9.3 Jet Engines and Jet Aircraft

During the 1930s and early 1940s, German-speaking scientists and engineers developed the first practical jet engines (Section 9.3.1) and installed them in a wide variety of revolutionary aircraft (Section 9.3.2). After the war, experts, hardware, and designs from the German-speaking world spread those jet technologies around the world. That German expertise provided the modern world with jet-powered passenger planes, fighters, and bombers, as well as closely related gas turbine engines that are used in power plants and in land and sea vehicles.[8]

9.3.1 Jet Engines

A turbojet engine (Turbinen-Luftstrahltriebwerk or TL in German) is a type of gas turbine engine that forcibly sucks in air, burns it with fuel, extracts a little energy from the process (turbo for turbine) to power the air intake, and expels the rest of the energy out the back with a high-speed, high-temperature exhaust (jet). Because the exhaust has both a large mass flow rate and a large velocity, its new rearward momentum is large, and hence it imparts a large forward thrust force to the engine, potentially larger than the thrust of a comparable propeller engine. However, because so much of the combustion energy ends up as kinetic and thermal energy in the exhaust and not as new forward kinetic energy of the aircraft, at moderate flying speeds the energy (fuel) efficiency of a turbojet is much lower than that of a propeller engine. Figure 9.51 shows the components and idealized gas pressures and temperatures in a typical turbojet engine:

- The diffuser impedes the incoming flow to slow it down, converting the initial kinetic energy of the flow to increased pressure (potential energy) and temperature (thermal energy).

- Since passive stagnation effects only cause a small increase in pressure even at high subsonic speeds, turbojet engines include an active, powered compressor that forcibly raises the pressure (and temperature) of the flow, thereby preparing the air to burn more efficiently with fuel in the subsequent burner section. (The compressor can also be viewed as actively sucking air into the engine, even if the external air speed is negligible, as it is when the aircraft is first started.) Typical axial compressor designs use alternating rotating and stationary blades (rotors and stators) as shown in the figure to squeeze the air as it passes through.

[8] Amtmann 1988; Bohr 2013; Brix 2022; Butler 1994, 2007; Christensen 2002; Christopher 2013; Cole 2015; Conner 2001; Constant 1980; Cooke and Ingells 1945; Daso 2002; Diedrich 1999; Dorr 2013; Duffy 2012; Erfurth 2006; Forsyth and Creek 2007; Franz 1985; General Electric 1979; von Gersdorff et al. 2004; Gleichmann 2013; Gleichmann and Bock 2009; Griehl 1990, 2004, 2005; Griehl 2015; Gunston 2006a, 2006b; Herwig and Rode 2000, 2003; Hill and Peterson 1991; Hirschel et al. 2004; Hyland and Gill 1998; Jacobsen 2011, 2014; Jakobs et al. 2009; Johnsen 2014; Kay 2002; Kerrebrock 1992; Kober 1990; Leist and Wiening 1963; Leyes and Fleming 1999; Lichtfuss and Schubert 2014; Longden 2009; Masters 1982; Hans-Ulrich Meier 2010; Miranda 2015; Myhra 1998a, 1998b, 2000a; Nowarra 1988; Pavelec 2007; Samuel 2004, 2010; Schick and Meyer 1997; Shepelev and Ottens 2015; Simons 2016; Smith and Creek 1992, 2001; Smith and Kay 2002; Thomas 1946; Vajda and Dancey 1998; CIOS XXV-9, XXVI-27, XXVI-28, XXVI-29, XXVI-30, XXXII-41; *Air World* 1946; *Chicago Daily Tribune* 1945-06-29 p. 4; *Daily Telegraph* 1, 2, 5, 9 Oct. 1945, p. 4 each issue; *L.A. Times* 1945-06-29; NYT 1945-06-08, 1945-07-26 p. 6, 1948-04-15 p. 17, 1948-12-04 p. 3; *Washington Post* 1945-06-29.

- The burner or combustion chamber (combustor) burns the incoming air with a much smaller amount of fuel to raise the temperature of the flow as high as possible without melting the blades in the subsequent turbine section.

- The turbine must extract enough work energy out of the gas after the burner to put the necessary work energy into powering the compressor before the burner.

- The nozzle decreases the pressure of the flow until it reaches the ambient pressure of the external air, converting that initial high-pressure potential energy into kinetic energy to maximize the exhaust velocity.

- Optionally, an afterburner can add extra fuel to the air just before the nozzle. Burning that extra fuel raises the pressure entering the nozzle and hence the thrust force produced by the engine, albeit at the expense of consuming fuel even faster than a plain turbojet engine would.

While a turbojet is a very powerful and compact engine, the propulsive efficiency of a turbojet is relatively low at subsonic aircraft speeds, since the engine's exhaust velocity is so high. To raise the efficiency of a turbojet engine for subsonic travel, it can be directly coupled to a large fan for airplane flight (a turbofan), propeller blades for airplane flight (a turboprop), or rotor blades for helicopter flight (a turboshaft engine), as shown in Fig. 9.52.

In a turbofan or bypass engine (Zweistrom-Turbinen-Luftstrahltriebwerk or ZTL in German), the inlet air can pass either through a relatively conventional turbojet engine (sometimes called the hot flow since it is heated by combustion), or else through a large enclosed fan (sometimes called the cold flow since it does not experience combustion). The bypass ratio β is defined as the ratio of the mass flow rates in the cold and hot flows. Compared to a pure turbojet engine, more of the exhaust energy in this turbojet is extracted in the turbine and less in the nozzle, which decreases the hot flow exhaust velocity. Because the turbine extracts more energy, it can power not only the compressor for the hot flow, but also the fan for the cold flow. The fan may be an enlarged front compressor blade through which both hot and cold flows pass, or it may be a separate blade whose speed has been appropriately geared down from the main turbine shaft. As the cold flow is merely accelerated by a fan and not heated by combustion to high temperatures, its exhaust velocity is rather low. Thus both the hot and cold fractions of the flow have lower exhaust velocities than the exhaust of a simple turbojet, improving the propulsive efficiency of the engine and lowering the fuel consumption rate.

