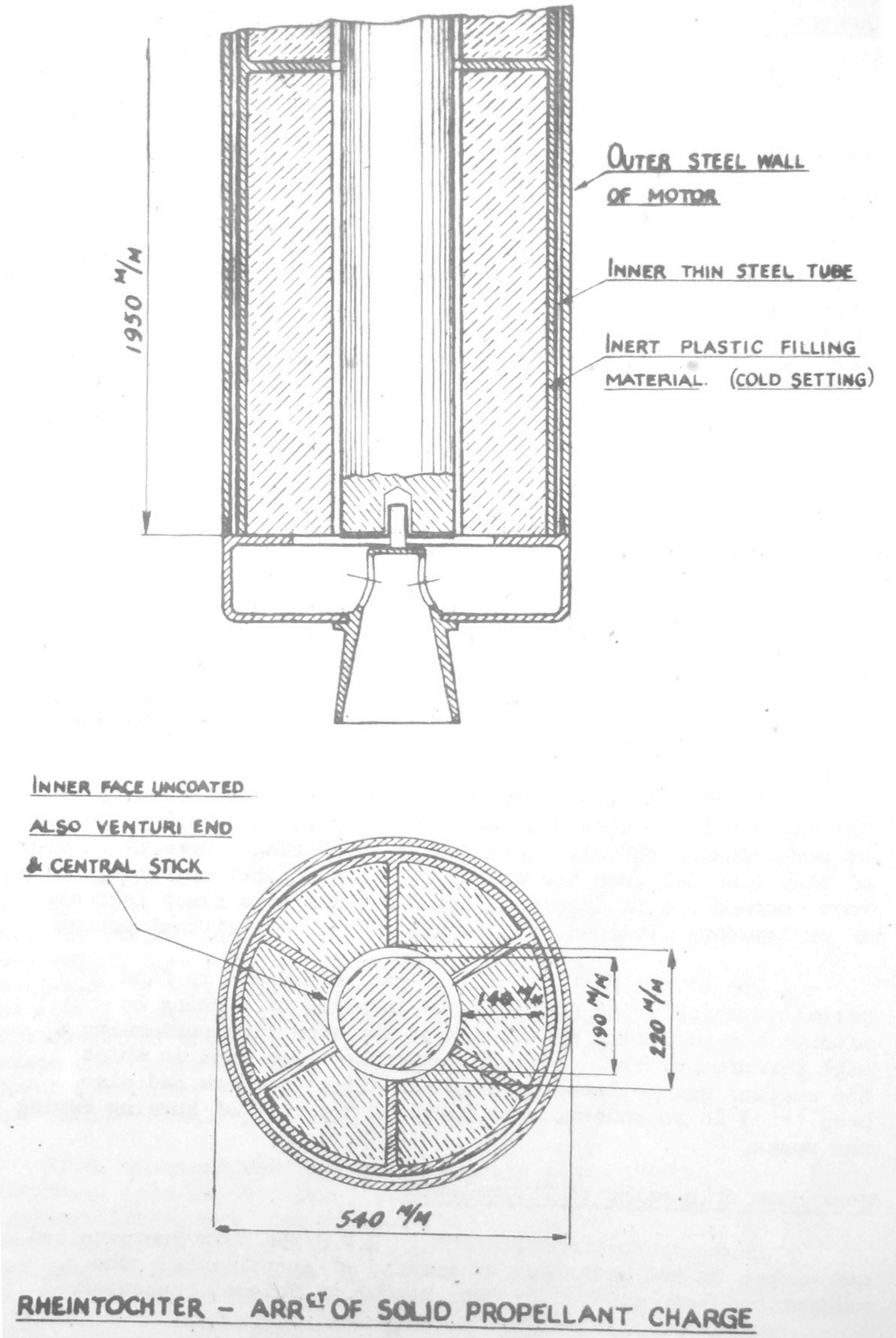


Figure E.213: Rod-and-tube grain design for constant thrust in the large Rheintochter solid propellant rocket engine [BIOS 1110, p. 10].

H. Vüllers, Design and Development of the Solid-Fuel Rocket

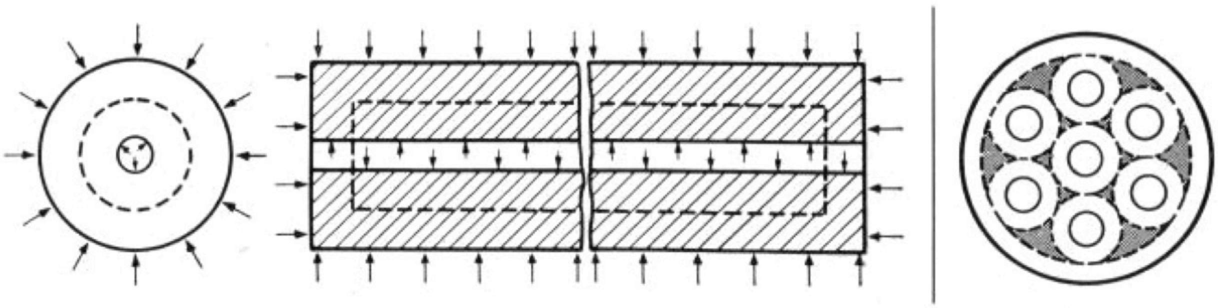


Fig. 1. Behaviour of powder surface during burning
Single-tube charge. Surface area decreases (regressive)
Multi-tube powder. Surface increases (progressive)
——— *Surface when burning starts*
– – – *Surface when burning finishes*

As shown in Fig. 1, the surface area of the powder is not a constant. The left part of this illustration shows a type of single-tube charge and the right, a type of multi-tube charge. As the single-tube charge burns out, its surface area decreases; it is therefore said to be "regressive". As the multi-tube charge burns out, its surface area increases ("progressive") during which process the triangular residues do not normally burn away completely but are discharged partly unburnt. It is, of course, possible to make a multi-tube charge with a cross-section so designed as to leave no unburnt residues whatever (so-called "profile powder"). For a single-tube charge, the regressivity R is expressed as follows:

$$R = \frac{S_a - S_e}{S_a} = \frac{2}{l/s + 1}, \tag{3}$$

where

S_a = surface area of powder when burning starts,
S_e = surface area of powder when burning is completed,
l = length of powder tube,
s = wall-thickness of powder tube.

Figure E.214: Hermann Vüllers's description of wartime practices for designing, calculating, and fabricating various regressive grain designs for steadily decreasing thrust (upper left) and progressive grain designs for steadily increasing thrust (upper right) [Benecke and Quick 1957, pp. 254–255].

[One of the main sources of information on solid propellant rocket development in Germany, Nils Werner Larsson, would be worthy of a complete book in his own right. He was a young engineer working on explosives in Sweden, and then in 1943 he defected to Germany and began working his way through its rocket research centers. In 1945 he provided everything he had learned about the German rocket programs to U.K. and U.S. intelligence, yet was officially condemned as a traitor by the Swedish government. Then he defected to the Soviet Union, worked his way through its rocket research centers, and came back to the West in 1960 with everything he had learned there. Currently there is not enough publicly available information to conclusively judge the true motivation behind Larsson's many moves. The most likely explanation is that he had been recruited by Western intelligence agencies to be an undercover agent first in the wartime German rocket programs, then in the postwar Soviet rocket programs. Alternatively, perhaps he just wanted to keep his life exciting by completely switching sides every few years. I would highly recommend that someone research Larsson's life more thoroughly and then make him the subject of a book and/or film.

In addition to large amounts of information about German solid propellant rockets, Larsson also provided U.K. and U.S. officials with large amounts of information about German liquid propellant rockets, including the intercontinental "V-10" (apparently another designation for the A-9/A-10). See pp. 5003–5004. Some brief reports are presented on the following pages, but where are the detailed Allied technical reports that must have been written about all of the liquid and solid rocket information that Larsson conveyed?]

Report Swedish Deserter Took Army Data to Nazis. *New York Times* 15 October 1943.

An engineer who until recently was in the service of the Swedish Army as an expert on explosives and shells has deserted to Germany with many army secrets, it is feared, according to an announcement here today. It concerns one Nils Werner Larsson, age 25, whose flight was only discovered by his failure to answer a lower court summons on charges of an expense account swindle after he had been discharged from army employment.

It now appears that Larsson fled to Germany some time this summer via Norway. He is now employed at a Berlin office of the Wehrmacht. Prior to his flight Larsson participated in a tour of Sweden's more important fortifications, among them being those at Borden and Karlsborg. His mission on this tour was to check grenade throwers, on which he was considered to be an expert. Prior to this he had also been engaged on many secret and highly confidential missions in connection with Swedish defense.

Nils Werner Larsson. 8 June 1945 interrogation at Augsburg [AFHRA C5094, frames 0874–0890].

[This is a lengthy written account by Larsson that described his personal history from the 1930s to 1945. While it did not provide many technical details of German projects, it did include his claim that in 1943, he was recruited and trained by U.S. and U.K. intelligence to work undercover on German military research programs.]

Engineer Arrested as Swedish Traitor. ***Toronto Daily Star*** **1 November 1945 p. 20.** [**http://news.google.com/newspapers?id=29QXAAAAIBAJ&sjid=pSMDAAAAIBAJ&pg=7981,5176166&dq=nils+werner+larsson**]

Nils Werner Larsson, a Swedish Engineer, has been arrested by Swedish police at Charlottenburg on his way home from Norway.

It is reported that four years ago he wanted to go to Germany to do intelligence work for Britain. The Germans didn't trust him and he had to find some way to show them that he was apparently a friend of Germany, so he stole drawings of a new Swedish gun.

When the war ended Larsson went over to the British lines.

Ein Mann namens Larsson [A Man Named Larsson]. ***Die Zeit*** **11 March 1960 p. 4.** [**https://www.zeit.de/1960/11/Ein-Mann-namens-Larsson**]

[...] Jenes andere Beispiel aber, von dem es hier zu erzählen gilt, ist die Geschichte des schwedischen Ingenieurs Nils Werner Larsson. Der Schwede hat mehrere Jahre als westlicher Agent hinter dem Eisernen Vorhang gelebt, ist ins Zentrum der östlichen Raketenforschung vorgedrungen, hat fünf Monate vor dem ersten Sputnik den Start einer roten Großrakete miterlebt und behauptet, er kenne das Geheimnis der atomgetriebenen sowjetischen Super-Rakete. Mit diesem Wissen meldete er sich jüngst wieder im Westen, bei den Dienststellen der US-Army. [...]

[...] But the other example we have to talk about here is the story of the Swedish engineer Nils Werner Larsson. The Swede lived behind the Iron Curtain as a Western agent for several years, penetrated the centre of Eastern missile research, witnessed the launch of a large communist rocket five months before the first Sputnik and claims to know the secret of the nuclear-powered Soviet super-rocket. With this knowledge he recently contacted the US Army again in the West. [...]

[See also:

3 March 1960. Soviet secrets about rockets... were discovered at a press conference in Hamburg by Swedish constructor Nils Werner Larsson. [Includes photo of Larsson in 1960, https://www.alamy.com/mar-03-1960-soviet-secrets-about-rockets-were-discovered-at-a-press-image69364205.html]

Chris Johnstone. 20 June 2015. Czech Episode of Nazi Rocket Science Uncovered by Historian. Czech Radio. [Archival research by Michal Plavec, curator at the National Technical Museum in Prague, https://english.radio.cz/czech-episode-nazi-rocket-science-uncovered-historian-8256618]]

Seventh Army Interrogation Center. 17 May 1945. Notes on Personalities and Establishments Associated with Development of V-Weapons. SAIC/12. [https://www.cia.gov/readingroom/document/cia-rdp83-00415r006200030002-7]

LARSSON, Nils, a Swedish engineer who has worked for two years in Germany on rocket research. He appears to have a well-rounded picture of German rocket production and plans, and although he admits that he is only a "small man in this field", he knows the more important men and where they can be found. [...]

Seventh Army Interrogation Center. 3 June 1945. Notes on German Weapons Developments. SAIC/38. [https://www.scribd.com/document/431240796/File-Datastream http://hydrastg.library.cornell.edu/fedora/objects/nur:01298/datastreams/pdf/content]

I. PREAMBLE

The following information was obtained from Dr Edgar RUPPELT, Dr Alfred NORDT, Dr Ernst KNUST, and Nils LARSSON, all of the PIBRANS, Czechoslovakia, SKODA Works Rocket Experimental Station. While all of them gave a certain amount of information, LARSSON, the head of the group, can be considered the main source.

LARSSON, Nils, is a 27-year-old Swedish engineer whose special field was the development of new weapons, especially in the rocket category. In summer 40 a proposed A/T weapon of his design was accepted by the Swedish military authorities. He attended a military technical school for some time and in winter 42/43 met the Norwegian Military attaché, Lt Col SMITH-KIELLAND, and through him, the American and British Military Attachés in STOCKHOLM. He attempted to leave Sweden to work for the United Nations, he claims, and when this proved impossible due to difficulties in transportation, he got in touch with an American intelligence official, a "Col ANDREWS", and a representative of the British Secret Service, a "Mr GREEN", who instructed him to go to Germany and keep in close touch with the latest developments in rockets and other weapons. Source claims to have obtained definite instructions as to his proposed mission in Germany.

Through a representative of the German Military Attaché, a 1st Lt "MÜLLER-LIEBENAU", source obtained permission to enter Germany as specialist in rocket development.

Source worked at first, starting on 1 Jul 43, for the firm MAGET in BERLIN/TEGEL. In order to avoid troubles with the German Police, his case was cleared by the German authorities through the at the time unimportant SS HPTSTUF (Capt) SKORZENY. Due to SKORZENY's subsequent rise in power and importance, it was possible for source to gain access to the top German agencies involved in the development of new weapons.

After short periods of work in various smaller agencies involved in rocket experiments, source was sent to the VERSUCHS-ANSTALT (Research Center) GROSSENDORF, on the HELA Peninsula, about May 44. Here source had occasion to acquaint himself with the latest developments in the rocket field, as well as to get to know the names of the leading scientists involved in the experiments and research work. From here, source claims, he sent reports through a contact-man in BERLIN as well as through his wife in STOCKHOLM. Furthermore, source made contact with the leading scientists of the Torpedo Research Center GOTENHAFEN (GDYNIA), which was a sub-post of the MARINE REICHSVERSUCHSANSTALT (REICH Naval Experimental Station), KIEL.

In winter 44/45 the GROSSENDORF Center was evacuated to PIBRANS, Czechoslovakia, where, together with the Research Post of the PIBRANS SKODA Plant, it formed a new elaborate Research Center under Eng Rolf ENGEL, former head of the GROSSENDORF Center. In Apr 45, when Germany's collapse was near, this Center was dissolved and the personnel were given permission to leave Czechoslovakia. Source left for Southern Germany, securing on his way important scientific data as well as some secret Police documents applying to the plant.

Source appears to have had occasion to form an overall picture not only of the latest developments in the rocket field, but in the general line of research on other new secret weapons as well. Due to his travels and his access to data in the top German research centers, he knows a remarkable number of names connected with latest German scientific developments. He wants, with the help of American and British influence, [to] re-instate his "good name" in Sweden where, it seems, he is regarded as a traitor because of his departure for Germany. Whatever his reasons, he is cooperative and helpful. He has an excellent memory, and his information is considered reliable.

Rating: B-2 Date of Information: Beg. May 45 Interrogator: M.N.

NOTE: The following report should be regarded as basis for further specialized interrogation. It is believed that sources would be able to furnish detailed technical data on many of the instruments described as well as on the experiments carried out. It should be noted that source LARSSON was Specialist in Charge (SACHBEARBEITER) of some of the developments.

[...]

II. GERMAN AGENCIES SUPERVISING RESEARCH AND DEVELOPMENT OF NEW WEAPONS [...]

ii) TORPEDO VERSUCHSANSTALT (Torpedo Research Center), GOTENHAFEN. KAP Z SEE (Navy Captain) PRALL was the head of the Center. In charge of the development of special torpedos was Dr SCHMIDT, and in charge of development of the "ROCHEN" ("Roe"—see III, A, 5, a, below) was Dipl Ing WONDRAK. [...]

Under the FORSCHUNGSFUEHRUNG source recalls the following departments:

i) RHEINTOCHTERENTWICKLUNG ("RHINE Daughter" Development - see III, A, 5, b, below). The man in charge of these experiments (REFERENT) was Prof Dr ORTHMANN.

ii) R-ENTWICKLUNG (Rocket Development), headed by Maj HARRAS. Specialists in Charge (SACHBEARBEITER) were HPTM (Capt) TILLING and FL STABSING (GAF Maj) HESSE.

iii) PULVERENTWICKLUNG (Powder Development); REFERENT in FoFü for this dept was Dr BUNDE. [...]

f) RUESTUNGSKOMMISSIONEN MIT FUEHRERVOLLMACHT (Armament Commissions with FUEHRER Authority) [...]

iii) PULVERKOMMISSION (Powder Commission), headed by the General Director of DYNAMIT AG Dr Paul MUELLER. Specialist in interior ballistics and powders in this dept was REGIERUNGS-BAURAT Dr POEPL, who also was in Wa Prüf 1. HPTM (Capt) Dr HIMMELHEBER, specialist of small assemblies for V-1, was head of the section for research in wood.

iv) SONDERKOMMISSION FUER R-ENTWICKLUNG BEIM RfRuK (Special Commission for Rocket Development in the SPEER Ministry) was headed by FL STABSING (GAF Maj) ZEYSS.

v) SONDERAUSSCHUSS FUER PULVER BEIM RfRuk (Special Section for Powder in SPEER Ministry) was headed by Director Dr WUNDER. [...]

III. GERMAN RESEARCH ON NEW WEAPONS

[...]

1. Projectors [...]

a) M 8 Projector

This projector, research on which was supervised by the SS WAFFENAMT (Ordnance Office) through SS HPTSTUF (Capt) HANNEBERG, was developed in the WAFFENWERKE BRUENN AG and in the GROSSENDORF, Pomerania, Research Center under Ing Rolf ENGEL. The specialists in charge of the research and experiments were Dr KALSCHEUER, Prof Dr BOEDENWADT, and Ing PROKOP. The projector has 48 barrels on a SP chassis. The rockets are 8 cm in diameter, have flight stabilizers and percussion fuzes. The maximum range of the rockets is 7 km. [...]

2. Rocket AA Weapons [...]

a) ORKAN FLA

This weapon, ordered by the OKL, ARBEITSSTAB (Staff) DORNBERGER and supervised by FL STABSING (GAF Maj) ZEYSS, was being developed in the Research Center of the WAFFEN-UNION in PIBRANS, Czechoslovakia. OBLT (1st Lt) FISCHER and Dr TEICHMANN were the specialists in charge of the experiments and research. The projector, consisting of 24 rails on a rotating chassis, was to be used against low-flying planes. The rockets have a cal of 55 mm, percussion fuzes, and flight stabilizers. They attain a distance of 5 km in 3 sec. The powder charge is placed in a single tube 48 x 15 x 1,100 mm and weighs 1.7 kg; the weight of the explosive charge carried by the rocket is 500 g. The experiments on the weapon were concluded, and it was planned to manufacture the first 50,000 rockets for combat employment. [...]

5. Controlled Rocket Weapons

a) ROCHEN ("Roe")

This is a rocket projectile which is controlled by means of impulses transmitted through a wire unwinding during its flight (see F, 2, below). The OKM (Navy High Command) was the agency interested in the development of this weapon, and Director SCHMIDT of the TVA (Torpedo Research Center), GOTESHAFEN was supervising the experiments. The research and experiments were carried out in the TVA GOTESHAFEN and in the GROSSENDORF Research Center under the supervision of KAP Z SEE (Navy Captain) VON PRALL. SACHBEARBEITER (specialists in charge) were Ing WONDRAK and Dr KALSCHEUER. The ROCHEN was to be used against naval and land targets. The projectile is 2 m long and approx 1 m wide. It has both a rocket starting mechanism (the DOV 21 is used for this purpose) and a rocket propelling device. The weight of the projectile before it is fired is 320 kg, of which 100 kg are the "Useful weight". Its flight can be controlled to a distance of 4–7 km, through a polarisation relay. The weight of the powder is 16[0] kg, the combustion time 3 tons-sec. The device was ready for experiments when hostilities ceased.

b) RHEINTOCHTER ("RHINE Daughter") (Source: Dr NORDT)

This is a controlled heavy AA missile, developed by RHEINMETAL-BORSIG, BERLIN/MARIENFELDE, under the management of Dr KLEIN, for the OKL. Supervisor of the project on the part of the OKL was Prof Dr ORTHMANN, and specialist in charge during the experiments and research work was OBERING MUELLER. The shell, containing an explosive charge of approx 100 kg, was to be used against bomber formations. It is controlled by means of an infra-red device, and has an acoustically controlled fuel ignition cut-out. The device consists of two parts, a starting device and a propelling device, each with a thrust of 25–30 tons and a fuel combustion time of approx 2 sec. After the ignition of the propelling device, the empty starting device is automatically dropped. It was planned to substitute the propelling device by a long-burning powder device, with a fuel combustion time of 30 sec, or by using a liquid propellant (SCHMETTERLING and WASSERFALL). Sources state that the steering problems of the "RHINE Daughter" had not been solved, as of beg May 45. Research was carried on up to the last minute.

7. Long Range Rocket Missiles

The V-series weapons are the representatives of this class. Also, future developments for communication purposes can be expected in rockets of this category.

a) V-l.

b) A-4, which was the prototype of V-2.

c) V-2.

d) TL (TURBOLADER)—for jet-propelled planes.

e) V-101.

This weapon, in the planning stages only, was being developed in the PIBRANS Experimental Center by Dr BOEDENWADT, Dr TEICHMANN, Dr KALSCHEUER, and Ing THOMAS. It is a giant rocket of a total weight of 140 tons, of which 100 tons were to be taken up by the fuel. It was to have a length of 30 m and a diameter of 2.8 m. It was to attain a velocity of 2,000 km per hour at an altitude of 200 km. Its maximum range was calculated to be 1,800 km. It was to be fired by a catapult mechanism, also rocket-operated. Source LARSSON claims that he would be able to prepare a complete report, with drawings, of this weapon. [...]

3. Heterogen Powders [...]

b) PER Powder

This powder was developed in the PIBRANS Experimental Station, under Dr TEICHMANN. Its developments were supervised by FL STABSING (GAF Maj) ZEYSS, of the OKL. The powder was synthesized from a plastic material and an inorganic oxygen carrier. Depending on this plastic material, the powder could be molded or poured into shape. The burning proceeds uniformly at atmospheric pressure and up. The linear burning velocity at one atm is 1 mm/sec. The burning velocity increases proportionately to the increase of pressure.

F. MEASURING AND AUXILIARY DEVICES

1. Radar Devices

Sources mention the DARMSTADT Device and Y-Device as the latest developments in this field.

2. Wire Control Device

This is the spinner used in the ROCHEN and wire controlled torpedo. It was developed in the TVA (Torpedo Experimental Station) GOTENHAFEN (GDYNIA) the head of which was KAP Z SEE (Navy Captain) VON PRALL, by Dir SCHMIDT and Dipl Ing WONDRAK, and several series of the device were already manufactured. The missile is controlled through polarization relays over a wire which unrolls during its traveling. The range of the device (and thus of the missile) is said to be from 7 to 12 km.

3. Remote-Control Devices

Generally, the devices send out high frequency signals, modulated light signals, infra-red, or acoustic signals. Sources know of a modulated-light device which was being developed at the PIBRANS Experimental Station by Dr SIMON and Dr TRENKA, under the supervision of OBLT (1st Lt) FISCHER, of OKL/GL FLAK. The device is said to have passed the experimental stage, as of beg May 45.

[This solid propellant mixture was probably dubbed "per powder" because its dominant ingredient was ammonium perchlorate. Was the Zeyss mentioned here the same as Wilhelm Zeyss (p. 1903), who played a role in other solid propellant rocket programs?]

NavTechMisEu 237-45. *Survey of German Activities in the Field of Guided Missiles.* August 1945. [NARA RG 38, Entry P5, Box 38]

[p. 46:]

SKETCH OF THE MISSILE	SKETCH OF MISSILE NOT AVAILABLE
MISSILE	V-101
CODE NAME	
USED AS	A GROUND TO GROUND MISSILE
1. SPEED RANGE	SUPER SONIC
2. DEVELOPED BY	DR.'s BUEDENWADT, TEICHMANN.
3. MANUFACTURED BY	PIBRANS EXP. CENTER
4. STATUS [...]	NONE [...]
5. METHOD OF LAUNCHING	GROUND MOUNTED CATAPULT
6. AUX. LAUNCHING PROPULSION UNIT [...] (a) TYPE [...]	ROCKETS NOT KNOWN [...]
7. LAUNCHING ATTITUDE	NOT KNOWN
8. LAUNCHING MECHANISM (a) LENGTH OF GUIDE (b) AIMING RANGE	ROCKET PROPELLED CATAPULT NOT KNOWN " "
9. VELOCITY, MAXIMUM (a) LAUCHING (b) END OF PROPULSION BURNING	SUPER SONIC NOT KNOWN 2000 KM./HR.
10. PROPULSION UNIT (a) MAKE [...] (i) THRUST	NOT KNOWN [...] 100 TONS
11. MISSILE DIMENSIONS (a) WEIGHT 1. TOTAL 2. EMPTY 3. WAR HEAD 4. EXPLOSIVE (b) DIMENSIONS 1. LENGTH 2. SPAN 3. DIAMETER	 140 TONS NOT KNOWN " " " " 30 METRES NOT KNOWN 2.8 METRES
12. CONTROL [...]	NOT KNOWN [...]
13. HOMING [...] (d) TYPES PROPOSED [...]	[...] NOT KNOWN [...]
14. FUSES [...]	NOT KNOWN [...]
15. OPERATING RANGE (a) RANGE (b) ALTITUDE	1800 KM. 200 KM.

[p. 190:]

V-101 LONG RANGE ROCKET

A. General

1. Introduction.

(a) The V-101 is a long range rocket missile which was in the planning stages at the Pibrans Rocket Experimental Station, a subsidiary of the SKODA Munitions Work at Pibrans, Czechoslovakia. The only information presently available is from a brief interrogation of Dr. Edgar Ruppelt, Dr. Alfred Nordt, Dr. Ernst Knust and Nils Larsson, in the 7th Army Interrogation Center. (Report Ref. No. SAIC/38 of June 1945).

(b) No drawings or illustrations are available.

(c) As in the case of the Rochen, reference to the V-101 has been made simply as an illustration of the extent of the German effort being utilized in the development of long range rockets and missiles.

B. Details

2. Description.

(a) It is believed that the projected purpose of the weapon was for use in long range area bombing. The type of explosive, fuel, and exact utilization had not been fully determined. The missile was to operate in the stratosphere.

(b) The rocket was to be about 30 meter long; the diameter was estimated to be 2.8 meters. The total weight was to be approximately 140 tons, with the fuel weight of approximately 100 tons.

(c) The speed of the rocket was estimated to be in the vicinity of 2000 km/hr when operating at an altitude of 200 kilometers. The proposed range was to be 1800 kilometers.

(d) The rocket was to be launched from a catapult mechanism.

[In the table of rockets on p. 46 of this report, the numbers from p. 190 of the report are repeated, but the thrust is indicated as 100 tons, and all other details are listed as "not known." In order to lift off, the rocket's thrust must be larger than the rocket's weight, so the actual thrust must have been greater than 140 tons.

This report stated that its only information on the V-101 came from the SAIC/38 interrogation report, which did not indicate the thrust of the rocket. The most likely explanation is that whoever typed the table in this NavTechMisEu 237-45 report misread the reported fuel weight of 100 tons as being a thrust of 100 tons.

A less likely explanation is that whoever typed this table was thinking of a thrust of 200 tons but mistyped it as 100 tons. 200 tons of thrust would give a very plausible thrust-to-weight ratio for a rocket weighing 140 tons when launched.

Note that the name given as "Dr BOEDENWADT" in SAIC/38 has been mangled to "BUEDENWADT" in this NavTechMisEu 237-45 report.]

HEC 5787. Headquarters, U.S. Forces, European Theater, Alsos Mission. 15 September 1945. Subject: Survey of Facilities in Germany for Development of Guided Missiles. [NARA RG 319, Entry NM3-82, Box 1582]

Part V

Development and Fabrication of Complete Missiles

[...] K. Skoda "V-101"

The large munitions work Skoda in Pilsen, Czechoslovakia, operated a rocket experimental station at Pribrans, Czechoslovakia. Here work was being done towards the development of a stratosphere rocket 100' long and weighing 140 tons.

L. "Rochen" ("Roe")

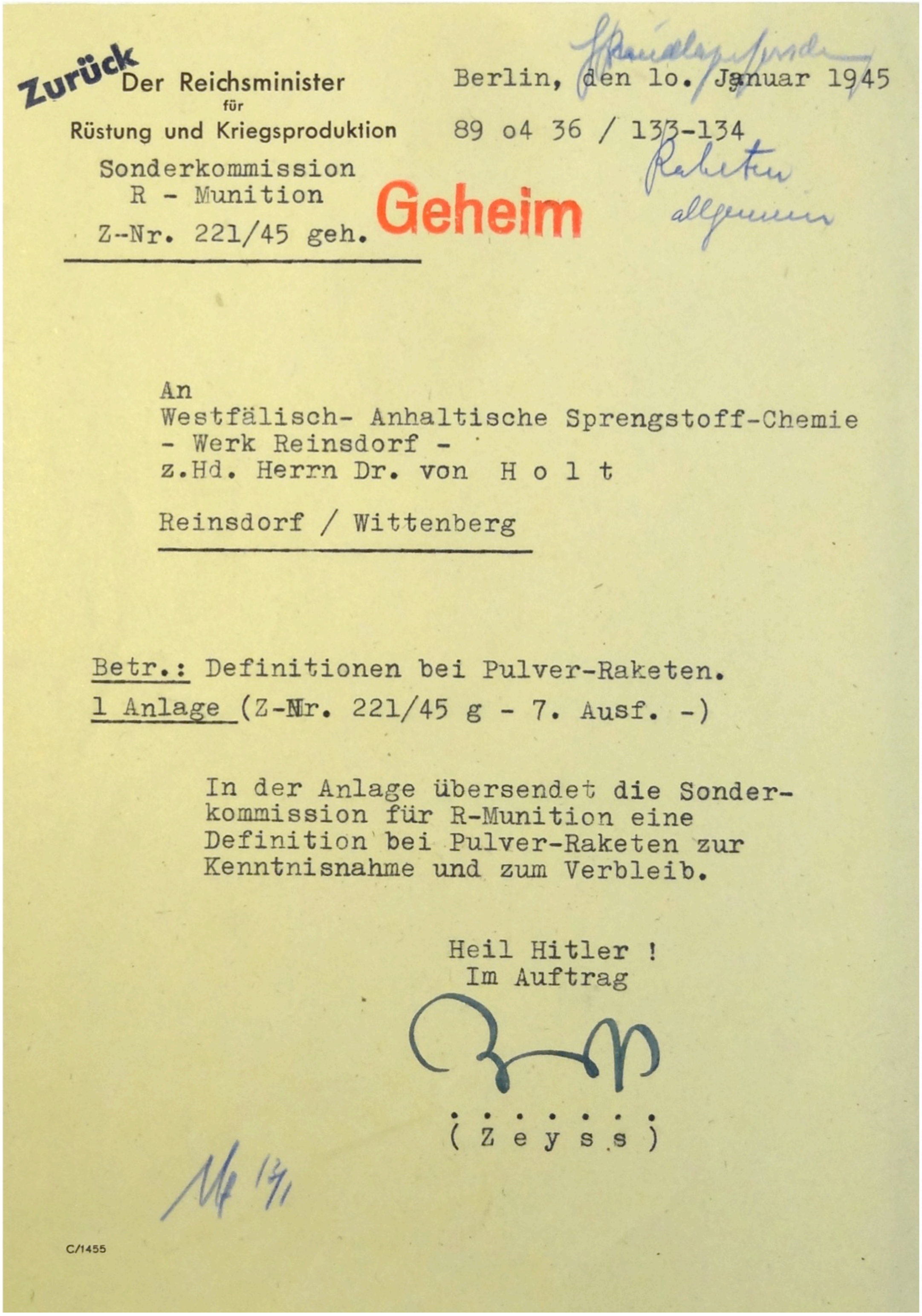
This was a rocket projectile for wire control under development by the Torpedo Research Station Gotenhaven. Tests were conducted there and at a research station Grossendorf. This project was under the cognizance of the Navy High Command.

[The Alsos Mission traveled around Europe independently investigating a wide range of scientific innovations and collecting vast numbers of German documents. Was this statement in HEC 5787 based on their own investigations, or was it simply rephrased from the earlier U.S. and U.K. reports?

As an example of at least one relevant German document collected by Alsos, please see the following pages. Was Alsos's statement that "work was being done towards the development of a stratosphere rocket 100' long and weighing 140 tons" based on other documents that they collected? If so, where are those documents now?

From this statement in HEC 5787, the V-101 sounds like more than a paper design study. The Alsos Mission reported the V-101 under the heading of "Development and Fabrication of Complete Missiles," alongside fully built (if not perfected) projects such as the Rochen wire-guided missile and Natter vertical take-off rocket plane, and with the wording that there was "work" toward its "development." It would have been very difficult to fully build such a large rocket, but what development work was actually done?]

NARA RG 319, Entry NM3-82A, Box 14, Folder OB-3



Zurück

Der Reichsminister
für
Rüstung und Kriegsproduktion
Sonderkommission
R - Munition
Z-Nr. 221/45 geh.

Geheim

Berlin, den 10. Januar 1945
89 04 36 / 133-134

An
Westfälisch- Anhaltische Sprengstoff-Chemie
- Werk Reinsdorf -
z.Hd. Herrn Dr. von Holt

Reinsdorf / Wittenberg

Betr.: Definitionen bei Pulver-Raketen.
1 Anlage (Z-Nr. 221/45 g - 7. Ausf. -)

In der Anlage übersendet die Sonderkommission für R-Munition eine Definition bei Pulver-Raketen zur Kenntnisnahme und zum Verbleib.

Heil Hitler !
Im Auftrag

(Z e y s s)

C/1455

Figure E.215: Excerpts from a 49-page book from Rolf Engel and Wilhelm Zeyss listing definitions of mathematical variables used for calculating the performance of solid propellant rockets, collected by the U.S. Alsos Mission. [NARA RG 319, Entry NM3-82A, Box 14, Folder OB-3]

**NARA RG 319, Entry NM3-82A,
Box 14, Folder OB-3**

Der Reichsminister für Rüstung
und Kriegsproduktion

Munitions-Kommission
Sonderkommission für R-Munition

**Definitionen
bei Pulver-Raketen**

ALSOS MISSION

Die nachstehende Zusammenstellung fasst alle Begriffe zusammen, für die ein Interesse nach einer einheitlichen Bezeichnungsweise besteht. Sie soll laufend ergänzt und vervollständigt werden. Weitere Vorschläge dieser Art sind zu richten an

R. f. R. u. K.
Sonderkommission
für R-Munition
(1) Berlin-Schmargendorf
Krantzerstr. 3

Die nachstehende Zusammenfassung wurde durchgeführt von der Versuchsanstalt der Waffen-Union Pibrans/Böhmen.

Verantwortlich: SS-Hstuf. R. Engel.

Figure E.216: Excerpts from a 49-page book from Rolf Engel and Wilhelm Zeyss listing definitions of mathematical variables used for calculating the performance of solid propellant rockets, collected by the U.S. Alsos Mission. [NARA RG 319, Entry NM3-82A, Box 14, Folder OB-3]

NARA RG 319, Entry NM3-82A, Box 14, Folder OB-3

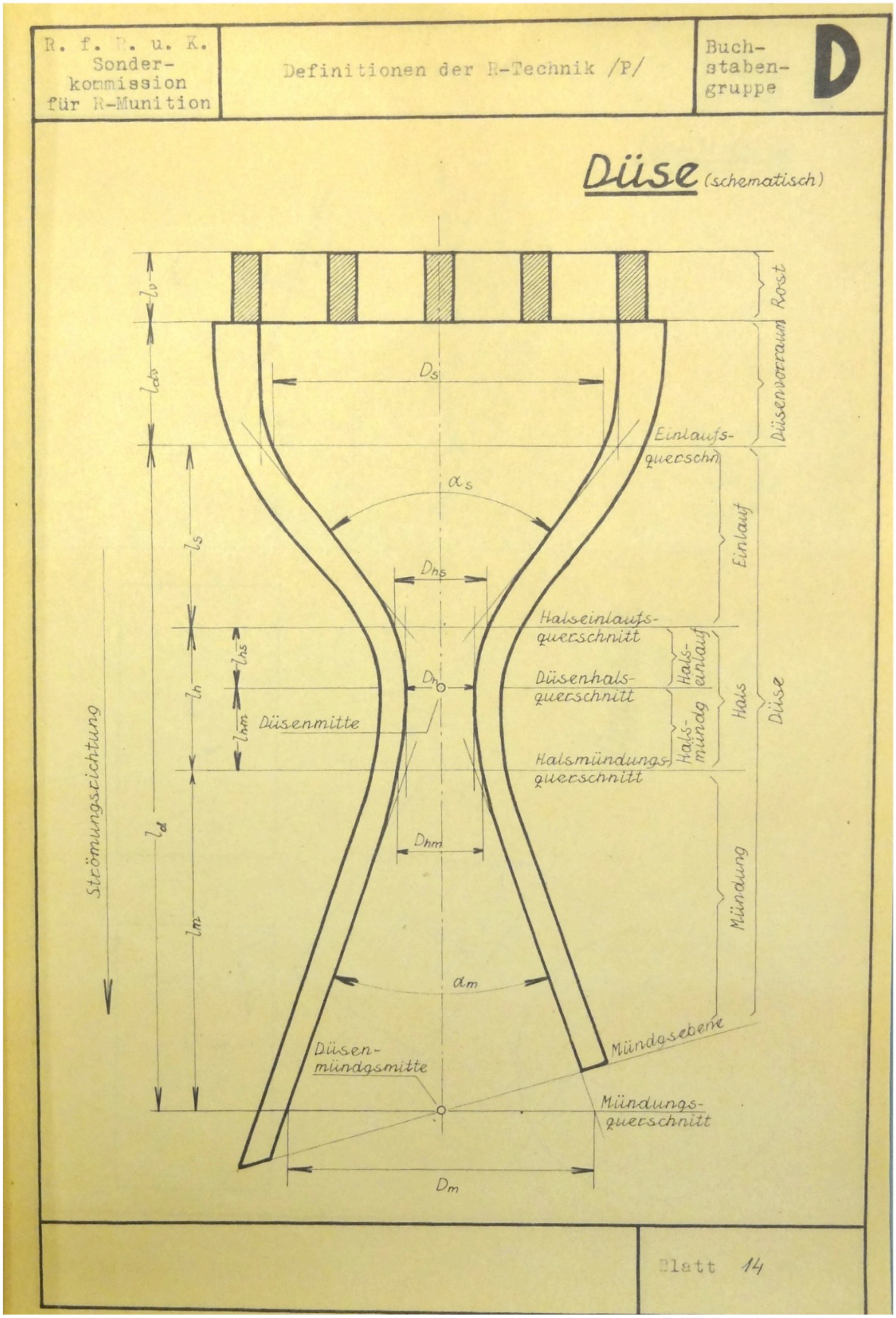


Figure E.217: Excerpts from a 49-page book from Rolf Engel and Wilhelm Zeyss listing definitions of mathematical variables used for calculating the performance of solid propellant rockets, collected by the U.S. Alsos Mission. [NARA RG 319, Entry NM3-82A, Box 14, Folder OB-3]

Fritz Hahn. 1998. *Waffen und Geheimwaffen des deutschen Heeres 1933-1945.* 3rd ed. Bonn: Bernard & Graefe. Vol. 2, pp. 180, 182.

V 101

Unter dieser Bezeichnung hatten 1944 Dr. Büdewald und Dr. Teichmann im *Zweigwerk Pibrans* der Firma *Skoda* mit der Entwicklung einer großen Feststoff-Rakete begonnen.

Bei 30,000 mm Länge und 2800 mm Durchmesser sollte diese dreistufige Rakete 140 t wiegen. Das Pulvertriebwerk der ersten Stufe war für einen Schub von 100 t ausgelegt, die rechnerische Flugbahn zeigte bei einer Reichweite von 1800 km eine Gipfelhöhe von 200 km. Der Entwurf war nur in groben Zügen festgelegt, über Einzelheiten existieren keine Unterlagen mehr. Dieses Projekt wäre, wie andere auch am Treibmittel, dem immer knapper werdenden Pulver gescheitert.

V 101

Under this designation Dr. Büdewald and Dr. Teichmann started the development of a large solid propellant rocket in the Pibrans branch of the Skoda company in 1944.

At 30 m in length and 2.8 m in diameter, this three-stage rocket was supposed to weigh 140 tons. The powder [solid propellant] engine of the first stage was designed for a thrust of 100 tons; the calculated trajectory showed a peak altitude of 200 km with a range of 1800 km. The design was only laid out in general outline; documents about details no longer exist. This project, like others on the propellant, failed because of the increasingly scarce powder.

[Almost all of Fritz Hahn's information appears to have come from the NavTechMisEu 237-45 report, including the erroneous thrust of 100 tons.

Dr. "Bödenwadt" (from SAIC/38) or "Büdenwadt" (from NavTechMisEu 237-45) has been further altered to "Büdewald." The scientist's actual name was Uwe Bödewadt (German, 1911–2003).

The only major new technical detail added by Hahn is that the rocket had three stages. That does not appear to be stated anywhere in the available U.S. or U.K. reports. Was that simply a guess by Hahn, or did sources with knowledge of the project give that additional information to Hahn? For the projected performance characteristics of the V-101, it seems probable that it would have had 2–4 stages, so three stages is highly plausible.]

BIOS 571. *German Rocket Propellants (Interrogation of Mr. N. W. Larsson).*

I. Introduction

Mr. N. W. Larsson is an engineer with great faculties of memorising technical data. He is a Swedish subject, talks German fluently, and claims that he went to Germany as an allied spy, working for the British Secret Service.

Mr. Larsson has been employed in German Armament Research from May 1943 to V.E. day. He first spent some months at the Rheinmetall-Borsig factories where he worked on the "Gehrlich" recoilless gun.

He was then transferred to Peenemünde, where he assisted in the development of various rocket weapons.

In December 1944 he went with the Peenemünde staff to a research station of the Skoda Works at Pibrans, Czechoslovakia, when he carried on his work until the cessation of hostilities.

During the interrogation Mr. Larsson gave some information upon the German 'alternative' rocket propellants Per-pulver and Giessling-pulver, as well as some indication upon the technique employed in making "cigarette-burning" charges.

II. Per-pulver

Mr. Larsson worked with the applications of this propellant to various rocket weapons, at the Skoda Works Rocket Research Station at Pibrans, Czechoslovakia, for about 6 months. Here he met the inventor of Per-pulver, Dr. Teichmann, and his two collaborators, Dr. Knust and Dr. Nord.

Per-pulver is also called Nider-druck-pulver, Super-pulver and Dauerbrand.

Composition:

Ammonium perchlorate	25–40%
Buna S3	25%
Vinapas	50–35%
Stabiliser	3–5%

Later interrogations of Dr. Teichmann, however, show that these figures are not exact. The composition contains about 80% of ammonium perchlorate.

Ingredients:

Buna S3. It appears that this synthetic rubber corresponds to Buna SG. Delivered in sheets, vulcanised, 2–3 mm. thick, the sheets being in rolls of about 100 Kg. weight.

The sheets were disintegrated in special machines, down to dimensions of the order of 3–5 mm. (The synthetic rubber industry was later asked to deliver the rubber in a more favourable state, such as an intermediate product consisting of small grains).

Vinapas. Produced by Wacker Chemie, Burghausen near Salzburg. This is a synthetic plastic, which also appears under other commercial names. It is used as a binder, conferring to the propellant a consistency somewhat like a plastic. The yellow colour of the propellant is due to the Vinapas. It is used as small flakes or a fine powder.

Ammonium perchlorate. It is added as fine crystals (particle size roughly as ordinary table salt). Also other perchlorates have been used, such as sodium perchlorate.

Preparation of the propellant.

The ingredients are mixed at room temperature (plus 15^{o}C) in a usual rotating incorporator. The mixture is then rolled on a roller-mill of the usual type employed for Digl. pulver.

The initial temperature is 60^{o}C, which is increased during milling to 90–95^{o}C. The milling time is dependent on the consistency of the dough, which in turn varies with the proportions of the constituents. The time appears to be 25–30 mins. for a batch of 25 Kg.

Mr. Larsson's notes do not make quite clear at which state of the process the perchlorate is introduced. On one occasion he said that it was added on the rolls, when a sheet was formed, and this appears to be most likely, as this procedure would be the safest.

The resulting dough is extruded or molded. The extrusion press is worked very much in the same way as for Digl. pulver. The extrusion pressure is, of course, dependent of the temperature.

The molding is, however, the most important method of preparing propellant charges, as it makes possible the production of charges of almost any size and shape. The propellant is molded at 110–120^{o}C, in jacketed moulds preferably warmed to a somewhat lower temperature. This temperature is maintained for 5–10 min. to allow air bubbles to mount and assemble in the upper part of the mould. The jacket is then cooled rapidly with cold water. After solidification of the propellant the mould is taken to pieces. 4–6 inches is cut off the top of the charge, to take away any air bubbles that may be included owing to the more rapid cooling of the surface of the charge during molding. The surface is then polished.

Ballistic properties.

The rate of burning exponent is "somewhat lower than 1". The propellant burns regularly under low pressure. It appears that the highest specific impulse was obtained when the propellant is burning at 25 atm. (350 p.s.i.) The flame temperature also gives a maximum at this pressure (1600^o–1800^{o}C.).

The rate of burning at 25 atm. is claimed to be 25 mm/sec. Striction ratio K=50–80.

There is danger of detonation when the pressure rises to 1100 atm. at which pressure the rate of burning is 1000 mm/sec. The pressure limit for which detonation occurs is increased by introducing more Vinapas in the propellant.

Physical properties.

Consistency somewhat like a plastic.
d- 1.85 to 1.90
Colour yellow to brown.
Smooth, hard surface.
Can be worked with cutting tools.

Applications.

Per-pulver was used in the A.T.O. unit of "Rochen", where it was burning at a pressure of 25 atm. with a rate of burning of 25 mm./sec.

"Rochen" is a heavy rocket missile, guided by wires. It was intended for use from light vehicles and MTBs against shipping and ground targets.
Weight about 300 Kg., 150 Kg. of explosives.
Guided by the "Spinner" system.

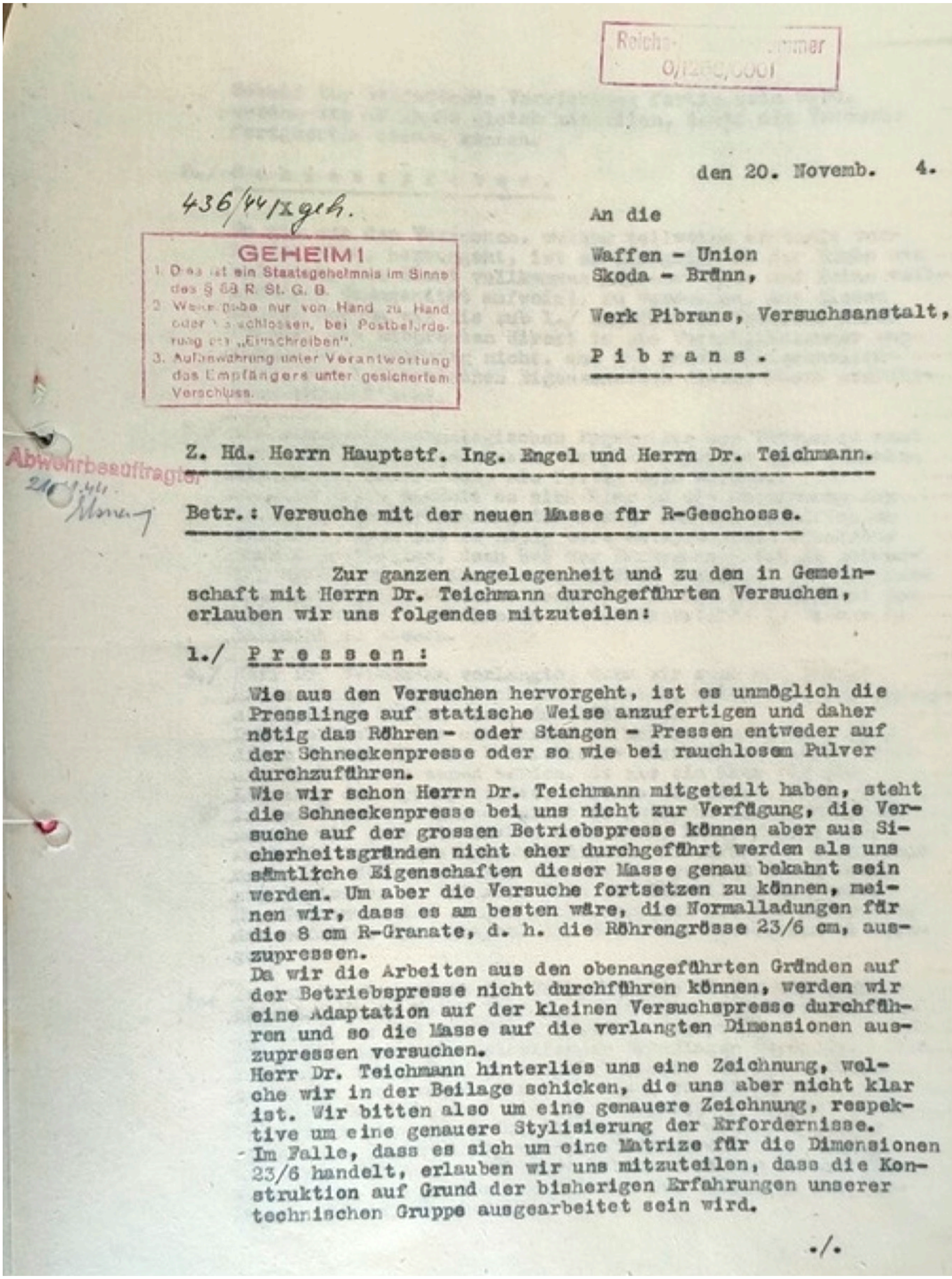
[This solid propellant mixture was probably dubbed Per-pulver or "per powder" because its dominant ingredient was ammonium perchlorate. It is mentioned in several of the documents in this section, and this appears to have been the origin and first use of truly modern solid propellant rocket propellant.

Where are the "later interrogations of Dr. Teichmann" that gave complete details about the solid rocket propellant, as mentioned in this report? An early interrogation of Teichmann appeared in the following report, BIOS 31, but in that early interrogation Teichmann was unwilling to reveal many of the details of his work on solid rocket propellant. Somewhere there must be much more detailed written reports on later interrogations of Teichmann, or even wartime or postwar reports written by Teichmann or others from his research group. Can those reports be located in archives?]

Hermann Teichmann. 7 June 1945. Survey of research work of Dr. Teichmann group [AFHRA C5094, frames 0770–0772]

[After the war, Hermann Teichmann and several other members of his solid propellant rocket group were interned at Camp Föhrenwald-Wolfratshausen in Bavaria by U.S. forces. They wrote this three-page letter to the American military occupying government in Munich offering their services to work for the United States. Without going into technical details, they explained that they had made important new inventions and discoveries with regard to solid rocket propellants.

While they were never hired by the United States or United Kingdom, they were apparently interrogated extensively by U.S. and U.K. scientific investigators. After they were released, they went to work in France.]



Reichs- ... nummer 0/1250/0001

den 20. Novemb. 4.

436/44/x geh.

GEHEIM!
1. Dies ist ein Staatsgeheimnis im Sinne des § 88 R. St. G. B.
2. Weitergabe nur von Hand zu Hand oder verschlossen, bei Postbeförderung als „Einschreiben".
3. Aufbewahrung unter Verantwortung des Empfängers unter gesichertem Verschluss.

An die
Waffen - Union
Skoda - Brünn,
Werk Pibrans, Versuchsanstalt,
P i b r a n s .

Abwehrbeauftragter
21.11.44

Z. Hd. Herrn Hauptstf. Ing. Engel und Herrn Dr. Teichmann.

Betr.: Versuche mit der neuen Masse für R-Geschosse.

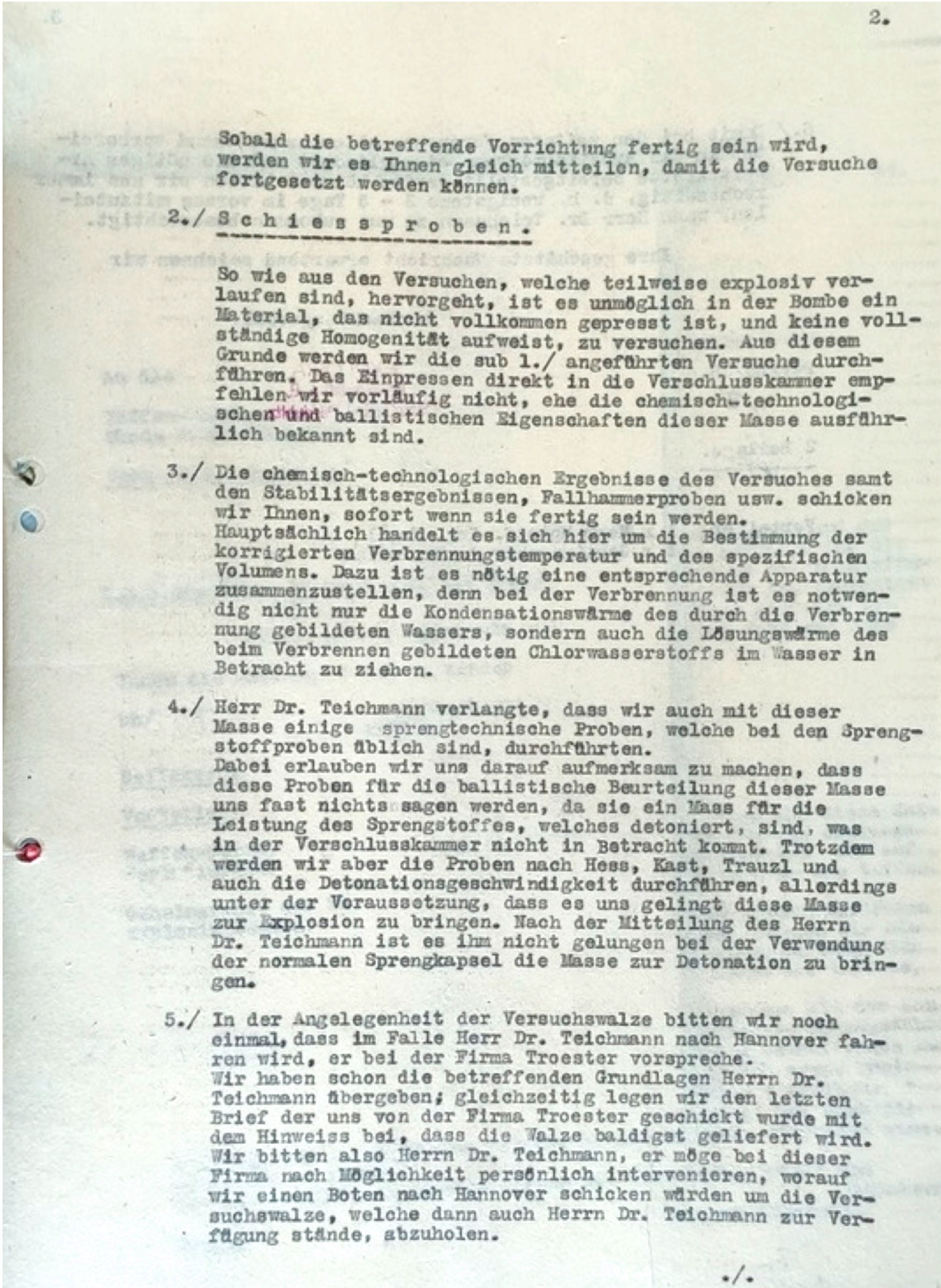
Zur ganzen Angelegenheit und zu den in Gemeinschaft mit Herrn Dr. Teichmann durchgeführten Versuchen, erlauben wir uns folgendes mitzuteilen:

1./ P r e s s e n :

Wie aus den Versuchen hervorgeht, ist es unmöglich die Presslinge auf statische Weise anzufertigen und daher nötig das Röhren- oder Stangen - Pressen entweder auf der Schneckenpresse oder so wie bei rauchlosem Pulver durchzuführen.
Wie wir schon Herrn Dr. Teichmann mitgeteilt haben, steht die Schneckenpresse bei uns nicht zur Verfügung, die Versuche auf der grossen Betriebspresse können aber aus Sicherheitsgründen nicht eher durchgeführt werden als uns sämtliche Eigenschaften dieser Masse genau bekannt sein werden. Um aber die Versuche fortsetzen zu können, meinen wir, dass es am besten wäre, die Normalladungen für die 8 cm R-Granate, d. h. die Röhrengrösse 23/6 cm, auszupressen.
Da wir die Arbeiten aus den obenangeführten Gründen auf der Betriebspresse nicht durchführen können, werden wir eine Adaptation auf der kleinen Versuchspresse durchführen und so die Masse auf die verlangten Dimensionen auszupressen versuchen.
Herr Dr. Teichmann hinterlies uns eine Zeichnung, welche wir in der Beilage schicken, die uns aber nicht klar ist. Wir bitten also um eine genauere Zeichnung, respektive um eine genauere Stylisierung der Erfordernisse.
Im Falle, dass es sich um eine Matrize für die Dimensionen 23/6 handelt, erlauben wir uns mitzuteilen, dass die Konstruktion auf Grund der bisherigen Erfahrungen unserer technischen Gruppe ausgearbeitet sein wird.

./.

Figure E.218: 20 November 1944 letter demonstrating the involvement of Hermann Teichmann and Rolf Engel in tests of a solid rocket propellant that produced hydrochloric acid in the exhaust (a key characteristic of Per-pulver, due its ammonium perchlorate—see p. 5234).



2.

Sobald die betreffende Vorrichtung fertig sein wird, werden wir es Ihnen gleich mitteilen, damit die Versuche fortgesetzt werden können.

2./ S c h i e s s p r o b e n .

So wie aus den Versuchen, welche teilweise explosiv verlaufen sind, hervorgeht, ist es unmöglich in der Bombe ein Material, das nicht vollkommen gepresst ist, und keine vollständige Homogenität aufweist, zu versuchen. Aus diesem Grunde werden wir die sub 1./ angeführten Versuche durchführen. Das Einpressen direkt in die Verschlusskammer empfehlen wir vorläufig nicht, ehe die chemisch-technologischen und ballistischen Eigenschaften dieser Masse ausführlich bekannt sind.

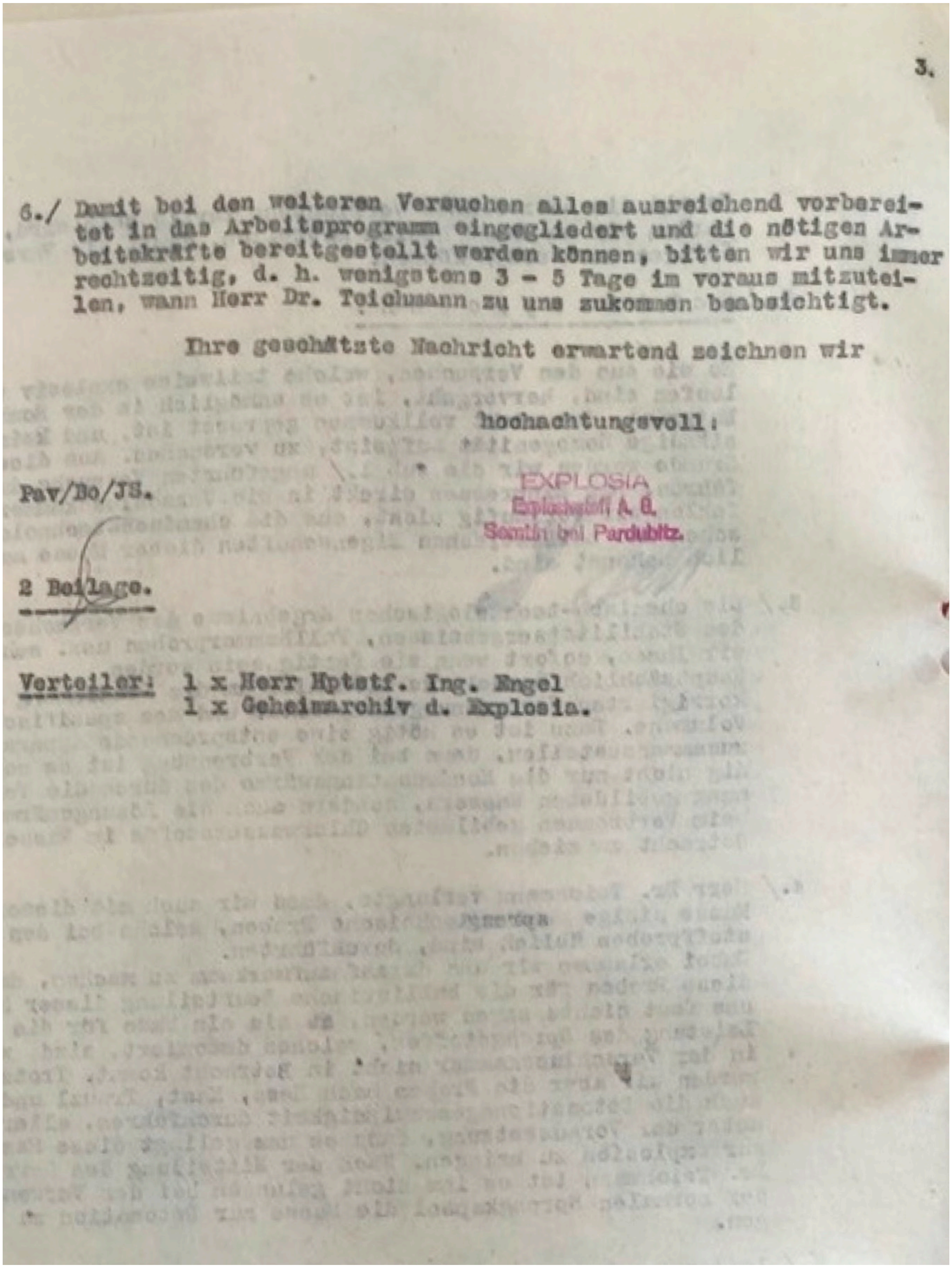
3./ Die chemisch-technologischen Ergebnisse des Versuches samt den Stabilitätsergebnissen, Fallhammerproben usw. schicken wir Ihnen, sofort wenn sie fertig sein werden.
Hauptsächlich handelt es sich hier um die Bestimmung der korrigierten Verbrennungstemperatur und des spezifischen Volumens. Dazu ist es nötig eine entsprechende Apparatur zusammenzustellen, denn bei der Verbrennung ist es notwendig nicht nur die Kondensationswärme des durch die Verbrennung gebildeten Wassers, sondern auch die Lösungswärme des beim Verbrennen gebildeten Chlorwasserstoffs im Wasser in Betracht zu ziehen.

4./ Herr Dr. Teichmann verlangte, dass wir auch mit dieser Masse einige sprengtechnische Proben, welche bei den Sprengstoffproben üblich sind, durchführten.
Dabei erlauben wir uns darauf aufmerksam zu machen, dass diese Proben für die ballistische Beurteilung dieser Masse uns fast nichts sagen werden, da sie ein Mass für die Leistung des Sprengstoffes, welches detoniert, sind, was in der Verschlusskammer nicht in Betracht kommt. Trotzdem werden wir aber die Proben nach Hess, Kast, Trauzl und auch die Detonationsgeschwindigkeit durchführen, allerdings unter der Voraussetzung, dass es uns gelingt diese Masse zur Explosion zu bringen. Nach der Mitteilung des Herrn Dr. Teichmann ist es ihm nicht gelungen bei der Verwendung der normalen Sprengkapsel die Masse zur Detonation zu bringen.

5./ In der Angelegenheit der Versuchswalze bitten wir noch einmal, dass im Falle Herr Dr. Teichmann nach Hannover fahren wird, er bei der Firma Troester vorspreche.
Wir haben schon die betreffenden Grundlagen Herrn Dr. Teichmann übergeben; gleichzeitig legen wir den letzten Brief der uns von der Firma Troester geschickt wurde mit dem Hinweiss bei, dass die Walze baldigst geliefert wird. Wir bitten also Herrn Dr. Teichmann, er möge bei dieser Firma nach Möglichkeit persönlich intervenieren, worauf wir einen Boten nach Hannover schicken würden um die Versuchswalze, welche dann auch Herrn Dr. Teichmann zur Verfügung stände, abzuholen.

./.

Figure E.219: 20 November 1944 letter demonstrating the involvement of Hermann Teichmann and Rolf Engel in tests of a solid rocket propellant that produced hydrochloric acid in the exhaust (a key characteristic of Per-pulver, due its ammonium perchlorate—see p. 5234).



3.

6./ Damit bei den weiteren Versuchen alles ausreichend vorbereitet in das Arbeitsprogramm eingegliedert und die nötigen Arbeitskräfte bereitgestellt werden können, bitten wir uns immer rechtzeitig, d. h. wenigstens 3 - 5 Tage im voraus mitzuteilen, wann Herr Dr. Teichmann zu uns zukommen beabsichtigt.

Ihre geschätzte Nachricht erwartend zeichnen wir

hochachtungsvoll:

EXPLOSIA
Explosivstoff A. G.
Semtin bei Pardubitz.

Pav/Bo/JS.

2 Beilage.

Verteiler: 1 x Herr Hptstf. Ing. Engel
1 x Geheimarchiv d. Explosia.

Figure E.220: 20 November 1944 letter demonstrating the involvement of Hermann Teichmann and Rolf Engel in tests of a solid rocket propellant that produced hydrochloric acid in the exhaust (a key characteristic of Per-pulver, due its ammonium perchlorate—see p. 5234).

BIOS 31. *Rocket Developments in South Germany and Austria.*

[pp. 8–11:]

Target	Dr. Hermann Teichmann.	(E)
Location	Lager Föhrenwald (D.P. camp) Wolfratshausen. M.48 WY. 778 (U.S. zone)	
Nature of Target	Research chemist.	
Date visited	2.8.45.	

Dr. Teichmann graduated at Hanover in 1937 and then worked as an assistant to Prof. Jost at Hanover and at Leipzig.

He worked for various organisations including the German Air Ministry in Berlin and Strassbourg, leaving the latter city in August 1944 to continue work in the explosives (H.E.) factory at Wolfratshausen. There he was in charge of a group developing solid propellants for rockets. He is still in touch with other members of his group and is desirous of continuing his work.

He was to a large extent co-operative, but frankly admitted that he did not intend to reveal all the results of his work to everybody who questioned him, without some assurances regarding his future.

From 1937 until quite recently he was engaged on an academic study of gaseous combustion. [...]

He stressed the importance of the gaseous reactions as the factor controlling the rate of burning of solid propellants, and claimed to have based his design of a propellant on the results of his study of gaseous combustion.

According to his theories, any solid propellant, the burning of which involves a "liquid" layer between the solid unburnt propellant and the gaseous phase, will not burn reliably at low pressures, because the rate of the slowest reaction in the gaseous phase is slower than the rate of thermal decomposition of the solid. The result is "chuffing" and incomplete combustion. At higher pressures the gaseous reaction rate is enormously increased, whereas the rate of thermal decomposition is practically unaffected. The gaseous reactions, therefore, take control and burning proceeds smoothly and continuously.

He said that in Germany there was a complete mathematical theory of the burning of solid propellants in rockets, based on the reactions occurring in the gaseous phase.

He discoursed on the properties of propellants consisting of ammonium perchlorate bound with various plastic materials, either thermoplastic or heat irreversible materials. These, he claimed, gave no "liquid" layer on thermal composition.

A few small samples, which he possessed, were examined. They had not the appearance of colloidal propellants, but rather that of a consolidated material. Although they were hard, they were not brittle as would be expected, on striking with a hammer.

In replies to questions Dr. Teichmann claimed the following properties for these propellants.

A. Burning Characteristics

1. Stable burning at pressures from 20 to 700 atms.
2. Rate of burning could be varied over a wide range, by altering the composition, and could be made many times greater than that of normal colloidal propellants, even at low pressures.
3. Erosion effect was small at low pressures.
4. Smokeless.
5. Almost flashless, since combustion was practically complete, the products being N_2, H_2O, CO_2, HCl and a little CO.
6. Calorimetric value about 1000 cals./grm.
7. Performance index, 250.
8. Ignition presented no difficulties, owing to the reliability of burning at low pressures.
9. No erosion of the venturi had been observed after firing. It was his practice to use venturis of comparatively large throat diameter.

B. Physical Properties

1. Mechanical properties could be varied over a wide range from soft thermo plastic materials to hard infusible solids, depending, presumably, on the nature of the binder. (Teichmann would not say what plastics were used as binders).
2. S.G. about 1.8.

C. Charge Design

1. The thermoplastic propellants could be extruded at 120^oC. and used as sticks, or the more plastic varieties could be pressed into star centred charges adhering to the walls of the tube.
2. The rigid types could be cast and hardened either by warming or in the cold. He claimed good adhesion to steel even for these, and preferred the cast, cold hardening materials for large charges and the extruded thermoplastic varieties for small charges.

D. Storage and Safety

1. No deterioration either chemically or physically on long storage. Gassing did not occur below 180^oC.
2. Spontaneous ignition temperature, 270^oC.
3. Could be detonated by powerful initiation.

Dr. Teichmann said that development had not proceeded beyond the stage of static firings in vented vessels. His idea was to burn the propellant at lower pressures (300 lb./sq. in.) and thus increase the performance of the rocket by saving weight on the metallic components.

This team was not impressed by the mechanical properties of the samples of propellant examined, and doubted Teichmann's claim of good, permanent adhesion to steel. He appears, however, to have done a considerable amount of fundamental work on gaseous combustion, but this team was not sufficiently well acquainted with this field to be able to assess its value. [...]

[p. 30:]

Work on liquid fuel rockets had been confined principally to fundamental research, rather than to specific projects, although some routine work connected with development had been done. Dr. Sänger had not worked with solid propellants.

The object of the research was to increase the efflux velocity of the gases. Two methods had been investigated using the hydrocarbon/liquid oxygen system.

1. Increasing the heat content of the products of combustion (H_2O and CO_2) of the fuel by the dispersion in the fuel of certain light elements, e.g. Be, B, Li, Mg or Al.

2. The use of liquid ozone mixed with liquid oxygen.

[...] Sedimentation of dispersions of the aluminium in the hydrocarbon fuel (diesel oil) presented some difficulty, which was finally solved by stabilisation with oppanol (a hydrocarbon polymer). Sedimentation was then very slight after standing for one month.

The hydrocarbon/aluminium fuel gave rise to a large amount of white smoke from the rocket motor, as would be expected.

[Polybutadiene synthetic rubber was invented by German scientists in 1929–1930 (see pp. 654–655). Teichmann appears to have been working in this field of rocket propulsion since 1937.

This report also stated that aluminum powder was being used to increase the performance of large liquid propellant rockets, and even that highly novel chemical methods had been developed and demonstrated in order to keep the aluminum powder suspended in the liquid propellant for over a month during storage. While this report does not specifically mention the use of aluminum powder in large solid propellant rockets, it seems likely that that was done as well. For examples of other reports on the use of aluminum powder to improve the performance of small solid propellant rockets or closely related solid explosives in wartime Germany, please see the following reports.]

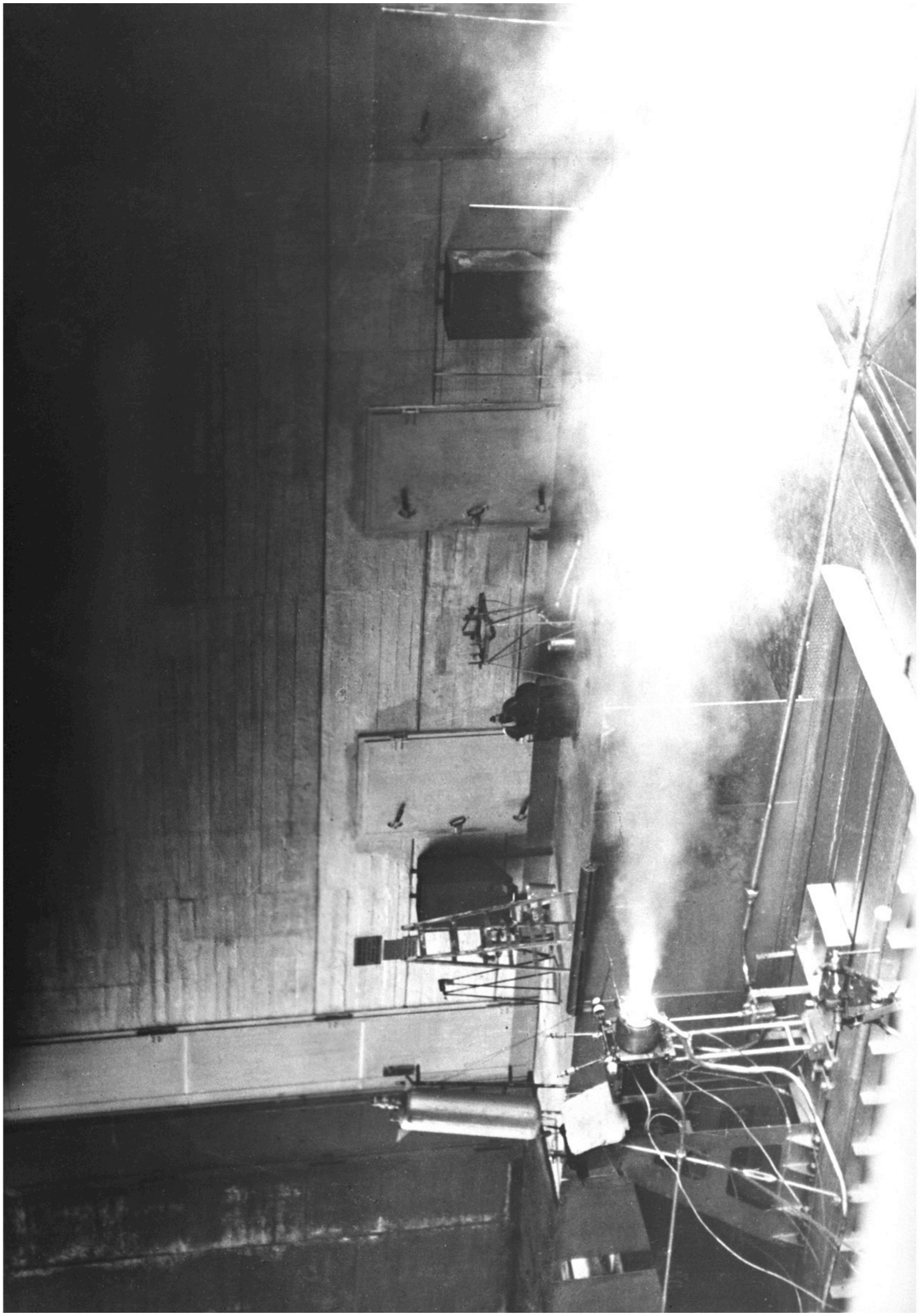


Figure E.221: 1941 test firing of one of Eugen Sänger's rocket engines using aluminum powder in the propellant mixture [Deutsches Museum Archive, photo 30389]

BIOS 27. *Modern High Explosive Developments at Deutsche Waffen und Munitions Fabriken, A.G., Schlutup near Lübeck.*

The factory normally received its explosives already mixed in the form of lumps but Dr. Weidle had carried out a certain amount of research in order to determine the optimum proportions of the various ingredients. He found that 20 per cent aluminium mixed with 80 per cent of the hexogen/wax mixture gave the best blast effect in small light cased munitions. [...] Aluminium in flake form was used in the early days of development but had been abandoned in favour of granulated owing to difficulties in handling the former. [...] The size of the granulated aluminium used was stated to be all through a 0.15 mm aperture sieve. [...]

Production of the mixture was said to be carried out in the following way. The T.N.T. was melted in a steam kettle, dry hexogen added with stirring and finally the aluminium. 50 litre kettles were used and the mixture stirred by a conventional propeller stirrer.

(iii) and (iv) were used as poured fillings for hollow charge ammunition[...]

BIOS 1261. *Visit to German High Explosive and Filling Factories.* pp. 9–10.

The W.A.S.A.G., Allendorf, Kreis Marburg, Hesse was visited on 16.10.45. [...]

Dr. Walther Naumann, formerly a director of the factory, was available for interrogation and demonstration of sections of the plant required. [...]

When preparing hexanite/aluminium the T.N.T. was first melted and run into a jacketed stainless steel mixer. The aluminium was added next and the hexanitrodiphenylamine last. Similarly when preparing trialen 105 or 106 the T.N.T. was charged first, the aluminium next and then the hexogen. [...]

Dr. Naumann stated that larger mixing units than the type seen had been installed more recently, these having a capacity of 1000 Kg. as compared with the 400 Kg. units of the original plant.

With regard to the aluminium powder it was stated that two types were used viz. Pyro-schliff and Griess. The first of these was prepared by grinding and the second was a fine blown aluminium. Pyro-schliff was very dusty but was less inclined to sedimentation than the coarser blown powder. All the aluminium was specified to pass a sieve of 6400 meshes per sq. cm., approximately 200-mesh. A chemical specification was in existence but not available for inspection. The management were conscious of the risk of ignition of airborne fine aluminium powder through electrical agency and had in fact experienced two ignitions attributable to this cause. Owing to the provision of a simple drenching apparatus fitted to the mixing unit there were no serious consequences to these ignitions. The aluminium was fed to the pan through a stainless steel funnel attached to the pan-cover and fitted with a wide skirt which directed the aluminium against the wall of the pan, the object being to remove as much as possible of any accumulated static charge on the powder.

BIOS 100. *Development of Panzerfaust.* pp. 10–11.

Langweiler appeared to attach more importance to the flame effect behind the target than the remaining power of the jet itself. The enhancing of this flame effect was in his opinion the most likely method of increasing the efficiency of hollow charges. This effect could be increased very greatly by incorporating into the H.E. charge up to 30% of powdered aluminium. This proportion could be used without impairing performance. Had it not been for the great shortage of aluminium in Germany this type of filling would have been used in Panzerfaust.

NavTecMisEu 327-45. *Solid Rocket Propellant. Translation of a Report by Dipl. Ing. Hans Grosse.* p. 14. [NARA RG 38, Entry P5, Box 46]

In general black powder was used as an auxiliary charge. Black powder causes a relatively slight ignition delay, however, is sensitive to moisture and as far as transportation is concerned, and increases the creation of smoke. In cold temperatures, furthermore, it does not always give a sufficiently intensive ignition, especially in the case of long charges. Therefore, besides black powder, boosters were also used. These consist of mixtures of a composition similar to that of flash light powder for photographic purposes, i.e., light metal dust, Al., Mg., together with salts giving off oxygen, such as potassium nitrate, barium nitrate, etc. These mixtures are firmly pressed in capsules of aluminum, lately also of cardboard. They produce, especially at low temperatures, a very hot flame and thus avoid ignition failure in this temperature range. At high temperature they do not effect such a great increase in gas pressure as does a black powder auxiliary charge of an equally strong ignition effect, because they develop relatively little gas.

HEC 2434. German patent D70226. Use of black powder for rocket propulsion, containing metal sulfides and/or metal alloys which give off oxygen on heating.

HEC 2485. Propellant for rockets which discharges vapours of metals or their salts.

HEC 2487 = HEC 2468. Powdered metals as ingredients of rocket propellants.

BIOS 477. *German Pyrotechnic Factories* [aluminum powder for pyrotechnic manufacture]

FIAT 1035. *German Developments in High Explosives.*

[See also the 1942 Peenemünde document on p. 5300.]

R. V. Shepherd. BIOS 313. *Report on Visit to Czechoslovakia by Armament Design Department. 16th November to 9th December, 1945.*

[p. 5:]

[...] All visits and official interviews were arranged in conjunction with the Czech military intelligence and a Czech officer was present on these occasions. [...]

[...] The following persons were interviewed at the Czech War Office:

[...] Dr. W. Voss	[...] Head of Waffen Union
[...] Ing. K. Staller	[...] Deputy to Dr. Voss
Ing. Musel	Managing Director, Zbrojovka
Ing. Šidlék	Czechomoravian Engineering Works
Dr. Frey	Jawa

[pp. 29–32:]

EXPERIMENTAL STATION AT PRIBRAM

[...] The preliminary work for the formation of the station was started late in 1943 and it was not until the early summer of 1944 that the staff commenced serious work. [...]

There is a fact which should be noted. When the buildings were visited in late November, they were completely stripped and only one engineer and a woman secretary left in charge. In answer to the query as to what had happened to the library, equipment and staff it was stated that the Mining Institute had been removed to Moravaka Ostrava and the scientific staff had returned to Charles University, the technical schools and firms from whom they had come originally. It is remarkable that a move of some magnitude involving a journey from the west side of Bohemia to the Eastern frontier should have been carried out with such completeness within six months of the end of the war in Europe considering the difficulties of road and rail transport during this period.

[...] Staff. The strength of the Institute was 350. This figure includes workmen as well as the higher staff. Skoda and Zbrojovka contributed engineers and designers, whilst the scientific staff was recruited from the Universities and technical schools.

The card index covering the whole of the staff was produced for inspection at Pribram. A cursory examination of the cards revealed a fair percentage of German staff[...]

The following details of some of the personnel were compiled from the card index and other sources. [...]

Engel, Rolf. Born in 1912. Came from the research institute at Grossendorf and arrived at Pribram on 23.7.44 to take charge of a section. A Diploma Engineer and a physicist. Later he took charge of the whole Institute. Stated to be a most able engineer and mathematician. Was Hauptsturmführer in the S.S. Escaped to Germany and was last heard of south of Munich. [...]

Bödewadt. Dr. Born 1911 at Essen. Came from the research institute at Grossendorf and was chief of ballistics. He escaped. [...]

Teichmann, Hermann. Dr. Born 1913. A doctor of engineering who worked on explosives and also did administration. Escaped.

Schmidt, Kurt. Dr. Born 1912. Also an engineer. Worked on chemical research.

Schmidt, Walter. Dr. Head of the Chemical Department and came from the Waffen-Union. Held in prison at Pribram.

Bock, Helmuth. Born 1923. A machine designer in the technical section.

Nordt, Dr. Worked on explosives. Escaped. [...]

Seifert, Hugo. Ing. In charge of the workshops. Imprisoned at Pribram.

Kucera. Leader of Werkschutz. Imprisoned at Pribram.

Larsson. A Swede engaged on the study of rockets.

Votruba, Karel. Dr. Ing. Was chief of the high frequency group. A Czech and now with VTR research.

Simon, Inval. Dr. Czech. Chief of the low frequency group. Now back at Charles University, Prague.

Truha, Zdenek. Dr. Ing. Czech. Chief of the section dealing with long distance control and measuring. Now working in a technical school in Prague.

Broz, Jaroslav, Dr. Czech. Head of the magnetic section. Now with VTR research.

Jahoda, Dr. Czech. Manager of range laboratories at Drahelcice.

Zbozinek, Arnost, Ing. A Skoda man and head of the general design. Now working in the national administration at Klastenec Nad Ohri.

Stelsovsky, Jan. Ing. Czech. Head of the rocket design section. Is now in the Czech Army.

Sternad, Dr. Czech. Born 1912. A Skoda man who worked in the physics section at Pribram. Considered one of the more outstanding technical men.

Kalendovsky, Dr. Czech. Born 1911. Worked as an engineer.

Buresova, Florentine, Ing. (Woman). Born 1922. A German chemical research worker.

Behounek, Dr. Ing. No other information other than that he is under interrogation as as doubtful Czech.

Knust, Dr. Born 1915. A chemist and belonged to the S.S. A German.

Odstracil, Ing. Czech. An engineer and scientist employed by Zbrojovka.

The above particulars are in many cases very sketchy, indeed some are just the bare facts taken from the card index. In others this information has been supplemented. [...]

[p. 42:]

The purpose of the institute was to prepare the documentation for production and to make prototypes of new products included into the manufacturing programme of the company Waffen Union. It was engaged in the study of rockets, especially from the theoretical point of view and therefore preparatory tests were carried out. As an example of the research work we are stating the high frequency transmission for transmitting the shooting elements at a distance of 10 km., stabilization device for shooting from tanks by means of a telescope on a gyroscope, simultaneous aiming and directing of a number of machine-guns, study of directing the rockets by means of infra red rays.

[p. 68:]

Baubin. Was permanent secretary of Skoda. A member of the S.D. [...]

Staller, Karel Ing. Acted as deputy to Voss but worked in the resistance movement and has been cleared of suspicion of collaboration. He has been given a certificate from Czech General Headquarters to this effect. One of the most able engineers in Czechoslovakia. Sent over 120 engineers and designers to Allies, as well as machine tools. [...]

Voss, Wilhelm, Dr. Born 1896. A jurist and accountant. Came from Rostock Mecklenberg and was educated at the Universities of Berlin and Leipzig. Trained as an accountant and worked in an agricultural organisation and the legal branch of an insurance company. Visited England in 1926 and read paper to an international congress of accountants. Joined the Nazi party in 1937. Was appointed in 1938 as General Director of Administration and Commerce in the Hermann Goering Trust in Berlin and in 1939 came to Prague.

Differences with Pleiger caused Goering to form the Skoda Brünn Waffen Union and Voss put in charge. He was dismissed in January 1945 as unsatisfactory. Now in prison in Prague.

[Despite the deep involvement of Hans Kammler and Erich Purucker with these facilities and programs, all mention of them has been carefully omitted from this BIOS report (compare with the information on p. 4480). Likewise all mention of nuclear-related work has been carefully omitted (compare with pp. 3613–3616).]

Tom Bower. 1987. *The Paperclip Conspiracy: The Hunt for the Nazi Scientists.* Boston: Little, Brown. p. 151.

Rolf Engel, an SS officer who during the war had supervised the production of solid-fuel rockets at a Skoda plant in Czechoslovakia, was recruited by French agents while hiding in the American zone, fearing arrest for his wartime activities.

[Rolf Engel, Uwe Bödewadt, and Hermann Teichmann all went to work for France after the war (p. 1876). Information on their postwar contributions is not publicly available, but presumably they were instrumental in developing modern solid propellant missiles and rockets in France, and they may have made important contributions in other areas—such as nuclear weapons—as well.]

Jan Kotůlek. František Čuřík (†June 7, 1944): The First Professor of Mathematics and Descriptive Geometry at Mining University (VŠB).
[http://homel.vsb.cz/∼kot31/Veda/23-3mi-s71-76Kotulek.pdf]

[...] Some of his colleagues from VŠB promoted the story that František Čuřík was forced by the Nazis to collaborate in their company Waffen-Union research institute in Příbram (contemporary German name of the town was Pibrans) on the ballistic computations of missiles V-2. He resolutely refused it as treason and, because he could not see any other way out of this situation, he took his own life, cf. [7].

However, the story is probably only partially based on the truth. The holding company Waffen-Union Skoda-Brünn worked in weapon industry within the concern Reichswerke Hermann Göring. The top management was exclusively German, but research divisions were under Czech governance, mathematical research division was led by Miloslav Hampl (1897–1974) and physics division by Professor Václav Dolejšek (1895–1945), who handed his responsibilities to dr. Miloslav Tayerle during 1940. Tayerle should have set up the research institute of Waffen-Union in Příbram. He brought his collaborators from Skoda, hired some researchers from Zbrojovka Brno (Brünn) and counted also with some professors from the closed VŠB in Příbram. Their names are listed in the report about the visit of the Mining University from October 9 1943: Jirkovský, Šebesta, Čechura, Glazunov and Mitinský. František Čuřík, then already pensioned for three years, was not considered. However, in this period, there was also no rocket research.

The situation changed rapidly in August 1944, when SS-Hauptsturmführer Rolf Engel, head of the Versuchsanstalt für Strahltriebwerke in Grossendorf, evacuated his institute from West Prussia to the Protectorate of Bohemia and Moravia and overtook the governance of the research facilities in Příbram. He had already worked intensively in the rocket research for SS and he strictly opposed the German army project of V-2, cf. [6]. When Engel came to Příbram, Čuřík was already dead. But even if Engel had looked for collaborators in the spring 1944, he would not have chosen Čuřík. Ballistics was a key discipline, controlled entirely by the Germans, and Engel had his own mathematicians with expertise in ballistics, namely Dr. Uwe Tim Bödewadt (1911–2003), Dr. Franz Kalscheuer (1913–2002), Niels W. Larsson or H. Teichmann, see [3].

[...]

[3] Kotůlek J.: Angewandte Mathematik in der Rüstungsforschung der Škoda-Werke; mit Akzent auf der Versuchsanstalt der Waffen-Union Škoda-Brünn in Příbram. In: Fothe M., Schmitz M., Skorsetz B., Tobies R. (eds.): *Mathematik und Anwendungen*, Forum 14 (Thillm, Bad Berka, 2014), 50–57.

[...]

[6] Neufeld M.J.: Rolf Engel vs. the German Army: a Nazi career in rocketry and repression, *History and Technology* 13 (1996), 53–72.

[7] Pajer M.: K vývoji a výrobě raketových zbraní v Příbrami v letech druhé světové války, *Podbrdsko* 13 (2006), 155–164.

Robert Taylor 3rd. 16 July 1946. Subject: Assembling Certain German Scientific Personnel for Interrogation. [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945]

1. This Headquarters has been advised by Dr. F. Zwicky, Director of Research, Aerojet Engineering Corporation, and Colonel R. L. Wassell, Power Plant Laboratory, Engineering Division, through Air Materiel Command, of the necessity of obtaining information and reliable data in the fields of thermochemistry and kinetics of chemical reactions to round out information obtained by them in Germany in 1945. Basic knowledge in these fields is considered of prime importance for future progress in jet propulsion. It is felt that much of this data may be obtained from interrogating German scientific personnel now in Germany. [...]

2. It is requested that the necessary action be taken to locate the scientists listed and that arrangements be made to assemble them in two or three locations so that they may be conveniently interrogated. [...]

PARTIAL LIST OF GERMAN THERMOCHEMISTS HAVING RECENT PUBLICATIONS

NAME	INSTITUTE ASSOCIATED WITH AT TIME OF PUBLICATION	LAST KNOWN ADDRESS
[...]	[...]	[...]
Teichmann, Dr.	He and staff were associated with Prof. Jost. Group has very good ideas about chemical reaction problems important for jet propulsion. Teichmann joined Waffen Union, Skoda, Pibrans in 1944. He and staff was at Camp Föhrenwald, Wolfratshausen, Bavaria in 1945. It is important to find Dr. Teichmann.	Hindenburgstrasse 96A, Berlin-Wilmersdorf

[Please see this complete memo on the following pages.]

RESTRICTED

009

16 July 1946

MEMORANDUM FOR DIRECTOR OF INTELLIGENCE, WDGS:
(Attn: Special Exploitation Branch)

SUBJECT: Assembling Certain German Scientific Personnel for Interrogation

1. This Headquarters has been advised by Dr. F. Zwicky, Director of Research, Aerojet Engineering Corporation, and Colonel R. L. Wassell, Power Plant Laboratory, Engineering Division, through Air Materiel Command, of the necessity of obtaining information and reliable data in the fields of thermochemistry and kinetics of chemical reactions to round out information obtained by them in Germany in 1945. Basic knowledge in these fields is considered of prime importance for future progress in jet propulsion. It is felt that much of this data may be obtained from interrogating German scientific personnel now in Germany. Since Dr. Zwicky was going to Paris to attend the conference on applied mechanics in September, and Col. Wassell is scheduled to go to Germany about the same time, it was suggested by Wright Field that they plan on going over in August to accomplish the mission of obtaining this information for T-2. Dr. Zwicky assented to this proposition and has furnished the names of the scientists he thinks should be contacted. This list is enclosed herewith.