Whereas the fan of a turbofan engine can operate at high-subsonic and supersonic speeds, at lower subsonic speeds it may be replaced by an ordinary airplane propeller, further increasing the efficiency. The propeller is still driven by the turbine of a turbojet engine, so this variation is called a turboprop engine (Propeller-Turbinen-Luftstrahltriebwerk or PTL in German). A turbojet engine designed for this purpose extracts almost all of the available exhaust energy in the turbine and not the nozzle, in order to send as much power as possible to the propeller. The propeller typically has a much larger diameter than the compressor and turbine blades, yet its tips should not approach the speed of sound to avoid compressibility losses. Therefore, a gearbox usually gears down power transmitted from the turbine shaft to a separate propeller shaft that rotates ~ 15 times more slowly. Turboprop engines are basically turbofan engines with a very high bypass ratio ($\beta > 50$) so that the large majority of the thrust comes from the cold propeller flow and not the hot turbojet flow. Because of their efficiency, they are widely used to power small, low-subsonic-speed aircraft.

Just as the shaft power from a turbojet engine can be geared down to drive an airplane propeller, it can also be geared down to power a helicopter rotor. This variation is called a turboshaft engine. The power shaft may be taken from either the compressor end (as shown in the figure) or the turbine end. In addition to aerospace applications, turboshaft gas turbine engines make excellent power sources for other machines ranging from military tanks to submarines to electric power plants.

At supersonic speeds (say Mach $\sim$2–3), the pressure increase due to stagnation effects in the diffuser is so large that there is no need for an active compressor, and thus there is also no need for a turbine to power a compressor, as shown in Fig. 9.53. Under these conditions, with the moving parts inside a turbojet removed, the engine becomes a much simpler ramjet. To operate at hypersonic speeds (Mach 5 and higher), the interior contours of the engine can be modified to make it a supersonic combustion ramjet (scramjet). A ramjet engine can even be modified to operate at subsonic speeds where the stagnation compression is relatively small, becoming a pulsejet whose operation continually alternates between air intake and air combustion.

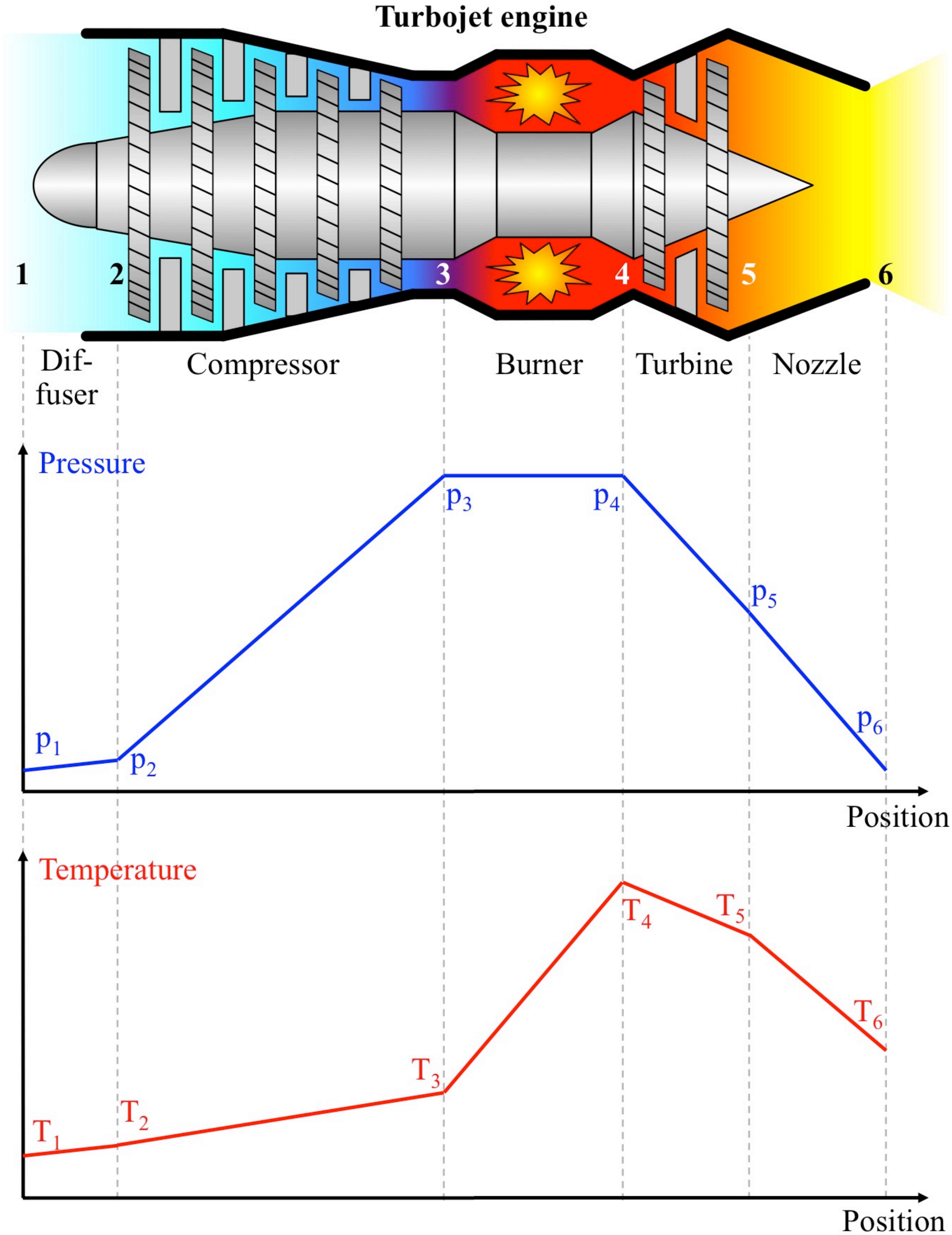
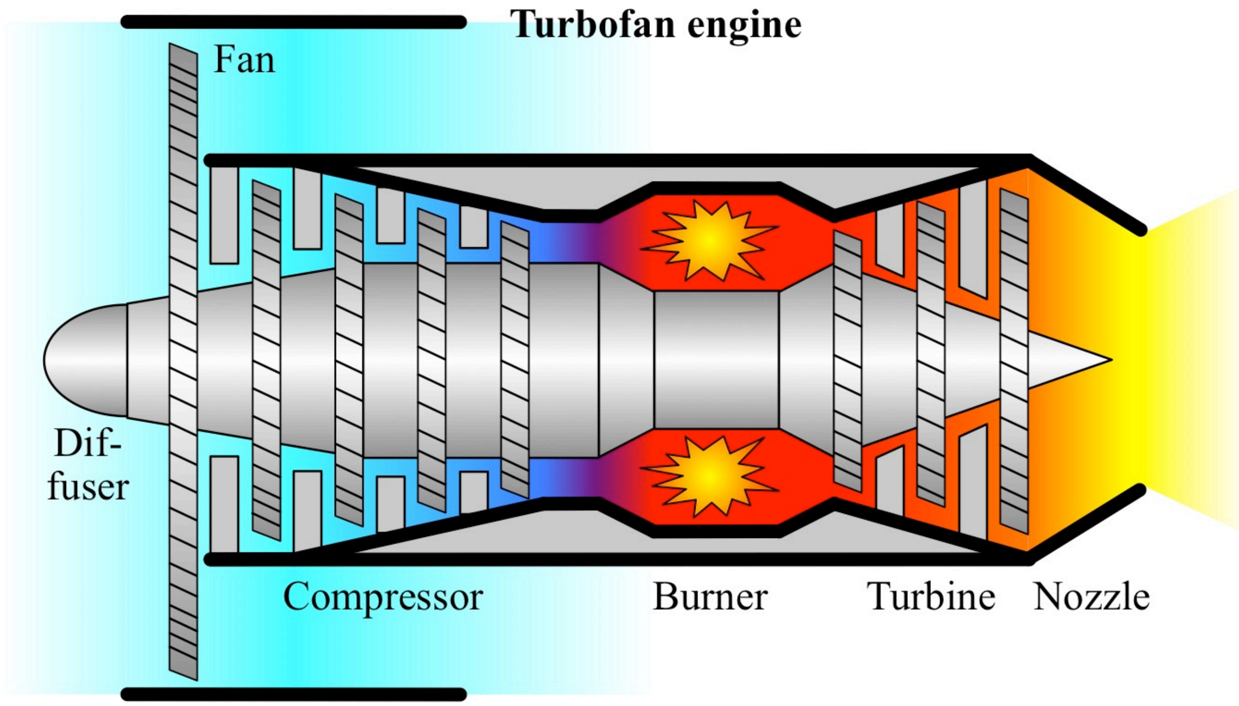


Figure 9.51: Turbojet engine design, showing a simplified view of its major components—the diffuser, compressor, burner, turbine, and nozzle—as well as simple models of the pressure and temperature at each point in the engine.



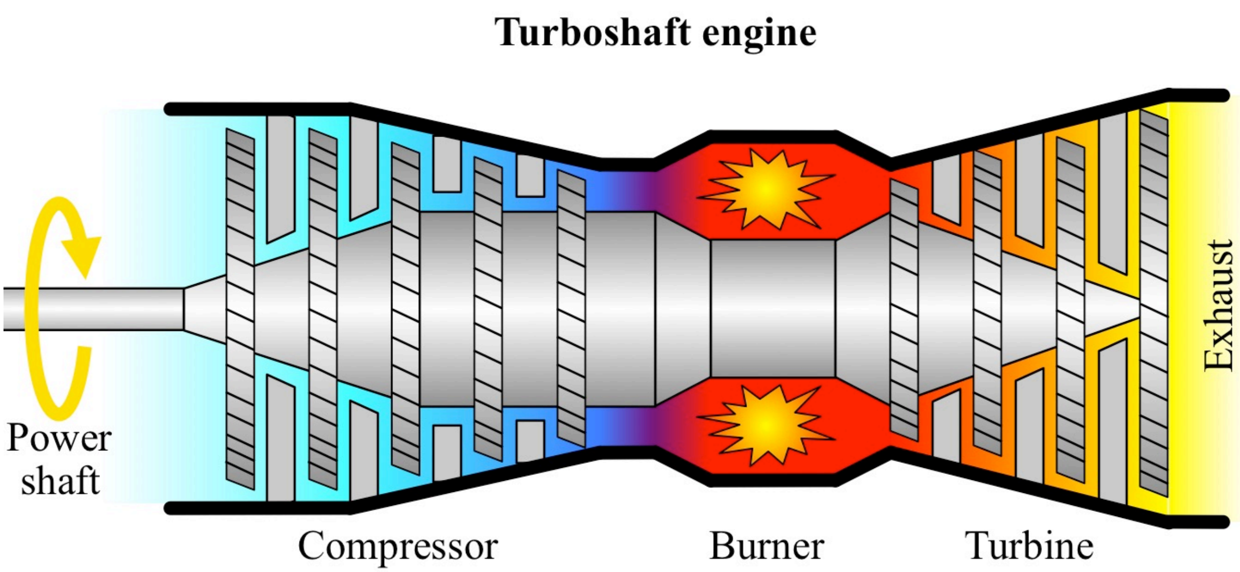


Figure 9.52: A turbojet engine design may be modified to become a turbofan design (above), or a turboshaft or turboprop design (below). In a turboshaft or turboprop design, the power shaft may be taken either from the compressor end as shown or from the turbine end, and generally transfers its power via a series of gears to an aircraft propeller or helicopter rotor shaft spinning at fewer revolutions per minute.