2. It is requested that the necessary action be taken to locate the scientists listed and that arrangements be made to assemble them in two or three locations so that they may be conveniently interrogated. The actual date of assembly will be furnished by this Headquarters as soon as the proposed date of departure of Dr. Zwicky and Col. Wassell is known. It will be necessary, however, that this matter be given expeditious handling in order that this may be accomplished the first part of August.

FOR THE COMMANDING GENERAL:

1 Incl:
List as above

ROBERT TAYLOR 3RD
Colonel, Air Corps
Chief, Collection Branch
Air Information Division
AC/AS-2

RESTRICTED

Figure E.222: 16 July 1946 list of German scientists to be interrogated by Fritz Zwicky. [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945]

PARTIAL LIST OF GERMAN THERMOCHEMISTS HAVING RECENT PUBLICATIONS

NAME	INSTITUTE ASSOCIATED WITH AT TIME OF PUBLICATION	LAST KNOWN ADDRESS
Eucken, A.	Dir. of Inst. for Physical Chemistry, Gottingen,	Herzberger Landstrasse 58, Gottingen
Becker, R.	Inst. for Theoretical Physics Göttingen	Bunsenstrasse 9, GÖTTINGEN
Berger, W.	Physical Chemistry Institute, Göttingen	Göttingen
Bertram, A.	" " " Göttingen	"
Woitineck, H.	" " "	"
Dannöhl, W.	" " "	"
Donath, E.	" " "	"
Hauck, F.	" " "	"
Hoffman, G.	" " "	"
Kuhn, G.	" " "	"
Laube, H.	" " "	"
Lüde, K.	" " "	"
Meyer, L.	" " "	"
Mücke, O.	" " "	"
d'Or, L.	" " "	"
Parts, A.	" " "	"
Seekamp, H.	" " "	"
Warrentrup, H.	" " "	"
Weigert, K.	" " "	"
Werth, H.	" " "	"
Aybar, S.	" " "	"
Schäfer, Klaus	" " "	"

Incl: "1

- 1 -

Figure E.223: 16 July 1946 list of German scientists to be interrogated by Fritz Zwicky. [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945]

NAME	INSTITUTE ASSOCIATED WITH AT TIME OF PUBLICATION	LAST KNOWN ADDRESS
Clusius, K.	Dir. of Inst. for Physical Chemistry, Munich	Kunigundenstrasse 41, Munich
Magnus, A.	Frankfurt a. M. Institute for Physical Chemistry	Frankfurt a. M.
Hodler, A.	" " "	" " "
Holzmann, H.	" " "	" " "
Oppenheimer, F.	" " "	" " "
Danz, H.	" " "	" " "
Herz, W.	" " "	" " "
Ueberriter, Kurt	Berlin-Dahlem Kaiser Wilhelm Institute	Berlin
Simon, Franz	" " " "	"
Lange, Fritz	" " " "	"
Weigand, K.	München	München
Frank, A.	"	"
Popp, L.	"	"
Bartholome, E.	Würtzburg	Würtzburg
Volmer, M.	Inst. for Physical Chemistry & Electrochemistry, at the Technische Hochschule, Berlin	Berlin
Heiber, W.	Heidelberg	Heidelberg
Reindel, E.	Heidelberg	Heidelberg
Harteck, P.	Technische Hochschule, Division of Physical Chemistry, Breslau & Dir. of Inst. for Physical Chemistry, Hamburg	Brselau or Hamburg
Lorenz, Richard	Technische Hochschule, Division of Physical Chemistry, Breslau	Breslau

Those whose namws are underlined, have been working recently in the fields of our special interest. The other have been working in thermochemistry, but with such things as low temperature heat capacities or densities of liquids at the temperature of liquid oxygen.

Incl: #1

- 2 -

Figure E.224: 16 July 1946 list of German scientists to be interrogated by Fritz Zwicky. [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945]

PARTIAL LIST OF GERMAN CHEMISTS IN THE FIELD OF

KINETICS OF CHEMICAL REACTIONS

NAME	INSTITUTE ASSOCIATED WITH AT TIME OF PUBLICATION	LAST KNOWN ADDRESS
Jost, Wilhelm, Prof.	Dir. of Inst. for Physical Chemistry, Marburg. Formerly Leipzig & Strassburg, Elsass, Inst. for Lubrication and Fuels	Mozartstrasse 2, Leipzig-Markkleeberg
Juza, Prof.	University at Heidelberg (Specialist in catalysis, inorganic Chemistry)	Possibly at Dustbin
Teichmann, Dr.	He and staff were associated with Prof. Jost. Group has very good ideas about chemical reaction problems important for jet propulsion. Teichmann joined Waffen Union, Skoda, Pibrans in 1944. He and staff was at Camp Föhrenwald, Wolfratshausen, Bavaria in 1945. It is important to find Dr. Teichmann.	Hindenburgstrasse 96A, Berlin-Wilmersdorf
Grube, G., Prof. Dr.	Dir. of Inst. for Physikalische Chemie u. Elektrochemie der technischen Hochschule, Stuttgart Development of the combustion of Al and Mg as fuels in atmospheres of steam and H_2O_2. Published in Zschr. für Metallkunde and Zschr. f. Elektrochemie.	Hangleiterstrasse 2, or Wiederholdstrasse 15, Stuttgart N.
Gusti, Prof.	Physikalische Technische Reichsanstalt, Berlin	Berlin
Schumacher, H. J. Prof.	Dir. of Inst. for Physical Chemistry, Frankfurt, a . Main	Frankfurt, a . Main
Geib, K. H. Dr.	Leipzig	Leipzig
Bonhoeffer, K. F., Prof.	Dir. of Inst. for Physical Chemistry, Leipzig	Leipzig
Förster, Th.,	Dir. of Inst. for Physics, Posen Left before the Russians occupied Posen	?

Incl: #1

- 3 -

Figure E.225: 16 July 1946 list of German scientists to be interrogated by Fritz Zwicky. [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945]

NAME	INSTITUTE ASSOCIATED WITH AT TIME OF PUBLICATION	LAST KNOWN ADDRESS
Groth, W., Dr.	Formerly with Harteck	Breslau
Patat, F., Dr.	I. G. Farben, Hoechst. Formerly with Eucken.	Göttingen
Cremer, Erika, Prof.,	Innsbruck University	Innsbruck
Scrabal, Anton, Prof.	Graz	Graz
Zeise, Heino, Dr.	DVL Berlin, Theoretical Investigations	Berlin

Incl: #1

Figure E.226: 16 July 1946 list of German scientists to be interrogated by Fritz Zwicky. [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945]

[Fritz Zwicky (Swiss, 1898–1974) moved to the United States in 1925, part of the wave of German-speaking scientific immigrants who came before the Third Reich. He recruited additional German-speaking scientific immigrants during and after the Third Reich and directly assisted the U.S. government in transferring as much scientific knowledge as possible out of the German-speaking world. While Zwicky is best remembered as an astrophysicist, he was keenly interested in all forms of aerospace propulsion and greatly aided the United States in that area. He was a professor at Caltech but also a research director/scientific advisor at Aerojet 1943–1961. Zwicky was deeply involved in scientific interrogations after the war in 1945, and this memo shows that in 1946 he was still interrogating large numbers of German-speaking scientists. He made the interrogations listed in this memo on behalf of Aerojet.

Although the memo said the list was aimed at "thermochemistry" or "jet propulsion," the listed scientists (and the interrogations that they were probably subjected to) covered a far broader range of fields. For example, many scientists on this list were primarily nuclear experts—Klaus Clusius, Max Volmer, Paul Harteck, Wilhelm Groth, etc. A few names on the list were underlined, and the memo noted: "Those whose names are underlined, have been working recently in the fields of our special interest." One of the underlined names was Paul Harteck. Was that unnamed "special interest" simply thermochemistry, or some other topic, such as heavy water production or uranium isotope separation? Was this "thermochemistry" memo an umbrella for a much broader and multipurpose series of scientific interrogations by the United States?

This memo demonstrates just how dependent the United States was on German-derived scientific knowledge. It emphasized how much important information was obtained "in Germany in 1945." Then it stated that it was "considered of prime importance for future progress" to obtain even more information, and that "this data may be obtained from interrogating German scientific personnel now in Germany" during 1946. The United States needed to transfer large amounts of scientific information and scientific personnel from the German-speaking world, and even that transfer process itself was directed by U.S. representatives such as Fritz Zwicky and Theodore von Kármán who were themselves German-speaking scientists.

Hermann Teichmann, who invented and demonstrated ammonium perchlorate/polybutadiene solid rocket propellant, was especially singled out on this list. The document gave more information about him than any other scientist on the list, and he was the only scientist for which it was specifically stated, "It is important to find" him. Apparently either Fritz Zwicky had been directly involved in interrogating Teichmann in 1945, or else Zwicky had read detailed reports on those interrogations (such as the other documents quoted in this section). Teichmann eventually ended up working for France. It is unclear from this and other available documents if Zwicky actually did interrogate Teichmann in 1946, but it seems evident that Zwicky and his employer Aerojet were keenly interested in and highly knowledgeable about Teichmann's revolutionary work on solid propellant rockets.

Presumably based on such information, in 1948 Aerojet began producing ammonium perchlorate/polymer propellants, and it even hired German-speaking scientists such as Karl Klager to perfect those propellants, along with the continuing guidance of Zwicky. Please see the following documents for more information.]

Donald L. Putt to Curtis B. LeMay. 23 January 1946. Research and Development of Solid Fuel Rockets. [AFHRA A2055 Frames 1109–1110]

HEADQUARTERS
AIR TECHNICAL SERVICE COMMAND

23 January 1946

SUBJECT Research and Development of Solid Fuel Rockets

TO Commanding General
Army Air Forces
Washington 23, D.C.

Attn: Major General Curtis B. LeMay
Deputy Chief of Air Staff for
Research and Development

1. It is understood that your office has recently received a communication setting forth the need for reviving research on solid fuel rockets.

2. For such use as can be made of the information, it is desired to present the following:

a. German aeronautical research establishments and industry have spent years working on subject development. It is believed that the Germans were considerably advanced beyond our own efforts in this field. Most of the documentary information covering this past research is available in the Air Document Division, Wright Field.

b. Every effort should be made to take advantage of this work which has already been done so as to profit from the mistakes made by the Germans and to prevent costly duplication of effort in repeating work already done.

c. There are presently stationed at Wright Field several German scientists who have worked in the rocket field. One scientist in particular has done research work on solid rocket fuels and motors for the past ten years. Another was instrumental in the development of the motor and liquid fuels for the ME-163. Both have plans and ideas for further research which would lead to improved fuels and increased efficiencies of rocket motors. Every effort should be made to provide means and facilities to acquire the projected thinking and plans of these scientists to assist and expedite our own research and development to the greatest possible extent.

d. These scientists are not now and can not be effectively and efficiently utilized at Wright Field, due to the current restrictive regulations governing the exploitation of German scientists, which, in the opinion of this office, have no sound or logical basis. Nearly all of the rocket motor and fuel research work has been done by agencies outside of Wright Field, such as N.A.C.A., California Institute of Technology and Monsanto Chemical Company. The regulations prohibit any contact between German scientists and those institutions, to whom they could be of great benefit. Certainly there can be no sound basis for prohibiting companies having contracts with the Army Air Forces or other Government agencies to interview German scientists at Wright Field to obtain their advice and assistance in furtherance of their Government contracts. This procedure would likewise bolster the morale of the German scientists and eliminate their complaint of having to live in a "scientific desert", which is occasioned by a complete lack of contact with people on the same scientific level.

3. Any assistance which your office might render to obtain a revision of regulations which would permit a full and complete utilization of the German scientists now in the United States would materially aid and benefit our own research and development program, not only in the field of rockets but in those of guided missiles, supersonics, jet engines and jet aircraft.

FOR THE COMMANDING GENERAL,

D. L. Putt
Colonel, Air Corps
Deputy Commanding General
Intelligence (T-2)

[At this point, by the year after the war, Donald Putt arguably had the best understanding in the world of all the rocket-related accomplishments up to that time both in Germany and in the United States. From that well-informed vantage point, Putt clearly stated that "the Germans were considerably advanced beyond our own efforts" on "solid fuel rockets." To back up that assertion, he explicitly said that he had "documentary information covering this past research" stored at the Wright Field Air Document Division, and that he also had under his direct supervision scientists with up to ten years of previous experience on solid propellant rockets in Germany. From his wartime and postwar jobs, Putt would also have been intimately familiar with other relevant evidence, scientists, and projects throughout Germany and the United States.

At the time of Putt's memo, Wolfgang Noeggerath was at Wright Field [e.g., AFHRA A2055 Frame 1165]. During the war, he had worked on hypergolic liquid propellants for the Me 163 rocket plane and other vehicles [John Clark 1972, pp. 13–17], so he appears to have been the second scientist that Putt referenced. Putt's memo succeeded in getting the German scientists to the U.S. programs that needed them, and Noeggerath became the lead scientist for the first U.S. solid propellant, submarine-launched ballistic missile, Polaris (p. 5264).

The first scientist that Putt referenced, someone who already had a decade of experience developing solid rocket fuels and motors, may have been Gerhard Braun, Rudolf Edse, or another German or Austrian expert who was at Wright Field at that time [e.g., compare p. 1899 and AFHRA A2055 Frame 1165]. Future scholars should delve much further into the wartime and postwar work of these and other German-speaking scientists.

Note that in addition to direct work credited to the German scientists, Putt also specifically mentioned the quiet transfer of their knowledge and ideas to U.S. scientists and organizations. Therefore the actual contributions and true impact of the German-speaking creators were probably far larger than what the preserved documents show.]

J. D. Hunley. 1999. The History of Solid-Propellant Rocketry: What We Do and Do Not Know. AIAA paper 99-2925. [Hunley 1999; https://doi.org/10.2514/6.1999-2925]

Integral to the stories of the propellants used on large rockets and missiles, smaller tactical missiles, and a host of smaller rockets for a variety of rockets and spacecraft were the various binders, fuels, and oxidizers that went into the propellants. For example, the motors for the Polaris A1 missile designed by Aerojet featured a cast, case-bonded polyether-polyester-polyurethane composition with 15 percent aluminum and ammonium perchlorate. Karl Klager at Aerojet has been credited with being largely responsible for developing both the grain and the propellant for these motors, but the story of their development is evidently quite complex. Klager received the U. S. Navy Distinguished Public Services Award in 1958 for his work on the Polaris missile, but the development of some of the propellant ingredients predates when Klager joined Aerojet in 1950. [...]

Karl Klager, who is credited with the development of HTPB [hydroxyl-terminated polybutadiene], was asked how he came to develop this low-cost, low-viscosity propellant that has become an industry standard. He said only that he started development in 1961 but waited until 1969 to propose the propellant to NASA for the Astrobee D and Astrobee F sounding rockets on which it flew successfully. Perhaps, however, Klager's response regarding how he came to discover unsymmetrical dimethylhydrazine (UDMH) (which is a liquid propellant used on the Bomarc missile, Titan 2 missile, Titan 3 and Titan 4 rockets, and other missiles and rockets) applies equally to HTPB. Klager said that he simply brought his knowledge of the science of chemistry to bear on the need for a propellant. He had earned a Ph.D. in chemistry from the University of Vienna in 1934 and had worked for several chemical firms in Europe from 1931 to 1948 before moving to the United States and starting work for Aerojet in 1950.

[Although aerospace historian J. D. Hunley focused mainly on the work of American engineers in the above paper and in the following book, he could not avoid mentioning the important contributions of Karl Klager (Austrian, 1908–2002) to the development of large solid-propellant rockets in the United States after the war.]

J. D. Hunley. *Preludes to U.S. Space-Launch Vehicle Technology: Goddard Rockets to Minuteman III.* [Hunley 2008a]

[pp. 154–156:]

Meanwhile, the first known castable solid propellant was the composite developed by John Parsons at the Guggenheim Aeronautical Laboratory at Caltech back in 1942 for use in JATO motors. Containing asphalt as a binder and potassium perchlorate as an oxidizer, this propellant—known as GALCIT 53 after the lab's acronym—did not have a particularly impressive performance compared, for example, with the double-base composition called ballistite. But it retained its performance at temperatures down to 40^{o}F far better than the compressed black powder Parsons had been using in JPL's JATO motors. At lower temperatures, however, GALCIT 53 cracked. It also melted in the tropical sun and was very smoky when burning. This last characteristic limited the takeoff of follow-on aircraft using JATO units on a single runway because the smoke restricted visibility. These shortcomings led researchers at GALCIT and its successor, JPL, to search for an elastic binder with storage limits beyond GALCIT 53's extremes of -9^{o}F and 120^{o}F. In particular, a young engineer named Charles Bartley, who was employed at JPL from June 1944 to August 1951, began examining synthetic rubbers and polymers, eventually hitting upon a liquid polysulfide compound designated LP-2, which worked as as solid-propellant binder. It was made by the Thiokol Chemical Corporation for sealing aircraft tanks and other applications. [...]

Before learning of LP-2, Bartley and his associates at JPL had tried a variety of moldable synthetic rubbers to use as binders and fuels, including Buna-S, Buna-N, and Neoprene. Neoprene worked best, both as a binder and as a fuel, but molding it required high pressures, like the extrusion process used with double-base propellants, which made the production of large propellant grains impractical. [...]

With encouragement from Army Ordnance and the Navy, Bartley—joined by John I. Shafer, a JPL design engineer, and H. Lawrence Thackwell Jr., whose expertise lay in aircraft structures—began in 1947 to develop a small rocket designated Thunderbird, which had a 6-inch diameter. The three researchers used it for testing whether polysulfide propellants could withstand the forces of high acceleration that a large launch vehicle might also encounter. [...]

Combining a polysulfide propellant with the star design and casting it in the case so that a bond formed, the team under Bartley produced the successful Thunderbird rocket that passed its flight tests in 1947–48.

While this rocket was being tested, another significant development for composite propellants was occurring—the replacement of potassium perchlorate by ammonium perchlorate, which offered higher performance and less smoke. [...] Already in 1947, however, JPL had developed a propellant designated JPL118 that used only ammonium perchlorate as an oxidizer together with polysulfide as the binder and couple of curing agents. Although this propellant had yet to be fully investigated in 1947, by mid-1948 it provided a specific impulse of 198 lbf-sec/lbm at sea level using an expansion ratio of 10 for the rocket nozzle. [...]

Aerojet likewise began using ammonium perchlorate in its Aeroplex (polyester polymer) propellants in 1948 in order to increase specific impulse and reduce smoke. Funded by the Navy Bureau of Aeronautics to develop a basic understanding of the production and employment of solid propellants, Aerojet increased the specific impulse of its ammonium perchlorate propellants to 235 lbf-sec/lbm, but its Aeroplex binder was not case bondable, leading the firm to switch in 1954 to a polyurethane propellant that was.

In the interim, Thiokol sought to sell its polymer to Aerojet and another manufacturer of rockets, the Hercules Powder Company, but both rejected Thiokol's product because its 32 percent sulfur content made it a poor fuel. [...]

[p. 295–296:]

It was not ARC's polyvinyl chloride, however, that served as the binder for Polaris. Rather it was a polyurethane developed by Aerojet. This development began under a small Navy nitropolymer program funded by the Office of Naval Research about 1947 to seek high-energy binders for solid propellants. A few Aerojet chemists synthesized a number of high-energy compounds, but the process required levels of heating that went beyond what was safe for potentially explosive compounds. Then one of the chemists, Rodney Fischer, found "an obscure reference in a German patent" suggesting that "iron chelate compounds would catalyze the reaction of alcohols and isocyanates to make urethanes at essentially room temperature." This discovery started the development of polyurethane propellants in many places besides Aerojet.

Meanwhile, in 1949 Dr. Karl Klager, then working for the Office of Naval Research in Pasadena, suggested to Aerojet's parent firm, General Tire, that it begin work on foamed polyurethane, leading to two patents held by Klager with Dick Geckler and R. Parette of Aerojet. In 1950 Klager, who had earned a Ph.D. in chemistry from the University of Vienna in 1934 and had come to this country as part of Project Paperclip, began working for Aerojet. By 1954 he headed the rocket firm's solid-propellant development group. Once the Polaris program began in December 1956, Klager's group decided to reduce the percentage of solid oxidizer as one component of the propellant by including oxidizing capacity in the binder itself, using a nitromonomer as a reagent to produce the polyurethane plus some inert polynitro compounds as plasticizers, or softening agents. [...T]hey came up with successful propellants for both stages of Polaris A1.

These consisted of a cast, case-bonded polyurethane composition including different percentages of ammonium perchlorate and aluminum for stages 1 and 2, both of them featuring an internal-burning six-point star configuration.

[p. 396:]

10. [...] According to Fuhrman, "Polaris to Trident," 12, "Tests at the Naval Ordnance Test Station in 1955, which were confirmed by the Atlantic Research Corporation in 1956, demonstrated a significant increase in specific impulse obtained by the addition of finely divided aluminum to the propellant."

11. [...] For his work in developing both the grain and the propellant, Klager received the Navy's Distinguished Public Service Award in 1958[...]

[p. 319:]

The Minuteman team delivered the first Minuteman I to the Strategic Air Command in October 1962, almost exactly four years after the first development contracts were signed. [...]

The first stage, developed and produced by Thiokol, included a new propellant binder developed by the company's chemists between 1952 and 1954.

[...] Thiokol added 10 percent acrylonitrile to the PBAA, creating polybutadiene-acrylic acid-acrylonitrile (PBAN). The binder and curing agent constituted only 14 percent of the propellant, with ammonium perchlorate (the oxidizer) and aluminum (the major fuel) being the two other main ingredients.

[A] Teflon-coated mandrel created the tapered six-point star that formed the internal-burning cavity. [...]

B. P. Mason and C. M. Roland. 2019. Solid Propellants. *Rubber Chemistry and Technology* 92:1:1–24. [https://arxiv.org/pdf/1904.01510.pdf]

[...] V. POLYMERIC BINDERS [...]

C. POLYSULFIDES

In the latter stages of World War II, SRM binder work for JATOs led to the use of a styrene-butadiene rubber, Buna-S, developed by IG Farben in Germany before the war. Although Buna-S performed well over a broad temperature range, dewetting of the motor grain from the case proved an insurmountable problem. Adhesion at the motor's bond line is critical because the debonded surface of the grain will burn prematurely, causing motor failure. [...]

D. PLASTISOLS

[...] Plastisol nitrocellulose (PNC), sometimes called "spheroidal" or "pelletized" nitrocellulose, was developed at ARC and also featured a long pot life, although not as long as PVC's. PNC used NC nitrated at 12.6%, dissolved in nitromethane and ethyl centralite, and emulsified in water. The nitromethane was then leached out and 5–50 micron spheres collected by centrifugation. While used sparingly in SRM, PNC was employed in warheads and gun propellants. The U.S. Navy deemed PNC important enough that it manufactured the material itself at the Naval Propellant Plant in Indian Head, Maryland, starting in 1958. Production ended when accidents forced closure of the facility in the 1990s.

E. POLY(BUTADIENE-ACRYLIC ACID)

In the mid-1950s, butadiene-containing copolymers reappeared with poly(butadiene-acrylic acid; PBAA), a random copolymer developed as a binder by Thiokol at Redstone Arsenal. PBAA had a molecular weight of about 3000 Da, but being made by free radical emulsion polymerization, it was a mixture of various polyfunctional chains, including some nonfunctional, resulting in poor reproducibility. Crosslinking was carried out by ring opening of difunctional epoxides and aziridines by the acrylic acid groups. Although the prepolymer had a sufficiently low viscosity to allow high solids loading, the resulting crosslinked polymer had poor mechanical properties because of the irregular network structure and for this reason was abandoned. However, PBAA was used by Thiokol as the binder for the first stage of the Minuteman I ICBM. [...]

H. HTPB

Hydroxyl-functionalized prepolymers had been combined with multifunctional isocyanates in the early 1950s, even before the introduction of PBAN and CTPB. General Tire & Rubber experimented with urethane crosslinked polyethers and polyesters for propulsion formulations as early as 1947. However, it was Aerojet that had the initial successes with these materials under the leadership of Karl Klager, an Austrian chemist who had worked for IG Farben during the Second World War and was brought to the United States by the U.S. Office of Naval Research under Operation Paperclip in 1949. Klager's polyurethanes were used in both stages of the Polaris A1 and in the second stage of the Minuteman I. These materials were a combination of poly(1,2-propylene oxide) (PPG) and poly(1,4-tetramethylene oxide) (PTMEG), cured with toluene diisocyanate and crosslinked with triethanolamine. Other examples of such binders included poly(ethylene oxide) (PEG), poly(neopentylglycol azelate), and poly(butylene oxide); commonly referred to as B-2000.

These types of binders had excellent stability, mechanical properties, and reliability for their era but nevertheless were passed over in favor of CTPB-based formulations.

So dominant was CTPB throughout the 1960s that although HTPB was first synthesized for use in binders in 1961, it did not see actual use in a rocket motor until 1968, when Aerojet used it in a dual-thrust radial-burning motor grain formulation for the Astrobee D, a NASA-sponsored meteorological sounding rocket. Gradually, HTPB gained widespread use as a replacement binder in older systems employing CTPB, for example, in the Maverick, Stinger, and Sidewinder missiles. After 50 years of use, HTPB remains the standard binder for nearly all U.S.-made SRM. HTPB-based polyurethane binders are relatively inexpensive, have low viscosity prepolymers, and exhibit good mechanical and aging properties. The binary system enables a high solids content, providing one of the highest specific impulses among solid propellants. [...]

VI. ENERGETIC POLYMERS [...]

A. POLY(GLYCIDYL NITRATE)

In 1953, formulators at the U.S. Naval Ordnance Test Station in China Lake, California, synthesized 800 to 3400 Da poly(glycidyl nitrate; PGN) using stannic chloride as a catalyst[...]

[Karl Klager had a huge number of patents on solid and liquid rocket propellants—see for example Figs. E.227–E.233.

The above article specifically credits some of the contributions of Karl Klager, but likely there were many other contributions from the German-speaking world to postwar solid propellant rockets. After the war, U.S. aerospace laboratories in places such as Redstone Arsenal, China Lake, and Indian Head were filled with German-speaking scientists, German-produced hardware, and German-derived documents and technical information. If many of these solid propellant innovations were not derived from German work, why were they not developed by the United States during World War II, before the German-speaking scientists and information arrived, when the United States had great need for such technologies in the war? It would be useful for future historians to search for specific people, paper trails, and other links connecting wartime German work on solid rocket propellants and postwar U.S. work on such propellants.]

United States Patent Office

3,214,474
Patented Oct. 26, 1965

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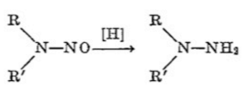
3,214,474
PREPARATION OF UNSYMMETRICAL HYDRAZINES
Karl Klager, Monrovia, Calif., assignor to Aerojet-General Corporation, Azusa, Calif., a corporation of Ohio
No Drawing. Filed Sept. 28, 1953, Ser. No. 382,828
6 Claims. (Cl. 260—583)

This invention relates to an improved process for preparing unsymmetrical alkyl hydrazines.

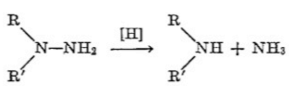
Unsymmetrical alkyl hydrazines have been known for many years and their properties as fuels have been well recognized in the art. However all of the known processes for their production produce poor yields of low purity. Accordingly, the use of alkyl hydrazines as fuels, in particular as propellant fuels, has been somewhat restricted for economic as well as for safety reasons, since a high degree of purity is required for this use in order to lessen the possibility of explosive reactions.

It is an object of this invention to provide an improved method for the preparation of unsymmetrical alkyl hydrazines which will provide increased yields of greater purity.

Classically unsymmetrical alkyl hydrazines are prepared by the reduction of nitroso dialkylamines. This reaction proceeds in accordance with the reaction scheme set forth below:



wherein R and R′ are the same or different alkyl radicals. However, it is known that the hydrazine bond may be dissolved under reductive conditions, this reaction taking place according to the following reaction scheme:



where R and R′ are the same as above.

Hence it becomes apparent that a catalyst or set of reaction conditions which favors the former reaction and disfavors the latter will result in a successful method for the preparation of such substituted hydrazines.

Alkyl hydrazines have been prepared by reducing the nitroso group in the classical manner with zinc and acetic acid, however these conditions usually result in a complicated work up, a yield of approximately 65%, and in a product of relatively low purity.

In recent years it has been found that lithium aluminum hydride may also be employed to effect this reaction. However the lithium aluminum hydride method is very expensive, ordinarily yields a product of low purity and generally provides a theoretical yield of only about 75%.

We have discovered that by using palladium catalysts to effect the reduction, a yield of approximately 85% of the theoretical may be obtained and that the product thus obtained possesses a high degree of purity. Suitable palladium catalysts are: palladium charcoal, palladium-calcium carbonate and palladium-barium sulfate. Colloidal palladium may also be used as well as finely divided palladium on carriers such as silica gel, infusorial earth, alumina and other commonly used catalyst carriers. Because of these improved results, this method is applicable to large scale production with considerable decrease in the overall cost of production. Moreover my reaction catalyst has been found to be useful for the preparation of any of the unsymmetrical alkyl hydrazines. The following examples are provided to more clearly illustrate the invention:

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Example I.—Preparation of palladium charcoal catalyst

1 part of 10% palladium charcoal and 10 parts of water was stirred in a hydrogen atmosphere until the catalyst was activated, that is, until no additional hydrogen was absolved.

Example II.—Preparation of dimethyl hydrazine

5 parts of nitroso dimethyl amine in 90 parts of water were added to the catalyst as prepared above and subjected to hydrogen atmosphere with rapid stirring. After a quantity equivalent to 2 moles of hydrogen had been absorbed the reaction was stopped, the catalyst filtered, and the water solution neutralized with hydrochloric acid. After evaporation of the water a yield equivalent to 81% of the theoretical of dimethyl hydrazine hydrochloride was isolated.

Example III.—Preparation of ethyl methyl hydrazine

5 parts of nitroso ethyl methyl amine in 90 parts of water were added to the catalyst as prepared in Example I and subjected to hydrogen atmosphere with rapid stirring. After an amount of hydrogen gas equivalent to 2 moles of hydrogen had been absorbed the reaction was stopped. The catalyst was filtered off and the water solution neutralized with hydrochloric acid. The water was distilled off and a theoretical yield of 79.2% ethyl methyl hydrazine hydrochloride was isolated.

In the same fashion simply by selecting the appropriate alkyl substituted nitroso amine and reducing it in accordance with the examples set forth above, any of the alkyl substituted hydrazines may be prepared.

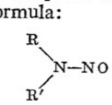
The concentration of the catalyst has not been found to be critical, however, we have found that optimum results are obtained when the palladium-charcoal catalyst is present in an amount below 2.0% by weight. No appreciable differences where observed when amounts in excess of 2.0% were used, however, when amounts below 0.2% were used, a slight decrease in the rate of reaction was observed.

Any of the aforementioned catalysts may be used successfully in the performance of my invention. The palladium metal, itself, being the catalytic substance, is substantially unaffected by the particular carrier or means of introduction employed.

My process, as is evident, lends itself equally well to continuous or batch processes, hence is well adapted to commercial production of unsymmetrical hydrazine compounds.

I claim:

1. The method of preparing unsymmetrical lower alkyl hydrazines which comprises reducing a nitroso amine having the general formula:



wherein R and R′ are lower alkyl radicals, with hydrogen in aqueous solution in the presence of a hydrogen activated palladium metal catalyst.

2. The method of claim 1 wherein the hydrogen activated palladium catalyst used is a catalyst selected from the group consisting of palladium on charcoal, palladium on calcium carbonate, palladium on barium sulfate, colloidal palladium metal, and finely divided palladium metal a catalyst carrier.

3. The method of claim 1 wherein the catalyst used is hydrogen activated palladium on charcoal.

4. The method of claim 1 wherein the hydrogen activated palladium catalyst is present in an amount of from about 0.2% to 2.0% by weight.

5. The method of preparing unsymmetrical dimethyl

Figure E.227: An example of Karl Klager's patents on rocket propellant.

United States Patent Office 3,000,968 Patented Sept. 19, 1961

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3,000,968

METHOD OF PREPARING NITRO COMPOUNDS

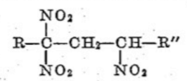
Karl Klager, Monrovia, Calif., assignor to Aerojet-General Corporation, Azusa, Calif., a corporation of Ohio

No Drawing. Filed Mar. 5, 1956, Ser. No. 570,204
13 Claims. (Cl. 260—644)

This invention relates to new high explosive compositions of matter and to a method of preparing them. This invention also relates to a new process for introducing nitroalkyl groups into organic compounds.

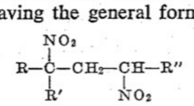
This application is a continuation-in-part of my co-pending application Serial No. 337,212, filed February 16, 1952, now abandoned.

The new compositions of matter of this invention are trinitroalkane compositions, having the general formula:



wherein R and R″ are hydrogen or lower alkyl radicals.

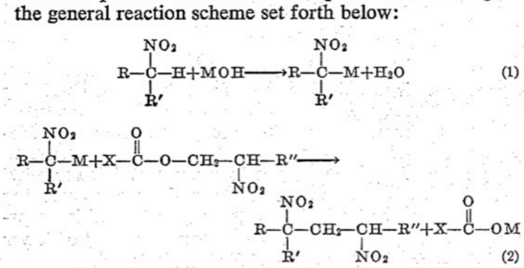
The new process of this invention is useful in preparing the compounds having the general formula:



wherein R is a nitro, halogen, hydrogen or lower alkyl radical and R′ and R″ are hydrogen or lower alkyl radicals.

This process can be used to prepare the new compounds of this invention, as well as a variety of other known compounds having different utilities and properties. The conventional method for introducing nitroalkyl groups into organic compounds has been to react the compound with a nitro-olefin. This process generally leads to relatively poor yields due to the tendency of nitro-olefins to polymerize, thereby preventing the occurrence of the reaction and at the same time rendering separation of the desired product, if any, difficult.

The new process of this invention permits the introduction of nitroalkyl groups into organic compounds without employing any nitro-olefin. The reaction proceeds smoothly and produces the desired product in high yield. The new process of this invention proceeds according to the general reaction scheme set forth below:



wherein R is a nitro, halogen, hydrogen or lower alkyl radical, R′ is a hydrogen or lower alkyl radical, R″ is a hydrogen or lower alkyl radical, X is a lower alkyl, phenyl or lower arylalkyl radical, such as benzyl, and M is a monovalent radical of an alkali or alkaline earth metal. The reaction is preferably conducted at a temperature of about 40° C., however, the reaction temperature can be varied over an extremely wide range of temperatures if desired. Methanol is the preferred solvent, however, any inert organic solvent can be used if desired. While any of the alkali or alkaline earth metal hydroxides can be used in the preparation of the aci-salt, it is preferred to use sodium hydroxide for reasons of economy, and because

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the sodium aci-salts are generally more soluble than other alkali and alkaline earth metal salts. The lithium salts are about as soluble as the sodium salts, however, the relatively high cost of lithium hydroxide makes it more economical to use sodium hydroxide in the practice of this invention.

X, the acid portion of the ester reactant in the general reaction scheme set forth above, can be any organic radical including phenyl, alkyl, benzyl, etc., since the acid portion of the ester does not enter into the reaction. For reasons of economy, X is preferably a methyl radical.

The alkali or alkaline earth metal aci-salt can be prepared in situ in the presence of the ester reactant or can be prepared separately in advance.

The following examples are presented to more clearly define my invention. It should be understood, however, that the examples are presented purely for purposes of illustration and that the invention is to be limited only by the scope of the appended claims.

EXAMPLE I

Preparation of 1,3,3-trinitrobutane

A solution of 120 g. of 2,2-dinitroethane was placed in 1000 ml. of 4% aqueous sodium hydroxide and the mixture heated to 40° C. With constant stirring, 133 g. of nitroethyl acetate in 150 ml. of methanol was added slowly over a period of 30 minutes. After additional stirring for two hours at 40–45° C., two phases were observed to form. The mixture was then diluted with 2000 ml. methylene chloride and twice washed with water. The solvent was then removed by evaporation and the residue distilled at a pressure of 10 microns. The product boiled between 102 and 102.5° C. The yield of 1,3,3-trinitrobutane was 87 g.

The calculated composition for the empirical formula is: $C_4H_3N_3O_6$: Percent C, 24.88; percent H, 3.65; percent N, 21.76.

The ultimate analysis of the above compound showed: percent C, 25.27; percent H, 3.74; percent N, 21.65.

The index of refraction at 25° was 1.4760.

EXAMPLE II

Preparation of 1,3-dinitro-3-chlorobutane

This compound was prepared by placing in a three-necked flask, having a stirrer, dropping funnel and a reflux condenser, 750 ml. of water containing 44 g. of sodium hydroxide and cooling the solution to between 10 and 15° C. 110 g. of 1-chloro-1-nitroethane was added slowly to form the sodium salt thereof. The mixture was heated to between 30–35° C. and to the solution was added slowly 133 g. of nitroethyl acetate. The temperature was raised to 40–45° C. and was maintained at that point for one hour. At this stage, two phases were seen to form.

2500 ml. of methylene chloride was added to the mixture and the mixture washed twice with water. After drying the methylene chloride solution over sodium sulfate, the solvent was evaporated and the residue distilled at one micron at a temperature of between 80 and 90° C. in an air bath. 60 g. of 1,3-dinitro-3-chlorobutane was produced. The index of refraction for this compound n_D^{25} was 1.4723.

EXAMPLE III

Preparation of 1,3-dinitro-3-methylbutane

44 g. of sodium hydroxide was dissolved in 750 ml. of water. To this solution, 89 g. of 2-nitropropane was added after cooling the solution to 10 to 15° C. When the aci-sodium salt formation was complete, a solution of 13.3 of nitroethyl acetate and 250 ml. of methanol was added slowly at a temperature between 40–45° C.

Figure E.228: An example of Karl Klager's patents on rocket propellant.

United States Patent Office

3,132,976
Patented May 12, 1964

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3,132,976
SOLID PROPELLANT COMPOSITIONS CONTAINING POLYURETHANE RESINS

Karl Klager, Richard D. Geckler, and Richard L. Parrette, Sacramento, Calif., assignors to Aerojet-General Corporation, Azusa, Calif., a corporation of Ohio

No Drawing. Filed July 20, 1959, Ser. No. 829,182
17 Claims. (Cl. 149—19)

This invention relates to novel solid propellant compositions and in particular to novel propellant compositions comprising a polyurethane binder with a finely divided oxidizing agent dispersed therein.

Solid propellant compositions are ordinarily composed of a resin fuel and an oxidizing material, the oxidizing material being intimately dispersed in the fuel. The ignition and burning properties of such propellant compositions, as well as their physical properties, are dependent to a large extent upon the particular resins employed as fuels.

In the novel propellant compositions of this invention polyurethanes are used as the resin fuel component to produce propellants of unexpectedly superior physical properties and performance characteristics. Our novel polyurethane propellants have substantially no internal strains due to the fact that there is little shrinkage and low heat of reaction during polymerization of the polyurethane fuel component. This lack of internal strain is important in that it assures substantial freedom of the propellant grain from cracking during burning. As those skilled in the art realize, propellant cracking is highly undesirable and dangerous and can result in erratic burning or even explosion of the propellant grain.

In addition to their freedom from cracking, the polyurethane propellants of this invention are superior in other ways. For example, they are possessed of sufficiently tenacious adhesive properties to enable them to be bonded directly to the rocket chamber lining, thus permitting optimum utilization of the available space in the rocket motor and simplifying manufacturing techniques. The novel polyurethane propellants of our invention are also possessed of many other desirable physical properties for example: rubbery mechanical qualities, low brittle point, excellent resilience and superior aging properties.

Our novel solid propellants can be used as the primary propulsion source in rocket-propelled vehicles or as a propellant for artillery missiles. When used as the primary propulsion source for rocket vehicles, they can be conveniently ignited by a conventional igniter, as for example, the igniter disclosed in assignee's copending application Serial No. 306,030, filed August 23, 1952 now, Patent No. 3,000,312. The propellant is preferably cast directly in the rocket chamber in which it is to be fired and restricted on one or both ends in the conventional manner with a relatively slow burning inert resin, such as a polyurethane or a polyester resin. The restriction is preferably accomplished by applying a relatively thin coating of the inert resin to the inner surfaces of the rocket chamber lining prior to casting the propellant therein. Rocket chambers such as those in which our novel solid propellants are employed are ordinarily of the conventional type having one end open and leading into a venturi rocket nozzle. Upon ignition, large quantities of gases are produced and exhausted through the nozzle creating propulsive force.

The polyurethane binders of our invention are prepared by reacting a compound having two active hydrogen groups capable of reacting with an isocyanate with an organic compound having as the sole reacting groups, two isocyanate or isothiocyanate groups. The compound having the active hydrogen groups is preferably an organic compound having as the sole reacting groups, hydroxyl or thiol groups.

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It will be appreciated that in any given batch of propellant the individual polyurethane molecules may vary in length from several to tens of thousands of repeating units, hence molecular weight figures on polyurethanes represent statistical averages. The exact nature of the terminal groupings is not known and will vary depending upon whether plasticizers, polymerization catalysts, etc., are present. Moreover a given molecule may even form a ring and thus leave no dangling radicals.

It is evident from the above that a wide variety of polyurethane binders for the propellants of this invention can be prepared simply by varying the particular isocyanate and hydroxy starting materials.

The isocyanate starting materials for our polyurethane binders are diisocyanate compounds which can be saturated or unsaturated; aliphatic or aromatic; open or closed chain; and, if the latter, monocyclic or polycyclic; and substituted or not by groups substantially unreactive with isocyanate or hydroxyl groups, such as, for example, ketone, halogen, ester, sulfide or ether groups. The following diisocyanate compounds are particularly suitable as reactant for the preparation of binders for our novel polyurethane propellants.

(*a*) Alkane diisocyanates such as:
- Ethylene diisocyanate;
- Trimethylene diisocyanate;
- Propylene-1,2-diisocyanate;
- Tetramethylene diisocyanate;
- Butylene-1,3-diisocyanate;
- Decamethylene diisocyanate;
- Octadecamethylene diisocyanate;
- etc.

(*b*) Alkene diisocyanates such as:
- 1-propylene-1,2-diisocyanate;
- 2-propylene-1,2-diisocyanate;
- 1-butylene-1,2-diisocyanate;
- 3-butylene-1,2-diisocyanate;
- 1-butylene-1,3-diisocyanate;
- 1-butylene-2,3-diisocyanate;
- etc.

(*c*) Alkylidene diisocyanates such as:
- Ethylidene diisocyanate;
- Propylidene-1,1-diisocyanate;
- Propylidene-2,2-diisocyanate;
- etc.

(*d*) Cycloalkylene diisocyanates such as:
- Cyclopentylene-1,3-diisocyanate;
- Cyclohexylene-1,2-diisocyanate;
- Cyclohexylene-1,3-diisocyanate;
- Cyclohexylene-1,4-diisocyanate;
- etc.

(*e*) Cycloalkylidene diisocyanates such as:
- Cyclopentylidene diisocyanates;
- Cyclohexylidene diisocyanate;
- etc.

(*f*) Aromatic diisocyanates such as:
- m-Phenylene diisocyanate;
- o-Phenylene diisocyanate;
- p-Phenylene diisocyanate;
- 1-methyl-2,4-phenylene diisocyanate;
- Naphthylene-1,4-diisocyanate;
- Diphenylene-4,4′-diisocyanate;
- 2,4-tolylene diisocyanate;
- 2,6-tolylene diisocyanate;
- 4,4′-diphenylmethane diisocyanate;
- 1,5-naphthalene diisocyanate;
- Methylene-bis-(4-phenylisocyanate);
- 2,2-propylene-bis-(4-phenylisocyanate);
- Xylene-1,4-diisocyanate;

Figure E.229: An example of Karl Klager's patents on rocket propellant.

United States Patent Office

3,245,849
Patented Apr. 12, 1966

1

3,245,849

SOLID PROPELLANT COMPOSITIONS CONTAINING POLYURETHANE RESINS OF LOW CURE TEMPERATURE

Karl Klager, Richard D. Geckler, and Richard L. Parrette, Sacramento, Calif., assignors to Aerojet-General Corporation, Azusa, Calif., a corporation of Ohio

No Drawing. Filed July 20, 1959, Ser. No. 829,180
32 Claims. (Cl. 149—19)

This invention relates to novel solid propellant compositions and in particular to novel propellant compositions comprising a cross-linked polyurethane binder with a finely divided oxidizing agent dispersed therein.

Solid propellant compositions are ordinarily composed of a resin fuel and an oxidizing material, the oxidizing material being intimately dispersed in the fuel. The ignition and burning properties of such propellant compositions, as well as their physical properties, are dependent to a large extent upon the particular resins employed as fuels.

In the novel propellant compositions of this invention, cross-linked polyurethanes are used as the resin fuel component to produce propellants of unexpectedly superior physical properties and performance characteristics.

The novel polyurethane propellants of our invention can be cured at low cure temperatures and in addition exhibit no measurable heat of reaction. As a result of these unique properties they are not subject to shrinkage and have no internal strains. Composite propellant systems heretofore used have all been severely restricted in their use because of high heats of reaction and the need for high cure temperatures which produce shrinkage and internal stresses. These faults have heretofore imposed severe restrictions upon the size of solid propellant motors because of their tendency toward cracking as a result of internal strains. We have produced a propellant which constitutes a major breakthrough in rocket technology in that solid propellant motors are no longer subject to size limitations and can be manufactured in sizes as large as desired using the novel propellant compositions of our invention.

In addition to their freedom from cracking, the polyurethane propellants of this invention are superior in other ways. For example, they are possessed of sufficiently tenacious adhesive properties to enable them to be bonded directly to the rocket chamber lining, thus permitting optimum utilization of the available space in the rocket motor and simplifying manufacturing techniques. The novel polyurethane propellants of our invention are also possessed of many other desirable physical properties, for example: rubbery mechanical qualities, low brittle point, excellent resilience, and superior aging properties.

Our novel solid propellants can be used as the primary propulsion source in rocket-propelled vehicles or as a propellant for artillery missiles. When used as the primary propulsion source for rocket vehicles, they can be conveniently ignited by a conventional igniter, as for example, the igniter disclosed in assignee's copending patent application Serial No. 306,030, filed August 23, 1952. The propellant is preferably cast directly in the rocket chamber in which it is to be fired and restricted on one or both ends in the conventional manner with a relatively slow burning inert resin, such as a polyurethane or a polyester resin. The restriction is preferably accomplished by applying a relatively thin coating of the inert resin to the inner surfaces of the rocket chamber lining prior to casting the propellant therein. Rocket chambers such as those in which our novel solid propellants are employed are ordinarily of the conventional type having one end open and leading into a venturi rocket nozzle. Upon ignition, large quantities of gases are produced

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and exhausted through the nozzle creating propulsive force.

The polyurethane binders of our invention are prepared by reacting a compound having two or more active hydrogen groups capable of polymerized with an isocyanate, with an organic compound having as the sole reacting groups, two or more isocyanate or isothiocyanate groups. The compound having the active hydrogen groups is preferably an organic compound having as its sole reacting groups, hydroxyl or thiol groups.

It will be apparent that, where there are more than two active hydrogen, isocyanate, or isothiocyanate groups present on any of the polyurethane reactions, the resulting molecular structure of the polyurethane binder will be at least to a certain extent of a cross-linked rather than a linear nature. The cross-linking is accomplished when all three functional groups of a sufficient number of the trifunctional molecules undergo the urethane reaction with other groups present in the mixture, thus resulting in a product having a "three-dimensional" molecular structure rather than mere aggregates of linear chains as is the case when bifunctional reactants are employed.

Where bifunctional reactants, such as dihydroxy compounds and diisocyanates, are employed to produce the polyurethane binders for our novel propellants, it is necessary to also employ a "cross-linking" agent to assure a product having the cross-linked structure essential to this invention. Cross-linking agents can also be used with polyurethane reactants having more than two functional groups, such as triols and/or triisocyanates, within the scope of this invention. Compounds suitable as cross-linking agents for our polyurethane binders are those organic compounds having as the sole reacting groups three or more groups polymerizable with hydroxy or isocyanate groups.

It will be appreciated that in any given batch of propellant the individual polyurethane molecules may vary in number of repeating units from several to tens of thousands of these units, hence molecular weight figures on polyurethanes represent statistical averages. The exact nature of terminal groupings is not known and will vary depending upon whether plasticizers, polymerization catalysts, etc., are present. Moreover, a given molecule may even form a ring and thus leave no dangling radicals.

It is evident from the above that a wide variety of polyurethane binders for the propellants of this invention can be prepared by varying the particular isocyanate and hydroxy starting materials.

The isocyanate starting materials for our polyurethane binders are preferably diisocyanates but not necessarily so since, as explained above, other polyisocyanates (such as triisocyanates) or polyisothiocyanates may be employed within the scope of the invention if desired.

Our preferred diisocyanate compounds can be saturated or unsaturated; aliphatic or aromatic; open or closed chain, and, if the latter, monocyclic or polycyclic; and substituted or not by groups substantially unreactive with isocyanate or hydroxyl groups such as, for example, ketone, halogen, ester, sulfide, or ether groups. The following diisocyanate compounds are particularly suitable as reactants for the preparation of binders for our novel polyurethane propellants:

(a) Alkane diisocyanates, such as:

Ethylene diisocyanate;
Trimethylene diisocyanate;
Propylene-1,2-diisocyanate;
Tetramethylene diisocyanate;
Butylene-1,3-diisocyanate;
Decamethylene diisocyanate;
Octodecamethylene diisocyanate;
etc.

Figure E.230: An example of Karl Klager's patents on rocket propellant.

United States Patent Office

3,187,053
Patented June 1, 1965

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3,187,053
4-NITRO-4-PENTENAL

Karl Klager, Sacramento, Calif., assignor to Aerojet-General Corporation, Azusa, Calif., a corporation of Ohio

No Drawing. Filed Dec. 21, 1959, Ser. No. 861,138
1 Claim. (Cl. 260—601)

This application is a continuation-in-part of my copending application Serial No. 387,023, filed October 19, 1953 and now abandoned, which was a continuation-in-part of application Serial No. 235,569, filed July 6, 1951, and now abandoned.

This invention relates to a novel method of preparing nitroolefins having the general formula

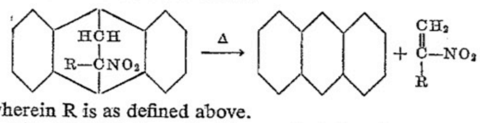
$$CH_2=\overset{NO_2}{\overset{|}{C}}-R$$

wherein R is an alkyl, halogen, ω-carboxyalkyl, ω-acyloxyalkyl, ω-carboalkoxyalkyl, cyanoalkyl, or ω-formylalkyl radical, and to nitroolefins prepared thereby.

The nitroolefins prepared by the method of this invention in which R is an ω-acyloxyalkyl radical, such as nitroallyl acetate, readily condense with nitro compounds having a labile hydrogen function, such as methyl 4,4-dinitrobutyrate, to form highly nitrated compounds, such as dimethyl 4,4,6,8,8-pentanitro-1,11-undecanedioate, useful as high explosives. A more complete description of this process can be found in my copending application Serial No. 636,839, filed January 28, 1957 and now Patent No. 3,000,932. In addition, all of the nitroolefins prepared by the method of this invention undergo an addition reaction with polynitro compounds having a labile hydrogen function, such as 2,2,4,4-tetranitrobutyl acetate, to form highly nitrated compounds useful as high explosives. 2,2,4,4-tetranitrobutyl acetate is disclosed in assignee's copending application Serial No. 617,667, filed October 22, 1956 and now Patent No. 2,978,455. The addition reaction is conducted according to the method set forth in copending application Serial No. 636,839.

The highly nitrated compounds obtained by the above-described methods are useful as high explosives and can be used in any conventional explosive missile, projectile, rocket, or the like, as the main explosive charge. An example of such a missile is disclosed in United States Patent 2,470,162, issued May 17, 1949. One way of using the high explosives of this invention in a device such as that disclosed in United States Patent 2,470,162 is to pack the crystalline explosive in powder form into the warhead of the missile. Alternatively, the crystals can be first pelletized and then packed. A charge thus prepared is sufficiently insensitive to withstand the shock entailed on the ejection of a shell from a gun barrel or from a rocket launching tube under the pressure developed from ignition of a propellant charge, and can be caused to explode on operation of an impactor time-fuse mechanism firing a detonating explosive such as lead azide or mercury fulminate.

The novel method of this invention comprises the simple pyrolysis of nitro-substituted endo anthracene compounds to decompose them into anthracene and the corresponding nitroolefins, in accordance with the general reaction scheme set forth below:



wherein R is as defined above.

The pyrolysis is preferably conducted under a vacuum so as to avoid the possibility of undesirable oxidation. The heat, as may be seen above, breaks the nitroolefin-anthracene bonds to yield anthracene and the desired nitroolefins.

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The following examples are provided to more clearly illustrate my invention. It should be understood, however, that these examples are provided purely for purposes of illustration and are not intended to limit the scope of the invention in any way.

EXAMPLE I

Preparation of methyl-4-nitro-4-pentenoate

One part of 11-(2-carbomethoxyethyl)-11-nitro-9,10-ethanoanthracene was heated in vacuum at 21 mm. to 185–200° C. A slightly yellow colored liquid was distilled and condensed in a receiver. The weight was 0.28 part of the starting material. At 230–240° C., at the same pressure, 0.62 gm. solid material distilled which was identified as anthracene (M.P. 215° C., mixed melting point 215° C.). The first fraction was redistilled at 96° C. and 4 mm. The analysis indicated that methyl-4-nitro-4-pentenoate was formed, $n_D^{24}=1.4612$.

EXAMPLE II

Preparation of nitroallyl acetate

A bulb tube charged with 1 gm. 11-acetoxymethyl-11-nitro-9,10-ethanoanthracene, prepared by acetylation of 11-methylol-11-nitro-9,10-ethanoanthracene with acetic anhydride, M.P. 103–105° C., was heated to 200–220° C. at 29 mm. in an airbath. Decomposition was observed and a greenish-yellow liquid distilled, accompanied by crystals. After redistillation at 90–120° C. airbath temperature and 5 mm. the light-yellow liquid (0.1 gm.) gave the following analysis for nitroallyl acetate:

Analysis.—Calc'd for $C_5H_7O_4N$: percent C, 41.38; percent H, 4.86; percent N, 9.65. Found: percent C, 41.53; percent H, 5.45; percent N, 8.83.

The anthracene fraction was purified by crystallization from tetrahydrofuran and methanol. The melting point and mixed melting point with pure anthracene were 214–216° C.

EXAMPLE III

Preparation of 4-nitro-4-pentenonitrile

A bulb tube was filled with 0.8 gm. 11-(2-cyanoethyl)-11-nitro-9,10-ethanoanthracene and heated to 195–200° C. at 28 mm. A yellow liquid and crystals distilled. The distillate was dissolved in ether and filtered from the insoluble anthracene. The extract was evaporated and distilled at 120° C. airbath temperature and 5 mm. producing a greenish-yellow liquid with a refractive index, n_D^{22} 1.4735.

Analysis.—Calc'd for $C_5H_6O_2N_2$: percent C, 47.61; percent H, 4.80; percent N, 22.22. Found: percent C, 47.97; percent H, 4.94; percent N, 22.62.

The ether insoluble portion was crude anthracene. It was dissolved in tetrahydrofuran and methanol was added. After two recrystallizations the melting point was 213–214° C. and the mixed melting point with anthracene (M.P. 214–216° C.) was 214–216° C.

It will be apparent that any nitroolefin within the scope of the general formula given above can be prepared by heating the corresponding nitro-substituted 9,10-ethanoanthracene in the manner described in the above examples. For example, 2-nitro-1-butene; 2-nitro-1-hexene; 2-nitropropylene; 1-chloro-1-nitroethylene; 1-bromo-1-nitroethylene; 1-fluoro-1-nitroethylene; ethyl-4-nitro-4-pentenoate; methyl-2-methyl-3-nitro-3-butenoate; 4-nitro-pentenoic acid; and 4-nitro-4-pentenal can be prepared by heating 11-ethyl-11-nitro-9,10-ethanoanthracene; 11-butyl-11-nitro-9,10 - ethanoanthracene; 11-methyl-11-nitro-9,10-ethanoanthracene; 11-chloro-11-nitro-9,10 - ethanoanthracene; 11-bromo-11-nitro-9,10-ethanoanthracene; 11-fluoro-

Figure E.231: An example of Karl Klager's patents on rocket propellant.

PATENT SPECIFICATION

NO DRAWINGS

974,805

974,805

Inventor: KARL KLAGER

Date of Application and filing Complete Specification: April 5, 1961.

No. 12241/61.

Complete Specification Published: Nov. 11, 1964.

Index at acceptance :—C2 C(1F3C3, 1F3D1, 2B29)

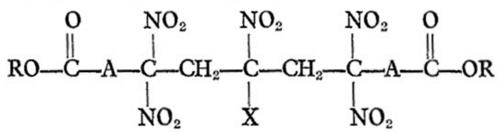
International Classification:—C 07 c

COMPLETE SPECIFICATION

Polynitro-Substituted Dibasic Acids and Esters

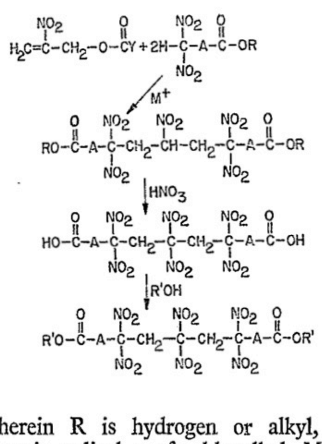
We, AEROJET-GENERAL CORPORATION, a corporation duly organized and existing under the laws of the State of Ohio, United States of America, of 6352 North Irwindale Avenue, Azusa, State of California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to new compounds, and in particular, to polynitro-substituted dibasic acids and esters thereof having the general formula:



wherein R is an alkyl group or hydrogen atom, A is a lower alkylene radical and X is hydrogen atom or nitro radical. By the term "lower alkylene radical" we mean an alkylene radical having from 1 to 4 carbon atoms.

The new compounds of this invention are prepared by condensing esters of nitroallyl alcohol with ω,ω-dinitroalkanoic acids or esters thereof, and in accordance with the general reaction scheme set forth below:



(I) (II) (III)

wherein R is hydrogen or alkyl, Y is an organic radical, preferably alkyl, M is an ion of an alkali or alkaline earth metal, A is a lower alkylene radical and R^1 is an alkyl radical.

In place of the ester of nitroallyl alcohol, a diester of 2 - nitro - 1,3 - propanediol can be used, as for example, 2 - nitro - 1,3-diacetoxypropane. It is believed that the diester generates the nitroallyl alcohol ester *in situ* and then reacts in the manner illustrated above.

Since the acid portion of the nitroallyl ester does not enter into or affect the reaction, Y can be any organic radical including phenyl, benzyl, heterocyclic, aliphatic, cycloaliphatic, or the like, without departing from the scope of the invention. Similarly, when a diester of 2 - nitro - 1,3 - propanediol is used as the starting material, the acid portion can be any organic acid inasmuch as this portion of the diester does not enter into or affect the reaction in any way.

R, the alcohol portion of the dinitroalkanoic acid ester is an alkyl radical. Likewise, the dibasic acids of this invention will react with any organic alcohol to form esters in the usual manner.

The corresponding dibasic acid is prepared by hydrolysis of the alkyl ester with a strong acid which is sulphuric acid, hydrochloric acid, hydrobromic acid, phosphoric acid, trifluoroacetic acid or mixtures thereof in the conventional manner. The reaction of compound (I) with nitric acid produces the hexanitro deriva-

[*Price 4s. 6d.*]

Figure E.232: An example of Karl Klager's patents on rocket propellant.

United States Patent [19]
Klager

[11] **Patent Number: 5,811,725**
[45] **Date of Patent: Sep. 22, 1998**

[54] **HYBRID ROCKET PROPELLANTS CONTAINING AZO COMPOUNDS**

[75] Inventor: **Karl Klager**, Sacramento, Calif.

[73] Assignee: **Aerojet-General Corporation**, Rancho Cordova, Calif.

[21] Appl. No.: **748,738**

[22] Filed: **Nov. 18, 1996**

[51] **Int. Cl.**[6] **C06B 45/10**

[52] **U.S. Cl.** **149/19.4**; 149/19.1; 149/19.5; 149/36; 149/109.4; 60/219

[58] **Field of Search** 60/219; 149/19.1, 149/19.4, 36, 19.5, 109.4

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Primary Examiner—Edward A. Miller
Attorney, Agent, or Firm—Townsend and Townsend and Crew LLP

[57] **ABSTRACT**

Hybrid rocket propellants are disclosed that contain azo compounds, i.e., compounds containing the group R—N═N—R' as part of their structure, where R and R' represent a variety of groups including aliphatic, alicyclic and heterocyclic groups. The azo compounds are mixed with the other solid components of the propellant grain and serve either as plasticizers, binders, fuels, or fillers. The effect of including the azo compounds is an increase in the regression rate of the grain as the propellant burns.

26 Claims, 2 Drawing Sheets

Figure E.233: An example of Karl Klager's patents on rocket propellant.

David Beers. 1996. *Blue Sky Dream: A Memoir of America's Fall from Grace.* [Beers 1996, pp. 38–39]

"The most beautiful missiles ever fired," a U.S. Navy Rear Admiral pronounced the nuclear-tipped A1X Polaris, having witnessed its successful submarine test on a summer day in 1960. The fully evolved, deployed Polaris, designed under the guidance of Wernher von Braun's friend and fellow former Nazi, Wolfgang Noeggerath, was capable of traveling 2,400 nautical miles in a few minutes and delivering, from its elusively mobile launchpad, three separate warheads to a single target deep within the Soviet Union—facts no doubt beautiful to a nuclear warfare strategist.

[The journalist David Beers, who grew up surrounded by the research of his father and his father's coworkers at Lockheed, singled out the importance of Wolfgang Noeggerath for the Polaris solid-propellant missile.]

***Baltimore Sun* 2000-11-29. Werner W. Hohenner, 93, Scientist Who Helped Develop Polaris Missile [https://www.baltimoresun.com/news/bs-xpm-2000-11-29-0011290120-story.html].**

[...] From 1947 until 1954, Mr. Hohenner was at the Point Mugu Naval Air Weapon Station in California, working in the Naval Ballistic Program that led to the development of the Polaris missile, the first U.S. submarine-launched ballistic missile.

During the rocket's development, Mr. Hohenner prevailed over Mr. von Braun, who insisted that the rocket be fueled by liquid rather than solid fuel.

"He brought a great knowledge ... in fuel handling, and convinced the Navy that if they followed von Braun's plan to use liquid fuel, which is dangerous, they could plan on losing a sub a year in accidents," said Robert L. Frohmuth, a retired Navy electrical engineer. "It was a breakthrough, and he was the one who got solid fuel missiles started, which are still being used today."

"His greatest achievement was the development of the Polaris," said Mr. Schmitz.

From 1957 until retiring in 1973, Mr. Hohenner was chief scientist at the air arm division at the Westinghouse plant in Linthicum, where he continued his work on weapon systems and ballistic missiles.

[The *Baltimore Sun* reported the death of another German scientist who played an important role in the development of the Polaris missile, which was confirmed in the later *Los Alamos Daily Post* article below.]

***Los Alamos Daily Post.* 2013-04-10. Rosmarie H. Frederickson.**
[https://ladailypost.com/new-living-treasures-of-los-alamos-unveiled/]

Rosmarie H. Frederickson was born in Germany and came to the US at age 12. She is the daughter of scientist Werner W. Hohenner who was able to bring his family to the US after the war, and once here he was able to help develop the Polaris missile. [...]

The Birth and Boyhood of Point Mugu by Captain Grayson Merrill, USN (Ret). 2003.
https://www.usna.com/tributes-and-stories—stories-1934
http://stagone.org/?page_id=28 [Merrill 2003]

Shortly after this I was detailed to witness some V-2 firings at Cuxhaven staged by the British and executed by Germans from Peenemunde. It reinforced, in my mind, the correctness of choosing Point Mugu. After the firings a small group of American observers gathered in a Bremen rathskeller to quaff beer and discuss what we had seen. A rumpled fake Army Colonel named Theodore von Kármán summed up our feelings, "You young fellows must now go home and arrange to put these Germans to work. In the meantime build a test range for the missiles to come."

Almost 20 years later it can be said that Point Mugu has borne out the committee's judgments. [...]

Many of the LOON technical successes are traceable to the "German Scientists" who migrated to Point Mugu. These included Willy Fiedler, Robert Lusser and Otto Schwede. But Dr. Herbert A. Wagner, now deceased, deserves special mention. [...]

I left in 1949 but nevertheless watched with pride as the range expanded in support of such missiles as LARK, SPARROW, REGULUS, RIGEL, POLARIS and TOMAHAWK.

[Grayson Merrill, a retired Navy Captain, also emphasized the central role of German-speaking scientists in the missile programs.

For considerable documentation on Willy Fiedler's aerospace work in both Germany and the United States, see https://earlyflightera.com/from-fledermaus-to-polaris/]

Figure E.234: Willy Fiedler made many major contributions to the Polaris missile program.

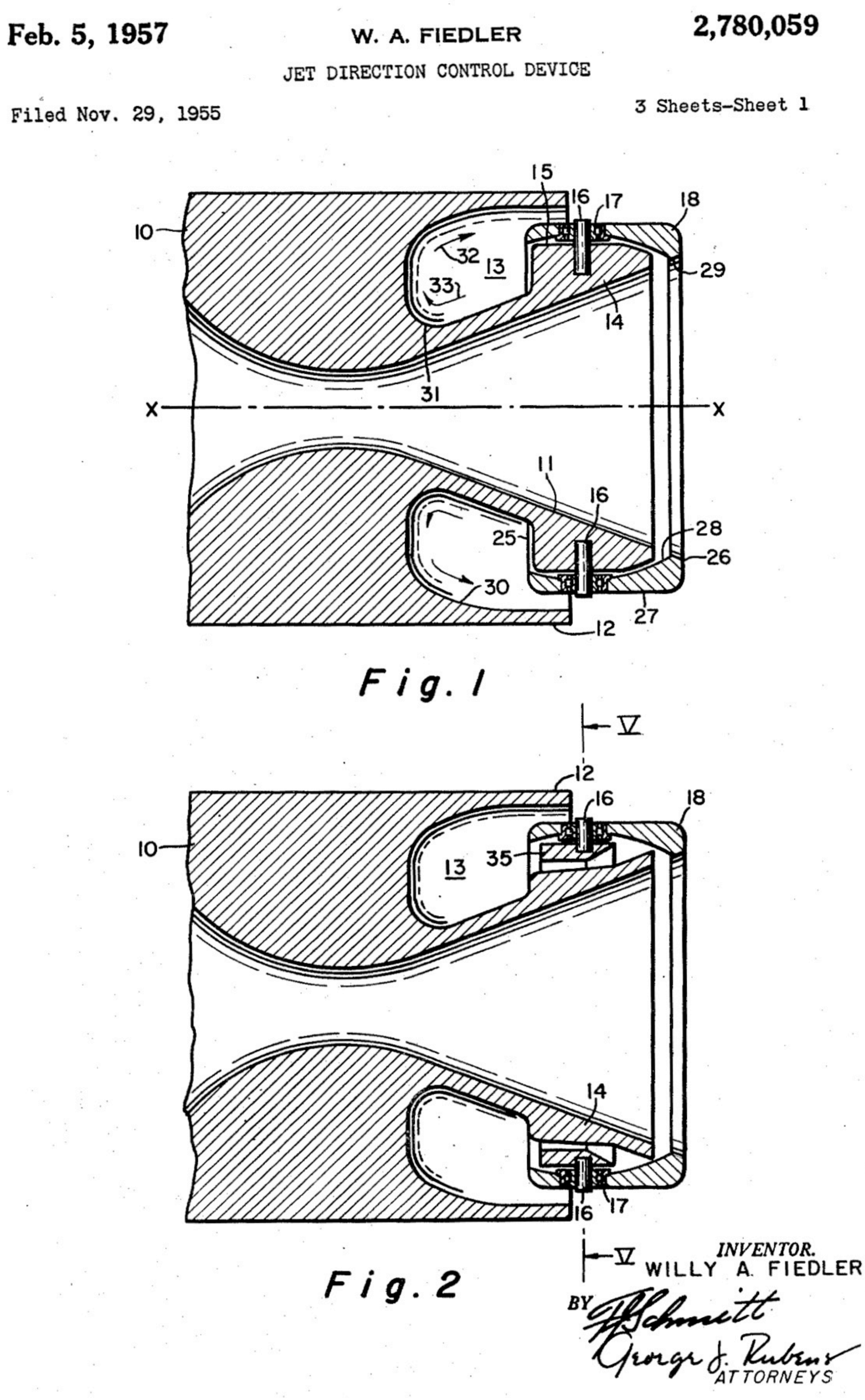

Figure E.235: An example of Willy Fiedler's patents related to the Polaris missile.

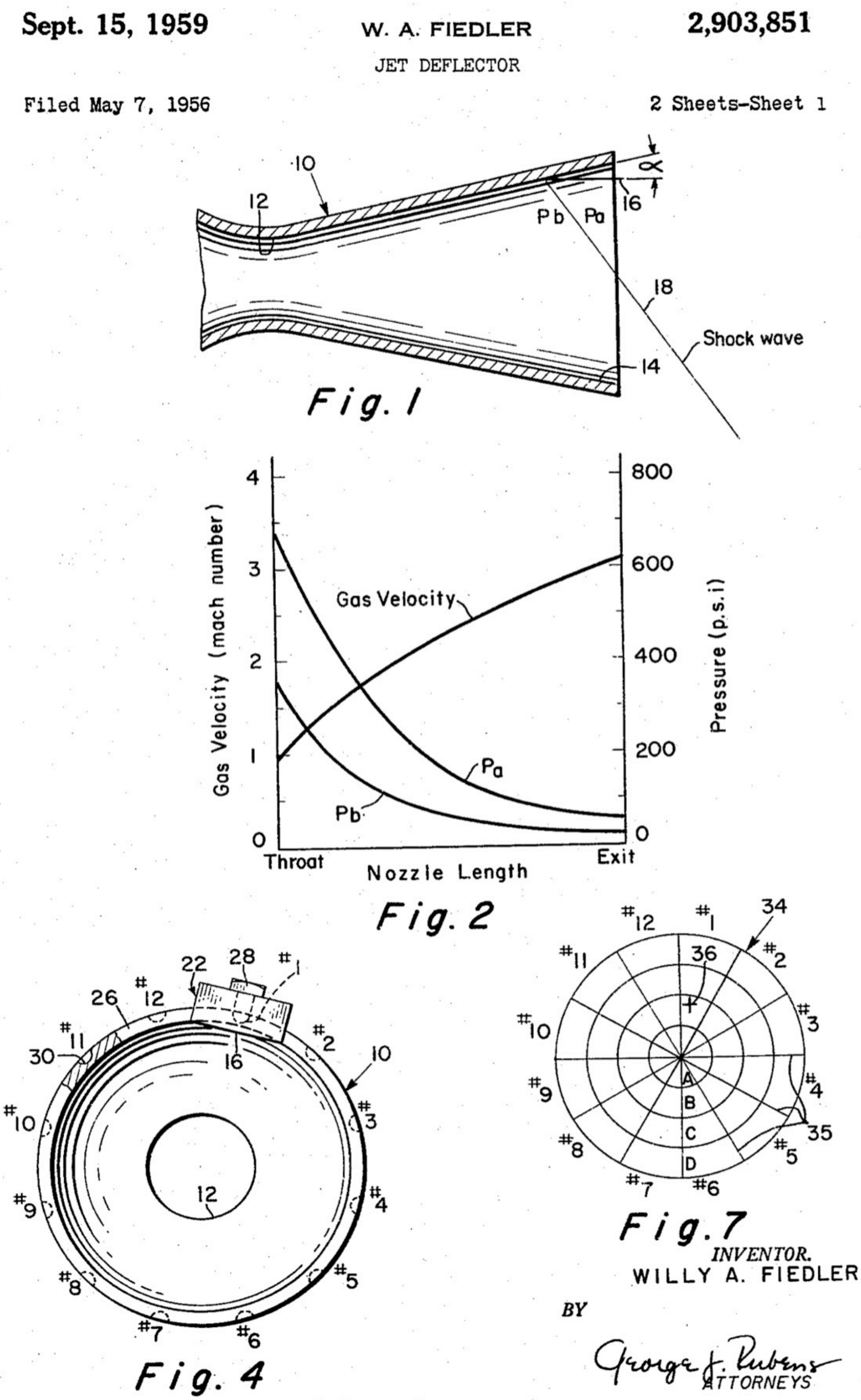

Figure E.236: An example of Willy Fiedler's patents related to the Polaris missile.

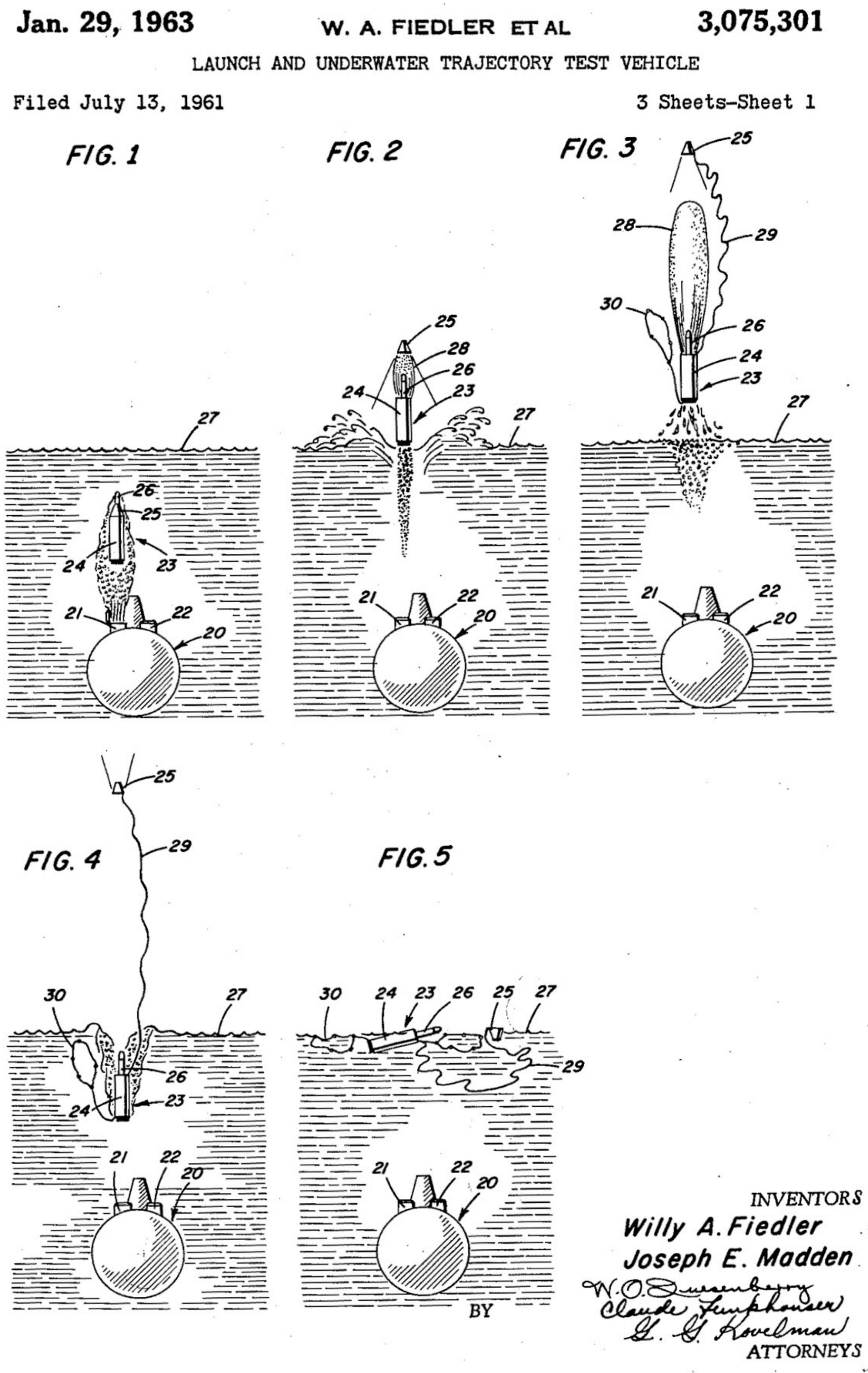

Figure E.237: An example of Willy Fiedler's patents related to the Polaris missile.

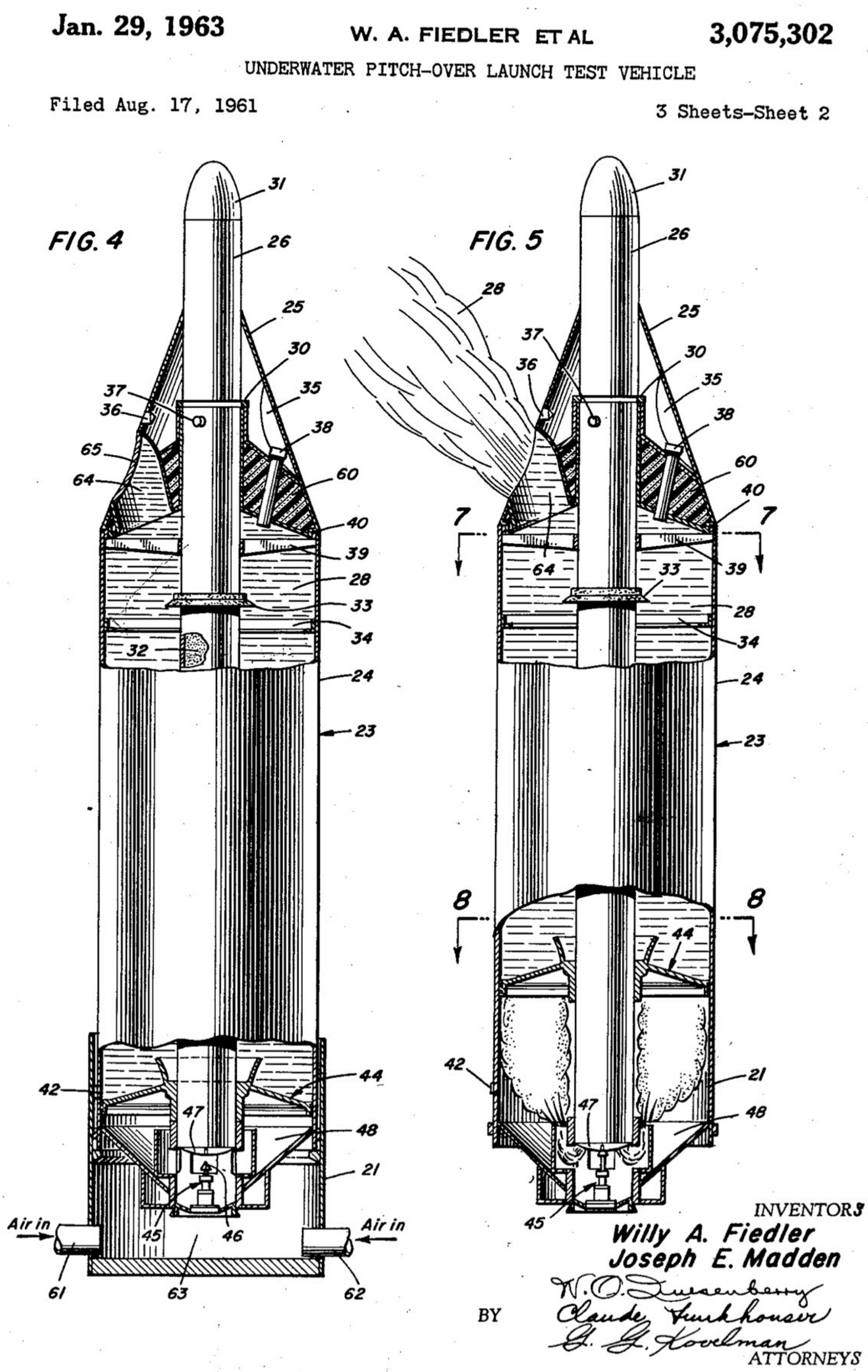

Figure E.238: An example of Willy Fiedler's patents related to the Polaris missile.

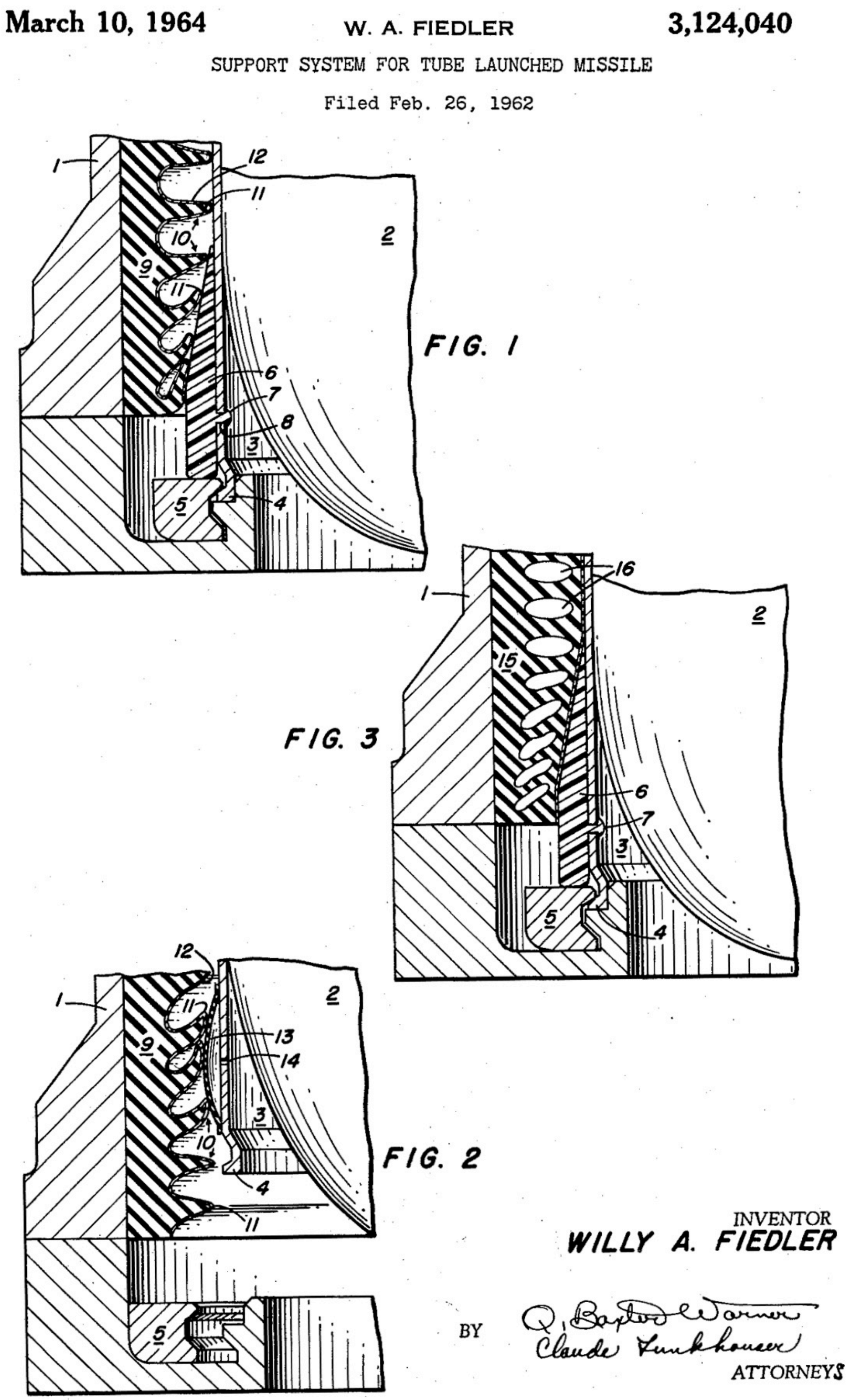

Figure E.239: An example of Willy Fiedler's patents related to the Polaris missile.

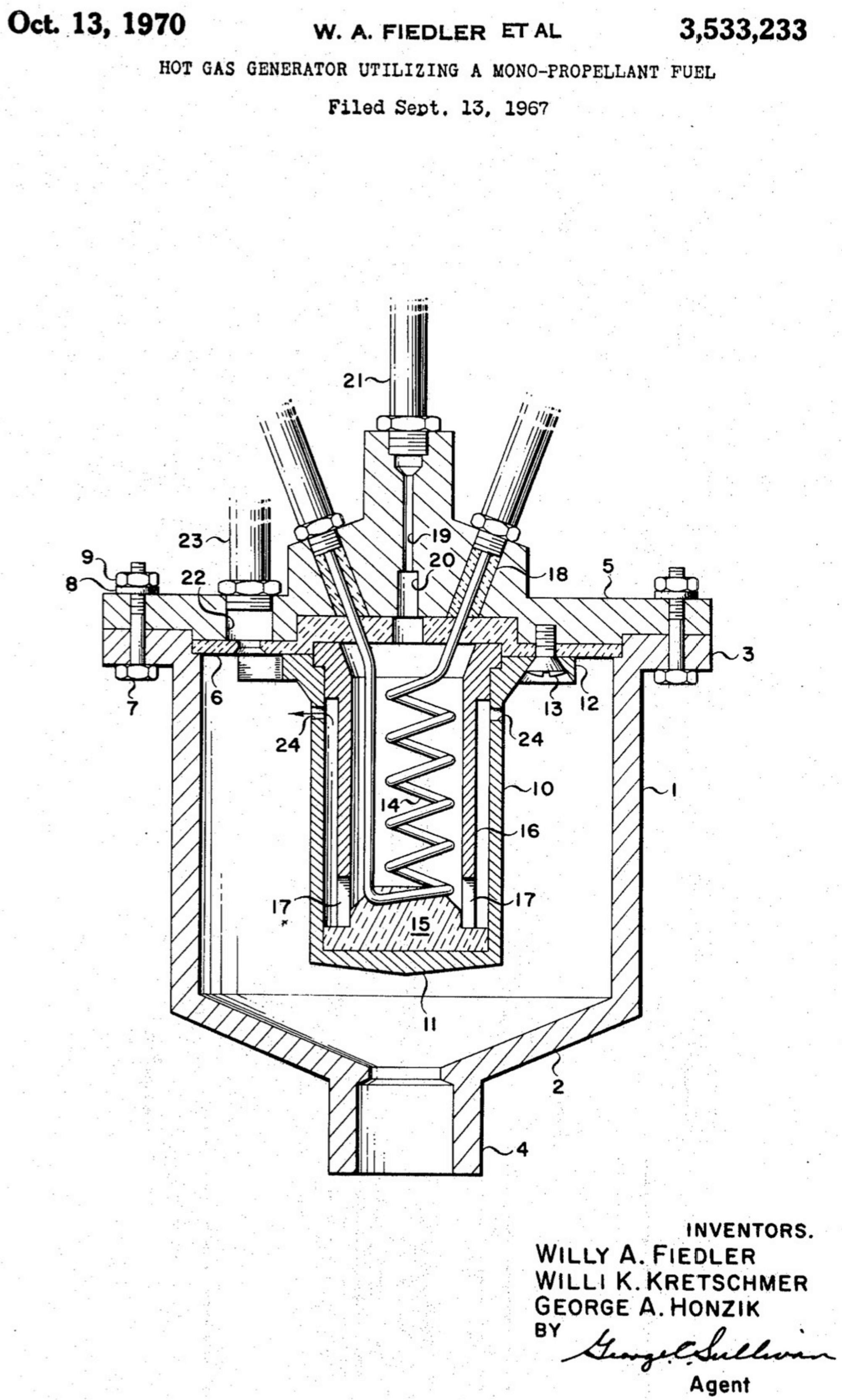

Figure E.240: An example of Willy Fiedler's patents related to the Polaris missile.

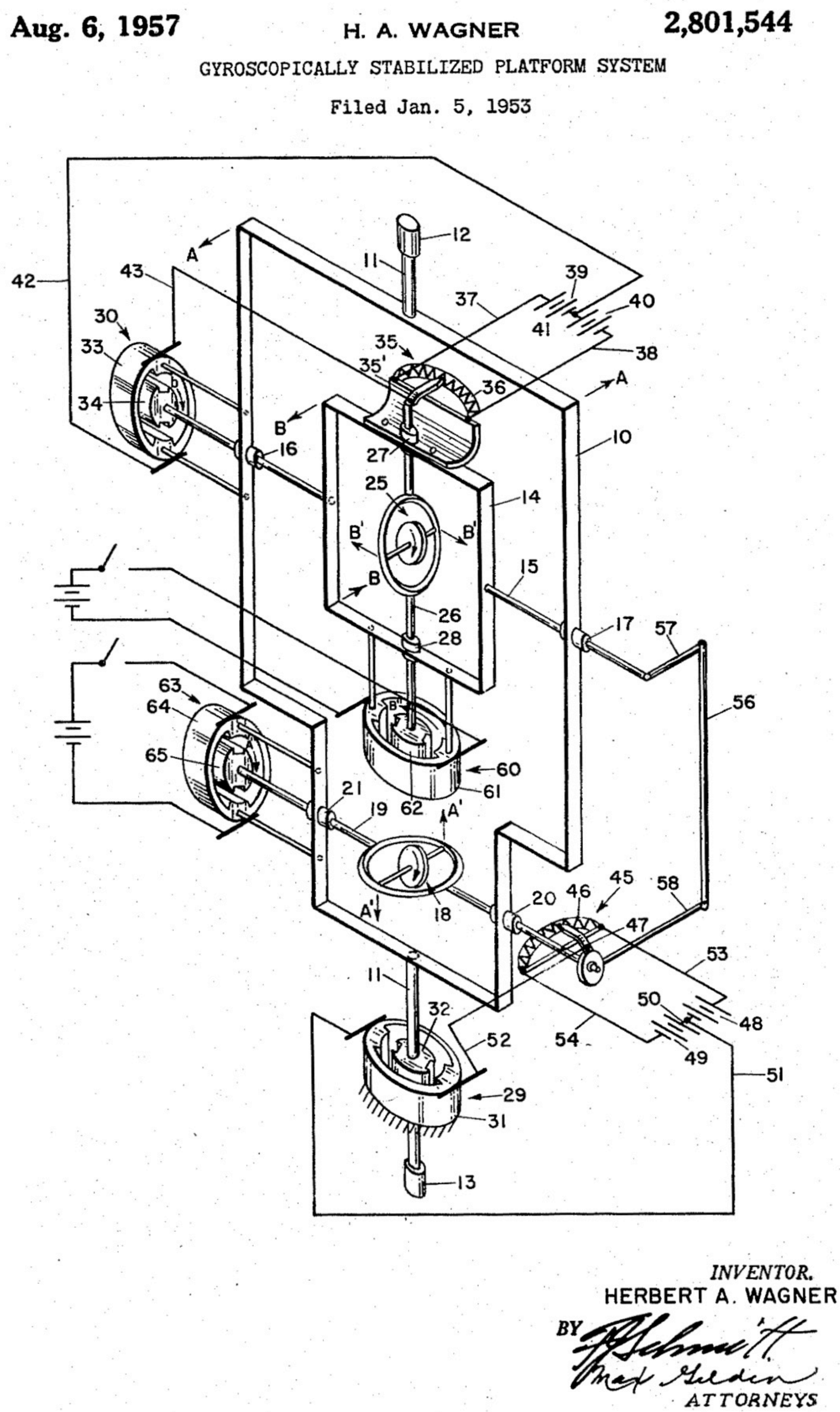

Figure E.241: A patent on missile guidance systems for the U.S. Navy by Herbert Wagner.