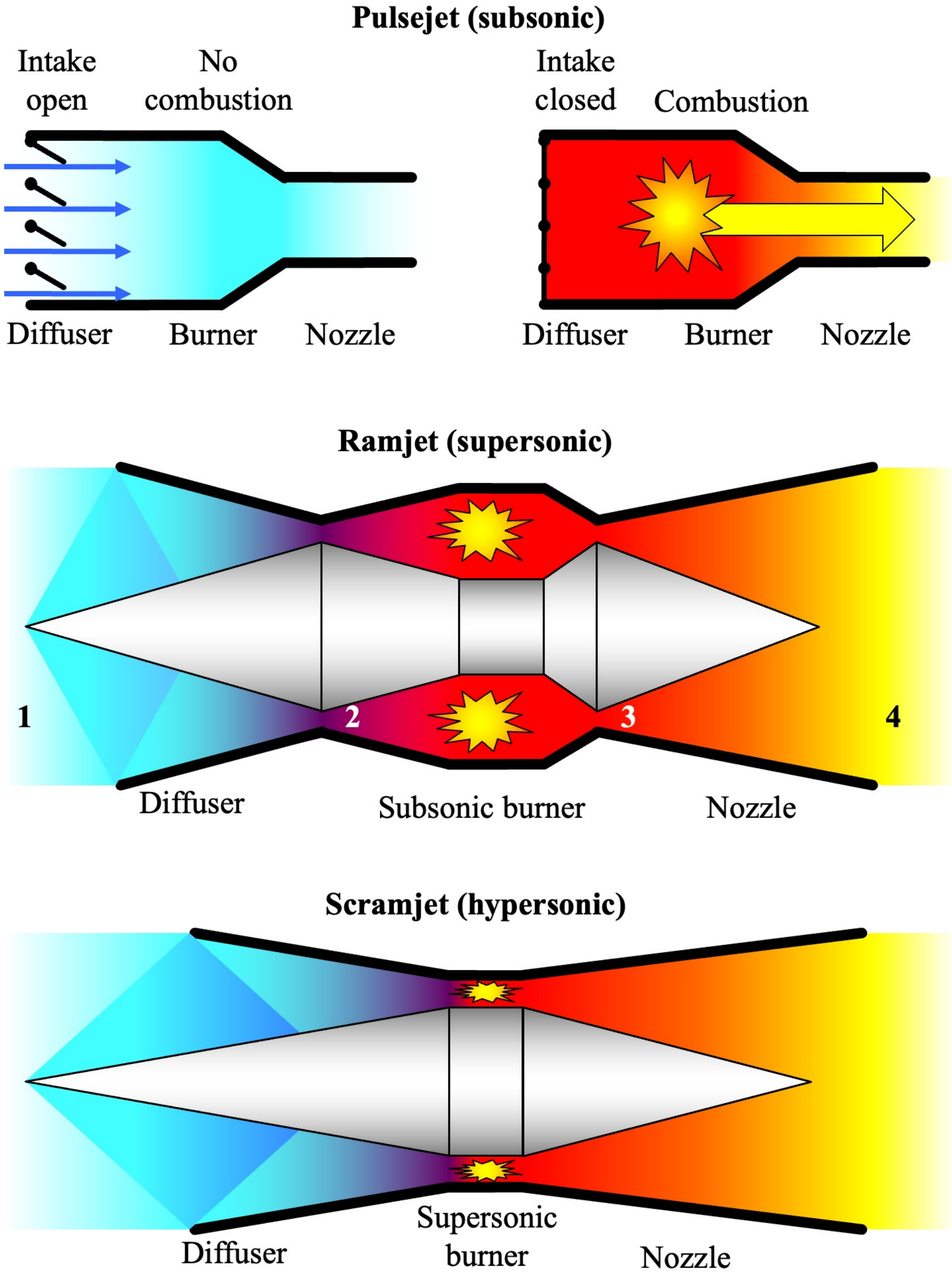


Figure 9.53: Bladeless aircraft engines include a pulsejet for subsonic speeds, a ramjet for supersonic speeds, and a supersonic combustion ramjet (scramjet) for hypersonic speeds.

Beginning in the nineteenth century, a long line of German-speaking creators invented, built, demonstrated, and improved gas turbine engines, first for stationary power applications or land vehicles and ultimately for aircraft. Some of the key early figures included:

- Franz Stolze (German, 1836–1910) began developing gas turbine engines in the 1860s and continued building test models and filing patents into the early 1900s (Fig. 9.54).

- Joseph Wertheim (German, 1834–1899) filed patent applications on gas turbine engines beginning in 1876 (Fig. 9.55).

- Christian Bröker (German, 18??–19??) filed patent applications on gas turbine engines in 1889 (Fig. 9.56).

- Aurel Stodola (Austro-Hungarian Slovak, 1859–1942) developed gas turbine engines from the 1890s through the 1930s (Figs. 9.57–9.58).

- Hans Holzwarth (German, 1877–1953) filed a large number of patent applications on gas turbine engines from around 1900 through the 1930s (Fig. 9.59). He built the first fully functional gas turbine engine in 1906 and later founded his own company that manufactured and sold gas turbine engines for industrial power production.

- Wilhelm Pape (German, 18??–19??) filed many patent applications on gas turbine engines from the 1910s through the 1920s (Fig. 9.60).

- Karl Röder (German, 1881–1965) filed numerous patent applications on gas turbine engines and built working versions from the 1910s through the 1930s (Fig. 9.61). As a professor at the University of Hannover, he also taught younger gas turbine engineers.

- Karl Enders (German, 18??–19??) filed a patent application on gas turbine engines in 1925 (Fig. 9.62).

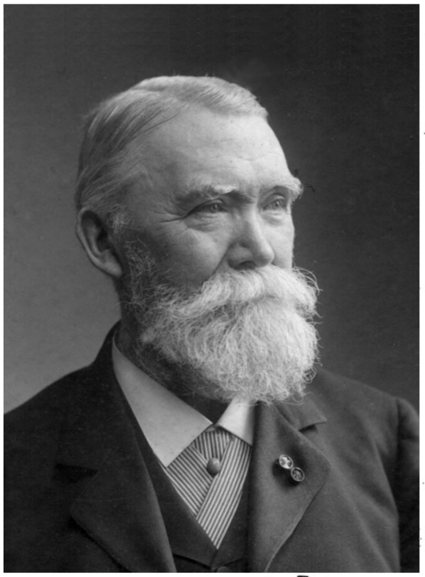
- Oscar Hart (German, 18??–19??) and Joseph Hetterich (German, 18??–19??) filed a patent application on gas turbine engines in 1925 (Fig. 9.63).