Marsha Freeman. 2003. Arthur Rudolph and the Rocket That Took Us to the Moon. 54th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law. IAC-03-IAA.2.1.02 [https://www.scientistsandfriends.com/files/arthur.pdf].

In 1956, the decision was made that the U.S. Army needed a "shoot and scoot" mobile missile, which meant it had to be solid-fueled. This was the Pershing program.

Arthur Rudolph was made the project director, with $500 million for its development. He assembled a team, and took bids. He visited the potential contractors in person, and, knowing the guidance system was critical, chose the Bendix plant in New Jersey for the job. After inspecting their facilities, he noted that it had the best precision machine tools for the job, which were made in Germany! "That was the firm for us!" he decided.

The creed that Arthur Rudolph developed to manage the Pershing rocket was that "nothing could fall through the cracks." Research and development laboratories were expanded for testing vibration, hearing, and other conditions that would face the rocket in flight.

Following the uproar after the Soviet launch of Sputnik in November 1957, the National Aeronautics and Space Administration (NASA) was established. The heart of the new civilian space program would be rockets, and the von Braun team was transferred from the Army—all but Arthur Rudolph. He was considered irreplaceable on the Pershing program.

In 1960, Arthur Rudolph, for his management of the Pershing missile program, received the Exceptional Civilian Service award, the highest civilian award in the Army. [...]

In 1962, at a meeting at NASA headquarters in Washington, Arthur Rudolph put forward his list of basic requirements for the Apollo rocket, and a mission plan that was based on his experience managing the Pershing program. In 1963, he was named the program manager for the Saturn V. [...]

Arthur Rudolph's management of the massive Saturn V rocket program involved his personal tracking of all of the aspects of the system. He had a chart in his office showing all of the components, large and small, to be able to immediately see their progress. This made the entire program transparent, and provided an overview of the massive coordination. Every problem was dealt with, in excruciating detail, by the program manager and his staff. [...]

For his management of the Saturn V program, Arthur Rudolph received both the Exceptional Service Medal and the Distinguished Medal from NASA.

His job of developing and producing the rocket to take men to the Moon completed, Arthur Rudolph retired from the space agency, and rocket research, on January 1, 1969.

Arthur Rudolph (1906–1996) managed the development of the Pershing 1 missile and then the Saturn V rocket

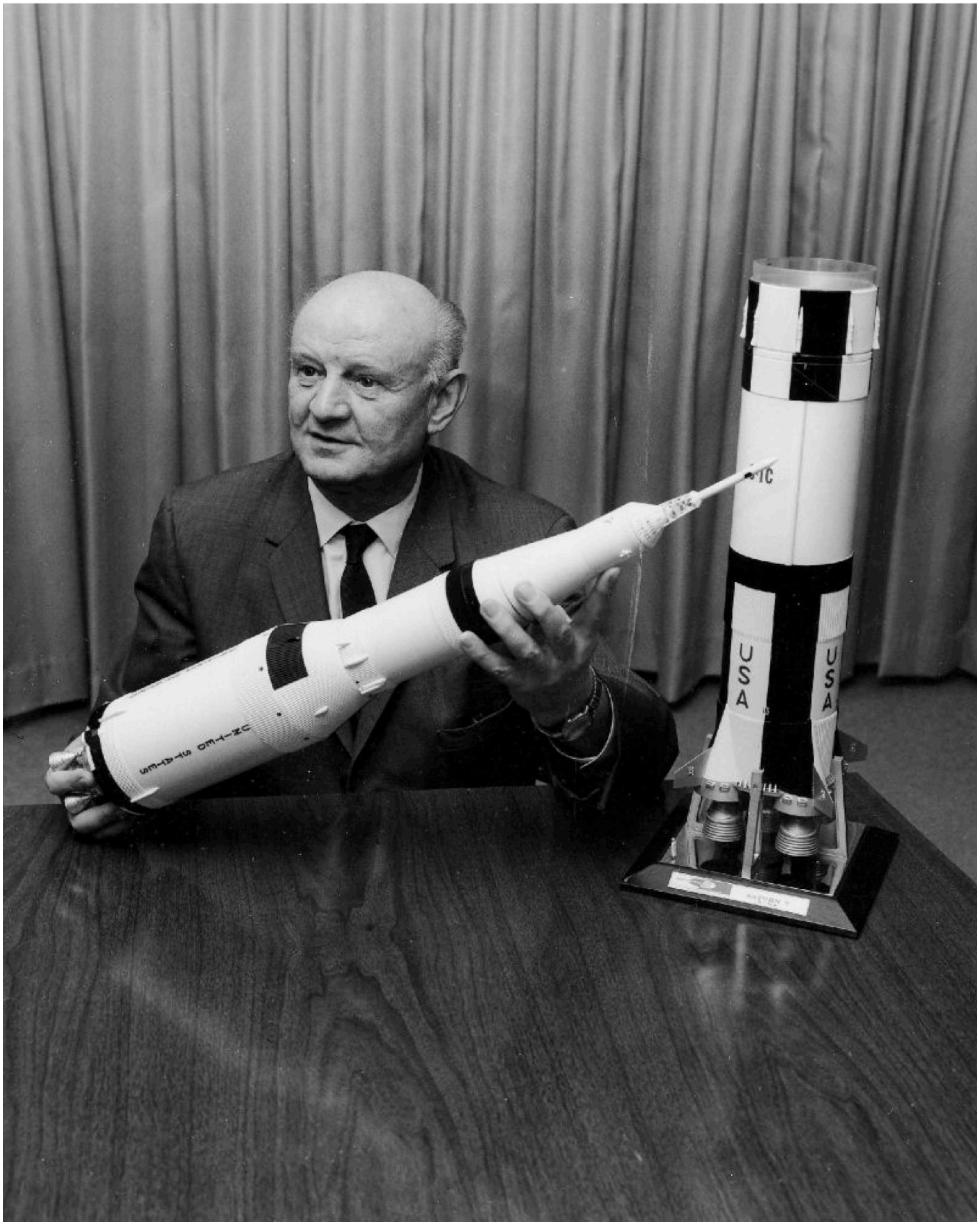

Figure E.242: Arthur Rudolph managed the development of the Pershing 1 missile, and then the development of the Saturn V moon rocket.

Figure E.243: German-speaking scientists played major roles in the development of postwar large solid propellant rockets such as the Polaris missiles.

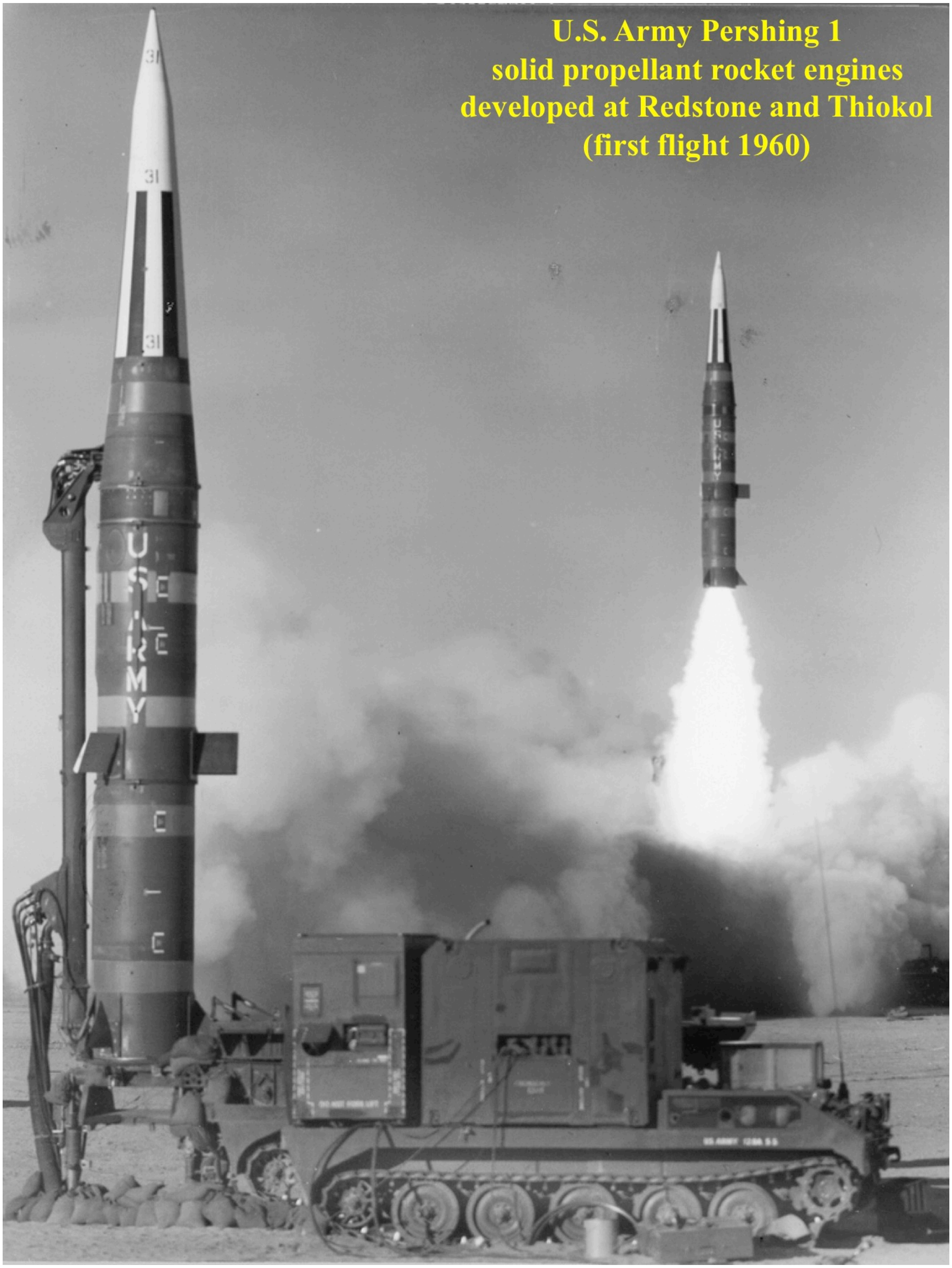

Figure E.244: German-speaking scientists played major roles in the development of postwar large solid propellant rockets such as the Pershing missiles.

Figure E.245: German-speaking scientists played major roles in the development of postwar large solid propellant rockets such as the Minuteman missiles.

E.5 Longer-Term Space Projects

[The prevailing public perception is that technologies for space exploration were developed by the United States and the Soviet Union, beginning with the October 1957 launch of the Soviet Sputnik satellite. However, scientists in interwar and wartime Germany did a great deal of work on technologies for space exploration, and continued to develop those technologies in other countries after World War II:

- Walter Hohmann published a detailed textbook of calculations for spacecraft trajectories and orbits in 1925 [Hohmann 1925]. See pp. 5281–5284.
- In 1928, Hermann Potočnik, under the pen name of "Hermann Noordung," published a book with detailed designs of a large, circular, rotating space station, as shown on pp. 5285–5288 [Noordung 1928].
- Guido von Pirquet and Hermann Oberth separately designed space stations in 1928–1929 [Ley 1928; Oberth 1929]. See Fig. 9.232.
- Plans for a space station were seriously considered by the German government during World War II, especially with regard to potential military applications. See p. 5289.
- There were detailed wartime designs for large three-stage rockets (A-11 through A-15) capable of launching cargo or vehicles into Earth orbit or beyond (p. 4950).
- Scientists at Peenemünde and the Reichspost began programs on fission thermal rocket propulsion no later than 1942 (p. 5299). Creators such as Krafft Ehricke continued those programs in the United States after the war.
- External pulse propulsion by nuclear explosives was first proposed in approximately 1942 by Wernher von Braun. By the end of the war, work in this area had apparently progressed at least as far as creating small test models powered by conventional chemical explosives. After the war, external fission pulse propulsion was explored in the United States by Stanislaw Ulam, another creator from the greater German-speaking world. See p. 5312.
- Electric rocket propulsion systems were first proposed by Hermann Oberth in 1929 (p. 5314). Experimental development of electric propulsion in Germany began no later than 1937 and continued until at least 1944 (p. 4860). Ernst Stuhlinger, Wernher von Braun, and other German-speaking scientists continued to develop and promote electric propulsion after the war (pp. 1951, 5314).
- Eugen Sänger was the first to propose matter-antimatter rockets and to work out their details, including using anti-hydrogen made from positrons and antiprotons, storing the antimatter without letting it come into contact with ordinary matter, and using highly novel types of nozzles to direct the matter-antimatter reaction products out the back of the rocket. See pp. 1949, 1951, and 5315.

These wartime German creators and their creations were directly responsible for the postwar space exploration programs in the United States, Soviet Union, and other countries [e.g., Chertok 2005–2012; Jürgen Michels 1997; Ordway and Sharpe 1979; Uhl 2001].

This section is subdivided into categories of sources that cover:

E.5.1. Orbital spacecraft and space stations.

E.5.2. Fission thermal rocket propulsion.

E.5.3. Fission pulse rocket propulsion.

E.5.4. Electric rocket propulsion.

E.5.5. Antimatter rocket propulsion.]

E.5.1 Orbital Spacecraft and Space Stations

[Walter Hohmann (German, 1880–1945) published a detailed textbook of calculations for spacecraft trajectories and orbits in 1925 [Hohmann 1925]. Figures E.246–E.249 show illustrations from his book for calculations regarding atmospheric reentry, aerobraking, and what are now called Hohmann ellipses—elliptical orbits for transferring from one nearly circular orbit (such as that of a planet) to another (such as that of another planet) with the smallest possible expenditure of energy. The methods that Hohmann proposed and worked out in 1925 have been utilized quite effectively since the 1960s and will continue to be widely used in future space missions.

In 1928, Hermann Potočnik (Austrian/Slovene, 1892–1929), under the pen name of "Hermann Noordung," published a book with detailed designs of a large, circular, rotating space station, as shown in Figs. E.250–E.253 [Noordung 1928]. Potočnik's designs accurately accounted for everything from the solar energy requirements of the space station's power plant to the artificial gravity in its living quarters. His book also incorporated many of Hohmann's proposed methods for interplanetary missions. Unfortunately Potočnik died from tuberculosis (which he had contracted during World War I) when he was only 36; if he had lived he might have helped to realize some of his visions.

Guido von Pirquet (Austrian, 1880–1966) and Hermann Oberth (German, 1894–1989) separately designed space stations in 1928–1929 [Ley 1928; Oberth 1929]. See Fig. 9.232. Oberth pointed out that such a station could for example tend large space-based mirrors to reflect sunlight on the earth. Depending on they were used, such mirrors might improve everything from agriculture to power production to weather, or they might incinerate opposing countries.

Plans for a space station and space mirror were seriously considered by the German government during World War II, especially with regard to potential military applications [NYT 1945-06-29 p. 1, 1945-06-30 p. 3; *Life* 1945-07-23 p. 78; *Time* 1946-09-02 p. 52]. See p. 5289.

There were detailed wartime designs for large three-stage rockets (A-11 through A-15) capable of launching cargo or vehicles into Earth orbit or beyond (see p. 4950). During the war, was any experimental work beyond the drawing board done on any of them—wind tunnel models, rocket engine mock-ups, etc? Considering the evidence for other developments in Appendices A–E, historians should not be too quick to rule out the possibility.]

DIE ERREICHBARKEIT
DER HIMMELSKÖRPER

UNTERSUCHUNGEN ÜBER
DAS RAUMFAHRTPROBLEM

VON

DR.-ING. W. HOHMANN, ESSEN

MÜNCHEN UND BERLIN 1925
DRUCK UND VERLAG R. OLDENBOURG

Figure E.246: Walter Hohmann published a detailed textbook of calculations for spacecraft trajectories and orbits in 1925 [Hohmann 1925].

28

The period of the orbits follows from the theorem (39), end of section III:

$$\frac{dF}{dt} = \text{constant} = \frac{v_a \cdot r_a}{2};$$

$$dF = \frac{v_a r_a}{2} \cdot dt;$$

$$F = \frac{v_a r_a}{2} \cdot t = ab\pi;$$

thus

$$t = \frac{2ab\pi}{v_a \cdot r_a}. \quad (18a)$$

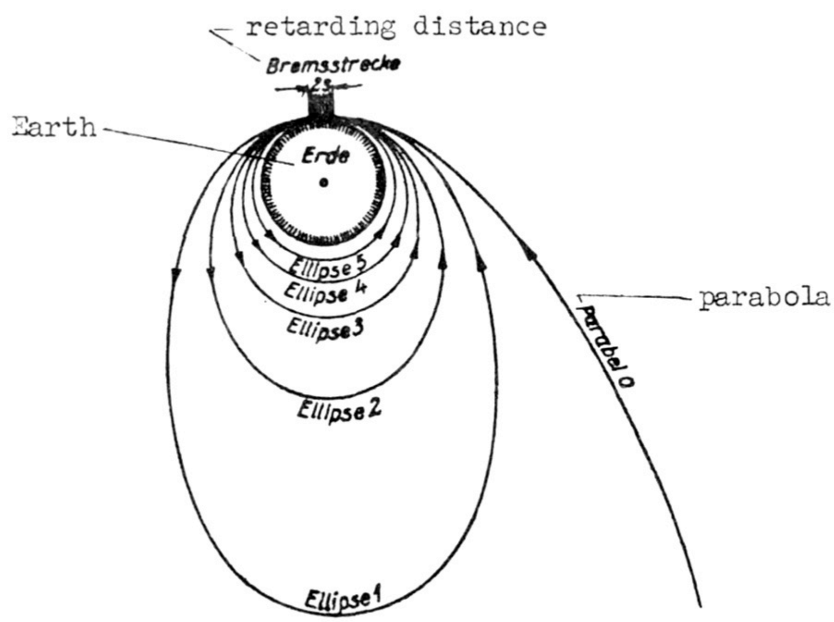

Figure 9

The time required for the 5 orbits is therefore:

$$t_1 = \frac{2 \cdot 25,000 \cdot 16,800 \cdot \pi}{10.4 \cdot 6,455} = 39,300 \text{ sec} = \sim 10.9 \text{ hours}$$

$$t_2 = \frac{2 \cdot 14,300 \cdot 11,950 \cdot \pi}{9.8 \cdot 6,455} = 16,900 \text{ sec} = \sim 4.7 \text{ hours}$$

Figure E.247: Walter Hohmann proposed and calculated aerobraking maneuvers to slow an interplanetary spacecraft by briefly dipping into the atmosphere of the target planet [Hohmann 1925].

$$\beta_a = 9 \text{ m/sec}^2$$

and

$$F_o = \frac{6.5}{0.342^2 \cdot 0.940} = 59 \text{ m}^2 \ (\sim 5 \text{ m} \cdot 12 \text{ m}).$$

I.e., the angle α of the wing has to increase from 0^o to 20^o to the horizontal for a constant wing area $F_o = 59$ m^2 and constant breaking area $F = 6.1$ m^2, while the distance $s_b = 3{,}250$ km is covered and the height drops from $h - y = 75$ down to 48 km, in order to have the radial deceleration ρ increase from zero to g, while the velocity $v_a = 7{,}850$ km/sec decreases down to $v_b = 1{,}150$ km/sec as a result of the constant resistance $w = 310$ km/m^2 (see Figures 12A-B).

From the height $h - y_b = 48$ km, β must be decreased to avoid an excessive descent, say, by eliminating the parachute type breaking area F, leaving only the component obtained last $\tau = 3.56$ m/sec^2 = 0.00356 km/sec^2, produced by the wing for the further retardation. This value may also not be maintained to the end, since it would result in too steep a trajectory after a short time.

(β decreasing from 3.56 to 0.102 m/sec^2)
($\rho \sim$ remaining = g) (ρ increasing from 0 to g)

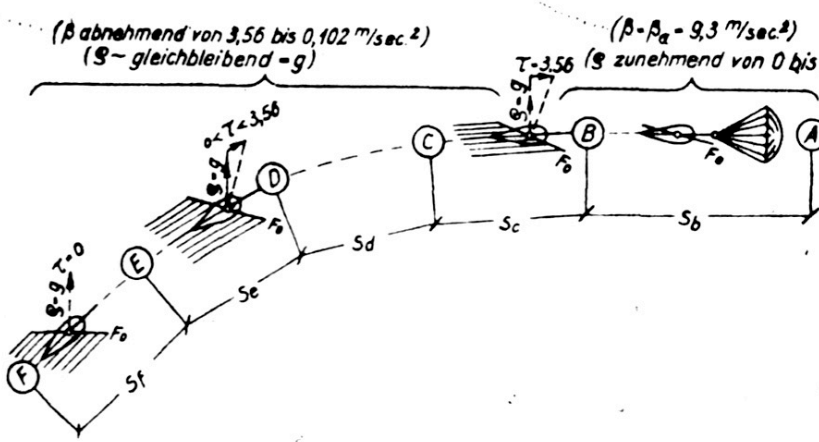

Figure 12.

If ρ remains constant (equal to g), then the retardation must be made to decrease, say, by changing the inclination of the wing F_o from B gradually to D and finally to the horizontal position at F (see Figure 12).

At all points of the trajectory:

Figure E.248: Walter Hohmann proposed and calculated reentry trajectories to slow a spacecraft returning to Earth without creating excessive g-forces from atmospheric drag [Hohmann 1925].

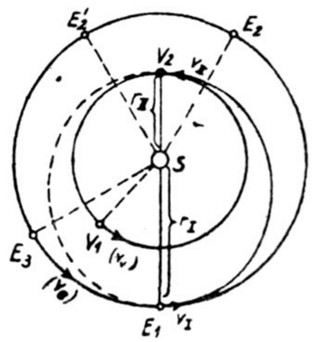

Figure 25.

Now the Earth velocity is v_e = 29.7 km/sec and accordingly the velocity to be imparted to the vehicle, after it reaches its apogee, has to be

$$\Delta v_I = v_I - v_e = 27.3 - 29.7 = -2.4 \text{ km/sec}$$

and could be the result of a tangential shot of mass

$$\Delta m = m \cdot \frac{\Delta v_I}{c},$$

where m is the mass of the vehicle before the shot and c is the velocity of the projectile. In this case, one can no longer use the value of c = 1 km/sec, assumed in section III, and also a single shot of the required strength would endanger the vehicle and its passengers. A system of continuous mass radiation as in section I must be used with a min. velocity of c = 2 km/sec. We have now for the ratio of total mass before and after the action by (32)

$$\frac{m_o}{m_1} = e^{\left(\frac{\Delta v}{c}\right)}.$$

But since during the initial parallel paths of planet and vehicle orbit interference is unavoidable, an additional safety factor [see Note], say ν = 1.1, must be added, which necessitates:

$$\left(\frac{m_o}{m_1}\right)_I = \nu \cdot e^{\frac{\Delta v_I}{c}} = 1.1 \cdot e^{\frac{2.4}{2.0}} = 1.1 \cdot e^{1.20} = 3.65,$$

where the mass has to be thrown forward in the direction of the Earth's motion.

([Note] Such interferences may be obviated by radiating the mass $\frac{dm}{dt} = -am$ (see (1c)), directed against the disturbing planet and

Figure E.249: Walter Hohmann proposed and calculated what are now called Hohmann ellipses—elliptical orbits for transferring from one nearly circular orbit (such as that of a planet) to another (such as that of another planet) with the smallest possible expenditure of energy [Hohmann 1925].

DAS PROBLEM
DER BEFAHRUNG DES
WELTRAUMS

DER RAKETEN-MOTOR

von

HERMANN NOORDUNG
Hauptmann a. D., Dipl.-Ing.

Mit 100 zum Teil farbigen Abbildungen

2. Auflage

RICHARD CARL SCHMIDT & CO.
BERLIN W 62

Figure E.250: Hermann Potočnik, under the pen name of "Hermann Noordung," published a book with detailed designs of a large, circular, rotating space station in 1928 [Noordung 1928].

Unter den unzählig vielen, überhaupt möglichen freien Umlaufbahnen um die Erde haben für unseren vorliegenden Zweck nur die wenigstens annähernd kreisförmig verlaufenden Bedeutung und hiervon wieder sind jene besonders interessant, deren Halbmesser (Abstand vom Erdmittelpunkt) 42 300 km beträgt (Abb. 54); denn diesem entspricht, bei einer zugeordneten Umlaufgeschwindigkeit von 3080 Meter je Sekunde, eine Umlauf-Winkelgeschwindigkeit, welche ebenso groß ist, wie jene der Erdrotation. D. h. aber nichts anderes, als daß ein Körper in einer dieser freien Umlaufbahnen die Erde ebenso schnell umkreist, als sie sich selber dreht: nämlich einmal in einem Tage („Stationärer Umlauf").

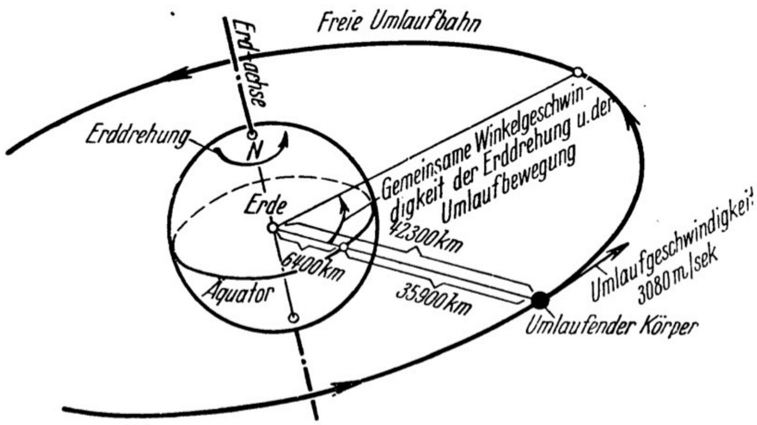

Abb. 54. Jeder Körper, der die Erde in der Ebene des Äquators, 42 300 km entfernt vom Erdmittelpunkte, in kreisförmiger Bahn umläuft, verharrt freischwebend beständig über demselben Punkte der Erdoberfläche.

Richten wir es nun außerdem noch so ein, daß die Umlaufbahn genau in der Äquatorebene liegt, dann würde der Körper dauernd über ein und demselben Äquatorpunkte stehen, und zwar in 35 900 km Höhe über der Erdoberfläche, wie sich nach Berücksichtigung des Erdhalbmessers von rund 6400 km ergibt (Abb. 54). Er würde dann gleichsam die Spitze eines ungeheuer hohen Turmes bilden, welcher selbst jedoch gar nicht vorhanden, dessen Tragkraft aber ersetzt wäre durch die Wirkung der Fliehkraft (Abb. 55).

Diese schwebende „Turmspitze" könnte nun bis zu jeder Größe ausgebaut und zweckentsprechend eingerichtet werden. Es entstünde so ein Bauwerk, das fest zur Erde gehört, ja sogar dauernd in unveränderlicher Stellung zu ihr verharrt und sich doch weit über der Lufthülle bereits im leeren Weltraum befin-

Figure E.251: Hermann Potočnik proposed placing a satellite into geosynchronous orbit, such that the satellite would make one orbit every 24 hours, the same as the Earth's rotation. Thus the satellite would stay over the same part of the Earth as it orbited [Noordung 1928].

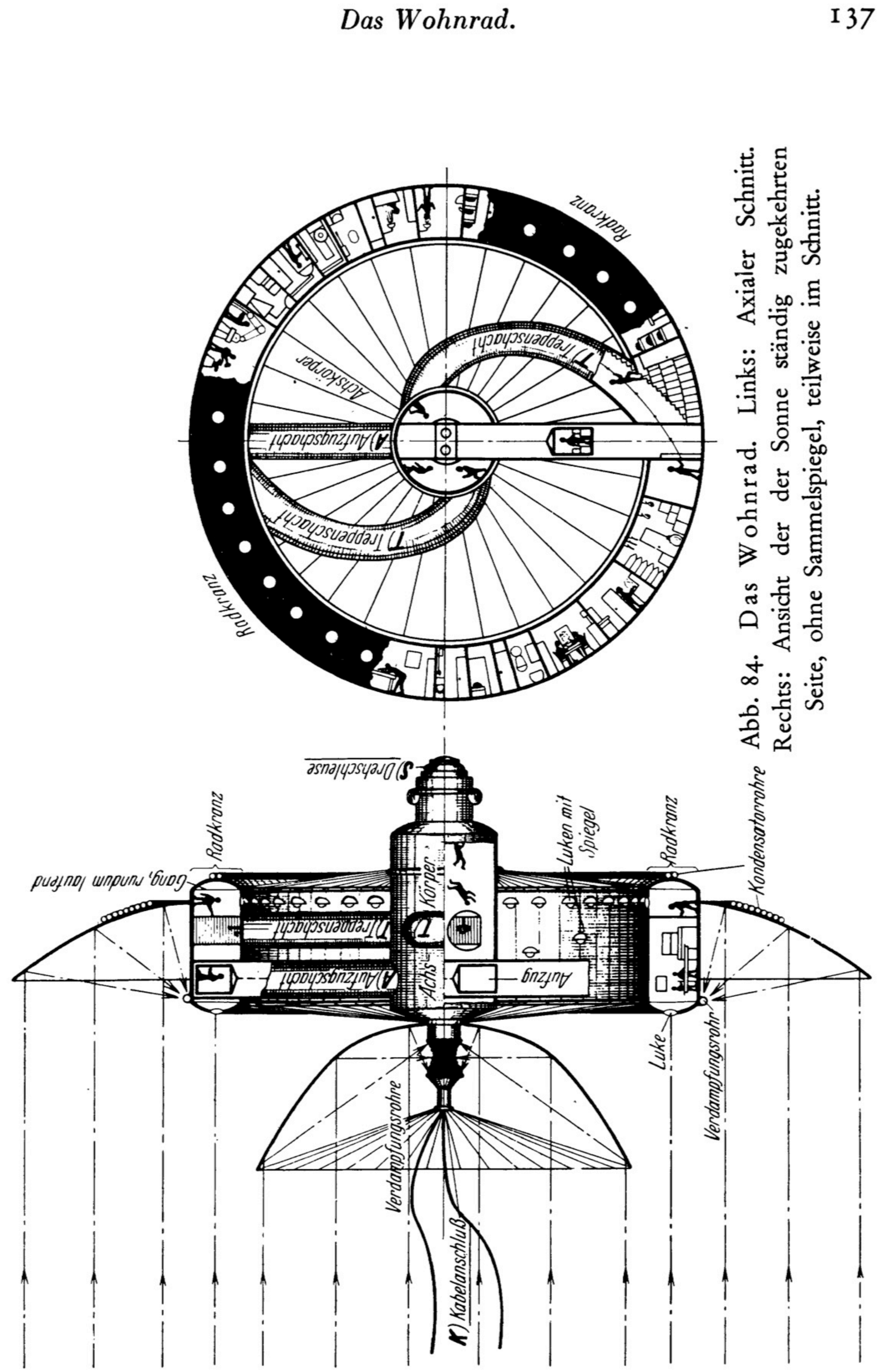

Figure E.252: Hermann Potočnik, under the pen name of "Hermann Noordung," published a book with detailed designs of a large, circular, rotating space station in 1928 [Noordung 1928].

142 *Das Wohnrad.*

Zur Verbindung zwischen Achskörper und Radkranz dienen Treppen und elektrische Aufzüge, welche in eigenen Röhrenschächten untergebracht sind. Letztere verlaufen für die Aufzüge

Abb. 89. Gesamtansicht der Sonnenseite des Wohnrades. Der mittlere Sammelspiegel könnte auch weggelassen und durch entsprechende Vergrößerung des äußeren Spiegels ersetzt werden.

„lotrecht", also radial (Abb. 84, A). Bei den Treppen hingegen, die ja geneigt sein müssen, sind sie — mit Rücksicht auf das Divergieren der Lotrichtung — nach logarithmischen Spiralen

Figure E.253: Hermann Potočnik, under the pen name of "Hermann Noordung," published a book with detailed designs of a large, circular, rotating space station in 1928 [Noordung 1928].

Gladwin Hill, Nazis' Scientists Planned Sun 'Gun' 5,100 Miles Up. *New York Times.* 29 June 1945 p. 1.

PARIS, June 28—German scientists, a high United States Army ordnance officer disclosed today, were soberly working on a project of contriving a platform 5,100 miles in the air from which, within a matter of fifty or 100 years, it was believed, it might be possible to harness the sun's rays to demolish nations at will and rule the world.

"Fantastic" is the only word that comes to mind for this project. Yet "fantastic," officers here avow on the basis of the caliber of the scientists involved and the cold, sound method of their work, is a classification into which the project definitely cannot be put.

"We were interested," ordnance officers said after exhaustive interrogation of the scientists, "with their practical engineering minds and their distaste for the fantastic." They had even figured the dimensions of a mirror that would be necessary up 5,100 miles to focus the sun's rays for the purpose—three kilometers [1.86 miles] square.

These are some of the scientists who devised so recently the inconceivable buzz-bombs and the V-2 rocket bombs. They are some of the scientists who, it was disclosed today, had virtually perfected, in addition to the previously revealed secret weapons, a method of launching V-2 rocket bombs from submarines 300 feet under water that might have blasted New York as London was blasted.

They are scientists who, on the basis of their amazing rocket work, take it for granted that transatlantic mail rockets are a development of only a few years hence and that forty-minute transatlantic passenger rockets are probable in fifteen to twenty-five years.

It was disclosed further that a number of these scientists—there were about 100 leading rocket researchers and around 1,100 others—are so dedicated to their researches and so aware that there is no hope of pursuing them in Germany during their lifetime that they are putting science ahead of nationality and volunteering to move to the United States and Britain to continue their work. Plans are under official discussion for a center in the United States to exploit their discoveries.

How many of these discoveries have been disclosed to the Japanese is not known, but an intelligence officer at Supreme Allied Headquarters said last week that the Germans had withheld some secrets from them.

The man who made these astonishing revelations and the fullest report yet on German weapons at a press conference today is Lieut. Col. John A. Keck, chief of the Ordnance Service's enemy technical intelligence branch in the European theatre. Colonel Keck is a retired Pittsburgh engineer whose home is in Greensburg, Pa. A World War I veteran, he went to London in April, 1943, when his branch was organized to work with a similar British hush-hush bureau.

Spies Traced Germans' Work

Colonel Keck indicated that there was a regular traffic of Allied spies in and out of Germany, and said that through undercover activities the Allies had been able to keep virtually day-to-day information on the work at the Germans' main rocket-development base at Peenemuende on the Baltic, making possible the famous Royal Air Force bombing attack there during a conclave of scientists, which inflicted hundreds of casualties and is believed to have set rocket development back a fatal six months. [...]

The final contemplated objective was to launch projectile vehicles from the sky platform into interstellar space.

Despite the weird nature of these notions, the scientists were described by the Allied examiners as "men of extremely practical and keen minds," Colonel Keck said.

Scientists Talkative on Ideas

One hundred and fifty rocket and other scientists were found by the Allied forces soon after the German surrender at a research center in Hillersleben, pondering their projects and waiting to discuss them. British officers have participated in the interrogations, which still are going on. The British War Office automatically receives copies of all American reports in this field, and Colonel Keck said the Russians had interrogated some of the same scientists and that it was intended to share German scientific information with "all the Allied nations."

The submarine V-2 project was developed in Toplitz Lake, in the Austrian Alps, by Dr. Heinrich Determann and fourteen assistants, who were arrested by the Eightieth Infantry Division after a small boy and an old shoemaker in the lakeside village of Gossl had told the Americans of "big metal fish jumping from the water into the air" and of "undersea boats that shot out fiery comets."

It transpired that the experimenters have started by shooting Nebelwerfer rocket field guns from a few feet under water and by last January had worked up to shooting from a depth of 300 feet a rocket that, once in the air, traveled like the V-2.

By the time the troops arrived the apparatus had been sunk in the lake and the records destroyed. Dr. Determann remarked: "Who knows? Perhaps German victory likes under Toplitz Lake." It is hoped the work can be reconstructed.

New Anti-Aircraft Weapon

Another of the secret weapons that Colonel Keck said the Germans had "practically perfected" was a rocket-propelled missle capabe of exploding within ten yards of a plane ten miles in the air.

"It is generally conceded that the Allies urgently need a more effective anti-aircraft weapon, and it is expected that the rocket will replace all other types of anti-aircraft guns," Colonel Keck said. "The German scientists' contribution to the rocket field in the last decade was unique and a great engineering accomplishment."

The speed attained by the V-2's—which, it had been previously disclosed, the Germans were developing not only to fire across the Atlantic, but also as far as from Britain to Japan—would get them from Europe to the United States in less than an hour, Colonel Beck said, and, in the light of progress up to now, the question of slowing them down at the end of the trip to make them feasible for mail and passengers is a relatively "minor problem." [...]

[This report describes detailed plans (and in some cases extensive development programs) for:

- Surface-to-air missiles that were "practically perfected" and had range and accuracy far better than anything possessed by the Allies.
- Submarine-launched ballistic missiles (note that much of the development and testing was being performed in the central European mountains, not just on the coast).
- Intercontinental rockets capable of crossing the Atlantic ocean (approximately 5000 km).
- Intercontinental rockets capable of traveling halfway around the Earth (approximately 20,000 km).
- A manned space station.
- Space-based solar energy collectors and directed energy weapons.
- Interplanetary (incorrectly stated as interstellar) space probes.

Versions of this story were also reported in:

Gladwin Hill, Sun Gun Weighed By Germans In 1929. *New York Times.* 30 June 1945 p. 3.

The German Space Mirror: Nazi Men of Science Seriously Planned to Use a Man-Made Satellite as a Weapon for Conquest. *Life.* 23 July 1945 p. 78.

Sun-Ray War. *The Evening Post* (Wellington, New Zealand). 29 June 1945 p. 5.
[https://paperspast.natlib.govt.nz/newspapers/evening-post/1945/06/29]

To Rocket Mail over Atlantic in 40 Minutes. *Toronto Daily Star.* 29 June 1945 p. 1.]

George Millar. Hitler's Crazy Gang Were Not So Crazy. *Daily Express* 29 June 1945 p. 1.

PARIS, Thursday.—Hitler's scientists planned permanent stations 5,100 miles above the earth, to harness the sun's energy.

Allied experts have found this plan to be technically sound, it was stated in Paris tonight by Lieut.-Colonel John A. Keck, the senior U.S. soldier in the job of questioning German scientists.

The value of their work, Colonel Keck says, is staggering, so staggering that it is likely to revolutionise the course of our lives. It shivers the imagination.

And it sprang from the mad energy of Hitler, who demanded "scare and screw-ball weapons."

When the first silver clouds of Flying Fortresses filled the German sky, while the Allied world hailed these planes as the height of modernity, our experts knew that they were already obsolete.

The German "dream of space" began from the horror weapons which attacked London.

To the German scientists V2 was only a toy. They had worked out A10, which had a range of from 1,200 to 1,800 miles, compared with the V2's 162 miles.

And then they worked on an advanced version of A10, a giant rocket with wings.

Colonel Keck added: "If the war had gone on another six months we know that V weapons would probably have been pounding New York."

He went on to the second stage of the V experiments. At 5,100 miles above the earth's surface, where gravity is known to be neutral, the Germans planned to establish within from 50 to 100 years a "space station"—a kind of solid platform in the sky to house a colony of scientists, astronomers and observers.

Rule the world

There they would set up a large reflector or reflectors for concentrating the sun's rays on the earth for power-generating purposes.

The rays would be directed at specific spots on the earth's surface, where the heat energy of generated steam would be converted into electrical energy.

One German scientist said that the first country to install these reflectors in the heavens would be able to rule the world by focusing them to:–

> Turn the oceans to steam;
> Kindle forest fires;
> Wipe out whole cities.

Even more fantastic is the next objective—the forming on those platforms of "space stations" for launching space-ships which would travel, presumably, to other planets.

Colonel Keck added that all this material was at the disposal of the British Government, and that much of it had undoubtedly been handed by the Nazis to the Japanese.

The Russians had been given access to some of the German scientists questioned.

Volney D. Hurd. Nazi Trick Weapons 'Out Of This World.' ***Christian Science Monitor*** **29 June 1945 p. 1.**

PARIS, June 29—Bombing of San Francisco by robot bombs launched in Japan cannot be considered entirely impossible, in the view of German physicists who stated that they would have been ready to shoot improved V-2's over a distance of 3,600 miles if they had been granted another six months' time for their research.

The step-by-step uncovering of German research work of the last five years has caused other surprises, too—none probably greater than the sensation provoked by the disclosure that German physicists gave serious thought even to fantastic plans for construction of a solar power station 5,100 miles above the earth's surface.

American ordnance experts are seriously interested in how far the Japanese have progressed in their rocket research. They find some German natural scientists very sound and think that an extension of the 3,600-mile range can be expected shortly.

Japan Given Data

Col. John A. Keck, chief of the Enemy Technical Intelligence branch, says he now can disclose this with the knowledge that the Japanese have full possession of German information.

Colonel Keck proved to the satisfaction of his office that German physicists would be so useful that plans are under consideration to bring a number of them to the United States and set up an exploitation center where United States armed forces and American industrialists may take advantage of their ability.

German rocket research followed two lines: Flight control and range. By 1938, a model had been developed which went 13 miles into the air and then came down with a parachute, allowing time to check the control instruments. From this grew the first V-2 used against London with a 150-mile range.

By the beginning of this year, the range was extended to 300 miles. A third model, the most recent, had a 1,200-to-1,800-mile range as a step to the 3,600-mile job scheduled to come up in November.

It is on this basis that Colonel Keck said he would very much like to know what Japan has done with the rocket information given it by the Germans.

According to Colonel Keck, the V-2, built on improved lines, weighs 13 tons, carries 2,150 pounds of TNT, and reaches a top speed of 3,600 miles an hour. This is achieved during the first third of the flight, at which time the fuel is exhausted. During the last two thirds of the flight, the bomb is carried by its own momentum through the stratosphere. It falls down to earth with a terminal velocity of 2,400 miles an hour.

There is no known defense against V-2's except to strike at the source from which they are launched.

Another phase of the German rocket research also promised plenty of trouble in the future. A group of researchists, headed by Dr. Heinrich Determann, explored the problems of underwater launching of rockets.

Colonel Keck pointed out that Hitler ordered all German artillery to be converted to rocket types by 1944. Actually the Germans have developed an antiaircraft or rocket flak gun able to range as high as 50,000 feet. Its explosion can be timed to within 10 feet of the objective, it was disclosed.

Other weapons of the rocket-launching variety were described as a 38-centimeter—about 15-inch—projector on a Tiger tank which could fire 760-pound shells and an 11-inch railway gun firing rocket-propelled missiles.

Flak Guns for U-Boats

By working on underwater launching, they developed flak guns for submarines. They had developed such a gun, so that their submarines in the future could have fired at low-flying airplanes without having to surface at all.

By January of this year, Dr. Determann had a rocket gun ready that could fire a rocket the size of a V-2 from 300 feet below the water surface at a predetermined point and angle of departure. It would burst out into the air in a typical V-2 flight.

This meant another answer to attacking the coast of the United States, for even with their short range of 300 miles, V-2's could be carried by submarines to a point 200 or 300 miles off the American coast. If fired from such a depth, chances of the German submarine being detected and caught would be very very slight. Unfortunately, Dr. Determann was able to destroy his blueprints, formulas, and other data and to sink the experimental machinery and equipment in the Toplitz See in Austria before American troops went there.

Technical Vistas Enlarged

Development of the rocket has opened vast vistas of technical marvels, long dreamed of by imaginative physicists all over the world.

One of these vistas, considered a "logical expectation within some 50 to 100 years," is the construction of a "space station," 5,100 miles up in the troposphere, with a 2-mile reflecting mirror capable of generating from the sun all the power needed in an area the size of Germany.

The space station is merely a theoretical projection, following the successful design of long-range load-carrying rockets with accurate controls.

So far, however, the Germans had not solved the problem of getting the "space stations" up there, or of controlling them when they arrived.

The conditions in the stratosphere and troposphere are well known enough to physicists so that factors to be met at great heights can be anticipated. The rocket's efficiency becomes the greater the higher it gets. It is on the basis of their recent achievements that German rocketeers look ahead and see the 5,100-mile altitude achieved in rocket travel within 50 to 100 years.

Of course it will be useful to remember that stories about exploitation of sun power have been a stock-in-trade of German pseudo- and popular-scientific literature. In most of the earlier instances, however, the scientifically valid idea of marshaling and transmitting sun energy by means of giant reflectors was coupled with the plan of building the power station in the Sahara desert.

Factor of Gravity

This 5,100 miles is a key number to the rocket engineers, because that is where the effect of gravity ends. [That idea is scientifically incorrect and does not appear in German reports. It is an American misunderstanding and seems to indicate that the general level of scientific understanding in the United States was quite backward compared to that in the German-speaking world at this time.] That means that all kinds of useful structures can be erected with minimum engineering problems because weight as such would no longer exist at such level. On the other hand, building without relying on the weight factor is bound to raise technical problems of a new kind.

Use of sun energy is a logical evolution of this "progressive" thinking. At this height, a large reflector concentrating the sun rays on a small area on the earth would offer tremendous potentialities. Sun rays massed and directed at a vast boiler area of some coastal country could generate enough steam to produce all the electric power the country could use, state the German natural scientists. And of course the warlike German thought must not be forgotten.

Concentrated sun energy could just as well be turned to destructive aims and used for the scorching and burning down of countries and the first state to develop the necessary devices would become all but invincible.

Moving back to the immediate future in rockets from Europe to America, there will be mail-carrying rockets first, and passenger-carrying rockets soon after, according to researchists. Like the advanced V-2, they would make the trip from Paris to New York in 40 minutes.

Nazis to Focus Rays of Sun for Slaughter. *Pittsburgh Post-Gazette* 29 June 1945 p. 63.

Paris, June 28—(UP)—German scientists at the end of the war were working on the idea of erecting stratospheric platforms 5,000 miles above the earth to be reached by rockets and used to launch attacks on targets on the earth's surface, it was revealed today by Lieutenant Colonel John A. Keck, chief of the work of salvaging enemy equipment.

The plan was known to 100 of Germany's foremost rocket experts, all of whom have been questioned by American and Russian army experts, he said. [...]

Another new German weapon, which was in the advanced stage, was a long-range transatlantic rocket called the A-10 which was designed to bomb the United States and which the scientists asserted would have been perfected in a few more months. [...]

A number of weapons were planned, Keck said. Among them were long-range rockets with a 3,000-mile radius, a 200-ton tank, a 5,000-pound multiple rocket with an anticipated 100-mile range, a transatlantic rocket which was to have been perfected this summer for the bombing of American cities, a "rocket assist" shell device designed to increase by 50 per cent the range of German artillery, and a "water to air" rocket fired from a submerged submarine which was to be used to bomb cities or as anti-aircraft against patrolling planes.

The Station in Space: Sun Power Stations Planned by Germans. *Journal of the American Rocket Society* September 1945, No. 63, pp. 8–9.

Disclosure of German war secrets found buried in mines and in the beds of rivers and lakes reveal that the Germans were contemplating the construction of solar space stations in the next 50 years. The stations, floating some 5,000 miles above the earth, were to function as an observatory, to possess a mirror, two miles in diameter, for focusing the sun's rays on earth steam-producing plants or for reflecting concentrated sunlight against hostile forces, and finally to act as a base for launching spaceships into outer regions.

The reported plans coincide so closely to proposals made on the subject in the late 20's and early 30's by Noordung, Pirquet, Oberth and others that apparently the Germans based their projects on these early theories. The terminal in space idea, which may at present appear visionary, generally takes the form of an elaborate rocket-powered plant of several sections circling the earth like a satellite at an altitude depending on its duties.

Noordung's Design

Captain Hermann Noordung, pen name of the Austrian Captain Potocnik, proposed a space station consisting of three separate units—living quarters, observatory and powerplant—connected by flexible air cables and pipelines to each other and moving in the same orbit. Placed some 22,300 miles above sea level the station was to revolve around the earth each 24 hours.

A large wheel-like structure about 100 feet in diameter, creating artificial gravity by rotating once every eight seconds, would house scientists and crew. This rotary house had rooms for every purpose located around the rim of the wheel and connected to the central airlock by elevators and stairs. All the necessities of life—light, heat, oxygen, water and food—were provided for, with energy from the sun supplying the power requirements of the station.

Captain Noordung intended that the cylindrical spatial observatory would observe weather conditions and other happenings on the earth's surface and report all observations in detail to ground stations. Due to the absence of air and dust and the lack of weight powerful telescopes of any size could be constructed and maintained. Study of the motions, distances, magnitudes and physical constitutions of the heavenly bodies would be undertaken by learned astronomers.

The sun power plant, consisting of a parabolic mirror and engine house, was to function in a manner similar to an ordinary steam turbine system. Liquid nitrogen vaporized by the sun's rays would drive a turbine coupled to an electric dynamo for providing direct current to the different buildings. The fluid on leaving the turbine would circulate to a dark-surfaced cooling unit and be pumped back for reuse.

The Triple Station

Count Guido von Pirquet, a co-founder of an Austrian rocket society, elaborating on the plans of Noordung suggested a three-unit arrangement consisting of an inner station for observations, an outer station for landing and refueling spaceships, and a transit station for contact purposes. The first two stations would travel in circular orbits around the earth while the transit stations circling in an elliptical orbit would approach within a mile of their orbits.

The approximate altitudes from the earth, length of orbits and time required for the stations to revolve around the earth are shown in the table. Speed of the transit station was to be three-quarters of a mile faster than the inner station as it neared the latter's orbit.

	Altitude above sea level (miles)	Length of orbits (miles)	Revolution around earth (minutes)
Inner Station	470	27000	100
Transit Station	470–3100	34000	150
Outer Station	3100	44600	200

Oberth Sun Mirror

Professor Hermann Oberth was much in favor of a station for observations which every four hours circled the earth at a height of 600 miles. He also conceived of a concave sun mirror constructed of small movable facets of metallic sodium mounted on a wire network in a circular frame. Sodium, a silver-white alkaline metallic element having high reflective properties, was considered most favorable for use in the non-corrosive airless regions of space. Adjustment of the facets by electro-magnets or other means would reflect the sun's rays over a large area or concentrate the heat energy into a single beam. Construction details were minutely worked out whereby free wires attached to a rotating spaceship could be made to spread out to form a huge network upon which strips of metallic sodium would be fastened.

Suggestions for shooting the sky station to its destination, towing or propelling it by rocket power were discarded in favor of the accepted idea of transporting the space plant piece by piece by rocket ship and assembling it in space. In the weightlessness of space workmen in space suits were conceded to have no difficulty in assembling heavy sections of the station.

The proposed sun mirror was to be employed beneficially or as a devastating force. Solar energy on being directed to ground turbine stations was to be utilized to generate steam for creating electrical power. Reflected heat would control weather, evaporate useless water and melt ice fields or illuminate large areas of the earth's surface at night.

Means for launching exploring spaceships to other planets and beyond into inter-stellar space was foreseen. Especially favorable was the suggestion of using the station as a refueling depot for spaceships ascending from the earth. The required fuel load from earth to space would be greatly reduced, as only enough fuel would need to be carried to overcome gravity from earth to the starting point for space travel.

History relates that in the siege of Syracuse, 212 B.C., Archimedes, Greek philosopher and inventor, set fire to the sails of the Roman ships by focusing the rays of the sun through newly invented burning glasses. As a weapon the Oberth reflector would also act much like a burning glass. Concentrated rays on earthly targets would turn bodies of water into steam while ships, cities and the implements of war would be burnt and destroyed.

Suggested References

Noordung, Hermann, Das Problem der Befahrung des Weltraums (The Problems of Space Flying). Revised English printing in Science Wonder Stories, 1929.

Oberth, Hermann, Wege zur Raumschifffahrt, 1929.

Ley, Willy, Rockets: The Future of Travel Beyond the Stratosphere, 1944.

[This article demonstrates that the space station and space exploration designs of the 1950s–1960s United States actually originated in the German-speaking world of the 1920s, and were transferred to the United States beginning before the war but especially at the end of World War II.]

TITLE	PROJ. NO.	DATE
"Evaluation of German Space Weapon Schemes"	3839	27 Aug. 47

ORIGINATOR	SUBMITTED BY (BRANCH)
Chief, Dissemination Branch	Scientific

PREPARED BY (NAME, RANK OR GRADE, BRANCH)	HOURS
Dr. Woodruff P-8	16
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Figure E.254: Over two years after World War II ended in Europe, the U.S. War Department General Staff (WDGS) Intelligence Division wrote a report summarizing what they had learned about "German Space Weapon Schemes" that had been developed during the war. Even after so many decades, that report remains classified and unavailable to the public. Why? What information is in the report? [NARA RG 319, Entry NM3-82, Box 2899, Folder Project 3839]

E.5.2 Fission Thermal Rocket Propulsion

[Whereas most rockets employ chemical reactions, non-chemical (i.e., nuclear) rockets could deliver much higher performance for deep space missions. German-speaking scientists began the development of such advanced rocket propulsion systems during World War II and continued to lead their development after the war.

Fission thermal rockets store energy onboard in the form of a relatively conventional fission reactor, which is powered by suitable fuel such as uranium-233, uranium-235, or plutonium-239. Like chemical rockets, fission thermal rockets also store propellant onboard, yet unlike chemical rockets, fission thermal rockets do not require the propellant to undergo chemical reactions and release energy of its own. The propellant is simply heated by the reactor to achieve very high temperatures and pressures, then expelled out of the rocket nozzle, as shown in the upper part of Fig. 9.239. Minimizing the molecular weight of the expelled propellant maximizes the exhaust velocity, so most proposed fission thermal rockets use hydrogen propellant. The temperature to which the propellant is heated is limited by how hot the fission reactor can become without melting the fission fuel or other reactor components, but that still yields an exhaust velocity roughly twice that of the best chemical rocket engine.]

16 September 1942 memorandum of understanding between Peenemünde and the Reichspost [Peenemünde Archive, AHT0205].

Als zweite Forschungsarbeit auf größere Sicht wird seitens der Heeresanstalt Peenemünde-EW vorgeschlagen:

"Untersuchung der Möglichkeit der Ausnutzung des Atomzerfalls und Kettenreaktion zum R-Antrieb".

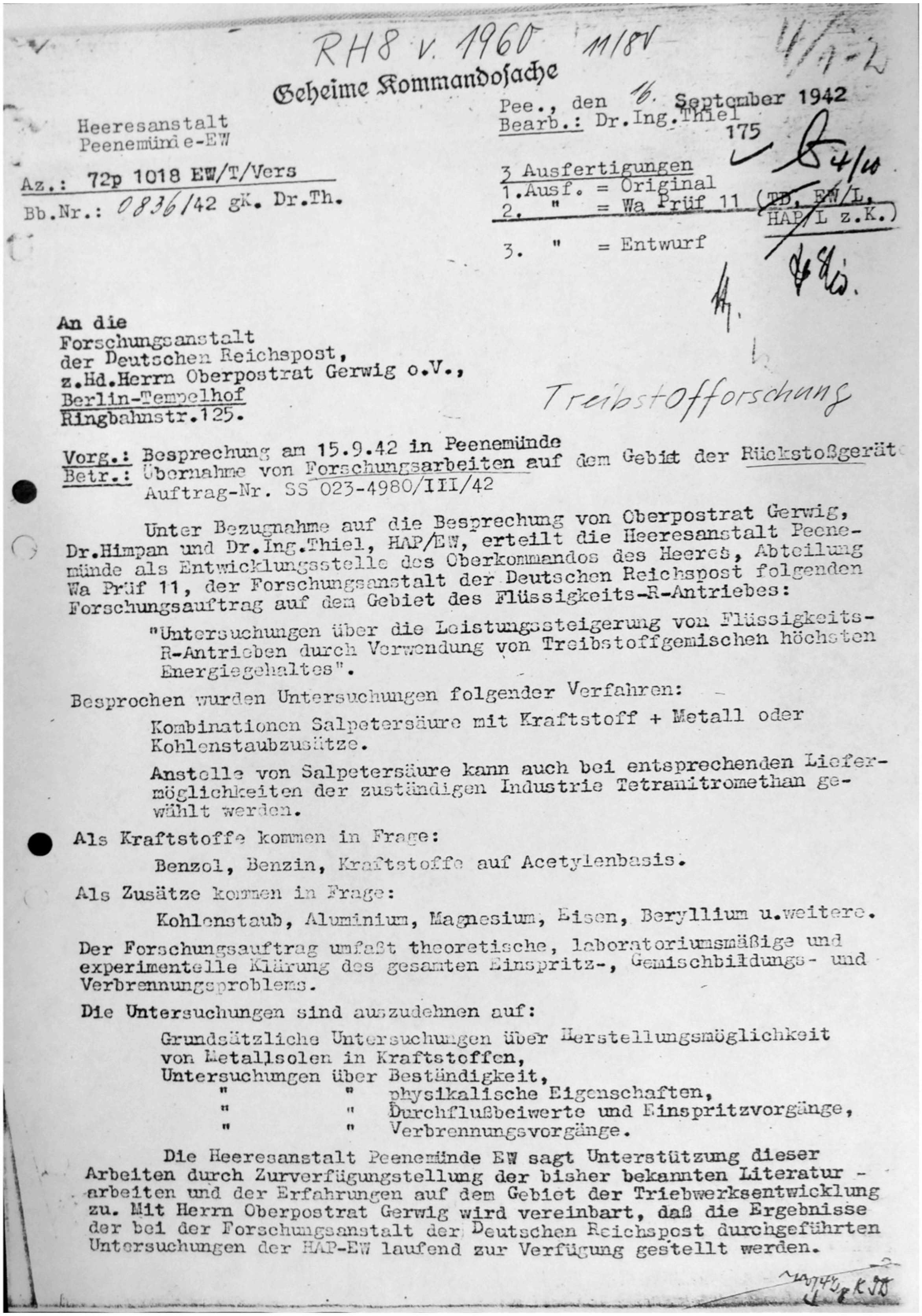
Die notwendigen Mittel für die Durchführung der Aufträge stellt das Reichspostministerium selbst zur Verfügung.

The second research project proposed by the Heeresanstalt Peenemünde-EW is a larger-scale research project:

"Exploring the possibility of exploiting atomic decay and chain reaction for rocket propulsion."

The Reichspost Ministry itself will provide the necessary funds to carry out the commission.

[This document proves that scientists at Peenemünde and the Reichspost began programs on nuclear rocket propulsion no later than 1942. See Figs. E.255–E.256.]



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Geheime Kommandosache

Heeresanstalt
Peenemünde-EW

Pee., den 16. September 1942
Bearb.: Dr.Ing.Thiel
175

Az.: 72p 1018 EW/T/Vers
Bb.Nr.: 0836/42 gK. Dr.Th.

3 Ausfertigungen
1.Ausf. = Original
2. " = Wa Prüf 11 (TB, EW/L, HAP/L z.K.)
3. " = Entwurf

An die
Forschungsanstalt
der Deutschen Reichspost,
z.Hd.Herrn Oberpostrat Gerwig o.V.,
Berlin-Tempelhof
Ringbahnstr.125.

Treibstofforschung

Vorg.: Besprechung am 15.9.42 in Peenemünde
Betr.: Übernahme von Forschungsarbeiten auf dem Gebiet der Rückstoßgeräte
Auftrag-Nr. SS 023-4980/III/42

Unter Bezugnahme auf die Besprechung von Oberpostrat Gerwig, Dr.Himpan und Dr.Ing.Thiel, HAP/EW, erteilt die Heeresanstalt Peenemünde als Entwicklungsstelle des Oberkommandos des Heeres, Abteilung Wa Prüf 11, der Forschungsanstalt der Deutschen Reichspost folgenden Forschungsauftrag auf dem Gebiet des Flüssigkeits-R-Antriebes:

"Untersuchungen über die Leistungssteigerung von Flüssigkeits-R-Antrieben durch Verwendung von Treibstoffgemischen höchsten Energiegehaltes".

Besprochen wurden Untersuchungen folgender Verfahren:

Kombinationen Salpetersäure mit Kraftstoff + Metall oder Kohlenstaubzusätze.

Anstelle von Salpetersäure kann auch bei entsprechenden Liefermöglichkeiten der zuständigen Industrie Tetranitromethan gewählt werden.

Als Kraftstoffe kommen in Frage:

Benzol, Benzin, Kraftstoffe auf Acetylenbasis.

Als Zusätze kommen in Frage:

Kohlenstaub, Aluminium, Magnesium, Eisen, Beryllium u.weitere.

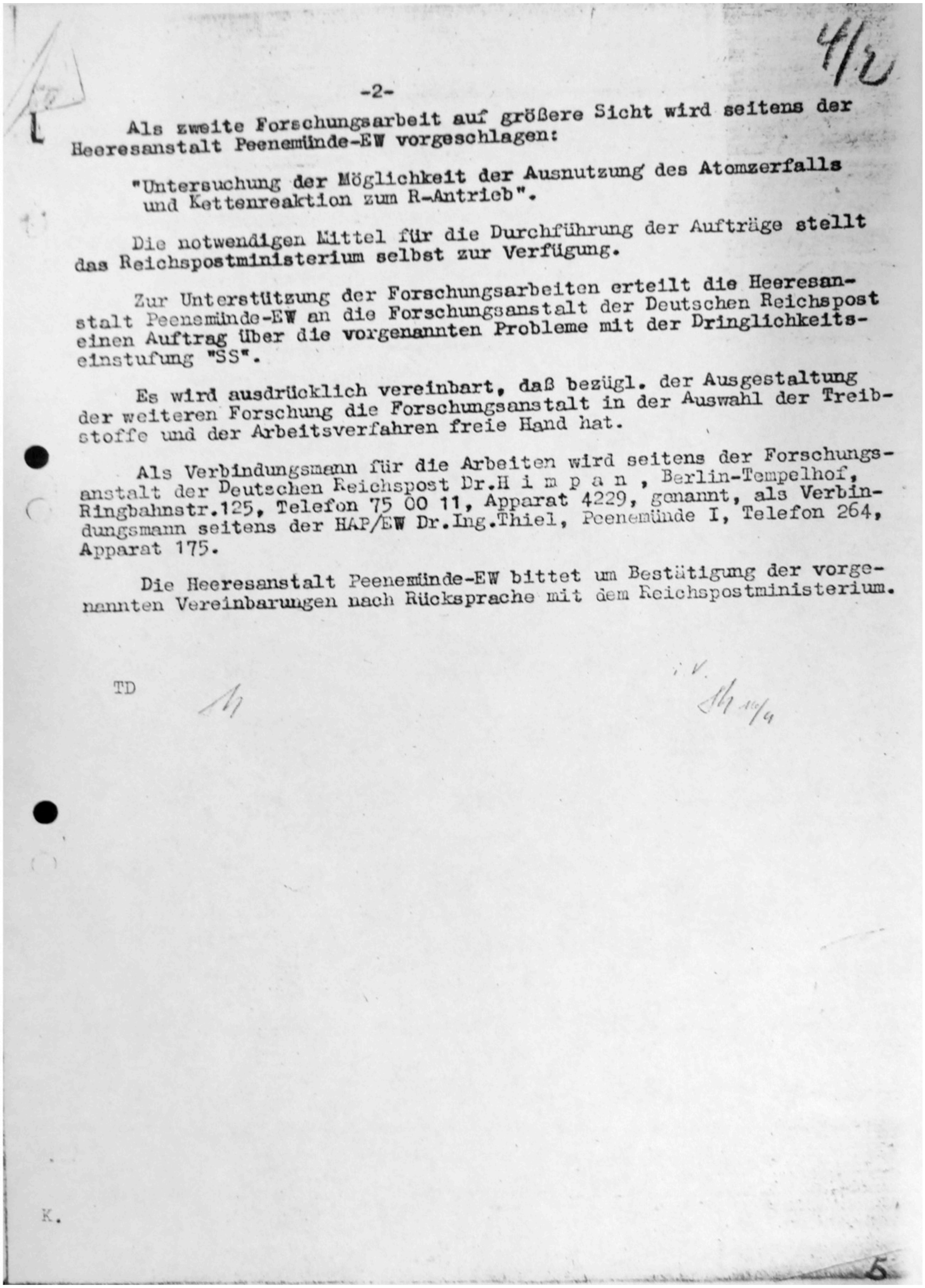
Der Forschungsauftrag umfaßt theoretische, laboratoriumsmäßige und experimentelle Klärung des gesamten Einspritz-, Gemischbildungs- und Verbrennungsproblems.

Die Untersuchungen sind auszudehnen auf:

Grundsätzliche Untersuchungen über Herstellungsmöglichkeit von Metallsolen in Kraftstoffen,
Untersuchungen über Beständigkeit,
" " physikalische Eigenschaften,
" " Durchflußbeiwerte und Einspritzvorgänge,
" " Verbrennungsvorgänge.

Die Heeresanstalt Peenemünde EW sagt Unterstützung dieser Arbeiten durch Zurverfügungstellung der bisher bekannten Literatur - arbeiten und der Erfahrungen auf dem Gebiet der Triebwerksentwicklung zu. Mit Herrn Oberpostrat Gerwig wird vereinbart, daß die Ergebnisse der bei der Forschungsanstalt der Deutschen Reichspost durchgeführten Untersuchungen der HAP-EW laufend zur Verfügung gestellt werden.

Figure E.255: Scientists at Peenemünde and the Reichspost began programs on nuclear rocket propulsion no later than 1942 [Peenemünde Archive, AHT0205].



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-2-

Als zweite Forschungsarbeit auf größere Sicht wird seitens der Heeresanstalt Peenemünde-EW vorgeschlagen:

"Untersuchung der Möglichkeit der Ausnutzung des Atomzerfalls und Kettenreaktion zum R-Antrieb".

Die notwendigen Mittel für die Durchführung der Aufträge stellt das Reichspostministerium selbst zur Verfügung.

Zur Unterstützung der Forschungsarbeiten erteilt die Heeresanstalt Peenemünde-EW an die Forschungsanstalt der Deutschen Reichspost einen Auftrag über die vorgenannten Probleme mit der Dringlichkeitseinstufung "SS".

Es wird ausdrücklich vereinbart, daß bezügl. der Ausgestaltung der weiteren Forschung die Forschungsanstalt in der Auswahl der Treibstoffe und der Arbeitsverfahren freie Hand hat.

Als Verbindungsmann für die Arbeiten wird seitens der Forschungsanstalt der Deutschen Reichspost Dr.H i m p a n , Berlin-Tempelhof, Ringbahnstr.125, Telefon 75 00 11, Apparat 4229, genannt, als Verbindungsmann seitens der HAP/EW Dr.Ing.Thiel, Peenemünde I, Telefon 264, Apparat 175.

Die Heeresanstalt Peenemünde-EW bittet um Bestätigung der vorgenannten Vereinbarungen nach Rücksprache mit dem Reichspostministerium.

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Figure E.256: Scientists at Peenemünde and the Reichspost began programs on nuclear rocket propulsion no later than 1942 [Peenemünde Archive, AHT0205].

Charles A. Masson, Headquarters United States Air Forces in Europe, Assistant Chief of Staff, A-2, to Assistant Chief of Staff, T-2, Headquarters Air Technical Service Command, Wright Field, Ohio. 1 February 1946. Transmittal of German Documents. [AFHRA C5098 frame 0393]

1. Forwarded herewith for evaluation are documents received from three German scientists:

[...] c. KRAFFT EHRICKE (or Müller)—"Discussion of Activity on Rocket Problems." This man apparently has a very extensive background in rocket propulsion. However, his assertions can probably be checked with the German scientists now at Wright Field.

2. It is requested that this headquarters be notified as soon as possible as to the decisions made with regard to these documents and their submitters, [...]

3 Incl: [...]
3. Krafft Ehricke (or Müller)—"Discussion of Activity on Rocket Problems."

H. M. McCoy, Acting Deputy Commanding General Intelligence (T-2), H.Q., AMC, Wright Field, Dayton, Ohio to U.S. Air Forces in Europe, Assistant Chief of Staff, A-2. 14 August 1946. Transmittal of German Documents. [AFHRA C5098 frame 0392]

1. Inclosures 2 and 3 to basic communication are returned with the request that, if possible, additional information be furnished this office on the following subjects:

[...] b. Metals in fuels and designs of atomic rockets and secret reports of Professor Heisenberg referred to in paragraph 2, page 4, inclosure 3.

c. Burning metals or use of uranium 235 for rocket propulsion referred to in paragraph 2, page 3, inclosure 3.

d. Experience on tetranitromethane referred to in paragraph 2, page 6, inclosure 3.

2. If additional data are available on the above subjects, it is requested such data as can be obtained be forwarded to this office for transmittal to the proper laboratory. [...]

2 Incls: [...]
3. Krafft Ehricke (or Müller)—"Discussion of Activity on Rocket Problems."

[Where are the enclosures and secret reports referenced in these two documents? Note that these two documents appear to be directly related to the document shown in Figs. E.255–E.256—in addition to nuclear propulsion there are mentions of tetranitromethane and burning metals.

Why was Krafft Ehricke apparently going by the pseudonym of "Müller"?

Exactly what work did Krafft Ehricke, Werner Heisenberg, and others scientists do on atomic rockets during the war? The United States seems to have interrogated them and also acquired many of their written reports. Where are those interrogation reports and scientific reports now?

How much effect did German-speaking scientists and their information have on postwar programs on atomic rockets in the United States and other countries?]

BIOS 142. *Information Obtained from Targets of Opportunity in the Sonthofen Area.* 1945. p. 8.

(e) High speed fighter aircraft

Ernst said that while he was in Camp Mecklenburg, he found out that there were three new types of high speed fighter aircraft. One of these was the P 1073, made by Messerschmitt with a B.M.W. 003 engine using petrol as fuel; and the second was a similar aircraft using crude oil as a fuel. The third was alleged to be powered with an atomic engine. The fuselage, which was the same as the P 1073, was of wooden construction and was fitted with skid landing gear. The engine was 60 cms. long and 20 cms. in diameter, and produced about 2,000 h.p. This aircraft was supposed to have a speed of 2,000 km./hr. and a ceiling of 18,000 m. The engines were made by the prisoners at Camp Mecklenburg. Only one model was ever in existence, and that was completely destroyed, as was the whole camp, by the S.S. during the Allied advance.

(f) Other work at Camp Mecklenburg

Ernst also stated that work was carried out at this camp on a new liquid air bomb, and liquid air gun (?), while trials on some kind of atomic bomb were made at or near the camp.

[During this postwar interrogation by British investigators, Josef Ernst described several now well-known wartime projects, as well as a mysterious wartime project to construct a supersonic fission-powered aircraft. He also mentioned other nuclear work at the same facility. There were several independent reports of nuclear-related work at that facility, which adds to the credibility of Ernst's story. For more information on the facility, see p. 3939.

See p. 4228 for a similar account of the wartime production of a nuclear-related supersonic jet aircraft by Horst Kirfes, an engineer captured by the Soviet Union after the war.

Was the nuclear device mentioned by Josef Ernst fission fuel for a nuclear-powered jet engine, or could it have been a nuclear weapon that would have been delivered by that aircraft?]

Robert E. Work. 17 April 1946. Preliminary Interrogation Report. Franz Focke. [AFHRA A5183 frames 0091–0092; see also frames 0108–0109]

Focke has been interested in atomic energy for many years. He claims to have worked out theories which involve the use of atomic energy as source power for aircraft engines. Focke is convinced that the unlocking of the energy of atomic kernels [nuclei] for industrial and transportation purposes can be effected. As a result of his extensive research work he applied for an/or obtained the following patents from the German Patent Office. [...]

This office plans to interrogate him regarding his ideas of the utilization of atomic energy in aircraft. [...]

[Can the patents, more detailed interrogation reports, and other information on Franz Focke's work on nuclear aircraft propulsion be located?]

Edmund Tilley. Brief Interrogation Report on Prof. Dr. Wernher von Braun. With additional statements on PROJECT ABSTRACT. FIAT, T-Force, SPEC-A 477/3. 8 July 1947. [TNA FO 1031/128]

1. On 8 March 1947 Dr. von BRAUN was brought to H.Q. USFET for an interrogation by Dr. John H. MARCHANT of BROWN University and by the undersigned. The interrogators were told of von BRAUN's status in the United States where many senior officers, especially in Army Ordnance, hold him in high esteem and consider him invaluable in his work. The interrogation was, therefore, conducted very informally and on cordial terms.

2. Indirectly intelligence had reached interested agencies in the United States that von BRAUN was aware of the existence of caches of PEENEMÜNDE documents and also instruments and that he had not yet revealed these caches to his employers in the United States. It was rumoured that he might use this knowledge as a bargaining point in any future negotiations in the United States. Furthermore, there was the feeling in some circles that he was not reproducing freely all the latest phases of German development in guided missiles, in particular in V-2. [...]

4. Recently Lt. Gen. DORNBERGER stated that von BRAUN and (Lt. Col.) AXTER were both present when he hid a tin, containing the location maps or sketches of hiding places, at OBERJOCH, in May 1945. He repeated this statement several times at OBERJOCH, during a search for the tin, in May 1947. When he discovered that the tin had been removed he recalled that von BRAUN had shown him some location maps in May 1945, a few days after they had surrendered to the American forces. [...]

70. Atomic Energy as Propellant for V-2. The second question about the possibility of using atomic charges in the warhead of V-2 was firmly rejected. "I had nothing to do with atomic energy". In the end he admitted that atomic energy had been considered by him in 1943.

71. "Two years before 1945" (i.e. in 1943) he had had "a private and not very definite contact with the KAISER WILHELM INSTITUT in DAHLEM" (now in the American Sector of BERLIN). In 1943 he talked to Professor Werner HEISENBERG and his fellow-workers, DR. WEIZAECKER, and Manfred von ARDENNE. In 1943 HEISENBERG was preparing a uranium pile with heavy water which had been produced in NORWAY. This work was financed by the German Navy which hoped to have submarine engines driven by atomic piles. The project was abandoned "because the atomic research people lacked the necessary quantities of raw materials". +) and Dr. RAMM

72. Once more he denied that there had been any discussion of atomic, BW or CW charges at BAD SACHSA; he had not even heard rumors of such charges for guided missiles. He stated that he had shown an interest in atomic energy in 1943 only to determine if it could be used for V-2 as well as for submarines, i. e. as a propellant, but not as a charge for the warhead.

73. He has not discussed this subject with anyone in the UNITED STATES. "Nobody has ever asked me about this".

74. GROETTROP and "PROPELLANT GREEN".
List of German V-2 Experts in Russia. Von BRAUN mentioned casually that a few days before this

interrogation a German expert who is now working for the Russians had visited him at LANDSHUT and had given him a list of all important Germans employed by the Russians in the field of guided missiles. Von BRAUN promised to send two copies of this list, through secure channels, to G-2 USFET. (From the UNITED STATES he was also going to forward a list of all projects at BAD SACHSA in 1945).

75. GROETTROP: According to other sources GROETTROP is the most important German V-2 expert with the Russians. Von BRAUN said of him: "He is a dangerous man. He copies all sorts of things that are not in his field."

84. Von BRAUN has made several mistakes. He did not inform American experts in the UNITED STATES of some important projects and activities in the field of guided missiles, such as the contemplated use of the ROECHLING Projectile (paras 64–69), the project to use atomic energy as a propellant (paras 70–73) and the various projects, whether good or bad, at BAD SACHSA. Above all, as late as March 1947 he failed to tell the truth about important caches of documents. As far as OBERJOCH or UPPER BAVARIA is concerned the evidence forces us to declare him deliberately untruthful [...]

88. (Note: While these notes were being written S/Ldr. KENNY informed the undersigned that von BRAUN had spoken of atomic energy at GARMISCH, in 1945. It is odd that, in March 1947, he should deny any previous discussion of this important point (Par. 73.)

[For information on Edmund Tilley, see pp. 4464–4465. For more information on Project Abstract, see Mills and Johanson 2019.

In point 88 above, Squadron Leader E. J. André Kenny (one of the most important British aerial photo interpreters for Operation Crossbow [David Irving 1965, see index; McGovern 1964, pp. 13, 268]) said that Wernher von Braun had discussed nuclear-armed rockets at Garmisch in 1945, in contrast to what von Braun was admitting to Tilley in 1947. Kenny had visited Garmisch and other German sites in early May 1945 as part of CIOS Team 183 [O'Mara 1945, pp. 544–547].

This information from Kenny was independently confirmed by British journalist Gordon Young, who interviewed von Braun and Walter Dornberger at Garmisch in June 1945. They told Young that the V-2 would have soon received a "much more powerful" warhead. Allied censorship forced Young to eliminate any reference to German nuclear weapons at that time, since the U.S. nuclear weapons program was still completely secret. In August 1945, after U.S. nuclear weapons were used on Japan and became publicly known, Young tried to publish a second article reporting what he had learned from von Braun about nuclear-armed rockets. That second article was censored completely; only a brief reference in another article in Young's own newspaper (*Daily Express*) and three short articles in Australian newspapers escaped that second and final censorship (pp. 4325–4327).

See also the testimony given by former Nordhausen forced laborer Alex Baum (p. 4882). Baum remembered that von Braun eagerly expected the arrival of a new rocket warhead with tremendous destructive power.

For further evidence of rockets with nuclear warheads, see the summary of the interrogation of engineer Horst Kirfes (p. 4228), as well as the July 1946 *AAF Review* (p. 4598).

For many more references to nuclear-armed rockets that were intended to attack Allied targets during the war, see the list of documents on p. 5363.]

Howard R. Schmidt. 14 November 1962. History of the Nuclear Rocket: Pre-NERVA Development. American Rocket Society conference paper.

[I need to find a copy of this. Pages 2–3 mention wartime German research on nuclear rocket propulsion.]

John Sloop. 1978. *Liquid Hydrogen as a Propulsion Fuel, 1945-1959.* NASA SP-4404. Washington, D.C.: U.S. Government Printing Office. pp. 191–192. [https://www.hq.nasa.gov/pao/History/SP-4404/ch10-3.htm]

The first rocket stage to fly using liquid hydrogen and liquid oxygen as propellants was the Centaur stage on top of an Atlas intercontinental ballistic missile. Centaur was the brainchild of Krafft Ehricke. For nearly three decades, Ehricke had prepared himself for the space age; when it dawned with Sputnik, he was ready. Within a month, he proposed a hydrogen-oxygen stage for use with the Atlas missile. Ehricke was able to move rapidly because previous work on the Atlas missile and the ideas of others about hydrogen-oxygen upper stages had laid the groundwork.

Ehricke became a space enthusiast at the age of eleven when he was captivated by Fritz Lang's "Girl in the Moon," shown in Berlin in 1928. Advanced in mathematics and physics for his age, he appreciated the great technical detail that Hermann Oberth had provided to make the film realistic. Young Krafft became acquainted with Tsiolkovskiy's space rocket using hydrogen-oxygen, which he read about in Scherschevsky's *Die Rakete fuer Fahrt und Flug*. He also tackled Oberth's *Wege zur Raumschifffahrt* in his early teens, but was slowed by the mathematics. Ehricke graduated from the Technical University in Berlin (aeronautical engineering) and took postgraduate courses at the Humboldt University in celestial mechanics and nuclear physics. He was conscripted into the army, served in a Panzer division on the Russian front during World War II, but was recalled and reassigned to rocket development work at Peenemunde in June 1942. There he came under the strong influence of Walter Thiel, in charge of rocket engine development, who was killed in the first British air raid on Peenemunde in October 1943. Peenemunde, under Maj. Gen. Walter Dornberger and Wernher von Braun, his technical director, had a single purpose—the rapid development of specific weapons—and there was no official tolerance of work not directly related to the main goal. In spite of this, Thiel shared Ehricke's desire to look beyond the immediate future to greater possibilities. Thiel himself drew plans for testing rockets larger than any yet dreamed of—on the order of 5–14 meganewtons (1–3 million lb thrust). He wanted to use natural gorges in Bavaria as testing sites. He talked to Ehricke about resuming his own earlier experiments with liquid hydrogen in small rocket thrust chambers. The experiments of Heisenberg and Pohl with a nuclear reactor using heavy water excited Thiel. When he heard that Heisenberg was planning to operate a turbine with steam heated by the heavy water reactor, Thiel urged Ehricke to study the possibilities of using nuclear energy for propulsion. Ehricke considered several working fluids, but both he and Thiel favored hydrogen and believed it was a fuel with a future.[11]

As the war was ending, Ehricke helped move Peenemunde records into Bavaria, to keep them out of Russian hands. He made his way on foot to Berlin where he found his wife and went into hiding until the Western Allies moved in. He was located by the U.S. Army, given a six-month contract, and came to the United States to rejoin the von Braun team as part of the Paperclip operation.*

Ehricke and von Braun recalled another time they had considered hydrogen. In 1947, von Braun asked Ehricke to check a report by Richard B. Canright of the Jet Propulsion Laboratory on the relative importance of exhaust velocity and propellant density for rockets of the V-2 size and larger (pp. 47–48). It had caught von Braun's attention because he and two associates had written a paper the previous year which Canright had cited.[12] Von Braun had found, under the assumptions of fixed tank volume and a relatively heavy structural mass, that propellants with the highest densities and reasonably high exhaust velocities had the greater ranges. Canright, on the other hand, found that for large rockets and his assumptions (which included a variable tank volume and relatively light structural mass), exhaust velocity was decidedly more important than density. Canright's analysis showed hydrogen to be superior to other fuels when using the same oxidizer. Both Ehricke and von Braun, familiar with Oberth's case for using hydrogen-oxygen in upper stages of rockets (appendix A-2), agreed that hydrogen had a good potential for certain applications. Practical experience with liquid hydrogen in rockets at that time, however, was still very small and its handling problems large. The Army, for whom von Braun and Ehricke worked, wanted practical propellants that could be stored and handled safely in the field. This convinced von Braun to stick to well tested and denser propellants, but Ehricke felt less restrained and hydrogen's potential remained prominent in his thinking.

[11] Interview with Krafft Ehricke, Rockwell International, El Segundo, CA. 26 Apr. 1974.

* Ehricke wanted to work for the Americans, and he hid each time someone knocked on his door, waiting for the right caller. One day his wife answered the door and routinely said, "I don't know where he is." As she did so, she recognized the insignia of a U. S. Army officer and immediately began screaming, "He's here! He's here!" Interview, 26 Apr. 1974. Paperclip was the project for bringing German rocket experts to the United States.

[12] Ibid.; Wemher von Braun to Monte D. Wright, NASA History Office, 29 Dec. 1975.

[Who was Pohl and what else did he do? Is that Robert Pohl from Göttingen or another Pohl?]

Charles A. Lindbergh. 1970. *The Wartime Journals of Charles A. Lindbergh.* New York: Harcourt Brace Jovanovich. pp. 970–971.

From the Wörthsee we drove to Allach to look for Dr. Neugebauer,[13] head of the Munich research center near Hohenbrunn, which never reached completion. Baeumker said he was one of the best men in Germany to give a comparison of the development and uses of their various types of engines. We found him living with his family in a small frame house not far from the Allach railroad station. He had one more week's work to close the research institute, he said. Then, since he had eleven people to support, including five children, he would apply for work in a locomotive factory.

Neugebauer is primarily interested in the development of a diesel turbine to be connected to a free-piston reciprocating engine, for use in long-range aircraft cruising at speeds of 500 to 550 kilometers per hour. This type of engine would be for the immediate future, Neugebauer thinks. The turbine engine will come later when we learn how to use higher temperatures. The sequence of engines used in aviation in the future will be 1) diesel; 2) turbine with propeller; 3) turbojet, according to Neugebauer. He thinks the Lorin jet [ramjet] will be used for speeds above 1,000 kilometers per hour. He says that a single-cylinder engine for his diesel development was almost finished.

I gave Dr. Neugebauer the rest of the candy I had with me for his children, and we started back to our billets.

[13]Dr. Franz Josef Neugebauer, engineer specializing in thermal systems for aircraft nuclear propulsion. He had been chief of initial development at the Junkers factory at Dessau, 1924–38; technical and plant manager at the Junkers factory in Munich, 1938–43; manager at the Luftfahrtforschungsanstalt in Munich, 1943–45. In 1945 he came to the U.S. and was a consulting engineer at headquarters, Air Materiel Command, Wright Field.

[Neugebauer apparently worked on both nuclear and non-nuclear aircraft propulsion during the war. Lindbergh, in collaboration with his editors, mentioned the nuclear work in a footnote. Lindbergh's personal discussions with Neugebauer seem to have focused on the non-nuclear work for one or more reasons:

1. Lindbergh's own career, knowledge, and interests were centered on long-range non-nuclear aircraft propulsion.

2. Maximizing the range of non-nuclear aircraft engines was a high priority in Germany by the end of the war.

3. Neugebauer did not want to discuss details of classified nuclear work with Lindbergh.

4. Lindbergh deliberately avoided writing down details about classified nuclear work.

5. Any nuclear details that Lindbergh did write down were censored before publication.]

Joyce Milton. 1993. *Loss of Eden: A Biography of Charles and Anne Morrow Lindbergh.* New York: HarperCollins. pp. 415–416.

Charles worked for United Aircraft in Connecticut until May of 1945, and shortly after V-E day, he joined a Naval Technical Mission in Europe as a civilian representative of the corporation. [...]

Joining the Technical Mission in Munich, Lindbergh became part of a team of observers who drove their jeeps into territory where the Wehrmacht, defeated but not yet demobilized, was still in effective control. [...] Lindbergh's group located Professor Willy Messerschmitt, who was living in a barn; Dr. Felix Kracht, the inventor of the rocket glider; Dr. Helmut Schelp, assistant head of development of the jet and rocket propulsion program; Dr. Franz Josef Neugebauer, who was working on a design for a nuclear-propelled aircraft; Dr. August Lichte, a developer of the Junker JU 004 turbojet engine; and Dr. Ulrich Henschke, who was working on artificial limbs capable of being controlled by neurological impulses.

Tom Agoston. 1985. *Blunder! How the U.S. Gave Away Nazi Supersecrets to Russia.* New York: Dodd, Mead. pp. 12-13.

By quirk of fate, the careers of Kammler and Voss overlapped at Skoda, where they jointly set up and operated what was generally regarded by insiders as the Reich's most advanced high-technology military research center. Working as a totally independent undercover operation for the SS, the center was under the special auspices of Hitler and Himmler. [...] In so doing the SS group was to go beyond the first generation of secret weapons.

Its purpose was to pave the way for building nuclear-powered aircraft, working on the application of nuclear energy for propelling missiles and aircraft; laser beams, then still referred to as "death rays"; a variety of homing rockets, and to seek other potential areas for high-technology breakthrough. In modern high-tech jargon, the operation would probably be referred to as an "SS research think tank." Some work on second-generation secret weapons, including the application of nuclear propulsion for aircraft and missiles, was already well advanced.

It was far from a mad Nazi scientist's dream of getting to the end of the nuclear rainbow. The field had been pioneered by Dr. Wernher von Braun, designer of the V-2, in the early 1930s. In addition, it was recently disclosed that one of the first top German engineers cleared for urgent work for the U.S. Air Force in 1945 was Dr. Franz Josef Neugebauer, a specialist in thermal systems for aircraft nuclear propulsion. In 1958 the United States launched Project Orion to probe the applicability of nuclear propulsion for aircraft, employing some Czech scientists. The project was continued until 1965 and then was turned over to the U.S. Air Force, plans for its application for the civilian space programs having been dropped.

The SS research operation at Skoda had been set up without the knowledge of Goering, Speer, or the German research centers. The builders of the V-1 and V-2 were likewise kept out of the picture. The undercover SS research operation fitted in with Himmler's dream that, as the Rheingold of the Nibelung's, if shaped into a ring, would give its possessor mastery of the world, so would the SS team give the Greater Reich mastery of much of the world.

A study of intelligence reports shows that blueprints, drawings, calculations, and other relevant documentation or materials were protected by a triple ring of SS counter-intelligence specialists Himmler had assigned to Pilsen to prevent security leaks and sabotage in the research divisions and the plant in general. The SS team was internally referred to as the Kammler Group. Taking a leaf from the armament ministry name for the special section Kammler headed there to iron out aircraft production bottlenecks, they were called the Kammler stab or Kammler "staff."

[This book by British journalist Tom Agoston was based on extensive postwar interviews with Wilhelm Voss, wartime manager of the Skoda works in German-occupied Czechoslovakia.]

[Franz Josef Neugebauer's 1946 U.S. Army Air Forces report, *Project No. NFE-64: Effect of Power-Plant Weight on Economy of Flight*, appears to be a translation of one of his wartime German reports [Neugebauer 1946]. Although the type of power plant is not specified in this particular report, weight would be one of the most important factors in nuclear versus more conventional propulsion systems. There may have been a classified, unreleased, longer version of the report that included details about the nuclear aspects of the project.

Neugebauer apparently continued his work on nuclear aircraft propulsion in the United States for many years. In 1962, working with both General Electric and the Office of Naval Research, he released an unclassified reference book on hot gases that was probably just one small part of his work on nuclear propulsion [Neugebauer 1962].

Would it be possible to locate and declassify uncensored versions of those or other reports by Neugebauer that do explicitly refer to nuclear propulsion?]

Heinrich Himmler's chief adjutant Werner Grothmann on nuclear rocket propulsion [Krotzky 2002]. For a discussion of the background and reliability of this source, see p. 3359.

[S. 47] Spätestens als wir in Peenemünde den Finger in die Tür bekamen, ist überlegt worden, ob es nicht möglich wäre, die Atombombe mit einer Rakete zu verschießen. Das war ja erst mal reine Theorie. weil wir doch Vorstellungen von dem Ding hatten, die sich nicht umsetzen ließen. Die Untersuchungen dazu sind aber weiter gelaufen. In Peenemünde selbst ist an der Frage, so weit ich weiß nicht mit großer Begeisterung geforscht worden, obwohl die ja eigene Atomlabors hatten. Ich war ja schließlich selbst drin. Für die war aber eher die Frage wichtig, ob eine Rakete mit Atomantrieb fliegen kann. Warum die daran geforscht haben, hatten Himmler und ich bei unserem ersten gemeinsamen Besuch auch gehört. Die Techniker hatten uns berichtet, dass der Antrieb schon wunderbar funktioniert, das konnte man dann später ja auch sehen. Es war aber so, dass der gesamte Treibstoff in kürzester Zeit verbraucht war und damit konnte man nur über eine kurze Entfernung schießen. Kurz ist eigentlich nicht richtig. Damals waren wir schon begeistert von der Entfernung, die man mit der Rakete hinbekommt. Wenn man jetzt aber weiß ,dass in dem Uran viel mehr Energie steckt als im gleichen Gewicht von dem Treibstoff, den die verwendet haben, also das war Sauerstoff und noch was, dann müsste es doch möglich sein, über weitere Strecken zu fliegen. So ist uns das erklärt worden. Man hat uns aber auch gesagt, die Forschung dazu steckt in den Kinderschuhen, das ist noch ein weiter Weg. Himmler hat dann gesagt, er begrüßt diese Forschung, wichtiger ist aber erst mal, dass man die Rakete so hinbekkommt, dass die überhaupt zuverlässig funktioniert, und das muß schnell gehen.

[p. 47] At last when we [SS] got a finger in the door in Peenemünde, it was considered whether it would be possible to launch the atomic bomb with a rocket. That was pure theory for the time being, because we had ideas about the thing that could not be implemented. However, the investigations continued. In Peenemünde itself, the question, as far as I know, had not been investigated with great enthusiasm, even though they had their own atomic laboratories. I was finally there myself. For them, however, the more important question was whether a rocket can fly with nuclear propulsion. On our first joint visit, Himmler and I heard why they researched that topic. The technicians told us that the propulsion already works wonderfully, we could also see that later. But it was true that all the propellant was consumed within a very short time, and so it could fly only over a short range. Short is actually not right. At that time, we were already excited by the range that the rocket gave. But if you now know that there is much more energy in the uranium than in the same mass of the fuel that they used, which was oxygen and something else, then it should be possible to fly over greater distances. That is how it was explained to us. But we were also told, the research is in its infancy, with still a long way to go. Himmler then said he welcomed this research, but it is more important that the rocket is perfected so that it works reliably, and that must be done quickly.

[Grothmann stated that the rocket research center at Peenemünde had its "own atomic laboratories" and was using those to develop nuclear rocket engines. How far did research on nuclear rocket engines get during the war? Did that work cover fission thermal engines, ion engines, external pulse propulsion, or other methods? How much did that wartime German research influence postwar work on nuclear rocket engines in the United States and other countries?]

E.5.3 Fission Pulse Rocket Propulsion

[In contrast to fission thermal propulsion, fission pulse propulsion employs fission reactions that occur outside of the rocket, and therefore are not constrained by the melting temperatures of the fission fuel or any rocket components. Thus the fission reactions can reach the highest possible temperatures—those of a fission explosion. Small fission bombs could be ejected from the rear of the spacecraft; they would explode near the spacecraft, and some fraction of the blast would be intercepted by a thick ablative "pusher plate," transferring momentum while protecting the rest of the spacecraft (Fig. 9.239 bottom). To smooth out the violent shocks of intermittent explosions into more continuous and more survivable acceleration for the spacecraft, the pusher plate would be connected to the rest of the spacecraft by giant compressible shock absorbers. The heat, radiation, and shock to which the vehicle would be subjected pose formidable constraints on the materials and engineering design, yet the prospect of achieving both very high exhaust velocities and high thrust-to-weight ratios with an available energy source (fission explosives) is attractive.

Most books on the subject say that nuclear pulse propulsion was first proposed after World War II by Stanislaw Ulam (Polish, 1909–1984), who was a creator from the greater German-speaking world [e.g., Dyson 2002, p. 2]. In fact, this approach was first proposed and explored by even earlier German-speaking creators.

External pulse propulsion by conventional chemical explosives was first proposed by Hermann Ganswindt (German, 1856–1934) [Ron Miller 1993, pp. 75–76; Ron Miller 2016, p. 48].

The following sources show that external pulse propulsion by nuclear explosives was first proposed in approximately 1942 by Wernher von Braun. Considering the German military's great wartime interest in and funding for rockets, nuclear weapons, and revolutionary methods of delivering heavy payloads long distances, it seems likely that fission pulse propulsion was seriously considered during the war, although little relevant documentation is currently available. By the end of the war, work in this area had apparently progressed at least as far as creating small test models powered by conventional chemical explosives, which is as far as the work ever progressed in the United States after the war before the U.S. program was cancelled.

Archives and personal collections worldwide should be searched for more information about nuclear pulse propulsion work that was conducted during the war.]

Friedwardt Winterberg. 2010. *The Release of Thermonuclear Energy by Inertial Confinement: Ways Towards Ignition.* Singapore: World Scientific. pp. v, vii.

Dedicated to [...]

Wernher von Braun
who first thought about nuclear rocket propulsion [...]

Having been born in Germany in 1929, I received my PhD in physics under Heisenberg in 1955.

[...] I was invited by the US government under "Operation Paperclip" to come to the United States. In San Diego I met Ted Taylor and Freeman Dyson, who were working on the famous "Orion" nuclear bomb propulsion concept. This concept is generally credited to Ulam, but as I know from conversations I had with Heisenberg, a similar idea was presented to Heisenberg by Wernher von Braun, who had visited Heisenberg in Berlin in or around 1942.

Seventh Army Interrogation Center. 3 June 1945. Notes on German Weapons Developments. SAIC/38. https://www.scribd.com/document/431240796/File-Datastream http://hydrastg.library.cornell.edu/fedora/objects/nur:01298/datastreams/pdf/content

8. "Detonation Rocket Weapons"

Contrary to the normal rockets, where the projectile is propelled forward by the rearward push of the gases during the explosions, the "detonation rockets" move through the utilization of the rearward impulses caused by the detonations themselves. For practical purposes this principle is applicable only at extremely high velocities. The DERA is the only rocket in which this principle was used. Ing LARSSON (source) was the specialist in charge of research on this rocket at the GROSSENDORF Experimental Station, under Ing THOMAS. Source explains that the successive detonation impulses are properly directed by means of a parabolic surface. Normal rocket mechanisms are used to attain a certain minimum velocity, at which time the "detonation" mechanism begins to function.

E.5.4 Electric Rocket Propulsion

[Electric rocket propulsion, or an ion-electron thruster, uses energy (heat, resonant electromagnetic waves, high-energy electrons from an electron gun, or other methods) to ionize initially electrically neutral propellant atoms into positively charged ions and negatively charged electrons, as shown in the upper half of Fig. 9.240. The positively charged ions are accelerated by the voltage difference between two electrically charged grids and ejected from the rear of the spacecraft at some desired velocity. To prevent the spacecraft from accumulating more and more net electric charge (as a result of the lost ions) that would actually draw the ejected ions back to the spacecraft, electrons that have been stripped off the ions must also be ejected, generally by harvesting them from the ionization chamber and firing them from electron guns toward the departing ion exhaust. This method of particle acceleration can produce much higher exhaust velocities than chemical combustion or even fission thermal rockets. However, because charged particle beams have far lower densities than flows of more traditional rocket propellant, their thrust is very low. Thus electric propulsion is best for deep space missions where a low thrust applied over the course of months or even years can yield useful final velocities or changes in the spacecraft's orbit. Although ion-electron thrusters could be powered by solar panels or any other source of electrical energy, it is usually proposed to power them with a fission reactor.

Electric rocket propulsion systems were first proposed by Hermann Oberth in 1929 (see below). Experimental development of electric propulsion in Germany began no later than 1937 and continued until at least 1944 (p. 4860). Ernst Stuhlinger, Wernher von Braun, and other German-speaking scientists continued to develop and promote electric propulsion after the war (p. 1951 and the document below). Currently very few documents on the wartime electric propulsion program are available, but it seems likely that Oberth, Stuhlinger, and von Braun were involved in it as well.]

Ernst Stuhlinger. 1964. *Ion Propulsion for Space Flight.* New York: McGraw-Hill. pp. vii, 2–3.

The present book was written during the years 1958 to 1962. From 1960 to 1961, the author directed the NASA program for the development of arc-jet and ion propulsion systems at the George C. Marshall Space Flight Center in Huntsville, Alabama. [...]

Hermann Oberth [...] contributed probably more to the theoretical foundation of the broad field of rockets and space flight than any other individual. [...] Many of his early thoughts found precipitation in the book "Wege zur Raumschiffahrt" (1929), probably the outstanding classic of rocketry and space travel. One chapter in this book deals with electric propulsion. In a later book, "Man into Space" (1957), the same ideas were taken up again and presented in a similar form. Oberth first described the old classroom experiment where a needlepoint, connected with a source of high voltage, produces an "electric wind," and he then elaborated on methods of generating a flow of electrically charged particles from the thrust engine of a space vehicle. Porous plates, he wrote, will provide a finely dispersed flow of propellant; high voltage applied to the plates will form a spray of charged particles which leaves the vehicle with high velocity. Almost any kind of material, even refuse from the vehicle crew, could be used as propellant. The rate of propellant flow will always be small, but since the exhaust velocity is high, a noticeable thrust will be developed. It is characteristic of electric propulsion engines that they will produce a low thrust over a long period of time; hence, electric systems will find application in space vehicles which are designed to travel to distant targets.

E.5.5 Antimatter Rocket Propulsion

[For equal amounts of matter and antimatter, 100% of the combined propellant mass could be converted to energy, versus $< 1\%$ for nuclear reactions, so antimatter propulsion could yield the maximum performance obtainable from a rocket, with exhaust velocities approaching the speed of light. Eugen Sänger was the first to propose matter-antimatter rockets and to work out their details, including using anti-hydrogen made from positrons and antiprotons, storing the antimatter without letting it come into contact with ordinary matter, and using highly novel types of nozzles to direct the matter-antimatter reaction products out the back of the rocket. Sänger did a great deal of work in this area after the war; it is possible that he did some related theoretical design work during the war as well. See Figs. 9.240 and 9.242.]

Eugen Sänger. 1965. *Space Flight: Countdown for the Future.* New York: McGraw-Hill. pp. 255–258. [This English translation of Sänger's original German book is rather sloppy. I have adjusted a few words to try to improve the accuracy.]

Pure photon rockets represent the final, though today still entirely hypothetical, goal of all rocket systems. It is expected of them that they will transform all of the propellant mass carried aboard the vehicle into energy. The directed exhaust of this energy, at the speed of light of 300,000 km/sec, corresponds to the absolute, lowest limiting value of the specific propellant consumption of rocket engines at 3.3×10^{-5} kg/ton-sec. [...]

An exhaust velocity of all propellants carried aboard which is equal to the speed of light will also permit a similarly close approximation of the flight velocity to the speed of light so that the relativistic effects, particularly the phenomenon of time dilation between launch site and spacecraft, will figure prominently in the flight mechanics involved. [...]

At the time when the idea of the photon rocket was conceived, the existence of positrons as antiparticles of electrons was already known. Soon thereafter followed the discovery of the antiproton as the antiparticle of the proton so that now the combination of a positron and an antiproton to form an antihydrogen atom seems quite feasible. The first building blocks of antimatter became visible at the horizon, of that antimatter which might annihilate spontaneously upon collision with the matter of our ordinary world, thus disintegrating into photons whose energy is equivalent to the rest mass of the matter from which they originated. [...]

At present there is no certainty at all as to whether the annihilation of matter and antimatter is the only method by which matter can be transformed into energy. [...]

The latter process would be more advantageous than the combination of matter and antimatter insofar as obviating the problem of storing large quantities of antimatter, which has to be protected from any contact with ordinary matter. [...]

Meanwhile basic research in pure photon rockets has made considerable progress toward the solution of a related problem, namely that of the generation and collimation of very intensive photon rays.

E.6 Analysis of Advanced Jet Developments

Very simple mathematical models of aircraft performance may be derived from first principles, and then applied to estimate the performance of various types of German aircraft.

The frame of reference is important for analyzing aircraft engines. In the frame of reference of the atmospheric air surrounding the aircraft (motionless if there is no wind, or moving with the wind if the wind speed is nonzero), the surrounding air has zero velocity and the aircraft has a forward velocity v_{aircraft} [Fig. E.257(a)]. The exhaust velocity v_{exh} from the aircraft's engines is measured relative to the aircraft, so in the frame of reference of the surrounding air, the exhaust has a rearward velocity of $v_{\text{exh}} - v_{\text{aircraft}}$. However, it is much easier to analyze aircraft engine performance in the frame of reference of the aircraft, in which the surrounding atmospheric air has a rearward velocity of v_{aircraft}, the aircraft has zero velocity, and the engine exhaust has a rearward velocity of v_{exh} [Fig. E.257(b)].

In either frame of reference, $\dot{m}$ is the mass of air per time flowing through the engine. Aircraft engines are generally powered by burning fuel stored on-board with the air flowing through; the rate at which fuel is added is $\dot{m}_{\text{fuel}}$, which is typically far smaller than the air flow rate $\dot{m}$. In the rest frame of the aircraft [Fig. E.257(b)], the momentum flow rate entering the engine is $\dot{m}v_{\text{aircraft}}$, and that leaving the engine is $(\dot{m} + \dot{m}_{\text{fuel}})v_{\text{exh}} \approx \dot{m}v_{\text{exh}}$.

The thrust force of the engine is the net change in momentum flow rate before and after passing through the engine (creating an equal and opposite momentum change or force on the engine), plus the net difference between the pressure p_{exhaust} pushing on the rear cross-sectional area A_{engine} of the engine and the pressure p_{atm} pushing on the front cross-sectional area A_{engine} of the engine:

$$F_{\text{thrust}} = (\dot{m} + \dot{m}_{\text{fuel}})v_{\text{exh}} - \dot{m}v_{\text{aircraft}} + A_{\text{engine}}(p_{\text{exh}} - p_{\text{atm}}) \quad \text{(E.1)}$$

$$\approx (\dot{m} + \dot{m}_{\text{fuel}})v_{\text{exh}} - \dot{m}v_{\text{aircraft}} \quad \text{(E.2)}$$

$$\approx \dot{m}(v_{\text{exh}} - v_{\text{aircraft}}) \quad \text{(E.3)}$$

Equation (E.3) was further simplified by assuming $\dot{m}_{\text{fuel}} \ll \dot{m}$. Because the exhaust pressure exerts a forward force against nozzle surfaces, it is advantageous to let the exhaust expand within the nozzle until its pressure has finally fallen to the external atmospheric pressure. During that time, the pressure potential energy of the flow is steadily converted into kinetic energy of the increasing exhaust velocity. Since the exhaust velocity gets multiplied by the typically large mass flow rate $\dot{m}$ in Eq. (E.1), that also maximizes the thrust. If the nozzle expands the exhaust until its pressure is below atmospheric pressure, that creates a net drag and reduces the thrust as shown in Eq. (E.1). If the nozzle expands the exhaust until it reaches external ambient pressure, the exhaust is said to fully expanded. Exhaust at higher than external ambient pressure is under expanded, and exhaust at lower than ambient pressure is over expanded. The nozzle shape and size of a given aircraft engine are designed to fully expand the flow until expected operating conditions for that engine, so the pressure term in Eq. (E.1) is generally zero or negligibly small, as assumed in Eqs. (E.2)–(E.3). Aircraft such as supersonic fighter jets that must operate under a variety of conditions use nozzles with moveable surfaces so that the nozzle shape and the degree of exhaust expansion can be tailored for maximum efficiency at the current conditions.

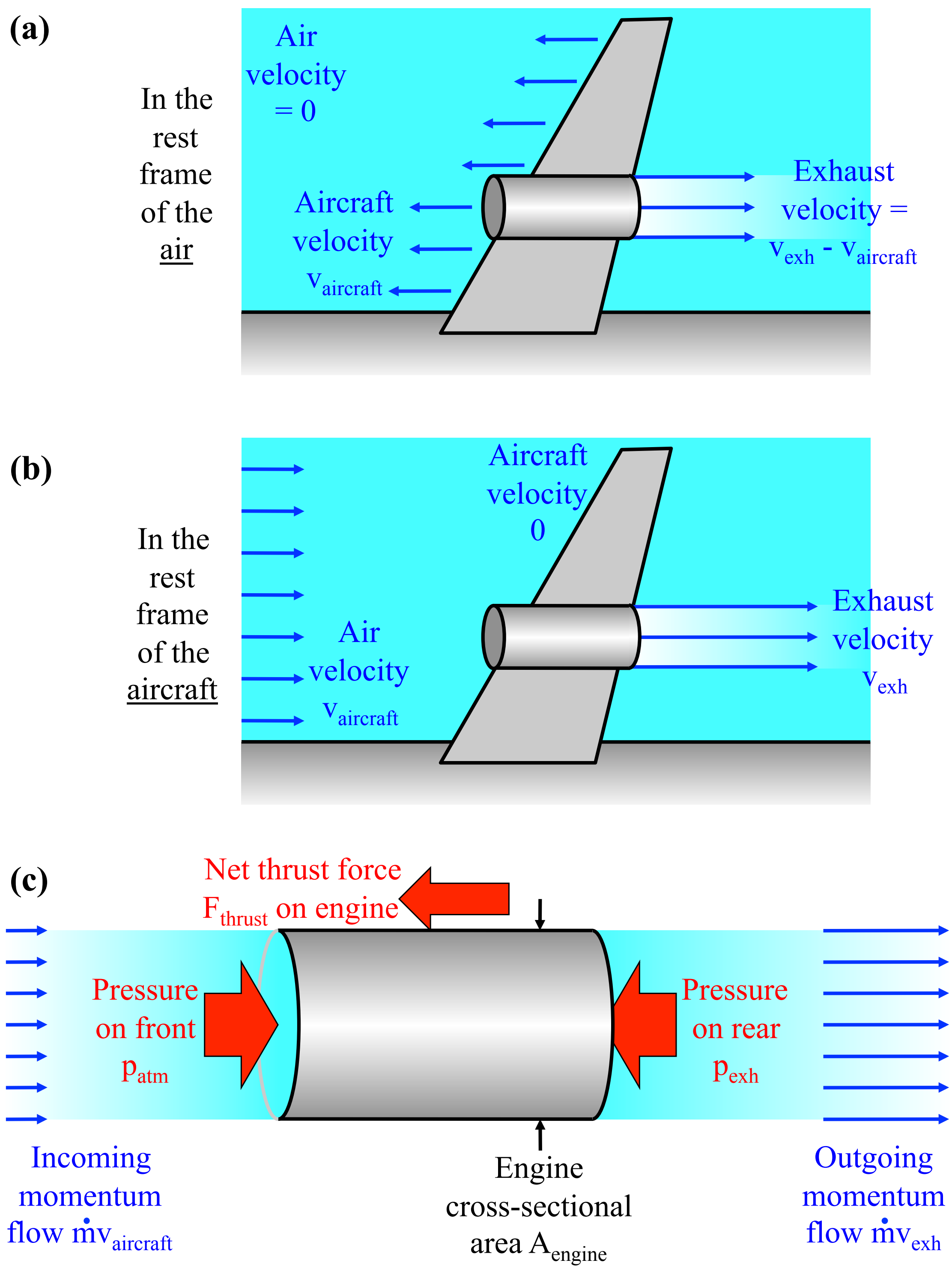

Figure E.257: Basics of aircraft propulsion. (a) Relative velocities of the atmospheric air, aircraft, and exhaust in the rest frame of the air. (b) Relative velocities of the atmospheric air, aircraft, and exhaust in the rest frame of the aircraft. (c) Factors affecting the thrust of an aircraft engine in the rest frame of the aircraft.

An aircraft propulsion system converts the chemical energy stored in on-board fuel into thermal energy by burning the fuel with oxygen from the surrounding air. As with any other heat engine, an aircraft propulsion system then converts some fraction of that thermal energy into kinetic energy (of the exhaust and/or aircraft), while the rest remains as waste heat energy that is exhausted to the surrounding air. The thermodynamic efficiency η_{thermo} of an aircraft engine is defined as follows and will be less than the Carnot efficiency:

$$\eta_{\text{thermo}} = \frac{\text{Energy converted to kinetic energy of aircraft or exhaust}}{\text{Total heat energy produced by combustion}} \tag{E.4}$$

$$< 1 - \frac{T_{\text{highest temperature in engine}}}{T_{\text{external air}}} \tag{E.5}$$

Since the work or energy put into an object is equal to the product of the applied force and the distance that force moves the object, the power (energy/time) put into an object is equal to the product of the applied force and the object's instantaneous velocity. Therefore in the rest frame of the surrounding air [Fig. E.257(a)], the rate of increase (denoted by an overhead dot) of the kinetic energy of the aircraft is simply the product of the thrust force on the aircraft and the aircraft's instantaneous velocity:

$$(\dot{\text{KE}})_{\text{aircraft}} = F_{\text{thrust}}\, v_{\text{aircraft}} \tag{E.6}$$

$$\approx \dot{m}(v_{\text{exh}} - v_{\text{aircraft}})v_{\text{aircraft}} \tag{E.7}$$

in which Eq. (E.7) used Eq. (E.3) for the thrust.

Likewise, in the rest frame of the surrounding air [Fig. E.257(a)], air has zero velocity before and velocity $v_{\text{exh}} - v_{\text{aircraft}}$ after passing through the engine, so the rate of increase of the kinetic energy of the exhausted air is:

$$(\dot{\text{KE}})_{\text{exh}} = \frac{1}{2}\dot{m}(v_{\text{exh}} - v_{\text{aircraft}})^2 \tag{E.8}$$

The propulsive efficiency η_{prop} is defined as the fraction of the total produced kinetic energy that ends up with the aircraft and not the exhaust:

$$\eta_{\text{prop}} = \frac{(\dot{\text{KE}})_{\text{aircraft}}}{(\dot{\text{KE}})_{\text{aircraft}} + (\dot{\text{KE}})_{\text{exh}}} \tag{E.9}$$

$$= \frac{\dot{m}(v_{\text{exh}} - v_{\text{aircraft}})v_{\text{aircraft}}}{\dot{m}(v_{\text{exh}} - v_{\text{aircraft}})v_{\text{aircraft}} + (1/2)\dot{m}(v_{\text{exh}} - v_{\text{aircraft}})^2} \tag{E.10}$$

$$= \frac{2}{1 + (v_{\text{exh}}/v_{\text{aircraft}})} \tag{E.11}$$

Note from Eq. (E.11) that the propulsive efficiency increases as the exhaust velocity decreases. A propulsive efficiency greater than 1 is nonphysical, since it would require $v_{\text{exh}} < v_{\text{aircraft}}$, or negative thrust due to the aircraft engine actually decelerating air passing through it, creating a net drag on the aircraft. A propulsive efficiency of 1 can be approached by making v_{exh} slightly larger than but as close to v_{aircraft} as possible, although of course in that case the thrust from Eq. (E.3) also goes to zero. For $v_{\text{exh}} \gg v_{\text{aircraft}}$, the thrust from Eq. (E.3) is very high, but the propulsive efficiency from Eq. (E.11) is very low–most of the kinetic energy ends up with the exhaust and not the aircraft. In practice, an aircraft engine's exhaust velocity must always be chosen based on the tradeoffs between the relative importance of high-thrust and high-efficiency operation.

The total efficiency of an aircraft engine is the product of its thermodynamic efficiency in converting heat to kinetic energy, and its propulsive efficiency in converting that kinetic energy to motion of the aircraft instead of the exhaust:

$$\eta_{\text{total}} = \eta_{\text{prop}}\,\eta_{\text{thermo}} \tag{E.12}$$

The specific impulse I_{sp} is the "bounce per ounce" of the fuel, the ratio of thrust produced to fuel consumed:

$$I_{\text{sp}} = \frac{F_{\text{thrust}}}{\dot{m}_{\text{fuel}}\, g} \tag{E.13}$$

in which $g \approx 9.807$ m/sec^2 is the earth's surface gravitational acceleration, multiplied by $\dot{m}_{\text{fuel}}$ so the fuel consumption is considered in terms of weight (force) per time and not mass per time.

Another oft-cited parameter is the thrust specific fuel consumption (TSFC), which is simply the inverse of the specific impulse:

$$\text{TSFC} = \frac{1}{I_{\text{sp}}} = \frac{\dot{m}_{\text{fuel}}\, g}{F_{\text{thrust}}} \tag{E.14}$$

By historical convention, I_{sp} is usually measured in seconds, yet TSFC is usually measured in inverse hours. Occasionally I_{sp} and/or TSFC are defined without the factor of g, resulting in more complicated units, but we won't worry about that here. Higher I_{sp} and lower TSFC both mean better fuel efficiency, with more thrust resulting from less fuel consumed. Typical values for different types of aircraft engines are:

$$\text{Turbojet engine:} \quad I_{\text{sp}} \approx 3600 \text{ sec} \quad \text{TSFC} \approx 1.0 \text{ hr}^{-1} \tag{E.15}$$

$$\text{Turbofan engine:} \quad I_{\text{sp}} \approx 6000 \text{ sec} \quad \text{TSFC} \approx 0.6 \text{ hr}^{-1} \tag{E.16}$$

$$\text{Propeller piston engine:} \quad I_{\text{sp}} \approx 6500 \text{ sec} \quad \text{TSFC} \approx 0.55 \text{ hr}^{-1} \tag{E.17}$$

$$\text{Turboprop engine:} \quad I_{\text{sp}} \approx 12,000 \text{ sec} \quad \text{TSFC} \approx 0.3 \text{ hr}^{-1} \tag{E.18}$$

One can use the specific impulse (or TSFC) to estimate an aircraft's maximum flying time Δt at cruising conditions, neglecting takeoffs and landings. Due to fuel consumption, the aircraft's weight W changes at a rate $dW/dt = -\dot{m}_{\text{fuel}}\, g$, so the specific impulse from Eq. (E.13) may be rewritten as:

$$I_{\text{sp}} = -\frac{F_{\text{thrust}}}{dW/dt} \tag{E.19}$$

$$dt = -\frac{I_{\text{sp}}}{F_{\text{thrust}}}\, dW = -I_{\text{sp}} \frac{L}{D} \frac{dW}{W} \tag{E.20}$$

$$= -I_{\text{sp}} \frac{C_L}{C_D} \frac{dW}{W} \tag{E.21}$$

Equations (E.20) and (E.21) used the facts that for an aircraft at steady cruising conditions, the forward thrust force must balance the rearward aerodynamic drag force D ($F_{\text{thrust}} = D$), the downward weight must balance the upward aerodynamic lift L ($W = L$), and the ratio of the lift and drag forces is simply the ratio of the lift and drag coefficients and can be assumed constant ($L/D = C_L/C_D$). Integrating Eq. (E.21) yields the maximum flying time:

$$\Delta t = I_{\text{sp}} \frac{C_L}{C_D} \ln\left(\frac{W_{\text{initial}}}{W_{\text{final}}}\right) = I_{\text{sp}} \frac{C_L}{C_D} \ln\left(\frac{M_{\text{initial}}}{M_{\text{final}}}\right) \tag{E.22}$$

The aircraft's maximum range R is just the product of its cruising speed v_{aircraft} and Δt:

$$R = v_{\text{aircraft}}\, \Delta t \tag{E.23}$$

$$= v_{\text{aircraft}}\, I_{\text{sp}} \frac{C_L}{C_D} \ln\left(\frac{M_{\text{initial}}}{M_{\text{final}}}\right) \tag{E.24}$$

As a sanity check, Eq. (E.24) can be applied to the U.S. Boeing B-29 bombers that were used to deliver the bombs to Hiroshima and Nagasaki. Using typical values of $v_{\text{aircraft}} \approx 100$ m/sec (Mach 0.33 at an altitude of 9–10 km), $I_{\text{sp}} \approx 6500$ sec for piston-powered propeller engines, $C_L/C_D \approx 16.8$, and $M_{\text{final}}/M_{\text{initial}} \approx 0.62$ (38% of the initial aircraft weight is fuel) yields

$$R \approx (100 \text{ m/sec})\,(6500 \text{ sec})\,(16.8)\, \ln\left(\frac{1}{0.62}\right) \tag{E.25}$$

$$\approx 5220 \text{ km} \approx 3240 \text{ mi} \tag{E.26}$$

Thus despite the simplifying assumptions involved in this method, the calculated range is in excellent agreement with the actual 5230 km (3250 mi) range of the B-29.

Equation (E.24) can also be applied to calculate the maximum theoretical range of various possible categories of German bombers. Like the B-29, such bombers would have had a likely cruising altitude of 9–10 km, where the speed of sound (Mach 1) is approximately 300 m/sec. Piston-powered propeller aircraft might have been designed to cruise at Mach 0.33 $\approx$ 100 m/sec with $I_{\rm sp} \approx 6500$ sec like the B-29. Turboprop aircraft might have been designed to cruise at Mach 0.5 $\approx$ 150 m/sec with $I_{\rm sp} \approx 12,000$ sec. Turbojet and turbofan aircraft might have been designed to cruise at Mach 0.8 $\approx$ 240 m/sec, with $I_{\rm sp} \approx 3600$ sec for turbojets and $I_{\rm sp} \approx 6000$ sec for turbofans. For all categories of aircraft, the largest likely lift-to-drag ratio would have been $C_L/C_D \approx 20$. The mass ratio likely would have been around $M_{\rm final}/M_{\rm initial} \approx 0.6$ (40% of the initial aircraft weight is fuel), although one can also consider the very optimistic case with $M_{\rm final}/M_{\rm initial} \approx 0.5$ (50% of the initial aircraft weight is fuel). Using Eq. (E.24), Tables E.1–E.2 present the results for these cases.

Characteristic	**Piston prop**	**Turbojet**	**Turbofan**	**Turboprop**
Cruising velocity v	100 m/sec	240 m/sec	240 m/sec	150 m/sec
Specific impulse $I_{\rm sp}$	6500 sec	3600 sec	6000 sec	12,000 sec
Lift/drag ratio C_L/C_D	20	20	20	20
Mass ratio $M_{\rm final}/M_{\rm initial}$	0.6	0.6	0.6	0.6
Maximum range R	6600 km	8800 km	15,000 km	18,000 km

Table E.1: Estimated characteristics and corresponding calculated maximum ranges for German bombers with a mass ratio $M_{\rm final}/M_{\rm initial} = 0.6$ using piston propeller, turbojet, turbofan, or turboprop engines.

Characteristic	**Piston prop**	**Turbojet**	**Turbofan**	**Turboprop**
Cruising velocity v	100 m/sec	240 m/sec	240 m/sec	150 m/sec
Specific impulse $I_{\rm sp}$	6500 sec	3600 sec	6000 sec	12,000 sec
Lift/drag ratio C_L/C_D	20	20	20	20
Mass ratio $M_{\rm final}/M_{\rm initial}$	0.5	0.5	0.5	0.5
Maximum range R	9000 km	12,000 km	20,000 km	25,000 km

Table E.2: Estimated characteristics and corresponding calculated maximum ranges for German bombers with a mass ratio $M_{\rm final}/M_{\rm initial} = 0.5$ using piston propeller, turbojet, turbofan, or turboprop engines.

German bombers likely would have been designed to make a round trip so that they and their crews could be reused if they survived the trip. New York seemed to be the preferred U.S. target mentioned by the German military; it was larger and also somewhat closer than Washington D.C.

The German launching point furthest west would have been someplace like Brest on the French coast, although such options were no longer available after the Allied invasion beginning in June 1944. (Intelligence about German plans might explain why the Allied invasion occurred when and where it did.) The distance from Brest to New York is approximately 5,400 km one-way, or 10,800 km round-trip.

A viable launching point up until the end of the war would have been the large German airfields around Oslo, Norway (Section E.1). The distance from Oslo to New York is approximately 6000 km one-way, or 12,000 km round-trip.

From these trans-Atlantic distances and Tables E.1–E.2, piston aircraft (such as the Ju 290) might have been able to make the one-way trip, but they certainly would not have been able to return to their launching point.

From Tables E.1–E.2, bombers powered by turbojets, the most readily available new aircraft engines in Germany, could have comfortably made a one-way trip. However, they would have had to operate at their maximum theoretical limits, with the best possible engine performance, lift/drag ratio, and mass ratio, in order to be able to make a 12,000 km round trip from Oslo to New York. Given realistic factors involved with technologies, missions, and payloads, that level of performance seems unlikely. Moreover, it would have been even more difficult to push that sort of technology to even greater ranges to reach other destinations (e.g., 12,500 km round trip from Oslo to Washington D.C. or 13,000 km round trip to Chicago).

Based on these fundamental considerations, aircraft powered by turbofan or turboprop engines would have been by far the best options for such round-trip missions.

Karl Leist (German, 1901–1960) built and demonstrated the first functional turbofan engine, the Daimler-Benz DB 007, also known as the Zweikreis Turbinen-Luftstrahltriebwerk ZTL 6001 (began development 1939, first run 1 April 1943). See pp. 1740, 4782–4790. At least three DB 007 turbofan engines were produced. The Heinkel company was also developing turbofan engines.

There were several notable turboprop engine development projects, including the Jumo 022 (p. 1742), BMW 028 (p. 1742), and Heinkel He S 021 (a turboprop version of the He S 011, p. 1725).

According to official histories, none of the turbofan or turboprop engines were used on aircraft before the end of the war. However, historians should carefully investigate whether some of the turbofan or turboprop work may have actually progressed further during the war, and how much it influenced postwar work on turbofan and turboprop engines, in view of:

1. The high priority placed on intercontinental jet bombers in the final years of the war.

2. The significantly higher fuel efficiency and hence longer range enabled by turbofan and turboprop engines compared to turbojet engines.

3. The great secrecy with which both wartime German scientists and postwar Allied investigators would have handled jet engine technology that was so advanced and had such strategic implications for intercontinental bombing.

E.7 Analysis of Advanced Rocket Developments

Very simple mathematical models of rocket performance may be derived from first principles, and then applied to estimate the performance of a wide variety of German rockets.

E.7.1 Fundamentals of Rocket Performance

A rocket expels exhaust rearward, accelerating the rocket forward as an equal and opposite reaction by Newton's laws. Ignoring forces such as gravity and aerodynamic drag for the moment, the maximum final velocity of the rocket depends on the mass $m_{\text{propellant}}$ of the propellant that is expelled as exhaust, the mass m_{final} of the empty rocket, and the velocity v_{exh} of the exhaust relative to the rocket. The result will also depend on whether the rocket body is divided into multiple stages that can be jettisoned along the way after the propellant in each stage has been consumed. One can derive a simple result for a single-stage rocket. By treating the rocket and exhaust as one combined system with a total momentum $p = p_{\text{rocket}} + p_{\text{exhaust}}$, and designating the current mass of the rocket and any remaining propellant it contains as m, conservation of total momentum yields:

$$\frac{dp_{\text{rocket}}}{dt} = -\frac{dp_{\text{exhaust}}}{dt} \tag{E.27}$$

$$m\frac{dv}{dt} = -(-v_{\text{exh}})\left(-\frac{dm}{dt}\right) \tag{E.28}$$

$$\frac{dv}{dt} = -\frac{v_{\text{exh}}}{m}\frac{dm}{dt} \tag{E.29}$$

$$\int dv = -v_{\text{exh}}\int\frac{dm}{m} \tag{E.30}$$

$$\Delta v = v_{\text{final}} - v_{\text{initial}} = v_{\text{exh}}\ln\left(\frac{m_{\text{initial}}}{m_{\text{final}}}\right) \tag{E.31}$$

in which v_{initial} is the initial velocity of the rocket before consuming its propellant, v_{final} is the final velocity of the rocket after consuming its propellant, $\Delta v = v_{\text{final}} - v_{\text{initial}}$ is the net change in velocity, and $m_{\text{initial}} = m_{\text{final}} + m_{\text{propellant}}$ is the initial mass of the rocket including propellant.

Equation (E.31) may be extended to cover rockets with two or more stages:

$$\Delta v = (v_{\text{exh}})_1 \ln\left[\frac{(m_{\text{initial}})_1}{(m_{\text{final}})_1}\right] + (v_{\text{exh}})_2 \ln\left[\frac{(m_{\text{initial}})_2}{(m_{\text{final}})_2}\right] + \ldots \tag{E.32}$$

in which $(v_{\text{exh}})_1$ is the exhaust velocity of the rocket engine(s) on stage 1, $(m_{\text{initial}})_1$ is the initial mass of the entire remaining rocket when stage 1 begins its burn, and $(m_{\text{final}})_1$ is the final mass of the entire remaining rocket when stage 1 finishes its burn, and so forth for stage 2 and any higher stages. After one stage has used all of its propellant, it is jettisoned and the next stage takes over. For most rocket stages, $(m_{\text{initial}})_i/(m_{\text{final}})_i \sim 2-4$ and $(\Delta v)_i \sim (v_{\text{exh}})_i$, so the total velocity change is typically $\Delta v \sim \sum_i (v_{\text{exh}})_i$.

From Eqs. (E.27)-(E.28), the exhaust exerts an equal and opposite thrust force F_{thrust} on the rocket, so the thrust, exhaust velocity, propellant mass, and burn time t_{burn} required to consume that propellant are interrelated:

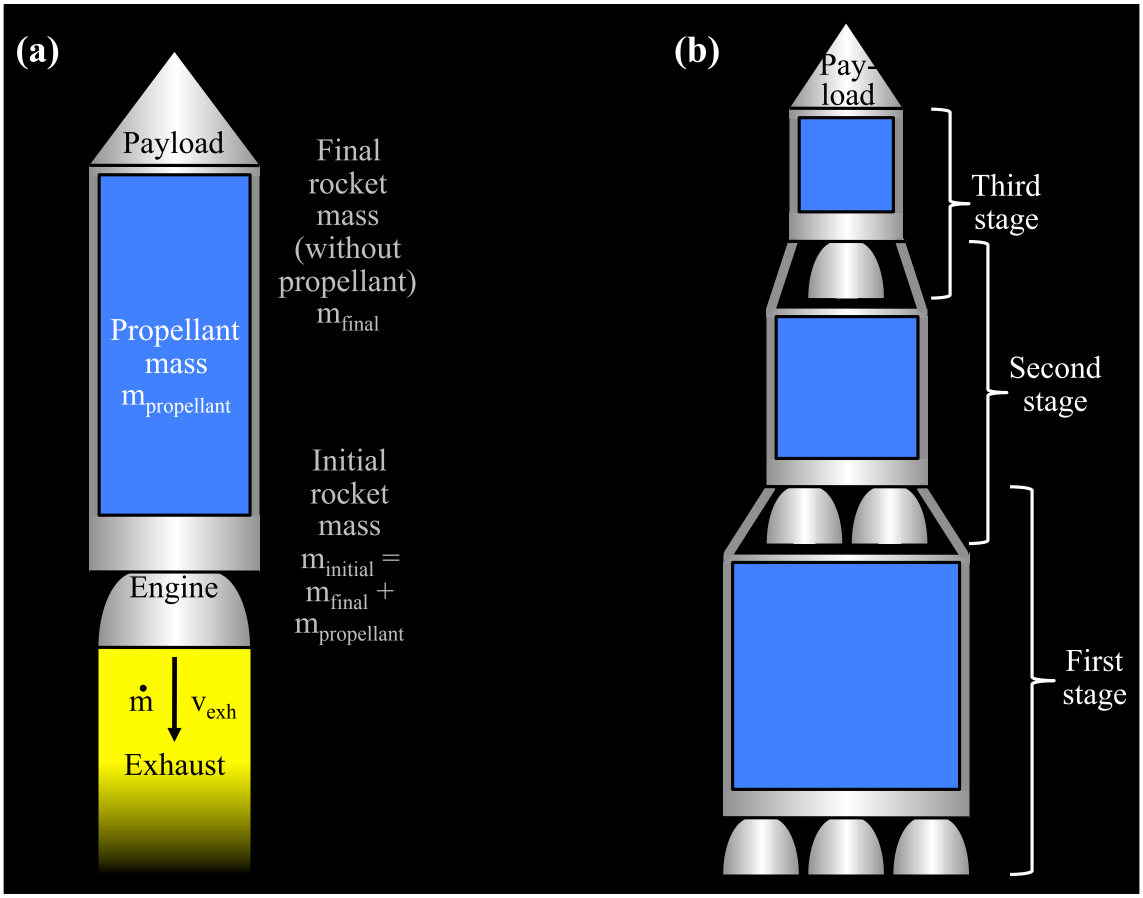

Figure E.258: Rockets (a) store propellant onboard and expel it out the back at a rate dm/dt and with an exhaust velocity v_{exh}, and (b) may be divided into multiple stages, such that each can be jettisoned as soon as its propellant has been consumed, reducing the rocket's mass later in flight and improving its overall performance.

$$\frac{dp_{\mathrm{exhaust}}}{dt} = v_{\mathrm{exh}} \frac{dm}{dt} , \quad \text{or}$$

$$F_{\mathrm{thrust}} = v_{\mathrm{exh}} \frac{m_{\mathrm{propellant}}}{t_{\mathrm{burn}}} \tag{E.33}$$

The exhaust velocity can be expressed as the product of the earth's standard gravitational acceleration $g \approx 9.807$ m/sec^2 and the specific impulse I_{sp} (measured in units of seconds):

$$v_{\mathrm{exh}} = I_{\mathrm{sp}}\, g \tag{E.34}$$

One could get along just fine by discussing the exhaust velocity and never using its alter-ego, the specific impulse. However, specific impulse became a widespread term of convention among rocket scientists since from Eqs. (E.33) and (E.34), it is basically the "bounce per ounce" of the propellant, the thrust force per propellant flow rate (weight per second):

$$I_{\mathrm{sp}} = \frac{F_{\mathrm{thrust}}}{g\, m_{\mathrm{propellant}}/t_{\mathrm{burn}}} \tag{E.35}$$

Liquid propellant rockets can achieve higher specific impulses/exhaust velocities than solid propellant rockets, but since liquid propellants are often cryogenic or chemically degrade over time, they usually cannot be stored for more than a few days. Therefore, they are primarily used for spacecraft launch vehicles, which can be fueled shortly before launch.

Figure E.259 shows schematic views of a liquid propellant rocket engine. As illustrated in Fig. E.259(a), burning of fuel and oxidizer in the combustion chamber generates hot gas with velocity $v_{\text{chamber}} \approx 0$ (initially nearly motionless in the combustion chamber, at least compared to the very high exhaust velocity coming out of the nozzle), pressure p_{chamber}, and temperature T_{chamber}. The hot gas expands in the nozzle until it has exhaust velocity v_{exh}, pressure p_{exh}, and temperature T_{exh} when it exits. For comparison, the ambient pressure outside the nozzle is p_{ambient}, which may be significant if the rocket is still inside the atmosphere.

Figure E.259(b) shows a schematic view of other components in a liquid propellant rocket engine. Pumps raise the pressure of oxidizer and fuel drawn from the propellant storage tanks to a pressure higher than p_{chamber} so they can be injected into the combustion chamber. Before entering the combustion chamber, fuel passes through coils wrapping the combustion chamber and nozzle, cooling the engine and preheating the fuel. To power the pumps, small amounts of oxidizer and fuel are diverted to burn in a gas generator, producing hot exhaust that powers a gas turbine and thereby the pumps. In some liquid rocket engine designs, the gas generator is powered by a small amount of dedicated solid rocket propellant, rather than diverted liquid propellant. A few combinations of fuels and oxidizers are hypergolic, or ignite on contact with each other, but most are not hypergolic, and require an igniter similar to a spark plug in the ignition chamber (not shown).

Thrust vector control or steering of a liquid propellant rocket engine during its burn may be accomplished in any of several ways. Gimbaling or tilting the entire engine (both the nozzle and the combustion chamber) is commonly used on large modern rockets. It is also possible to tilt just the nozzle if it is connected to the combustion chamber by a flexible yet heat-resistant seal or joint. Older, simpler methods include moving heat-resistant rudders or vanes that protrude into the exhaust stream (the method of choice for the A-4 and related rockets), or injecting fluid into one side of the exhaust to divert the rest of the hot exhaust gas. Those simpler methods are still used on smaller modern rockets. Of course, if there are multiple engines, they can be tilted in different directions to control roll around the long axis of the rocket, as well as pitch and yaw (tilting one way or the other) of the rocket's long axis relative to its flight path.

If a rocket accelerates in bursts instead of continuously, the temporarily increased propellant pressure during a burst of acceleration can be amplified by the pumps, temporarily increase propellant flow to the engine, and thus reinforce the transient bursts of thrust and acceleration. This propellant instability is called pogo, since the rocket seems to vibrate like a toy pogo stick. (Pogo was even shown for the fictionalized depiction of an A-10 rocket engine in the 1965 film *Operation Crossbow*.) To prevent this problem, some rocket engines have pogo accumulators between the propellant tanks and the propellant pumps, such that gas-filled regions of the accumulators allow the liquid propellant to expand when necessary and dampen the pogo vibrations.

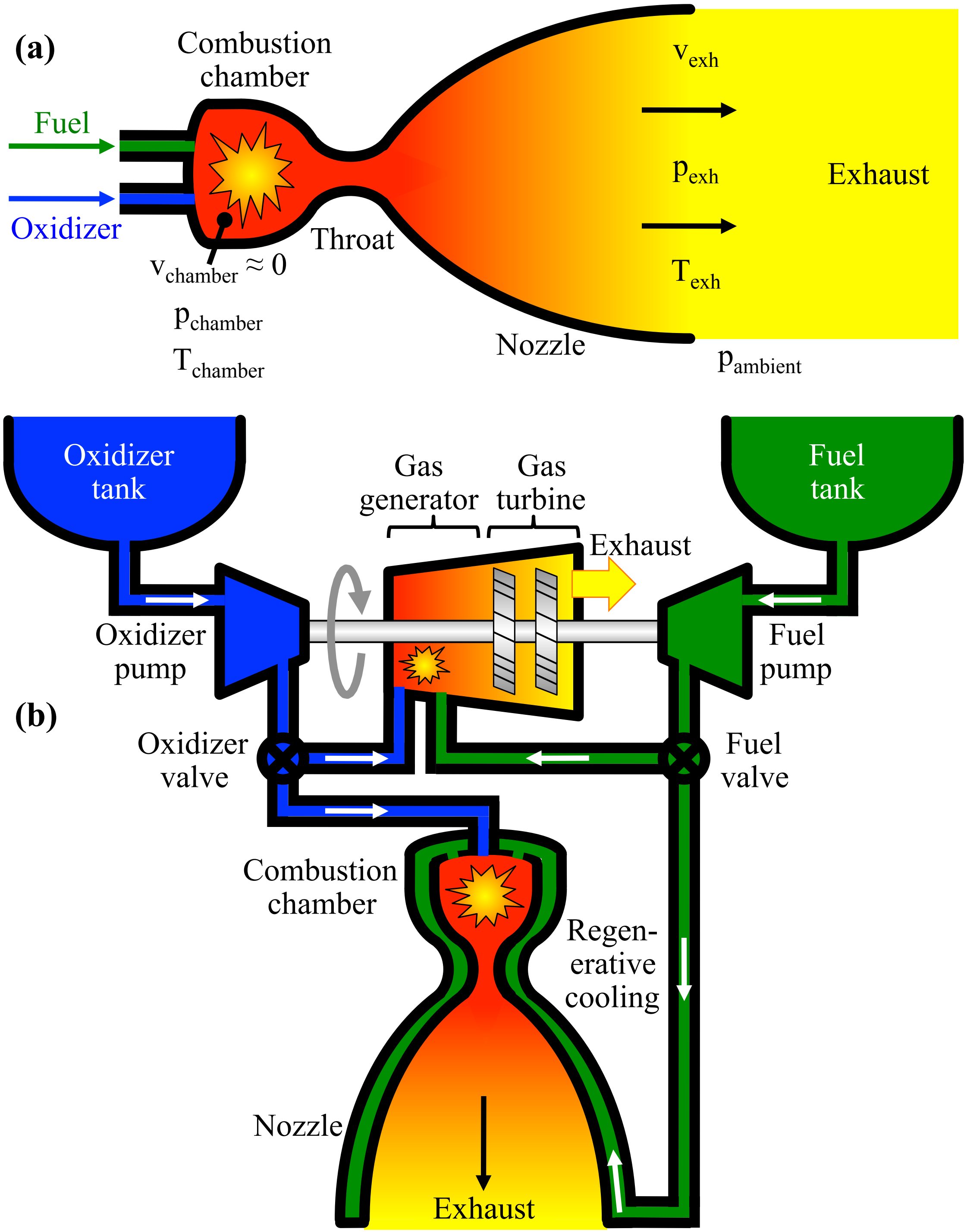

Figure E.259: Liquid propellant rocket design. (a) Burning of fuel and oxidizer in the combustion chamber generates hot gas with velocity $v_{\text{chamber}} \approx 0$, pressure p_{chamber}, and temperature T_{chamber}, which expands in the nozzle until it has exhaust values v_{exh}, p_{exh}, and T_{exh}. (b) Pumps raise the pressure of oxidizer and fuel from the storage tanks and inject it into the combustion chamber. Along the way, fuel detours through coils wrapping the combustion chamber and nozzle, cooling the engine and preheating the fuel. Small amounts of oxidizer and fuel are diverted to burn in a gas generator, producing hot exhaust that powers a gas turbine and thereby the pumps.

Burning of propellant in the combustion chamber produces an exhaust gas of molecules with both a high thermal energy due to the temperature T_{chamber} and also a high potential energy in the form of the pressure p_{chamber}. The rocket nozzle is shaped in such a way to convert as much as possible of that gas's thermal energy and pressure potential energy into directed kinetic energy of the molecules moving straight out of the rear of the nozzle. From basic thermodynamics, molecules with D degrees of freedom (three degrees of freedom for linear motion in three dimensions, plus three more degrees of freedom for rotation around three axes, plus more degrees of freedom if each molecular bond has enough energy to vibrate) will have an initial thermal energy of

$$\text{Thermal energy per mole} \quad = \quad \frac{D}{2} R_0 T_{\text{chamber}} \,, \tag{E.36}$$

in which the universal gas constant is $R_0 \approx 8314$ J/(kg ^{o}K).

Also from basic thermodynamics, the initial pressure potential energy will be

$$\text{Pressure energy per mole} \quad = \quad R_0 T_{\text{chamber}} \,. \tag{E.37}$$

The exhaust gas leaving the nozzle will have a kinetic energy of

$$\text{Kinetic energy per mole} \quad = \quad \frac{1}{2}(\text{M.W.}) v_{\text{exh}}^2 \,, \tag{E.38}$$

in which M.W. is the molecular weight of the exhaust molecules (basically the total number of protons and neutrons in each molecule).

Using Eqs. (E.36)–(E.38), if the rocket engine nozzle converts the initial thermal and pressure energy of the exahust to final kinetic energy with some conversion efficiency ϵ_{nozzle}, one can calculate the exhaust velocity:

$$\text{Kinetic energy per mole} \quad = \quad \text{Efficiency} \times (\text{Thermal energy per mole} \; + \; \text{Pressure energy per mole})$$

$$\begin{aligned} \frac{1}{2}(\text{M.W.}) v_{\text{exh}}^2 \quad &= \quad \epsilon_{\text{nozzle}} \; \frac{D+2}{2} \; R_0 T_{\text{chamber}} \,, \quad \text{or} \\ v_{\text{exh}} \quad &= \quad \sqrt{\frac{\epsilon_{\text{nozzle}}(D+2) R_0 T_{\text{chamber}}}{\text{M.W.}}} \end{aligned} \tag{E.39}$$

$$I_{\text{sp}} \quad = \quad \frac{v_{\text{exh}}}{g} \quad = \quad \frac{1}{g} \sqrt{\frac{\epsilon_{\text{nozzle}}(D+2) R_0 T_{\text{chamber}}}{\text{M.W.}}} \tag{E.40}$$

Most exhaust products from chemical rockets are triatomic molecules (H_2O, CO_2, etc.) with $D =$ 8 degrees of freedom (linear motion in three dimensions, plus rotation around three axes, plus vibration of two bonds). Using that assumption and the values $R_0 \approx 8314$ J/(kg ^{o}K) and $g \approx 9.807$ m/sec^2, Eqs. (E.39)–(E.40) become

$$v_{\rm exh} \quad = \quad 288.3 \sqrt{\frac{\epsilon_{\rm nozzle}\, T_{\rm chamber} \text{ (in } ^o\text{K)}}{\text{M.W.}}} \;\; \frac{\text{meters}}{\text{sec}} \tag{E.41}$$

$$I_{\rm sp} \quad = \quad 29.40 \sqrt{\frac{\epsilon_{\rm nozzle}\, T_{\rm chamber} \text{ (in } ^o\text{K)}}{\text{M.W.}}} \;\; \text{sec} \tag{E.42}$$

The nozzle efficiency is $\epsilon_{\rm nozzle} \approx 1$ for rocket engines designed to operate in the vacuum of space, where the nozzle can be so large that it expands the exhaust gas until its pressure is virtually zero, and all of the exhaust gas's energy has become kinetic energy. For rocket engines designed to operate within the atmosphere (generally launching from the surface, where the atmospheric pressure is greatest), the nozzle can only be large enough to expand the exhaust gas until its pressure reaches the pressure of the outside atmosphere. (If the nozzle expanded the exhaust to a pressure lower than that of the atmosphere, the rocket would lose thrust as a result of the higher atmospheric pressure "dragging" on the outside of the rocket nozzle that had lower exhaust pressure inside.) For sea-level atmospheric pressure, typical values of nozzle efficiency are around $\epsilon_{\rm nozzle} \approx 0.64$ ($\sqrt{\epsilon_{\rm nozzle}} \approx 0.8$).

The combustion chamber temperature $T_{\rm chamber}$ is limited not by any chemical properties of the propellants, but rather by the requirement not to damage the engine by overheating. Whereas jet engines (Section E.6) must run for hours without overheating, most rocket engines only need to operate for a few minutes, and their propellant can also circulate outside the combustion chamber and nozzle to cool the engine before the propellant is burned. As a result, rocket engine combustion chambers can operate at higher temperatures than jet engines, typically ranging from $T_{\rm chamber} \sim 2200^o$K for the standard A-4 engine to $\sim 3500^o$K for most modern rocket engines.

The molecular weight (M.W.) of the exhaust depends on the propellant used. For hydrogen as fuel and oxygen as oxidizer, the reaction product is water (H_2O), with a molecular weight M.W. ≈ 18. To lower the average molecular weight, most hydrogen-oxygen engines burn hydrogen-rich; the excess molecular hydrogen (M.W. ≈ 2) in the exhaust reduces the average exhaust molecular weight to M.W. ≈ 12. Hydrogen/oxygen propellant yields the best performance currently available from chemical propellants, but both the fuel and oxidizer are cryogenic, so they cannot be stored in onboard tanks for long. Hydrogen also has a very low density even when liquified, so it requires a fairly large and massive fuel tank on a rocket. Despite these difficulties, hydrogen/oxygen is the preferred fuel for most stages of most modern launch vehicles.

Liquid oxygen may also be used with storable fuels such as ethanol (CH_3CH_2OH, as in the A-4) or petroleum oil derivatives (typically a mixture of molecules $\sim C_nH_{2n+2}$, where $n \sim 6$–20, as in some proposed German rockets or the first stage of the Saturn V). For a standard A-4 rocket with oxygen as oxidizer and 75% ethanol/25% water as fuel (the water was added both to cool the engine and to lower the average molecular weight of the exhaust), roughly 2/3 of the reaction products are water (M.W. ≈ 18) and roughly 1/3 are carbon dioxide (CO_2, M.W. ≈ 44), yielding an average molecular weight of M.W. ≈ 27. The effective molecular weight could vary slightly, depending on what the exact propellant mix was and how one does the averaging, but M.W. ≈ 27 is a representative number, and small variations in that number are relatively insignificant, since it is in the square root in Eqs. (E.41)–(E.42).

Using these values and Eqs. (E.41), Table E.3 presents the approximate sea-level ($\epsilon_{\text{nozzle}} \approx 0.64$) and vacuum ($\epsilon_{\text{nozzle}} \approx 1$) exhaust velocities for various propellants and combustion temperatures.

Rocket fuel	**Rocket oxidizer**	**Exhaust M.W.**	**Combustion temperature**	**Sea-level exh. velocity**	**Vacuum exh. velocity**
Hydrogen	Oxygen	12	2200^oK	3120 m/sec	3900 m/sec
Hydrogen	Oxygen	12	3500^oK	3940 m/sec	4920 m/sec
Ethanol	Oxygen	27	2200^oK	2080 m/sec	2600 m/sec
Ethanol	Oxygen	27	3500^oK	2630 m/sec	3280 m/sec
Fuel oil	Oxygen	27	2200^oK	2080 m/sec	2600 m/sec
Fuel oil	Oxygen	27	3500^oK	2630 m/sec	3280 m/sec

Table E.3: Approximate exhaust velocities for rocket engines with various propellants, different combustion temperatures, and exhaust nozzles optimized for either sea-level and or vacuum conditions.

The thrust of a rocket engine may be estimated from the physical size of the engine, or vice versa. The combustion chamber pressure p_{chamber} pushes on all the forward inside areas of the chamber, but not on the open throat area A_{throat} in the rear of the chamber, producing an imbalanced pressure-based thrust force of $p_{\text{chamber}} A_{\text{throat}}$. The velocity and mass escaping through the throat produce a momentum-based thrust force of comparable value, doubling the total. Including the nozzle efficiency ϵ_{nozzle}, the total thrust including both pressure and momentum effects is

$$F_{\text{thrust}} \approx 2\,\epsilon_{\text{nozzle}}\, p_{\text{chamber}}\, A_{\text{throat}} \tag{E.43}$$

Like the chamber temperature, the chamber pressure p_{chamber} is limited not by any chemical properties of the propellants, but rather by the stresses that the combustion chamber can endure. Chamber pressures vary from $p_{\text{chamber}} \approx 1.45$ MPa for the standard A-4 engine to $p_{\text{chamber}} \approx 20$ MPa for the Space Shuttle Main Engines. (For reference, sea-level atmospheric pressure is approximately 0.1 MPa.)

Expressing the chamber pressure in MPa and writing the throat area in terms of the throat diameter, $A_{\mathrm{throat}} \approx (\pi/4) D^2_{\mathrm{throat}}$, the thrust from Eq. (E.43) may be rewritten as:

$$F_{\mathrm{thrust}} \ \text{[in Newtons]} \ \approx \ 1.6 \times 10^6 \, \epsilon_{\mathrm{nozzle}} \, D^2_{\mathrm{throat}} \ \times \ p_{\mathrm{chamber}} \ \text{[in MPa]} \tag{E.44}$$

For the standard A-4 engine with sea-level nozzle efficiency $\epsilon_{\mathrm{nozzle}} \approx 0.64$, throat diameter $D_{\mathrm{throat}} = 0.405$ m, and chamber pressure $p_{\mathrm{chamber}} \approx 1.45$ MPa, Eq. (E.44) predicts a thrust of $F_{\mathrm{thrust}} \approx 2.44 \times 10^5$ N, very close to the stated sea-level A-4 thrust of 2.65×10^5 N.

In order to reduce the exhaust gas pressure from the chamber pressure $p_{\mathrm{chamber}} > 1$ MPa to atmospheric pressure $p_{\mathrm{atm}} \sim 0.1$ MPa for a first-stage engine, the flared nozzle must have an exhaust area that is $A_{\mathrm{exh}}/A_{\mathrm{throat}} \sim$ 4–16 times as large as the throat area, or an exhaust diameter that is $D_{\mathrm{exh}}/D_{\mathrm{throat}} \sim$ 2–4 times as large as the throat diameter (taking the square root of the area ratio). Vacuum-optimized upper-stage engines typically have typical area ratios of $A_{\mathrm{exh}}/A_{\mathrm{throat}} \sim$ 25–100, or diameter ratios of $D_{\mathrm{exh}}/D_{\mathrm{throat}} \sim$ 5–10.

Although solid propellant rockets have lower specific impulses/exhaust velocities than liquid propellant rockets, they can generally be stored for years without degradation. Therefore, they are primarily used for military rockets and “off-the-shelf” boosters that can be strapped to the side of the first stage of a spacecraft launch vehicle. Despite their internal differences (see p. 1898), solid propellant rockets obey the same thrust equations derived above for liquid propellant rockets.

Very complex calculations would be required to analyze the performance of a rocket including factors such as the duration and angle of its rocket engine burn, aerodynamic drag, variations in the gravitational acceleration g, curvature of the earth, and rotation of the earth. However, for suborbital rockets, adequate approximations may be obtained using much simpler methods. As shown in Fig. E.260, major categories of potential flight paths for rockets include: (a) a ballistic trajectory, (b) a glide trajectory, (c) a ballistic trajectory followed by a glide trajectory, and (d) a ballistic trajectory with multiple skips off the upper atmosphere (followed by a glide).

a. Ballistic trajectory

For a crude but simple calculation of a ballistic trajectory (the path of a rocket without aerodynamic lift or wings), one can model the rocket's performance as that of a ballistic projectile which is instantaneously accelerated to a velocity Δv at launch, is fired some initial angle relative to the flat surface of the earth, and follows a parabolic trajectory to its target. Using Eq. (E.31) and assuming a 10% loss for aerodynamic drag and gravitational forces, the effective launch velocity of a ballistic rocket in this model is:

$$\Delta v \quad = \quad 0.9\, v_{\text{exh}}\, \ln\left(\frac{m_{\text{initial}}}{m_{\text{final}}}\right) \tag{E.45}$$

As shown in Fig. E.260(a), such a ballistic projectile achieves the greatest range when it is fired at a 45^o angle from the surface, devoting equal amounts of its velocity to achieving a maximum height and traveling a maximum distance before it falls back to the earth. If the projectile has a mass m and an initial velocity Δv, its total kinetic energy is $m(\Delta v)^2/2$, of which half goes to carry it to a maximum height ΔH and half goes to carry it to a maximum downrange distance Δx when it impacts at time Δt after being launched. Since half the initial kinetic energy is used up to achieve the gravitational potential energy $mg\Delta H$ at maximum height, that height may be found:

$$\frac{1}{2}\left[\frac{1}{2}m(\Delta v)^2\right] \quad = \quad m\,g\,\Delta H\ , \quad \text{or} \tag{E.46}$$

$$\Delta H \quad = \quad \frac{(\Delta v)^2}{4g} \tag{E.47}$$

Half of the total time Δt is spent reaching height ΔH, and half to fall from it back to the ground:

$$\Delta H \quad = \quad \frac{1}{2}\,g\left(\frac{\Delta t_{\text{ballistic}}}{2}\right)^2\ , \quad \text{or} \tag{E.48}$$

$$\Delta t_{\text{ballistic}} \quad = \quad \sqrt{\frac{8\Delta H}{g}} \tag{E.49}$$

$$\quad = \quad \sqrt{2}\,\frac{\Delta v}{g} \tag{E.50}$$

in which Eq. (E.50) used Eq. (E.47).

An amount $\Delta v/\sqrt{2}$ of the projectile's velocity is directed horizontally, carrying it a distance

$$\Delta x_{\text{ballistic}} \quad = \quad \frac{\Delta v}{\sqrt{2}}\ \Delta t_{\text{ballistic}} \tag{E.51}$$

$$\quad = \quad \frac{(\Delta v)^2}{g} \tag{E.52}$$

in which Eq. (E.52) used Eq. (E.50).

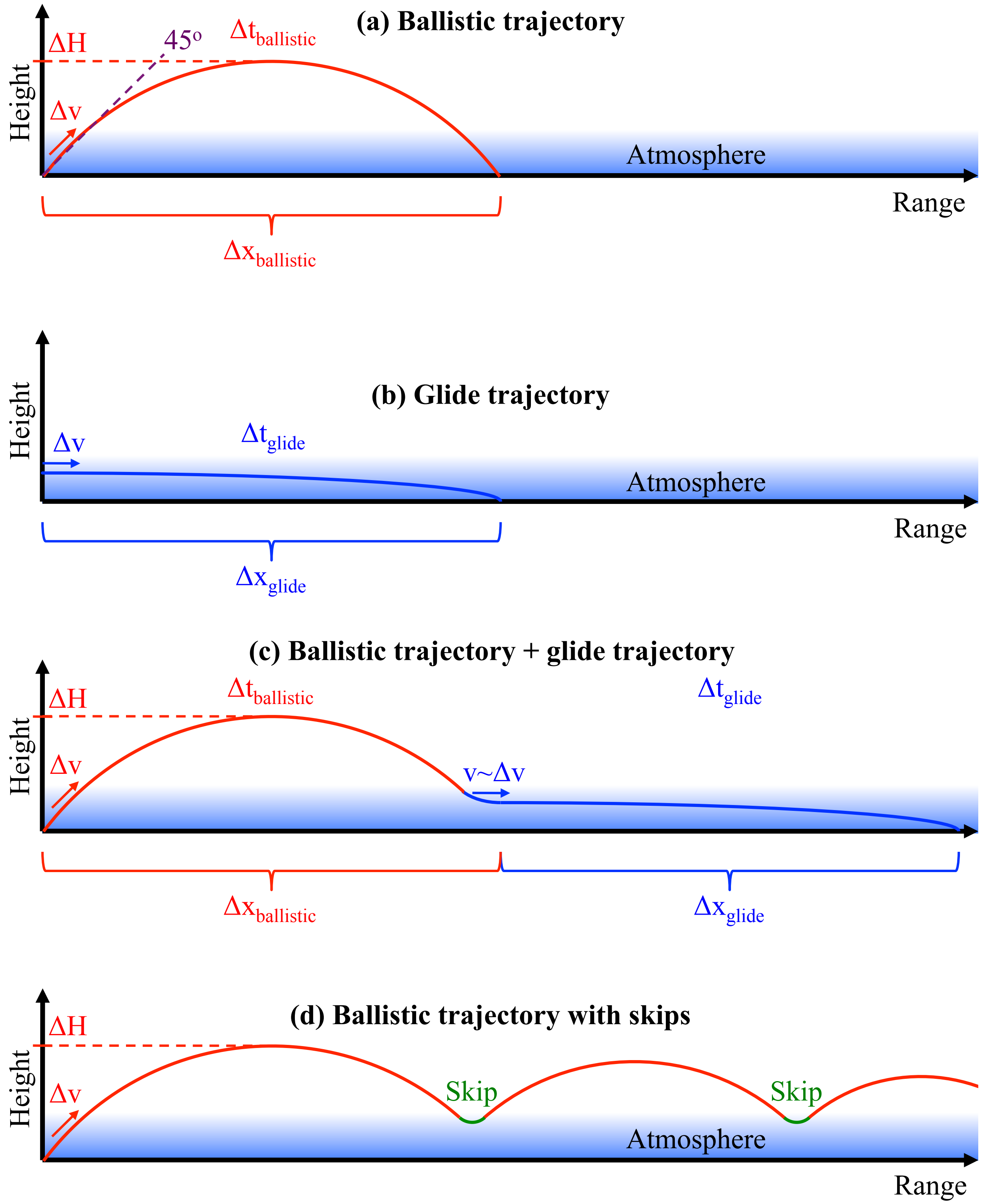

Figure E.260: Major categories of potential flight paths for rockets include: (a) a ballistic trajectory, (b) a glide trajectory, (c) a ballistic trajectory followed by a glide trajectory, and (d) a ballistic trajectory with multiple skips off the upper atmosphere (followed by a glide).

b. Glide trajectory

In a gliding trajectory as illustrated in Fig. E.260(b), the rocket is boosted to an initial velocity Δv that is horizontal but high enough in the atmosphere that it will not crash before it loses its horizontal velocity. If the rocket has wings, it can use the aerodynamic lift force generated by those wings to maintain a nearly horizontal gliding flight path for as long as possible, until aerodynamic drag has slowed its forward velocity to zero (or in practice, to a low enough velocity that the wings no longer generate enough lift to keep the vehicle aloft).

For the rocket to maintain a horizontal trajectory, the upward lift force L must balance the downward gravitational force mg, in which m is the mass of the rocket and g is the gravitational acceleration:

$$L = mg \tag{E.53}$$

Using Newton's second law, the aerodynamic drag force D in the horizontal direction causes the rocket's forward velocity to decelerate at a rate a (where a is defined to be positive for deceleration):

$$D = ma \tag{E.54}$$

Dividing Eq. (E.54) by Eq. (E.53), one finds:

$$\frac{D}{L} = \frac{a}{g}\,, \quad \text{or}$$

$$a = g\,\frac{D}{L} \tag{E.55}$$

Note that the deceleration is constant and only depends on the rocket's lift-to-drag ratio (D/L). At that uniform deceleration, the time required to decelerate from initial velocity Δv to $v = 0$ is:

$$\begin{aligned} \Delta t_{\text{glide}} &= \frac{\Delta v}{a} \\ &= \frac{\Delta v}{g}\,\frac{L}{D} \end{aligned} \tag{E.56}$$

For uniform deceleration, the average velocity during the glide is $\Delta v/2$, so the range travelled during the glide is:

$$\begin{aligned} \Delta x_{\text{glide}} &= \frac{\Delta v}{2}\,\Delta t_{\text{glide}} \\ &= \frac{1}{2}\,\frac{L}{D}\,\frac{(\Delta v)^2}{g} \end{aligned} \tag{E.57}$$

Dividing Eq. (E.57) by Eq. (E.52), the range of a gliding trajectory compared to the range of a ballistic trajectory with the same initial velocity is:

$$\frac{\Delta x_{\text{glide}}}{\Delta x_{\text{ballistic}}} = \frac{1}{2}\frac{L}{D} \tag{E.58}$$

Thus the gliding range is at least as large as the ballistic range for lift-to-drag ratios of

$$\frac{L}{D} \geq 2 \tag{E.59}$$

For reference, the lift-to-drag ratio of the U.S. space shuttle was $L/D \approx 2.5$, and Silbervogel was designed to have L/D in the range 6.4–7.5 (the ratio varied slightly with the velocity of the vehicle).

c. Ballistic trajectory followed by a glide trajectory

As shown in Fig. E.260(c), greater range may be achieved if a rocket first follows a ballistic trajectory, then follows a glide trajectory. For simplicity, one can assume that the glide begins after the rocket's ballistic trajectory has fallen enough that the rocket has regained virtually all of its initial velocity Δv, yet is still high enough that it can glide nearly horizontally until its forward velocity is gone, without hitting the ground prematurely. With this simplistic but useful assumption, the total range travelled during both the ballistic and glide phases is:

$$\Delta x_{\text{total}} \approx \Delta x_{\text{ballistic}} + \Delta x_{\text{glide}} = \left(1 + \frac{1}{2}\frac{L}{D}\right)\frac{(\Delta v)^2}{g} \tag{E.60}$$

$$\approx \left(1 + \frac{1}{2}\frac{L}{D}\right)\Delta x_{\text{ballistic}} \tag{E.61}$$

If $L/D = 2$, adding a glide to the end of a ballistic trajectory would approximately double the total range, compared to a purely ballistic trajectory. If $L/D = 4$, adding a glide to the end of a ballistic trajectory would approximately triple the total range.

The total time required for both the ballistic and glide phases is:

$$\Delta t_{\text{total}} \approx \Delta t_{\text{ballistic}} + \Delta t_{\text{glide}} = \left(\sqrt{2} + \frac{L}{D}\right)\frac{\Delta v}{g} \tag{E.62}$$

$$\approx \left(1 + \frac{\sqrt{2}}{2}\frac{L}{D}\right)\Delta t_{\text{ballistic}} \tag{E.63}$$

d. Skip trajectory

In a skip trajectory as illustrated in Fig. E.260(d), the rocket follows an initial ballistic trajectory but then instead of gliding back through the atmosphere, it bounces off the upper atmosphere to follow a second ballistic trajectory. If the rocket has wings, it can use those wings to generate enough aerodynamic lift for the skip back out of the atmosphere, instead of a nearly horizontal glide. However, there will also be a corresponding amount of aerodynamic drag during the atmospheric skip, so the rocket will lose some of its velocity and the second ballistic trajectory will not achieve as much altitude or as much range as the first ballistic trajectory. In principle the rocket can execute several skips and several ballistic trajectories, each smaller than the preceding one, before eventually settling into a conventional glide trajectory. The skip trajectory is analogous to skipping a stone off the surface of a pond of water. The equations for the skip trajectory are too complicated to include here, but will be discussed in Section E.7.7. Yet even without equations, one can see that a skip trajectory has the potential to have a total range several times larger than a simple ballistic trajectory, and larger even than a combined ballistic and glide trajectory.

Methods of improving rocket performance

Throughout the war, Germany was strongly motivated to improve the performance of its rockets to increase their range in order to reach more distant targets, and/or to increase their payload capacity in order to deliver larger bombs (conventional explosive, incendiary, fuel-air explosive, fission, radiological, chemical, or biological). Once Allied military forces began advancing into territory previously held by Germany, making potential Allied targets like London and Moscow even further away, this motivation became even stronger.

The A-4 or V-2 rocket was the most successful, most visible, and most widely produced German rocket, and was able to carry a 1-ton payload to a maximum range of approximately 350 km. There were six major ways to improve its performance, which could be done individually or in any combinations:

- Increasing the size of the rocket.
- Increasing the exhaust velocity of the rocket engine.
- Adding a booster stage to the rocket.
- Adding strap-on boosters to the rocket.
- Adding wings to the rocket.
- Decreasing stresses during atmospheric reentry.

Evidence for wartime German progress on each of these approaches will now be analyzed.

E.7.2 Increasing the Size of the Rocket

Length was the most straightforward improvement, since it would have simply involved producing longer cylinders for the fuel and oxidizer tanks, and possibly increasing the propellant flow rate to the engine to produce more thrust to lift the larger rocket mass. Whereas the regular A-4 rocket was approximately 14 meters long, including the fins and nosecone, there is evidence for extended versions of the A-4, especially a ∼18-meter version and a ∼21-meter version. There is also evidence for larger rockets such as the A-10.

For some publicly available sources on the wartime development of rockets larger than the standard A-4, see for example:

Wernher von Braun (pp. 4324, 5041–5042)

U.S. Army in France (p. 4572)

Henry H. Fowler (pp. 4756–4757)

Convair (pp. 4758–4761)

Roy Fedden (pp. 4795–4798)

French launch sites (pp. 4844–4845, 4860)

Franz Peter (pp. 4860–4864)

John A. O'Mara (pp. 4865–4866)

U.S. Army Air Forces General Henry Arnold (pp. 4865, 4867, 4999–5011)

Multiple *New York Times* sources (p. 4869)

Albert Speer (p. 4870)

Gerhard Reisig (pp. 4871–4872)

Allen Dulles (p. 4873)

Prisoner of war from Friedrichshafen (pp. 4875–4876)

Another prisoner of war from Friedrichshafen (pp. 4877–4878)

Allied intelligence (pp. 4879–4880)

Peenemünde chemist (p. 4881)

CIOS Final Report XXVIII-56 (p. 4881)

Forced laborers (p. 4882)

U.S. Army Air Forces General Lowell Weicker (pp. 4884–4885)

German engineer (p. 4886)

German prisoner of war (p. 4887)

Strategic Air Forces in Europe (p. 4888)

Cläre Werner (p. 4889)

Werner Kasper (pp. 4889–4890)

Albin Kummer (p. 4891)

Alfred Gründler (p. 4892)

Otto Skorzeny (p. 4897)

Henry Picker (pp. 4310–4314)

Gordon Cooper (pp. 4898–4899)

Werner Grothmann (pp. 4900–4904)

Allied intelligence reports (p. 4907)

U.S. Army (pp. 4908–4920)

Former French forced laborers (pp. 4921–4924)

Albert Ducrocq (p. 4925)

Walter Dornberger (pp. 4926–4928)

Heinz Stoelzel (pp. 4929–4941)

Kurt Eckener (p. 4937)

1945 St. Georgen an der Gusen train log book (p. 4942)

Karl Pohlhausen (p. 4943)

Winston Churchill (p. 4943)

Ernst Krause (pp. 4944–4945)

U.S. Army (pp. 4946–4947)

Gladwin Hill (pp. 4948–4949)

CIOS Final Report XXXII-125 (pp. 4950–4963)

NavTechMisEu Final Report 237-45 (p. 4974–4982)

U.S. Navy Secretary James Forrestal (pp. 4986–4988)

CIOS chairs R. P. Linstead and T. J. Betts (pp. 4989–4992)

W. G. A. Perring (pp. 4993–4996)

French Ministry of Defense (p. 4997)

Nils Werner Larsson (pp. 5003–5004)

U.S. Army Air Forces General Carl Spaatz (p. 5010)

U.S. Army Air Forces General Joseph T. McNarney (p. 5014)

Canadian investigators (pp. 5015–5016)

U.S. Army Air Forces Colonel Donald L. Putt (p. 5017)

U.S. Senator Elbert D. Thomas (pp. 5023–5026)

U.S. Army Ordnance Office (p. 5027)

Headquarters, U.S. Air Forces in Europe (pp. 5028–5029)

Central Intelligence Group (pp. 5029–5030)

Charles J. V. Murphy (pp. 5033–5034)

U.S. Army Air Forces (pp. 5035–5036)

U.S. Senator Harry F. Byrd (pp. 5037–5040)

Aage Woldike (pp. 5048–5052)

Time magazine (pp. 5059–5060)

V. L. Rychly (p. 5061–5091)

B. A. Haartt (pp. 5073– 5077)

Egmont F. Koenig (p. 5087)

August 1947 U.S. intelligence report (p. 5103)

Czech officials (pp. 5106–5108)

October 1947 U.S. intelligence report (p. 5109)

H. Tellmann (pp. 5110–5111)

Using German engineers, plans, and technologies after the war, the United States produced the Redstone missile, which was essentially a 21-meter-long A-4 (p. 5046).

Using German engineers, plans, and technologies after the war, France was developing and considering producing the Super V-2 missile, which was essentially an A-4 with enlarged propellant tanks (p. 5127).

Using German engineers, plans, and technologies after the war, the Soviet Union produced the SS-2 (R-2) missile, which was basically an 18-meter-long A-4, and the SS-3 (R-5M) missile, which was essentially a 21-meter-long A-4 (p. 5117).

Boris Chertok mentioned that the 21-m-long SS-3/R-5, but not the 14-m SS-1/R-1 and 18-m SS-2/R-2, suffered from unforeseen guidance problems. The SS-3 was so long that there was appreciable structural bending between the nose of the rocket, where the motion-sensing guidance system was, and the tail of the rocket, where the steering fins were. The guidance system erroneously interpreted small bending motions of the intervening structure as course changes of the entire rocket, and then led the rocket astray. (See pp. 5115–5115.) Because these Soviet rockets were directly based on German technology, it is likely that this same problem would have afflicted a 21-m A-4 but not 14-m or 18-m versions of the A-4. The wartime German program could certainly have overcome this problem just as the postwar Soviet program ultimately did, but it might have been one more cause for critical delays in the German rocket program.

Characteristic	**A-4**	**18 m A-4**	**21 m A-4**	**SS-1**	**SS-2**	**SS-3**	**Super V-2**	**Redstone**
Country	Germany	Germany	Germany	USSR	USSR	USSR	France	US
Operational	1942–45	1945?	1945?	1950–53	1953–56	1956–67	1946 design	1958–64
Diameter (m)	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.77
Length (m)	14	18	21	14	18	21	14.5	21
Body (kg)	4000	4000	4000	4000	5000	4000	3000	4000
Propellant (kg)	9000	16,000	24,000	9000	16,000	24,000	16,000	24,000
Payload (kg)	1000–2000	1000–2000	1000–2000	1000	1000	2000	1000	4000
Total mass (kg)	14,000–15,000	21,000–22,000	29,000–30,000	14,000	22,000	30,000	20,000	32,000
Fuel	Ethanol	Ethanol	Ethanol	Ethanol	Ethanol	Ethanol	Kerosene	Ethanol
Oxidizer	LOX	LOX	LOX	LOX	LOX	LOX	Nitric acid	LOX
v_{exh} **(m/s)**	2000	2000	2000	2000	2000	2300	2630	2300
Thrust (kN)	270	380	400	280	380	490	392	460
Burn time (s)	68	85	120	63	85	112	108	120
Range (km)	300	600	900	300	600	1200	1500	400
Est. velocity Δv **(m/s)**	1850–1650	2600–2300	3200–2900	1850	2300	3300	3800	2900
Est. flight time Δt **(min)**	4.5–4.0	6.2–5.6	7.6–7.0	4.5	5.6	8.0	9.2	6.9
Est. altitude ΔH **(km)**	88–70	170–140	250–210	88	140	280	370	210
Est. range Δx **(km)**	350–280	680–560	1000–860	350	560	1100	1500	840

Table E.4: Approximate values from known German (14-meter regular A-4), German-based Soviet (SS-1, SS-2, and SS-3), German-based French (Super V-2), and German-based U.S. (Redstone) rockets used to extrapolate characteristics of possible German extended A-4 rockets (18-meter and 21-meter versions) [data adapted from Jürgen Michels 1997; Uhl 2001; http://www.astronautix.com]. Extended German rockets may have also used kerosene (or other hydrocarbon fuel) and nitric acid oxidizer like the proposed Super V-2.

From Table E.4, note that the estimated altitude and range agree very well with the A-4 trajectory shown in Heinz Stoelzel's diagram in Fig. E.90.

E.7.3 Increasing the Exhaust Velocity of the Rocket Engine

Another way to improve the overall performance of the rocket would be to increase the exhaust velocity of the engine. This solution was presumably being pursued with better metal alloys and improved regenerative engine cooling systems to allow higher combustion temperatures, and improved fuels (especially liquid hydrogen) to lower the average molecular weight of the exhaust gas, since the range varies like:

$$\begin{aligned} \Delta x &\propto (\Delta v)^2 \propto v_{\text{exh}}^2 \\ &\propto \frac{T_{\text{chamber}}}{\text{M.W.}} \end{aligned} \tag{E.64}$$

Because the range is directly proportional to the engine combustion chamber temperature, using more heat-resistant materials and increasing the temperature from 2200^oK (standard for the A-4) to 3500^oK (typical for modern rockets) would increase the range by a factor of

$$\frac{3500^o\text{K}}{2200^o\text{K}} \approx 1.59 , \tag{E.65}$$

or approximately 59%. For example, the maximum range of the A-4 would increase from approximately 350 km to approximately 557 km.

It seems likely that A-4 engines with higher combustion temperatures would have been actively researched and possibly even mass-produced during the war:

a. There was an urgent wartime demand for rockets with longer ranges, especially after D-Day as rockets had to be launched from deeper and deeper into the European continent.

b. German-led engineering teams in postwar Allied countries made simultaneous and similar improvements to A-4 engine technology to raise the combustion temperatures.

c. There were a number of wartime and early postwar documents that mentioned "improved V-2s."

d. Rocket engine testing was so important that a number of testing facilities were built and operated in addition to Peenemünde. If the engine technology was standardized and remained unchanged, those engine testing sites are harder to explain. (Ordinary quality control would have required less extensive testing of some fraction of the mass-produced engines.)

Indeed, there is at least one photograph from a postwar U.S. report showing an advanced A-4 engine that was apparently mass-produced (p. 4833). Much more archival research should be conducted to determine the performance characteristics and production history of that and other advanced wartime rocket engines.

Since the range is inversely proportional to the molecular weight of the exhaust molecules, changing the fuel from ethanol or hydrocarbons to liquid hydrogen would reduce the average molecular weight from M.W. ≈ 27 (a mixture of roughly 1/3 CO_2 and roughly 2/3 H_2O) to M.W. = 12 (H_2O with some H_2, if a fuel-rich propellant mix is used) while keeping the combustion chamber temperature the same (2200^{o}K) would increase the range by a factor of

$$\frac{27}{12} \approx 2.25 , \tag{E.66}$$

or approximately 125%. For example, the maximum range of the A-4 would increase from approximately 350 km to approximately 788 km.

Both changing the fuel from ethanol to liquid hydrogen and increasing the combustion chamber temperature from 2200^{o}K to 3500^{o}K would increase the range by a factor of

$$\frac{3500^o\text{K}}{2200^o\text{K}} \frac{27}{12} \approx 3.58 , \tag{E.67}$$

or approximately 258%. For example, the maximum range of the A-4 would increase from approximately 350 km to approximately 1250 km.

Although liquid hydrogen is even more cumbersome than liquid oxygen, using it would yield a huge increase in range, whether or not the combustion chamber temperature could be increased. For this reason, there would have been very strong incentive for the German rocket program to pursue liquid hydrogen fuel. In fact, there is some evidence that it did so:

a. A 1944 prisoner of war report stated that German rockets using hydrogen fuel had been successfully tested (p. 4860).

b. A November 1945 conference presentation reporting details of postwar Allied investigations of the German rocket program mentions hydrogen fuel (p. 4993).

c. A 1946 U.S. intelligence report mentions wartime German hydrogen and oxygen production plants in conjunction with the report of V-2 and A-9 rocket programs that were taken over by Soviet forces (p. 5082).

d. Walter Dornberger mentioned wartime interest in liquid hydrogen to increase the performance of the A-4 (p. 5082).

e. Krafft Ehricke mentioned wartime research on liquid hydrogen for rockets (p. 5306).

f. Is there other evidence?

E.7.4 Adding a Booster Stage to the Rocket

Another solution to increase the rocket performance was to use two or more stages, such that the structural mass of each stage could be jettisoned once all of the propellant in that stage had been consumed. This solution is very effective and therefore widely used in modern launch vehicles, but it is also fairly complex as it requires the development and perfection of a larger and entirely new rocket engine and stage to serve as the first-stage booster of a smaller rocket.

In the wartime German rocket program, the best-known example of this approach was the A-9/A-10 two-stage rocket; Table E.5 gives approximate specifications for the A-9 and A-10 stages. The Silbervogel space plane may also be viewed as a two-stage system, in which the rocket-powered catapult booster sled was effectively the first stage and the rocket plane itself was the second stage. Table E.6 gives approximate specifications for that system. Exact values for the A-9/A-10 and Silbervogel specifications vary among different sources in the literature and for different versions of these systems[8], but the approximate values given in these tables are sufficient to estimate the performance of each system.

Characteristic	**Symbol**	**Approximate value**
Payload mass	m_{payload}	2000 kg
A-9 empty mass	m_{A9}	3000 kg
A-9 propellant mass	$m_{\text{A9 propellant}}$	12,000 kg
A-9 total initial mass	$(m_{\text{initial}})_2 = m_{\text{payload}} + m_{\text{A9}} + m_{\text{A9 propellant}}$	17,000 kg
A-9 total final mass	$(m_{\text{final}})_2 = m_{\text{payload}} + m_{\text{A9}}$	5000 kg
A-9 effective exhaust velocity	$(v_{\text{exh}})_2$	2000 m/sec
A-9 burn time	t_2	95 sec
A-9 thrust	$(F_{\text{thrust}})_2$	3×10^5 N
A-10 empty mass	m_{A10}	17,000 kg
A-10 propellant mass	$m_{\text{A10 propellant}}$	52,000 kg
A-9/A-10 total initial mass	$(m_{\text{initial}})_1 = m_{\text{payload}} + m_{\text{A9}} + m_{\text{A9 propellant}} + m_{\text{A10}} + m_{\text{A10 propellant}}$	86,000 kg
A-9/A-10 total final mass	$(m_{\text{final}})_1 = m_{\text{payload}} + m_{\text{A9}} + m_{\text{A9 propellant}} + m_{\text{A10}}$	34,000 kg
A-10 effective exhaust velocity	$(v_{\text{exh}})_1$	2000 m/sec
A-10 burn time	t_1	50 sec
A-10 thrust	$(F_{\text{thrust}})_1$	2×10^6 N

Table E.5: Specifications for estimating performance of A-9/A-10 rocket.

[8] Fritz Hahn 1998, Vol. 2, pp. 162–170; Hölsken 1994, p. 335; Huzel 1962, pp. 236–237; Ley 1968, pp. 390–392; Jürgen Michels 1997, pp. 35, 71–75; Miranda and Mercado 1996, pp. 65–80; Myhra 2002; Sänger and Bredt 1944; Hartmut Sänger 2006, p. 52.

Characteristic	**Symbol**	**Approximate value**
Payload mass	m_{payload}	2000 kg
Silbervogel empty mass	m_{plane}	10,000 kg
Silbervogel propellant mass	$m_{\text{plane propellant}}$	88,000 kg
Silbervogel total initial mass	$(m_{\text{initial}})_2 = m_{\text{payload}} + m_{\text{plane}} + m_{\text{plane propellant}}$	100,000 kg
Silbervogel total final mass	$(m_{\text{final}})_2 = m_{\text{payload}} + m_{\text{plane}}$	12,000 kg
Silbervogel effective exhaust velocity	$(v_{\text{exh}})_2$	3000 m/sec
Silbervogel burn time	t_2	168 sec
Silbervogel thrust	$(F_{\text{thrust}})_2$	1×10^6 N
Booster sled empty mass	m_{sled}	??
Booster sled propellant mass	$m_{\text{sled propellant}}$	?? kg
Sled + Silbervogel total initial mass	$(m_{\text{initial}})_1 = m_{\text{payload}} + m_{\text{plane}} + m_{\text{plane propellant}} + m_{\text{sled}} + m_{\text{sled propellant}}$	?? kg
Sled + Silbervogel total final mass	$(m_{\text{final}})_1 = m_{\text{payload}} + m_{\text{plane}} + m_{\text{plane propellant}} + m_{\text{sled}}$	?? kg
Booster sled effective exhaust velocity	$(v_{\text{exh}})_1$	2000 m/sec
Booster sled Δv	$(\Delta v)_1$	500 m/sec
Booster sled burn time	t_1	11 sec
Booster sled thrust	$(F_{\text{thrust}})_1$	?? N

Table E.6: Specifications for estimating performance of Silbervogel space plane.

Using the A-9/A-10 rocket specifications from Table E.5 in Eq. (E.32), the A-9/A-10 had a maximum velocity $\Delta v \approx 4300$ m/sec. Assuming $\sim 10\%$ loss for aerodynamic drag and gravitational losses, the effective maximum velocity was

$$(\Delta v)_{\rm A9/A10} \approx 3870 \text{ m/sec} \tag{E.68}$$

Using Eq. (E.68) in Eqs. (E.47), (E.50), and (E.52), the maximum altitude, flight time, and range of the A-9/A-10 rocket during its ballistic trajectory (not counting the subsequent gliding reentry using its wings) were:

$$(\Delta H)_{\rm A9/A10} \approx 380 \text{ km} \tag{E.69}$$

$$(\Delta t_{\rm ballistic})_{\rm A9/A10} \approx 9.3 \text{ min} \tag{E.70}$$

$$(\Delta x_{\rm ballistic})_{\rm A9/A10} \approx 1500 \text{ km} \tag{E.71}$$

Note that this maximum altitude and range agree very well with the early (ballistic) part of the A-9/A-10 trajectory shown in Heinz Stoelzel's diagram in Fig. E.90. This does not include the additional range from using the A-9's wings to follow a gliding trajectory after the ballistic trajectory; that effect will be calculated shortly.

Using the Silbervogel space plane/booster sled specifications from Table E.6 in Eq. (E.32), the two-stage Silbervogel system had a maximum velocity $\Delta v \approx 6860$ m/sec. Assuming $\sim 10\%$ loss for aerodynamic drag and gravitational losses, the effective maximum velocity was

$$(\Delta v)_{\rm Silbervogel} \approx 6170 \text{ m/sec} \tag{E.72}$$

Using Eq. (E.72) in Eqs. (E.47), (E.50), and (E.52), the maximum altitude, flight time, and range of the Silbervogel during its ballistic trajectory (not counting the subsequent skip and/or gliding trajectories using its wings) were:

$$(\Delta H)_{\rm Silbervogel} \approx 970 \text{ km} \tag{E.73}$$

$$(\Delta t_{\rm ballistic})_{\rm Silbervogel} \approx 15 \text{ min} \tag{E.74}$$

$$(\Delta x_{\rm ballistic})_{\rm Silbervogel} \approx 3900 \text{ km} \tag{E.75}$$

The effect of the Silbervogel's wings will be calculated shortly.

E.7.5 Adding Strap-on Boosters to the Rocket

Strap-on boosters could also improve the performance of rocket such as the A-4, just as they have been used to improve the performance of many modern launch vehicles such as the U.S. Space Shuttle, Titan, and Delta. Do any reports give the empty mass, propellant mass, exhaust velocity, burn time, and thrust of suitable strap-on boosters? If so, one can calculate how much they would improve the performance of an A-4, A-9, or other rocket.

E.7.6 Adding Wings to the Rocket

Wings would enable a rocket to execute a long gliding reentry into the atmosphere instead of a steep ballistic reentry, so that a rocket of the same size would have greatly extended range. This solution was being pursued with the winged A-9 and Silbervogel space plane, but it was more complex due to the large aerodynamic and heating loads on the reentering vehicle and the need for real-time onboard or remote human guidance during the tricky reentry phase to reach the intended target.

From Eq. (E.61), using wings to add a glide trajectory after a ballistic trajectory increases the total range by a factor of $[1 + (L/2D)]$. It also increases the total flight time by factor of $[1 + (L/\sqrt{2}D)]$.