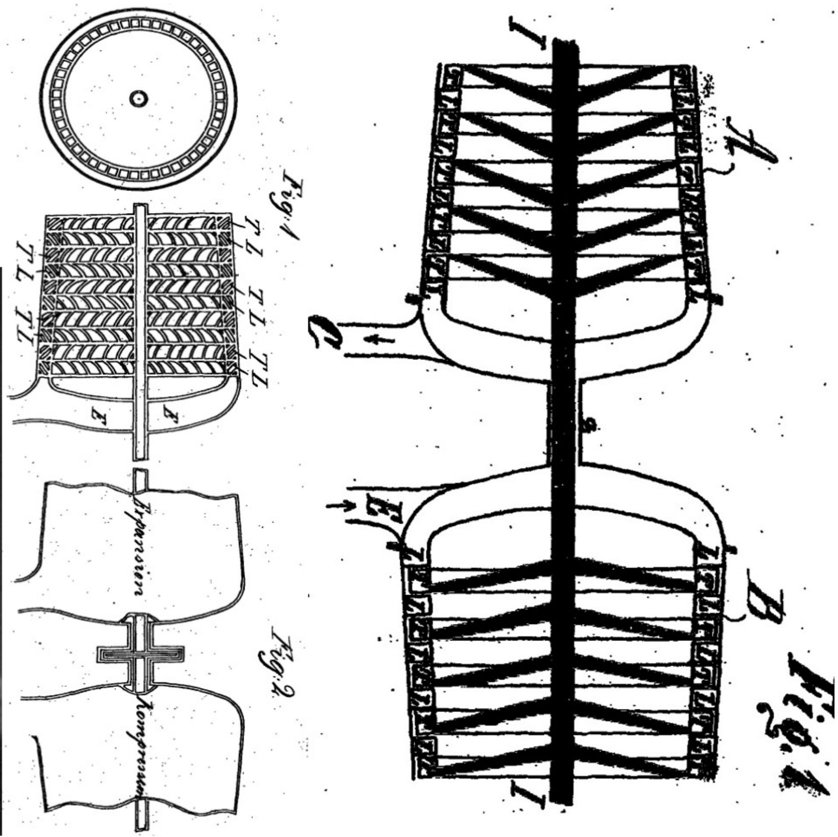
- Hermann Oberth (Austro-Hungarian, 1894–1989), best known for his work on rockets (Section 9.7.1) and early space station designs (Section 9.10.2), also created very early designs for jet engines. He filed a patent application on gas turbine engines for aircraft in 1925 (Fig. 9.64).

Some engineers outside the German-speaking world also proposed or worked on early gas turbine engines, although they tended to be fewer in number, more isolated, and often less able to find the support and resources required to fully realize their ideas. Some noteworthy figures were Ægidius Elling (1861–1949) in Norway, Gustaf de Laval (1845–1913) and the brothers Birger Ljungström (1872–1948) and Fredrik Ljungström (1875–1964) in Sweden, Maxime Guillaume (1888–19??) and René Anxionnaz (1894–19??) in France, and Charles Parsons (1854–1931) in the United Kingdom.

Franz Stolze (1836–1910)

Gas turbine engines (1860s–1900s)





N° 7398 A.D. 1898

Date of Application, 28th Mar., 1898
Complete Specification Left, 28th Dec., 1898—Accepted, 28th Apr., 1899

PROVISIONAL SPECIFICATION.

Improvements in Hot Air Engines.

I, Franz Stolze, of 23, Eichen Allee, Berlin-Westend, Germany, Doctor of Philosophy, do hereby declare the nature of this invention and the manner in which it is to be performed, to be particularly described and ascertained in and by the following statement:—

My invention relates to certain improvements in hot air engines. Heretofore the compression and expansion cylinders of hot air engines were made use of to drive compressed air into the boiler, where it was heated and from whence it was conducted into the expansion cylinder to therein do its work.

As the compression as well as the heating in the boiler cannot be carried beyond a certain limit on account of the wear on the machinery, the cylinders and the pistons had to be made of very large dimensions, with the result that the friction increased in proportion to the gain in piston surface.

The employment of inner boiler heating, although often tried, has not been found as profitable as expected on account of the getting hot of the lubricants, which absolutely necessitates water cooling and on account of the imperfect combustion even with liquid and gaseous fuel. Solid fuel, even powdered coal, cannot be made use of, as all experiments, to do away with the solid particles in the smoke have met with a negative result.

My new engine has for its object the drawing out of all the caloric power out of the fuel by doing away with the friction between the working parts and by making innoxious all solid products of combustion in case solid fuel in the internal furnace is used.

In order to attain this end, I provide systems of compression and expansion turbines in place of the ordinary compression and expansion cylinders.

The number of single turbines, making up a system and being mounted upon the same shaft, varies according to requirements. In front of each working wheel a rigid guide wheel is arranged. If compressed air now enters into such a system of turbines the latter will rotate in a sense opposite to the direction of the lower ends of the turbine blades. If however the shaft is turned by some means in the same direction as lie the lower ends of the turbine blades, the system sucks in air through the outer or first turbine.

Such a compression turbine system is to be connected with a hot air furnace, having inner firing; the compressed air is pressed into the furnace, heated and then conducted to a correspondingly larger system of expansion turbines. The latter will be rotated and will rotate in its part the compression turbine system aforesaid. The air having increased in volume by the heating process will now have a certain surplus of energy, which can be made use of in any desirable manner. The two turbine systems preferably run on the same shaft, when friction will be done away with almost entirely. Turbines do not need to be packed, only the shaft would have to run through a stuffing box. If however the two turbine systems are mounted upon the same shaft, no stuffing box is needed and the shaft runs in an airtight casing. A disk mounted upon the shaft between the two systems of turbines and being also

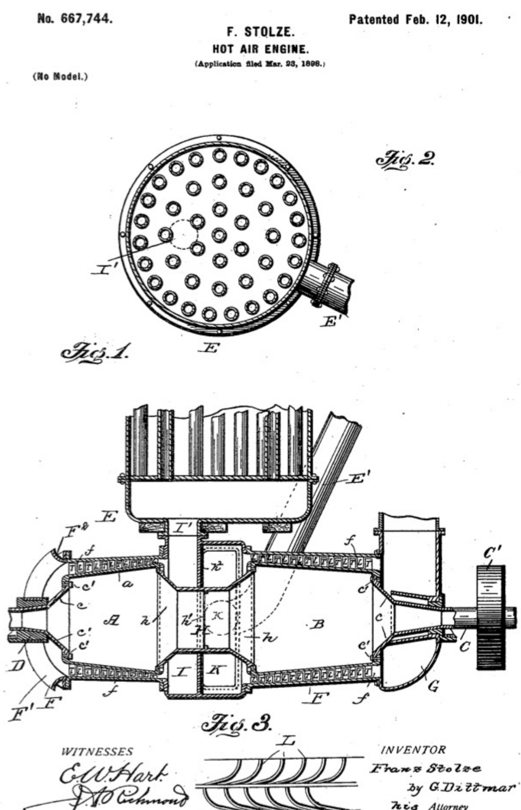


Figure 9.54: Franz Stolze (1836–1910) began developing gas turbine engines in the 1860s.