Assuming a lift-to-drag ratio of $L/D \approx 5$, adding wings to a standard A-4 with a range of 350 km and a flight time of 4.5 min would produce an A-4b (or A-9) with a range and flight time of

$$(\Delta x_{\text{ballistic+glide}})_{\text{A4b}} \approx 1200 \text{ km} \tag{E.76}$$

$$(\Delta t_{\text{ballistic+glide}})_{\text{A4b}} \approx 20 \text{ min} \tag{E.77}$$

For this same lift-to-drag ratio of $L/D \approx 5$, adding wings to an A-9/A-10 with a range of 1500 km and a flight time of 9.3 min would yield a total range and flight time of

$$(\Delta x_{\text{ballistic+glide}})_{\text{A9/A10}} \approx 5300 \text{ km} \tag{E.78}$$

$$(\Delta t_{\text{ballistic+glide}})_{\text{A9/A10}} \approx 42 \text{ min} \tag{E.79}$$

Note that these ranges agree very well with those for the winged A-9 or A-9/A-10 trajectories shown in Heinz Stoelzel's diagram in Fig. E.90.

Assuming a lift-to-drag ratio of $L/D \approx 6.5$ for the Silbervogel, adding a glide (but no skips) would extend its purely ballistic range of 3900 km and flight time of 15 min to a total range and flight time of

$$(\Delta x_{\text{ballistic+glide}})_{\text{Silbervogel}} \approx 17{,}000 \text{ km} \tag{E.80}$$

$$(\Delta t_{\text{ballistic+glide}})_{\text{Silbervogel}} \approx 84 \text{ min} \tag{E.81}$$

Adding skips would extend the Silbervogel's range and flight time even further. The detailed effects of the skips are difficult to calculate precisely but will be addressed in Section E.7.7.

In general, the A-9/A-10 and Silbervogel plane/sled systems had many similarities. Both were two-stage rockets that launched a winged space plane on an intercontinental trajectory involving both ballistic and glide phases. However, Silbervogel was approximately 6 times larger than A-9 (100,000 kg vs. 17,000 kg), and over 50% faster, with a much more advanced trajectory (repeated skips) and more serious reentry stress and heating requirements. Even if experimental work did not get as far on it as the experimental work for the A-9/A-10, the Silbervogel was an incredibly advanced design for its time and the true predecessor of the U.S. Space Shuttle and other space planes. Its planned skip trajectory led to the double-dip reentry trajectory for returning missions from beyond Earth orbit, as will be discussed in Section E.7.7.

E.7.7 Decreasing Stresses During Atmospheric Reentry

Very simple mathematical models of reentry performance may be derived from first principles, and then applied to estimate the reentry deceleration, heating, and range of the A-4, A-9, and Silbervogel and show how they would compare to the reentry performance of modern ballistic missiles and spacecraft.

General considerations

The typical velocity of vehicles reentering the atmosphere from orbit may be found by considering a vehicle of mass m in a circular orbit just above the earth's atmosphere, say at a height $H = 150$ km above the earth's surface. Because H is much smaller than the radius of the earth $R_\oplus \approx 6380$ km, one may simply use $R_\oplus$ for the orbital radius and the surface value $g \approx 9.807$ m/sec^2 for the gravitational acceleration. In a circular orbit at velocity v_o, viewed in a rotating reference frame, the outward centrifugal force $mv_o^2/R_\oplus$ balances the inward gravitational force mg:

$$\frac{mv_o^2}{R_\oplus} = mg \ , \ \text{or} \tag{E.82}$$

$$v_o = \sqrt{gR_\oplus} \approx 7.91 \ \text{km/sec} \approx \text{Mach} \ 23 \tag{E.83}$$

At this speed, each kg of the vehicle has a kinetic energy 1 kg $\cdot \ v_o^2/2 \ \approx \ 3.13 \times 10^7$ J that is equivalent to the explosive energy of roughly 7 kg of TNT–the vehicle's energy is equivalent to seven times its mass in high explosives. This enormous kinetic energy must be safely dissipated before the vehicle reaches the earth's surface. A rocket could slow an orbiting vehicle to a stop, but such a decelerating rocket would need to be as large as the one that initially accelerated the vehicle to orbital speed, and then sending the decelerating rocket into orbit would require an unimaginably large initial launch vehicle.

The simplest solution is to use aerodynamic drag in the atmosphere to steadily dissipate a vehicle's kinetic energy before it lands. However, the reentry trajectory must be chosen so that both:

1. Deceleration of the vehicle is not too severe for the instrumentation or the passengers (if there are any). The deceleration must be prolonged over at least a few minutes to limit it to levels that can be tolerated by humans. At the upper limit of human endurance, a $\sim 10g \sim 100$ m/sec^2 deceleration would require 80 seconds to brake an initial velocity of 8000 m/sec, and a more readily tolerated $\sim 3g \sim 30$ m/sec^2 deceleration would require ~ 4.5 minutes.

2. Heating of the vehicle from aerodynamic drag is not too great. The kinetic energy ~ 30 MJ/kg that must be dissipated is 2-4 times larger than the energy required to vaporize most materials. Methods for safely dissipating this much energy without vaporizing the vehicle will now be discussed.

When air flow impacts a reentering vehicle, the kinetic energy density $\rho v^2/2$ of the flow relative to the vehicle is converted to thermal energy density $\rho c_p T$, heating the air to a temperature T far higher than the ambient air temperature. As the temperature rises, air molecules first are excited into higher energy states, then dissociate into individual atoms, and then finally are progressively stripped of their electrons and ionized. While the specific heat capacity at constant pressure c_p is a constant for air at lower temperatures, at higher temperatures c_p is a function of temperature, to account for these various effects. Air is mostly nitrogen, and monatomic nitrogen would have $c_p \approx 717.5$ J/(kg ^{o}K). As the nitrogen atoms are excited and partially ionized, they gain more degrees of freedom (the electrons can be in various energy levels), so c_p increases. The extent of excitation and ionization and hence the value of c_p vary over the temperature range characteristic of reentry, but in general a good value to use for Earth reentry is:

$$c_p \quad \approx \quad 5000 \ \frac{\text{J}}{\text{kg}\ ^{\text{o}}\text{K}} \tag{E.84}$$

A vehicle reentering at velocity v heats the flow directly impacting it (converting virtually all of the kinetic energy $\frac{1}{2}mv^2$ to thermal energy mc_pT, where m is the mass of the air) to a stagnation temperature of

$$T \quad \approx \quad \frac{v^2}{2c_p} \ \approx \ 10^{-4}\, v^2_{\text{m/sec}} \quad ^{\text{o}}\text{K} \tag{E.85}$$

For a vehicle with orbital velocity $v \sim 8000$ m/sec, the stagnation temperature is $T \sim 6400^o$K. This is high enough to melt or vaporize virtually all materials, and is even hotter than the surface of the sun, which is approximately 5800^oK.

Since the drag force per cross-sectional area of a vehicle is $C_D\rho v^2/2$ and power is the product of force and velocity, the rate at which a reentering vehicle's kinetic energy is converted to heat is $C_D\rho v^3/2$. Using a coefficient of drag $C_D \approx 2$ for a blunt hypersonic vehicle, the heat production rate is

$$q_{\text{total}} \quad \approx \quad \rho\, v^3 \ \frac{\text{W}}{\text{m}^2} \tag{E.86}$$

For a typical high-altitude atmospheric density $\rho \sim 10^{-4}$ kg/m^3 and vehicle velocity $v \sim 8000$ m/sec, the total heat production rate is an incredible $q_{\text{total}} \sim 50$ MW/m^2.

Fortunately, for a well-designed vehicle, only a small fraction of this heat is transferred to the vehicle, and the rest is imparted to the surrounding air. Ideally a reentry vehicle should have blunt instead of sharp leading surfaces, in order to minimize heating of the vehicle. At hypersonic speeds, a streamlined vehicle creates a weaker shock wave and heats the air less, but the vehicle absorbs much more of the heat that is generated, since the shock and boundary layers are so close to the vehicle, especially where the shock wave is attached at the vehicle's nose. (For such a streamlined design, reentry would first melt the nose, and then proceed to destroy the rest of the vehicle.) In contrast, a very blunt vehicle creates a stronger shock wave and heats the air more, but the vehicle absorbs much less of the heat that is generated, since the shock wave is detached from the vehicle, and the intervening boundary layer serves to insulate the vehicle from most of the heat. Thus modern reentry capsules have broad, flattened heat shields facing the oncoming flow, and modern space-shuttle-type reentry vehicles have blunt noses and rounded leading wing edges and also reenter at a high angle of attack with the flat underside facing the oncoming flow.

At the velocities that will be considered in this section, convection is the dominant mode of heat transfer, although at higher velocities, radiative heat transfer would also need to be considered. The heat transferred from a medium at temperature T_∞ through a boundary layer of thickness δ and thermal conductivity κ to a vehicle of surface temperature T_s and radius R is

$$q_{\text{vehicle}} \quad \approx \quad \frac{\kappa(T_\infty - T_s)}{\delta(R)} \tag{E.87}$$

The laminar boundary layer thickness for a vehicle of size R is $\delta \sim R/\sqrt{\mathrm{Re}_R}$, where Re_R is the Reynolds number, so the heat transfer is

$$q_{\mathrm{vehicle}} \sim \sqrt{\mathrm{Re}_R}\,\frac{\kappa(T_\infty - T_s)}{R} \tag{E.88}$$

Empirical measurements yield the best numerical factor for heat transfer to a sphere:

$$q_{\mathrm{vehicle}} \approx 2\sqrt{\mathrm{Re}_R}\,\frac{\kappa(T_\infty - T_s)}{R} \tag{E.89}$$

Assuming that the air temperature just beyond the boundary layer is the stagnation temperature $T_\infty = v^2/(2c_p)$, that the stagnation temperature is much higher than the vehicle temperature ($T_\infty \gg T_s$), and that the Reynolds number is $\mathrm{Re}_R = \rho v R/\mu$, Eq. (E.89) becomes

$$q_{\mathrm{vehicle}} \approx \frac{\kappa/c_p}{\sqrt{\mu}}\sqrt{\frac{\rho}{R}}\,v^{2.5} \approx \sqrt{\mu}\sqrt{\frac{\rho}{R}}\,v^{2.5} \tag{E.90}$$

in which Eq. (E.90) used the relation $\mu \approx \kappa/c_p$ from the Prandtl number for air, $\mathrm{Pr} = c_p\mu/\kappa \approx 1$.

The viscosity of air varies with temperature according to Sutherland's law. Assuming $\mu_0 \approx 1.72 \times 10^{-5}$ Pa·sec and $T_0 \approx 273^o$K, neglecting S in comparison to the temperatures, and using Eq. (E.85), the viscosity may be expressed as:

$$\mu \approx 1.0 \times 10^{-6}\sqrt{T_{^oK}}\,\frac{\mathrm{kg}}{\mathrm{m\ sec}} \approx 1.0 \times 10^{-8}\,v_{\mathrm{m/sec}}\,\frac{\mathrm{kg}}{\mathrm{m\ sec}} \tag{E.91}$$

Combining Eqs. (E.90) and (E.91), the heat transfer becomes

$$q_{\mathrm{vehicle}} \approx 1 \times 10^{-4}\sqrt{\frac{\rho}{R}}\,v^3\ \frac{\mathrm{W}}{\mathrm{m}^2} \tag{E.92}$$

Of course, a reentering vehicle is generally not spherical, and the precise local and total heat transfer rates will depend on the specific shape of the vehicle. However, Eq. (E.92) is extremely useful for obtaining initial estimates of reentry heat transfer before doing more detailed calculations.

Taking the ratios of Eqs. (E.92) and (E.86), the fraction of the heat transferred to the vehicle is

$$\frac{q_{\mathrm{vehicle}}}{q_{\mathrm{total}}} \approx 10^{-4}\frac{1}{\sqrt{\rho R}} \tag{E.93}$$

For ballpark values of high-altitude atmospheric density $\rho \sim 10^{-4}$ kg/m^3 and reentry capsule size $R \sim 1$ m, the ratio is $q_{\mathrm{vehicle}}/q_{\mathrm{total}} \sim 10^{-2}$. Thus only $\sim 1\%$ of the produced heat is imparted to the vehicle, but that is still a very considerable ~ 0.5 MW/m^2. Likewise, the boundary layer insulates the vehicle from the $\sim 6000^o$K stagnation temperature of the airflow, although heat transfer across the boundary layer can still heat the leading surfaces of the vehicle to 1000–2000^{o}K.

To protect the vehicle, these leading surfaces are covered by a heat shield. The underside of the U.S. Space Shuttle was covered with low-density tiles made of silica fibers (the tiles had a net density only $\sim 6\%$ that of solid silica, the remainder of the volume being empty space to minimize thermal conductivity) covered with black borosilicate paint, and the shuttle's nose and leading wing edges had tiles of carbon-carbon composite (graphite fibers for strength embedded in amorphous carbon for lower thermal conductivity than carbon lattices) better able to withstand the higher temperatures in those locations. Because these tiles were very good thermal radiators and insulators, they reradiated most of the heat they acquired back to the airflow, and conducted very little of the heat to the rest of the shuttle. Most other reentry vehicles are single-use and employ ablative heat shields that are gradually vaporized during reentry in order to remove the thermal energy they have absorbed before it can be conducted to the rest of the vehicle. For example, each U.S. Apollo command module used a fiberglass heat shield that was initially $\sim 25\%$ silica fibers and $\sim 75\%$ epoxy resin; after reentry most of the silica fibers remained, but the epoxy resin had been charred until only carbon remained from its initial composition.

Since the power dissipated by atmospheric deceleration is $\sim \rho v^3$, to limit deceleration and heating to tolerable levels, it is important to choose reentry trajectories that remain as high as possible (to minimize ρ) while the velocity v is still very large. Reentry trajectories suitable for different types of missions are shown in Fig. E.261: (a) ballistic reentry, (b) lifting reentry, (c) skip reentry, and (d) double-dip reentry.

The atmospheric density decays exponentially with increasing altitude, starting from the sea level value $\rho_o \approx 1.225$ kg/m^3. Physically, higher air weighs on lower air, making it more dense, and all of that weighs even more on air below that, making the density vary exponentially:

$$\rho \;=\; \rho_o\, e^{-H/H_o} \tag{E.94}$$

$$\text{where } H_o \;\equiv\; \frac{RT}{g} \;\approx\; 29.3\, T_{^o\mathrm{K}} \text{ m} \qquad \text{Atmospheric scale height} \tag{E.95}$$

The stratosphere is the most important layer of the atmosphere for reentry. For the temperature $T \approx 220$ ^{o}K typical of the stratosphere, the scale height is $H_o \approx 6.5$ km.

A vehicle of cross-sectional area A experiences aerodynamic drag D and lift L forces:

$$D \;=\; \frac{1}{2} C_D A \rho v^2 \tag{E.96}$$

$$L \;=\; \frac{1}{2} C_L A \rho v^2 \tag{E.97}$$

where the drag and lift coefficients C_D and C_L are assumed to be constant for simplicity.

Although centrifugal force is considered (in a rotating frame of reference that effectively follows the vehicle around the earth), curvature of the Earth with respect to the flight path is generally neglected in the following calculations.

To convert the equations of motion into an easily solvable form, reentry calculations commonly change the independent variable in differential equations by taking the ratio of derivatives, as will be shown.

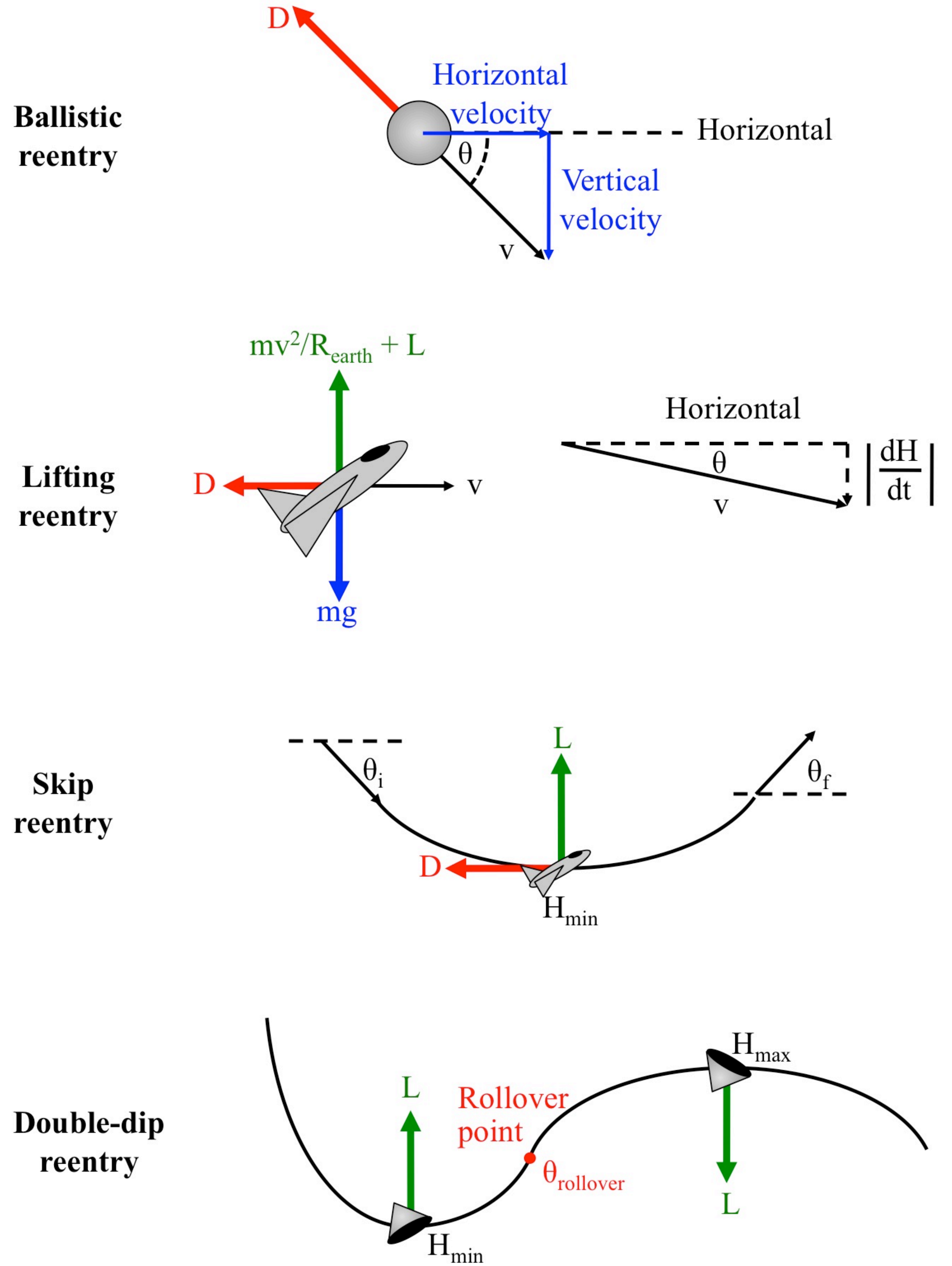

Figure E.261: Atmospheric reentry approaches include ballistic reentry, lifting-body reentry, skip reentry, and double-dip reentry.

A. Ballistic reentry

In a ballistic reentry (Fig. E.261), the vehicle cannot generate aerodynamic lift; this applies to many warheads and the Vostok and Mercury space capsules. The effective gravitational acceleration, the difference between the downward gravitational acceleration and the upward centrifugal acceleration, is between 0 and 1 g. (0 g would be a circular orbit with the gravitational and centrifugal forces balanced, and 1 g would be falling with no forward velocity.) As will be shown, the vehicle deceleration due to aerodynamic drag is far larger than this, so gravity and centrifugal force may be neglected. The vehicle's initial velocity v_i is typically of the order of v_o from Eq. (E.83). The pitch angle θ between the trajectory and the local horizontal is defined to be negative when downward; for simplicity it is assumed to be constant. Using Eq. (E.96), Newton's second law for the acceleration a along the trajectory is

$$a = \frac{dv}{dt} = -\frac{1}{2m} C_D A \rho v^2 \tag{E.98}$$

Taking the ratio of $d\rho/dH = -\rho/H_o$ [using Eq. (E.94)] and $dH/dt = -v\,|\sin\theta|$, one finds:

$$\frac{d\rho}{dt} = \frac{d\rho}{dH}\frac{dH}{dt} = \frac{\rho v}{H_o}\,|\sin\theta| \tag{E.99}$$

Equation (E.99) may be used to rewrite Eq. (E.98), changing the independent variable from t to ρ:

$$\frac{dv}{d\rho} = \frac{dv/dt}{d\rho/dt} = -\frac{C_D A H_o}{2m\,|\sin\theta|}\,v \tag{E.100}$$

Equation (E.100) is simply an equation for exponential decay, so its solution is

$$v = v_i \exp\left(-\frac{C_D A H_o}{2m\,|\sin\theta|}\,\rho\right) \tag{E.101}$$

$$= v_i \exp\left(-\frac{C_D A H_o \rho_o}{2m\,|\sin\theta|}\,e^{-H/H_o}\right) \tag{E.102}$$

Inserting Eq. (E.101) into Eq. (E.98) yields the acceleration as a function of the local density:

$$a = -\frac{C_D A \rho v_i^2}{2m} \exp\left(-\frac{C_D A H_o \rho}{m\,|\sin\theta|}\right) \tag{E.103}$$

Setting $d/d\rho$ of Eq. (E.103) equal to zero, one finds the density at which maximum deceleration occurs:

$$\frac{da}{d\rho} = -\frac{C_D A v_i^2}{2m} \exp\left(-\frac{C_D A H_o \rho}{m\,|\sin\theta|}\right)\left(1 - \frac{C_D A H_o \rho}{m\,|\sin\theta|}\right) = 0$$

$$\Longrightarrow \rho_{\text{max decel}} = \frac{m\,|\sin\theta|}{C_D A H_o} \tag{E.104}$$

Inserting Eq. (E.104) into (E.101) and (E.94) gives the velocity and altitude for the maximum deceleration:

$$v_{\text{max decel}} = e^{-1/2}\, v_i \approx 0.607\, v_i \tag{E.105}$$

$$H_{\text{max decel}} = H_o \ln\left(\frac{\rho_o}{\rho_{\text{max decel}}}\right) = H_o \ln\left(\frac{C_D A H_o \rho_o}{m\,|\sin\theta|}\right) \tag{E.106}$$

Note that for an object with a sufficiently large mass and small cross section for drag ($m/A \to \infty$), atmospheric drag does not slow an object much, and Eq. (E.106) predicts that maximum deceleration would not occur until a theoretical negative altitude, whereas of course the solid ground (not included in the equation) intervenes to cause maximum deceleration at $H = 0$. The reentry and impact of a large, dense meteorite would be a good example.

Plugging Eq. (E.104) into Eq. (E.103) gives the maximum deceleration:

$$\begin{aligned} |a|_{\text{max decel}} &= \frac{v_i^2\,|\sin\theta|}{2H_o e} = \frac{R_\oplus}{2H_o e}\;|\sin\theta|\,\left(\frac{v_i}{v_o}\right)^2\;\text{g} \\ &\approx 180\;|\sin\theta|\,\left(\frac{v_i}{v_o}\right)^2\;\text{g} \end{aligned} \tag{E.107}$$

From Eq. (E.107), the maximum deceleration is independent of the vehicle drag coefficient. For a given reentry angle, vehicles with different values of C_D experience the same maximum deceleration, though higher-drag vehicles experience it at a higher altitude, according to Eq. (E.106).

The deceleration can be over 100 g for $v_i \sim v_o$ and large reentry angles θ. This justifies the original assumption that the effective gravitational acceleration could be neglected. If the reentry angle could be made arbitrarily small, Eq. (E.107) shows that the deceleration would approach zero. Unfortunately, even in a ballistic reentry into the atmosphere from a circular orbit with $v_i = v_o$, the decelerating vehicle will begin to lose altitude as its decreasing upward centrifugal acceleration fails to balance the downward gravitational acceleration, so there is a minimum achievable value of θ and hence a minimum achievable value for the peak deceleration. At the point of maximum deceleration, this difference between the gravitational and centrifugal forces produces a net downward effective gravitational acceleration of

$$|g_{\text{effective}}|_{\text{max decel}} = g - \frac{(v_o/\sqrt{e})^2}{R_\oplus} = \frac{e-1}{e}\,g \tag{E.108}$$

Assuming that θ is small, the vehicle's horizontal velocity at the point of maximum deceleration is approximately

$$\frac{v_o}{\sqrt{e}} = v_o - |a|_{\text{avg}}\,\Delta t \tag{E.109}$$

$$\Longrightarrow \Delta t = \frac{v_o}{|a|_{\text{avg}}}\,\frac{\sqrt{e}-1}{\sqrt{e}}\;, \tag{E.110}$$

in which Δt is the time between the beginning of reentry and the point of maximum deceleration, and $|a|_{\text{avg}}$ is the average deceleration during that time.

Similarly, for small θ the downward vertical velocity at the point of maximum deceleration is approximately

$$\frac{v_o}{\sqrt{e}}\,\theta \;=\; |g_{\text{effective}}|_{\text{avg}}\;\Delta t \tag{E.111}$$

$$\Longrightarrow\; \theta \;=\; (\sqrt{e}-1)\,\frac{|g_{\text{effective}}|_{\text{avg}}}{|a|_{\text{avg}}} \tag{E.112}$$

$$\approx\; (\sqrt{e}-1)\,\frac{|g_{\text{effective}}|_{\text{max decel}}}{|a|_{\text{max decel}}}\;, \tag{E.113}$$

which may be used to find the minimum achievable ballistic reentry angle.

Inserting Eqs. (E.115) and (E.107) into Eq. (E.113) and solving for θ yields

$$\theta \;=\; \left[\frac{(\sqrt{e}-1)(e-1)}{180e}\right]^{1/2} \;\approx\; 0.0477\text{ radians} \quad (\text{or } \; 2.73^o) \tag{E.114}$$

$$|a|_{\text{max decel}} \;=\; 180\theta\text{ g} \;\approx\; 8.6\text{ g} \tag{E.115}$$

The Soviet Vostok and U.S. Mercury capsules executed a shallow-angle ballistic reentry and hence experienced $\sim 8-9$ g of deceleration, at the upper limit of what their pilots could tolerate. Reducing $|a|_{\text{max}}$ below this value requires aerodynamic lift, so that the spacecraft can remain longer at very high altitudes, where the air is less dense and the aerodynamic drag less severe.

For a Vostok or Mercury reentry with typical values $H_o \approx 6500$ m, $C_D \approx 2$, $A \sim 3$ m^2, $\rho_o \approx 1.225$ kg/m^3, $m \sim 2000$ kg, and $\theta \approx 0.0477$, Eqs. (E.104) and (E.106) indicate that maximum deceleration for a capsule reentering from circular orbit occurs at an atmospheric density $\rho_{\text{max decel}} \approx 2 \times 10^{-3}$ kg/m^3 and an altitude $H_{\text{max decel}} \approx 40$ km.

Inserting Eq. (E.101) into Eq. (E.92), the heat transfer rate to the vehicle during ballistic reentry is

$$q_{\text{vehicle}} \;\approx\; 1\times 10^{-4}\, v_i^3 \sqrt{\frac{\rho}{R}}\, \exp\left(-\frac{3C_D A H_o}{2m\,|\sin\theta|}\,\rho\right)\;\frac{\text{W}}{\text{m}^2} \tag{E.116}$$

Using Eq. (E.116) and setting $dq_{\text{vehicle}}/d\rho = 0$, one finds that the maximum heat transfer occurs when the atmospheric pressure is

$$\rho_{\text{max heat}} \;=\; \frac{m\,|\sin\theta|}{3C_D A H_o} \;=\; \frac{1}{3}\,\rho_{\text{max decel}}\;, \tag{E.117}$$

or $\rho_{\text{max heat}} \sim 7\times 10^{-4}$ kg/m^3 for the Vostok/Mercury case.

Inserting Eq. (E.117) into Eq. (E.116) gives the maximum heat transfer:

$$q_{\text{vehicle, max}} \approx 1 \times 10^{-4}\, v_i^3 \sqrt{\frac{m\,|\sin\theta|}{3eC_D A H_o R}}\ \frac{\text{W}}{\text{m}^2} \tag{E.118}$$

For a Vostok or Mercury capsule with $v_i = v_o \approx 8000$ m/sec, $m \sim 2000$ kg, $\theta \sim 0.0477$, $C_D \approx 2$, $A \sim 3$ m^2, $H_o \approx 6500$ m, and $R \sim 1$ m, the maximum heat transfer is $q_{\text{vehicle, max}} \sim 1$ MW/m^2. As predicted by Eqs. (E.86) and (E.93), this is indeed only a small fraction of the total generated heat, although it is still a large number and required a very good ablative heat shield.

On the other hand, a reentering A-4 (or a warhead or capsule separated from an A-4, if that were done) would have a much lower initial velocity than the Vostok and Mercury capsules, since it would not be coming from orbit. From Table E.4, a typical value for the A-4 would have been more like $v_i \approx 1750$ m/sec, or around 0.22 of orbital velocity (8000 m/sec). Assuming for simplicity that all other parameters were roughly the same, Eq. (E.118) shows that the maximum heat transfer to the A-4 would have been roughly $(1750/8000)^3 \approx 0.01$ times as large as that for reentering orbital capsules, or $q_{\text{vehicle, max}} \sim 10$ kW/m^2, a much more manageable number. Of course, that is the peak heat transfer on a reentry trajectory designed to be as shallow as possible in order to minimize the deceleration and heating. An A-4 on a steeper reentry trajectory would experience greater heating.

Inserting Eq. (E.117) into Eq. (E.101) and (E.94) gives the velocity and altitude for the maximum heating:

$$v_{\text{max heat}} = e^{-1/6}\, v_i \approx 0.846\, v_i \tag{E.119}$$

$$H_{\text{max heat}} = H_o \ln\left(\frac{\rho_o}{\rho_{\text{max heat}}}\right) = H_o \ln\left(\frac{3C_D A H_o \rho_o}{m\,|\sin\theta|}\right) \tag{E.120}$$

$$= H_o \ln\left(\frac{3C_D A H_o \rho_o}{m\,|\sin\theta|}\right) + H_o \ln 3 \approx H_{\text{max decel}} + 1.10 H_o \tag{E.121}$$

Thus the point of maximum heating occurs earlier during reentry than the point of maximum deceleration, or when the vehicle is approximately 1.1 $H_o \approx 7$ km higher.

B. Lifting-body reentry

Lifting reentry (Fig. E.261) covers the case in which the vehicle generates aerodynamic lift as well as drag. For simplicity, the ratio of the lift and drag forces from Eqs. (E.97) and (E.96), $L/D = C_L/C_D$, is assumed to remain constant during the reentry, and the initial velocity is assumed to be the orbital velocity v_o from Eq. (E.83). Because very small angles minimize the deceleration (as shown for ballistic reentry) and the vehicle now has lift to help support it, one can assume that the trajectory is essentially horizontal.

Neglecting vertical acceleration, the downward gravitational and upward centrifugal and lift forces must balance:

$$mg = \frac{mv^2}{R_\oplus} + L \tag{E.122}$$

Using Eq. (E.97) for L in Eq. (E.122) and solving for the velocity v yields:

$$mg = \frac{mv^2}{R_\oplus} + \frac{1}{2}C_L A\rho v^2 \tag{E.123}$$

$$\Longrightarrow v = \frac{v_o}{\sqrt{1+\frac{R_\oplus C_L A\rho}{2m}}} = \frac{v_o}{\sqrt{1+\frac{R_\oplus C_L A\rho_o}{2m}\,e^{-H/H_o}}} \tag{E.124}$$

$$\approx \sqrt{\frac{2mg}{C_L A\rho_o}}\,e^{H/2H_o} \tag{E.125}$$

The approximation in the last step is valid once the velocity is low enough that the centrifugal force is much smaller than the lift.

Equation (E.122) may be turned around into a form that will be useful in a moment:

$$\frac{1}{m} = \frac{g}{L}\left[1-\left(\frac{v}{v_o}\right)^2\right] \tag{E.126}$$

Newton's second law along the trajectory is:

$$\frac{dv}{dt} = -\frac{D}{m} \tag{E.127}$$

Substituting Eq. (E.126) into Eq. (E.127), one finds the acceleration:

$$\frac{dv}{dt} = -g\,\frac{D}{L}\left[1-\left(\frac{v}{v_o}\right)^2\right] \tag{E.128}$$

Thus the magnitude of the deceleration increases as the velocity v decreases, asymptotically approaching gD/L:

$$|a|_{\text{max decel}} \;=\; \frac{D}{L}\;\text{g} \tag{E.129}$$

The Gemini, Apollo, and Soyuz capsules had a lift-to-drag ratio $L/D \approx 0.5$, giving a maximum deceleration ~ 2 g, much better than the earlier Mercury and Vostok. The U.S. Space Shuttle's lift-to-drag ratio was $L/D \approx 2.5$, so its peak deceleration was even more gentle, ~ 0.4 g. A-9 would have had $L/D \approx 5$, or a ~ 0.2 g peak deceleration. Silbervogel would have had $L/D \approx 6.5$, or a ~ 0.15 g peak deceleration during the gliding portion of its terminal trajectory. (Silbervogel would have experienced brief periods of greater acceleration during its skips off the atmosphere before that; see p. 5360.)

The reentry trajectory of a lifting body actually deviates from the horizontal by a small negative (downward) angle θ, which may be found from the relation:

$$\sin\theta \;=\; \frac{1}{v}\,\frac{dH}{dt} \;=\; \frac{1}{v}\,\frac{dv/dt}{dv/dH} \tag{E.130}$$

Taking the derivative d/dH of both sides of Eq. (E.125) produces

$$\frac{dv}{dH} \;=\; \frac{Lv}{2mgH_o} \tag{E.131}$$

Inserting Eqs. (E.127) and (E.131) into Eq. (E.130), one finds:

$$\sin\theta \;=\; 2\,\frac{D}{L}\,\frac{H_o g}{v^2} \tag{E.132}$$

Equation (E.132) shows that the magnitude of θ increases (the vehicle drops more rapidly) as the velocity v decreases, since there is less centrifugal force and lift to keep the vehicle aloft.

θ is small enough that the approximation $\sin\theta \approx \theta$ is valid. Using a mid-reentry value of the velocity, $v \sim v_o/2$, yields an estimate of θ during reentry:

$$\theta \;\sim\; 8\,\frac{D}{L}\,\frac{H_o}{R_\oplus} \;\approx\; \frac{D}{L}\,0.5^{\,o}\,, \tag{E.133}$$

validating the initial assumption of nearly horizontal flight.

The ground range Δx travelled during reentry may be estimated from θ and the altitude drop during that time, say $\Delta H \sim 2H_o$:

$$\Delta x \;\sim\; \frac{\Delta H}{\sin\theta} \sim \frac{2H_o}{\theta} \sim \frac{1}{4}\,\frac{L}{D}\,R_\oplus \tag{E.134}$$

Since the U.S. Space Shuttle had $L/D \approx 2.5$, Eq. (E.134) shows that it could travel $\sim$ 4000 km during reentry. Thus the reentry began very far from the actual landing site. Because the shuttle had no fuel to maneuver during landing, it arrived at the landing site with excess altitude to ensure that it would not fall short of the runway. If the extra altitude was not needed for contingencies, the shuttle banked back and forth to burn off the extra altitude before approaching the runway.

Inserting Eqs. (E.94) and (E.124) into Eq. (E.92), the heat transfer to a lifting reentry vehicle is

$$q_{\text{vehicle}} \approx 1 \times 10^{-4} \sqrt{\frac{\rho_o}{R}}\, v_o^3\, e^{-H/2H_o} \left(1 + \frac{R_\oplus C_L A \rho_o}{2m}\, e^{-H/H_o}\right)^{-3/2} \frac{\text{W}}{\text{m}^2} \qquad \text{(E.135)}$$

Setting $dq_{\text{vehicle}}/dH = 0$ and solving for H yields the altitude where peak heat transfer occurs:

$$H_{\text{max heat}} = H_o \ln\left(\frac{R_\oplus C_L A \rho_o}{m}\right) \qquad \text{(E.136)}$$

Inserting Eq. (E.136) into Eq. (E.135), the maximum heat transfer to a lifting reentry vehicle is

$$q_{\text{vehicle, max}} \approx 5 \times 10^{-5}\, v_o^3 \sqrt{\frac{\rho_o m}{R R_\oplus C_L A \rho_o}} \quad \frac{\text{W}}{\text{m}^2} \qquad \text{(E.137)}$$

As a good number to keep in mind for comparison, sunlight warms an absorbing surface with a heat transfer rate of approximately 1.4 kW/m^2 above the Earth's atmosphere (or somewhat less on Earth's surface, after the atmosphere has filtered out some of the solar radiation).

For a Space Shuttle reentry with typical values $H_0 \approx 6500$ m, $R_\oplus \approx 6.38 \times 10^6$ m, $C_L \approx 2$, $A \sim 400$ m^2, $\rho_o \approx 1.225$ kg/m^3, and $m = 1 \times 10^5$ kg, Eq. (E.136) indicates that maximum heat transfer occurs at an altitude $H_{\text{max heat}} \sim 70$ km, or an atmospheric pressure $\rho_{\text{max heat}} = m/(R_\oplus C_L A) \sim 2 \times 10^{-5}$ kg/m^3. Also using the representative values $R \sim 20$ m and $v_o \approx 8000$ m/sec, the maximum heat transfer is $q_{\text{vehicle, max}} \sim 25$ kW/m^2, or ~40x lower than the ballistic case. Note that the large lift means the decelerating vehicle can stay much higher in the atmosphere much longer than a ballistic vehicle with no lift, changing the point of maximum heating to a much higher altitude, much lower atmospheric density, and much lower peak heat transfer. In fact, the heat transfer is sufficiently low that silica tiles were sufficient to insulate the vehicle and re-radiate the heat to the surrounding atmosphere, whereas higher heat transfer values would require single-use ablative heat shields.

Neglecting relatively insignificant changes in the other parameters in Eq. (E.137), the main difference between the U.S. Space Shuttle and the older German spacecraft that were under development was velocity. The Space Shuttle had to reenter from an orbital velocity $v \approx 8000$ m/sec. The German vehicles did not have to reach orbit and would have had lower velocities. Because the velocity is cubed in Eq. (E.137), their heat transfer rates were much lower.

For the A-9 by itself (launched without the A-10 booster stage), the maximum velocity would have been $v \approx 1750$ m/sec (based on the A-4 from Table E.4), so the maximum heat transfer during reentry would have been $q_{\text{vehicle, max}} \sim 0.26$ kW/m^2, much smaller even than solar heating. Thus reentry heating would not have been a problem at all, at least with a properly chosen trajectory.

For the A-9 launched from the A-10 booster stage, the maximum velocity would have been higher, $v \approx 3870$ m/sec from Eq. (E.68). The maximum reentry heat transfer would have been $q_{\text{vehicle, max}} \sim 2.8$ kW/m^2, only about twice as much as solar heating, and roughly nine times smaller than the heating experienced by the U.S. Space Shuttle. Again, reentry heating would not have been a problem with a properly chosen trajectory.

For Silbervogel, the maximum velocity would have been even higher, $v \approx 6170$ m/sec from Eq. (E.72). The maximum reentry heat transfer would have been $q_{\text{vehicle, max}} \sim 11$ kW/m^2, still less than half the heating experienced by the U.S. Space Shuttle. Silbervogel also would have experienced this heating for a shorter period of time than the Space Shuttle, since it would not have been coming all the way from orbital velocity. Suitable metal alloys might have withstood and re-radiated the heat during Silbervogel's reentry while insulation protected the interior, or ablative coatings could have been added to the exterior. The greatest problem with Silbervogel's design is that heating would have been concentrated at the sharp leading edges of the vehicle, as opposed to the rounded leading edges of the Space Shuttle. However, because realistically the Silbervogel would not have been reused if launched during wartime, whereas the Space Shuttle was designed to be reused for many flights, this level of heating could have been acceptable.

Thus from this simple theoretical analysis, it appears that there are no fundamental reasons why an A-9, A-9/A-10, or Silbervogel could not have survived reentry.

C. Skip reentry

If desired, a vehicle can skip off the upper atmosphere like a fast-moving flat rock skipping off the surface of a pond, and this is called a skip reentry (Figs. E.260 and E.261). This was the main idea of Silbervogel, which would have used rocket power to achieve a suborbital flight and then would have repeatedly skipped off the atmosphere to travel most of the way around the Earth before reentering for a final time and landing. One skip with initial velocity v_i will be considered here to illustrate the basic principle.

Gravity and centrifugal force are negligible relative to the strong aerodynamic forces involved in skipping off the atmosphere. Newton's second law parallel and perpendicular to the trajectory is

$$m\,\frac{dv}{dt} = -D \tag{E.138}$$

$$mv\,\frac{d\theta}{dt} = L \tag{E.139}$$

Taking the ratio of Eqs. (E.138) and (E.139) gives the variation of velocity with vehicle pitch angle,

$$\frac{dv}{d\theta} = \frac{dv/dt}{d\theta/dt} = -\frac{D}{L}\,v \tag{E.140}$$

Equation (E.140) describes exponential decay due to drag during the skip, so its solution is

$$v = v_i \exp\left[-\frac{D}{L}(\theta - \theta_i)\right] , \tag{E.141}$$

in which θ_i is the initial pitch angle for atmospheric entry. If the vehicle does not lose much of its velocity during the skip, its pitch angle θ_f leaving the atmosphere is approximately the mirror image of the angle entering the atmosphere, $\theta_f = -\theta_i$, like a light ray reflecting off a surface. Using these angles in Eq. (E.141) yields

$$v_f = v_i \exp\left(-2\theta_i \frac{D}{L}\right) \tag{E.142}$$

Newton's second law perpendicular to the trajectory in Eqs. (E.138) and (E.139) indicates that

$$\frac{d\theta}{dt} = \frac{C_L A \rho v}{2m} \tag{E.143}$$

An equation for the altitude may be found by taking the ratio of $dH/dt = v \sin\theta$ and Eq. (E.143):

$$\begin{aligned} \frac{dH}{d\theta} &= \frac{dH/dt}{d\theta/dt} = \frac{2m\sin\theta}{C_L A \rho} \\ &= \frac{2m\sin\theta}{C_L A \rho_o e^{-H/H_o}} \end{aligned} \tag{E.144}$$

Separating variables in Eq. (E.144) and integrating gives the minimum altitude during the skip:

$$\begin{aligned} \frac{C_L A \rho_o}{2m} \int_{\infty}^{H_{\min}} dH\, e^{-H/H_o} &= \int_{\theta_i}^{0} d\theta\, \sin\theta \\ \Longrightarrow \quad H_{\min} &= H_o \ln\left[\frac{C_L A \rho_o H_o}{2m(1-\cos\theta_i)}\right] \end{aligned} \tag{E.145}$$

Pilots are generally happier if $H_{\min}$ is greater than 0, which means that the argument of the logarithm in Eq. (E.145) must be greater than 1. For small values of θ_i, the approximation $\cos\theta_i \approx 1 - \theta_i^2/2$ may be used, and the positive altitude requirement reduces to:

$$\theta_i^2 < \frac{C_L A \rho_o H_o}{m} \tag{E.146}$$

Thus skipping requires a small entry angle θ_i and/or large coefficient of lift C_L.

Using Eq. (E.145), the atmospheric density at the minimum altitude is

$$\rho_{\text{at min}} = \rho_o\, e^{-H_{\min}/H_o} = \frac{2m(1-\cos\theta_i)}{C_L A H_o} \tag{E.147}$$

The maximum acceleration is lateral due to the lift and occurs at the minimum altitude:

$$
\begin{aligned}
|a|_{\max} &= \frac{L_{\text{atmin}}}{m} = \frac{C_L A \rho_{\text{at min}} v_{\text{at min}}^2}{2m} \\
&= \frac{v_i^2}{H_o}(1-\cos\theta_i)\exp\left(-2\theta_i\,\frac{D}{L}\right) \\
&\approx 490\left(\frac{v_i}{v_o}\right)^2 \theta_i^2 \exp\left(-2\theta_i\,\frac{D}{L}\right) \ \text{g}
\end{aligned}
\tag{E.148}
$$

Using $v_i \sim v_o$ and $\theta_i = 5^o \approx 0.087$ rad and neglecting the exponential factor yields $|a|_{\max} \approx 3.7$ g.

The ground range Δx traversed while the angle changes by $\Delta\theta$ may be estimated from Eq. (E.143):

$$
\Delta\theta \sim \frac{C_L A \rho}{2m}\, v\,\Delta t \sim \frac{C_L A \rho}{2m}\,\Delta x \tag{E.149}
$$

Using Eq. (E.149) with $\Delta\theta = 2\theta_i$, the ground range covered during the entire skip maneuver is

$$
(\Delta x)_{\text{skip}} \sim \frac{2m}{C_L A \rho_{\text{atmin}}}\, 2\theta_i = \frac{2\theta_i}{1-\cos\theta_i}\, H_o \approx \frac{26\ \text{km}}{\theta_i}\,, \tag{E.150}
$$

which is ~ 300 km for $\theta_i = 5^o \approx 0.087$ rad. The range travelled above the atmosphere between each skip would be much larger than that (Fig. E.260).

In addition to suborbital bombers, skip reentries are extremely useful for aerobraking, or slowing an interplanetary spacecraft into orbit when it arrives at its target planet. By plotting the spacecraft's trajectory so that its perigee slightly dips into the planet's upper atmosphere, one can cause the spacecraft to lose enough velocity to lower its apogee from infinity (escape velocity) to some finite value for an orbit around the planet. If the velocity loss on one skip is not too great, just the trajectory of the spacecraft tangentially grazing the curved atmosphere of the planet is enough to cause the spacecraft to "pull up" from the skip, even if the vehicle is not capable of lift. In practice, though, it is better to employ lift as in the skip example calculated above, since it affords much more control over the aerobraking process to deal with fluctuations in atmospheric density. If necessary to minimize the forces and heating the spacecraft experiences during each skip, several successive passes through a planet's atmosphere with a small skip each time can be used to aerobrake from very large initial velocities.

D. Double-dip reentry

Skip reentries are also useful as part of a more complicated maneuver called a double-dip reentry (Fig. E.261), which is used by spacecraft returning to the Earth from deep space, such as in the Apollo missions to the moon.

E.8 Conclusions

This final section gives a brief overview of some possible combinations of payloads and delivery vehicles, as well as broader conclusions based on information in this and the other appendices.

While rocket pioneers such as Hermann Oberth and Wernher von Braun always wanted to use rockets to carry scientific instruments or astronauts to explore space, and jet pioneers such as Hans von Ohain hoped to utilize faster aircraft to improve transportation networks, wartime priorities and wartime funding compelled the creators of new aerospace vehicles to consider methods of using those vehicles to deliver destructive payloads to military targets.

E.8.1 Payloads

Military payloads that were used or planned may be divided into several categories:

- Conventional explosives. These were extensively used with the V-1 cruise missile, A-4 or V-2 liquid propellant ballistic missile, Rheinbote solid propellant ballistic missile, and a wide variety of aircraft. Yet the enormous expense of developing such vehicles, and the great difficulty of successfully sending many of them to distant Allied targets, strongly suggest that conventional explosives were not the primary intended payload, but only an interim measure while other payloads were being perfected or debated.

- Fuel-air explosives. Although fuel-air explosives also use conventional explosives, they disperse those in the air before igniting them, then combust them with oxygen from the air, so the resulting blast affects a much larger area than a conventional bomb with the same amount of explosive would. Beginning in the 1930s, large teams of German-speaking scientists developed and demonstrated fuel-air explosives. By the end of the war, fuel-air explosive bombs weighing up to several tons each had been mass-produced and stockpiled (pp. 538–555). Such fuel-air explosives could have been intended for delivery by aircraft or by large missiles.

- Biological weapons. According to official histories, Germany's wartime work on biological weapons was only defensive (developing methods to protect against biological weapons) instead of offensive (developing biological weapons and methods to disseminate them). Yet as shown by the examples in Section A.3, many credible wartime and early postwar documents from archives mentioned offensive development of biological weapons, and even mass production and packaging of such weapons into deployable bombs. Since so many other relevant documents were either destroyed or remain buried in classified archives, the details of the German biological weapons program are even more mysterious than those of the German nuclear weapons program. Nonetheless, if biological weapons were indeed produced, they could have been intended for delivery by a wide range of aircraft, missiles, or other methods.

- Chemical weapons. The nerve agents tabun and sarin were mass-produced and packaged into bombs in wartime Germany (Section 3.5). Soman was produced and tested on an experimental scale, and could potentially have been packaged into bombs before the end of the war. The even more deadly V-series nerve agents were invented, synthesized, and tested during the war (Section A.4); it is possible that they were produced on a large scale. Germany also produced a number of chemical weapons other than nerve agents, ranging from highly corrosive chemicals to endothermic reactions reported to cause freezing conditions. Any of those chemical weapons could potentially have been delivered by aircraft, missiles, or other means.

- Nuclear weapons, including fission bombs (Section D.8), fusion bombs (H-bombs, Section D.9), and radiological weapons (radioactive "dirty" bombs, p. 4724). There is considerable evidence that fission bombs were successfully tested during the war (Sections D.10, D.11, and D.12), and that a hydrogen bomb was nearing completion when the war ended (Section D.9). Given the enormous amount of resources that would have been invested in developing nuclear weapons, and Germany's desperate state late in the war, there must have been concrete plans and methods for delivering such weapons to Allied targets, including targets in the United States. In the usual German fashion, several different delivery methods, including aircraft and large missiles, were probably developed in parallel.

E.8.2 Delivery Vehicles

There is significant evidence that Germany was developing the following specific methods to deliver weapons of mass destruction (especially nuclear weapons) to Allied targets such as New York and Washington, D.C.:

1. There is documentary evidence for intercontinental bomber aircraft, and for nuclear weapons designed to be dropped by such aircraft (often dropped with a parachute, indicating that the expected blast was so large that the aircraft needed more time to escape to a safe distance after dropping the bomb). See for example:

Erwin Respondek (p. 3949)

Werner Grothmann (pp. 4010 and 4145)

Edmund Tilley (p. 4078)

Stars and Stripes, *Washington Post*, and other major newspapers (p. 4749)

Hermann Goering (p. 4752)

Alexander P. de Seversky (p. 4754)

Chicago Daily Tribune (p. 4754)

Allen Dulles (p. 4755)

German prisoner of war (p. 4756)

Henry H. Fowler (pp. 4756–4757)

Convair (p. 4758)

Albert Ducrocq (p. 4768)

Roy Fedden (p. 4795)

New York Times (p. 4948)

Other postwar Allied discoveries of intercontinental jet bombers intended to attack the United States (Section E.1)

2. There is documentary evidence that V-1 cruise missiles were modified to attack the United States with a payload sufficiently destructive to justify the mission. There were several different versions of the V-1 that could be ground-launched, submarine-launched, or air-launched from a large aircraft, and that were either unmanned or manned. See for example:

Allied discoveries of piloted and air-launched V-1 missiles (p. 1835)

Interrogation of Edmund Sorg regarding nuclear-armed V-1 missiles (pp. 4466–4467)

Hans Kammler's 23 April 1945 telegram ordering the destruction of special V-1s near Berlin to prevent them from being captured by Russian forces (p. 4467)

Allied intelligence reports on submarine-launched V-1 missiles intended to attack the United States (pp. 5161–5170)

3. There is a great deal of evidence that the A-4 (V-2), A-9/A-10, Silbervogel, or other rockets were intended and even fully built to carry nuclear weapons. (Such rockets were primarily ground-launched, although the A-4 or smaller rockets could be submarine-launched.) See for example:

Hermann Zumpe (p. 4082)
Wernher von Braun (pp. 4084–4085)
Eugen Sänger and Irene Bredt (p. 4086)
G. Ward Price (p. 4088)
Defense Minister Rodolfo Graziani (p. 4089)
Air Intelligence Report (p. 4091)
OSS, October 1944 (p. 4118)
Luigi Romersa (p. 4142)
Felix Kersten (p. 4166)
Wilhelm Wulff (p. 4167)
General Ivan Ilyichev (p. 4182)
Igor Kurchatov (4192)
Horst Kirfes (p. 4228)
German film captured by Soviets (p. 4229)
Swiss intelligence report (p. 4274)
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E.8.3 Forgotten History

History is a series of factual events that actually occurred. Something either really happened, or really did not. An event either happened one way, or it happened another way. Afterward, different sources may make contradictory claims about what happened, or all references to a particular historical event may be silenced or erased. As a result, it may not be possible to know exactly what happened at certain places and times in the past, yet that does not change the fact that concrete events and actions did in fact occur.

Conventional history almost uniformly paints a particular picture of advanced weapons technology during and after World War II. According to conventional history, Germany experimented with nerve agents but never considered using them for fear of Allied chemical weapons. According to conventional history, Germany never produced nuclear weapons, biological weapons, or fuel-air bombs. According to conventional history, Germany never built intercontinental jet bombers, V-1 cruise missiles capable of striking the United States, or any rockets with larger sizes or longer ranges than the A-4 (V-2). According to conventional history, the V-1 and V-2 programs were foolish and counterproductive for Germany. According to conventional history, the steady march toward Allied victory was simply a matter of time, drawn out only by an irrational German stubbornness to admit the inevitable defeat. According to conventional history, the United States and United Kingdom demonstrated technological superiority over Germany by inventing radar, building and exploding the first fission bombs, and winning World War II. According to conventional history, the United States further proved its own inherent technological superiority after the war by inventing the hydrogen bomb, jet fighters, stealth technology, smart bombs, transistors, computers, lasers, plastics, the contraceptive pill, and biotechnology, as well as by winning the Space Race and the Cold War.

That conventional history, taught nearly worldwide and learned by heart for 75+ years, appears to be a fictional canvas that was painted by a combination of people who knew it was false and others who hoped it was true. That fictional canvas is punctured and torn by large numbers of highly placed Allied and German sources quoted in this book, by more that could be cited, and by others that remain yet to be discovered in archives. Behind that tattered canvas lies the true history of wartime and postwar advanced technologies.

Documents record that German-speaking scientists invented and successfully demonstrated jet fighters, radar, stealth technology, smart bombs, transistors, computers, plastics, the contraceptive pill, and biotechnology, and were developing lasers when the war ended. Documents record that all of those creations and countless others were transferred to the United States, which later claimed credit for them. Documents record that German-controlled territory was filled with an interconnected infrastructure of hundreds of high-tech research and manufacturing sites from Norway to Strassburg (Strasbourg) to Budapest to Königsberg (Kaliningrad), many of them in huge, fully furnished underground installations, some of them even equipped with video conferencing systems and computers. Documents record that wartime Germany successfully developed fuel-air bombs, chemical weapons up to advanced V-series nerve agents, biological weapons, and fission bombs, and that it was close to finishing a hydrogen bomb when the war ended. Documents record that wartime Germany built at least 40 intercontinental jet bombers, several different types of rockets larger than the A-4, and at least two different types of piloted space planes. Documents record that weapons of mass destruction were integrated with delivery vehicles corresponding to all elements of the modern nuclear triad—ground-launched intercontinental missiles, submarine-launched missiles, and intercontinental jet bombers—for missions to Allied targets, including U.S. cities.

Then the Allies won.

What happened, what really happened? The conventional historical explanation that those advanced German technologies never existed is simply untenable in the face of so much evidence. Perhaps the weapons of mass destruction or their delivery vehicles were not quite ready before the end of the war, slowed by Allied attacks, sabotage, or mismanagement by senior German officials. Maybe the weapons and vehicles were ready, but their numbers and their probability of success were too small for it to be strategically useful to employ them late in the war. It could be that the novel threat of mutual assured destruction (MAD, by primitive but effective chemical weapons from the Allied side, and by nuclear, biological, and advanced chemical weapons from the German side) constrained both sides to fight the war to its end using only conventional weapons. Perhaps during the war, the Allies secretly contacted key German officials, such as Hans Kammler, and made it far more personally rewarding for those officials to turn over German advanced weapons technologies to the Allies than to employ them against the Allies. Or maybe some combination of those factors is the true explanation.

There are countless questions that still need to be answered, vast amounts of evidence that still must be sought in classified archives and industrial archaeological excavations. What is certain is that the real history of wartime and postwar technology does not resemble the fictions that have been repeated in history books, documentaries, and films for 75+ years. The real history, the full story, was far more dramatic than that.

And it deserves to be told.

Bibliography

Jeder, der den ganzen Verlauf der wissenschaftlichen Entwickelung kennt, wird natürlich viel freier und richtiger über die Bedeutung einer gegenwärtigen wissenschaftlichen Bewegung denken als derjenige, welcher, in seinem Urtheil auf das von ihm selbst durchlebte Zeitelement beschränkt, nur die augenblickliche Bewegungsrichtung wahrnimmt.

They that know the entire history of the development of science, will, as a matter of course, judge more freely and more correctly of the significance of any present scientific movement than they, who limited in their views to the age in which their own lives have been spent, contemplate merely the momentary trend that the course of intellectual events takes at the present moment.

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Newspaper articles, series of government reports, and archival references are given in separate lists later in the Bibliography.

Last names with von or vom retain that prefix, but are alphabetized as if it were not there.

Names, dates, and abbreviations used to cite each reference in the book are indicated in bold red font. Dates for newspapers are given as year-month-day, as in 1945-04-30.

I hope that this Bibliography, including its topical sections and especially its sections of report titles and archival locations, will serve as a useful roadmap for other researchers to investigate some of these topics more deeply and to make additional historical discoveries in the future.

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NYT 1944-10-22 p. E5. Germans Are Still Striving to Perfect New V Weapons.

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NYT 1945-04-18 p. 6. Picture: Zeiss Plant in Ruins.

NYT 1945-04-19 p. 5. Big Rubber Factory Near Leipzig Seized.

NYT 1945-05-15. U-Boat Aimed V-Bomb Here, Army Paper Says.

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NYT 1945-06-16 p. 15. German Synthetic Rubber Data Brought Back To U.S. By Experts.

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NYT 1945-07-07 pp. 1, 3. Use of [German] Armament Seized in Europe Ask in Pacific.

NYT 1945-07-07 p. 5. Disposal of German War Material Poses Severe Problem for Allies.

NYT 1945-07-08 p. 4. Russia Said to Strip U.S. [Claimed] Plants in Reich.

NYT 1945-07-10 p. 4. Reich War Power Declared Strong [By Sen. H. M. Kilgore Report].

NYT 1945-07-15 p. E7. Aloofness of Scientists Condemned.

NYT 1945-07-17 p. 2. Berlin's Factories Stripped by Soviet.

NYT 1945-07-26 p. 6. 2,000 Reich Planes Found By British.

NYT 1945-07-29 p. 18. U.S. Gets Secrets Of Reich Industry.

NYT 1945-08-03 p. 1. Germany Stripped Of Industry By Big 3.

NYT 1945-08-05 p. 6. Soviet Said to Get Its Yalta Demand [half of movable Reich property].

NYT 1945-08-08 p. 15. German Industry Grew under Raids–Coal a Major Problem.

NYT 1945-08-09. Hitler Bluff Reported. [Luftwaffe General Wolfgang von Chamier-Glisczinski

was apparently in charge of coordination between the rocket and nuclear programs. He seems to have been killed in the August 1943 Allied bombing of Peenemünde, although he was "officially" reported to have been killed in an unrelated plane crash in Croatia that month.]

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NYT 1945-08-24 p. 8. German War Scientists Will Work For Our Forces.

NYT 1945-08-27 p. 10. 17-Minute Oversea Rocket Plane Among Germany's War Secrets.

NYT 1945-08-28 p. 15. Industry Will Get Enemies' Secrets.

NYT 1945-09-18 p. 4. Interrogation Camps Hold 225 High Nazis. ["Dust Bin"]

NYT 1945-09-21 p. 5. Synthetic Blood Plasma Developed by Germany.

NYT 1945-09-25 p. 10. Industrial Plots of Germans Bared.

NYT 1945-09-26 p. 8. U.S. Allies to Get 5 Plants In Reich.

NYT 1945-09-30 p. 25. U.S. Will Transfer 11 More Reich Plants.

NYT 1945-09-30 p. 16. Reich Technicians Brought To Boston.

NYT 1945-10-02 p. 2. Germans Will Aid U.S. In War Research.

NYT 1945-10-04 pp. 1, 14. Truman to Seize Oil Plants Today.

NYT 1945-10-05 p. 2. Russia Would Take Big Plants in Reich.

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NYT 1945-10-09 p. 5. Reich Device Mines Coal without Drilling or Blasting.

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NYT 1945-10-11 p. 4. Opel's Equipment Sought by Russians.

NYT 1945-10-11 p. 6. 75% of Industries in Reich Survived.

NYT 1945-10-13 p. 3. Allies Confiscate 300 Farben Plants.

NYT 1945-10-15 p. 4. Russians Believed Near Atom Secret. [Bornholm]

NYT 1945-10-21 p. 1. Smash I. G. Farben Empire, Eisenhower Advises Allies.

NYT 1945-10-27 p. 4. U.S. Set to Blast Reich Arms Plant.

NYT 1945-10-27 p. 4. Bearings Plants Dismantled.

NYT 1945-10-31 p. 6. Russia Confident on Bomb. [Bornholm]

NYT 1945-11-04 p. 31. German Arms Plant Destroyed.

NYT 1945-11-08 p. 8. Will Give Nazi Fuel Data.

NYT 1945-11-14 p. 11. 90 German Scientists Coming.

NYT 1945-11-17 pp. 1, 6. 88 German Scientists Reach Here.

NYT 1945-11-18 p. 20. Reich Experts Identified.

NYT 1945-11-20 p. 5. 5 More Arms Plants Doomed in Germany.

NYT 1945-11-22 p. 16a. Ten U-Boats for Russia to be Yielded in Ulster.

NYT 1945-11-22 p. 16b. Russian Seizures in Austria Aired.

NYT 1945-11-22 p. 17. U.S. Plans To Sell German Machines.

NYT 1945-11-26 p. 23. Ickes Pushes Test Of Synthetic Fuel [German Process].

NYT 1945-11-28 pp. 33, 36. Calls Gr-S Rubber Synthetic Leader.

NYT 1945-12-02 p. E9. German Synthetic Fuel.

NYT 1945-12-07 p. 4. 25 More Scientists Here From Germany.

NYT 1945-12-11 p. 4. 26 German Plants Divided By Allies.

NYT 1945-12-13 p. 8. Army Cartel Expert Sees Farben Threat.

NYT 1945-12-23 p. 7. 26 German Plants Ready For Delivery.

NYT 1945-12-30 p. 5. U.S. Said To Pamper Nazi Industrialists.

NYT 1946-01-02 p. 26. Synthetic Rubber to Ease Shortage.

NYT 1946-01-02 p. 32. 3 of 725 Research Scientists for Farben Retained.

NYT 1946-01-06 p. 20. Factories on Sale in Germany Listed.

NYT 1946-01-09 p. 15. Americans Prepare Reparations Plan.

NYT 1946-01-09 p. 14. 28 Aircraft Plants to Be Razed.

NYT 1946-01-10 p. 17. Allies Set Limit on German Steel.

NYT 1946-01-10 p. 20. Hahn, Atom-Splitter, Was Held in Britain.

NYT 1946-01-17 p. 14. 21 Farben Plants Wiped Out By U.S.

NYT 1946-01-17 p. 42. Asks Rubber Plan Before Plants Go.

NYT 1946-01-24 p. 26. Norwegian Skiers Played Big Role in Resistance against the Nazis.

NYT 1946-01-25 p. 4. German Guns to Be Tested.

NYT 1946-01-27 p. 11. Germans Ship Synthetic Rubber. [to Russia]

NYT 1946-01-29 p. 1. Russians Operating Czech Uranium Mine.

NYT 1946-01-29 p. 5. Austrians to Build Radios–for Others.

NYT 1946-02-11 p. 30. Big German Guns Arrive.

NYT 1946-02-15 p. 6. 130 German Scientists Are At Work In U.S. On Experiments For The Army And Navy.

NYT 1946-02-15 p. 6. U.S. Seen 'Fumbling' Its Job in Germany–Germany Seen as Vacuum.

NYT 1946-02-18 p. 3. U.S. Urged To Free Nazi Scientists Barred From Working By Politics.

NYT 1946-02-18 p. 8. German Fuel Patents Available.

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NYT 1946-02-25 p. 2. Bohemian Raids Gambled Lives to Recover German Documents.

NYT 1946-02-28 p. 2. Secret Arms Maker Seized in Germany.

NYT 1946-03-01 p. 1. Army To Use V-2 Bombs To Test Radar As Atom-Rocket Defense.

NYT 1946-03-03 p. 23. Russian Denies Interview—Mukden General Says He Did Not Tell of Looting Factories.

NYT 1946-03-08 p. 2. Austrians See Drain by Soviet on Output. [Russians taking all synthetic rubber]

NYT 1946-03-08 p. 5. Infa-Red Ray Gave German Sniper Edge.

NYT 1946-03-09 p. 6. Germans [Scientists] To Aid British.

NYT 1946-03-11 p. 30. German Data On Dyes Are Available Here.

NYT 1946-03-14 p. 44. German Patents To Aid U.S. Plants.

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NYT 1946-03-24 p. 18. Russians To Strip 600 German Mills.

NYT 1946-03-29 p. 10. German Industry Gets Allies' Bill.

NYT 1946-04-02 p. 12. Map Showing N.Y. City As Target For German Rocket.

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NYT 1946-04-12 p. 11. German Rocket in White Sands N. M.

NYT 1946-04-17 p. 13. Germany Moving Out Factory Equipment.

NYT 1946-04-20 p. 6. American Plants in Germany in Use.

NYT 1946-04-22 p. 6. V-2 Rockets To Test Upper Atmosphere.

NYT 1946-04-24 p. 14. U.S. To Get 4,209,000 Tons of Germany's Shipping.

NYT 1946-04-30 p. 1. German Research for War Banned by Control Council.

NYT 1946-05-07 p. 3. The V-2 Ready For Launching At White Sands.

NYT 1946-05-08 p. 34. Germany's Research On Color Film Told.

NYT 1946-05-13 p. 4. Washington Gives Plans Of German Helicopters.

NYT 1946-05-22 p. 4. Russians Said To Use German War Experts.

NYT 1946-06-19 p. 13. Nazi [Captured Poison Gas] Bombs Fell 40 In Alabama.

NYT 1946-06-23 p. 3. Our Army Drains A Deadly German Gas Bomb.

NYT 1946-06-29 p. 11. German V-2 Sets The Altitude Record At U.S. Army, Navy Test.

NYT 1946-07-05 p. 4. Russians Increase German Industry-Reparations in Kind.

NYT 1946-07-06 p. 12. New Tube Expands Radio Possibilities.

NYT 1946-07-11 p. 5. Russia for Seizing 200 German Firms.

NYT 1946-07-25 p. 6. Allies Will Share 11 German Plants.

NYT 1946-08-02 p. 1. Soviet 'Take' From 4 Losers Now Set At $3,000,000,000.

NYT 1946-08-03 p. 7. Russians Charge Looting of Reparations from Plants in U.S. Zone of Germany.

NYT 1946-08-07 p. 11. Reparations Wait on German Unity.

NYT 1946-08-09 p. 8. 100,000 German Patents Available.

NYT 1946-08-26 p. 7. 200 German Firms Seized By Soviet.

NYT 1946-08-27 p. 12. Transfers Of Plants From American Zone To Russia Ahead Of Schedule.

NYT 1946-09-10 p. 16. Russians Take 90% Of Zeiss Output.

NYT 1946-10-09 p. 22. German Plant Ask as U.S. Reparations.

NYT 1946-10-10 p. 5. 14 Countries Score Reparations Lag—Germans Urge Revision.

NYT 1946-10-19 p. 25. General Aniline and Film Wants Assurances for the Future.

NYT 1946-10-20 p. 30. 658 German Plants Listed For Payment.

NYT 1946-10-24 p. 14. Seizure Of 3,000 [Germans] Laid To Russians—Human Reparations.

NYT 1946-10-27 p. 32. Germans Report More Removals—310 Plants In Thuringia Removed And Sent To Russia.

NYT 1946-10-29 p. 10. Germans Strike Against Removals.

NYT 1946-11-01 p. 16. Germans Going To Britain–Ten Technicians Sign Voluntary Contracts For Work.

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NYT 1946-11-04 p. 15. Soviet Said To Enlist Physicians In Berlin.

NYT 1946-11-13 p. 5. Army To Tell Its Use Of German Scientists.

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NYT 1946-11-28 p. 16. Uranium Field In Poland.

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NYT 1946-12-04 p. 36. Nazi Scientists Aid Army On Research.

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NYT 1946-12-06 p. 17. Hahn Says Soviet Lags In Cyclotrons–Hints At 'Kidnapping' Of German Scientists.

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NYT 1946-12-17 p. 18. 3,000,000 Axis POW on Siberian Projects.

NYT 1946-12-21 p. 4. Former German Officers Reported Sent To Russia.

NYT 1946-12-28 p. 7. Soviet Seen Ready To Shift Workers–Technicians Are Needed In The East.

NYT 1946-12-28 p. 6. German Progress in Paying Own Way.

NYT 1946-12-30 p. 21. Citizenship Opposed For Nazi Scientists.

NYT 1946-12-31 p. 24. Synthetic Rubber 73% of the 1946 Total.

NYT 1947-01-04 p. 6. Nazis Sent To U.S. As Technicians.

NYT 1947-02-12 p. 10. Nazi U-Boat Ideas Aid [U.S.] Navy.

NYT 1947-02-16 p. 3. U.S. Said To Seize German Patents.

NYT 1947-02-23 pp. SM33–35. George H. Copeland. Nazi Science Secrets: A Technological Treasure Hunt in Conquered Germany Enriches U.S. Research and Business.

NYT 1947-02-24 p. 1. Soviet Said To 'Buy' [German] Atom Men.

NYT 1947-02-24 p. 26. Synthetic Rubber Held Vital To U.S.

NYT 1947-03-01 p. 5. German Atom Expert Kept from Argentina.

NYT 1947-03-02 p. 17. Reich Kin Join [German] Scientists [in Texas].

NYT 1947-05-17 p. 2. German Scientists' Help Said To Save Us 10 Years.

NYT 1947-05-18 p. 42. 'Get Tough' Policy In Germany Begins.

NYT 1947-05-18 p. 45. Nazi Rocket Base In Complete Ruin: Russians Open Up Peenemuende for First Time.

NYT 1947-05-19 pp. 1, 11. Scientists See U.S. Vulnerable To Germ Warfare.

NYT 1947-05-25 p. 42. Synthetic Blood Plasma: 'Periston,' Used By Germans In War, Chemists Are Told.

NYT 1947-05-26 p. 35. German Secrets Net U.S. $1,500,000: 400,000 Copies of Documents Already Sold to Industry—Russia Good Customer. [6000 U.S. industry experts sent to Germany in search of files, patents, and factories]

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BIOS 87.

BIOS 88. *Lehr Spinnerei (Model Spinning Mill) Denkendorf.*

BIOS 89.

BIOS 90. [Albumen]

BIOS 91.

BIOS 92. *Production of Acrylonitrile at Leverkusen Plant of I. G. Farbenindustrie.*

BIOS 93. *German Leather Goods and Ancillary Industry.*

BIOS 94. *Kalie-Chemie Rhenania Phosphat Werke, Brunsbüttelkoog.*

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BIOS 97. *Interrogation of German Technicians Engaged on the Design of Turretry and Gun Mountings for Armoured Fighting Vehicles.*

BIOS 98. *Report on German Development of Gas Turbines for Armoured Fighting Vehicles.*

BIOS 99. *Development of German Panzerfaust and Other Hollow Charge Weapons.*

BIOS 100. *Development of Panzerfaust.*

BIOS 101. *German Large Fatigue Testing Machines.*

BIOS 102. *German Electric Detonators, Caps and Fuzeheads.*

BIOS 103. *"Komet"—Installation. A Proposed German Long Range Radio Navigational Aid.*

BIOS 104.

BIOS 105. *Interrogation of Dr. Heinrich Langweiler.*

BIOS 106. *Textile Finishing Machinery for Cotton & Rayon Piece Goods.*

BIOS 107. *Production of a Phosphate Fertiliser by Sintering of Phosphate Rock with Sodium Sulphate and Lignite.*

BIOS 108.

BIOS 109. *Report on German Steel Foundries.*

BIOS 110. *Drägerwerk Factories at Lübeck, Hamburg and Uetersen.* [Protective clothing, respiration filters, sensors, etc. for chemical warfare]

BIOS 111. *Production of Flour and Bread in Germany.*

BIOS 112. *Interim Report of Freon-12 at I. G. Works, Hoechst.*

BIOS 113.

BIOS 114.

BIOS 115. *Report on the Interrogation of Dr. Kurt Stenge.*

BIOS 116. *Pharmaceuticals: Research and Manufacture at I.G. Farbenindustrie.* With supplement. [very large and detailed report]

BIOS 117. *Electrical Dynamometer.*

BIOS 118. *Munich Technical High School. Interrogation of Dr. E. H. Kadmer and Dr. K. Schnauffer.*

BIOS 119. *Deutsche Versuchsanstalt für Luftfahrt (D.V.L.) Institut für Betriebstoff Forschung.*

BIOS 120. *Wirtschaftliche Forschungsgesellschaft m.b.H. Hitzacker Depot.*

BIOS 121. *Wirtschaftliche Forschungsgesellschaft m.b.H. (WIFO), Heiligenstadt Installation.*

BIOS 122. *Wirtschaftliche Forschungsgesellschaft m.b.H. Interrogation of Herr Helmut Plote of the Construction Department.*

BIOS 123. *RATO and Walther propulsion.*

BIOS 124.

BIOS 125. *Ernst Beuttler Werke, Dinglingen, Near Lahr.*

BIOS 126.

BIOS 127. *The Aluminum Fabricating Plant of Aluminium Wals-on Persbedrljvon N. V., Utrecht, Holland.*

BIOS 128.

BIOS 129. *Some Phases of German Electrical Utility Practice.* [Electricity in Berlin]

BIOS 130. [CW]

BIOS 131. *German Spring Making Industry.*

BIOS 132. *Production and Further Investigation of Wesch Anti-Radar Material.*

BIOS 133. *Visit to Brunswick Region to Study German Developments in Mechanics of Materials Applied to Armaments.*

BIOS 134.

BIOS 135.

BIOS 136. *Investigation of Koepe Winding Practice in the Ruhr District of Germany and the Limburg District of Holland.*

BIOS 137. *Cyclopolyolefines (Paper by Dr. J. W. Reppe, I.G. Farben Research Chemist).* With Appendix.

BIOS 138. [CW]

BIOS 139.

BIOS 140. *The Work Done During the War by the Static Unit of the D.V.L.*

BIOS 141.

BIOS 142. *Information Obtained from Targets of Opportunity in the Sonthofen Area.* [Zuse, atomic aircraft, fuel-air explosives, Josef Ernst, von Ardenne, Zippermayr, etc.]

BIOS 143. *German Porous Ceramic Industry.*

BIOS 144. *Wrought Light Alloy Plants in North-West Germany.*

BIOS 145. *Technical High School, Munich.*

BIOS 146. *Air and Oil Filtration in Germany.*

BIOS 147. *Reciprocating Aero Engines (Daimler Benz).*

BIOS 148. *German Betatrons.*

BIOS 149. *Report on Visit to H. Maihak A.G., Hamburg.*

BIOS 150. *Some Aspects of the German Leather Industry.*

BIOS 151. *German Aluminum and Magnesium Melting and Rolling Practices.*

BIOS 152. *Developments in Protective Clothing in Germany.*

BIOS 153. *Miscellaneous German Radio and Communication Targets.*

BIOS 154. *Turntable for German Railway Gun. 28 cm. K 5 (E).*

BIOS 155. [Synthetic fibres]

BIOS 156. *Vereinigte Glanzstoff G.m.b.h. 14–16 Auerschule Strasse, Elberfeld, Wuppertal.*

BIOS 157.

BIOS 158. *Production of Beryllia and Beryllium at Degussa Plants.*

BIOS 159. *Report on Visit to Aerodynamische Versuchsanstalt Göttingen.* [Canadian team]

BIOS 160. *Luftforschungsanstalt Hermann Göring Volkenrode, Brunswick.* [Canadian team]

BIOS 161. *Interview with Dr. Barchfeld, Chemist at Dynamit A.G. at Troisdorf.*

BIOS 162.

BIOS 163. *Some German Aircraft Armament Projects with Particular Reference to Fire Control Developments.*

BIOS 164. *German Oil Seal Manufacturers.*

BIOS 165. *German Shuttle Block Industry.*

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BIOS 168.

BIOS 169. [Lofer—missing at IWM]

BIOS 170. *Visits to American and French Zones. Aircraft and Aircraft Engines.*

BIOS 171. *Catalytic Hydrogenation of Acetylene to Ethylene, Dr. Alexander Wacker Ges. für Elektrochemische Industrie, Burghausen.*

BIOS 172. *Continental Gummiwerke—"Excelsior" Factory, Limmer, Hanover.* [Rubberized clothing for CW protection]

BIOS 173. *Gummiwaren Fabrik Pheonix, Harburg/Hamburg.*

BIOS 174. *Hanauer Gummischuh Fabrik A.G., Hanau am Main.*

BIOS 175. *Dräger Werke, Lübeck and Hamburg.* [CW protective clothing]

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BIOS 178. *Textile Testing in Germany.*

BIOS 179. *German Cable Industry.*

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BIOS 182. *German Coast Artillery Equipment Employed in the Defence of the West Coast of Denmark.*

BIOS 183. *Report on Investigation of the Design and Operation of High Voltage Networks in Central Germany.*

BIOS 184. *German Camera Industry.*

BIOS 185. *The Cellulose Plastics Industry in Germany.*

BIOS 186. *Dehydrated Potatoes and Vegetables.*

BIOS 187. [CW]

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BIOS 192. *Supersonic Wind Tunnels and Static Testing of V2.*

BIOS 193.

BIOS 194.

BIOS 195. *Interrogation of Personnel of Elektro-Mekanische Werke.* [Rockets]

BIOS 196. *German Rayon Industry.*

BIOS 197. *Reichsinstitut für Erdolforschung, Technische Hochschule, Hannover.*

BIOS 198.

BIOS 199. *"Ten Years of Oxygen-Gasification at Leuna" by Oberingenieur Sabel.*

BIOS 200. *Organisation of Deutsche Versuchsanstalt für Luftfahrt (D.V.L.).*

BIOS 201. *Visit to C.H.F. Müller AG Röntgenstr. 24 Bahrenfeld, Hamburg.*

BIOS 202.

BIOS 203. *The Non-destructive Testing of Materials and X-Ray Protection Methods.*

BIOS 204. *Hochfrequenz Forschungsinstitut of Dr. Plendl, Thumersbach, Austria.*

BIOS 205. *The K.W.I. für Eisen Forschung Düsseldorf.* [X-ray stress measurement]

BIOS 206.

BIOS 207. *The Magnetophon of A.E.G. 150 Hohenzollern Damm. Berlin/Grunewald.* [short and grumpy]

BIOS 208. *Acoustics Laboratories of the Physikalische Technische Reichsanstalt Göttingen.*

BIOS 209.

BIOS 210. [Submarine anti-sonar coating]

BIOS 211. *Infra-red Research, Dr. A. Becker, 36 Blumenthal Strasse, Heidelberg.*

BIOS 212. *Ultra-sonic Research and Development in X-Ray Equipment. Siemens-Reiniger Werke, AG Erlangen.* [6 MeV betatron]

BIOS 213. *Siemens-Halske Werke, Erlangen.*

BIOS 214. *Non-destructive Testing of Materials, Siemens-Werner Werk "M", Berlin/Siemenstadt.* [ultrasonic sonograms of objects]

BIOS 215. *Interview with Prof. Dr. Rudolf Hase, Bismark Strasse, Gehrden.* [IR bolometer]

BIOS 216. *Report on Visits to (1) the Technical High School, Darmstadt, (2) C. F. Boehringer und Söhne, Mannheim—Waldhof, (3) Dr. Freudenberg, Heidelberg University, (4) Dr. Wolman, Wood Preservation Specialist, Bad Kessingen, (5) Imbert Gas Producer Plant, Cologne.*

BIOS 217.

BIOS 218. *Investigation of Planetaria.*

BIOS 219. *Work on Synthesis and Production of Drugs 3065 (2:2^1-Dihydroxy-5:5^1-Dibrome Benzil) and 3214 (2:2^1-Dihydroxy-3:3^1-5:5^1-Tetrachlor Benzil).*

BIOS 220. *Citric acid from fermentation process.*

BIOS 221. *Propeller Development at V.D.M., Frankfurt am Main.*

BIOS 222.

BIOS 223. *Visit to Austro-American Magnesite Co., Radenthein, Austria.*

BIOS 224. *German Underwater Ballistics.*

BIOS 225. *German Gear Cutting Plant, Gear Manufacturing Technique and Design Development.*

BIOS 226. *Metallised Paper Capacitors.*

BIOS 227. *Manufacture of Harmonicas (Mouth Organs) and Accordions.*

BIOS 228.

BIOS 229. *Wrought Light Alloy Plants in Southern Germany.* [Aluminum]

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BIOS 232. *Production of Tantalum at the Works of Siemens and Halske.*

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BIOS 235.

BIOS 236. *Developments in Pure and Applied Microbiology (American, British and French Zones) During World War II.* [lots of biotech]

BIOS 237. *Housing Research of the Institut f"ur Technische Physik, Technische Hochschule Stuttgart.*

BIOS 238. *Visit to Mahle Kom. Ges. Pragstrasse 26, Stuttgart, Bad Cannstadt.*

BIOS 239.

BIOS 240. *Synthetic Tanning Agents and Leather Auxiliary Products of the I. G. Farbenindustrie.*

BIOS 241.

BIOS 242. *Lurgi Apparatebau G.m.b.H. Electro Filter Section.*

BIOS 243.

BIOS 244. *I.G. Hoechst and Ludwigshafen, Manufacture of Sulphuric Acid, I.G. Converter Design and Vanadium Catalyst.*

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BIOS 246.

BIOS 247. *German Chemical Plant with Particular Reference to Centrifuges.*

BIOS 248. *The Radio Valve and Lamp Industry in Vienna.*

BIOS 249. *Rockets and Guided Missiles.*

BIOS 250. *German Research into Increasing Range and Performance of Flame Throwers.*

BIOS 251. *German Landing Gear, Design and Testing.*

BIOS 252. *I. G. Photopapier Fabrik (AGFA), Leverkusen, Near Cologne.*

BIOS 253. *Production of Silumin Alloys, Horrem.*

BIOS 254. *German Aircraft Industry.*

BIOS 255. *Gas Turbine and Reciprocating Engine Activities.* [piezo sensors, etc.]

BIOS 256. *Phosphoric Acid and Sodium Phosphates in Germany.* [Synthetic citric acid]

BIOS 257. *Metallgesellschaft A.G., Frankfurt, Chemicals for Phosphating Iron and Steel.*

BIOS 258. *Carbon Electrodes, I.G. Farben, Griesheim.*

BIOS 259.

BIOS 260.

BIOS 261. *Hydrofluoric Acid Vereinigte Flusspathgruben G.m.b.H. Stulln.*

BIOS 262. *German Photographic Film Base Industry.*

BIOS 263. *Part I. I.G. Farben Industrie-Oppau Works, Ludwigshafen (Report on Nickel and Iron Powder Plants. Part II. Nord Deutsche Affinerie, Hamburg (Report on the Treatment of Nickel-Copper Ores and Residues).*

BIOS 264. *German Brass and Copper Wire Industry.*

BIOS 265. *The German Bichromate and Chrome Compound Industry.*

BIOS 266. *New Technical Applications of Acetylene.* With Appendix. [Periston]

BIOS 267.

BIOS 268. *German Test Equipment for Materials and Vehicle Components.*

BIOS 269. *A Survey of Some Aspects of German Development on Power Plants and Air Compressors Suitable for A.F.V.*

BIOS 270. *Investigations in Germany by Tank Armament Research, Ministry of Supply.*

BIOS 271.

BIOS 272. *Some Aspects of German Work on High Temperature Materials.* [High temp jet materials + SiC]

BIOS 273. *Symposium of Interrogations and Reports on German Methods of Statistical Reporting.*

BIOS 274. *Technical Developments in German Margarine Industry.* With Addendum.

BIOS 275. *Food Preservation with Special Reference to the Application of Refrigeration.*

BIOS 276. *Telefunken Gesellschaft für Drahtlose Telegraphie m.b.h., Berlin; Special Materials for Radio Valves.*

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BIOS 278. *Preliminary Survey of the German Hydraulic Industry.*

BIOS 279. *German Technique in the Production of Light Alloys.*

BIOS 280. *Interrogation of Professor Alexander von Philippovich. Petroleum Technologist.*

BIOS 281. *German Circular Lace Braiding Machine Building Industry.*

BIOS 282. *German Casein Plastics Industry.*

BIOS 283. *Precision Machine Tools and Gauges.* With Appendix.

BIOS 284. *German Production of Guns, Gun Mountings and Carriages and Small Arms.*

BIOS 285. *Structural Work at Focke-Wulf, Bad Eilson.*

BIOS 286. *Krupps, Essen and Incorporating Information on Luftfahrtgerätewerke, Hakenfeld Berlin and Activities by Dudenhausen at Rietberg.*

BIOS 287. *Barytes and Pyrite in North-West Germany.*

BIOS 288. *Aluminium Hydrate and Alumina Production in German Factories.*

BIOS 289. *Report on German Textile Machinery Firms.*

BIOS 290. *The Viscose Continuous and Rayon Staple Fibre Plants of the British, American and French Occupation Zones of Germany.*

BIOS 291. *Visit to Deutsche Eisenwerke and Deutsche Rohrenwerke, at Mulheim.*

BIOS 292. *German Aircraft Development as Applicable to Civil Transport.*

BIOS 293. *Methods of Shock Wave Measurement in German Armament Research Establishment.*

BIOS 294. *Hydrogen Peroxide Works of Otto Schickert & Co., at Bad Lauterberg and Rhumspringe.* [Silicon detectors]

BIOS 295. *German S.A.A. Factories.*

BIOS 296. *German Non-Ferrous (Copper-Base) Foundry Industry.*

BIOS 297. *Norddeutsche Seekabelwerke Nordenhaus.*

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BIOS 299. *The German Ham Canning Industry.*

BIOS 300. *Investigation of the Developments in the German Automobile Industry During the War Period.*

BIOS 301. *German Piston and Piston Ring Industry.*

BIOS 302. *Investigation of Henk Heinrichs' Claim in Connection with the Refining of Aluminium Alloy Scrap.*

BIOS 303. *Production of Luminous Compounds at the Works of Auer Gesellschaft A.G.*

BIOS 304.

BIOS 305. [Insulin]

BIOS 306. *The Manufacture of Caffeine and Theophyline in the U.S. and French Zones.*

BIOS 307. *German Secondary Batteries (with Special Reference to Those Used by Army Signals).* [Alkaline batteries]

BIOS 308.

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BIOS 310. *Flexible Pipes, Flexible Fuel Tanks and Self-Sealing Fuel Tank Coverings for Aircraft.*

BIOS 311. *Production of Aluminium Sulphate Giulini.*

BIOS 312. *German Papermaking Industry.*

BIOS 313. *Report on Visit to Czechoslovakia by Armament Design Department.* [mentions many significant people and places but gives no significant scientific details]

BIOS 314. *The German Electricity Supply System.*

BIOS 315. *Berliner Lübecker Maschinen Fabrik, Lübeck.*

BIOS 316. *German Light Alloy Foundry Industry.*

BIOS 317. *German Glass Manufacture as Applied to Illumination with Particular Reference to Aviation Lighting.*

BIOS 318. [Oxygen breathing apparatus + suits Draeger]

BIOS 319. *Production of Beryllium "Degussa".*

BIOS 320. *German Aero Engine Industry.*

BIOS 321. *Steel Propellor Blade Development at V.D.M., Hamburg.*

BIOS 322. *Rheinmetal Borsig A.G. Düsseldorf.* [brief report on guns, not missiles]

BIOS 323. *Waggonfabrik A.G. (Ringfeder G.m.b.H.), Uerdingen.*

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BIOS 327. *Dandy Roll Making Industry.*

BIOS 328. *Antimony Smelting Industry.*

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BIOS 330. *Wirtschaftliche Forschungsgesellschaft m.b.H. (WIFO) Eickeloh Installation. Investigation of the Installation and Interrogation of the Personnel.*

BIOS 331. *Amalia Benzole Refinery, Harpener Bergwerksverein, Bochum.*

BIOS 332. *Chemische Fabrik Weyl A.G., Sandhoferstr. 96–106, Mannheim—Waldhof.*

BIOS 333. *Winkler Generators for Manufacture of Water Gas, Etc.*

BIOS 334. *Developments of Geophysical Prospecting in Germany During the War.*

BIOS 335.

BIOS 336. *Investigation of Steam Generating Plants and Boiler Practice in Central Germany.*

BIOS 337. *German Graphitising Furnances at Meitingen (Siemens Plania).*

BIOS 338. *German Carbon Electrode Manufacture at Griesheim (I.G.F.).*

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BIOS 340. *German Small Arms Ammunition.*

BIOS 341. *German Chemical Plant Manufacture.*

BIOS 342. *The German Wartime Electricity Supply: Conditions, Development, Trends.*

BIOS 343. *German Diesel Engine Industry.*

BIOS 344.

BIOS 345. *A German Thermometer for Use in the Range 400°–1200°C.* [thermometer using gallium instead of mercury]

BIOS 346. *The German Ball and Roller Bearing Industry.*

BIOS 347.

BIOS 348. *German Plywood, Improved Wood, Shuttle Block and Joinery Industries.*

BIOS 349. *German General Rubber Goods Industry.*

BIOS 350. *The Synthesis of Intermediates for Polyamides on an Acetylene Basis (Translation of a Report by Dr. W. Reppe, Ludwigshafen).* [Use of acetylene to synthesize dicarboxylic acids, amino acids, diamines, and polyhydric alcohols]

BIOS 351. *Preparation of Adipic Acid from Tetrahydrofuran and Carbon Monoxide.*

BIOS 352. *Cyclopolyolefines. Miscellaneous Report Compiled from Interviews with Dr. Reppe, Dr. Schlichting and Dr. Kröper (I.G. Farben, Ludwigshafen).*

BIOS 353. *Preparation of 5-Diethylaminopentanol-2 by the Reppe Process.*

BIOS 354. *Polvinyl Pyrrolidones. Translation of a Report by Dr. Fikentscher and Dr. Herrle, Ludwigshafen, with an Addendum on Periston (Synthetic Blood Serum).*

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BIOS 356. *Characterisation of Butadiene Catalysts by X-Ray and Chemical Analysis.*

BIOS 357.

BIOS 358. *Acrylic Esters, Synthesis from Acetylene and Nickel Carbonyl.*

BIOS 359.

BIOS 360. *Notes on Manufacture of Ethylene Oxide by I.G. Farben.*

BIOS 361. *Non-Metallic Materials for Aircraft: Visits to Research Establishments in Germany.* [engine oils, coolants, paints, etc.]

BIOS 362. *German Primary Battery Industry.*

BIOS 363.

BIOS 364. *Kalle and Co., Aktiengesellschaft, Wiesbaden, Biebrich.* [Enzymes]

BIOS 365. *German Aircraft Paints.* [Heat reflecting paints]

BIOS 366. *German Textile Dyeing, Drying and Finishing Engineers.*

BIOS 367. *Manufacture of 1:4 Butinediel at I. G. Ludwigshafen, Including Manufacture of 1:4 Butanediel and Tetrahydrofuran, Precautions in Handling Acetylene, and Semitechnical Precautions of 1:4 Butenediel.* [Synthetic rubber]

BIOS 368. *Manufacture of Adipic Dinitrile and Hexamethylene Diamine.*

BIOS 369. *Manufacture of Hydrazine Hydrate.*

BIOS 370. *Manufacture of Acetaldehyde.*

BIOS 371. *Regeneration of Nickel Carbonyl (from Aqueous Solutions).*

BIOS 372. *German Tin Smelting and Allied Industries.*

BIOS 373. *I.G. Farbenindustry AG Ludwigshafen (Fuels and Lubricants).*

BIOS 374. *German Aluminium Foil Industry.*

BIOS 375. [Aluminum]

BIOS 376. *Recovery of Aluminium Alloys from Aircraft Scraps.*

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BIOS 378. *Investigation in Germany on Methods of Coating Propellants and their use for Reaction and Fuel Ejection Systems.*

BIOS 379. *The German Zinc Smelting Industry.*

BIOS 380. *The Bentheim Gas Field (History and Present Status as a Source of Natural Gas).*

BIOS 381. *Investigation into the Design, Manufacture and Inspection Technique of Aero Engine Gears.*

BIOS 382.

BIOS 383. *Search for Buried Technical Equipment at Krupp's Range at Meppen.*

BIOS 384. *German Battery Electric Vehicles and the German Storage Battery Industry.*

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BIOS 386. *The Extruded Brass Rod Industry in Germany.*

BIOS 387. *Winding Engine Manufacturers Association Report on Winding Engines in Germany.*

BIOS 388. *Technical Aspect of Pectin Manufacture in Germany.*

BIOS 389. *Production of Alcohol and Yeast from Waste Sulphite Liquor by the Zellstofffabrik Waldhof Company.*

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BIOS 391. *A New Coke Breaker.*

BIOS 392. *Welding of Aluminium and Aluminium Alloys with Particular Reference to the Manufacture of Pressure Vessels.*

BIOS 393. *Development and Production of Electrical Components, Especially of Relays, by Siemens and Halske and Other German Firms.*

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BIOS 395. *German Fluorescent Lamp Industry and Phosphor Chemical Manufacture.*

BIOS 396. *Report on Visit to Germany and Austria to Investigate Alloys for Use at High Temperature.*

BIOS 397. *Agfa Colour.*

BIOS 398. *The German Activated Bleaching Earth Industry, with Some Observations on German Bentonite and Neuburg Chalk.*

BIOS 399. *German Surgical and Veterinary Instrument Industry.*

BIOS 400. *The Cerium Industry in German Territory including Reports on Radium and Mesothorium.*

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BIOS 402. *Rolled Non-ferrous Metal Industries in Germany.*

BIOS 403. [Glass fibers]

BIOS 404. *German Asbestos Industry.*

BIOS 405. *German Butuminous Roofing Felt Industry.*

BIOS 406. *Sugar Confectionery and Chocolate Manufacture in Germany.*

BIOS 407. *D.R.P. Broadcasting Studios, München.*

BIOS 408. *Contact Rectifier for Heavy Currents, by Siemens Schuckert—Berlin.*

BIOS 409. *D.C. Cup Type Motors by Siemens Schuckert Zaehlerwerk, Nürnberg.*

BIOS 410. *Some Electrical Factories in Berlin—British Zone.*

BIOS 411. *Miscellaneous Electrical Factories in the British and American Zones.* [Condensers of metallized paper, durac batteries]

BIOS 412. *The Ott Differential Analyser.*

BIOS 413. *Primary Cells by Prof. A. Schmid.*

BIOS 414. *Prof. Dr. Ing. Humburg, Technische Hochschule—Hannover.*

BIOS 415. *P.J. Kipp en Zonen.*

BIOS 416.

BIOS 417. *M.A.N. Track Testing Equipment.*

BIOS 418. *Textile Auxiliary Products—Manufacture, I.G. Farbenindustrie, Hoechst.*

BIOS 419. *I.G. Waxes: Manufacture at Gershofen and Oppau.*

BIOS 420.

BIOS 421. *Textile Auxiliary Products: Manufacture by I.G. Farbenindustrie, Ludwigshafen.*

BIOS 422.

BIOS 423. *Deutsche Gold und Silber Scheide Anstalt (Degussa)—Frankfurt.* With Appendix. [Dental quick hardener]

BIOS 424. *Chemische Fabrik Dr. Jacob—Bad Kreuznach. Manufacture of Carbon Bi-sulphide, Thiourea and Ammonium Thiocyanate.*

BIOS 425. *A.G. für Chemische Industrie, Gelsenkirchenschalke (a Controlled Subsidiary of the I.G.). Manufacture of Carbon Bi-sulphide.*

BIOS 426. *German Organic Chemical Industry.*

BIOS 427. *Investigation of German Engravers of Rollers and Plates as Used by Wall Paper, Leather and Leather Cloth Industries.*

BIOS 428. *German Rayon and Staple Fibre Industry and Allied Engineering Industry.*

BIOS 429. *German Electroplating Industry.* [Electroplating on aluminum]

BIOS 430. *The German Locomotive Industry.*

BIOS 431. *German Watch and Clock Industry.*

BIOS 432. *German Pyrotechnic Dyestuffs and Synthetic Consolidating Materials to Obviate the Pressing of Pyrotechnic Compositions.*

BIOS 433. *Investigation of German Plastics Plants: Part IV. Additional Information on Thermosetting Resins and Processing of Polystyrene.*

BIOS 434. *Sunlicht A.G., Mannheim.*

BIOS 435. *Ozalid Light-Sensitive Materials, Kalle & Co., Wiesbaden—Biebrich (I.G. Farbenindustrie A.G.).* [Ozalid chemical-coated paper for dry photocopying]

BIOS 436. *Enzyme Products and "Acrisin" Finishing Agents for Textiles: Rohm and Haas G.m.b.H., Darmstadt.* [Enzymes for washing]

BIOS 437. *Production of Cast Iron Porcelain Enamelled Baths in Germany.*

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BIOS 441. *The Platinum Metals Industry in Germany.* [Rhodium mirrors]

BIOS 442. *Performance of Pfauter Hobbing Machine Employing "Giant" Hobs.*

BIOS 443. *Some Notes on German Hollow Turbine Blade Manufacture.*

BIOS 444. *Compressed Air Turbine Developed by the Karlsruhe Technical High School.*

BIOS 445. *Investigation of German Plastics Plants Part III. Processing of Polyvinyl Chloride.*

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BIOS 448. *Manufacture of Sulphate of Copper in Germany.*

BIOS 449. *German Medical Targets.* [Pharmaceuticals, hormones, antibiotics, cancer research, DDT]

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BIOS 451. *Titanium Pigments. Titangesellschaft, Leverkusen.*

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BIOS 455. *Loom Making in Germany and Textile Machinery Accessories.*

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BIOS 461. *German Pyrotechnic Industry: Some Factories Visited.*

BIOS 462. *Impact Extrusion.*

BIOS 463. *Miscellaneous Technical Information on the Development of Pyrotechnics.*

BIOS 464. *German Pest Control Industry, Pflanzenschutz—Stahler, Erbach—Rheingau.* [Fungicides]

BIOS 465. *High Temperature Refractories and Ceramics.*

BIOS 466. *German Parachute Design and Manufacture.*

BIOS 467. *German Secondary Battery Industry.* [Alkaline batteries]

BIOS 468. *The Manufacture of Synthetic Crystals in the Plant of I.G. Farbenindustrie Oppau—Ludwigshafen.* [halite crystals]

BIOS 469. *Slotted Tube Catapult Operated by T and Z Stoff for Launching the Flying Bomb (Preliminary Survey).*

BIOS 470. *Specialized Ceramic Materials with Particular Reference to Ceramic Gas Turbine Blades.* [High-temp ceramics]

BIOS 471.

BIOS 472. *German Lead, Copying and Coloured Pencil Manufacture, and Allied Industries.*

BIOS 473.

BIOS 474.

BIOS 475.

BIOS 476.

BIOS 477. *German Pyrotechnic Factories.* [Aluminum powder for pyrotechnic manufacture]

BIOS 478. *Textile Auxiliary Products: Development of Mersol and Hostapon Processes by I.G. Farbenindustrie, Höchst.*

BIOS 479. *Some Aspects of the German Peat Industry.*

BIOS 480. *German Spectacle Frame Industry.*

BIOS 481.

BIOS 482. *German Reclaimed Rubber Industry.*

BIOS 483. *Report on Investigation of Research in Animal Diseases in Germany and Austria 1939–1945.* [relatively mundane work, nothing on Riems]

BIOS 484. *The German Printing Industry.* [Photocopying, color printing, and photography]

BIOS 485. *German Filtration Industry.* [Electron microscopes]

BIOS 486. *The Manufacture of Line Telecommunications Equipment in Germany.*

BIOS 487. *German Wheel Manufacture.*

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BIOS 489. *Chemische Fabrik Joh. A. Benckiser, G.m.b.H. Ladenburg Works. Manufacture of Calcium Citrate.*

BIOS 490. *Primary Battery Development by the Chemische-Physikalische Versuchsanstalt, Danisch Nienhof.*

BIOS 491. *Some German Pulse Communication and F.M. Systems.*

BIOS 492. *Explosives Work and Associated Photographic Technique.* [measurement techniques according to some of Hubert Schardin's staff]

BIOS 493. *Certain Aspects of the German Fishing Industry.* [flash freezing and antioxidants for fish preservation]

BIOS 494. *Research and Development of Life Saving Equipment Medical Aspects of Shipwreck.* [Human expts]

BIOS 495. *Copper and Copper Base Alloy Tube Manufacture in Germany.*

BIOS 496. *Extraction of Copper and Other Metals from Pyrites Cinder.*

BIOS 497.

BIOS 498. *Wartime Development in the Design of Boilers and Combustion Equipment in Germany.*

BIOS 499.

BIOS 500. *The Ljungström Turbines in Germany.*

BIOS 501. *Rugged Valves and Mechanical Tests for Valves and Components.* [fuzes for rockets]

BIOS 502. *Plant Breeding.*

BIOS 503. *Materials and Aerodynamics Research Institutes, Sonthofen, Bavaria.*

BIOS 504. *Visit to Metallgesellschaft A.G., Frankfurt a.M.*

BIOS 505.

BIOS 506. *German Skate Industry.*

BIOS 507.

BIOS 508. *Fried. Krupp, Germaniawerft, Kiel: Water Brake Dynamometers.*

BIOS 509. *Voith-Schneider Propellor.* [Visit to J. M. Voith Works at Heidenheim]

BIOS 510. *Samples of Petroleum Products Collected from the Hamburg, Hannover, Bremen and Kiel Area.*

BIOS 511. *Ruhr-Chemie A.G. Sterkrade Holten. Interrogation of Dr. O. Roelin.*

BIOS 512. *Schlafhorst Chemische Werke G.m.b.H., Hamburg, Germany: Lubricants.*

BIOS 513. *Notes on the Organisation of the German Petroleum Industry During the War.*

BIOS 514. *German Textile Industry.*

BIOS 515. *Report on the Interrogation of Dr. Erich Scholz, an Expert on Electric and Percussion Caps, Formerly Employed by D.W.M. (Grötzingen).*

BIOS 516. *Petrological Microscopes (Germany).* [polarizing microscopes]

BIOS 517. *Brass Hardware and Fittings.*

BIOS 518. *Textile Auxiliary Products of I.G. Farbenindustrie: Application, Testing and Miscellaneous Information.* [Fire proofing of fabrics]

BIOS 519.

BIOS 520. *German Experimental Work on the Attack of Reinforced Concrete by Explosives and Projectiles and Inspection of the Möhne and Eder Dams, September, 1945.*

BIOS 521. *Lurgi High Pressure Gasification.*

BIOS 522. *I.G. Farbenindustrie A.G., Höchst. The De-Ashing of Coal by Combined Jig Washing, Froth-Flotation, and Extraction with Caustic Soda.*

BIOS 523. *Carl Alexander Mine, Baesweiler Near Alsdorf. The De-Ashing of Coal by Froth Flotation and Acid Extraction and the Ruhrwerks Coal Cleaning Process.*

BIOS 524. *Deutsche Gasolin A.G., Hamburg, Germany: Lubricants.*

BIOS 525. *Staatlisches Material Prüfungsamt, Unter den Eichen 86–87, Berlin-Dahlem.*

BIOS 526. *Development and Manufacture of Alberich.* [Submarine sonar absorbing coating]

BIOS 527. *Iron, Steel and Non-Ferrous Metal Works Plant and Machinery.*

BIOS 528. *Report on Dams and Hydro-electric Schemes in South West Germany.*

BIOS 529. *Investigation of Targets Connected with the German Plywood Industry.*

BIOS 530. *Photosurfaces, a Report on German Developments of Photocells, Electron Multipliers, Television Pick-Up Tubes.* [Electron multipliers, photocells, guided projectiles, TV valve]

BIOS 531.

BIOS 532. [Magnetic analyzer for oxygen in air, IR spectroscopy of gases]

BIOS 533. *Electric Furnace Design. Manufacture and Application in Germany.*

BIOS 534. *The Organisation of the German Chemical Industry and Its Development for War Purposes.*

BIOS 535. *German Edgewise Pressure Gauge Manufactured by Dreyer, Rosenkranz and Droop.*

BIOS 536. *Tallöl: Its Processing and Utilization in Germany.*

BIOS 537. *Investigation of Production Control and Organisation in German Factories.*

BIOS 538. *Report on German Patent Records.*

BIOS 539. *German Incendiary Bomb Manufacture and Development: German Explosive, Propellant and Cellulose Derivative Manufacture.*

BIOS 540. *German Types of Heating and Coolers for Marine and Land Applications.*

BIOS 541. *Some German Methods of Grading and Surface Coating of Abrasives.*

BIOS 542. *Interrogation of Certain German Personalities Connected with Chemical Warfare.*

BIOS 543. *The German Cycle and Cycle Components Industry.*

BIOS 544. *Interrogation of Generalmajeur Holzhauer.* [tank development]

BIOS 545. *Seifenfabrik Rose, Frankfurt-Osthafen.*

BIOS 546. *Melliand Textilberichte, Heidelberg.*

BIOS 547. *"Tylose" Cellulose Derivatives, Kalle & Co. A.G., Wiesbaden-Biebrich.*

BIOS 548. *German Camera Manufacture, Plant and Equipment.* [Camera lenses and shutters]

BIOS 549. *Calculating Machines: Plant and Equipment.*

BIOS 550. *Investigation of Beryllium Production in Germany and Italy Including Production and Uses of Oxides and Alloys.*

BIOS 551. *German Wireless Communication: Mainly with Reference to Cm, Dm, and Pulse Technique.* [Klystrons]

BIOS 552. *Report on the Investigation on the Production of Synthetic Crystals in Germany and Copenhagen.* [IR and UV crystals, piezoelectrics]

BIOS 553.

BIOS 554. *Ampules and Vial Making Machines, Improvements and Developments in Germany.*

BIOS 555. *German Naval Distilling Equipment.*

BIOS 556.

BIOS 557. *Visits to Radio Targets in Germany.* [Batteries]

BIOS 558. *Boule Manufacture, Wiede's Carbidwerk—Bavaria.*

BIOS 559. *German Flying Boat Research and Development.*

BIOS 560.

BIOS 561. *The Manufacture of Sodium Sulphide at I.G. Farben Fabrik, Wolfen.*

BIOS 562. *The German Phosphorus Industry at Bitterfeld & Piesteritz.*

BIOS 563. *The German Radio Component Industry.* [condensers, amplifiers, photo-electric cells,

rectifiers, novel batteries, etc.]

BIOS 564. *Industrial Electronic Measuring Equipment.* [X-ray dosimeter]

BIOS 565. *German Chain Industry.*

BIOS 566. *A Visit to Germany to Investigate Wartime Advances in Certain Branches of Applied Physiology. (Revised)* [aviation medicine experiments; immersion of "dogs" (probably actually humans) in cold water and then revival, etc.]

BIOS 567. *Resistors and Fixed Capacitors Produced in Germany.*

BIOS 568. *Printing Process Used by the Wehrmacht.*

BIOS 569. *German Glass or Enamelled Lined Equipment on Mild Steel and Cast Iron for Chemical–Food–Drink and Allied Industries.*

BIOS 570. *Development of Hollow-Charge Work by Rheinmetall Borsig, Berlin.* [interview with Dr. Hermann]

BIOS 571. *German Rocket Propellants (Interrogation of Mr. N. W. Larsson).* [Solid rocket propellant with butadiene and ammonium perchlorate]

BIOS 572. *Investigation into Manufacture and Use of Carbon Blacks and Lamp Blacks in Germany.*

BIOS 573.

BIOS 574. *A Survey of the German Cotton, Rayon and Silk Industries.*

BIOS 575. [Autobahn]

BIOS 576. *German Limeburning Industry.*

BIOS 577. *German Car Industry, Special Servicing Equipment for Cars.*

BIOS 578.

BIOS 579. *The Z.F. Electro-Magnetic Transmission with a Special Application for the Panther Tank.*

BIOS 580. *Reports on Tests of the Wagner Boiler Company with a Model Boiler.*

BIOS 581. *Hot Rolled Strip Mills.*

BIOS 582.

BIOS 583. [Teleprinter]

BIOS 584. *Investigation of the German Oil Engine Industry: Design, Research and Production.*

BIOS 585.

BIOS 586. *Ernst Schliemann's Oelwerke und Export-Cerecin-Fabrik, Hamburg—Germany.*

BIOS 587. *German Naval Mining Relays and Moulded Powder Permanent Magnets.*

BIOS 588.

BIOS 589. *German Light Alloy Die Casting Industry—Machine Tools for Die Sinking.*

BIOS 590.

BIOS 591. *Large Scale Production of Oxygen and Atmospheric Gases.* [focuses mainly on Linde process, mainly on Leuna]

BIOS 592.

BIOS 593. *Dynamit A.G. Schlebusch.*

BIOS 594. *The Production and Application in Germany of High Silicon Acid Resisting Iron.*

BIOS 595. *Sintered Iron and Steel Components.*

BIOS 596. *Gesellschaft für Teerverwertung, Varziner-Strasse, Duisburg-Meiderich, Ruhr.* [tar distillation]

BIOS 597. *Interrogation of Dr. C. H. N. Bensmann, October 10th, 1945.* [oil]

BIOS 598. *Oelwerke Julius Schindler G.m.b.H., Hamburg—Germany.*

BIOS 599.

BIOS 600. *German Heavy Electrical Industry: Motors and Power Transformers.*

BIOS 601. *German Mattress and Furnishing Spring Making Industry.*

BIOS 602. *German Plywood Industry: Interrogation of Dr. Doffine.* With Appendix.

BIOS 603. *The Investigation in Germany of Technical Developments in Prefabricated Housing.*

BIOS 604. *The Shellac Industry in Germany.*

BIOS 605. *Some Marine Applications of Light Alloys in Germany.*

BIOS 606. *The Design of German Telephone Subscribers' Apparatus.* [Crystal telephone amplifiers, audiometer, telecommunications]

BIOS 607. *German Wire Rope Industry.*

BIOS 608. *The Manufacture of Electrical Measuring Instruments in Germany.* [Selenium rectifiers]

BIOS 609. *Non-destructive Testing of Materials.* [ultrasound imaging]

BIOS 610.

BIOS 611. *Utilisation of Washery Refuse as Boiler Fuel in Ruhr Coal Mines.*

BIOS 612. *Klein Schanglin and Becker A.G.: Hydraulic Couplings and Torque Converters.*

BIOS 613. *Cordage Industry.*

BIOS 614. *Welding Design & Fabrication of German Tank Hulls & Turrets.*

BIOS 615. *The Continuous Tar Distillation Still at Gesellschaft für Teerverwertung.*

BIOS 616. *Inspection of Krupp-Lurgi Plants for the Carbonisation of Coal at Low Temperatures.*

BIOS 617. *Top Stripping Equipment Used in Open Caste Coal Working.*

BIOS 618. *German Bright Steel Bar Industry.*

BIOS 619. *Developments in the German Steel Tube Industry.* With two Addenda.

BIOS 620. *The German Motor-Cycle Industry.*

BIOS 621. *The Manufacture of Wofatit Base-Exchange Resins.* [anion exchange resins for purification]

BIOS 622. *Investigation of Cold-Cathode Tubes Made by Siemens Reiniger Werke, Rudolstadt: Part II—Production Details.*

BIOS 623. *Lurgi Gesellschaft für Warmetechnik, Frankfurt-am-Main.* [Bacteriological process for phenol removal]

BIOS 624. *German Jute Industry.*

BIOS 625. *German Wire Rod Rolling Industry.*

BIOS 626. *Drying, Briquetting and Low-Temperature Carbonisation of Brown Coal in Lurgi-Spülgas Retorts.*

BIOS 627. *The Worsted Spinning Industry in the British and U.S. Zones of Germany.* [glass fibers]

BIOS 628.

BIOS 629. *Investigation of Synthetic Resins Used in the German Surface Coating Industry.* [polyurethane and other synthetic polymer coatings]

BIOS 630. *German Dental Industry.*

BIOS 631. *Netting Industry.*

BIOS 632. *German Gauge and Tool Industry.*

BIOS 633. *Manufacture of Oxalic Acid at I.G. Farbenindustrie, Bitterfeld.*

BIOS 634. *The Processing of Rayon Staple Fibre on Cotton Spinning Machinery in Germany.*

BIOS 635. *Mineralölwerke Albrecht: Lubricants.*

BIOS 636. *Mineralölwerke F. Harmsen, Kiel—Germany: Lubricants.*

BIOS 637. *Olex Deutsche Benzin und Petroleum Gesellschaft: Fuels and Distribution.*

BIOS 638. *Deutsche Erdöl A.G., Hamburg—Germany: Crude Oil and Products.*

BIOS 639. *Deurag-Nerag Gewerkschaft, Deutsche Erdöl Raffinerie und Neue Erdöl Raffinerie: Fuels and Lubricants.*

BIOS 640. *German Precision Chain Industry (British and American Zones Only).*

BIOS 641. *The German Machine Tool Industry.* [electronic control of machine tools—not much information beyond the fact that it existed in wartime Germany]

BIOS 642. *Performance of Pfauter Hobbing Machine Employing "Giant" Hobs.*

BIOS 643. *German Anodising Practice.*

BIOS 644. *Detonator Factory, D.A.G., Troisdorf.*

BIOS 645. *German Woodbending Industry.*

BIOS 646. *German Paper Machine Wire Industry.*

BIOS 647. *Research and Development of Snow-Moving and Snow Crossing Vehicles in Germany.*

BIOS 648. *Ordnance Muzzle Brakes.*

BIOS 649.

BIOS 650. *Armament Production and Design.*

BIOS 651. *German Docks and Harbours.*

BIOS 652. *German Furnishing Fabric Industry.*

BIOS 653.

BIOS 654. *Lead-Zinc-Copper Mining in the Harz and Lead-Zinc Mining in the Ruhr Coalfield.* [many tons of zinc, lead, and copper]

BIOS 655. *Manufacture of Brushes in Germany.*

BIOS 656.

BIOS 657. *German Laboratory Porcelain Industry.*

BIOS 658. *German Photographic Industry.*

BIOS 659. *Interview with Dr. Stocklin, Formerly of the Leverkusen Laboratories of A.G. Farbenindustrie A.G.* [Buna]

BIOS 660. *Rütgerswerke A.G. Rauxel.*

BIOS 661. *Manufacture of Vulcanisation Accelerators and Antioxidants.*

BIOS 662. *Manufacture of Phenylbetanaphthylamine at I.G. Farbenindustrie, Ludwigshafen.*

BIOS 663.

BIOS 664. *I.G. Farbenindustrie Leverkusen.* [Salicylic acid]

BIOS 665. *C. F. Boehringer & Sohne, Sandhoferstr., Mannheim-Waldhof. Manufacture of Vanillin Coumarin Anisaldehyde.*

BIOS 666. *I.G. Farbenindustrie Uerdingen. Manufacture of Phthalic Anhydride, Benzoic Acid,*

Etc.

BIOS 667. *I.G. Farbenindustrie Mainkur.* [Thiamine S and thiamine T chemical manufacture]

BIOS 668. *"Eumuco" Shell Forging Press Usage.*

BIOS 669. *Interview with Dr. Roelig, Formerly of the Leverkusen Laboratories of I.G. Farbenindustrie A.G.* [Hysteresis machine]

BIOS 670. *German Methods of Manufacture of Copper Tuyeres for Blast Furnaces.*

BIOS 671.

BIOS 672. *Production of Nitrous-Oxide GMI.*

BIOS 673. *Production of Krypton-Xenon Mixture.*

BIOS 674. *The German Electrically Welded Steel Tube Industry.*

BIOS 675. *The Production of Thorium and Uranium in Germany.*

BIOS 676. *German Metallurgical Laboratories for Ferrous Metals with Special Reference to the K. W. Institute for Iron Research.* [KWI measuring boron in steel]

BIOS 677. *German Clock and Watch Dial Production.*

BIOS 678. *Manufacture of Cement and Sulphuric Acid from Anhydrite, I.G. Farbenfabrik Wolfen.*

BIOS 679. *I.G. Farben Works at Bitterfeld. Manufacture of Potassium Dichromate and Chromic Oxide.*

BIOS 680. *Manufacture of Caustic Soda, Chlorine and HCl, I.G. Farbenfabrik Wolfen.*

BIOS 681. *German Cold Rolled Strip Industry.*

BIOS 682. *German Transformer Industry.*

BIOS 683. *Hydrogen Peroxide—Production by Electrolysis of 35 Per Cent. Solutions. Deutsche Gold und Silber Anstalt.*

BIOS 684. *Production of Molybdenum & Tungsten for Radio Valves & Electric Lamps, Metallwerke Plansee, Reutte, Tyrol.* [Advanced lamp bulbs, radio valves]

BIOS 685. *German Ingot Moulds for the Casting of Steel Ingots.*

BIOS 686.

BIOS 687. *The Design of German Line Telecommunications Transmission Systems.* [Amplifiers, condensers, valves]

BIOS 688. *Interview with Dr. Stocklin & Dr. Roelig, Formerly of the Leverkusen Laboratories of I.G. Farbenindustrie A.G.* [Buna interrogation]

BIOS 689. *Interrogation of Dr. Casper, Dr. Eisenmann, Dr. Mersch, Dr. Stocklin.* [several different polymers]

BIOS 690. *Prevention of Atmospheric Pollution by Noxious or Offensive Gases, Fumes or Dusts.*

BIOS 691. *Some Aspects of Microbiological Research in Germany.* [Lots of microbiology]

BIOS 692. *German Watch-Jewel Industry.*

BIOS 693. *The Investigation of the Light Alloy Forging Industry in Germany.*

BIOS 694. *Magnesium Pressure Die Casting, Mahlewerk, Fellbach, Stuttgart.*

BIOS 695. *The Design and Operation of German Telephone Exchange Equipment.* [Automatic telephone exchange]

BIOS 696. *The Manufacture of Phosphate Esters at Bitterfeld.*

BIOS 697. *Fire Protection of Oil Installations in Germany.* [protein-based firefighting foams and dispersal methods]

BIOS 698. *Survey of the German Heavy Textile Proofing Industry.* [Fireproofing of fabrics]

BIOS 699. *Methods of Production in Germany of General Heavy Forgings and Railway Axles, Tyres & Wheels.*

BIOS 700. *The German Centrifugal Castings Industry with Special Reference to the Production of Cast Iron Pipe, Cylinder Liners and Piston Rings.*

BIOS 701. *The German Asbestos Textile, Jointing and Friction Lining Industries.*

BIOS 702. *Interview with Dr. Roelig of the I. G. Rubber Service Laboratories, Leverkusen.* [Synthetic rubber]

BIOS 703. *German Methods of Excavating and Briquetting Brown Coal.*

BIOS 704. *Mechanical Foam Liquid and Equipment.* [Fire fighting foam]

BIOS 705. *Mechanical Stokers for Shell Type Boilers.*

BIOS 706. *Metal Powders (Sintered).*

BIOS 707. *Investigation of Research Technique and Testing Equipment in Germany with Reference to Problems in the Automobile Engineering Industry.*

BIOS 708. *German Alkaline Accumulator Industry.* [Alkaline batteries]

BIOS 709.

BIOS 710. *Manufacture of Biolase (Starch-Hydrolysing Enzyme) at Kalle & Co. (I. G. Farben A. G.) Wiesbaden, Biebrich.*

BIOS 711. *Interrogation of Dr. Hans-Albrecht Kind of Böhme Fettchemie and Henkel & Cie, Düsseldorf.*

BIOS 712. *German Artists' Colour Manufacturers.*

BIOS 713. *Notes on Items of Chemical Plant at Works of: I.G. Farbenindustrie, Knapsack; Dr. Alexander Wacker, Burghausen; Anorgana, Gendorf; I.G. Farbenindustrie Hoechst.* [no CW infor-

mation]

BIOS 714. *The Development of New Insecticides and Chemical Warfare Agents.* [original edition; revised edition only covers insecticides and is less than half as long!]

BIOS 715. *The Microanalytical Methods Employed in the Analytical Laboratories of I.G. Farben, Elberfeld-Wuppertal, Germany.*

BIOS 716. *German Steel Foundries.*

BIOS 717. *The German Permanent Magnet Industry.*

BIOS 718. *Milling of Barley and Oats in Germany.*

BIOS 719. *Interview with Professor Otto Bayer, Formerly Member of the Directorate and Head of the Scientific Laboratories of the I.G. Farbenindustrie, Leverkusen.* [isocyanates–superglue!]

BIOS 720. *Metallurgical Research and Testing Laboratories in the Stuttgart Area.* [KWI Physics, sonde for testing materials]

BIOS 721.

BIOS 722. *Lurgi Gesellschaft für Wärmetechnik Frankfurt. High Pressure Gasification of Brown Coal.*

BIOS 723.

BIOS 724. *Electronic Principles as Applied in Germany to the Testing of Materials.* [Piezo-electric, electronic materials testing]

BIOS 725. *German Research on Rectifiers and Semi-Conductors.*

BIOS 726. *Television Development at Fernseh.*

BIOS 727. *Manufacture of Anti-Fouling Paints in Germany and Related Matters.* [Anti-IR and anti-radar coatings]

BIOS 728. *A Survey of Certain German Manufacturers of Grain Handling, Cleaning and Milling Machinery.*

BIOS 729.

BIOS 730.

BIOS 731. *Manufacture of Carbon Tetrachloride at I.G. Farben, Bitterfeld.*

BIOS 732. *Lüneburger Wachswerke A.G., Lüneburg—Germany. Waxes.*

BIOS 733. *Brewing and Malting Machinery. Seitz Filter Media.*

BIOS 734. *German Brown Coal Industry.*

BIOS 735.

BIOS 736. *Chemical Laboratory Instrumentation in Germany.* [Mass spectrographs, micro-photometer, etc.]

BIOS 737. *The Investigation of Cast Iron Roll Manufacture in Germany, with Notes on the Usage in Rolling Mill Plants.*

BIOS 738. *Bast Fibre Textile Machinery in Germany.*

BIOS 739. *Maleic Anhydride by Oxidation of Crotonaldehyde at I.G. Ludwigshafen.*

BIOS 740. *C. F. Boehringer und Soehne, Mannheim-Waldhof. Commercial Organic Solvent Production.*

BIOS 741. *Zellstoffabrik A. G., Mannheim.*

BIOS 742. *Preparation and Polymerisation of Vinyl Ethers and Preparation of Acetaldehyde from Methyl Vinyl Ether at I.G. Farbenindustrie, Ludwigshafen.*

BIOS 743. *Manufacture of Cyclohexanol, Cyclohexanone, Cycloketone Resins at I.G. Ludwigshafen.*

BIOS 744. *Manufacture of Vinyl Acetate Polymers and Derivatives at I.G. Hoechst.*

BIOS 745. *Manufacture of Monomeric Vinyl Acetate at I.G. Hoechst.*

BIOS 746. *Vinyl Carbazole and Vinyl Pyrollidone at I.G. Ludwigshafen.*

BIOS 747. *Acetylene by the ARC. Also the Oxosynthesis at Ruhrchemie, Holten.*

BIOS 748. *Manufacture of Fatty Acids by Oxidation of Paraffins, Hydrogenation of the Fatty Acids at I.G. Ludwigshafen-Oppau.* [synthetic fatty acids made from synthetic paraffins made from acetylene, primarily used for making soap]

BIOS 749. *Pilot Plant at I.G. Höchst on the Manufacture of Diketene from Acetic Acid.*

BIOS 750. *Manufacture of Monomeric Styrene at I.G. Ludwigshafen.*

BIOS 751. *Pilot Plant Manufacture of Vinylacetylene at I.G. Hoechst.*

BIOS 752.

BIOS 753. *Manufacture of Phthalic Anhydride and Phthalates at I.G. Ludwigshafen.*

BIOS 754. *Hydrocyanic Acid, I.G. Oppau and Ludwigshafen.*

BIOS 755. *Manufacture of Butanol, Methoxybutanol, Butyraldehyde, Glycerogen at I.G. Hoechst.*

BIOS 756. *Polymeric Processes at I.G. Ludwigshafen.* [several different types of polymers]

BIOS 757. *Manufacture of Ethylene Cyanhydrin at I.G. Ludwigshafen.*

BIOS 758.

BIOS 759. *Pilot Plant for Manufacture of Acrylonitrile at I.G. Oppau.* [Synthetic rubber]

BIOS 760. *German War-Time Development in Fluid Turbulence with Particular Reference to the Lower Atmosphere and the Meteorology of Chemical Warfare.*

BIOS 761. *German Bursting Coloured Smoke Shell. Interrogation of Dipl. Ing. C. von Watzdorf and Dr. W. Sauermilch.*

BIOS 762.

BIOS 763. *Identification of Dyestuffs in I.G.*

BIOS 764. *Production of Aluminium Compounds in Germany.*

BIOS 765. *German Locomotive Experience with Pulvarised Fuels and Lump Brown Coal.*

BIOS 766. *The Manufacture of Pharmaceuticals and Fine Chemicals in the U.S. and French Zones of Germany.* [lots! 3065, etc.]

BIOS 767. *Accumulator Manufacture in Germany.*

BIOS 768. *The German Automobile Industry.*

BIOS 769. *German Manufacture of Sewing Machines, Garment Making Machines, Cloth Cutting Machines, Sewing Machine Needles.* [gives lists of documents and machines to be "evacuated" from Germany for "research" purposes]

BIOS 770. *Further Developments in Dairying in Germany.* [Milk pasteurization by UV]

BIOS 771. *Specification and Testing of Oils, Fuels and Lubricants in Germany.* [Rocket fuels p. 30]

BIOS 772. *Manufacture of Diazo Chemicals, Kalle & Co., Wiesbaden/Biebrich.* [Photocopiers]

BIOS 773. *Manufacture of Photographic Developing Substances at I.G. Farbenfabrik, Wolfen.*

BIOS 774. *German Mine Parachutes and Barometric Fuzes.*

BIOS 775. *Investigation into Steel Shaving Machines in the French Zone of Germany.*

BIOS 776. *Manufacture of Ethylene Oxide, Ethylene Glycols and Ethylene Chloride at I.G. Farbenfabrik, Wolfen.*

BIOS 777.

BIOS 778. *German Manufacture of Wires and Strips for Electrical Heating.*

BIOS 779. [Nickel-chrome alloys for pyrometers.]

BIOS 780. *The Manufacture of Cigarettes, Cigars and Pipe Tobacco in Germany.*

BIOS 781. *Some German Synthetic-Resin. Moulding Plants and Processes.*

BIOS 782. *Interrogation of Professor Ferdinand Flury and Dr. Wolfgang Wirth on the Toxicology of Chemical Warfare Agents.*

BIOS 783. *Manufactures at HIAG, Mainz-Mombach. Particularly Acetone Cyanhydrin, Acrolein and Acetonitrile.*

BIOS 784. *Interrogation of Dr. Gross, Prof. Flury and Dr. Wirth on Industrial Hygiene and Toxicology.* [cancer research]

BIOS 785. *The German Mica Industry.* [Synthetic mica]

BIOS 786. *Investigation of Methods of Development and Evaluation of New Plastic Products in Certain German Establishments.* [Plastics research labs]

BIOS 787. *Report on German Engineers' Tool Industry.*

BIOS 788. *The German Vitreous Enamel Industry.* With Appendix.

BIOS 789. *Special Steels. Notes on Practice at Krupp A.G., Essen, and Deutsche Edelstahlwerke A.G., Krefeld.*

BIOS 790. *Armour Plate. Notes of Gas Carburising Process Carried Out at Krupp A.G., Essen.*

BIOS 791. *Dynamic Properties of Rubber. Interrogation of Dr. H. Roelig.*

BIOS 792. *Properties and Testing of Rubber. Interrogation of Dr. P. Stöcklin at Beltane Schools S.W.19.*

BIOS 793.

BIOS 794. *Investigation of the Scrap Position in Germany.*

BIOS 795.

BIOS 796. *Coated, Gummed and Fancy Paper and Board Mills.*

BIOS 797. *The German Metal Rectifier Industry.* [Selenium rectifiers]

BIOS 798. *The German Ferro-Alloy Industry.*

BIOS 799.

BIOS 800. *Chemistry of Polymerisation as Applied to the Preparation of Buna Synthetic Rubbers. Interview with Dr. Becker.*

BIOS 801. *German Photo-Engraving Industry. Collodion Emulsion Cross-Line Screens.*

BIOS 802. *Bomb, Rocket & Guided Missile Control Gear Targets in Berlin.*

BIOS 803. *Production of Tantalum in Germany.*

BIOS 804.

BIOS 805. *Aspects of the Synthetic Fatty Acid and Synthetic Fat Industries in Germany.* [Synthetic fats for both soap and cooking fat]

BIOS 806. *Investigation of the Methods Used by a Few Selected Firms of German Ball and Roller Bearing Manufacturers.*

BIOS 807.

BIOS 808.

BIOS 809.

BIOS 810. *German Wool Textile and Mantle Plush Manufacture.*

BIOS 811. *Tetrachloroethane, Vinyl Chloride and Polyvinyl Chloride at Dr. Alexander Wacker. Gesellschaft für Electrochemische Industrie Burghausen, Germany.*

BIOS 812.

BIOS 813. *Zinc Works at Porto Marghera, Italy (Montecatini-Montevecchio, Soc. Italiana del Piombo e dello Zinco).*

BIOS 814. *A Survey of the German Pile Fabric Industry.*

BIOS 815. *Manufacture of Hydrazine Hydrate, I.G. Farben A.G., Leverkusen, Germany.*

BIOS 816. *Gewerkschaft Rheinpreussen Utfort/Mörs. Tar Distillation.*

BIOS 817. *Krupp-Lurgi Low-Temperature Carbonisation Plant at Krupp Treibstoffwerke, Wanne-Eickel.*

BIOS 818. *Foundries. Notes on German Iron and Steel Foundries Including Centrifugal Casting.*

BIOS 819. *Blast Furnaces. Notes on German Practice.*

BIOS 820. *Tungsten Carbide. Notes on Krupp Widia Plants.*

BIOS 821.

BIOS 822. *Shipbuilding. Notes on Visits to Blohm und Voss, Deutsche Werft, Germania Werft and Deschimag.*

BIOS 823. *Steel Wire. Notes on German Wire Drawing and Steel Rope Manufacture.*

BIOS 824. *Rolling Mills. Notes on German Practice.*

BIOS 825. *Steelmaking. Notes on German Practice.*

BIOS 826. *Investigation of German Researches on Fine Structure of Metals with Especial Reference to X-Ray Diffraction Techniques.* [Magnetically focusing X-ray tubes and X-ray diffraction analysis of metals]

BIOS 827. *German Filling Factories.*

BIOS 828.

BIOS 829. *German Agricultural Engineering Industry.*

BIOS 830.

BIOS 831. *Heat Treatment of Refractory Materials.*

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BIOS 833. *Investigation of German Commercial Explosives Industry.*

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Report series/number??? J. A. J. Bennett. January 1945. *Notes on a BIOS Mission to Germany and Austria to Investigate German Flettner Helicopter Fl 282 'Kolibri' Developments.*

Report series/number??? Bartram Kelley and Hugh J. Mulvey. CIOS Target No. 25/488. 17 August 1947. [helicopters]

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BIOS Misc 19 Vol. 1 and Vol. 2. *A Survey of German Wartime Food Processing, Packaging, and Allocation.* [Vacuum freeze drying and synthetic butter]

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CIOS XXIV-29. *German I-43 Military Bridge.*

CIOS XXIV-30. *German Refrigeration Industry.*

CIOS XXIV-31. *Brixlegg Jet Engine Testing Station.*

CIOS XXV-1. *Kaiser Wilhelm Institut Fur Kohlnforschung, Mulheim.*

CIOS XXV-2. *Luftfahrtforschungsanstalt, Hermann Goering, Volkenrode, Brunswick.* [rockets]

CIOS XXV-3. *Rheinmetall-Borsig Werke, Unterluss.*

CIOS XXV-4. *Wirtschaftliche Forschungsgesellschaft M.B.H., Aussenstelle München I.*

CIOS XXV-5. *Medical Targets in Southern Germany.*

CIOS XXV-6. *Steinkohlen-Bergwerk Rheinpreussen, Moers-Meerbeck.*

CIOS XXV-7. *Plant of Klocknerwerke AG, Castrop-Rauxel.*

CIOS XXV-8. *Land and Air Service Fire Control Instruments, Carl Zeiss, Jena—Production of Optical Glass Schott and Genossen Lenses and Graduated Scales, Zeiss and Others.*

CIOS XXV-9. *Development of Ceramic Materials for Use in Gas Turbine Engines.*

CIOS XXV-10. *Research and Development on Gas Turbines Hermann Goering Institute Volkenrode.*

CIOS XXV-11. *Montage-Werkstadt, Lichtenfels; Carl Schenck G.m.b.H., Darmstadt.*

CIOS XXV-12. *Report on C. Lorenz AG*

CIOS XXV-13. *Messrs. Steeg and Reuter Bad Homburg.* [Piezoelectrics and optical crystals]

CIOS XXV-14. *Gebruder Bohler AG, Buderich.*

CIOS XXV-15. *Man Augsberg and Harburg, The Franciskaner Keller, Munich.*

CIOS XXV-16. *Manufacture of Phlegmatized Petn at Fabrik Zur Verwertung Chemischer Erzeugnisse G.m.b.H. Wolfratshausen.*

CIOS XXV-17. *The Electrochemical Industry in the Berghausen Area.* [Hydrogen production]

CIOS XXV-18. *I.G. Farbenindustrie AG, Höchst am Main Wehrmacht Items.*

CIOS XXV-19. *I.G. Farbenindustrie, Wolfen Farbenfabrik, Wolfen near Halle.* [Ion exchange resins, DDT research]

CIOS XXV-20. *Dr. Alexander Wacker, Gesellschaft für Elektrochemische Industrie, Burghausen.*

CIOS XXV-21. *Prof. Dr. Alfred Schmid, Konstenz Holig Homogenholz Werke G.m.b.H., Baiersbronn.*

CIOS XXV-22. *Aerodynamische Versuchsanstalt and Kaiser Wilhelm Institut, Göttingen.*

CIOS XXV-23. *Junkers Flugzeug und Motorenwerke AG, Dessau.* [Jumo engine]

CIOS XXV-24. *Die Staatliche Materialprüfungsanstalt and der Technische Hochschule, Stuttgart.*

CIOS XXV-25. *Krupp Treibstoffe Werke G.m.b.H., Wanne-Eickel.*

CIOS XXV-26. *I.G. Farbenindustrie, Mainkur-Hoechst.* [Pharmaceuticals]

CIOS XXV-27. *Wartime Research on Synthetic Fuel. Kaiser Wilhelm Institut für Kohlenforschung.*

CIOS XXV-28. *Diesel Engine Research and Development in Germany during the War and Pre-War Period.*

CIOS XXV-29. *German Army Einheitstuch Statndard Cloth Field Gray.*

CIOS XXV-30. *Felten and Guilleaume Carlswerke, Cologne.*

CIOS XXV-31. *Suddeutsche Kabelwerke, Mannheim.*

CIOS XXV-32. *Hackethal Draht Und Kabelwerke AG, Hanover.*

CIOS XXV-33. *Land Und Seekabelwerke, Cologne.*

CIOS XXV-34. *I. G. Farbenindustrie Laboratory, Leverkusen (Miscellaneous Chemicals).*

CIOS XXV-35. *German Locomotive Industry.*

CIOS XXV-36. *German Mechanical Engineering Industry.*

CIOS XXV-37. *Hugo Schneider Aktien Gesellschaft, Leipzig.*

CIOS XXV-38. *Deutsche Edelstahlwerke, Krefeld.*

CIOS XXV-39. *Anschütz and Co., Kiel.*

CIOS XXV-40. *Power Plant, Buna-Werke GMBA, Schkopau.*

CIOS XXV-41. *Underwater Explosion Research, C.P.V.A., Kiel.*

CIOS XXV-42. *Survey of Production Techniques Used in the German Aircraft Industry.*

CIOS XXV-43. *Hydrogen Peroxide as a Source of Power an the German Application to Torpedo Propulsion.*

CIOS XXV-44. *Hydrogen Peroxide Electro Chemische Werke, Hollriegelskreuth.*

CIOS XXV-45. *German Aircraft Maintenance.*

CIOS XXV-46. *German Naval Magnetic Land Mine.*

CIOS XXV-47. *The Horn Geratebau, Leipzig and Plauen.*

CIOS XXV-48. *Henkel and CIE AG, Dusseldorf.*

CIOS XXV-49. *Interrogation of German Scientific Personnel, I.G. Farbenindustrie AG, Ludwigshafen.*

CIOS XXV-50. *Bartensleben Salt Mine, Morsleben (Division of Askania Werke, Berlin).* [autopilot]

CIOS XXV-51. *The Schacht Marie Salt Mine, Beendorf (Dispersal of Siemens, Berlin).* [autopilot]

CIOS XXV-52. *Production and Uses of Calcium Carbide in Germany.*

CIOS XXV-53. *German Aircraft Industry Bremen-Hamburg Area.*

CIOS XXV-54. *Pharmaceuticals at I.G. Farbenindustrie Plant Elberfeld.* [antibiotics, antimalarials, periston, steroid hormones]

CIOS XXVI-1. *Proximity Fuze Development, Rheinmetall-Borsig AG, Mülhausen.*

CIOS XXVI-2.

CIOS XXVI-3. *Seefliegerhorst Wesermünde (Evacuation from Erprobungsstelle der Luftwaffe, Karlshagen).* [missiles and smart bombs]

CIOS XXVI-4. *M. W. M. Mannheim, Daimler Benz, Rothenbach Brown Boveri Co., Mannheim.*

CIOS XXVI-5. *Wirtschaftliche Forschungs G.m.b.H., Stassfurt and Bad Berka.*

CIOS XXVI-6. *Focke Wulf Designing Offices and General Management, Bad Eilsen.*

CIOS XXVI-7. *Focke Wulf Photo Reproduction Department, Bad Eilsen.*

CIOS XXVI-8. *Focke Wulf Structural Research Laboratory, Detmold.*

CIOS XXVI-9. *C.H. Boehringer und Sohn, Ingleheim am Rhein.* [Pharmaceuticals]

CIOS XXVI-10. *Heeresmunitionsanstalt St. Georgen, Bavaria, Germany.*

CIOS XXVI-11. *I.G. Farbenindustrie AG Höchst am Main.* [wide range of products]

CIOS XXVI-12. *Reich Ministry of Armaments and War Production. (Part I—Organization).*

CIOS XXVI-13. *Reich Ministry of Armaments and War Production. (Part II—Summary of Technical Information).* [sonic weapons, Speer on atomic weapons research]

CIOS XXVI-14. *Reich Ministry of Armaments and War Production. (Part III—Summary of Economics and General Information).*

CIOS XXVI-15. *Deutsches Gummi-Regenierwerke Wilhelm Galombeck and Co, Hamburg.*

CIOS XXVI-16. *NY Hamburger Gummiwaren-Compagnie, Harburg.*

CIOS XXVI-17. *Gummiwarenfabrik Phoenix AG, Harburg.*

CIOS XXVI-18. *Rheinische Gummi Celluloid AG, Mannheim.*

CIOS XXVI-19. *Harburger Gummiwarenfabrik Phoenix AG Harburg.* [rubber, etc.]

CIOS XXVI-20. *Franz Clouth Rheinische Gummiwarenfabrik Nippes, Cologne.* [rubber]

CIOS XXVI-21. *Continental Gummiwerke, Hanover.*

CIOS XXVI-22. *Light Steel Building Products.*

CIOS XXVI-23. *Medical, Dental and Veterinary Education and Practice in Germany as Reflected by the Universities of Leipzig, Jena, Halle and Erlangen.*

CIOS XXVI-24. *The Schornsteinfeger Project.* [anti-radar]

CIOS XXVI-25. *Pulverised Magnesium.*

CIOS XXVI-26. *Voigtlander Und Sohn AG, Braunschweig-Gliesmarode.*

CIOS XXVI-27. *Research and Development of Engines at Hermann Goering Institute, Volkenrode.*

CIOS XXVI-28. *Research and Development on Gas Turbines at Hermann Goering Institute, Volkenrode.*

CIOS XXVI-29. *Research and Development on Gas Turbines at Junkers Motoren Werke, Dessau.*

CIOS XXVI-30. *Gas Turbine Development by B. M. W.*

CIOS XXVI-31. *Technische Akademie der Luftwaffe, Eckertal.*

CIOS XXVI-32. *August Thyssen Hutte AG, Hamborn.*

CIOS XXVI-33. *Werke Koholyte, Luelsdorf.*

CIOS XXVI-34. *Aschaffenburger Zellstoffwere AG*

CIOS XXVI-35. *Electro Schmelzewerke AG, Kempton, Allgau, Bavaria.*

CIOS XXVI-36. *Kaiser Wilhelm Institut für Arbeitsphysiologie at Bad Ems and at Dietz a.d. Lahn.*

CIOS XXVI-37. *The Treatment of Shock from Prolonged Exposure to Cold, Especially in Water.*

CIOS XXVI-38. *German Submarine Construction at Bremen and Kiel.*

CIOS XXVI-39. *German Destroyers at Bremen and Kiel.*

CIOS XXVI-40. *Daimler Benz Plant at Wendlingen.*

CIOS XXVI-41. *The Manufacture of Krupp Cemented Armor.*

CIOS XXVI-42. *The Manufacture of Armor Piercing Projectiles for the German Navy.*

CIOS XXVI-43. *The Manufacture of Armor Plate by Hoerder Huttenverein, Dortmund.*

CIOS XXVI-44. *Messerschmitt Bombproof Assembly Plant, Landsberg.*

CIOS XXVI-45. *German Submarine Pens in France.*

CIOS XXVI-46. *Sterephon Sound Recording System Developed by Dr. Carl-Heinz Becker.*

CIOS XXVI-47. *Gebr. Ciulini G.m.b.H., Ludwigshafen.*

CIOS XXVI-48. *Dr. F. Raschig G.m.b.H., Chemische Fabrik, Ludwigshafen.*

CIOS XXVI-49. *Heeresgasschutzschule I, Celle.* [chemical warfare]

CIOS XXVI-50. *Production of Synthetic Fatty Acids and Edible Fats—Deutsche Fettsaurewerke, Witten.*

CIOS XXVI-51. *Plant of Chemische Werke, Huls.*

CIOS XXVI-52. *Manufacture of Fabrication of Polyvinyl Chloride (PCU and PC) at I.G. Farbenindustrie Bitterfeld.*

CIOS XXVI-53. *Manufacture of Caprolactam at I.G. Farbenindustrie Leunawerke, Merseburg.*

CIOS XXVI-54. *I.G. Farbenindustrie AG, für Stickstoff-Duenger Knapsack.*

CIOS XXVI-55. *Chemische Werke Albert, Biebrick.*

CIOS XXVI-56. *Research in Aviation Medicine for the German Air Force.*

CIOS XXVI-57. *German Development of Homing Devices.*

CIOS XXVI-58. *The Status of Synthetic Training in Germany.*

CIOS XXVI-59. *German Anti-Fouling Compositions.*

CIOS XXVI-60. *Light Metal Production and Development for Aircraft I.G. Farbenindustrie, Bitterfeld.*

CIOS XXVI-61. *Film Production and Methods, Agfa Film Fabrik Plant, Wolfen.*

CIOS XXVI-62. *The German Chlorine Industry with Particular Emphasis on I.G. Farbenindustrie AG and the War Influence.*

CIOS XXVI-63. *Rohm and Haas, Darmstadt.* [Enzymatic pharmaceutical production]

CIOS XXVI-64. *Manufacture of Hydrocyanic Acid, I.G. Farbenindustrie, Oppau.*

CIOS XXVI-65. *Findings on German Proximity Fuze Developments in 21 Army Group Area.*

CIOS XXVI-66. *Klein Schanglin and Becker AG, Hydraulic Couplings and Torque Converters.*

CIOS XXVI-67. *German Ordnance Research and Developments.*

CIOS XXVI-68. *Wirtschaftliche Forschungs G.m.b.H. (WIFO). Fuel Blending Station, Eferbachtel.*

CIOS XXVI-69. *Steel Forging Industry of Germany.*

CIOS XXVI-70. *Rottweil AG* [Explosives R&D]

CIOS XXVI-71. *Seigfried Junghans Schorndorf.*

CIOS XXVI-72. *Maschinen für Massenverpackung G.m.b.H., Schultrup.*

CIOS XXVI-73. *Insecticides, Insect Repellents, Rodenticides and Fungicides of I. G. Farbenin-*

dustrie A. G., Elberfeld and Leverkusen, Germany.

CIOS XXVI-74. *The Manufacture of German Steel Cartridge Case, Part I.*

CIOS XXVI-75. *Production of Cellulose Acetate, I. G. Farbenindustrie, Dormagen/Cologne.*

CIOS XXVI-76. *Manufacture of Polyisobutylene—I. G. Farbenindustrie, Oppau.*

CIOS XXVI-77. *Rotary Air Compressors Built by Demag AG, Duisburg.*

CIOS XXVI-78. *French Oil Shale Industry.*

CIOS XXVI-79. *I. G. Farbenindustrie, Meinkur-Hoechst.*

CIOS XXVI-80. *Steinkohlen-Bergwerk Rheinpreussen, Moers-Meerbeck.*

CIOS XXVI-81. *Neuropsychiatric Organizations in the German Air Force.*

CIOS XXVI-82. *German Production Methods for High Test Peroxide.*

CIOS XXVI-83. *Bayerische Motor Werke (BMW).*

CIOS XXVI-84. *Mahle KG (Piston Plant).*

CIOS XXVI-85. *The Luftwaffe Signal School, Köthen.*

CIOS XXVI-86.

CIOS XXVI-87. *Dachs Lubricating Oil Plant, Porta, Germany.*

CIOS XXVII-1. *Neuropathology and Neurophysiology, Including Electroencephalography, in Wartime Germany.*

CIOS XXVII-2. *The German Surgical Instrument Industry in the Tuttlingen Area.*

CIOS XXVII-3. *Military and Civilian Dental Education and Practice in Germany.*

CIOS XXVII-4. *Insecticides and Fungicides at the I.G. Farbenindustrie Plant, Höchst.*

CIOS XXVII-5. *German Clock and Watch Industry.*

CIOS XXVII-6. *Manufacture of Styrene and Polystyrene, I.G. Farbenindustrie, Schkopau.*

CIOS XXVII-7. *Vereinigte Lichtmetalle Werke, Hanover.*

CIOS XXVII-8. *Teuto Metall Werke, Osnabruck.*

CIOS XXVII-9. *Kupfer U Drahtwerke, Osnabruck.*

CIOS XXVII-10. *Hanomag, Hanover.*

CIOS XXVII-11. *The Winter Proofing Establishment, St Johann, Austria.*

CIOS XXVII-12. *Westfalische Draftindustrie, Hamm.*

CIOS XXVII-13. *Research and Development in Hydraulic Couplings (Fluid Power Transmissions), J.M. Voith, Heidenheim/Brenz.*

CIOS XXVII-14. *I.G. Farbenindustrie, Mainkur/Hoechst.* [Penicillin]

CIOS XXVII-15. *Manufacture of Acetaldehyde, I.G. Farbenindustrie, Schkopau.*

CIOS XXVII-16. *Fabrication of Plastics, I.G. Farbenindustrie Wolfen.*

CIOS XXVII-17. *I.G. Farbenindustrie Plant, Hoechst/Main.*

CIOS XXVII-18. *The Oxo Plant, Ruhrchemie Oberhausen-Holden.*

CIOS XXVII-19. *Steel Metallurgy at Messerchmitt, Oberammergau and Garmisch-Partenkirchen.*

CIOS XXVII-20. *Prof. Dr. Ing. Emil Sorensen, Maschinenfabrik Augsberg-Nurnberg AG, Augsberg.* [Ceramic gas turbine blades]

CIOS XXVII-21. *Research Activity at Deutsche Versuchsanstalt für Luftfahrt, Garmisch.*

CIOS XXVII-22. *Gas Turbine and Wind Tunnel Activity, Brown Boverie CIE, Heidelberg.*

CIOS XXVII-23. *Optical Grinding and Centering Equipment Used by Carl Zeiss, Jena.*

CIOS XXVII-24. *Machine Used by Carl Zeiss, Jena, to Grind Aspheric Lens Surfaces.*

CIOS XXVII-25. *Waggonfabrik Verdingen AG, Krefeld-Verdingen.*

CIOS XXVII-26. *Deutsche Edelstahlwerke AG, Krefeld.*

CIOS XXVII-27. *Recoilless Guns Development of Rheinmetall-Borsig.*

CIOS XXVII-28. *Research Institute for Materials of the D.V.L., Sonthofen.* [High-temperature alloys for jets]

CIOS XXVII-29. *Metallurgical High Lights in the Recent Manufacture of Rolled Steel Plates and Sheets in Germany.*

CIOS XXVII-30. *Repair of Damage to Armor Structures.*

CIOS XXVII-31. *Rocket Ballistics (Guiding and Stabilization) Research and Development Work at "Luftfahrtforschungsanstalt, Hermann Goering," Volkenrode.*

CIOS XXVII-32. *A Series of Interviews with Members of German Medical Schools, Research Institutes and Hospitals.*

CIOS XXVII-33. *German Acoustic Torpedoes and Torpedo Pistols.*

CIOS XXVII-34. *War Gas Production and Miscellaneous Chemical Warfare Information, Anorgana G.m.b.H., Gendorf.*

CIOS XXVII-35. *Rheinmetall-Borsig AG Werk, Unterlüss.*

CIOS XXVII-36. *Manufacture of Steel Case Small Arms Ammunition, Dynamit AG, Stadelin and Nurnberg.*

CIOS XXVII-37. *Fuzing System of German A4 Rocket (V-2).*

CIOS XXVII-38. *Manufacture of Initiating Explosives and Their Handling for Use in Cap Det-*

onator Loadings at Fabrik Wolfratshausen Chemischer Erzeugnisse and Dynamit AG, Stadeln.

CIOS XXVII-39. *I.G. Farbenindustrie, Uerdigen.* [Plastics patents]

CIOS XXVII-40. *Deutsche Edelstahlwerke AG, Hochfrequenz-Tregelstahl G.m.b.H., Bochum.*

CIOS XXVII-41. *Tovarna Na Nabojky A Kovove Zbozi (Patronen Hulsen Und Metallwaren Fabrik), Rokycany, Czechoslovakia.*

CIOS XXVII-42. *Bochumer Verein AG, ABT Stahlwerke, Bochum.*

CIOS XXVII-43. *Manufacture of Glass Fabric Impregnated Fibre Used as a Substitute for Mica Insulation Between Commutator Segments in Motors and Generators.*

CIOS XXVII-44. *Manufacture of Metalized Paper Fixed Capacitor Units by the Robert Bosch Co., Stuttgart.* [Metallized paper capacitors]

CIOS XXVII-45. *Suddeutsche Apparate-Fabrik.*

CIOS XXVII-46. *Design of Radar Test Equipment, Siemens Halske Plant, Munich.*

CIOS XXVII-47. *Interrogation of Dr. Stiele von Heydenkampf, President of the Panzer Kommission.*

CIOS XXVII-48. *Chemische Werke Albert and Other Pharmaceutical Targets, Weisbaden.* [Neuroscience]

CIOS XXVII-49. *Thermocolour Paints, I.G. Farbenindustrie, Oppau.* [Heat sensitive paints]

CIOS XXVII-50. *Manufacture of Hydroquinone, I.G. Farbenindustrie, Wolfen.*

CIOS XXVII-51. *Manufacture of Vinyl Chloride and Polyvinyl Chloride, I.G. Farbenindustrie, Schkopau.*

CIOS XXVII-52. *Proposed T-44 Class German Destroyers.*

CIOS XXVII-53. *Production of Electric Cable and Molded Rubber-to-Metal Bonded Products.*

CIOS XXVII-54. *Chemische Werke Essener Steinkohle AG, Bergkamen, Germany.*

CIOS XXVII-55. *Gesellschaft für Linde's Eismachinen, Hollriegelskreuth.*

CIOS XXVII-56. *German Aircraft and Naval Torpedoes.*

CIOS XXVII-57. *Personnel Anti-Bomb Shelters.*

CIOS XXVII-58. *The Wilhelm Schmidding Werke, Koln.*

CIOS XXVII-59. *Underground German Liquid Oxygen Plant, Wittring.*

CIOS XXVII-60. *The Wesseling Synthetic Fuel Plant.*

CIOS XXVII-61. *Drägerwerk, Lübeck Germany.* [Oxygen breathing apparatus, CO2 measuring instruments]

CIOS XXVII-62. *German Safety Fuze and Dynamo Exploders.*

CIOS XXVII-63. *Rocket Fuel and Explosive Mixtures Containing Peroxides.*

CIOS XXVII-64. *German Aircraft Maintenance and Overhaul Methods.*

CIOS XXVII-65. *The Rheinmetall Borsig Works and Proving Grounds, Unterluss.*

CIOS XXVII-66. *Description of the Construction and Performance of the Anti-Aircraft Rocket "Enzian E4."*

CIOS XXVII-67. *Aerodynamics of Rockets and Ramjets Research and Development Work at "Luftfahrtforschungsanstalt, Hermann Goering," Volkenrode.*

CIOS XXVII-68. *Fischer-Tropsch Unit at Leipzig Gas Works.*

CIOS XXVII-69. *The Fischer-Tropsch Plant of Ruhrchemie AG, Sterkrade-Holten.*

CIOS XXVII-70. *Gutehoffnungshutte AG, Sterkrade.*

CIOS XXVII-71. *The Medical School Curriculum in Wartime Germany.*

CIOS XXVII-72. *Manufacture of Solventless Type Smokeless Powder and Nipolit, Kraiburg Works, Deutsche Spreng-Chemie G.m.b.H.*

CIOS XXVII-73. *The Manufacture of Nitrocellulose, Deutsche Sprengstoffe, Aschau and Ebenhausen.*

CIOS XXVII-74. *The Proving Ground, Hillersleben, Germany.*

CIOS XXVII-75. *Electrical Induction Face, Hardening of Thick Armour Plate.*

CIOS XXVII-76. *Summary of Visits to German Die-Casting Plants.*

CIOS XXVII-77. *The Neustadt Wire and kabel Werke, Neustadt Bei Cobarg.*

CIOS XXVII-78. *German Cast Armor.*

CIOS XXVII-79. *Rheinmetall-Borsig AG, Düsseldorf.*

CIOS XXVII-80. *I.G. Farbenindustrie AG, Uerdingen.* [Selenium Rectifiers]

CIOS XXVII-81. *J. Riedel–E. de Haen, Seelze.*

CIOS XXVII-82. *Fischer Tropsch and Allied Processes.*

CIOS XXVII-83. *AG für Stickstoffduenger Knapsack.*

CIOS XXVII-84. *I.G. Farbenindustrie AG, Ludwigshafen and Oppau Wehrmacht Items.* [Dyes fluorescent in UV]

CIOS XXVII-85. *Miscellaneous Chemicals, I.G. Farbenindustrie AG, Ludwigshafen and Oppau.*

CIOS XXVII-86. *Research Activities at Göttingen on Aerodynamics of Projectiles, Missiles and Ramjets.* [transonic/supersonic airfoil shapes]

CIOS XXVII-87. *German Electronic, Physical and Optical Instrument Targets.*

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CIOS XXVII-89. *German Minesweeping and Mining.*

CIOS XXVII-90. *German Marine Engines.*

CIOS XXVII-91. *Robert Bosch, Stuttgart and Fuerbach.*

CIOS XXVII-92. *German Carbide, Cyanamide and Cyanide Industry.*

CIOS XXVII-93. *Wirtschaftliche Forschungs G.m.b.H., Fuel Blending Station, Heiligenstadt.*

CIOS XXVII-94. *Vereinigte Deutsche Metallwerke AG*

CIOS XXVII-95. *Heraeus Vacumschmelze AG, Hanau.*

CIOS XXVII-96. *Oberfeldarzt Professor Hugo Spatz, The Department of Brain Research, Kaiser Wilhelm Institute.*

CIOS XXVII-97. *Dr. Habs, German Malariologist.*

CIOS XXVII-98. *Siemens Halske, Asche.*

CIOS XXVII-99. *The Manufacture of Homogeneous Light Armor.*

CIOS XXVII-100. *Stahlwerk Krieger Oberkassel.*

CIOS XXVIII-1. *Continuous and Staple Fibre Plants of Germany.*

CIOS XXVIII-2. *Artillery Experimental Range, Hillersleben.*

CIOS XXVIII-3. *Translation of German Progress Report on Development of the E-100 Tank.*

CIOS XXVIII-4. *Investigation of Rocket Research Elektromechanische Werke G.m.b.H.*

CIOS XXVIII-5. *The Medical Faculty of the University of Leipzig.*

CIOS XXVIII-6. *Venereal Disease Control Office for Thuringia.*

CIOS XXVIII-7. *Aircraft Electrical Accessories and Materials.*

CIOS XXVIII-8. *Methods of Influencing International Scientific Meetings as Laid Down by German Scientific Organizations.*

CIOS XXVIII-9. *German Aircraft Industry, Friedrichshafen-Munich Area.*

CIOS XXVIII-10. *Machine Tool Targets, Leipzig.*

CIOS XXVIII-11. *Dental Education, Practice and Equipment in Germany.*

CIOS XXVIII-12. *Jumo 109,004 Jet Propulsion Engine.*

CIOS XXVIII-13. *Synthetic Rubber Plant, Buna Werke Schkopau A. G., Schkopau.*

CIOS XXVIII-14. *Medical Faculty of the Friedrich-Schiller-University, Jena.*

CIOS XXVIII-15. *German Machinery Spring Industry.*

CIOS XXVIII-16.

CIOS XXVIII-17. *German High Speed Aircraft Developments.*

CIOS XXVIII-18. *The Universal Fauth System Extraction Process.*

CIOS XXVIII-18, Item 22. *Gesellschaft Zur Verwertung Fauthscher G.m.b.H., Wiesbaden.*

CIOS XXVIII-19. *Food Chemistry Institute, Franfurt-a-Main.*

CIOS XXVIII-20. *Radio Sonde Transmitters, Wurt Radio G.m.b.H.—Stuttgart and Neuhausen.* [Meteorology R&D]

CIOS XXVIII-21. *German Submarine Rotary Wing Kite.*

CIOS XXVIII-22. *Dornier Werke G.m.b.H., Friedrichshafen.*

CIOS XXVIII-23. *AG Sachsische Werke-Espenhain.*

CIOS XXVIII-24. *Institut für Bauforschung und Material Prufungen des Bauwesens, Stuttgart.*

CIOS XXVIII-25. *German Airframe Tooling and Methods, Messerschmitt Works.*

CIOS XXVIII-26. *Signal Items, I.G. Farben Plants, Mainkur and Höchst.*

CIOS XXVIII-27. *Leuna Works Near Merserberg.*

CIOS XXVIII-28. *Wolfen Works, I.G. Farben.*

CIOS XXVIII-29. *Chemicals Made at Schkopau Works.*

CIOS XXVIII-30. *Nutrition Studies, Institut für Vetinerie Physiologie, University of Leipzig.*

CIOS XXVIII-31. *Investigation of the X-Ray Industry in Germany.*

CIOS XXVIII-32. *Deustche Maizena Werke AG (Barby).*

CIOS XXVIII-33. *Experimental Production of Penicillin, St. Jacob's Hospital, Leipzig.*

CIOS XXVIII-34. *The Wulf Hefefabrik, Dessau.* [Bakers yeast production]

CIOS XXVIII-35. *Production of Fatty Acids from By-Products of the Fischer-Tropsch Process.*

CIOS XXVIII-36. *H. Koppers G.m.b.H., Essen.*

CIOS XXVIII-37. *German Magnesium Forging Industries.*

CIOS XXVIII-38. *Selenium Rectifiers—S.A.F., Nürnberg Institut für Anorganische und Physikalische Chemie, Darmstadt.*

CIOS XXVIII-39. *Luftwaffe Research Institute, Bad Blankenburg.*

CIOS XXVIII-40. *The High Pressure Hydrogenation Plant Especially for Brown Coals Wesseling.*

CIOS XXVIII-41. *Institut für Physikalische Forschung, Neu Drossenfeld.* [TV homing device]

CIOS XXVIII-42. *Wood Sugar Yeast Manufacture, I.G. Farbenindustrie, AG, Wolfen.*

CIOS XXVIII-43. *The German "Fasteners" Industry.*

CIOS XXVIII-44. *Kienzle Apparate G.m.b.H., Villingen/Schwarzwald.*

CIOS XXVIII-45. *Group 2 Targets in Nordhausen Area.* [p. 12 Walter Riedel located in Thuringia and brought to Nordhausen]

CIOS XXVIII-46. *Automotive Targets in 12th Army Group Area.*

CIOS XXVIII-47. *High Speed Tunnels and Other Research in Germany.*

CIOS XXVIII-48. *Hosiery and Hosiery Machinery Industry, Hosiery Needle Making Industry.*

CIOS XXVIII-49. *German Military Neuropsychiatry and Neurosurgery.*

CIOS XXVIII-50. *Public Mental Health Practices in Germany.*

CIOS XXVIII-51. *Dipl. Ing. Hans Ludwig, Gross Quern.* [missile homing device, etc.]

CIOS XXVIII-52. *German Submarine and Anti-Submarine Methods and Equipment.*

CIOS XXVIII-53. *Walter Werke, Kiel.* [Submarine propulsive ducts research, ballistics]

CIOS XXVIII-54. *Production Statistics German Steel Industry 1943 and 1944.*

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CIOS XXVIII-56. *Rockets and Guided Missiles.* [overview by von Braun]

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CIOS XXIX-12, Part II. *Polyurethanes Dr. O. Bayer (I.G. Farbenindustrie, Leverkusen).*

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CIOS XXXI-35. *Interview with Dr Stoeckicht on Gear Design.*

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CIOS XXXI-37. *Institutes of the Bevollmaechtigter für Hochfrequenz-Forschung.* [Fuses for missiles, R&D]

CIOS XXXI-38. *The I.T.T., Siemens and Robert Bosch Organizations.* [Missile TV, autopilot]

CIOS XXXI-39. *Messerschmitt Engineering and Research Facilities, Oberammergau and Aeronautical Research Institute of Vienna.* [Lippisch, etc.]

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CIOS XXXI-81. *The Manufacture and Physical Properties of Iporka.*

CIOS XXXI-82. *German Fifty-Two Centimeter Mamouth Press for the Extrusion of Rocket Propellant.*

CIOS XXXI-83???. *German Research Institutes.* [radar CM, speech systems, calculating machines, etc.]

CIOS XXXI-83???. *Report to Secretariat Concerning Physikalisch-Technische Reichsanstalt.*

CIOS XXXI-84. *German and Danish Industries.* [electronics, optics, anti-radar, smart bombs, railgun]

CIOS XXXI-85. *Edeleanu G.m.b.H., Altenburg.*

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Note: There are several cases in which one FIAT report was given two different numbers. There are an inexplicably large number of cases in which two different, unrelated FIAT reports were assigned the same number. If fact, there may well be additional FIAT final reports that are not listed here but that have the same number as a different report that is listed. It is unclear if the numerical mayhem was due to administrative carelessness by FIAT, or if there were intended to be two different series of FIAT final reports, or if more mundane reports with a given number were used as an unclassified placeholder to help conceal the existence of then-classified reports with the same number.

FIAT 1. *Investigation of Machine Tool Practice of M.A.N. at Augsburg, Germany.*

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FIAT 3. *Investigation of Machine Tools of Adam Opel at Russelsheim, Germany.*

FIAT 4. *German Infrared Targets in South Germany and Austria.*

FIAT 4. *Investigation of Measuring Instruments, Gages and Cutting Tools.*

FIAT 5. *Interrogation of General Gerhard Rose, Vice-President of the Robert Koch Institute, Berlin, and Chief Consultant in Tropical Medicine to the German Air Force.*

FIAT 6. *Viscose Making at Suddeutsche Zellwolle A.G. Kelheim.*

FIAT 7. *Rayon Tow (Spinnband) and Staple in the Worsted Spinning Industry. Augsburger Kammgarm Spinnerei, Augsburg.*

FIAT 8. *Investigation of Textiles, I.G. Farbenindustrie Bobingen.*

FIAT 9. *Investigation of Scientific and Laboratory Glassware Area of Thuringia, Germany.*

FIAT 10. *Continuous Process for Spinning Viscose Yarn at Zellwolle Lenzing Aktiengesellschaft Lenzing, Oberdonau, Austria.*

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FIAT 15. *Research on the Cyclopoly Olefines at I.G. Farbenindustrie Gendorf.*

FIAT 16. *P.C. Fibers. I.G. Farbenindustrie Wolfen.*

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FIAT 19. *Viscose Staple Fiber (Spinning) at Lonziger Zellwolle Fabrik, A.G. Lenzing, Ost.*

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FIAT 21. *Documents Relating to Cottonizing and Bleaching Bast Fibers at I.G. Farbenindustrie Sauerstoff-Werke, Griesheim.*

FIAT 22. *Viscose Rayon Staple Manufacture at Shia Viscosa Cesana Maderno (Milano).*

FIAT 23. *Viscose Rayon Staple Manufacture at Shia Viscosa Cesana Maderno (Milano).*

FIAT 24. *"Animalized" Viscose and Acetate Staple at I.G. Farbenindustrie, A.G., Bobbingen, Höchst and München.*

FIAT 25. *Synthetic Fiber-Forming High Polymers at Kaiser Wilhelm Institut für Physikalische Chemie Berlin Dahlem.*

FIAT 26. *Raw Materials Used in German Iron and Steel Industry.*

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FIAT 27. *"Cottonin" or Cottonized Flax, 3rd Army Intelligence Center Freising.*

FIAT 28. *Making of Acetic Anhydride by Pyrolysis of Acetic Acid at C.S. Boehringer & Sohne, Mannheim-Waldorf.*

FIAT 29. *Manufacture of Acetic Anhydride at Consortium für Elektrochemie, Hollriegelskreuth.*

FIAT 30. *Polyvinyl Chloride Manufacture—Vinol HH at Alexander Wacker, Burghausen.*

FIAT 31. *Manufacture of Rayon Tire Yarn, Cord and Fabric at Pirelli S.P.A. Azienda Tessile Artificial Pizzaghetone, Italy.*

FIAT 32. *Acetic Anhydride, Cellulose Acetate Production and Weak Acid Recovery at I.G. Farben Dormagen.*

FIAT 33. *Production of Cellulose Acetate Staple, Cellulose Acetate, Acetic Anhydride, and Acetic Acid at Alexander Wacker Electrochemische Industrie Burghausen.*

FIAT 34. *Preparation of Cuprammonium Spinning Solution, Production of Cuprammonium Staple and Specialties, Recovery of Copper and Ammonia at I.G. Farbenindustrie, Dormagen.*

FIAT 35. *Bobbin Spinning Process of Viscose Rayon Textile Yarn and of Yarn for Tire Cord at Shia Viscosa Cesana Maderno.*

FIAT 36. *Staple Fiber Production, "Vistra", Normal and High Tenacity at I.G. Farbenindustrie A.G. Wolfen.*

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FIAT 54. *German Developments in Semi-Conducting Materials.* [by T. M. Odarenko]

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FIAT 55. *German "Upon" Universal Milling Machine.* [by T. M. Odarenko]

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FIAT 61. *Cuppramonium Rayon Continuous Process. I.G. Farbenindustrie, Dormagen.*

FIAT 61. *Radar Camouflage Radiation Absorption Materials.* [by T. M. Odarenko]

FIAT 62. *I.G. Work on Polyamides, I.G. Farben, Ludwigshafen.*

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FIAT 63. *Activities of the Second Institute of Physics of the University of Vienna.* [by T. M. Odarenko; the original German version of this report is G-345]

FIAT 63. *Manufacture of Cellulose Acetate Flake and Yarn. Rhodiaseta A.G., Freiburg, Germany.*

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TNA AIR 2/ 8415–8416 [V weapons]

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TNA AVIA 12/ 82 [Operation Surgeon], 191 [Reparations from Germany]

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TNA AVIA 54/ 1294 [Employment of Germans in UK under DCOS Scheme], 1295 [Employment of Germans in UK under DCOS Scheme], 1403 [Employment of German Scientists and Technicians], 1404 [Halstead Exploiting Centre], 1826 [Long-Term Employment of German Scientists]

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TNA DEFE 2/ 1107 [30 Assault Unit]

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TNA FO 371/ 71038 [Unterluss]

TNA FO 800/ 565 [German nuclear scientists]

TNA FO 935/ 1, 25, 140 [Technology targets in Germany]

TNA FO 936/ 39 [FIAT]

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TNA FO 943/ 42 [Reparations]

TNA FO 1010/ 20 [Reparations]

TNA FO 1012/ 420–421 [Reparations]

TNA FO 1013/ 373 [German scientists in U.K.]

TNA FO 1031/ 1–86 [Technology transfer from Germany], 138 [Russian recruitment of German scientists]

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TNA HW 8/ 104 [History of 30 Commando]

LAB: Ministry of Labour papers

TNA LAB 8/ 1198 [Darwin Panel], 1450 [General policy and correspondence]

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TNA PREM 8/ 373 [Interrogation of German Scientists in United Kingdom]

T: Treasury papers

TNA T 294/ 15 [Assembly reports 1951 and 1961]

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AFHRA A0417.

AFHRA A0548. [34th Squadron at Gusen.]

AFHRA A0572. [Frame 1974 Linz.]

AFHRA A0599.

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AFHRA A1007. [Many CIOS Evaluation Reports.]

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AFHRA A1035. [1945–1947 intelligence, including some information related to wartime German work.]

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AFHRA A1166.

AFHRA A1258. [Schmidding rocket documents.]

AFHRA A1259. [Many wartime Allied reports on German secret weapons.]

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AFHRA A2055. [*History of AAF Participation in Project Paperclip.*]

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AFHRA A4200.

AFHRA A5065. [Mauthausen]

AFHRA A5066. [pp. 266– secret weapons]

AFHRA A5067. [Report on SS medical research.]

AFHRA A5069. [Long report on I.G. Farben.]

AFHRA A5070. [CIOS-related reports.]

AFHRA A5071.

AFHRA A5109. [Captured jets and rockets.]

AFHRA A5127. [Crossbow target intelligence fall 1944–spring 1945.]

AFHRA A5128. [Frame 562 On-site report and photos from large rocket launching sites on French coast. Frame 677 V3 and V4 rockets. Frame 690 1944 rumor of V2 to V5.]

AFHRA A5183. [Interrogations of German and Austrian scientists.]

AFHRA A5184. [Frame 0690 scientists from Russian zone; other lists of scientists.]

AFHRA A5185. [Wartime Allied reports on German secret weapons.]

AFHRA A5186. [Wartime Allied reports on German secret weapons; postwar CIOS final reports.]

AFHRA A5187. [CIOS final reports.]

AFHRA A5188. [CIOS final reports.]

AFHRA A5189. [CIOS Evaluation Reports.]

AFHRA A5190. [CIOS documents.]

AFHRA A5191. [CIOS documents.]

AFHRA A5199. [CIOS documents.]

AFHRA A5200. [CIOS documents.]

AFHRA A5286. [Frames 0156-165 Auschwitz. Frames 0391-0402 Kummersdorf.]

AFHRA A5399. [Frame 1474 list of Peenemünde scientists targeted for capture, including von

Braun.]

AFHRA A5413. [Wartime intelligence from Germans held as prisoners of war.]

AFHRA A5414. [Wartime intelligence from Germans held as prisoners of war.]

AFHRA A5415. [Wartime intelligence from Germans held as prisoners of war.]

AFHRA A5416. [Wartime intelligence from Germans held as prisoners of war.]

AFHRA A5417. [Wartime intelligence from Germans held as prisoners of war.]

AFHRA A5459. [Heavy water memo says Allies want information but do not have it.]

AFHRA A5465. [Locations of “oil” plants including Austria.]

AFHRA A5466. [Locations of German aircraft factories, including Posen.]

AFHRA A5467. [BIOS final reports.]

AFHRA A5496.

AFHRA A5498.

AFHRA A5689A. [Scientific exploitation in Austria.]

AFHRA A5721. [pp. 1865-1945 Focke-Wulf Triebflugel and FW 183 jet, He-Hirth jet engine]

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AFHRA A5723. [Air Intelligence Summary 1944–1945.]

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AFHRA A5726. [Interrogations of captured German officers and scientists.]

AFHRA A5727. [Files on various aspects of Luftwaffe organization.]

AFHRA A5729. [Lots of wartime and postwar intelligence on secret weapons. pp. 255 and 561: An Evaluation of German Capabilities in 1945.]

AFHRA A5730. [Long, detailed lists of captured German technologies.]

AFHRA A5730A. [Long, detailed lists of captured German technologies.]

AFHRA A5731. [Long, detailed lists of captured German technologies.]

AFHRA A5732. [Long, detailed lists of captured German technologies.]

AFHRA A5733. [Long, detailed lists of captured German technologies.]

AFHRA A5734. [Long, detailed lists of captured German technologies; Peenemünde.]

AFHRA A5735. [Some documents on captured German technologies.]

AFHRA A5924. [Frames 999–1110 bombing of Oranienburg and Gusen on 15 March 1945.]

AFHRA A6091. [Frames 961– Lots of PW reports of underground factories, etc.]

AFHRA A6494. [Frames 1332–1812 Auschwitz bombings.]

AFHRA A6539. [Frames 127–136 Auschwitz aerial photos.]

AFHRA A6544. [Frames 1139-1239 Aerial photos of Melk, Gusen, etc.]

AFHRA A7123.

AFHRA A7737.

AFHRA A7739.

AFHRA A7741.

AFHRA A7744.

AFHRA B0082. [Frame 1325: Linz occupation, but only mundane details of daily life.]

AFHRA B0187. [U.S. photo booklet of Ohrdruf and other concentration camps, written in German for Germans.]

AFHRA B0240.

AFHRA B0498. [Frames 1033-1045 bombing Pilsen, Linz, etc.]

AFHRA B0673.

AFHRA B0678.

AFHRA B0679.

AFHRA B0680.

AFHRA B0852.

AFHRA B1728. [*Intelligence Review.*]

AFHRA B1729. [*Intelligence Review.*]

AFHRA B1730. [*Intelligence Review.*]

AFHRA B1731. [Intelligence documents.]

AFHRA B1734. [Frames 0997– *Scientific Intelligence Review* 1946.]

AFHRA B1735. [Intelligence Bulletins.]

AFHRA B1736. [Intelligence Bulletins.]

AFHRA B1756. [Lots of intelligence reports, including V2; frame 0774 calculated V2 ranges with heavier payloads; frame 0794 Allied prediction of 2-stage rocket with uranium bomb produced underground.]

AFHRA B1759. [Frame 607 Lise "Keltner."]

AFHRA B1760.

AFHRA B1761.

AFHRA B1763. [Frame 432 Ahnenerbe; implosion diagnostics–lots of important people; etc.]

AFHRA B1764.

AFHRA B1806. [Frame 895 V-weapons history; Kammler.]

AFHRA B1901.

AFHRA B1974. [Doenitz on German Navy history in 1946; frame 1900 overview of German aircraft.]

AFHRA B1975. [Frame 1326 Lectures by Heinz Schlicke!!! Frame 1695 IR homing.]

AFHRA B1976. [Frame 0305 Sonar in the German Navy. Frame 700 DFS? 346 supersonic aircraft. Frame 737 rockets according to Dornberger interrogation.]

AFHRA B5017. [Frames 299-483 Arnstadt, Ohrdruf, etc. bombing information.]

AFHRA B5287. [Frames 1676-1724 bombing photos including Ohrdruf, Arnstadt.]

AFHRA B5350. [Frames 797-930 bombing reports of relevant areas but not much information.]

AFHRA B5736.

AFHRA B5737. [p. 340 Second Zinsser report.]

AFHRA B5965. [Frame 0895 TAL Report 5/44 Röntgenblitzaufnahmen detonierdener H-Körper mit kegelförmigem Hohlraum–Zimmer, Thomer]

AFHRA C5087A. [Interrogations of Luftwaffe high command.]

AFHRA C5088. [*German Armaments and Munitions.*]

AFHRA C5089. [FIAT-related documents.]

AFHRA C5090. [FIAT-related documents.]

AFHRA C5091.

AFHRA C5092. [FIAT-related documents; postwar intelligence.]

AFHRA C5093. [Lots of interrogations of Peenemünde personnel.]

AFHRA C5094. [Lots of interrogations of detained German and Austrian scientists/engineers. Frame 1546 First report on Rudolph Zinsser.]

AFHRA C5095. [Frame 0021 Justice Jackson received information from George McDonald, CIOS, and OSS.]

AFHRA C5096. [FIAT-related documents; postwar intelligence.]

AFHRA C5097. [FIAT-related documents; postwar intelligence.]

AFHRA C5098. [Frame 0886 Hans Kammler available for interrogation in November 1945.]

AFHRA C5099. [FIAT-related documents; postwar intelligence.]

AFHRA C5099A. [Aviation medicine.]

AFHRA C5100. [Aviation medicine.]

AFHRA C5107.

AFHRA 15390. [Frame 557 Paperclip history and accomplishments.]

AFHRA 25011. [Lots of intelligence reports, especially file 188.]

AFHRA 25082. [No. 18 V weapons part 1: Auschwitz/Silesia as major area, Zipf, V-5.]

AFHRA 25141.

AFHRA 25172. [Target 1192 Floridsdorf.]

AFHRA 25177. [Target 1341 Arnstadt: Siemens & Halske V-2 guidance plant. Target 1391 Redl Zipf thorium, beryllium.]

AFHRA 25181. [Auschwitz.]

AFHRA 25189. [Frames 1181–1184 Arnstadt target file.]

AFHRA 25190. [Other target files.]

AFHRA 25191. [Other target files; V-weapons file 2171 just one card.]

AFHRA 25192. [Other target files.]

AFHRA 25193. [File 2508 Memmingen: "The largest flying bomb factory is the DORNIER WERKE at MEMMINGEN on railway KEMPTEN-MEMMINGEN-ULM. V.1 to V.4 types are made there."]

AFHRA 25194. [Frames 28-43 St. Georgen/Gusen target file.]

AFHRA 25216. [Underground locations producing secret weapons.]

AFHRA 25220. [No. 4476 onward Jockey Committee–jet factories to bomb.]

AFHRA 25227. [Doc. 92 Bomb factory prisoners die rapidly with burns and yellow skin.]

AFHRA 25239. [Aerial photos of Austria.]

AFHRA 25245.

AFHRA 34628. [U.S. postwar aircraft nuclear propulsion projects.]

AFHRA 36713.

AFHRA 39812. [Frame 1145 Japanese atomic bomb research.]

AFHRA 40051.

AFHRA 40505. [Goering. 1943 bombing of targets in Austria.]

AFHRA 43811. [Allied intelligence on German secret weapons. Preparing the American Public for a V-3 Attack. German Long-Range Missiles]

AFHRA 43826. [Long interviews with Donald Putt–few pages on Germans, mentions wartime research on lasers.]

U.S. National Archives and Records Administration (NARA), College Park, Maryland

RG 38: Records of the Office of the Chief of Naval Operations

NARA RG 38, Entry P-5, Boxes 1–64. [Alsos and Naval Technical Mission in Europe reports.]

NARA RG 38, Entry UD-16, Boxes 1–8. [Lists of documents and cargo from U-234.]

NARA RG 38, Entry UD-38, Box 13. [Interrogations of U-234 crew and passengers.]

NARA RG 38, Entry 72, Box 15. Naval Technical Mission in Europe, Serials and Enclosures 312 to 198, Serial 338. [examples of equipment transported to US, including submarine, 39 aircraft, V-1 and V-2 missiles, etc.]

NARA RG 38, Entry 98C, Boxes 1–17. Intelligence Division [Formerly] Top Secret Reports of Naval Attachés 1944–1947. [Some wartime and many postwar intelligence reports on advanced nuclear and rocket research programs that were conducted during the Third Reich.]

RG 40: General Records of the Department of Commerce

NARA RG 40, Entry UD-70, Boxes 1-25. Office of Technical Services, Records of John Weber.

NARA RG 40, Entry UD-71, Boxes 1-28. Office of Technical Services, Industrial Research and Development Division Project Files.

NARA RG 40, Entry UD-72, Boxes 29-35. Office of Technical Services, Industrial Research and Development Division Contract Files.

NARA RG 40, Entry UD-73, Boxes 36-38. Office of Technical Services, Industrial Research and Development Division Reports.

NARA RG 40, Entry UD-74, Boxes 39-67. Office of Technical Services, Industrial Research and Development Division Subject Files.

NARA RG 40, Entry UD-75, Boxes 1-71. Office of Technical Services, Policy and Program Files of the Technical Industrial Intelligence Division. [Extremely enlightening office files from some of the key U.S. officials behind the technology transfer from Germany and Austria to the United States.]

NARA RG 40, Entry UD-76, Boxes 1-10. Office of Technical Services, Records of Interdepartmental Committees.

NARA RG 40, Entry UD-77, Boxes 1-11. Office of Technical Services, Records Accumulated by the Publications Board.

NARA RG 40, Entry UD-78, Boxes 1-6. Office of Technical Services, *FIAT Review of German Science*.

RG 59: Department of State Central Files

NARA RG 59. Conant, James B. 1956. Memorandum to Secretary of State (13 July), State Department "Operation Paperclip" microfiche, Civil Reference Branch.

NARA RG 59, Entry A1-3008A, Box 489. Joliot-Curie.

RG 65: Records of the Federal Bureau of Investigation

NARA RG 65, Entry A1-136AB, Box 35. Karl Fiebinger.

RG 72: Records of the Bureau of Aeronautics

NARA RG 72, Entry ??, Boxes ??. German aerodynamics information in U.S. Navy files.

RG 77: Records of the Office of the Chief of Engineers [Manhattan Engineer District]

NARA RG 77, Entry UD-22A (General Records), Boxes 160–177. Manhattan Engineer District Foreign Intelligence Section. [Virtually all of these boxes and most of their folders contain information related to the German nuclear program, even if the box/folder titles do not sound relevant.]

NARA RG 77, Microfilm M1108. Harrison-Bundy Files Relating to the Development of the Atomic Bomb, 1942–1946. [Available online at https://downloads.paperlessarchives.com]

NARA RG 77, Microfilm M1109. Correspondence ("Top Secret") of the Manhattan Engineer District, 1942–1946.

RG 80: General Records of the Department of the Navy, 1798–1947

NARA RG 80, Entry UD-17, Boxes 1–57. U.S. Navy top secret files.

RG 84: Records of Foreign Service Posts of the Department of State

NARA RG 84, Entry UD-2467, Box 3. German Atomic Energy Files.