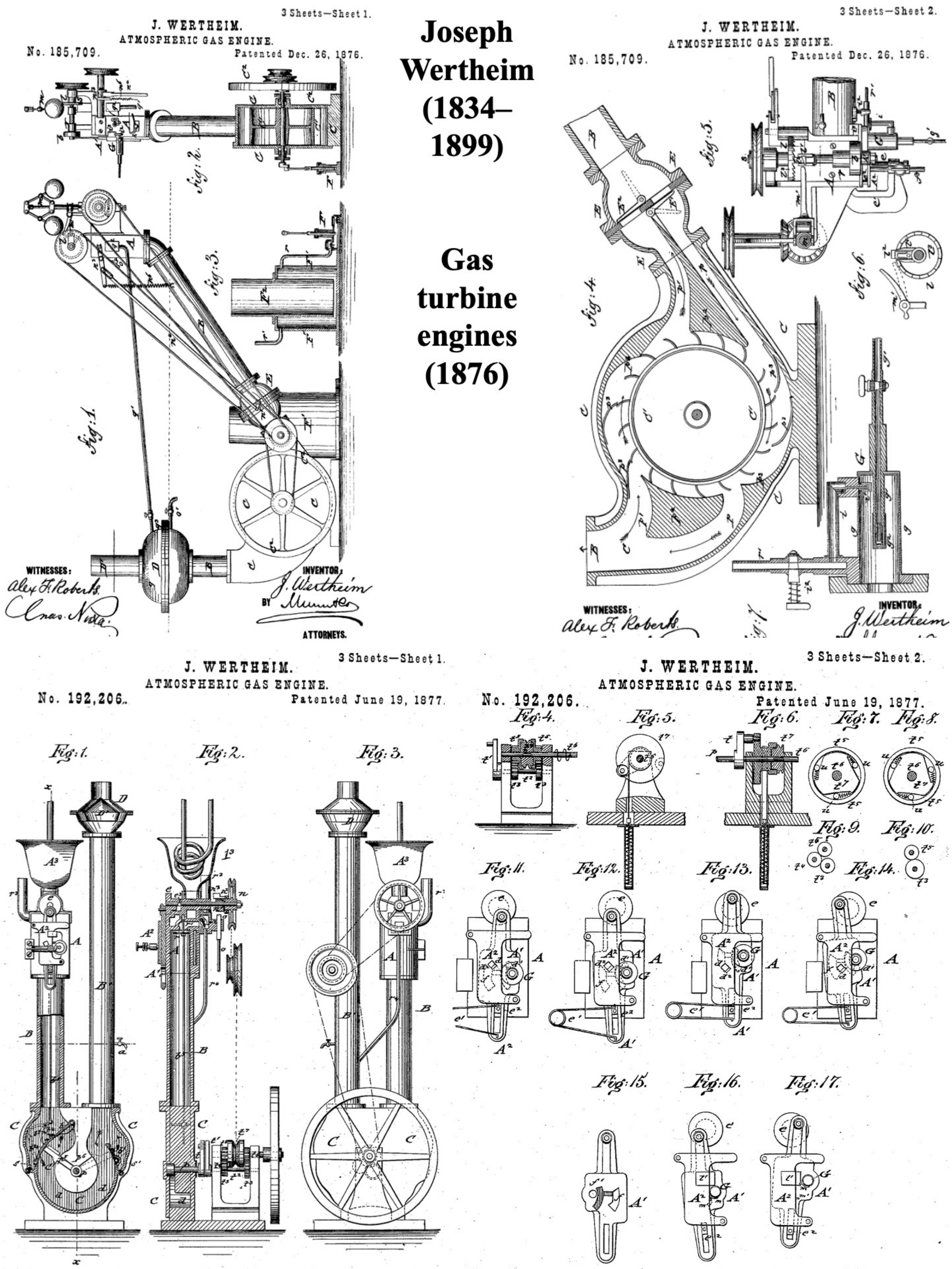


Figure 9.55: Joseph Wertheim filed patent applications on gas turbine engines beginning in 1876.

Christian Bröker (18??–19??)

Gas turbine engines (1889)

EIDGEN. AMT FÜR GEISTIGES EIGENTHUM

PATENTSCHRIFT

Patent Nr. **2050** 13. Dezember 1889, 3 Uhr, p. Klasse 93

CHRISTIAN BRÖKER, in MANNHEIM.

Einrichtung für Gas- oder Wassermotoren.

Der Gas- oder Wassermotor gegenwärtiger Erfindung besitzt ein grosses Schwungrad, auf dessen Umfang in annähernd tangentialer Richtung die Kraft der Explosion des Gases, oder die Kraft des Wasserdruckes wirkt, um das Rad in Rotation zu versetzen und mit einer daran befestigten Riemenscheibe die Kraft auf Arbeitsmaschinen u. drgl. zu übertragen.

Es ist auf der Zeichnung:

Fig. 1 die Seitenansicht des Gasmotors;

Fig. 2 die Vorderansicht desselben theilweise im Schnitt;

Fig. 3 die Ansicht der Steuerungsmechanismen etc.;

Fig. 4 der Vertikalschnitt durch den Wassermotor;

Fig. 5 die Vorderansicht desselben theilweise im Schnitt;

Fig. 6 die Ansicht der Steuerungsmechanismen etc.

Der Gas- oder Wassermotor hat eine Grundplatte mit einem Ständer A, in welchem ein horizontalliegender Zapfen B, Fig. 4, befestigt ist, um den sich das Schwungrad C mit der Riemenscheibe D dreht. Das Schwungrad C hat an seinem Umfang drei Kammern C^1. Die Kanten desselben sind eingeschnitten und der unten auf der Bodenplatte zum Heben und Senken eingerichtete Steuerkasten ist mit seiner oberen Fläche dem Umfang des Schwungrades angepasst. Auf der Nabe des Schwungrades ist zum Heben und Senken und Steuern die Nasenscheibe F mit Feder und Nut verschiebbar befestigt. Auf derselben sitzt auch ein Zahnrad E für den Gasmotor, um mit einer Pumpe Gas und Luft anzusaugen und das Gemisch durch das Schlauchrohr G in den Steuerkasten einzudrücken.