RG 153: Records of the Office of the Judge Advocate General

NARA RG 153, Entry A1-144, Box 91 (August Eigruber–Mauthausen/Auschwitz) and Box 95 (Gusen).

RG 165: Records of the War Department General and Special Staffs

NARA RG 165, Entry NM84-79 (Security Classified Intelligence Reference Publication Files, 1940-45), Boxes 161–164 (Alsos personnel photo album and other records), Boxes 577–585 (CIOS Evaluation Reports and other records), and Boxes 899–900 (FIAT Evaluation Reports and other records).

NARA RG 165, Entry NM84-187, Boxes 137–140. Alsos.

NARA RG 165, Entry NM84-489, Boxes 170–177. Crossbow, biological warfare, etc.

NARA RG 165, Entry UD-27, Box 6. Walther Schieber.

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Hunt)

RG 208: Records of the Office of War Information

NARA RG 208, Entry 198, Box 1042. Press release Franklin-2994, NB-3297. Technical Industrial Intelligence Committee. 25 August 1945. Germany's Inner War Secrets, 26 August 1945. [significant German atomic progress]

NARA RG 208, Entry NC148-358, Box 109. Germany–Secret weapons.

RG 216: Records of the Office of Censorship

NARA RG 216.

RG 218: Records of the U.S. Joint Chiefs of Staff

NARA RG 218, Entry UD-1 (Central Decimal File 1942-45), Box 95 (File CCS 471.9, Sec. 5. Ernest W. Gruhn to Secretary, JIC. JIOA Memorandum attached to Draft press release, 11 March 1946) and Box 475 (Folder: CCS 471.9... (5-1- 45)... Sec. 3. Joint Intelligence Committee. Exploitation of German Scientists and Technicians. 5 January 1946. J.I.C. 317/10.)

NARA RG 218, Entry UD-93, Boxes 1–4. Biological warfare, missiles, exploitation of German scientists, etc.

RG 226: Records of the Office of Strategic Services 1940–1946

NARA RG 226, Entry UD-90, Boxes 1–10 (OSS Washington Radio and Cables). See especially Box 6, Folder 64 SUNRISE [Allen Dulles, Cable IN 9061, 1 April 1945] and Box 7, Folder 86 BERN–IN OUT 1944–1945 [Cable IN 9470, 5 April 1945].

NARA RG 226, Entry UD-125, Box 6, Folder 78. [Intelligence reports from Frederick Loofbourow and "Dr. Berg."]

NARA RG 226, Entry A1-134, Box 216 (Toledo In/Out Folders 1359–1360) and Box 219 (Azusa In/Out Folders 1370–1371).

NARA RG 226, Entry UD-165A, Box 15. [Underground installations.]

NARA RG 226, Entry UD-190 (Field Station Files), Box 551, Folder 170 (JIC 317: Exploitation of German and Austrian scientists in science and technology in the U.S.); Box 552, Folder 173 (JIC 317: Interim procedures for the coordinated exploitation of German specialists in science and technology in the US, December 1945) and Folder 174 (Basic direction re: JIOA); OSS Washington Director's Office Files (Microfilm Publication M1642) (Check series index under "German scientists").

NARA RG 226, Entry A1-210, Box 447, Folder WN16162–16171. Erwin Respondek. 6 November 1945. Übersicht des Standes der wissenschaftlichen Arbeiten in Deutschland zur Atom-Bombe, Berlin.

NARA RG 226, Entry A1-211 (Sources and Methods Files—Previously Withdrawn Material), Box 8, Folder 116. Incoming Cable Form, 21 April 1945. [V-4.]

NARA RG 226, Entry A1-212, Box 3 (Folder WN 20796), Box 5 (Folder WN 20939), and Box 7 (Folder WN 24481). [German atomic work.]

NARA RG 226, Entry A1-214, Box 2, Folder: WN 21090-21105. [A. J. Saxon.]

NARA RG 226, Entry A1-215, Box 6, Folder: WN 26150-26164. [List of 75 German nuclear scientists.]

RG 227: Records of the Office of Scientific Research and Development

NARA RG 227, Microfilm M1392. Bush-Conant File Relating to the Development of the Atomic Bomb, 1940–1945. [Available online at https://downloads.paperlessarchives.com]

RG 238: National Archives Collection of World War II War Crimes Records

NARA RG 238, Entry P-66, Box 39. Mauthausen/Gusen staffs.

NARA RG 238, Entry NM70-160, Box 30, Folder FIAT—Misc.—Reports—No. 1–10. Office of Military Government for Germany (US). Field Information Agency, Technical. DI 254-82 (FIAT) EP. 24 June 1946. Personality List No 2. Also Box 42, Walther Schieber.

NARA RG 238, M1019 Roll 80. War Crimes Records, Interrogation Summaries 4476 (1 December 1947) and 4453 (16 December 1947). [Secret weapon expected soon in Feb. 1945.]

NARA RG 238, M1270 Roll 24. Interrogation Records Prepared for War Crimes Proceedings at Nuernberg, 1945–1947.

RG 242: National Archives Collection of Captured German Records

NARA RG 242, Entry P-33, Box 17. [Walther Schieber.]

NARA RG 242, Entry UD-282AU1, Box 20. [Underground factories.]

NARA RG 242, Entry UD-282AY, Box 55. [Underground installations.]

NARA RG 242, Microfilm Series T-83. [Financial records.]

NARA RG 242, Microfilm Series T-321. [Underground and other records.]

NARA RG 242, Microfilm Series T-976. [SS economic records.]

NARA RG 242, Microfiche Series ??. German reports on atomic energy.

RG 243: Strategic Bombing Survey

NARA RG 243, Entry 27 I-10, Box 46 (Ebensee), Box 59 (Gaisbach, Wartberg), Box 107 (Mauthausen), Box 134 (Redl-Zipf), Box 171 (Zipf).

RG 260: Records of U.S. Occupation Headquarters, World War II

NARA RG 260, Entry A1-170, Boxes 1–15. FIAT Administrative Records, 1945–1947.

NARA RG 260, Entry A1-171, Boxes 16–21. FIAT Daily Journals, 1945–1947.

NARA RG 260, Entry A1-172, Boxes 22–23. FIAT Index Card File, 1946–1947.

NARA RG 260, Entry A1-173, Boxes 24–44. FIAT General Records, 1945–1947.

NARA RG 260, Entry A1-174, Boxes 45–46. FIAT Document Evaluation Forms, 1946.

NARA RG 260, Entry A1-175, Boxes 566–575. FIAT Administrative, Program, and Publications Files.

NARA RG 260, Entry A1-224, Box 101. [Reichspost.]

NARA RG 260, Entry A1-455, Box 649. [Messerschmitt Oberammengau.]

NARA RG 260, Entry A1-1573, Boxes 506–508. [Records Relating to German Scientists.]

NARA RG 260, Entry ??, Box 20-3/5. OMGUS (U.S. Office of Military Government for Germany) Historical Office. History of Field Information Agency, Technical (FIAT). Period 8 May 1945–30 June 1946. Period 1 July 1946–30 June 1947. [4994 FIAT investigators visited Germany during that 12-month period]

NARA RG 260, Microfilm Roll 0084. Records of the German External Assets Branch of the U.S. Allied Commission for Austria Section, 1945–1950.

RG 263: Records of the Central Intelligence Agency

NARA RG 263, Entry ZZ-16. CIA Name Files First Release.

NARA RG 263, Entry ZZ-18. CIA Name Files Second Release.

RG 298: Records of the Office of Naval Research

NARA RG 298, Entry UD-1, Boxes 66–67.

RG 319: Records of the Army Staff

NARA RG 319, Entry A1-84E, Box 124. [BID 8600.0711 Nuclear Physics (Atomic Energy)—Uses—Rockets. History of German Trans-Atlantic Rocket A-10. 4 March 1947.]

NARA RG 319, Entry A1-134A (Records of the Investigative Records Repository [IRR], Impersonal File).

NARA RG 319, Entry A1-134B (Records of the Investigative Records Repository [IRR], Personal Name File).

NARA RG 319, Entry NM3-47B, Box 991, Folder Implementation, General Policy & History.

NARA RG 319, Entry NM3-58, Box 7. Folders 1. TO: CZECHOSLOVAKIA 9-16-45–12-31-45 and 1. FR: CZECHOSLOVAKIA... (MISC) 9-3-45–12-31-45.

NARA RG 319, Entry NM3-82 (Publication Files), especially Boxes 375–426 [BIOS Evaluation Reports and Final Reports], Boxes 668–695 [CIOS Final Reports], Boxes 1264–1283 [FIAT Final Reports], Boxes 1545–1547 and 1622 [Guided Missiles], Boxes 1550–1621 [Halstead Exploitation Centre (HEC) Reports], Boxes 1674–1684 [German documents collected by Alsos Mission], Boxes 2151–2153 [JIOA], Box 2879 [Project 2784].

NARA RG 319, Entry NM3-82A, Boxes 1–19. [German documents collected by Alsos Mission.]

NARA RG 319, Entry NM3-85A (Army Intelligence Document File), especially Box 2126 (Folder 324361–324370), Box 2144 (Folder 326851–326860), Box 2534 (Folder 390731–390740).

NARA RG 319, Entry NM3-85M, Box 19. Folders 925253 and 925256. [Czechoslovakia.]

NARA RG 319, Entry UD-57, Boxes 76–81. [Wernher von Braun.]

NARA RG 319, Entry UD-151. [Counter Intelligence Corps.]

NARA RG 319, Entry UD-1080. [Counter Intelligence Corps.]

NARA RG 319, Entry UD-1041, Box 27, Folder 925497. [The Commanders Intelligence Digest. 19 January 1945.]

NARA RG 319, Entry ZZ-5 (Records of the Investigative Records Repository [IRR], Selected Personal Name Files).

NARA RG 319, Entry ZZ-6 (Records of the Investigative Records Repository [IRR], Selected Impersonal Files).

RG 326: Records of the Atomic Energy Commission

NARA RG 326.

RG 330: Records of the Office of the Secretary of Defense

NARA RG 330, Entry A1-1A, Boxes 1–43. General Correspondence of the Joint Intelligence Objective Agency (JIOA). 1946–1952.

Archival location??? Objective List of German and Austrian Scientists. (1,600 "Scientists"). 2 January 1947. https://www.smecc.org/heinz_muller/german_and_austrian_scientists_interrogated.pdf

NARA RG 330, Entry A1-1B, Boxes 1–186. JIOA Foreign Scientist Case Files. Index of names and boxes available online: https://www.archives.gov/files/iwg/declassified-records/rg-330-defense-secretary/foreign-scientist-case-files.pdf

NARA RG 330, Entry A1-1C, Boxes 1–3. Defense Scientist Immigration Program (DEFSIP) Administrative Records.

RG 331: Records of Allied Operational and Occupation Headquarters, World War II

NARA RG 331, Entry UD-13D. [CIOS reports.]

NARA RG 331, Entry NM8-18, Boxes 142–144. Subject File, 1944–45 (Re: Target Lists And Reports Of Target Teams, 1944–45). [FIAT records.]

NARA RG 331, Entry 83D, Box 33. Folder Com. Z. Releases: 1 May to 30 June 1945. John A. Keck. 28 June 1945 press release.

RG 341: Records of Headquarters United States Air Force (Air Staff)

NARA RG 341, Entry NM15-44 (Historical Branch Subject File), Box 152. Historical Studies Re: Project Paperclip.

RG 374: Records of the Defense Threat Reduction Agency

NARA RG 374, Microfilm A1218. Manhattan District History. [Available online at https://ia803409.us.archive.org/14/items/ManhattanDistrictHistory/]

RG 407: Records of the Adjutant General's Office, 1917–

NARA RG 407, Entry NM3-427 (WW II Operations Reports, 1941–48), especially Box 10127 (80th Infantry Division G-2, April 1945), Boxes 11005–11006 (89th Infantry Division G-2, April 1945), Boxes 12341–12345 (4th Armored Division, 1945), Boxes 12364–12366 (4th Armored Division G-2, April 1945), and Box 14465 (102nd Infantry Division G-2, 1945).

RG 457: Records of the National Security Agency

NARA RG 457, Entry A1-9004, Japanese Army Attaché Messages Translations, SRA 14,200 thru 15,000. SRA 14628–14632.

RG 498: Records of Headquarters, European Theater of Operations, U.S. Army

NARA RG 498, Entry UD-639, Boxes 4116–4117. FIAT Intelligence Reports, 1946.

NARA RG 498, Entry UD-640, Box 4117, FIAT [Background and] History, 1944–1946.

NARA RG 498, Roll MP63-9_0137 (Series Historical Reports and Monographs—Miscellaneous Reports), File 604k, Ordnance Section, ETO Monographs, Ordnance Technical Services, Section VI, pp. 156–181. [Report of John A. Keck after inspecting Hillersleben facility.]

GOUDS: Samuel A. Goudsmit Papers, 1943–1967

NARA RG GOUDS, Entry UD-7420, Boxes 1–9.

LRG: Leslie R. Groves Papers, 1941–1970

NARA RG LRG.

U.S. National Archives and Records Administration at Boston (NARA Boston), Waltham, Massachusetts

NARA Boston RG 181. 1st Naval District. Office of the Assistant Chief of Staff for Operations. Formerly Security Classified General Correspondence 1944–1945. Box 26. Relevant documents in three folders: Surrender of German Submarines (1 of 2); Enemy Submarines, Surrender of; U-Boats, Surrender of.

Figure Credits

Wo ein Begeisterter steht, ist der Gipfel der Welt.	Where an enthusiast is standing is the summit of the world.

Joseph von Eichendorff. 1815.
Ahnung und Gegenwart [*Idea and Present*]
Book II, Chapter 15.

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Fig. 1.3: U.S. government, public domain [https://www.nsf.gov/statistics/2018/nsb20181/figures];
World Intellectual Property Organization [https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2019.pdf].

Fig. 1.4: Courtesy of: Nicholas Bloom [Bloom et al. 2020; Jonathan Huebner Huebner 2005; Jan Vijg Vijg 2011].

Fig. 1.5: Courtesy of Michael Park and Russell Funk [Park et al. 2023].

Fig. 1.6: U.S. Library of Congress, public domain.

Fig. 1.7: Todd Rider.

Fig. 2.1: commons.wikimedia.org and public domain.

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Fig. 2.8: commons.wikimedia.org and Todd Rider.

Fig. 2.9: commons.wikimedia.org and public domain.

Fig. 2.10: commons.wikimedia.org and public domain.

Fig. 2.11: commons.wikimedia.org and public domain.

Fig. 2.12: [Weinberg 1908].

Fig. 2.13: commons.wikimedia.org and public domain.

Fig. 2.14: commons.wikimedia.org and public domain.

Fig. 2.15: Top: commons.wikimedia.org, public domain, and Archiv der Max-Planck-Gesellschaft (Berlin-Dahlem).
Bottom: [Timoféeff-Ressovsky, Zimmer, and Delbrück 1935].

Fig. 2.16: commons.wikimedia.org; Friedrich-Freksa 1940.

Fig. 2.17: commons.wikimedia.org; Schramm and Rebensburg 1942; Schramm 1943.

Fig. 2.18: commons.wikimedia.org and public domain.

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Fig. 2.26: public domain [Haustein 2004].

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Fig. 2.33: [Widmark 1889; Hammer 1891] and public domain.

Fig. 2.34: omni.ie and public domain.

Fig. 2.35: https://www.pizbuin.com/en/our-heritage and Archiv der Max-Planck-Gesellschaft (Berlin-Dahlem).

Fig. 2.36: Todd Rider.

Fig. 2.37 Top: Todd Rider. Bottom: commons.wikimedia.org.

Fig. 2.38: commons.wikimedia.org and public domain.

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Fig. 2.40: commons.wikimedia.org and public domain.

Fig. 2.41: commons.wikimedia.org, archive.org, and public domain.

Fig. 2.42: commons.wikimedia.org and public domain.

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Fig. 2.45 Top: Todd Rider. Bottom: commons.wikimedia.org and public domain.

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Fig. 2.52: [Pregl 1917].

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Fig. 2.69: *Bulletin de la Société Chimique de France* 9:728–730 (1893); European Patent Office, Swiss patent CH 90,955, public domain.

Fig. 2.70: public domain.

Fig. 2.71: Todd Rider [FIAT 195; BIOS 1776].

Fig. 2.72: Todd Rider [BIOS 236; FIAT 910].

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Fig. 2.83: Friedrich Loeffler Institute, commons.wikimedia.org, and public domain.

Fig. 2.84: Friedrich Loeffler Institute, commons.wikimedia.org, and public domain.

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Fig. 2.100 Top: Todd Rider. Bottom: commons.wikimedia.org and public domain.

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Fig. 2.174: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 2.175: commons.wikimedia.org and public domain.

Fig. 2.176: *Journal of Laboratory and Clinical Medicine* (1945) 30:1034–1036.

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Fig. 2.191: https://www.muvs.org and commons.wikimedia.org.

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Fig. 2.207: U.S. government, commons.wikimedia.org, and public domain.

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Fig. 3.55: European Patent Office, commons.wikimedia.org, and public domain.

Fig. 3.56: Todd Rider [FIAT 885; BIOS 449].

Fig. 3.57: commons.wikimedia.org and public domain.

Fig. 3.58: U.S. Patent and Trademark Office, commons.wikimedia.org, and public domain.

Fig. 3.59: European Patent Office and public domain.

Fig. 3.60: Todd Rider [BIOS 805].

Fig. 3.61: Todd Rider [BIOS 236; BIOS 691].

Fig. 3.62: Todd Rider [BIOS 236; BIOS 1417; BIOS 1481; BIOS 1513].

Fig. 3.63: commons.wikimedia.org and public domain.

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Fig. 3.69: commons.wikimedia.org and public domain.

Fig. 3.70: commons.wikimedia.org and public domain.

Fig. 3.71: commons.wikimedia.org and public domain.

Fig. 3.72: commons.wikimedia.org and public domain.

Fig. 3.73: commons.wikimedia.org and public domain.

Fig. 3.74: commons.wikimedia.org and public domain.

Fig. 3.75: Norberto Lahuerta [NARA RG 319, Entry NM3-82, Box 2899, Folder Project 3826].

Fig. 3.76: European Patent Office.

Fig. 3.77: Norberto Lahuerta [Bundesarchiv, Berlin-Lichterfelde, R 26/III, Aktenbestand Nr. 52].

Fig. 3.78: Manuel Lukas [AFHRA A5183 frame 0351].

Fig. 3.79: Todd Rider [NARA RG 77, Entry UD-22A, Box 163, Folder Australia].

Fig. 3.80: Norberto Lahuerta [NARA RG 319, Entry NM3-85A, Box 1007, Folder 157361 THRU 157370].

Fig. 3.81: Norberto Lahuerta [NARA RG 319, Entry NM3-85A, Box 1007, Folder 157361 THRU 157370].

Fig. 3.82: Norberto Lahuerta [NARA RG 319, Entry NM3-85A, Box 1007, Folder 157361 THRU 157370].

Fig. 3.83: Norberto Lahuerta [NARA RG 319, Entry NM3-85A, Box 1007, Folder 157361 THRU 157370].

Fig. 3.84: David Bleecker [NARA RG 165, Entry NM84-79, Box 1916, PW Intelligence Bulletin 2/32, 30 January 1945].

Fig. 3.85: David Bleecker [NARA RG 165, Entry NM84-79, Box 1916, PW Intelligence Bulletin 2/32, 30 January 1945].

Fig. 3.86: Todd Rider [BIOS 142].

Fig. 3.87: Norberto Lahuerta [NARA RG 331, Entry UD-18A, Box 157,
Folder 319.1-2 Reports—Evacuation of Targets & Target Addresses].

Fig. 3.88: Norberto Lahuerta [NARA RG 331, Entry UD-18A, Box 157,
Folder 319.1-2 Reports—Evacuation of Targets & Target Addresses].

Fig. 3.89: European Patent Office, public domain.

Fig. 3.90: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.91: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.92: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.93: U.S. Patent and Trademark Office, public domain.

Fig. 3.94: U.S. Patent and Trademark Office, public domain.

Fig. 3.95: Todd Rider.

Fig. 3.96: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.97: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.98: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.99: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.100: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.101: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.102: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.103: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.104: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.105: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.106: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.107: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.108: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 3.109: U.S. Army, public domain.

Fig. 3.110: Todd Rider [BIOS 714].

Fig. 3.111: European Patent Office, public domain.

Fig. 3.112: commons.wikimedia.org and public domain.

Fig. 3.113: commons.wikimedia.org and public domain.

Fig. 3.114: commons.wikimedia.org and public domain.

Fig. 3.115: commons.wikimedia.org and public domain.

Fig. 3.116: commons.wikimedia.org and public domain.

Fig. 3.117: commons.wikimedia.org and public domain.

Fig. 3.118: commons.wikimedia.org and public domain.

Fig. 3.119: commons.wikimedia.org and public domain.

Fig. 3.120: commons.wikimedia.org and public domain.

Fig. 3.121: commons.wikimedia.org and public domain.

Fig. 3.122: [Schönbein 1839].

Fig. 3.123: [Sinsteden 1854].

Fig. 3.124: U.S. Patent and Trademark Office, public domain.

Fig. 3.125: European Patent Office, public domain.

Fig. 3.126: BIOS 362; BIOS 467; FIAT 800.

Fig. 3.127: U.S. Patent and Trademark Office, public domain.

Fig. 3.128: European Patent Office and U.S. Patent and Trademark Office, public domain.

Fig. 3.129: commons.wikimedia.org and public domain.

Fig. 3.130: commons.wikimedia.org and public domain.

Fig. 3.131: commons.wikimedia.org and public domain.

Fig. 3.132: commons.wikimedia.org and public domain.

Fig. 3.133: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 3.134: commons.wikimedia.org and public domain.

Fig. 3.135: commons.wikimedia.org and public domain.

Fig. 3.136: European Patent Office and public domain.

Fig. 3.137: commons.wikimedia.org and public domain.

Fig. 3.138: U.S. Patent and Trademark Office, public domain.

Fig. 3.139: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 3.140: Todd Rider [FIAT 678].

Fig. 3.141: Todd Rider [FIAT 678].

Fig. 3.142: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 3.143: commons.wikimedia.org and public domain.

Fig. 3.144: commons.wikimedia.org and public domain.

Fig. 3.145: commons.wikimedia.org and public domain.

Fig. 3.146: commons.wikimedia.org and public domain.

Fig. 3.147: commons.wikimedia.org and public domain.

Fig. 3.148: commons.wikimedia.org and public domain.

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Fig. 3.153: commons.wikimedia.org and public domain.

Fig. 3.154: commons.wikimedia.org and public domain.

Fig. 3.155: commons.wikimedia.org and public domain.

Fig. 3.156: commons.wikimedia.org and public domain.

Fig. 3.157: commons.wikimedia.org and public domain.

Fig. 3.158: commons.wikimedia.org and public domain.

Fig. 3.159: commons.wikimedia.org and public domain.

Fig. 3.160: commons.wikimedia.org and public domain.

Fig. 3.161: commons.wikimedia.org and public domain.

Fig. 3.162: velcro.com, commons.wikimedia.org, and U.S. Patent and Trademark Office.

Fig. 3.163: Todd Rider [NARA RG 40, Entry UD-75, Box 61, Folder Booster Letters].

Fig. 3.164: commons.wikimedia.org and public domain.

Fig. 3.165: commons.wikimedia.org and public domain.

Fig. 3.166: commons.wikimedia.org and public domain.

Fig. 3.167: commons.wikimedia.org and public domain.

Fig. 3.168: commons.wikimedia.org and public domain.

Fig. 3.169: commons.wikimedia.org and public domain.

Fig. 3.170: [CIOS XXXI-22, FIAT 617].

Fig. 3.171: commons.wikimedia.org and public domain.

Fig. 3.172: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 3.173: Todd Rider [BIOS 563] and public domain.

Fig. 3.174: Todd Rider [AFHRA A5729 electronic pp. 1650–1651].

Fig. 3.175: Todd Rider [BIOS 1340].

Fig. 3.176: U.S. government, public domain [Adenstedt 1948].

Fig. 3.177: U.S. government, public domain [Adenstedt 1948].

Fig. 3.178: commons.wikimedia.org and public domain.

Fig. 3.179: commons.wikimedia.org and public domain.

Fig. 3.180: https://www.heraeus.com, commons.wikimedia.org, and public domain.

Fig. 3.181: https://www.heraeus.com, commons.wikimedia.org, and public domain.

Fig. 3.182: commons.wikimedia.org and public domain.

Fig. 3.183: commons.wikimedia.org and public domain.

Fig. 3.184: commons.wikimedia.org and public domain.

Fig. 3.185: [BIOS 1179; BIOS 1770; CIOS XXVI-60; CIOS XXIX-3].

Fig. 3.186: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Press Releases].

Fig. 3.187: [Runge1850] and commons.wikimedia.org, public domain.

Fig. 3.188: [Schönbein 1861; Goppelsröder 1861] and commons.wikimedia.org, public domain.

Fig. 3.189: [Goppelsröder 1901].

Fig. 3.190: [Goppelsröder 1901].

Fig. 3.191: [Goppelsröder 1901].

Fig. 3.192: commons.wikimedia.org and public domain.

Fig. 3.193: commons.wikimedia.org and European Patent Office, public domain.

Fig. 3.194: commons.wikimedia.org and public domain.

Fig. 3.195: commons.wikimedia.org and public domain.

Fig. 3.196: U.S. Patent and Trademark Office and public domain.

Fig. 3.197: U.S. Patent and Trademark Office and public domain.

Fig. 3.198: commons.wikimedia.org, U.S. Patent and Trademark Office, and European Patent Office, public domain.

Fig. 3.199: U.S. Patent and Trademark Office and public domain.

Fig. 3.200: European Patent Office and public domain.

Fig. 3.201: [BIOS 518].

Fig. 3.202: [BIOS 518].

Fig. 3.203: [BIOS 518].

Fig. 4.1: commons.wikimedia.org and public domain.

Fig. 4.2: commons.wikimedia.org and public domain.

Fig. 4.3: commons.wikimedia.org and public domain.

Fig. 4.4: commons.wikimedia.org and public domain.

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Fig. 4.36: commons.wikimedia.org and public domain.

Fig. 4.37: commons.wikimedia.org and public domain.

Fig. 4.38: commons.wikimedia.org and U.S. government, public domain.

Fig. 4.39: commons.wikimedia.org and public domain.

Fig. 4.40: commons.wikimedia.org and public domain.

Fig. 4.41: commons.wikimedia.org and public domain.

Fig. 4.42: commons.wikimedia.org and public domain.

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Fig. 4.60: commons.wikimedia.org and public domain.

Fig. 4.61: commons.wikimedia.org and public domain.

Fig. 5.1: commons.wikimedia.org and public domain.

Fig. 5.2: commons.wikimedia.org and public domain.

Fig. 5.3: commons.wikimedia.org and public domain.

Fig. 5.4: commons.wikimedia.org and public domain.

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Fig. 5.11: commons.wikimedia.org and public domain.

Fig. 5.12: commons.wikimedia.org and public domain.

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Fig. 5.14: commons.wikimedia.org and public domain.

Fig. 5.15: commons.wikimedia.org and public domain.

Fig. 5.16: commons.wikimedia.org and public domain.

Fig. 5.17: commons.wikimedia.org and public domain.

Fig. 5.18: Todd Rider.

Fig. 5.19: commons.wikimedia.org and public domain.

Fig. 5.20: commons.wikimedia.org and public domain.

Fig. 5.21: commons.wikimedia.org and public domain.

Fig. 5.22: commons.wikimedia.org and public domain.

Fig. 5.23: commons.wikimedia.org and public domain.

Fig. 5.24: Todd Rider.

Fig. 5.25: commons.wikimedia.org and public domain.

Fig. 5.26: commons.wikimedia.org and public domain.

Fig. 5.27: commons.wikimedia.org and public domain.

Fig. 5.28: commons.wikimedia.org and public domain.

Fig. 5.29: commons.wikimedia.org and public domain.

Fig. 5.30: commons.wikimedia.org and public domain.

Fig. 5.31: commons.wikimedia.org and public domain.

Fig. 5.32: Todd Rider.

Fig. 5.33: [Wirtz 1918, 1922a, 1922b, 1924]

Fig. 5.34: Todd Rider.

Fig. 5.35: commons.wikimedia.org and public domain.

Fig. 5.36: commons.wikimedia.org and public domain.

Fig. 5.37: commons.wikimedia.org and public domain.

Fig. 5.38: commons.wikimedia.org and public domain.

Fig. 5.39: commons.wikimedia.org, public domain, and Archiv der Max-Planck-Gesellschaft (Berlin-Dahlem).

Fig. 5.40: Todd Rider.

Fig. 5.41: Todd Rider.

Fig. 5.42: commons.wikimedia.org and public domain.

Fig. 5.43: commons.wikimedia.org and public domain.

Fig. 5.44: commons.wikimedia.org and public domain.

Fig. 5.45: commons.wikimedia.org and public domain.

Fig. 5.46: commons.wikimedia.org and public domain.

Fig. 5.47: commons.wikimedia.org and public domain.

Fig. 5.48: commons.wikimedia.org and public domain.

Fig. 5.49: Todd Rider.

Fig. 5.50: commons.wikimedia.org and public domain.

Fig. 5.51: commons.wikimedia.org and public domain.

Fig. 5.52: commons.wikimedia.org and public domain.

Fig. 5.53: commons.wikimedia.org and public domain.

Fig. 5.54: commons.wikimedia.org and public domain.

Fig. 5.55: commons.wikimedia.org and public domain.

Fig. 5.56: commons.wikimedia.org and public domain.

Fig. 5.57: Todd Rider.

Fig. 6.1: commons.wikimedia.org and public domain.

Fig. 6.2: commons.wikimedia.org and public domain.

Fig. 6.3: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.4: commons.wikimedia.org and public domain.

Fig. 6.5: commons.wikimedia.org and public domain.

Fig. 6.6: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.7: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.8: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.9: commons.wikimedia.org and public domain.

Fig. 6.10: commons.wikimedia.org and public domain.

Fig. 6.11: commons.wikimedia.org and public domain.

Fig. 6.12: https://www.lamptech.co.uk, U.S. Patent and Trademark Office, and European Patent Office, public domain.

Fig. 6.13: https://www.lamptech.co.uk and U.S. Patent and Trademark Office, public domain.

Fig. 6.14: commons.wikimedia.org, U.S. Patent and Trademark Office, and http://edison.rutgers.edu/digital/search?query=John+Kruesi&query_type=keyword&submit_search=Search

Fig. 6.15: commons.wikimedia.org and public domain.

Fig. 6.16: commons.wikimedia.org and public domain.

Fig. 6.17: commons.wikimedia.org and public domain.

Fig. 6.18: commons.wikimedia.org and public domain.

Fig. 6.19: commons.wikimedia.org and public domain.

Fig. 6.20: Philips Eindhoven photo archive, European Patent Office, and commons.wikimedia.org, public domain.

Fig. 6.21: commons.wikimedia.org and public domain.

Fig. 6.22: commons.wikimedia.org, siemens.com, and public domain.

Fig. 6.23: commons.wikimedia.org and Deutsches Museum, public domain.

Fig. 6.24: commons.wikimedia.org and public domain.

Fig. 6.25: commons.wikimedia.org and public domain.

Fig. 6.26: commons.wikimedia.org and public domain.

Fig. 6.27: commons.wikimedia.org and public domain.

Fig. 6.28: commons.wikimedia.org and public domain.

Fig. 6.29: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.30: commons.wikimedia.org and public domain.

Fig. 6.31: commons.wikimedia.org and public domain.

Fig. 6.32: Verkehrsmuseum Nürnberg and commons.wikimedia.org, public domain.

Fig. 6.33: commons.wikimedia.org and public domain.

Fig. 6.34: commons.wikimedia.org and public domain.

Fig. 6.35: commons.wikimedia.org and public domain.

Fig. 6.36: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Replies to Letters of April 29, 1947].

Fig. 6.37: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 6.38: commons.wikimedia.org and public domain.

Fig. 6.39: Gernsback 1909 and commons.wikimedia.org, public domain.

Fig. 6.40: commons.wikimedia.org and public domain.

Fig. 6.41: Todd Rider and public domain.

Fig. 6.42: commons.wikimedia.org and public domain.

Fig. 6.43: commons.wikimedia.org and public domain.

Fig. 6.44: commons.wikimedia.org and public domain.

Fig. 6.45: commons.wikimedia.org and public domain [archival video in Kloft 2000].

Fig. 6.46: Norberto Lahuerta and Todd Rider.

Fig. 6.47: Norberto Lahuerta and Todd Rider.

Fig. 6.48: Norberto Lahuerta.

Fig. 6.49: commons.wikimedia.org and public domain.

Fig. 6.50: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.51: public domain.

Fig. 6.52: *Look*, 11 August 1964, p. 9.

Fig. 6.53: commons.wikimedia.org and public domain.

Fig. 6.54: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 6.55: https://www.welte-mignon.de and commons.wikimedia.org.

Fig. 6.56: www.dutchaudioclassics.nl/awards-for-philips-compact-disc-scientist-piet-kramer-gijs-bouwhuis-klaas-compaan and commons.wikimedia.org.

Fig. 6.57: www.mp3-history.com/en/the_mp3_team.html and commons.wikimedia.org.

Fig. 6.58: commons.wikimedia.org and public domain; *Verhandlungen der Deutschen Physikalischen Gesellschaft* (1916) 18:13–14:318–323; *Mitteilungen der Physikalischen Gesellschaft Zürich* (1916) 18:47–62.

Fig. 6.59: commons.wikimedia.org and public domain; *Zeitschrift für Physik* (1923) 20:1:145–152.

Fig. 6.60: commons.wikimedia.org and public domain; *Zeitschrift für Physik* (1930) 65:3–4:167–188; *Zeitschrift für Physikalische Chemie* (1928) 139:1:375–385.

Fig. 6.61: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. 6.62: commons.wikimedia.org and public domain.

Fig. 6.63: commons.wikimedia.org and public domain.

Fig. 6.64: Todd Rider.

Fig. 6.65: Wiedemann and Franz 1853; Debye and Sommerfeld 1913; Debye 1912; Drude 1900.

Fig. 6.66: commons.wikimedia.org and public domain.

Fig. 6.67: commons.wikimedia.org and public domain.

Fig. 6.68: commons.wikimedia.org and public domain.

Fig. 6.69: commons.wikimedia.org and public domain.

Fig. 6.70: commons.wikimedia.org and public domain.

Fig. 6.71: commons.wikimedia.org and public domain.

Fig. 6.72: commons.wikimedia.org and public domain.

Fig. 6.73: U.S. Patent and Trademark Office, public domain.

Fig. 6.74: U.S. Patent and Trademark Office, public domain.

Fig. 6.75: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.76: European Patent Office, public domain.

Fig. 6.77: U.S. Patent and Trademark Office, public domain.

Fig. 6.78: Philips Eindhoven photo archive and U.S. Patent and Trademark Office, public domain.

Fig. 6.79: [Hilsch and Pohl 1938].

Fig. 6.80: commons.wikimedia.org, public domain.

Fig. 6.81: Günter Nagel.

Fig. 6.82: European Patent Office, public domain.

Fig. 6.83: commons.wikimedia.org, Zeitschrift für Physik 118:9–10:539–592 (1942), and NARA RG 40, Entry UD-75, Box 24, Folder Selenium Rectifier Machinery.

Fig. 6.84: European Patent Office, public domain.

Fig. 6.85: European Patent Office, public domain.

Fig. 6.86: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.87: CIOS XXXI-2.

Fig. 6.88: BIOS 1658.

Fig. 6.89: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.90: European Patent Office, public domain.

Fig. 6.91: CIOS ER 350, commons.wikimedia.org, and European Patent Office, public domain.

Fig. 6.92: U.S. Patent and Trademark Office, public domain.

Fig. 6.93: commons.wikimedia.org and public domain.

Fig. 6.94: Todd Rider.

Fig. 6.95: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain. NARA RG 40, Entry UD-75, Box 28, Folder Edwin Y. Webb, Jr. 1945 memo from Harry Dauber.

Fig. 6.96: U.S. Patent and Trademark Office, public domain.

Fig. 6.97: Todd Rider [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda].

Fig. 6.98: Todd Rider [NARA RG 40, Entry UD-75, Boxes 24 and 58].

Fig. 6.99: BIOS 30, BIOS 276, FIAT 272, FIAT 294.

Fig. 6.100: BIOS 725, BIOS 1751, BIOS 30, BIOS 276.

Fig. 6.101: commons.wikimedia.org and public domain.

Fig. 6.102: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.103: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.104: U.S. Patent and Trademark Office, public domain.

Fig. 6.105: CIOS XXVII-44.

Fig. 6.106: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 6.107: European Patent Office, public domain.

Fig. 6.108: https://www.fed.de/fileadmin/user_upload/Roentgentest__eine_zerstoerungsfreie_Analysemethode.pdf

Fig. 6.109: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.110: Todd Rider [NARA RG 40, Entry UD-75, Box 25, Folder Odarenko, Dr. T. M., undated press release (probably late 1946)].

Fig. 6.111: European Patent Office and U.S. Patent and Trademark Office, public domain.

Fig. 6.112: European Patent Office, public domain.

Fig. 6.113: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.114: U.S. Patent and Trademark Office, public domain.

Fig. 6.115: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.116: U.S. Patent and Trademark Office, public domain.

Fig. 6.117: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.118: U.S. Patent and Trademark Office, public domain.

Fig. 6.119: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.120: commons.wikimedia.org and *Zeitschrift für Physik* 18:1:199–206 (1923).

Fig. 6.121: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.122: U.S. Patent and Trademark Office, public domain.

Fig. 6.123: commons.wikimedia.org and *IEEE Journal of Quantum Electronics* 23:6:659–673 (1987)

Fig. 6.124: U.S. Patent and Trademark Office, public domain.

Fig. 6.125: commons.wikimedia.org and U.S. Patent and Trademark Office, public domain.

Fig. 6.126: commons.wikimedia.org and public domain.

Fig. 6.127: commons.wikimedia.org and public domain.

Fig. 6.128: commons.wikimedia.org and public domain.

Fig. 6.129: G-345, courtesy of Deutsches Museum Archive, FA 002/0712; English translation in FIAT 63.

Fig. 6.130: G-345, courtesy of Deutsches Museum Archive, FA 002/0712; English translation in FIAT 63.

Fig. 6.131: commons.wikimedia.org and public domain.

Fig. 6.132: commons.wikimedia.org and public domain.

Fig. 6.133: commons.wikimedia.org and public domain.

Fig. 6.134: commons.wikimedia.org and public domain.

Fig. 6.135: [BIOS 724; BIOS 1316; CIOS XXV-13; FIAT 641].

Fig. 6.136: [BIOS 255].

Fig. 6.137: [FIAT 575].

Fig. 6.138: commons.wikimedia.org and public domain.

Fig. 6.139: [BIOS Misc 66].

Fig. 6.140: U.S. government, public domain.

Fig. 6.141: BIOS Misc 66 and U.S. government, public domain.

Fig. 6.142: U.S. government, public domain.

Fig. 6.143: [BIOS Misc 66].

Fig. 6.144: Top [BIOS Misc 66]. Bottom [U.S. government photo, reprinted in *Popular Mechanics*, August 1950, p. 256]. See also: CIOS XXXI-14.

Fig. 6.145: public domain.

Fig. 6.146: U.S. government, public domain.

Fig. 6.147: commons.wikimedia.org, Benecke and Quick 1957, and U.S. government, public domain.

Fig. 6.148: [Benecke and Quick 1957].

Fig. 6.149:

Fig. 6.150:

Fig. 6.151: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 6.152: [BIOS 2; BIOS Misc 66].

Fig. 6.153: *Dayton Daily News*, 8 December 1946, p. 55 and U.S. government, public domain.

Fig. 6.154: U.S. government, public domain, and Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Webb].

Fig. 6.155: U.S. government and U.S. Patent and Trademark Office, public domain.

Fig. 6.156: commons.wikimedia.org and U.S. government, public domain.

Fig. 6.157: U.S. Patent and Trademark Office, public domain.

Fig. 6.158: commons.wikimedia.org and public domain.

Fig. 6.159: commons.wikimedia.org and public domain.

Fig. 6.160: commons.wikimedia.org and public domain.

Fig. 6.161: U.S. Patent and Trademark Office, commons.wikimedia.org, and public domain.

Fig. 6.162: Technisches Museum Wien; U.S. Patent and Trademark Office, public domain.

Fig. 6.163: U.S. Patent and Trademark Office, commons.wikimedia.org, and public domain.

Fig. 6.164: commons.wikimedia.org and public domain.

Fig. 6.165: European Patent Office, public domain.

Fig. 6.166: Todd Rider.

Fig. 6.167: Todd Rider.

Fig. 6.168: [Zuse 1993].

Fig. 6.169: Todd Rider.

Fig. 6.170: Historisch-Technisches Museum Peenemünde Archive.

Fig. 6.171: commons.wikimedia.org and public domain.

Fig. 6.172: European Patent Office and U.S. Patent and Trademark Office, public domain.

Fig. 6.173: commons.wikimedia.org and public domain.

Fig. 6.174: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 6.175: U.S. government, commons.wikimedia.org, and public domain.

Fig. 6.176: U.S. government, commons.wikimedia.org, and public domain.

Fig. 6.177: U.S. Patent and Trademark Office, commons.wikimedia.org, and public domain.

Fig. 6.178: commons.wikimedia.org and Todd Rider collection.

Fig. 6.179: commons.wikimedia.org and public domain.

Fig. 6.180: commons.wikimedia.org and public domain.

Fig. 6.181: commons.wikimedia.org and public domain.

Fig. 6.182: https://www.cryptomuseum.com/crypto/bombe, commons.wikimedia.org, and public domain.

Fig. 6.183: commons.wikimedia.org and public domain.

Fig. 6.184: commons.wikimedia.org and public domain.

Fig. 6.185: commons.wikimedia.org and public domain.

Fig. 6.186: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 6.187: [Faensen 2001].

Fig. 6.188: U.S. government and public domain.

Fig. 6.189: commons.wikimedia.org and public domain.

Fig. 6.190: commons.wikimedia.org and public domain.

Fig. 6.191: commons.wikimedia.org and public domain.

Fig. 6.192: U.S. Patent and Trademark Office, commons.wikimedia.org, and public domain.

Fig. 6.193: commons.wikimedia.org, European Patent Office, and public domain.

Fig. 6.194: U.S. government, commons.wikimedia.org, and public domain.

Fig. 6.195: commons.wikimedia.org and public domain.

Fig. 6.196: commons.wikimedia.org and Deutsches Museum Archive, courtesy of Diane McWhorter.

Fig. 6.197: Deutsches Museum Archive, courtesy of Diane McWhorter.

Fig. 6.198: Deutsches Museum Archive.

Fig. 6.199: Deutsches Museum Archive.

Fig. 6.200: European Patent Office, public domain.

Fig. 6.201: European Patent Office, public domain.

Fig. 6.202: commons.wikimedia.org and public domain.

Fig. 6.203: commons.wikimedia.org and public domain.

Fig. 6.204: U.S. Patent and Trademark Office and public domain.

Fig. 6.205: U.S. Patent and Trademark Office and public domain.

Fig. 6.206: commons.wikimedia.org and public domain.

Fig. 6.207: commons.wikimedia.org and public domain.

Fig. 6.208: commons.wikimedia.org and public domain.

Fig. 6.209: U.S. Patent and Trademark Office and public domain.

Fig. 6.210: courtesy of Norberto Lahuerta.

Fig. 6.211: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment].

Fig. 6.212: commons.wikimedia.org and public domain.

Fig. 6.213: commons.wikimedia.org and public domain.

Fig. 6.214: commons.wikimedia.org and public domain.

Fig. 6.215: Todd Rider [BIOS 866].

Fig. 6.216: European Patent Office, public domain.

Fig. 6.217: Todd Rider [NavTecMisEu 530-45].

Fig. 6.218: Todd Rider [NavTecMisEu 530-45].

Fig. 6.219: Todd Rider [NavTecMisEu 530-45].

Fig. 6.220: Todd Rider [NavTecMisEu 530-45].

Fig. 6.221: commons.wikimedia.org and public domain.

Fig. 6.222: Woo 2006 and public domain.

Fig. 6.223: Todd Rider [BIOS 609; BIOS 1679].

Fig. 6.224: Todd Rider [CIOS XXXII-77], commons.wikimedia.org, and public domain.

Fig. 6.225: U.S. government and public domain.

Fig. 6.226: commons.wikimedia.org and public domain.

Fig. 6.227: commons.wikimedia.org and public domain.

Fig. 6.228: commons.wikimedia.org and public domain.

Fig. 6.229: commons.wikimedia.org and public domain.

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Fig. 6.231: commons.wikimedia.org and public domain.

Fig. 6.232: commons.wikimedia.org and public domain.

Fig. 6.233: commons.wikimedia.org and public domain.

Fig. 6.234: commons.wikimedia.org and public domain.

Fig. 6.235: commons.wikimedia.org and public domain.

Fig. 6.236: commons.wikimedia.org and public domain.

Fig. 6.237: commons.wikimedia.org and public domain.

Fig. 6.238: commons.wikimedia.org and Caltech.

Fig. 6.239: commons.wikimedia.org and public domain.

Fig. 6.240: U.S. Patent and Trademark Office and European Patent Office, public domain.

Fig. 6.241: U.S. government, public domain.

Fig. 6.242: commons.wikimedia.org and European Patent Office, public domain.

Fig. 6.243: European Patent Office, public domain.

Fig. 6.244: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Budget].

Fig. 6.245: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. 6.246: Todd Rider.

Fig. 6.247: commons.wikimedia.org and public domain.

Fig. 6.248: commons.wikimedia.org and public domain.

Fig. 6.249: commons.wikimedia.org and public domain.

Fig. 6.250: commons.wikimedia.org and public domain.

Fig. 6.251: commons.wikimedia.org and public domain.

Fig. 6.252: commons.wikimedia.org and public domain.

Fig. 7.1: commons.wikimedia.org and public domain.

Fig. 7.2: commons.wikimedia.org and public domain.

Fig. 7.3: commons.wikimedia.org, public domain, Technisches Museum Wien.

Fig. 7.4: https://oztypewriter.blogspot.com/2011/09/on-this-day-in-typewriter-history-cxxii.html, Smithsonian Institution, and U.S. Patent and Trademark Office, public domain.

Fig. 7.5: commons.wikimedia.org and public domain.

Fig. 7.6: commons.wikimedia.org and public domain.

Fig. 7.7: commons.wikimedia.org and public domain.

Fig. 7.8: commons.wikimedia.org and public domain.

Fig. 7.9: commons.wikimedia.org and public domain.

Fig. 7.10: commons.wikimedia.org and public domain.

Fig. 7.11: commons.wikimedia.org, public domain, Technisches Museum Wien.

Fig. 7.12: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Press Releases].

Fig. 7.13: commons.wikimedia.org and public domain.

Fig. 7.14: commons.wikimedia.org and public domain.

Fig. 7.15: commons.wikimedia.org and public domain.

Fig. 7.16: commons.wikimedia.org and public domain.

Fig. 7.17: commons.wikimedia.org and public domain.

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Fig. 7.23: commons.wikimedia.org and public domain.

Fig. 7.24:

Fig. 7.25: commons.wikimedia.org and public domain.

Fig. 7.26: U.S. Patent and Trademark Office, public domain.

Fig. 7.27: U.S. Patent and Trademark Office, public domain.

Fig. 7.28: commons.wikimedia.org, U.S. Patent and Trademark Office, public domain.

Fig. 7.29: commons.wikimedia.org and public domain.

Fig. 7.30: commons.wikimedia.org and public domain.

Fig. 7.31: commons.wikimedia.org and public domain.

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Fig. 7.39: commons.wikimedia.org and public domain.

Fig. 7.40: commons.wikimedia.org and public domain.

Fig. 7.41: commons.wikimedia.org and public domain.

Fig. 7.42: commons.wikimedia.org and public domain.

Fig. 7.43: https://www.press.bmwgroup.com/global/photo/detail/P90094341/ernst-henne-land-speed-records-1937-12/2012 and commons.wikimedia.org, public domain.

Fig. 7.44: commons.wikimedia.org and public domain.

Fig. 7.45: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Press Releases].

Fig. 7.46: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Press Releases].

Fig. 7.47: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Press Releases].

Fig. 7.48: European Patent Office, public domain.

Fig. 7.49: European Patent Office and https://www.roru.de/airbag/gasgenerator.htm.

Fig. 7.50: commons.wikimedia.org, European Patent Office, public domain.

Fig. 7.51: commons.wikimedia.org and public domain.

Fig. 7.52: commons.wikimedia.org and public domain.

Fig. 7.53: commons.wikimedia.org and public domain.

Fig. 7.54: European Patent Office, public domain.

Fig. 7.55: Burstyn 1912.

Fig. 7.56: commons.wikimedia.org and public domain.

Fig. 7.57: commons.wikimedia.org and public domain.

Fig. 7.58: commons.wikimedia.org and public domain.

Fig. 7.59: U.S. Patent and Trademark Office, commons.wikimedia.org, public domain.

Fig. 7.60: U.S. government, public domain.

Fig. 7.61: European Patent Office, commons.wikimedia.org, public domain.

Fig. 7.62: U.S. Patent and Trademark Office, commons.wikimedia.org, public domain.

Fig. 7.63: Todd Rider.

Fig. 7.64: commons.wikimedia.org and public domain.

Fig. 7.65: Top: commons.wikimedia.org and public domain. Bottom: Todd Rider.

Fig. 7.66: commons.wikimedia.org and public domain.

Fig. 7.67: commons.wikimedia.org and public domain.

Fig. 7.68: commons.wikimedia.org and public domain.

Fig. 7.69: commons.wikimedia.org and public domain.

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Fig. 7.74: commons.wikimedia.org and public domain.

Fig. 7.75: commons.wikimedia.org and public domain.

Fig. 7.76: European Patent Office, commons.wikimedia.org, public domain.

Fig. 7.77: commons.wikimedia.org, U.S. government, public domain.

Fig. 7.78: commons.wikimedia.org and public domain.

Fig. 7.79: commons.wikimedia.org and public domain.

Fig. 7.80: commons.wikimedia.org and public domain.

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Fig. 7.90: commons.wikimedia.org and public domain.

Fig. 7.91: commons.wikimedia.org and public domain.

Fig. 7.92: commons.wikimedia.org and public domain.

Fig. 7.93: Top: William Schneck. Bottom: commons.wikimedia.org and public domain.

Fig. 7.94: commons.wikimedia.org and public domain.

Fig. 7.95: commons.wikimedia.org and public domain.

Fig. 7.96: commons.wikimedia.org and public domain.

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Fig. 7.98: commons.wikimedia.org and public domain.

Fig. 7.99: commons.wikimedia.org and public domain.

Fig. 7.100: commons.wikimedia.org and public domain.

Fig. 7.101: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28]; U.S. government and public domain.

Fig. 7.102: commons.wikimedia.org and public domain.

Fig. 7.103: commons.wikimedia.org and public domain.

Fig. 7.104: commons.wikimedia.org and public domain.

Fig. 7.105: commons.wikimedia.org and public domain.

Fig. 7.106: commons.wikimedia.org and public domain.

Fig. 7.107: commons.wikimedia.org and public domain.

Fig. 7.108: commons.wikimedia.org and public domain.

Fig. 7.109: commons.wikimedia.org and public domain.

Fig. 7.110 Top: commons.wikimedia.org and public domain. Bottom: Todd Rider.

Fig. 7.111: commons.wikimedia.org and public domain.

Fig. 7.112: Todd Rider.

Fig. 7.113: Todd Rider.

Fig. 7.114: Todd Rider.

Fig. 7.115: Todd Rider.

Fig. 7.116: Todd Rider.

Fig. 7.117: Todd Rider.

Fig. 7.118: *Pittsburgh Press*, 21 November 1946, p. 9; http://www.navsource.org/archives/08/08358.htm and U.S. government, public domain.

Fig. 7.119: commons.wikimedia.org and public domain.

Fig. 7.120: [NYT 1958-10-09 p. 73].

Fig. 7.121: https://www.cia.gov/readingroom/document/cia-rdp80-00809a000600360061-4.

Fig. 7.122: commons.wikimedia.org and public domain.

Fig. 7.123: commons.wikimedia.org and public domain.

Fig. 7.124: commons.wikimedia.org and public domain.

Fig. 7.125: commons.wikimedia.org and public domain.

Fig. 7.126: commons.wikimedia.org and public domain.

Fig. 7.127 Top: commons.wikimedia.org and public domain. Bottom: Lori Rider.

Fig. 7.128: Public domain.

Fig. 7.129: Public domain.

Fig. 7.130: Public domain.

Fig. 7.131: commons.wikimedia.org and public domain.

Fig. 7.132: commons.wikimedia.org and public domain.

Fig. 7.133: commons.wikimedia.org and public domain.

Fig. 7.134: commons.wikimedia.org and public domain.

Fig. 7.135: commons.wikimedia.org and public domain.

Fig. 7.136: commons.wikimedia.org and public domain.

Fig. 7.137: Technisches Museum Wien, commons.wikimedia.org, and public domain.

Fig. 7.138: commons.wikimedia.org and public domain.

Fig. 7.139 Top: commons.wikimedia.org and public domain. Bottom: Todd Rider.

Fig. 7.140: commons.wikimedia.org and public domain.

Fig. 7.141: commons.wikimedia.org and public domain.

Fig. 7.142: https://www.deutsches-museum.de/bibliothek/unsere-schaetze/technikgeschichte/schaeffer-waschmaschine and commons.wikimedia.org, public domain.

Fig. 7.143: commons.wikimedia.org and public domain.

Fig. 7.144: commons.wikimedia.org and public domain.

Fig. 7.145: commons.wikimedia.org and public domain.

Fig. 8.1: commons.wikimedia.org and public domain.

Fig. 8.2: commons.wikimedia.org and public domain.

Fig. 8.3: [Leopold Freund 1903].

Fig. 8.4: commons.wikimedia.org and public domain.

Fig. 8.5: Archiv der Österreichischen Akademie der Wissenschaften, Bildarchiv.

Fig. 8.6: commons.wikimedia.org and public domain.

Fig. 8.7: commons.wikimedia.org and public domain.

Fig. 8.8: commons.wikimedia.org and public domain.

Fig. 8.9: commons.wikimedia.org and public domain.

Fig. 8.10: *Archiv für Elektrotechnik* (1928) 21:4:387–406; NARA RG 319 Entry NM3-82A, Box 6, Folder ALSOS G-20; U.S. Patent and Trademark Office, U.S. patent 2,572,551; public domain.

Fig. 8.11: commons.wikimedia.org and European Patent Office, German patent DE 698,867, public domain.

Fig. 8.12: commons.wikimedia.org and public domain.

Fig. 8.13: commons.wikimedia.org and public domain.

Fig. 8.14: commons.wikimedia.org and public domain.

Fig. 8.15: *Zeitschrift für Physik* (1927) 42:9–10:741–758; *Zeitschrift für Physik* (1935) 96:7–8:431–458; Mayer and Jensen 1955; Blatt and Weisskopf 1952.

Fig. 8.16: Todd Rider.

Fig. 8.17: Todd Rider.

Fig. 8.18: commons.wikimedia.org and public domain.

Fig. 8.19: Todd Rider.

Fig. 8.20: commons.wikimedia.org and public domain.

Fig. 8.21: commons.wikimedia.org and public domain.

Fig. 8.22: commons.wikimedia.org and public domain.

Fig. 8.23: commons.wikimedia.org and public domain.

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Fig. 8.25: commons.wikimedia.org and public domain.

Fig. 8.26: commons.wikimedia.org and public domain.

Fig. 8.27: commons.wikimedia.org and public domain.

Fig. 8.28: commons.wikimedia.org and public domain.

Fig. 8.29: commons.wikimedia.org and public domain.

Fig. 8.30: commons.wikimedia.org and public domain.

Fig. 8.31: Todd Rider.

Fig. 8.32: European Patent Office; Rainer Karlsch, Heiko Petermann, and Matthias Uhl.

Fig. 8.33: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.34: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.35: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.36: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.37: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.38: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.39: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.40: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.41: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.42: commons.wikimedia.org, public domain, Archiv der Max-Planck-Gesellschaft (Berlin-Dahlem), and Günter Nagel.

Fig. 8.43: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.44: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.45: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.46: commons.wikimedia.org, public domain, Günter Nagel, and Archiv der Österreichischen Akademie der Wissenschaften, Bildarchiv.

Fig. 8.47: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.48: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.49: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.50: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.51: commons.wikimedia.org, public domain, and Norberto Lahuerta.

Fig. 8.52: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.53: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.54: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 8.55: commons.wikimedia.org, public domain, Archiv der Max-Planck-Gesellschaft (Berlin-Dahlem), and Günter Nagel.

Fig. 8.56: commons.wikimedia.org and public domain.

Fig. 8.57: commons.wikimedia.org and public domain.

Fig. 9.1: commons.wikimedia.org and public domain.

Fig. 9.2: commons.wikimedia.org and public domain.

Fig. 9.3: commons.wikimedia.org and public domain.

Fig. 9.4: commons.wikimedia.org and public domain.

Fig. 9.5: commons.wikimedia.org and public domain.

Fig. 9.6: commons.wikimedia.org and public domain.

Fig. 9.7: commons.wikimedia.org and public domain.

Fig. 9.8: commons.wikimedia.org and public domain.

Fig. 9.9: commons.wikimedia.org and public domain.

Fig. 9.10: *Bridgeport Sunday Herald*, 18 August 1901, p. 5
[see this and many other examples of 1901 newspaper articles at gustavewhitehead.info].

Fig. 9.11: 1948 contract between the Wright estate and the Smithsonian Institution, public domain
[see http://historybycontract.org for this and additional related documents and information].

Fig. 9.12: 1948 contract between the Wright estate and the Smithsonian Institution, public domain
[see http://historybycontract.org for this and additional related documents and information].

Fig. 9.13: commons.wikimedia.org and Todd Rider.

Fig. 9.14: commons.wikimedia.org, archive.org, and Todd Rider.

Fig. 9.15: commons.wikimedia.org and public domain.

Fig. 9.16: commons.wikimedia.org and public domain.

Fig. 9.17: public domain [http://www.histaviation.com/AVA.html].

Fig. 9.18: commons.wikimedia.org and public domain.

Fig. 9.19: U.S. government, public domain.

Fig. 9.20: commons.wikimedia.org and public domain.

Fig. 9.21: U.S. government, public domain.

Fig. 9.22: U.S. government, public domain.

Fig. 9.23: commons.wikimedia.org and public domain.

Fig. 9.24: Historisch-Technisches Museum Peenemünde Archive, commons.wikimedia.org, and public domain.

Fig. 9.25: commons.wikimedia.org and public domain.

Fig. 9.26: *Dayton Daily News*, 8 December 1946, p. 55 and U.S. government, public domain.

Fig. 9.27: commons.wikimedia.org and public domain.

Fig. 9.28: commons.wikimedia.org and public domain.

Fig. 9.29: commons.wikimedia.org and public domain.

Fig. 9.30: commons.wikimedia.org and public domain.

Fig. 9.31: commons.wikimedia.org and public domain.

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Fig. 9.35: commons.wikimedia.org and public domain.

Fig. 9.36: commons.wikimedia.org and public domain.

Fig. 9.37: commons.wikimedia.org and public domain.

Fig. 9.38: commons.wikimedia.org and public domain.

Fig. 9.39: commons.wikimedia.org and public domain.

Fig. 9.40: commons.wikimedia.org and public domain.

Fig. 9.41: Todd Rider.

Fig. 9.42 Top: commons.wikimedia.org and public domain. Bottom: Todd Rider.

Fig. 9.43: commons.wikimedia.org and public domain.

Fig. 9.44: U.S. government and public domain.

Fig. 9.45 Top: commons.wikimedia.org and public domain. Bottom: Todd Rider.

Fig. 9.46: Norberto Lahuerta [NARA RG 319, Entry NM3-82, Box 1568, HEC 842].

Fig. 9.47: Norberto Lahuerta [NARA RG 319, Entry NM3-82, Box 1568, HEC 842].

Fig. 9.48: hoernerfluiddynamics.com.

Fig. 9.49: commons.wikimedia.org and public domain.

Fig. 9.50: commons.wikimedia.org and public domain.

Fig. 9.51: Todd Rider.

Fig. 9.52: Todd Rider.

Fig. 9.53: Todd Rider.

Fig. 9.54: European Patent Office, U.S. Patent and Trademark Office, and commons.wikimedia.org, public domain.

Fig. 9.55: U.S. Patent and Trademark Office, public domain.

Fig. 9.56: European Patent Office, public domain.

Fig. 9.57: commons.wikimedia.org, public domain.

Fig. 9.58: U.S. Patent and Trademark Office and European Patent Office, public domain.

Fig. 9.59: European Patent Office, U.S. Patent and Trademark Office, and commons.wikimedia.org, public domain.

Fig. 9.60: European Patent Office and U.S. Patent and Trademark Office, public domain.

Fig. 9.61: European Patent Office and commons.wikimedia.org, public domain.

Fig. 9.62: European Patent Office, public domain.

Fig. 9.63: European Patent Office, public domain.

Fig. 9.64: European Patent Office and commons.wikimedia.org, public domain.

Fig. 9.65: commons.wikimedia.org and public domain.

Fig. 9.66: commons.wikimedia.org and public domain.

Fig. 9.67: commons.wikimedia.org and public domain.

Fig. 9.68: commons.wikimedia.org and public domain.

Fig. 9.69: commons.wikimedia.org and public domain.

Fig. 9.70: commons.wikimedia.org and public domain.

Fig. 9.71: commons.wikimedia.org and public domain.

Fig. 9.72: European Patent Office, public domain.

Fig. 9.73: European Patent Office, public domain.

Fig. 9.74: European Patent Office, public domain.

Fig. 9.75: European Patent Office, public domain.

Fig. 9.76: commons.wikimedia.org and public domain.

Fig. 9.77: U.S. government, public domain.

Fig. 9.78: U.S. Patent and Trademark Office, public domain.

Fig. 9.79: European Patent Office and U.S. Patent and Trademark Office, public domain.

Fig. 9.80: European Patent Office and U.S. Patent and Trademark Office, public domain.

Fig. 9.81: commons.wikimedia.org and public domain.

Fig. 9.82: U.S. government, public domain.

Fig. 9.83: commons.wikimedia.org and public domain.

Fig. 9.84: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.85: commons.wikimedia.org and public domain.

Fig. 9.86: U.S. government; *Cincinnati Enquirer*, 15 June 1997, p. 32.

Fig. 9.87: U.S. government and commons.wikimedia.org, public domain.

Fig. 9.88: U.S. government and commons.wikimedia.org, public domain.

Fig. 9.89: U.S. government, public domain.

Fig. 9.90: U.S. government, public domain.

Fig. 9.91: [Carpenter 2003].

Fig. 9.92: European Patent Office and U.S. Patent and Trademark Office, public domain.

Fig. 9.93: U.S. Patent and Trademark Office, public domain.

Fig. 9.94: U.S. Patent and Trademark Office, public domain.

Fig. 9.95: U.S. Patent and Trademark Office and commons.wikimedia.org, public domain.

Fig. 9.96: U.S. Patent and Trademark Office and commons.wikimedia.org, public domain.

Fig. 9.97: U.S. Patent and Trademark Office, public domain.

Fig. 9.98: General Electric and U.S. government, public domain. Fleet Ballistic Missile, Kings Bay https://books.google.com/books?id=Ex86AQAAMAAJ&pg=SA9-PA241&lpg=SA9-PA241&dq=%22walter+brisken%22+engines&source=bl&ots=cG4CgxXj-x&sig=ACfU3U0ZTV-nr0aORDptfUMHY7GrX3YvFA&hl=en&sa=X&ved=2ahUKEwjN2evWiLD5AhXOxoUKHRtsBAcQ6AF6BAgXEAM#v=onepage&q&f=false

Fig. 9.99: Todd Rider [AFHRA A2055 Frame 1257].

Fig. 9.100: commons.wikimedia.org and public domain.

Fig. 9.101: commons.wikimedia.org and public domain.

Fig. 9.102: commons.wikimedia.org and public domain.

Fig. 9.103: commons.wikimedia.org and public domain.

Fig. 9.104: commons.wikimedia.org and public domain.

Fig. 9.105: commons.wikimedia.org and public domain.

Fig. 9.106: Top: commons.wikimedia.org and public domain. Bottom: Lori Rider.

Fig. 9.107: commons.wikimedia.org and public domain.

Fig. 9.108: commons.wikimedia.org and public domain.

Fig. 9.109: commons.wikimedia.org and public domain.

Fig. 9.110: commons.wikimedia.org and public domain.

Fig. 9.111:

Fig. 9.112: [BIOS 466; FIAT 465].

Fig. 9.113: [BIOS 466].

Fig. 9.114: [BIOS 466].

Fig. 9.115: Courtesy of Deutsches Museum Archive, photo 39529.

Fig. 9.116: *Dayton Daily News*, 8 December 1946, p. 55 and U.S. government, public domain.

Fig. 9.117: commons.wikimedia.org and public domain.

Fig. 9.118: European Patent Office, public domain.

Fig. 9.119: European Patent Office, public domain.

Fig. 9.120: European Patent Office, public domain.

Fig. 9.121: commons.wikimedia.org and public domain.

Fig. 9.122: Todd Rider.

Fig. 9.123: commons.wikimedia.org and public domain.

Fig. 9.124: commons.wikimedia.org and public domain.

Fig. 9.125: commons.wikimedia.org and public domain.

Fig. 9.126: commons.wikimedia.org and public domain.

Fig. 9.127: commons.wikimedia.org and public domain.

Fig. 9.128: commons.wikimedia.org and public domain.

Fig. 9.129: commons.wikimedia.org and public domain.

Fig. 9.130: commons.wikimedia.org and public domain.

Fig. 9.131: commons.wikimedia.org and public domain.

Fig. 9.132: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.133: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.134: U.S. government and public domain.

Fig. 9.135: U.S. government and public domain.

Fig. 9.136: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.137: Todd Rider.

Fig. 9.138: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.139: U.S. government and public domain.

Fig. 9.140: U.S. government and public domain.

Fig. 9.141: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.142: Ron Barrett, University of Kansas, and Martin UAV.

Fig. 9.143: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.144: U.S. government and public domain.

Fig. 9.145: U.S. government and public domain.

Fig. 9.146: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.147: commons.wikimedia.org and public domain.

Fig. 9.148: Todd Rider [BIOS Overall 8] and public domain.

Fig. 9.149: Todd Rider [BIOS Overall 8] and public domain.

Fig. 9.150: Todd Rider [FIAT 604].

Fig. 9.151: commons.wikimedia.org and public domain.

Fig. 9.152: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.153: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.154: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.155: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.156: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.157: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.158: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.159: U.S. government and public domain.

Fig. 9.160: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.161: *Los Angeles Times* and *Oxnard Press-Courier*.

Fig. 9.162: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.163: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.164: commons.wikimedia.org and public domain.

Fig. 9.165: Todd Rider.

Fig. 9.166: commons.wikimedia.org and public domain.

Fig. 9.167 Left: commons.wikimedia.org and public domain. Right: Todd Rider.

Fig. 9.168: commons.wikimedia.org and public domain.

Fig. 9.169: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.170: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.171: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.172: Todd Rider collection.

Fig. 9.173: commons.wikimedia.org, public domain.

Fig. 9.174: commons.wikimedia.org, public domain.

Fig. 9.175: commons.wikimedia.org, public domain.

Fig. 9.176: U.S. government (via heroicrelics.org), commons.wikimedia.org, and public domain.

Fig. 9.177: public domain.

Fig. 9.178: commons.wikimedia.org and public domain.

Fig. 9.179: commons.wikimedia.org and public domain.

Fig. 9.180: Mark Wade [www.astronautix.com/g/g-5.html].

Fig. 9.181: [Przybilski 2002a].

Fig. 9.182: commons.wikimedia.org and public domain.

Fig. 9.183: commons.wikimedia.org, public domain.

Fig. 9.184: U.S. Patent and Trademark Office, public domain.

Fig. 9.185: public domain.

Fig. 9.186: commons.wikimedia.org, public domain.

Fig. 9.187: commons.wikimedia.org, public domain.

Fig. 9.188: commons.wikimedia.org, public domain.

Fig. 9.189: commons.wikimedia.org, public domain.

Fig. 9.190: [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. 9.191: [NavTecMisEu 500-45].

Fig. 9.192: [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. 9.193: U.S. government and public domain [http://www.cv41.org/photos/gallery3/index.php/op/opsandy].

Fig. 9.194: U.S. government and public domain [http://www.usscusk.com/1953.htm].

Fig. 9.195: U.S. government, public domain; Lori Rider.

Fig. 9.196: commons.wikimedia.org, public domain.

Fig. 9.197: Courtesy of Norberto Lahuerta.

Fig. 9.198: commons.wikimedia.org, public domain.

Fig. 9.199: Todd Rider.

Fig. 9.200: U.S. government, commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 9.201: U.S. government, commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 9.202: U.S. government, commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 9.203: U.S. government, commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 9.204: U.S. government, commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 9.205: public domain.

Fig. 9.206: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.207: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.208 Top: BIOS 571. Bottom: HEC 5787.

Fig. 9.209: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.210: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.211: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.212: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.213: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.214: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.215: *Dayton Daily News*, 8 December 1946, p. 55 and U.S. government, public domain.

Fig. 9.216: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.217: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.218: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.219: Todd Rider.

Fig. 9.220: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.221: U.S. government and public domain.

Fig. 9.222: U.S. government, commons.wikimedia.org, Peenemünde Archive, and public domain.

Fig. 9.223: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.224: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.225: Washington Dulles International Airport, public domain.

Fig. 9.226: commons.wikimedia.org and public domain.

Fig. 9.227: commons.wikimedia.org and public domain.

Fig. 9.228: commons.wikimedia.org and public domain [Hohmann 1925].

Fig. 9.229: [Hohmann 1925].

Fig. 9.230: commons.wikimedia.org and public domain.

Fig. 9.231: commons.wikimedia.org and public domain [Noordung 1928].

Fig. 9.232: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.233: Todd Rider collection.

Fig. 9.234: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.235: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.236: U.S. government, public domain [Belew 1977].

Fig. 9.237: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.238: U.S. government, commons.wikimedia.org, and public domain.

Fig. 9.239: Todd Rider.

Fig. 9.240: Todd Rider.

Fig. 9.241 Top: Peenemünde Archive, AHT0205. Bottom: U.S. government and public domain.

Fig. 9.242: Todd Rider collection.

Fig. 10.1: commons.wikimedia.org and public domain.

Fig. 10.2: commons.wikimedia.org and public domain.

Fig. 10.3: commons.wikimedia.org and public domain.

Fig. 10.4: commons.wikimedia.org and public domain.

Fig. 10.5: Todd Rider.

Fig. 10.6: Todd Rider.

Fig. 10.7: Todd Rider [Bundesarchiv Militärarchiv Freiburg N822/6].

Fig. 10.8: commons.wikimedia.org and public domain.

Fig. 10.9: commons.wikimedia.org and public domain.

Fig. 10.10: commons.wikimedia.org and public domain.

Fig. 10.11: commons.wikimedia.org and public domain.

Fig. 10.12: commons.wikimedia.org, public domain, and Günter Nagel.

Fig. 10.13: Todd Rider.

Fig. 10.14: commons.wikimedia.org and public domain.

Fig. 10.15: Todd Rider.

Fig. 10.16: Todd Rider.

Fig. 11.1: U.S. government, public domain [Gross 2014].

Fig. 11.2: commons.wikimedia.org and public domain.

Fig. 11.3: Todd Rider [AFHRA A2055 Frame 1062].

Fig. 11.4: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.5: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.6: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.7: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.8: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.9: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.10: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.11: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.12: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.13: U.S. government, public domain.

Fig. 11.14: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.32. Germ. Incl. TA].

Fig. 11.15: commons.wikimedia.org, public domain.

Fig. 11.16: public domain.

Fig. 11.17: commons.wikimedia.org, public domain.

Fig. 11.18: Todd Rider, adapted from commons.wikimedia.org.

Fig. 11.19: Todd Rider, adapted from commons.wikimedia.org.

Fig. 11.20: Todd Rider, adapted from commons.wikimedia.org.

Fig. 11.21: Todd Rider, adapted from commons.wikimedia.org.

Fig. 11.22: https://books.google.com/books?id=U9Q9TS-FtSgC

Fig. 11.23: https://books.google.com/books?id=U9Q9TS-FtSgC

Fig. 11.24: https://books.google.com/books?id=U9Q9TS-FtSgC

Fig. 11.25: BIOS 342.

Fig. 11.26: BIOS 342.

Fig. 11.27: Todd Rider [NARA RG 40, Entry UD-75, Box 12, Folder Technical Inquiries - H -, Technical Industrial Intelligence Division to R. P. Isaacs, 21 April 1947].

Fig. 11.28: Todd Rider [NARA RG 40, Entry UD-75, Box 12, Folder Technical Inquiries - H -, Technical Industrial Intelligence Division to R. P. Isaacs, 21 April 1947].

Fig. 11.29: *Dayton Daily News*, 8 December 1946, p. 55 and U.S. government, public domain.

Fig. 11.30: Todd Rider.

Fig. 11.31: Todd Rider.

Fig. 11.32: Todd Rider [NARA RG 40, Entry UD-75, Box 62, Report German Documents Conference].

Fig. 11.33: Todd Rider [NARA RG 40, Entry UD-75, Box 62, Report German Documents Conference].

Fig. 11.34: commons.wikimedia.org and public domain.

Fig. 11.35: [Cocroft 2010].

Fig. 11.36: Todd Rider [HEC files at Imperial War Museum, Duxford].

Fig. 11.37: [Cocroft 2010].

Fig. 11.38: Todd Rider [AFHRA A5186 electronic p. 907].

Fig. 11.39: Todd Rider [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

Fig. 11.40: Todd Rider [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

Fig. 11.41: Todd Rider [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

Fig. 11.42: Todd Rider [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

Fig. 11.43: Todd Rider [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

Fig. 11.44: Todd Rider [NARA RG 330, Entry A1-1A, Box 4, Folder 383.7 Policy–1946].

Fig. 11.45: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.46: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.47: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss].

Fig. 11.48: Todd Rider [AFHRA A2056 electronic p. 405].

Fig. 11.49: Todd Rider [AFHRA A2056 electronic p. 406].

Fig. 11.50: Todd Rider [AFHRA A2055 Frame 1265].

Fig. 11.51: Todd Rider [AFHRA A2055 Frame 1177].

Fig. 11.52: Todd Rider [AFHRA A2055 Frame 1178].

Fig. 11.53: Todd Rider [AFHRA A2055 electronic p. 747].

Fig. 11.54: Todd Rider [AFHRA K2838 (15390) electronic p. 887].

Fig. 11.55: Todd Rider [AFHRA K2838 (15390) electronic p. 894].

Fig. 11.56: commons.wikimedia.org and public domain.

Fig. 11.57: U.S. government, public domain [Steelman 1947].

Fig. 11.58: https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd

Fig. 11.59: https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd
https://saylordotorg.github.io/text_introduction-to-economic-analysis/s05-05-government.html#mcafee-ch04_s05_f10

Fig. 11.60: https://www.nsf.gov/statistics/2018/nsb20181/figures

Fig. 11.61: https://www.nsf.gov/statistics/2018/nsb20181/figures

Fig. 11.62: commons.wikimedia.org and public domain.

Fig. 11.63: commons.wikimedia.org and public domain.

Fig. 11.64: commons.wikimedia.org and public domain.

Fig. 11.65: commons.wikimedia.org and public domain.

Fig. 11.66: commons.wikimedia.org and public domain.

Fig. 11.67: commons.wikimedia.org and public domain.

Fig. 11.68: commons.wikimedia.org and public domain.

Fig. 11.69: Todd Rider.

Fig. 11.70: commons.wikimedia.org and public domain.

Fig. 11.71: Todd Rider.

Fig. 11.72: commons.wikimedia.org and public domain.

Fig. 11.73: Todd Rider [redrawn based on Carr 2015].

Fig. 12.1: Todd Rider.

Fig. A.1: *Bulletin de la Société Chimique de France* 9:728–730 (1893).

Fig. A.2: *Bulletin de la Société Chimique de France* 9:728–730 (1893).

Fig. A.3: *Bulletin de la Société Chimique de France* 9:728–730 (1893).

Fig. A.4: European Patent Office, Swiss patent CH 90,955, public domain.

Fig. A.5: [Pregl 1917].

Fig. A.6: [Pregl 1917].

Fig. A.7: [Pregl 1917].

Fig. A.8: [Pregl 1917].

Fig. A.9: [Pregl 1917].

Fig. A.10: Todd Rider [BIOS 236].

Fig. A.11: Todd Rider [BIOS 236].

Fig. A.12: Todd Rider [BIOS 236].

Fig. A.13: Todd Rider [BIOS 236].

Fig. A.14: Todd Rider [BIOS 236].

Fig. A.15: Todd Rider [BIOS 236].

Fig. A.16: Todd Rider [BIOS 236].

Fig. A.17: Todd Rider [BIOS 236].

Fig. A.18: Todd Rider [BIOS 236].

Fig. A.19: Todd Rider [BIOS 236].

Fig. A.20: Todd Rider [BIOS 236].

Fig. A.21: Todd Rider [BIOS 266 Appendix].

Fig. A.22: Todd Rider [BIOS 266 Appendix].

Fig. A.23: Todd Rider [BIOS 266 Appendix].

Fig. A.24: Todd Rider [BIOS 354].

Fig. A.25: Todd Rider [BIOS 354].

Fig. A.26: Todd Rider [BIOS 354].

Fig. A.27: Todd Rider [BIOS 354].

Fig. A.28: Todd Rider [BIOS 354].

Fig. A.29: Todd Rider [BIOS 354].

Fig. A.30: Todd Rider [BIOS 354].

Fig. A.31: Todd Rider [BIOS 354].

Fig. A.32: Todd Rider.

Fig. A.33: Todd Rider [BIOS 449].

Fig. A.34: Todd Rider [BIOS 449].

Fig. A.35: Todd Rider [BIOS 449].

Fig. A.36: Todd Rider [BIOS 449].

Fig. A.37: Todd Rider [BIOS 691].

Fig. A.38: Todd Rider [BIOS 691].

Fig. A.39: Todd Rider [BIOS 691].

Fig. A.40: Todd Rider [BIOS 766].

Fig. A.41: Todd Rider [BIOS 770].

Fig. A.42: Todd Rider [BIOS 770].

Fig. A.43: European Patent Office, German patent DE 894,956, public domain.

Fig. A.44: European Patent Office, German patent DE 877,100, public domain.

Fig. A.45: European Patent Office, German patent DE 877,100, public domain.

Fig. A.46: European Patent Office, German patent DE 885,954, public domain.

Fig. A.47: Todd Rider [BIOS 784].

Fig. A.48: Todd Rider [BIOS 784].

Fig. A.49: Todd Rider [BIOS 784].

Fig. A.50: Todd Rider [BIOS 1253].

Fig. A.51: European Patent Office, German patent DE 740,593, public domain.

Fig. A.52: European Patent Office, German patent DE 740,593, public domain.

Fig. A.53: European Patent Office, German patent DE 740,593, public domain.

Fig. A.54: European Patent Office, German patent DE 740,593, public domain.

Fig. A.55: European Patent Office, German patent DE 731,494, public domain.

Fig. A.56: European Patent Office, German patent DE 731,494, public domain.

Fig. A.57: European Patent Office, German patent DE 731,494, public domain.

Fig. A.58: European Patent Office, German patent DE 731,494, public domain.

Fig. A.59: Todd Rider [BIOS 1481].

Fig. A.60: Todd Rider [BIOS 1481].

Fig. A.61: Todd Rider [BIOS 1481].

Fig. A.62: https://mediatum.ub.tum.de/1554376

Fig. A.63: Todd Rider [BIOS 1487].

Fig. A.64: Todd Rider [BIOS 1513].

Fig. A.65: Todd Rider [BIOS 1776].

Fig. A.66: Todd Rider [BIOS 1776].

Fig. A.67: Todd Rider [BIOS 1776].

Fig. A.68: Todd Rider [CIOS ER 1].

Fig. A.69: Todd Rider [CIOS ER 10].

Fig. A.70: Todd Rider [CIOS ER 10].

Fig. A.71: Todd Rider [CIOS ER 10].

Fig. A.72: Todd Rider [CIOS ER 10].

Fig. A.73: Todd Rider [CIOS ER 10].

Fig. A.74: Stephen Walton [CIOS XXIV-16].

Fig. A.75: Stephen Walton [CIOS XXV-54].

Fig. A.76: Stephen Walton [CIOS XXV-54].

Fig. A.77: Stephen Walton [CIOS XXV-54].

Fig. A.78: Stephen Walton [CIOS XXV-54].

Fig. A.79: Stephen Walton [CIOS XXV-54].

Fig. A.80: Stephen Walton [CIOS XXV-54].

Fig. A.81: Stephen Walton [CIOS XXV-54].

Fig. A.82: Stephen Walton [CIOS XXV-54].

Fig. A.83: Stephen Walton [CIOS XXV-54].

Fig. A.84: Stephen Walton [CIOS XXV-54].

Fig. A.85: Stephen Walton [CIOS XXV-54].

Fig. A.86: Stephen Walton [CIOS XXV-54].

Fig. A.87: Stephen Walton [CIOS XXV-54].

Fig. A.88: Stephen Walton [CIOS XXV-54].

Fig. A.89: Stephen Walton [CIOS XXV-54].

Fig. A.90: Stephen Walton [CIOS XXV-54].

Fig. A.91: Stephen Walton [FIAT 371].

Fig. A.92: Stephen Walton [FIAT 371].

Fig. A.93: Stephen Walton [FIAT 371].

Fig. A.94: Stephen Walton [FIAT 371].

Fig. A.95: Stephen Walton [FIAT 371].

Fig. A.96: Stephen Walton [FIAT 371].

Fig. A.97: Stephen Walton [FIAT 371].

Fig. A.98: Stephen Walton [FIAT 371].

Fig. A.99: European Patent Office, public domain.

Fig. A.100: European Patent Office, public domain.

Fig. A.101: European Patent Office, public domain.

Fig. A.102: European Patent Office, public domain.

Fig. A.103: European Patent Office, public domain.

Fig. A.104: European Patent Office, public domain.

Fig. A.105: Todd Rider [FIAT 871].

Fig. A.106: Todd Rider [FIAT 910].

Fig. A.107: Todd Rider [FIAT 910].

Fig. A.108: Todd Rider [FIAT 910].

Fig. A.109: Stephen Walton [FIAT 964].

Fig. A.110: Stephen Walton [FIAT 964].

Fig. A.111: Stephen Walton [FIAT 964].

Fig. A.112: Stephen Walton [FIAT 964].

Fig. A.113: Stephen Walton [FIAT 964].

Fig. A.114: Stephen Walton [FIAT 964].

Fig. A.115: Stephen Walton [FIAT 964].

Fig. A.116: Stephen Walton [FIAT 996].

Fig. A.117: Stephen Walton [FIAT 996].

Fig. A.118: Stephen Walton [FIAT 996].

Fig. A.119: Stephen Walton [FIAT 996].

Fig. A.120: Stephen Walton [FIAT 996].

Fig. A.121: Stephen Walton [FIAT 996].

Fig. A.122: Stephen Walton [FIAT 996].

Fig. A.123: Stephen Walton [FIAT 996].

Fig. A.124: Stephen Walton [FIAT 996].

Fig. A.125: Stephen Walton [FIAT 1014].

Fig. A.126: Stephen Walton [FIAT 1014].

Fig. A.127: Stephen Walton [FIAT 1059].

Fig. A.128: Stephen Walton [FIAT 1059].

Fig. A.129: Stephen Walton [FIAT 1059].

Fig. A.130: Stephen Walton [FIAT 1059].

Fig. A.131: Stephen Walton [FIAT 1059].

Fig. A.132: Stephen Walton [FIAT 1059 Supplement].

Fig. A.133: Stephen Walton [FIAT 1059 Supplement].

Fig. A.134: Stephen Walton [FIAT 1059 Supplement].

Fig. A.135: Stephen Walton [FIAT 1059 Supplement].

Fig. A.136: Stephen Walton [FIAT 1059 Supplement].

Fig. A.137: Stephen Walton [FIAT 1059 Supplement].

Fig. A.138: U.S. Patent and Trademark Office, U.S. patent 2,480,856, public domain.

Fig. A.139: U.S. Patent and Trademark Office, U.S. patent 2,489,291, public domain.

Fig. A.140: U.S. Patent and Trademark Office, U.S. patent 2,561,370, public domain.

Fig. A.141: U.S. Patent and Trademark Office, U.S. patent 2,490,806, public domain.

Fig. A.142: *Report from Heidelberg: The Story of the Army Air Forces Aero Medical Center in Germany 1945–1947.* 28 February 1947 [https://collections.nlm.nih.gov/ext/dw/14130150R/PDF/14130150R.pdf].

Fig. A.143: *Report from Heidelberg: The Story of the Army Air Forces Aero Medical Center in Germany 1945–1947.* 28 February 1947 [https://collections.nlm.nih.gov/ext/dw/14130150R/PDF/14130150R.pdf].

Fig. A.144: Todd Rider [AFHRA A2055 Frames 1214-1216].

Fig. A.145: Todd Rider [AFHRA A2055 Frame 1283].

Fig. A.146: Todd Rider [AFHRA A2055 Frame 1286].

Fig. A.147: Malcolm C. Grow. Hydraulic Leg. *AAF Review* July 1946, p. 8. In *Report from Heidelberg: The Story of the Army Air Forces Aero Medical Center in Germany 1945–1947.* 28 February 1947 [https://collections.nlm.nih.gov/ext/dw/14130150R/PDF/14130150R.pdf].

Fig. A.148: Ad Hoc Committee on Fluid-Controlled Legs. 1960. *Final Summary Report: Henschke-Mauch "Hydraulik" System, Model B (Swing-Phase Control) for Above-Knee Prostheses.* Washington, D.C.: National Research Council. Bess Furman. 1962. *Progress in Prosthetics.* Washington, D.C.: U.S. Government Printing Office [www.oandplibrary.org/assets/pdf/ProgressInProsthetics.pdf].

Fig. A.149: U.S. Patent and Trademark Office, U.S. patent 2,590,101, public domain.

Fig. A.150: U.S. Patent and Trademark Office, U.S. patent 2,590,101, public domain.

Fig. A.151: U.S. Patent and Trademark Office, U.S. patent 2,590,101, public domain.

Fig. A.152: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1942–1943, MC019.09_c44.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c44].

Fig. A.153: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1942–1943, MC019.09_c44.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c44].

Fig. A.154: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1942–1943, MC019.09_c44.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c44].

Fig. A.155: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1360 OUT TOLEDO].

Fig. A.156: Todd Rider [AFHRA 43811 electronic p. 1075].

Fig. A.157: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.158: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1360 OUT TOLEDO].

Fig. A.159: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1360 OUT TOLEDO].

Fig. A.160: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.161: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.162: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1360 OUT TOLEDO].

Fig. A.163: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1360 OUT TOLEDO].

Fig. A.164: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.165: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.166: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.167: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.168: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.169: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.170: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.171: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.172: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.173: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.174: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.175: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.176: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1944 May-July 15, MC019.09_c46.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c46].

Fig. A.177: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.178: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.179: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1360 OUT TOLEDO].

Fig. A.180: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.181: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.182: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.183: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1359 IN TOLEDO].

Fig. A.184: Todd Rider [NARA RG 226, Entry A1-134, Box 216, Folder 1360 OUT TOLEDO].

Fig. A.185: Todd Rider [NARA RG 165, Entry NM84-187, Box 137, Folder BW 55].

Fig. A.186: Todd Rider [NARA RG 165, Entry NM84-187, Box 137, Folder BW 55].

Fig. A.187: Todd Rider [NARA RG 38, Entry P5, Box 8, Folder ALSOS Intelligence Report B-C-H-H/305].

Fig. A.188: Todd Rider [NARA RG 38, Entry P5, Box 8, Folder ALSOS Intelligence Report B-C-H-H/305].

Fig. A.189: Todd Rider [NARA RG 38, Entry P5, Box 8, Folder ALSOS Intelligence Report B-C-H-H/305].

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Fig. A.198: Todd Rider [NARA RG 319, Entry NM3-82A, Box 4, Folder DCL-1].

Fig. A.199: Todd Rider [NARA RG 38, Entry P5, Box 8, Folder ALSOS Intelligence Report B-C-H-H/305].

Fig. A.200: Todd Rider [NARA RG 319, Entry NM3-82A, Box 4, Folder DCL-1].

Fig. A.201: Todd Rider [NARA RG 319, Entry NM3-82A, Box 4, Folder Biological Warfare/BW # 25].

Fig. A.202: Todd Rider [NARA RG 319, Entry NM3-82A, Box 4, Folder Data/DCC-2].

Fig. A.203: Todd Rider.

Fig. A.204: Todd Rider [NARA RG 38, Entry P5, Box 8, Folder ALSOS Intelligence Report B-C-H-H/305].

Fig. A.205: Todd Rider [NARA RG 319, Entry NM3-82A, Box 4, Folder DCL-1].

Fig. A.206: Todd Rider.

Fig. A.207: Todd Rider [NARA RG 319, Entry A1-84E, Box 124].

Fig. A.208: Todd Rider [NARA RG 319, Entry A1-84E, Box 124].

Fig. A.209: European Patent Office, public domain.

Fig. A.210: European Patent Office, public domain.

Fig. A.211: European Patent Office, public domain.

Fig. A.212: European Patent Office, public domain.

Fig. A.213: Todd Rider [BIOS 714].

Fig. A.214: Todd Rider [BIOS 714].

Fig. A.215: Todd Rider [BIOS 714].

Fig. A.216: Todd Rider [BIOS 714].

Fig. A.217: Todd Rider [BIOS 714].

Fig. A.218: Todd Rider [BIOS 714].

Fig. A.219: Todd Rider [BIOS 714].

Fig. A.220: Todd Rider [BIOS 714].

Fig. A.221: Todd Rider [BIOS 714].

Fig. A.222: Todd Rider [BIOS 714].

Fig. A.223: Todd Rider [BIOS 714].

Fig. A.224: Todd Rider [BIOS 714].

Fig. A.225: Todd Rider [BIOS 714].

Fig. A.226: Todd Rider [BIOS 714].

Fig. A.227: Todd Rider [BIOS 714].

Fig. A.228: Todd Rider [BIOS 714].

Fig. A.229: Todd Rider [BIOS 714].

Fig. A.230: Todd Rider [BIOS 714].

Fig. A.231: Todd Rider [BIOS 714].

Fig. A.232: Todd Rider [BIOS 714].

Fig. A.233: Todd Rider [BIOS 714].

Fig. A.234: Todd Rider [BIOS 714].

Fig. A.235: Todd Rider [BIOS 714].

Fig. A.236: Todd Rider [BIOS 714].

Fig. A.237: Manuel Lukas [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1942–1943, MC019.09_c44.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c44].

Fig. A.238: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.239: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.240: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.241: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.242: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.243: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.244: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.245: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin 1/47, 13 March 1945].

Fig. A.246: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.247: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.248: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.249: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.250: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.251: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.252: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.253: David Bleecker [PW Intelligence Bulletin 2/45, 14 March 1945. AFHRA A5186, frames 0482–0489. Also available at NARA RG 165, Entry NM84-79, Box 1917].

Fig. A.254: Gellermann 1986, p. 245.