Die Mischung tritt aus dem Kanal H durch eine Bohrung H^1 zu dem Drehschieber J, welcher derselben bei entsprechender Stellung den Einlass in den Explosionsraum C^1 gestattet, worin die Mischung entzündet und so das Schwungrad C herumgedreht wird. Das Drehschiebergehäuse wird während einer Umdrehung des Schwungrades mit drei Explosionsräumen C^1 drei Mal gehoben und gesenkt und es erfolgt dieses durch die mit drei Nasen versehene auf der Schwungradnabe verschiebbar sitzende Scheibe F, welche durch den Hebel F^1 mit der Zugstange F^2 die auf der Drehschieberachse sitzende Kurbel K dreht, womit auch die auf derselben Achse sitzenden Hebel K^1 und K^2 gedreht werden, von welchen der nach unten stehende Hebel K^1 mit einer Stange L^1 die mit zwei Kurbeln L verbundene Stange L^2 verschiebt und dadurch die Achsen L^3 der Kurbeln L dreht, auf welchen Axen je zwei Exzenternasen L^4 angebracht sind, die den Drehschieberkasten heben, um ihn während des Einströmens des Gasgemisches und der Explosion luftdicht an das rotirende Schwungrad zu drücken und ihn darauf wieder davon zu entfernen, damit möglichst wenig Reibung verursacht wird; der Drehschieberkasten führt sich bei seiner Auf- und Abbewegung an vier auf den Grundplatten befestigten senkrechten Stiften M. Der nach oben stehende Hebel K^2 ist durch eine Stange mit dem auf der Achse des Auslassdrehschiebers N sitzenden Hebel K^3 verbunden, so dass auch dieser Drehschieber N gleichzeitig geöffnet und geschlossen wird. Die verbrannten explodirten Gase treten durch die Oeffnung N^1 des Kastens und durch den Drehschieber N in den Kasten und werden durch ein Schlauchrohr N^2 abgeleitet.

Die Pumpe wird durch die Zahnräder E, E^1 angetrieben, indem an letzterem ein Kurbelzapfen sitzt, an welchem die Kurbelstange E^2 eingreift u. s. w.

Der Regulator besteht aus einer in der Rinnenscheibe D laufenden Kugel D^1, welche mit dem Hebel D^2 beweglich an den Hebel D^3 angehängt ist. Letzterer ist auf der durch die Achse B zentral hindurchgehenden Stange R befestigt, welche hinten ein Segment R^1 trägt, das an seiner Unterfläche einen schrägen Einschnitt für einen in denselben eingreifenden Stift R^2 hat, welcher durch die Drehung der Stange R hin- oder hergeschoben wird und dadurch mit der durch den Ständer A gehenden Stange R^3 und der Gabel F^3 die Nasenscheibe F auf der Nabe des Schwungrades C verschiebt, so dass die Nasen derselben nicht auf den Hebel F wirken können und die Explosionen ausbleiben, wenn das Schwungrad C zu schnell rotirt und die Kugel D^1 in der Rinnenscheibe D aus ihrer normalen Lage mitgerissen wird.

Die Zündung erfolgt mittelst einer aussen am Schiebergehäuse brennenden Flamme J^1, welche durch einen kurzen Kanal in den Explosionsraum C^1 hineinschlägt, wenn das Schiebergehäuse gehoben wird.

Der Wassermotor, Fig. 4, 5, 6, hat dieselben Anordnungen wie der Gasmotor, nämlich ein um den Zapfen B sich drehendes Schwungrad C mit drei Druckräumen C^1, einen sich hebenden und senkenden Steuerkasten und denselben Regulator D^1, um dem Zufluss des Wassers vorzubeugen, wenn das Schwungrad zu schnell rotirt. Der Ständer A wird als Windkessel benutzt. Das Wasser tritt durch ein Ventil in den Windkessel und in das Steuergehäuse ein, wirkt bei geöffnetem Drehschieber J im Druckraum C^1 des Schwungrades C und fliesst darauf durch das Gehäuse und das Schlauchrohr U ab. Eine Pumpe und die dazu gehörigen Maschinentheile sind nicht vorhanden, jedoch sind zum Heben und Senken des Schiebergehäuses und zum Drehen des Schiebers J dieselben Mechanismen wie vorher angewendet, d. i. die auf der Schwungradnabe verschiebbare Exzenterscheibe F, die damit bewegten Hebel F^1, F^2 und K, zum Drehen des Schiebers J, und die damit bewegten Hebel K^1, L^1, L^2 und L, zum Heben und Senken des Steuerkastens mittelst der Exzenternasen L^4, ferner in Verbindung mit der Regulatorkugel D^1 die Gabel F^3 zum Verschieben der Scheibe F auf der Nabe des Schwungrades C, um bei zu schnellem Gang der Maschine den Wasserzufluss abzustellen.

Zum Betrieb der Maschine können auch Wasserdampf oder andere Dämpfe verwendet werden.

PATENT-ANSPRÜCHE:

1. Eine Einrichtung für Gas- oder Wassermotoren, bestehend aus einem um einen festen Zapfen B rotirenden mit Druckräumen C^1 versehenen Schwungrad C, in Verbindung mit einem Drehschiebergehäuse, das sich hebt und senkt, was durch die auf der Schwungradnabe verschiebbar sitzende Nasenscheibe F mittelst der Hebel F^1, F^2, der Kurbeln K, K^1, L und der Nasenexzenter L^4 geschieht, womit auch der Drehschieber J geöffnet und geschlossen wird;
2. Bei der durch Anspruch 1 gekennzeichneten Motoreinrichtung die in der Rinnenscheibe D laufende Regulatorkugel D^1, welche bei zunehmender Rotationsgeschwindigkeit die durch den festen Zapfen B hindurchgehende Stange R und damit das Segment R^1 dreht, welches mit einer schrägen Nute den in derselben befindlichen Stift R^2 der Stange R^3 bewegt und dadurch mit der Gabel F^3 die Scheibe F verschiebt.

CHRISTIAN BRÖKER.

Vertreter: Ed. v. WALDKIRCH.