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Bottom: *December 1943: Hell Over Bari* [https://www.youtube.com/watch?v=XGJQpmFJYyI]

Fig. A.256: NARA, https://www.nhd.org/sites/default/files/The%20Bari%20Incident%20-%20Lesson%20Plan.pdf

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Fig. B.2: U.S. Patent and Trademark Office, U.S. patent 1,745,175, public domain.

Fig. B.3: U.S. Patent and Trademark Office, U.S. patent 1,745,175, public domain.

Fig. B.4: U.S. Patent and Trademark Office, U.S. patent 1,745,175, public domain.

Fig. B.5: U.S. Patent and Trademark Office, U.S. patent 1,745,175, public domain.

Fig. B.6: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.7: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.8: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.9: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.10: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.11: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.12: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.13: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

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Fig. B.15: U.S. Patent and Trademark Office, U.S. patent 1,900,018, public domain.

Fig. B.16: U.S. Patent and Trademark Office, U.S. patent 1,877,140, public domain.

Fig. B.17: U.S. Patent and Trademark Office, U.S. patent 1,877,140, public domain.

Fig. B.18: U.S. Patent and Trademark Office, U.S. patent 1,877,140, public domain.

Fig. B.19: U.S. Patent and Trademark Office, U.S. patent 1,877,140, public domain.

Fig. B.20: U.S. Patent and Trademark Office, U.S. patent 1,877,140, public domain.

Fig. B.21: U.S. Patent and Trademark Office, U.S. patent 1,877,140, public domain.

Fig. B.22: U.S. Patent and Trademark Office, U.S. patent 1,877,140, public domain.

Fig. B.23: European Patent Office, Swiss patent CH184,396, public domain.

Fig. B.24: European Patent Office, Swiss patent CH184,396, public domain.

Fig. B.25: European Patent Office, Swiss patent CH184,396, public domain.

Fig. B.26: European Patent Office, U.K. patent GB439,457, public domain.

Fig. B.27: European Patent Office, U.K. patent GB439,457, public domain.

Fig. B.28: European Patent Office, U.K. patent GB439,457, public domain.

Fig. B.29: European Patent Office, U.K. patent GB439,457, public domain.

Fig. B.30: U.S. Patent and Trademark Office, U.S. patent 2,173,904, public domain.

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Fig. B.33: *Zeitschrift für Physik* (1938) 111:399–408.

Fig. B.34: *Zeitschrift für Physik* (1938) 111:399–408.

Fig. B.35: *Die Naturwissenschaften* (1939) 27:489–492.

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Fig. B.37: European Patent Office, German patent 971,775, public domain.

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Fig. B.40: Günter Nagel.

Fig. B.41: *Zeitschrift für Physik* (1942) 118:539–592.

Fig. B.42: European Patent Office, German patent 841,174, public domain.

Fig. B.43: European Patent Office, German patent 841,174, public domain.

Fig. B.44: European Patent Office, German patent 841,174, public domain.

Fig. B.45: European Patent Office, German patent 841,174, public domain.

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Fig. B.47: European Patent Office, German patent 841,174, public domain.

Fig. B.48: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Selenium Rectifier Machinery].

Fig. B.49: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Selenium Rectifier Machinery].

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Fig. B.54: European Patent Office, German patent 980,084, public domain.

Fig. B.55: European Patent Office, German patent 980,084, public domain.

Fig. B.56: U.S. Patent and Trademark Office, U.S. patent 2,673,948, public domain.

Fig. B.57: U.S. Patent and Trademark Office, U.S. patent 2,673,948, public domain.

Fig. B.58: U.S. Patent and Trademark Office, U.S. patent 2,673,948, public domain.

Fig. B.59: U.S. Patent and Trademark Office, U.S. patent 2,673,948, public domain.

Fig. B.60: Todd Rider [CIOS XXXI-2].

Fig. B.61: Todd Rider [CIOS XXXI-2].

Fig. B.62: Todd Rider [CIOS XXXI-2].

Fig. B.63: Todd Rider [BIOS 1658].

Fig. B.64: Todd Rider [BIOS 1658].

Fig. B.65: Todd Rider [BIOS 1658].

Fig. B.66: Todd Rider [BIOS 1658].

Fig. B.67: Todd Rider [BIOS 1658].

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Fig. B.69: European Patent Office, German patent 721,677, public domain.

Fig. B.70: European Patent Office, German patent 721,677, public domain.

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Fig. B.73: U.S. Patent and Trademark Office, U.S. patent 2,648,805, public domain.

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Fig. B.81: U.S. Patent and Trademark Office, U.S. patent 2,648,805, public domain.

Fig. B.82: Todd Rider [CIOS ER 350].

Fig. B.83: Todd Rider [CIOS ER 350].

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Fig. B.85: U.S. Patent and Trademark Office, U.S. patent 2,701,216, public domain.

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Fig. B.91: U.S. Patent and Trademark Office, U.S. patent 2,773,224, public domain.

Fig. B.92: U.S. Patent and Trademark Office, U.S. patent 2,773,224, public domain.

Fig. B.93: U.S. Patent and Trademark Office, U.S. patent 2,773,224, public domain.

Fig. B.94: European Patent Office, U.K. patent 15,077, public domain.

Fig. B.95: European Patent Office, U.K. patent 15,077, public domain.

Fig. B.96: European Patent Office, U.K. patent 15,077, public domain.

Fig. B.97: European Patent Office, U.K. patent 15,077, public domain.

Fig. B.98: European Patent Office, U.K. patent 15,077, public domain.

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Fig. B.100: European Patent Office, U.K. patent 4681, public domain.

Fig. B.101: European Patent Office, U.K. patent 4681, public domain.

Fig. B.102: European Patent Office, U.K. patent 4681, public domain.

Fig. B.103: European Patent Office, U.K. patent 4681, public domain.

Fig. B.104: European Patent Office, U.K. patent 4681, public domain.

Fig. B.105: European Patent Office, U.K. patent 4681, public domain.

Fig. B.106: https://www.fed.de/fileadmin/user_upload/Roentgentest__eine_zerstoerungsfreie_Analysemethode.pdf

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Fig. B.108: U.S. Patent and Trademark Office, U.S. patent 2,441,960, public domain.

Fig. B.109: U.S. Patent and Trademark Office, U.S. patent 2,441,960, public domain.

Fig. B.110: U.S. Patent and Trademark Office, U.S. patent 2,441,960, public domain.

Fig. B.111: U.S. Patent and Trademark Office, U.S. patent 2,441,960, public domain.

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Fig. B.120: U.S. Patent and Trademark Office, U.S. patent 2,441,960, public domain.

Fig. B.121: U.S. Patent and Trademark Office, U.S. patent 2,441,960, public domain.

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Fig. B.124: Todd Rider [NARA RG 40, Entry UD-75, Box 25, Folder Odarenko, Dr. T. M., undated press release (probably late 1946)].

Fig. B.125: Todd Rider [NARA RG 40, Entry UD-75, Box 25, Folder Odarenko, Dr. T. M., undated press release (probably late 1946)].

Fig. B.126: Todd Rider [NARA RG 40, Entry UD-75, Box 25, Folder Odarenko, Dr. T. M., undated press release (probably late 1946)].

Fig. B.127: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.128: Strauss 1998.

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Fig. B.131: U.S. Patent and Trademark Office, U.S. patent 3,056,370, public domain.

Fig. B.132: U.S. Patent and Trademark Office, U.S. patent 3,056,370, public domain.

Fig. B.133: European Patent Office, U.K. patent 715,055, public domain.

Fig. B.134: European Patent Office, U.K. patent 715,055, public domain.

Fig. B.135: Todd Rider [Peenemünde Archive, Folder ARK 41].

Fig. B.136: Courtesy of Deutsches Museum Archive, photo 10890.

Fig. B.137: European Patent Office, German patent DE 833,366, public domain.

Fig. B.138: European Patent Office, German patent DE 833,366, public domain.

Fig. B.139: Todd Rider [NARA RG 40, Entry UD-75, Box 28, Folder Edwin Y. Webb, Jr.].

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Fig. B.144: U.S. Patent and Trademark Office, U.S. patent 2,993,998, public domain.

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Fig. B.209: *Zeitschrift für Physik* (1923) 18:1:199–206.

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Fig. B.211: U.S. Patent and Trademark Office, U.S. patent 2,254,957, public domain.

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Fig. B.235: U.S. Patent and Trademark Office, U.S. patent 3,121,203, public domain.

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Fig. B.242: U.S. Patent and Trademark Office, U.S. patent 3,309,553, public domain.

Fig. B.243: Todd Rider [NARA RG 40, Entry UD-75, Box 23, Folder Communications Subcommittee Agenda].

Fig. B.244: Todd Rider [NARA RG 40, Entry UD-75, Box 23, Folder Communications Subcommittee Agenda].

Fig. B.245: Todd Rider [NARA RG 40, Entry UD-75, Box 23, Folder Communications Subcommittee Agenda].

Fig. B.246: Todd Rider [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda].

Fig. B.247: Todd Rider [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel I Agenda].

Fig. B.248: Todd Rider [NARA RG 40, Entry UD-75, Box 23, Folder Advisory Panel II Agenda].

Fig. B.249: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. B.250: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. B.251: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. B.252: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. B.253: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. B.254: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. B.255: Norberto Lahuerta [NARA RG 407, Entry NM3-427, Box 14465, Folder G-2 Journal—102nd Inf Div Jun–Jul 45].

Fig. B.256: Norberto Lahuerta [NARA RG 238, Entry NM70-160, Box 30, Folder FIAT—Misc.—Reports—No. 1–10].

Fig. B.257: Norberto Lahuerta [NARA RG 238, Entry NM70-160, Box 30, Folder FIAT—Misc.—Reports—No. 1–10].

Fig. B.258: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment].

Fig. B.259: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment].

Fig. B.260: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment].

Fig. B.261: [NYT 1946-07-06].

Fig. B.262: [Schnitger and Weber 1949].

Fig. B.263: Norberto Lahuerta [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 3 of 3].

Fig. B.264: Norberto Lahuerta [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 3 of 3].

Fig. B.265: Norberto Lahuerta [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 2 of 3].

Fig. B.266: Norberto Lahuerta [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 2 of 3].

Fig. B.267: Norberto Lahuerta [NARA RG 319, Entry A1-134A, Box 29, Folder ZA 019293 Vol. 1, Fldr. 2 of 3].

Fig. B.268: Norberto Lahuerta [https://www.cia.gov/readingroom/document/cia-rdp82-00457r001900550002-3].

Fig. B.269: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.270: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.271: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.272: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.273: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.274: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.275: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.276: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.277: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.278: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.279: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.280: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.281: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.282: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.283: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.284: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.285: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment].

Fig. B.286: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.287: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.288: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.289: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.290: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. B.291: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment].

Fig. B.292: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment].

Fig. B.293: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Record of Captured Elec. Equipment].

Fig. B.294: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.295: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Administration Personnel TIID].

Fig. B.296: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Administration Personnel TIID].

Fig. B.297: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

Fig. B.298: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Webb].

Fig. B.299: FIAT 54.

Fig. B.300: FIAT 54.

Fig. B.301: FIAT 54.

Fig. B.302: BIOS 725.

Fig. B.303: BIOS 725.

Fig. B.304: BIOS 725.

Fig. B.305: BIOS 725.

Fig. B.306: BIOS 725.

Fig. B.307: BIOS 725.

Fig. B.308: BIOS 725.

Fig. B.309: BIOS 725.

Fig. B.310: BIOS 1751.

Fig. B.311: BIOS 1751.

Fig. B.312: BIOS 1751.

Fig. B.313: BIOS 1751.

Fig. B.314: BIOS 1751.

Fig. B.315: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.316: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.317: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Replies to Letters of April 29, 1947].

Fig. B.318: Todd Rider [NARA RG 40, Entry UD-75, Box 24, Folder Bell System].

Fig. B.319: Todd Rider [NARA RG 40, Entry UD-75, Box 58, Folder Webb].

Fig. C.1: Todd Rider.

Fig. C.2: Todd Rider.

Fig. C.3: *Archiv für Elektrotechnik* (1928) 21:4:387–406.

Fig. C.4: U.S. Patent and Trademark Office, U.S. patent 2,572,551, public domain.

Fig. C.5: U.S. Patent and Trademark Office, U.S. patent 2,572,551, public domain.

Fig. C.6: U.S. Patent and Trademark Office, U.S. patent 2,572,551, public domain.

Fig. C.7: U.S. Patent and Trademark Office, U.S. patent 2,572,551, public domain.

Fig. C.8: U.S. Patent and Trademark Office, U.S. patent 2,698,384, public domain.

Fig. C.9: U.S. Patent and Trademark Office, U.S. patent 2,698,384, public domain.

Fig. C.10: U.S. Patent and Trademark Office, U.S. patent 2,698,384, public domain.

Fig. C.11: U.S. Patent and Trademark Office, U.S. patent 2,510,448, public domain.

Fig. C.12: U.S. Patent and Trademark Office, U.S. patent 2,631,234, public domain.

Fig. C.13: U.S. Patent and Trademark Office, U.S. patent 2,550,212, public domain.

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Fig. C.15: European Patent Office, German patent DE 698,867, public domain.

Fig. C.16: European Patent Office, German patent DE 698,867, public domain.

Fig. C.17: European Patent Office, German patent DE 698,867, public domain.

Fig. C.18: European Patent Office, German patent DE 698,867, public domain.

Fig. C.19: European Patent Office, German patent DE 698,867, public domain.

Fig. C.20: European Patent Office, German patent DE 698,867, public domain.

Fig. C.21: European Patent Office, German patent DE 698,867, public domain.

Fig. C.22: David Bleecker [NARA RG 165, Entry NM84-79, Box 1916, PW Intelligence Bulletin 2/32, 30 January 1945].

Fig. C.23: David Bleecker [NARA RG 165, Entry NM84-79, Box 1916, PW Intelligence Bulletin 2/32, 30 January 1945].

Fig. C.24: Todd Rider [AFHRA A5730, frames 0488–0492].

Fig. C.25: Todd Rider [AFHRA A5730, frames 0488–0492].

Fig. C.26: Todd Rider [AFHRA A5730, frames 0488–0492].

Fig. C.27: Todd Rider [AFHRA A5730, frames 0488–0492].

Fig. C.28: Todd Rider [AFHRA A5730, frames 0488–0492].

Fig. C.29: Manuel Lukas [NARA RG 242, Copies of Research Materials on the Role of the German Air Force in World War II, Microfilm 15, Frames 305–310. https://catalog.archives.gov/id/316278533?objectPage=465].

Fig. C.30: Manuel Lukas [NARA RG 242, Copies of Research Materials on the Role of the German Air Force in World War II, Microfilm 15, Frames 305–310. https://catalog.archives.gov/id/316278533?objectPage=465].

Fig. C.31: Manuel Lukas [NARA RG 242, Copies of Research Materials on the Role of the German Air Force in World War II, Microfilm 15, Frames 305–310. https://catalog.archives.gov/id/316278533?objectPage=465].

Fig. C.32: Manuel Lukas [NARA RG 242, Copies of Research Materials on the Role of the German Air Force in World War II, Microfilm 15, Frames 305–310. https://catalog.archives.gov/id/316278533?objectPage=465].

Fig. C.33: Manuel Lukas [NARA RG 242, Copies of Research Materials on the Role of the German Air Force in World War II, Microfilm 15, Frames 305–310. https://catalog.archives.gov/id/316278533?objectPage=465].

Fig. C.34: Manuel Lukas [NARA RG 242, Copies of Research Materials on the Role of the German Air Force in World War II, Microfilm 15, Frames 305–310. https://catalog.archives.gov/id/316278533?objectPage=465].

Fig. C.35: Todd Rider [NARA RG 319 Entry NM3-82A, Box 6, Folder ALSOS G-20].

Fig. C.36: Todd Rider [NARA RG 319 Entry NM3-82A, Box 6, Folder ALSOS G-20].

Fig. C.37: Todd Rider [NARA RG 319 Entry NM3-82A, Box 6, Folder ALSOS G-20].

Fig. C.38: Todd Rider [NARA RG 319 Entry NM3-82A, Box 6, Folder ALSOS G-20].

Fig. C.39: Todd Rider [NARA RG 319 Entry NM3-82A, Box 6, Folder ALSOS G-20].

Fig. C.40: Todd Rider [BIOS 1730].

Fig. C.41: Todd Rider [BIOS 1730].

Fig. C.42: Todd Rider [BIOS 1730].

Fig. C.43: U.S. government, commons.wikimedia.org, and public domain.

Fig. C.44: Rudolf Kollath and Gerhard Schumann. 1947. Untersuchungen an einem 15-MV-Betatron. *Zeitschrift für Naturforschung* 2a:634–642 [http://zfn.mpdl.mpg.de/data/Reihe_A/2/ZNA-1947-2a-0634.pdf].

Fig. C.45: Todd Rider [NARA RG 77, Entry UD-22A, Box 167, Folder 32.12-2 GERMANY: Personnel (Jan 45–Dec 45)].

Fig. C.46: U.S. government and public domain.

Fig. C.47: *Verhandlungen der Deutschen Physikalischen Gesellschaft* (1916) 18:13–14:318–323.

Fig. C.48: *Mitteilungen der Physikalischen Gesellschaft Zürich* (1916) 18:47–62.

Fig. C.49: *Zeitschrift für Physik* (1923) 20:1:145–152.

Fig. C.50: *Handbuch der Physik* (1926) 23:641–775].

Fig. C.51: *Zeitschrift für Physik* (1928) 48:1–2:15–25.

Fig. C.52: *Zeitschrift für Physik* (1928) 48:1–2:26–50.

Fig. C.53: *Zeitschrift für Physik* (1928) 48:1–2:51–61.

Fig. C.54: *Zeitschrift für Physik* (1928) 48:3–4:192–204.

Fig. C.55: *Zeitschrift für Physik* (1930) 65:3–4:167–188.

Fig. C.56: *Zeitschrift für Physik* (1930) 65:3–4:189–206.

Fig. C.57: *Zeitschrift für Physikalische Chemie* (1928) 139:1:375–385.

Fig. C.58: *Zeitschrift für Physik* (1930) 63:9–10:616–633.

Fig. C.59: *Zeitschrift für Physik* (1930) 63:9–10:634–639.

Fig. C.60: *Zeitschrift für Physik* (1932) 79:1–2:42–61.

Fig. C.61: *Zeitschrift für Physik* (1933) 83:3–4:234–246.

Fig. C.62: *Zeitschrift für Physik* (1933) 85:5–6:366–372.

Fig. C.63: U.S. Patent and Trademark Office, public domain.

Fig. C.64: U.S. Patent and Trademark Office, public domain.

Fig. C.65: U.S. Patent and Trademark Office, public domain.

Fig. C.66: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.67: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.68: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.69: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.70: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.71: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.72: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.73: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.74: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.75: Todd Rider [NARA RG 319, Entry NM3-82A, Box 6, Folder G3].

Fig. C.76: public domain.

Fig. C.77: public domain.

Fig. C.78: public domain.

Fig. C.79: Todd Rider.

Fig. C.80: public domain.

Fig. C.81: European Patent Office, German patent DE2308071, public domain.

Fig. C.82: European Patent Office, German patent DE2308071, public domain.

Fig. C.83: European Patent Office, German patent DE2308071, public domain.

Fig. C.84: European Patent Office, German patent DE2308071, public domain.

Fig. C.85: European Patent Office, German patent DE2308071, public domain.

Fig. C.86: European Patent Office, German patent DE2308071, public domain.

Fig. C.87: European Patent Office, German patent DE2308071, public domain.

Fig. C.88: European Patent Office, German patent DE2308071, public domain.

Fig. C.89: Todd Rider [BIOS 1504].

Fig. C.90: Todd Rider [BIOS 1504].

Fig. C.91: Todd Rider [BIOS 1504].

Fig. C.92: Todd Rider [BIOS 1504].

Fig. C.93: Todd Rider [BIOS 609].

Fig. C.94: Todd Rider [BIOS 1679].

Fig. C.95: Todd Rider [BIOS 1679].

Fig. C.96: Todd Rider [CIOS XXXII-77].

Fig. C.97: Todd Rider [CIOS XXXII-77].

Fig. C.98: Todd Rider [CIOS XXXII-77].

Fig. C.99: Todd Rider [CIOS XXXII-77].

Fig. C.100: Todd Rider [CIOS XXXII-77].

Fig. C.101: U.S. government, commons.wikimedia.org, and public domain.

Fig. C.102: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.103: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.104: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.105: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.106: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.107: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.108: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.109: U.S. Patent and Trademark Office, U.S. patent 782,312, public domain.

Fig. C.110: European Patent Office, German patent DE643316, public domain.

Fig. C.111: European Patent Office, German patent DE643316, public domain.

Fig. C.112: European Patent Office, German patent DE643316, public domain.

Fig. C.113: European Patent Office, German patent DE643316, public domain.

Fig. C.114: European Patent Office, German patent DE643316, public domain.

Fig. C.115: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.116: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.117: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.118: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.119: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.120: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.121: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.122: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.123: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.124: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.125: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.126: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.127: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.128: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.129: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.130: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.131: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.132: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.133: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.134: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.135: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.136: Todd Rider [NARA RG 319, Entry NME-82A, Box 15, Folders OB-27 and OB-28].

Fig. C.137: English translation of French intelligence reports from February 1944 [Witkowski 2010, pp. 129–131, and 2013, pp. 93–94].

Fig. C.138: English translation of French intelligence reports from February 1944 [Witkowski 2010, pp. 129–131, and 2013, pp. 93–94].

Fig. C.139: English translation of French intelligence reports from February 1944 [Witkowski 2010, pp. 129–131, and 2013, pp. 93–94].

Fig. C.140 U.S. government and public domain.

Fig. D.1: Todd Rider [NARA RG 226, Entry A1-134, Box 219, Folder 1371: OUT AZUSA Nov. '43 Sept. '45].

Fig. D.2: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.7002 GERMANY—ALSOS MISSION ∗ Administrative Matters (1940–1945)].

Fig. D.3: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.7002 GERMANY—ALSOS MISSION ∗ Administrative Matters (1940–1945)].

Fig. D.4: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.7002 GERMANY—ALSOS MISSION ∗ Administrative Matters (1940–1945)].

Fig. D.5: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.7002 GERMANY—ALSOS MISSION ∗ Administrative Matters (1940–1945)].

Fig. D.6: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.7002 GERMANY—ALSOS MISSION ∗ Administrative Matters (1940–1945)].

Fig. D.7: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.7002 GERMANY—ALSOS MISSION ∗ Administrative Matters (1940–1945)].

Fig. D.8: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.9: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.10: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.11: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-3 GERMANY: US Wartime Positive Int. (Nov. 44–June 45)].

Fig. D.12: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder APR–Dec. '45].

Fig. D.13: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.7002 GERMANY—ALSOS MISSION ∗ Administrative Matters (1940–1945)].

Fig. D.14: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.15: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.16: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.17: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.18: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.19: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1 GERMANY—Research—TA—(1943–June 1946)].

Fig. D.20: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 202.2 LONDON OFFICE: Combined Intell Disc.].

Fig. D.21: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 202.2 LONDON OFFICE: Combined Intell Disc.].

Fig. D.22: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.24-2 GERMANY: Research—Res. Inst. & other Facilities (May 45–Dec 46)].

Fig. D.23: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.24: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder British–U.S. Relations on Atomic Energy Intelligence (War Period) to 8 Oct 1945].

Fig. D.25: Todd Rider [NARA RG GOUDS, Entry UD-7420, Box 6, Folder Rosbaud].

Fig. D.26: Norberto Lahuerta [Goudsmit 1945].

Fig. D.27: Norberto Lahuerta [Goudsmit 1945].

Fig. D.28: Norberto Lahuerta [Goudsmit 1945].

Fig. D.29: Norberto Lahuerta [Goudsmit 1945].

Fig. D.30: Norberto Lahuerta [Goudsmit 1945].

Fig. D.31: Norberto Lahuerta [Goudsmit 1945].

Fig. D.32: Todd Rider [NARA RG GOUDS, Entry UD-7420, Box 6, Folder Alsos Mission].

Fig. D.33: Todd Rider [NARA RG GOUDS, Entry UD-7420, Box 6, Folder Alsos Mission].

Fig. D.34: Todd Rider [NARA RG GOUDS, Entry UD-7420, Box 6, Folder Alsos Mission].

Fig. D.35: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1 GERMANY—Research—TA—(1943–June 1946), Henry Lowenhaupt to Major Mattina, 11 May 1946].

Fig. D.36: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.37: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.38: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.39: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.40: [Pash 1969, frontispiece].

Fig. D.41: Todd Rider [NARA RG 77, Entry UD-22A, Box 167, Folder 202.3-2 LONDON OFFICE: Combined Oper Ger Group].

Fig. D.42: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder 205.3 Cables Outgoing, Secret and Under January 1946 thru December 1946].

Fig. D.43: Otto Hahn and Fritz Strassmann. January 1939. Über den Nachweis und das Verhalten der bei der Bestrahlung des Urans mittels Neutronen entstehenden Erdalkalimetalle. *Die Naturwissenschaften* 27:11–15.

Fig. D.44: Todd Rider [NARA RG GOUDS, Entry UD-7420, Box 6, Folder ALSOS—Reports and Operations].

Fig. D.45: Siegfried Flügge. Kann der Energieinhalt der Atomkerne technisch nutzbar gemacht werden? *Die Naturwissenschaften* 27:402–410. 9 June 1939. [https://digital.deutsches-museum.de/item/FA-002-746

Fig. D.46: Siegfried Flügge. Kann der Energieinhalt der Atomkerne technisch nutzbar gemacht werden? *Die Naturwissenschaften* 27:402–410. 9 June 1939. [https://digital.deutsches-museum.de/item/FA-002-746

Fig. D.47: Siegfried Flügge. Kann der Energieinhalt der Atomkerne technisch nutzbar gemacht werden? *Die Naturwissenschaften* 27:402–410. 9 June 1939. [https://digital.deutsches-museum.de/item/FA-002-746

Fig. D.48: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.49: Bundesarchiv Lichterfelde, NS 19-2012.

Fig. D.50: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.51: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.52: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.53: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.54: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.55: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.56: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.57: Todd Rider [NARA RG 319, Entry NM3-82A, Box 5, Folder Documents from which ALSOS reports were made].

Fig. D.58: Manuel Lukas [NARA RG 242, Records of the Reich Leader of the Schutzstaffel (SS) and Chief of the German Police, Microfilm 183, NAID 273992206 (https://catalog.archives.gov/id/273992206)].

Fig. D.59: NARA RG 238, Microfilm M1270, Interrogation Records Prepared for War Crimes Proceedings at Nuernberg, Roll 24.

Fig. D.60: NARA RG 238, Microfilm M1270, Interrogation Records Prepared for War Crimes Proceedings at Nuernberg, Roll 24.

Fig. D.61: NARA RG 238, Microfilm M1270, Interrogation Records Prepared for War Crimes Proceedings at Nuernberg, Roll 24.

Fig. D.62: NARA RG 238, Microfilm M1270, Interrogation Records Prepared for War Crimes Proceedings at Nuernberg, Roll 24.

Fig. D.63: NARA RG 238, Microfilm M1270, Interrogation Records Prepared for War Crimes Proceedings at Nuernberg, Roll 24.

Fig. D.64: commons.wikimedia.org and public domain.

Fig. D.65: Todd Rider.

Fig. D.66: Todd Rider.

Fig. D.67: Todd Rider [NARA RG 77, Entry UD-22A, Box 173, Folder 57.70. Poland Misc].

Fig. D.68: Google Earth, courtesy of Gernot Eilers.

Fig. D.69: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder APR 45—Dec. '45].

Fig. D.70: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder APR 45–Dec. '45].

Fig. D.71: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.32. Germ. Incl. TA].

Fig. D.72: Deutsches Museum Archive [G-32].

Fig. D.73: Deutsches Museum Archive [G-33].

Fig. D.74: Deutsches Museum Archive [G-33].

Fig. D.75: Deutsches Museum Archive [G-33].

Fig. D.76: Deutsches Museum Archive [G-28].

Fig. D.77: Deutsches Museum Archive [G-28].

Fig. D.78: Deutsches Museum Archive [G-28].

Fig. D.79: Deutsches Museum Archive [G-28].

Fig. D.80: Deutsches Museum Archive [G-157].

Fig. D.81: Deutsches Museum Archive [G-157].

Fig. D.82: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin No 1/34, 5 February 1945, pp. 9–11].

Fig. D.83: David Bleecker [NARA RG 165, Entry NM84-79, Box 1915, PW Intelligence Bulletin No 1/34, 5 February 1945, pp. 9–11].

Fig. D.84: Georg Bredig. 1895. Ueber den Einfluss der Zentrifugalkraft auf chemische Systeme. *Zeitschrift für Physikalische Chemie A* 17:459. https://doi.org/10.1515/zpch-1895-1726

Fig. D.85: Georg Bredig and Fritz Haber. 1904. Prinzipien der Gasscheidung durch Zentrifugalkraft. *Zeitschrift für Angewandte Chemie* 17:452. https://doi.org/10.1002/ange.19040171503

Fig. D.86: Helmuth Hausen and R. Schlatterer. 1939. Aussichten der Zerlegung von Gasgemischen durch Zentrifugieren. *Z. VDI Beiheft Verfahrenstechnik* 1939:1:15–21.

Fig. D.87: Helmuth Hausen. 1942. Zerlegung von Gasgemischen in einer Zentrifuge mit Gegenstromwirkung. *Z. VDI Beiheft Verfahrenstechnik* 1942:4:93–102.

Fig. D.88: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.89: European Patent Office, German Patent DE 833,487, public domain.

Fig. D.90: European Patent Office, German Patent DE 833,487, public domain.

Fig. D.91: European Patent Office, German Patent DE 872,936, public domain.

Fig. D.92: European Patent Office, German Patent DE 906,094, public domain.

Fig. D.93: European Patent Office, German Patent DE 906,094, public domain.

Fig. D.94: European Patent Office, German Patent DE 906,094, public domain.

Fig. D.95: European Patent Office, German Patent DE 906,094, public domain.

Fig. D.96: *Zeitschrift für Physikalische Chemie A* (1941) 189:219–316.

Fig. D.97: *Zeitschrift für Physikalische Chemie A* (1941) 189:317–326.

Fig. D.98: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-2 GERMANY: US Wartime Positive Int. (July–Oct. 44)].

Fig. D.99: Deutsches Museum Archive [G-331].

Fig. D.100: Deutsches Museum Archive [G-331].

Fig. D.101: European Patent Office, public domain.

Fig. D.102: European Patent Office, public domain.

Fig. D.103: European Patent Office, public domain.

Fig. D.104: European Patent Office, public domain.

Fig. D.105: Deutsches Museum Archive FA 002/811. http://digital.deutsches-museum.de/item/FA-002-811/

Fig. D.106: Deutsches Museum Archive FA 002/811. http://digital.deutsches-museum.de/item/FA-002-811/

Fig. D.107: Deutsches Museum Archive FA 002/811. http://digital.deutsches-museum.de/item/FA-002-811/

Fig. D.108: Deutsches Museum Archive FA 002/811. http://digital.deutsches-museum.de/item/FA-002-811/

Fig. D.109: Deutsches Museum Archive FA 002/811. http://digital.deutsches-museum.de/item/FA-002-811/

Fig. D.110: Deutsches Museum Archive FA 002/811. http://digital.deutsches-museum.de/item/FA-002-811/

Fig. D.111: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1 GERMANY—Research—TA—(1943–June 1946), CIOS ER 318].

Fig. D.112: NARA RG 227, Microfilm M1392, Bush-Conant File Relating to the Development of the Atomic Bomb, https://downloads.paperlessarchives.com, pp. 6084–6089.

Fig. D.113: NARA RG 227, Microfilm M1392, Bush-Conant File Relating to the Development of the Atomic Bomb, https://downloads.paperlessarchives.com, pp. 6084–6089.

Fig. D.114: NARA RG 227, Microfilm M1392, Bush-Conant File Relating to the Development of the Atomic Bomb, https://downloads.paperlessarchives.com, pp. 6084–6089.

Fig. D.115: Todd Rider [BIOS 1487].

Fig. D.116: Todd Rider [BIOS 1487].

Fig. D.117: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1 GERMANY—Research—TA—(1943–June 1946)].

Fig. D.118: [G-139].

Fig. D.119: [G-139].

Fig. D.120: [G-139].

Fig. D.121: [G-139].

Fig. D.122: [G-139].

Fig. D.123: [G-139].

Fig. D.124: [G-139].

Fig. D.125: [G-139].

Fig. D.126: Rainer Karlsch.

Fig. D.127: Rainer Karlsch.

Fig. D.128: Rainer Karlsch.

Fig. D.129: Rainer Karlsch.

Fig. D.130: Rainer Karlsch.

Fig. D.131: Rainer Karlsch.

Fig. D.132: Rainer Karlsch.

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Fig. D.137: Rainer Karlsch.

Fig. D.138: Rainer Karlsch.

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Fig. D.144: Rainer Karlsch.

Fig. D.145: Rainer Karlsch.

Fig. D.146: Rainer Karlsch.

Fig. D.147: Rainer Karlsch.

Fig. D.148: Todd Rider and Annette Gowin.

Fig. D.149: Todd Rider [FIAT Rev: *Nuclear Physics and Cosmic Rays* Vol. II, pp. 80–10].

Fig. D.150: Todd Rider [FIAT Rev: *Nuclear Physics and Cosmic Rays* Vol. II, pp. 80–10].

Fig. D.151: Todd Rider [FIAT Rev: *Nuclear Physics and Cosmic Rays* Vol. II, pp. 80–10].

Fig. D.152: Todd Rider [FIAT Rev: *Nuclear Physics and Cosmic Rays* Vol. II, pp. 80–10].

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Fig. D.159: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-1 GERMANY: US Wartime Positive Int. (July 42–June 44)].

Fig. D.160: U.S. Patent and Trademark Office, U.S. patent 1,486,521, public domain.

Fig. D.161: U.S. Patent and Trademark Office, U.S. patent 1,486,521, public domain.

Fig. D.162: U.S. Patent and Trademark Office, U.S. patent 1,486,521, public domain.

Fig. D.163: U.S. Patent and Trademark Office, U.S. patent 1,498,097, public domain.

Fig. D.164: U.S. Patent and Trademark Office, U.S. patent 1,498,097, public domain.

Fig. D.165: European Patent Office, Austrian Patent AT 107,571, public domain.

Fig. D.166: European Patent Office, Austrian Patent AT 107,571, public domain.

Fig. D.167: European Patent Office, Austrian Patent AT 107,571, public domain.

Fig. D.168: U.S. government [https://s3.documentcloud.org/documents/22799707/reed-manufacture-at-the-metallweberei-neustadtorla-vvb-tewa.pdf].

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Fig. D.173: commons.wikimedia.org and public domain.

Fig. D.174: European Patent Office, French Patent FR 881,316, public domain.

Fig. D.175: European Patent Office, French Patent FR 881,316, public domain.

Fig. D.176: European Patent Office, French Patent FR 881,316, public domain.

Fig. D.177: European Patent Office, French Patent FR 881,316, public domain.

Fig. D.178: European Patent Office, French Patent FR 881,316, public domain.

Fig. D.179: European Patent Office, French Patent FR 881,316, public domain.

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Fig. D.181: Deutsches Museum Archive [G-124; G-202].

Fig. D.182: Deutsches Museum Archive FA 002/782. https://digital.deutsches-museum.de/item/FA-002-782/

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Fig. D.190: Todd Rider.

Fig. D.191: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-2 GERMANY: US Wartime Positive Int. (July–October 1944)].

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Fig. D.199: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. D.200: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-3 GERMANY: US Wartime Positive Int. (Nov. 44–June 45)].

Fig. D.201: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

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Fig. D.205: Todd Rider [NARA RG 226, Entry A1-134, Box 219, Folder IN AZUSA Nov. '43 Sept. '45].

Fig. D.206: Todd Rider [AFHRA A5183 frames 0497–0504].

Fig. D.207: Todd Rider [AFHRA A5183 frames 0497–0504].

Fig. D.208: Jaroslav Mareš [SOkA Příbram, Elektrifikace—1944, AM Příbram—S, inv. č. 1001].

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Fig. D.210: Jaroslav Mareš [Národní archiv, Ústřední výbor KSČ, Klement Gottwald, sv. 81, aj. 1031, courtesy of Jaroslav Mareš].

Fig. D.211: AFHRA, courtesy of Gunther Hebestreit.

Fig. D.212: Jaroslav Mareš.

Fig. D.213: Jaroslav Mareš.

Fig. D.214: Jaroslav Mareš.

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Fig. D.216: Jaroslav Mareš.

Fig. D.217: U.S. government, public domain [www.archives.gov/publications/prologue/2007/winter/stechovice.html].

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Fig. D.223: Jaroslav Mareš [Archiv Bezpečnostních Složek. File 304_81_5].

Fig. D.224: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder 205.4 Cables Outgoing, Top Secret].

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Fig. D.226: Adam Kretschmer [Czech National Archive].

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Fig. D.230: Adam Kretschmer [Czech National Archive].

Fig. D.231: Adam Kretschmer [Czech National Archive].

Fig. D.232: Todd Rider [AFHRA A5415 frame 284].

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Fig. D.234: Ida Noddack. 1934. Über das Element 93. *Angewandte Chemie.* 47:37:653–655.

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Fig. D.241: Deutsches Museum Archive [G-59].

Fig. D.242: Deutsches Museum Archive [G-94].

Fig. D.243: Deutsches Museum Archive [G-94].

Fig. D.244: Deutsches Museum Archive [G-94].

Fig. D.245: Deutsches Museum Archive [G-94].

Fig. D.246: Deutsches Museum Archive [G-94].

Fig. D.247: Deutsches Museum Archive [G-94].

Fig. D.248: Deutsches Museum Archive [G-94].

Fig. D.249: Deutsches Museum Archive [G-94].

Fig. D.250: Todd Rider [NARA RG 77, Entry UD-22A, Box 167, Folder 32.12-2 GERMANY: Personnel (Jan 45–Dec 45)].

Fig. D.251: Todd Rider [NARA RG 77, Entry UD-22A, Box 167, Folder 32.12-2 GERMANY: Personnel (Jan 45–Dec 45)].

Fig. D.252: Todd Rider [NARA RG 77, Entry UD-22A, Box 167, Folder 32.12-2 GERMANY: Personnel (Jan 45–Dec 45)].

Fig. D.253: Todd Rider [NARA RG 77, Entry UD-22A, Box 173, Folder 60.22-1 RUSSIA: Research—TA (43–Jun 46)].

Fig. D.254: Todd Rider [NARA RG 77, Entry UD-22A, Box 163, Folder Australia].

Fig. D.255: Todd Rider [NARA RG 77, Entry UD-22A, Box 163, Folder Australia].

Fig. D.256: Todd Rider.

Fig. D.257: Deutsches Museum Archive [G-371].

Fig. D.258: Deutsches Museum Archive [G-371].

Fig. D.259: Deutsches Museum Archive [G-371].

Fig. D.260: Todd Rider.

Fig. D.261: U.S. government, public domain.

Fig. D.262: Todd Rider.

Fig. D.263: Todd Rider.

Fig. D.264: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1—GERMANY—Research—TA—(1943–June 1946)].

Fig. D.265: Günter Nagel.

Fig. D.266: Günter Nagel.

Fig. D.267: Todd Rider [Bundesarchiv Militärarchiv Freiburg N 822/13].

Fig. D.268: Todd Rider.

Fig. D.269: Todd Rider.

Fig. D.270: Todd Rider.

Fig. D.271: Todd Rider.

Fig. D.272: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.32. Germ. Incl. TA].

Fig. D.273: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.32. Germ. Incl. TA].

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Fig. D.285: https://thebulletin.org/2021/08/rebranding-chernobyl/ and
https://www.oxfordmail.co.uk/news/14780388.decommissioning-harwell-nuclear-site-mired-controversy-high-court-ruling/

Fig. D.286: https://www.energy.gov/em/articles/crews-begin-pre-demolition-work-lawrence-livermore-national-laboratory-reactor

Fig. D.287: AFHRA, courtesy of Gunther Hebestreit.

Fig. D.288: AFHRA, courtesy of Gunther Hebestreit.

Fig. D.289: Rudolf Haunschmied and Todd Rider.

Fig. D.290: Sammlung Franz Jakob, courtesy of Andreas Sulzer.

Fig. D.291: Sammlung Franz Jakob, courtesy of Andreas Sulzer.

Fig. D.292: Sammlung Franz Jakob, courtesy of Andreas Sulzer.

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Fig. D.295: Sammlung Franz Jakob, courtesy of Andreas Sulzer.

Fig. D.296: Sammlung Franz Jakob, courtesy of Andreas Sulzer.

Fig. D.297: [AFHRA C5098 electronic version p. 925].

Fig. D.298: [AFHRA C5098 electronic version p. 923].

Fig. D.299: Todd Rider.

Fig. D.300: Top: commons.wikimedia.org. Bottom: Rudolf Haunschmied.

Fig. D.301: Rudolf Haunschmied.

Fig. D.302: Rudolf Haunschmied.

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Fig. D.304: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-3 GERMANY: US Wartime Positive Int. (Nov. 44–June 45)].

Fig. D.305: Todd Rider [AFHRA B1763 frames 0004–0034].

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Fig. D.308: Todd Rider [AFHRA B1763 frames 0004–0034].

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Fig. D.319: CIOS XXVIII-31.

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Fig. D.321: CIOS XXVIII-31.

Fig. D.322: CIOS XXVIII-31.

Fig. D.323: CIOS XXVIII-31.

Fig. D.324: CIOS XXVIII-31.

Fig. D.325: CIOS XXVIII-31.

Fig. D.326: CIOS XXVIII-31.

Fig. D.327: CIOS XXVIII-31.

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Fig. D.333: Jaroslav Mareš [Vojenský historický archiv, Vědecký technický ústav 1945–1946, kart. 1].

Fig. D.334: Jaroslav Mareš [Vojenský historický archiv, Vědecký technický ústav 1945–1946, kart. 1].

Fig. D.335: Jaroslav Mareš [Vojenský historický archiv, Vědecký technický ústav 1945–1946, kart. 1].

Fig. D.336: Jaroslav Mareš [Vojenský historický archiv, Vědecký technický ústav 1945–1946, kart. 1].

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Fig. D.338: Todd Rider.

Fig. D.339: Lori Rider.

Fig. D.340: Lori Rider.

Fig. D.341: Lori Rider.

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Fig. D.348: Norberto Lahuerta [NARA RG 319, Entry NM3-85M, Box 51, Folders 926136–926139].

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Fig. D.356: Todd Rider [FIAT 295].

Fig. D.357: Todd Rider [FIAT 750].

Fig. D.358: Todd Rider [BIOS 158].

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Fig. D.360: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.32 Germ. Incl. TA].

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Fig. D.386: Todd Rider.

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Fig. D.402: Rainer Karlsch.

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Fig. D.410: [Diebner 1962].

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Fig. D.416: European Patent Office, U.K. Patent GB 508,233, public domain.

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Fig. D.418: U.S. Patent and Trademark Office, U.S. patent 2,251,190, public domain.

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Fig. D.427: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder 32.32. Germ. Incl. TA].

Fig. D.428: Manuel Lukas [Technical Oil Mission Microfilm 119 (BM-6—Ludwigshaven), Folder LU III-2. https://www.fischer-tropsch.org/Tom%20Reels/Linked/TOM%20119%20Partial/TOC_TOM-119.htm].

Fig. D.429: Manuel Lukas [Technical Oil Mission Microfilm 119 (BM-6—Ludwigshaven), Folder LU III-2. https://www.fischer-tropsch.org/Tom%20Reels/Linked/TOM%20119%20Partial/TOC_TOM-119.htm].

Fig. D.430: Manuel Lukas [Technical Oil Mission Microfilm 119 (BM-6—Ludwigshaven), Folder LU III-2. https://www.fischer-tropsch.org/Tom%20Reels/Linked/TOM%20119%20Partial/TOC_TOM-119.htm].

Fig. D.431: Manuel Lukas [Technical Oil Mission Microfilm 119 (BM-6—Ludwigshaven), Folder LU III-2. https://www.fischer-tropsch.org/Tom%20Reels/Linked/TOM%20119%20Partial/TOC_TOM-119.htm].

Fig. D.432: Manuel Lukas [Technical Oil Mission Microfilm 119 (BM-6—Ludwigshaven), Folder LU III-2. https://www.fischer-tropsch.org/Tom%20Reels/Linked/TOM%20119%20Partial/TOC_TOM-119.htm].

Fig. D.433: Manuel Lukas [Technical Oil Mission Microfilm 119 (BM-6—Ludwigshaven), Folder LU III-2. https://www.fischer-tropsch.org/Tom%20Reels/Linked/TOM%20119%20Partial/TOC_TOM-119.htm].

Fig. D.434: Todd Rider [NARA RG 38, Entry 98C, Box 11, Folder TSC # 3001–3100. NARA RG 319, Entry A1-134A, Box 31, Folder 02/006 430.].

Fig. D.435: Todd Rider [NARA RG 319, Entry A1-134B, Box 749, Folder 23 Nov 95 Georg Stetter XA001081. NARA RG 330, Entry A1-1B, Box 103, Folder Lintner, Karl.].

Fig. D.436: Rainer Karlsch.

Fig. D.437: Todd Rider [NARA RG 77, Entry UD-22A, Box 167, Folder 32.12-2 GERMANY: Personnel (Jan 45–Dec 45)].

Fig. D.438: *Zeitschrift für Naturforschung.* 2a:245–249 (1947). [https://doi.org/10.17617/3.GRUJYR].

Fig. D.439: Todd Rider collection.

Fig. D.440: Frank Doebert [TNA FO 1031/57].

Fig. D.441: Frank Doebert [TNA FO 1031/57].

Fig. D.442: Top: [Diebner 1962]. Bottom: [Winterberg 1981].

Fig. D.443: [Winterberg 1981].

Fig. D.444: Courtesy of Deutsches Museum Archive, NL 080/270-66, final page.

Fig. D.445: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.446: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.447: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.448: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.449: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.450: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.451: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.452: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.453: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.454: Todd Rider [NARA RG 330, Entry A1-1B, Box 134, Folder Richter, Ronald W. Dr.].

Fig. D.455: commons.wikimedia.org and Norberto Lahuerta.

Fig. D.456: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-2 GERMANY: US Wartime Positive Int. (July–Oct. 44)].

Fig. D.457: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-2 GERMANY: US Wartime Positive Int. (July–Oct. 44)].

Fig. D.458: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.7003-2 GERMANY: US Wartime Positive Int. (July–Oct. 44)].

Fig. D.459: Todd Rider [NARA RG 330, Entry A1-1B, Box 35, Folder Edse, Rudolf] and https://www.geni.com/people/Rudolf-Zinsser/6000000016349874663.

Fig. D.460: Todd Rider [AFHRA Folder 533.619-5 1945].

Fig. D.461: Todd Rider [AFHRA Folder 533.619-5 1945].

Fig. D.462: Todd Rider [AFHRA Folder 533.619-5 1945].

Fig. D.463: Todd Rider [AFHRA Folder 533.619-5 1945].

Fig. D.464: Todd Rider [AFHRA Folder 533.619-5 1945].

Fig. D.465: Todd Rider [AFHRA Folder 533.619-5 1945].

Fig. D.466: U.S. government and public domain.

Fig. D.467: Todd Rider [AFHRA A5186 frames 0023–0027].

Fig. D.468: Todd Rider [AFHRA A5186 frames 0023–0027].

Fig. D.469: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.470: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.471: U.S. government, public domain, courtesy of Marek Michalski.

Fig. D.472: commons.wikimedia.org and public domain.

Fig. D.473: commons.wikimedia.org and public domain.

Fig. D.474: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 37, courtesy of Rainer Karlsch.

Fig. D.475: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 37, courtesy of Rainer Karlsch.

Fig. D.476: Courtesy of Deutsches Museum Archive, photo CD74787.

Fig. D.477: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 37, courtesy of Rainer Karlsch.

Fig. D.478: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 37, courtesy of Rainer Karlsch.

Fig. D.479: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 37, courtesy of Rainer Karlsch.

Fig. D.480: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 37, courtesy of Rainer Karlsch.

Fig. D.481: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 24–25, courtesy of Rainer Karlsch and Heiko Petermann.

Fig. D.482: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 24–25, courtesy of Rainer Karlsch and Heiko Petermann.

Fig. D.483: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 24–25, courtesy of Rainer Karlsch and Heiko Petermann.

Fig. D.484: Archive of the President of the Russian Federation, Fund 93, Division 81 (45), List 24–25, courtesy of Rainer Karlsch and Heiko Petermann.

Fig. D.485: commons.wikimedia.org and public domain.

Fig. D.486: commons.wikimedia.org.

Fig. D.487: Lori Rider.

Fig. D.488: commons.wikimedia.org.

Fig. D.489: Todd Rider.

Fig. D.490: commons.wikimedia.org.

Fig. D.491: Todd Rider.

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Fig. D.494: commons.wikimedia.org.

Fig. D.495: Archive of the President of the Russian Federation, Fund 93, Division 77 (45), List 4–11 [Riabev 2006c, pp. 60–64].

Fig. D.496: Archive of the President of the Russian Federation, Fund 93, Division 77 (45), List 4–11 [Riabev 2006c, pp. 60–64].

Fig. D.497: Archive of the President of the Russian Federation, Fund 93, Division 77 (45), List 4–11 [Riabev 2006c, pp. 60–64].

Fig. D.498: Archive of the President of the Russian Federation, Fund 93, Division 77 (45), List 4–11 [Riabev 2006c, pp. 60–64].

Fig. D.499: Todd Rider [NARA RG 77, Entry UD-22A, Box 174, Folder 10.70 Austria Misc].

Fig. D.500: Archive of the President of the Russian Federation, courtesy of Rainer Karlsch.

Fig. D.501: U.S. government, public domain, via Gunther Hebestreit.

Fig. D.502: U.S. government, public domain, via Gunther Hebestreit.

Fig. D.503: U.S. government, public domain, via Gunther Hebestreit.

Fig. D.504: U.S. government, public domain, via Gunther Hebestreit.

Fig. D.505: U.S. government, public domain, via Gunther Hebestreit.

Fig. D.506: Todd Rider.

Fig. D.507: Todd Rider.

Fig. D.508: Todd Rider.

Fig. D.509: Heiko Petermann.

Fig. D.510: Lori Rider.

Fig. D.511: [Ziegert 2011].

Fig. D.512: U.S. Holocaust Memorial Museum, public domain.

Fig. D.513: Lori Rider.

Fig. D.514: Todd Rider collection.

Fig. D.515: Todd Rider.

Fig. D.516: U.S. government, commons.wikimedia.org, and public domain.

Fig. D.517: commons.wikimedia.org.

Fig. D.518: commons.wikimedia.org.

Fig. D.519: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1—GERMANY—Research—TA—(1943–June 1946)].

Fig. D.520: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1—GERMANY—Research—TA—(1943–June 1946)].

Fig. D.521: [Weingand 1995, pp. 60–61; https://diglib.tugraz.at/die-technische-hochschule-graz-im-dritten-reich-1995].

Fig. D.522: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. D.523: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. D.524: NARA RG 227, Microfilm M1392, Bush-Conant File Relating to the Development of the Atomic Bomb, https://downloads.paperlessarchives.com, pp. 11,357–11,361.

Fig. D.525: NARA RG 227, Microfilm M1392, Bush-Conant File Relating to the Development of the Atomic Bomb, https://downloads.paperlessarchives.com, pp. 11,357–11,361.

Fig. D.526: Norberto Lahuerta [Franklin Delano Roosevelt Library, Hyde Park, New York, Margaret Suckley Papers, Journal Group E, 06/30/1944-12/29/1944, Journal Entry 1-253, 9 December 1944].

Fig. D.527: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 Germany: Summary Reports (1945–1946)].

Fig. D.528: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 Germany: Summary Reports (1945–1946)].

Fig. D.529: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.530: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.531: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.532: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.533: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.534: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.535: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 203.11—Tech. Countermeasures + RW—1943–1944].

Fig. D.536: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.537: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 203.11—Tech. Countermeasures + RW—1943–1944].

Fig. D.538: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.539: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.540: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.541: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.542: Todd Rider [NARA RG 77, Entry UD-22A, Box 170, Folder 32.60-1 GERMANY: Summary Reports (1944)].

Fig. D.543: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.544: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 203.11—Tech. Countermeasures + RW—1943–1944].

Fig. D.545: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 203.11—Tech. Countermeasures + RW—1943–1944].

Fig. D.546: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 203.11—Tech. Countermeasures + RW—1943–1944].

Fig. D.547: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 203.11—Tech. Countermeasures + RW—1943–1944].

Fig. D.548: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 Germany: Summary Reports (1945–1946)].

Fig. D.549: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 Germany: Summary Reports (1945–1946)].

Fig. D.550: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 Germany: Summary Reports (1945–1946)].

Fig. D.551: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 Germany: Summary Reports (1945–1946)].

Fig. D.552: Todd Rider [NARA RG GOUDS, Entry UD-7420].

Fig. D.553: Todd Rider [NARA RG GOUDS, Entry UD-7420].

Fig. D.554: Todd Rider [NARA RG GOUDS, Entry UD-7420].

Fig. D.555: Todd Rider [NARA RG GOUDS, Entry UD-7420].

Fig. D.556: Todd Rider [NARA RG GOUDS, Entry UD-7420].

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Fig. D.558: Todd Rider [NARA RG GOUDS, Entry UD-7420].

Fig. D.559: Todd Rider [NARA RG GOUDS, Entry UD-7420].

Fig. D.560: Todd Rider [FIAT 63].

Fig. D.561: Todd Rider [FIAT 63].

Fig. D.562: Todd Rider [NARA RG 319, Entry A1-134B, Box 749, Folder 23 Nov 95 Georg Stetter XA001081].

Fig. D.563: Todd Rider [NARA RG 319, Entry A1-134B, Box 749, Folder 23 Nov 95 Georg Stetter XA001081].

Fig. D.564: Todd Rider [NARA RG 319, Entry A1-134B, Box 749, Folder 23 Nov 95 Georg Stetter XA001081].

Fig. D.565: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 202.2 LONDON OFFICE: Combined Intell Disc.].

Fig. D.566: Norberto Lahuerta [TNA FO 800/565, Henry Maitland Wilson to John Anderson, 26 October 1945].

Fig. D.567: Norberto Lahuerta [TNA FO 800/565, Henry Maitland Wilson to John Anderson, 26 October 1945].

Fig. D.568: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.569: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.570: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.571: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.572: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.573: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.574: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.575: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.576: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.577: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.578: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.579: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.580: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.581: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.582: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.583: Todd Rider [NARA RG 77, Entry UD-22A].

Fig. D.584: courtesy of Norberto Lahuerta.

Fig. D.585: Todd Rider [NARA RG 77, Entry UD-22A, Box 169, Folder British Liason].

Fig. D.586: Todd Rider [NARA RG GOUDS, Entry UD-7420, Box 3].

Fig. D.587: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. D.588: Archives of the French Army Ministry of Defense, courtesy of Norberto Lahuerta.

Fig. D.589: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.590: U.S. government, public domain.

Fig. D.591: Todd Rider [NARA RG 38, Entry UD-16, Box 4, Folder Manifest of U-234].

Fig. D.592: Todd Rider [NARA RG 38, Entry UD-38, Box 13, Folder U-234 and RG 330, Entry A1-1B, Box 145, Folder Schlicke, Heinz].

Fig. D.593: Todd Rider [NARA Boston RG 181].

Fig. D.594: Todd Rider [NARA Boston RG 181].

Fig. D.595: Manuel Lukas [NARA RG 242, Records of the Reich Leader of the Schutzstaffel (SS) and Chief of the German Police, Microfilm 183, NAID 273992206 (https://catalog.archives.gov/id/273992206)].

Fig. D.596: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder Apr 45—Dec. '45].

Fig. D.597: Norberto Lahuerta [NARA RG 238, Entry NM70-160, Box 26, Folder: Hq—FIFTEENTH USA Reports—TIC-PIR / Interr. Kaltenbrunner].

Fig. D.598: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 196, Folder XE061504 Fiebinger, Karl].

Fig. D.599: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 196, Folder XE061504 Fiebinger, Karl].

Fig. D.600: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 196, Folder XE061504 Fiebinger, Karl].

Fig. D.601: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.602: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.603: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.604: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.605: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.606: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.607: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.608: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.609: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.610: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.611: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.612: Manuel Lukas [NARA RG 319, Entry A1-134B, Box 831, Folder XE065651 Voss, Wilhelm].

Fig. D.613: Todd Rider [NARA RG 77, Entry UD-22A, Box 166, Folder 32.22-1 GERMANY—Research—TA—(1943–June 1946)].

Fig. D.614: Courtesy of Rainer Karlsch; published in Reuter et al. 2019, p. 168.

Fig. D.615: Manuel Lukas [https://digital.library.cornell.edu/catalog/nur01453].

Fig. D.616: Manuel Lukas [https://digital.library.cornell.edu/catalog/nur01453].

Fig. D.617: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.618: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.619: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.620: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.621: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.622: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.623: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.624: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.625: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.626: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.627: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.628: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.629: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.630: George Cully [AFHRA folder 570.605 1944–46, Misc. Documents G-2 Miscellaneous Data].

Fig. D.631: Tom Kunkle [NARA RG 260, DN1929, Roll 0126, pp. 26 ff.].

Fig. D.632: Tom Kunkle [NARA RG 260, DN1929, Roll 0126, pp. 26 ff.].

Fig. D.633: Todd Rider [AFHRA folder 570.6501A 1945–46, Special Projects—Current].

Fig. D.634: Tammy Horton [AFHRA C5098 frames 0886–0890].

Fig. D.635: Tammy Horton [AFHRA 00043922 SQ-BOMB-34-HI 1–31 July 1945].

Fig. D.636: Tammy Horton [AFHRA 00043922 SQ-BOMB-34-HI 1–31 July 1945].

Fig. D.637: Tammy Horton [AFHRA 00043922 SQ-BOMB-34-HI 1–31 July 1945].

Fig. D.638: Rudolf Haunschmied.

Fig. D.639: U.S. Holocaust Memorial Museum, public domain.

Fig. D.640: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder APR 45–Dec. '45].

Fig. D.641: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder APR 45–Dec. '45].

Fig. D.642: U.S. Holocaust Memorial Museum, public domain.

Fig. D.643: Todd Rider.

Fig. D.644: commons.wikimedia.org and public domain.

Fig. D.645: Todd Rider [NARA RG 38, Entry 98C, Box 12, Folder TSC # 3301–3400. Vladimir L. Rychly, 5 December 1946].

Fig. D.646: PB 123064. *Underground Installations: Foreign Installations* [Library of Congress].

Fig. D.647: PB 123064. *Underground Installations: Foreign Installations* [Library of Congress].

Fig. D.648: PB 123064. *Underground Installations: Foreign Installations* [Library of Congress].

Fig. D.649: PB 123064. *Underground Installations: Foreign Installations* [Library of Congress].

Fig. D.650: PB 123064. *Underground Installations: Foreign Installations* [Library of Congress].

Fig. D.651: PB 123064. *Underground Installations: Foreign Installations* [Library of Congress].

Fig. D.652: Todd Rider [NARA RG 330, Entry A1-1B].

Fig. D.653: Todd Rider [NARA RG 330, Entry A1-1B, Box 66].

Fig. D.654: Todd Rider [NARA RG 330, Entry A1-1B, Box 43, Folder Flügge, Siegfried].

Fig. D.655: Todd Rider [NARA RG 319, Entry A1-134B, Box 202, Folder XE196681 Siegfried Fluegge].

Fig. D.656: Todd Rider [NARA RG 319, Entry A1-134B, Box 202, Folder XE196681 Siegfried Fluegge].

Fig. D.657: Todd Rider [NARA RG 319, Entry A1-134B, Box 202, Folder XE196681 Siegfried Fluegge].

Fig. D.658: Todd Rider [NARA RG 77, Entry UD-22A, Box 167, Folder 202.3-2 LONDON OFFICE: Combined Oper Ger Group].

Fig. D.659: Todd Rider [NARA RG 319, Entry A1-134B, Box 202, Folder XE196681 Siegfried Fluegge].

Fig. D.660: Todd Rider [NARA RG 319, Entry A1-134B, Box 202, Folder XE196681 Siegfried Fluegge].

Fig. D.661: Todd Rider [NARA RG 319, Entry A1-134B, Box 202, Folder XE196681 Siegfried Fluegge].

Fig. D.662: Todd Rider [AFHRA A2055 Frames 1173, 1362].

Fig. D.663: Frank Doebert [AFHRA C5094 frames 0957–0958].

Fig. D.664: Manuel Lukas [AFHRA A5183 frames 0346, 0609].

Fig. D.665: Norberto Lahuerta [NARA RG 40, Entry 75, Box 62].

Fig. D.666: Todd Rider [NARA RG 226, Entry A1-134, Box 219, Folder 1371: OUT AZUSA Nov. '43 Sept. '45].

Fig. D.667: Todd Rider [NARA RG 77, Entry UD-22A, Box 168, Folder 202.2 LONDON OFFICE: Combined Intell Disc.].

Fig. D.668: Todd Rider [NARA RG 77, Entry UD-22A, Box 160, Folder Apr 45–Dec. '45].

Fig. D.669: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.670: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.671: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.672: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.673: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.674: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.675: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.676: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.677: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.678: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.679: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.680: [Princeton University Library, Special Collections, Moe Berg Papers (C1413), Box 20, Folder 3—Loose Notes: Central Intelligence Agency].

Fig. D.681: Todd Rider [NARA RG 77, Entry UD-22A, Box 163, Folder Czechoslovakia].

Fig. D.682: Todd Rider [NARA RG 40, Entry UD-75, Box 3, Folder Press Releases].

Fig. D.683: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.684: Todd Rider [NARA RG 77, Entry UD-22A, Box 171, Folder 32.60-2 GERMANY: Summary Reports (1945–1946)].

Fig. D.685: Woods 1946.

Fig. D.686: Todd Rider [NARA RG 319, Entry A1-84E, Box 124].

Fig. D.687: Todd Rider [NARA RG 319, Entry A1-84E, Box 124].

Fig. D.688: Todd Rider.

Fig. D.689: Todd Rider.

Fig. D.690: Todd Rider.

Fig. D.691: Todd Rider.

Fig. D.692: Todd Rider.

Fig. D.693: Todd Rider.

Fig. D.694: Todd Rider.

Fig. D.695: Todd Rider.

Fig. D.696: Manhattan District History. Book I, Volume 12, Part 1, p. 12.5.
https://ia803409.us.archive.org/14/items/ManhattanDistrictHistory/MDH-B1V12P01-General-CEW_Central_Facilities.pdf

Fig. D.697: Manhattan District History. Book I, Volume 12, Part 2, Appendix C-7.
https://ia803409.us.archive.org/14/items/ManhattanDistrictHistory/MDH-B1V12P02-General-CEW_Central_Facilities_Appendices_A-C.pdf

Fig. D.698: Todd Rider.

Fig. D.699: Todd Rider.

Fig. D.700: Todd Rider.

Fig. D.701: U.S. government, commons.wikimedia.org, and public domain.

Fig. D.702: https://commons.wikimedia.org/wiki/File:Fat_Man_Internal_Components.png

Fig. E.1: commons.wikimedia.org and public domain.

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Fig. E.3: commons.wikimedia.org and public domain.

Fig. E.4: commons.wikimedia.org and public domain.

Fig. E.5: commons.wikimedia.org and public domain.

Fig. E.6: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1942–1943, MC019.09_c44.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c44].

Fig. E.7: *Life*, 27 August 1945.

Fig. E.8: *Life*, 27 August 1945.

Fig. E.9: U.S. Army, public domain.

Fig. E.10: U.S. Army, public domain.

Fig. E.11: commons.wikimedia.org.

Fig. E.12: commons.wikimedia.org.

Fig. E.13: Frank Doebert.

Fig. E.14: Frank Doebert.

Fig. E.15: commons.wikimedia.org.

Fig. E.16: Todd Rider [Newton 1946].

Fig. E.17: Todd Rider [Newton 1946].

Fig. E.18: commons.wikimedia.org and public domain.

Fig. E.19: FOIA: Operation Harass and the Horton [sic: Horten] Brothers. Control Number: FP-10-027542. Activity Number: FA-10-4911. Initial Reception Date: 7/13/2010. Requested by: Jacobsen, Annie. pp. 202–205 and 318–325. [documents.theblackvault.com/documents/foia/4402F-12Greenewald_Redacted.pdf]

Fig. E.20: FOIA: Operation Harass and the Horton [sic: Horten] Brothers. Control Number: FP-10-027542. Activity Number: FA-10-4911. Initial Reception Date: 7/13/2010. Requested by: Jacobsen, Annie. pp. 202–205 and 318–325. [documents.theblackvault.com/documents/foia/4402F-12Greenewald_Redacted.pdf]

Fig. E.21: FOIA: Operation Harass and the Horton [sic: Horten] Brothers. Control Number: FP-10-027542. Activity Number: FA-10-4911. Initial Reception Date: 7/13/2010. Requested by: Jacobsen, Annie. pp. 202–205 and 318–325. [documents.theblackvault.com/documents/foia/4402F-12Greenewald_Redacted.pdf]

Fig. E.22: FOIA: Operation Harass and the Horton [sic: Horten] Brothers. Control Number: FP-10-027542. Activity Number: FA-10-4911. Initial Reception Date: 7/13/2010. Requested by: Jacobsen, Annie. pp. 202–205 and 318–325. [documents.theblackvault.com/documents/foia/4402F-12Greenewald_Redacted.pdf]

Fig. E.23: Courtesy of Deutsches Museum Archive, photo 9664.

Fig. E.24: Historisch-Technisches Museum Versuchsstelle Kummersdorf.

Fig. E.25: Todd Rider.

Fig. E.26: Todd Rider.

Fig. E.27: Todd Rider.

Fig. E.28: commons.wikimedia.org and public domain.

Fig. E.29: Historisch-Technisches Museum Peenemünde, commons.wikimedia.org, and public domain.

Fig. E.30: Todd Rider.

Fig. E.31: Todd Rider.

Fig. E.32: Todd Rider.

Fig. E.33: Public domain.

Fig. E.34: commons.wikimedia.org.

Fig. E.35: [Przybilski 2002a].

Fig. E.36: U.S. government, public domain [heroicrelics.org/info/v-2/a-4-combustion-chamber.html].

Fig. E.37: Courtesy of Deutsches Museum Archive, photo 32307.

Fig. E.38: Michael Haupt [TNA AVIA 40/717]. See also Henshall 2000, p. 123.

Fig. E.39: Todd Rider.

Fig. E.40: Todd Rider.

Fig. E.41: U.S. government, public domain.

Fig. E.42: U.S. government, public domain.

Fig. E.43: U.S. government, public domain.

Fig. E.44: Todd Rider.

Fig. E.45: Todd Rider.

Fig. E.46: Todd Rider.

Fig. E.47: U.S. government, public domain.

Fig. E.48: commons.wikimedia.org.

Fig. E.49: Frank Doebert [Zeitgeschichte Museum Ebensee, copy of original in Deutsches Museum Archive].

Fig. E.50: U.S. government, public domain.

Fig. E.51: commons.wikimedia.org.

Fig. E.52: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.53: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.54: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.55: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.56: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.57: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.58: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.59: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.60: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.61: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.62: Todd Rider [PW Intelligence Bulletin No 1/57. 12 April 1945. AFHRA A5185 frames 1029–1047].

Fig. E.63: Courtesy of Deutsches Museum Archive, photo CD61663.

Fig. E.64: U.S. government, public domain.

Fig. E.65: Todd Rider [NARA RG 38, Entry 98C, Box 3, Folder TSC #1001–1100].

Fig. E.66: Todd Rider [AFHRA A5734 frame 1369].

Fig. E.67 Top: Norberto Lahuerta. Bottom: Lori Rider.

Fig. E.68: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1942–1943, MC019.09_c44.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c44].

Fig. E.69: Todd Rider [Princeton University Library, Allen Dulles Papers, Series 4, Subseries 4K: Telegrams d'etat, 1942–1945, 1942–1943, MC019.09_c44.pdf, https://findingaids.princeton.edu/catalog/MC019-09_c44].

Fig. E.70: Todd Rider [AFHRA A5417 electronic p. 970].

Fig. E.71: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. E.72: Todd Rider [NARA RG 77, Entry UD-22A, Box 165, Folder ALSOS MATERIAL].

Fig. E.73: Todd Rider [AFHRA A5729 electronic version p. 289].

Fig. E.74: U.S. government, public domain, courtesy of Friedrich Georg.

Fig. E.75: U.S. government, public domain, courtesy of Friedrich Georg.

Fig. E.76: Todd Rider [NARA RG 407, Entry NM3-427, Box 12365, Folder 604-2.3 (1688-4) G-2 Jrnl File 4th Armd Div. 7–8 Apr 45].

Fig. E.77: [Gordon Cooper 1960].

Fig. E.78: Todd Rider.

Fig. E.79: Todd Rider.

Fig. E.80: commons.wikimedia.org/

Fig. E.81: Todd Rider [NARA RG 407, Entry NM3-427, Box 11005, Folder 389-2.2 G-2 Jrnl File—89th Inf Div. 8–9 Apr 45].

Fig. E.82: U.S. government, public domain, courtesy of Dietmar Staude and Tobias Keidel.

Fig. E.83: Todd Rider [NARA RG 407, Entry NM3-427, Box 11005, Folder 389-2.2 G-2 Jrnl File—89th Inf Div. 8–9 Apr 45].

Fig. E.84: Todd Rider [NARA RG 407, Entry NM3-427, Box 12365, Folder 604-2.3 (1688-4) G-2 Jrnl File 4th Armd Div. 7–8 Apr 45].

Fig. E.85: Todd Rider [NARA RG 407, Entry NM3-427, Box 11005, Folder 389-2.2 G-2 Jrnl File—89th Inf Div. 8–9 Apr 45].

Fig. E.86: Todd Rider [NARA RG 407, Entry NM3-427, Box 11005, Folder 389-2.2 G-2 Jrnl File—89th Inf Div. 8–9 Apr 45].

Fig. E.87: Todd Rider [AFHRA A5729 frame 1573].

Fig. E.88: NASA, public domain.

Fig. E.89: Gordon James Brown and the family of Heinz Stoelzel.

Fig. E.90: Gordon James Brown and the family of Heinz Stoelzel.

Fig. E.91: Gordon James Brown and the family of Heinz Stoelzel.

Fig. E.92: Gordon James Brown and the family of Heinz Stoelzel.

Fig. E.93: http://epizodsspace.airbase.ru/bibl/k-r/1998/5/fau2.html.

Fig. E.94: U.S. government, public domain.

Fig. E.95: U.S. government, public domain.

Fig. E.96: Collection Rudolf A. Haunschmied, from St. Georgen an der Gusen train station.

Fig. E.97: Todd Rider [NARA RG 331, Entry 83D, Box 33, Folder S.H.A.E.F. Releases (2 folders)/ 1 June 20 June 45].

Fig. E.98: Stephen Walton [CIOS XXXII-125].

Fig. E.99: Stephen Walton [CIOS XXXII-125].

Fig. E.100: Stephen Walton [CIOS XXXII-125].

Fig. E.101: Stephen Walton [CIOS XXXII-125].

Fig. E.102: Stephen Walton [CIOS XXXII-125].

Fig. E.103: Stephen Walton [CIOS XXXII-125].

Fig. E.104: Stephen Walton [CIOS XXXII-125].

Fig. E.105: Stephen Walton [CIOS XXXII-125].

Fig. E.106: Stephen Walton [CIOS XXXII-125].

Fig. E.107: Stephen Walton [CIOS XXXII-125].

Fig. E.108: Stephen Walton [CIOS XXXII-125].

Fig. E.109: Stephen Walton [CIOS XXXII-125].

Fig. E.110: Todd Rider [CIOS XXVIII-56].

Fig. E.111: Todd Rider [CIOS XXVIII-56].

Fig. E.112: Todd Rider [CIOS XXVIII-56].

Fig. E.113: Todd Rider [CIOS XXVIII-56].

Fig. E.114: Todd Rider [CIOS XXVIII-56].

Fig. E.115: Todd Rider [CIOS XXVIII-56].

Fig. E.116: Todd Rider [CIOS XXVIII-56].

Fig. E.117: Todd Rider [CIOS XXVIII-56].

Fig. E.118: Todd Rider [CIOS XXVIII-56].

Fig. E.119: Todd Rider [NavTechMisEu 237-45, NARA RG 38, Entry P5, Box 38].

Fig. E.120: Todd Rider [NavTechMisEu 237-45, NARA RG 38, Entry P5, Box 38].

Fig. E.121: Todd Rider [NavTechMisEu 237-45, NARA RG 38, Entry P5, Box 38].

Fig. E.122: Todd Rider [NavTechMisEu 237-45, NARA RG 38, Entry P5, Box 38].

Fig. E.123: Todd Rider [NavTechMisEu 237-45, NARA RG 38, Entry P5, Box 38].

Fig. E.124: Todd Rider [NavTechMisEu 237-45, NARA RG 38, Entry P5, Box 38].

Fig. E.125: Todd Rider [AFHRA A5186 frame 0965].

Fig. E.126: Todd Rider [AFHRA A5186 frame 0966].

Fig. E.127: https://www.gracesguide.co.uk/images/6/6d/ImILN12071946_003.jpg.

Fig. E.128: Archives of the French Army Ministry of Defense, courtesy of Norberto Lahuerta.

Fig. E.129: *Life*, 15 November 1945.

Fig. E.130: *Life*, 15 November 1945.

Fig. E.131: *Life*, 15 November 1945.

Fig. E.132: *Life*, 15 November 1945.

Fig. E.133: Todd Rider [AFHRA C5098 electronic version p. 523].

Fig. E.134: Todd Rider [NARA RG 319, Records of the Army Staff, Entry A1-84E, Box 124. BID 8600.0711 Nuclear Physics (Atomic Energy)—Uses—Rockets].

Fig. E.135: Norberto Lahuerta [NARA RG 319, Entry NM3-85M, Box 47, Folder 926087 (former SD-3676)].

Fig. E.136: Norberto Lahuerta [NARA RG 319, Entry NM3-85M, Box 47, Folder 926087 (former SD-3676)].

Fig. E.137: commons.wikimedia.org.

Fig. E.138: commons.wikimedia.org.

Fig. E.139: *Life*, 5 October 1959, p. 30.
https://books.google.com/books?id=rkwEAAAAMBAJ&pg=PA30#v=onepage&q&f=false

Fig. E.140: Todd Rider [NARA RG 319, Entry NM3-85M, Box 19, Folder 925253].

Fig. E.141: Todd Rider [NARA RG 319, Entry NM3-85M, Box 19, Folder 925253].

Fig. E.142: Todd Rider.

Fig. E.143: Todd Rider.

Fig. E.144: Todd Rider [NARA RG 319, Entry NM3-85M, Box 19, Folder 925253].

Fig. E.145: Todd Rider [NARA RG 319, Entry NM3-85M, Box 19, Folder 925253].

Fig. E.146: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.147: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.148: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.149: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.150: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.151: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.152: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.153: Todd Rider [NARA RG 38, Entry 98C, Box 9, Folder TSC # 2601–2700].

Fig. E.154: Todd Rider [NARA RG 38, Entry 98C, Box 10, Folder TSC # 2801–2900].

Fig. E.155: Todd Rider [NARA RG 38, Entry 98C, Box 10, Folder TSC # 2801–2900].

Fig. E.156: Todd Rider [NARA RG 38, Entry 98C, Box 10, Folder TSC # 2801–2900].

Fig. E.157: Todd Rider [NARA RG 38, Entry 98C, Box 10, Folder TSC # 2801–2900].

Fig. E.158: Norberto Lahuerta [NARA RG 319, Entry NM3-85M, Box 44, Folder 926047].

Fig. E.159: Norberto Lahuerta [NARA RG 319, Entry NM3-85A, Box 2138, Folder 326051 to 326060].

Fig. E.160: Todd Rider [NARA RG 77, Entry UD-22A, Box 175, Folder World].

Fig. E.161: Norberto Lahuerta [NARA NARA RG 77, Entry UD-22A, Box 175, Folder World; and RG 319, Entry NM3-85A, Box 2229, Folder 339171 to 339180].

Fig. E.162: Norberto Lahuerta [NARA NARA RG 77, Entry UD-22A, Box 175, Folder World; and RG 319, Entry NM3-85A, Box 2229, Folder 339171 to 339180].

Fig. E.163: https://www.cia.gov/readingroom/document/cia-rdp83-00415r003100040008-4

Fig. E.164: https://www.cia.gov/readingroom/document/cia-rdp83-00415r003100040008-4

Fig. E.165: Norberto Lahuerta [NARA RG 319, Entry NM3-82, Box 2899, Folder Project 3837].

Fig. E.166: http://www.astronautix.com/g/g-2.html.

Fig. E.167: Adapted from https://commons.wikimedia.org/wiki/User:H_A_A.

Fig. E.168: Adapted from https://commons.wikimedia.org/wiki/File:Cold_war_europe_military_alliances_map.png.

Fig. E.169: Left: Archives of the French Army Ministry of Defense, in Jürgen Michels 1997, p. 278.
Right: http://www.astronautix.com/s/superv-2.html.

Fig. E.170: http://www.luft46.com/misc/sanger.html.

Fig. E.171: U.S. government, public domain [Saenger and Bredt 1944, English translation].

Fig. E.172: U.S. government, public domain [Saenger and Bredt 1944, English translation].

Fig. E.173: U.S. government, public domain [Saenger and Bredt 1944, English translation].

Fig. E.174: Courtesy of Deutsches Museum Archive, photo 30394.

Fig. E.175: Courtesy of Deutsches Museum Archive, photo 30391.

Fig. E.176: U.S. government, public domain [Saenger and Bredt 1944, English translation].

Fig. E.177: U.S. government, public domain [Saenger and Bredt 1944, English translation].

Fig. E.178: Courtesy of Deutsches Museum Archive, photo CD56143.

Fig. E.179: Norberto Lahuerta.

Fig. E.180: U.S. government, public domain [Robert Godwin 2003, pp. 38–51].

Fig. E.181: U.S. government, public domain [Robert Godwin 2003, pp. 38–51].

Fig. E.182: U.S. government, public domain [Robert Godwin 2003, pp. 38–51].

Fig. E.183: U.S. government, public domain [Robert Godwin 2003, pp. 38–51].

Fig. E.184: Norberto Lahuerta [Franklin Delano Roosevelt Library, Map Room Files, Box 164, Folder Naval Aides. Files: A/16—General Correspondence].

Fig. E.185: U.S. government, public domain.

Fig. E.186: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.187: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.188: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.189: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.190: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.191: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.192: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.193: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.194: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/369].

Fig. E.195: Todd Rider [NavTecMisEu 500-45].

Fig. E.196: Todd Rider [NavTecMisEu 500-45].

Fig. E.197: Todd Rider [NavTecMisEu 500-45].

Fig. E.198: Todd Rider [NavTecMisEu 500-45].

Fig. E.199: Todd Rider [NavTecMisEu 500-45].

Fig. E.200: Todd Rider [NavTecMisEu 500-45].

Fig. E.201: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.202: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.203: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.204: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.205: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.206: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.207: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.208: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.209: Todd Rider [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

Fig. E.210: commons.wikimedia.org.

Fig. E.211: U.S. government, public domain [http://www.cv41.org/photos/gallery3/index.php/op/opsandy].

Fig. E.212: commons.wikimedia.org.

Fig. E.213: Todd Rider [BIOS 1110, p. 10].

Fig. E.214: [Benecke and Quick 1957, pp. 254–255].

Fig. E.215: Todd Rider [NARA RG 319, Entry NM3-82 A, Box 14, Folder OB-3].

Fig. E.216: Todd Rider [NARA RG 319, Entry NM3-82 A, Box 14, Folder OB-3].

Fig. E.217: Todd Rider [NARA RG 319, Entry NM3-82 A, Box 14, Folder OB-3].

Fig. E.218: Czech National Archive (Prague), courtesy of Andreas Sulzer.

Fig. E.219: Czech National Archive (Prague), courtesy of Andreas Sulzer.

Fig. E.220: Czech National Archive (Prague), courtesy of Andreas Sulzer.

Fig. E.221: Courtesy of Deutsches Museum Archive, photo 30389.

Fig. E.222: Norberto Lahuerta [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945].

Fig. E.223: Norberto Lahuerta [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945].

Fig. E.224: Norberto Lahuerta [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945].

Fig. E.225: Norberto Lahuerta [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945].

Fig. E.226: Norberto Lahuerta [NARA RG 319, Entry NM3-47B, Box 991, Folder 400. 112 Research/009. 14 May 1945].

Fig. E.227: U.S. Patent and Trademark Office, public domain.

Fig. E.228: U.S. Patent and Trademark Office, public domain.

Fig. E.229: U.S. Patent and Trademark Office, public domain.

Fig. E.230: U.S. Patent and Trademark Office, public domain.

Fig. E.231: U.S. Patent and Trademark Office, public domain.

Fig. E.232: U.S. Patent and Trademark Office, public domain.

Fig. E.233: U.S. Patent and Trademark Office, public domain.

Fig. E.234: U.S. government, public domain.

Fig. E.235: U.S. Patent and Trademark Office, public domain.

Fig. E.236: U.S. Patent and Trademark Office, public domain.

Fig. E.237: U.S. Patent and Trademark Office, public domain.

Fig. E.238: U.S. Patent and Trademark Office, public domain.

Fig. E.239: U.S. Patent and Trademark Office, public domain.

Fig. E.240: U.S. Patent and Trademark Office, public domain.

Fig. E.241: U.S. Patent and Trademark Office, public domain.

Fig. E.242: U.S. government, public domain.

Fig. E.243: U.S. government, public domain.

Fig. E.244: U.S. government, public domain.

Fig. E.245: U.S. government, public domain.

Fig. E.246: [Hohmann 1925].

Fig. E.247: [Hohmann 1925].

Fig. E.248: [Hohmann 1925].

Fig. E.249: [Hohmann 1925].

Fig. E.250: [Noordung 1928].

Fig. E.251: [Noordung 1928].

Fig. E.252: [Noordung 1928].

Fig. E.253: [Noordung 1928].

Fig. E.254: Norberto Lahuerta [NARA RG 319, Entry NM3-82, Box 2899, Folder Project 3839].

Fig. E.255: Todd Rider [Peenemünde Archive, AHT0205].

Fig. E.256: Todd Rider [Peenemünde Archive, AHT0205].

Fig. E.257: Todd Rider.

Fig. E.258: Todd Rider.

Fig. E.259: Todd Rider.

Fig. E.260: Todd Rider.

Fig. E.261: Todd Rider.

p. 5847: Lori Rider.

About the Author

> About 1670, religious persecution caused [his father] to uproot his home and seek refuge at Frankenstein, and here Johann Konrad was born at the castle on 10 August 1673... With his flair for disputation he soon established a reputation for brilliance, which in its turn brought adulation from fellow-students and from tutors...
>
> About 1700, Dippel became interested in the oil obtained by the destructive distillation of animal parts... The oil came to be associated with the name of Dippel through his claim that in it he had discovered a universal medicine: a large part of his M.D. thesis (*Vitae animalis morbus et medicina suae vindicata origini*, 1711) is devoted to establishing this claim...
>
> Johann Konrad ceased to hope for either university or Church appointments, and removed himself to Berlin to follow an alchemical career... Further evidence about Dippel's relationships with other chemical workers emerges from the story of Prussian blue...
>
> The remainder of the old philosopher's life was lived out in comparative obscurity... As a guest of the Duke of Wittgenstein-Gützow, he was provided with a laboratory at Wittgenstein Castle... A last flamboyant gesture of fantasy in the face of reality was his prediction, a few months before his death, that he would live until 1808.

E. E. Aynsley and W. A. Campbell. 1962. Johann Konrad Dippel, 1673–1734. *Medical History* Vol. 6, No. 3, pp. 281–286.

Through reading about scientists such as Nikola Tesla, Albert Einstein, John von Neumann, Wernher von Braun, and Edward Teller, Todd Rider was inspired from an early age to pursue a career in scientific innovation, ultimately winning the Grand Prize at the 1986 International Science and Engineering Fair and filing his first patent application at age 17. He studied at MIT and Harvard 1986–1995, covering electrical engineering, nuclear engineering, mechanical and aerospace engineering, physics, biomedicine, chemistry, applied mathematics, and other areas, and received his Ph.D. in 1995. He headed the DNA sequencing program at the startup biotechnology company Aeiveos 1995–1996, became Senior Staff Scientist at MIT Lincoln Laboratory 1997–2013, and served as senior Laboratory Technical Staff at Draper Laboratory 2013–2015. In 2015 he founded the RIDER (Revolutionary Innovation, Discovery, Education, and Research) Institute.

During his career, Dr. Rider has invented a much more efficient rocket staging system and worked on antimatter rocket engine approaches; developed and tested methods of coherently combining multiple laser beams into a more powerful laser beam; discovered fundamental limitations on controlled fusion reactors; invented and demonstrated the CANARY rapid pathogen identifier; invented and developed the DRACO and PANACEA broad-spectrum antiviral therapeutics; and conducted research in various other areas. He has also worked to improve kindergarten through twelfth grade (K–12) science education, creating and running the MIT Science on Saturday program, writing educational guides for *Science News* magazine, judging state and national science fairs and competitions, and conducting presentations and hands-on lab activities on a wide range of science topics in K–12 classrooms in over 100 schools. Dr. Rider and his projects have been featured in *Science*, *Nature Biotechnology*, *Time*, *Scientific American*, *Technology Review*, *National Geographic*, *Der Spiegel*, the *New York Times*, *NBC Nightly News*, BBC, ZDF, Discovery Channel, and numerous other outlets. An inveterate acronym engineer, he has dubbed the work summarized in this book High-Yield Directed Research Approaches.

Zusammenfassung

Umwälzende wissenschaftliche Neuerungen scheint die Welt nicht länger in demselben Tempo wie früher hervorzubringen (was ganz offenkundig wird, wenn man das heutige Forschungspersonal oder die bereitgestellten Fördergelder nach revolutionären Innovationen bemisst). Statt sich an die grundsätzliche Lösung dieses systemischen Problems zu wagen, kann man genausogut untersuchen, was für Bedingungen zu anderen Zeiten und andernorts den Erfolg von Innovatoren begünstigten (Kapitel 1).

Erfindungen und Entdeckungen wurden überall und zu jeder Zeit gemacht—die größte Häufung an umwälzenden Neuerungen jedoch ist mit Wissenschaftlern und Ingenieuren verbunden, die im 19. und frühen 20. Jahrhundert in der vornehmlich deutschsprachigen Forschungslandschaft Mitteleuropas ausgebildet wurden. Durch den Ersten und Zweiten Weltkrieg, den Kalten Krieg, durch Sprachbarrieren und infolge kultureller Stereotypen verblaßte die Geschichte dieser Innovatoren und ihrer Neuerungen, so dass die moderne Welt kaum noch Einzelheiten kennt und wenig willens zu sein scheint, die Forschungsbedingungen, die einst zu so zahlreichen revolutionären Errungenschaften führten, nachzuahmen.

Die Ziele dieses Buches bestehen somit darin

- Aufklärung über die wichtigsten Schöpfer im deutschsprachigen Raum und deren Werke in verschiedenen Bereichen der Natur- und Ingenieurwissenschaften zu leisten (Kapitel 2–9),
- die systemischen Faktoren zu ermitteln, die in diesem Raum so zahlreiche revolutionäre Innovationen hervorbrachten (Kapitel 10),
- erfolgreiche, aber auch fehlgeschlagene Anläufe einer Übertragung des Wissens und der systemischen Faktoren auf andere Forschungslandschaften zu bewerten (Kapitel 11),
- Methoden vorzuschlagen, mithilfe derer heutige Regierungen, Organisationen und/oder Einzelpersonen dem Erfolg des früheren deutschsprachigen Forschungsraums besser nacheifern können (Kapitel 12).

Die Archivrecherchen für dieses Buch förderten darüber hinaus zahlreiche Dokumente zutage, die darauf hindeuten, dass die deutschen Forschungsprogramme zur Zeit des Zweiten Weltkrieges in den Bereichen Biotechnik, Mikroelektronik, Technik der Energiewaffen, Kernwaffen sowie Luft- und Raumfahrt viel fortgeschrittener waren als durch die heutige Geschichtsschreibung anerkannt wird, und dass diese Programme nach dem Krieg entsprechende Aktivitäten in anderen Ländern nach sich zogen (Anhänge A–E).

Und so, nachdem ich mir den Scherz erlaubt, dem eine Stelle zu gönnen in diesem durchweg zweideutigen Leben kaum irgend ein Blatt zu ernsthaft seyn kann, gebe ich mit innigem Ernst das Buch hin, in der Zuversicht, daß es früh oder spät Diejenigen erreichen wird, an welche es allein gerichtet seyn kann, und übrigens gelassen darin ergeben, daß auch ihm in vollem Maaße das Schicksal werde, welches in jeder Erkenntniß, also um so mehr in der wichtigsten, allezeit der Wahrheit zu Theil ward, der nur ein kurzes Siegesfest beschieden ist, zwischen den beiden langen Zeiträumen, wo sie als paradox verdammt und als trivial geringgeschätzt wird. Auch pflegt das erstere Schicksal ihren Urheber mitzutreffen.—Aber das Leben ist kurz und die Wahrheit wirkt ferne und lebt lange: sagen wir die Wahrheit.

Arthur Schopenhauer. 1819. *Die Welt als Wille und Vorstellung.* 1. Auflage. Leipzig.

Abstract

The world does not appear to be producing truly revolutionary scientific innovations at the same rate as it once did (certainly if measured in terms of revolutionary innovations per researcher or per amount of funding). Rather than trying to create solutions for this modern systemic problem from scratch, one may study what conditions facilitated the successes of innovators in other times and places (Chapter 1).

Inventions and discoveries have been made throughout the world and throughout history, yet the highest concentration of revolutionary innovations appears to have come from scientists and engineers who were trained in the predominantly German-speaking central European research world in the nineteenth and early twentieth centuries. Unfortunately, the history of those innovators and innovations has been significantly obscured by World Wars I and II, the Cold War, language barriers, and cultural stereotypes, leaving the modern world less aware of the details and less able to fully reproduce the research conditions that led to so many revolutionary achievements.

Therefore the objectives of this book are to:

- Elucidate the major creators and creations produced by that German-speaking world in various fields of science and engineering (Chapters 2–9).
- Determine the systemic factors that promoted so much revolutionary innovation in that particular place and time (Chapter 10).
- Evaluate the previous successes and failures of transferring that scientific knowledge and those systemic methods to other research systems (Chapter 11).
- Propose methods by which modern governments, organizations, and/or individuals could better emulate the success of the earlier German-speaking research world (Chapter 12).

Archival research for this book also yielded many documents that suggest that World War II German programs in biotechnology, microelectronics, directed energy technologies, nuclear weapons, and aerospace technologies progressed much further than has been acknowledged in conventional histories, and that they aided postwar programs in other countries (Appendices A–E).

And now that I have allowed myself the jest to which in this ambiguous life hardly any page can be too serious to grant a place, I part with the book with deep seriousness, in the sure hope that sooner or later it will reach those to whom alone it can be addressed; and for the rest, patiently resigned that the same fate should, in full measure, befall it, that in all ages has, to some extent, befallen all knowledge, and especially the weightiest knowledge of the truth, to which only a brief triumph is allotted between the two long periods in which it is condemned as paradoxical or disparaged as trivial. The former fate is also wont to befall its author.—But life is short, and truth works far and lives long: let us speak the truth.

Arthur Schopenhauer. 1819. *The World as Will and Representation.* 1st ed. Leipzig.