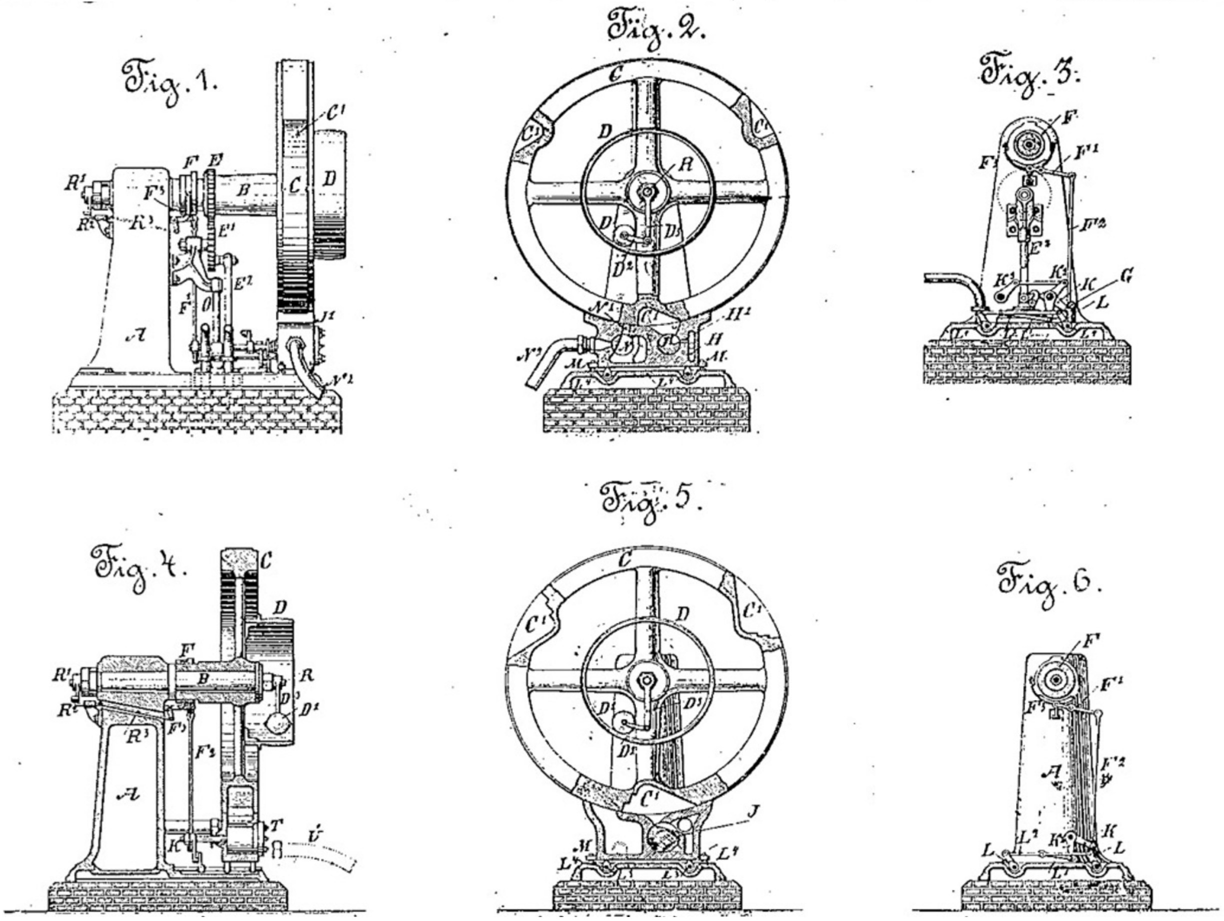
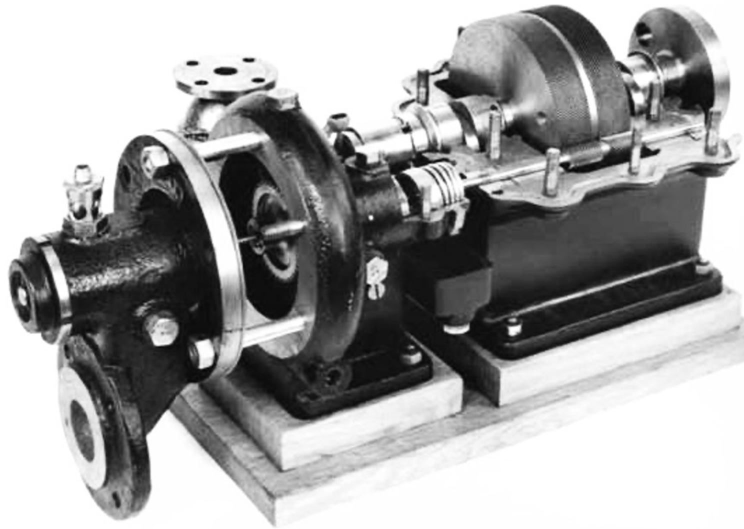
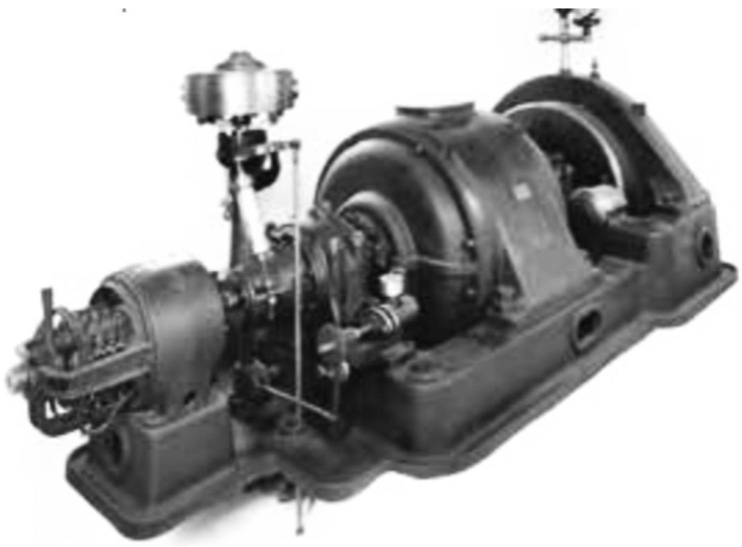


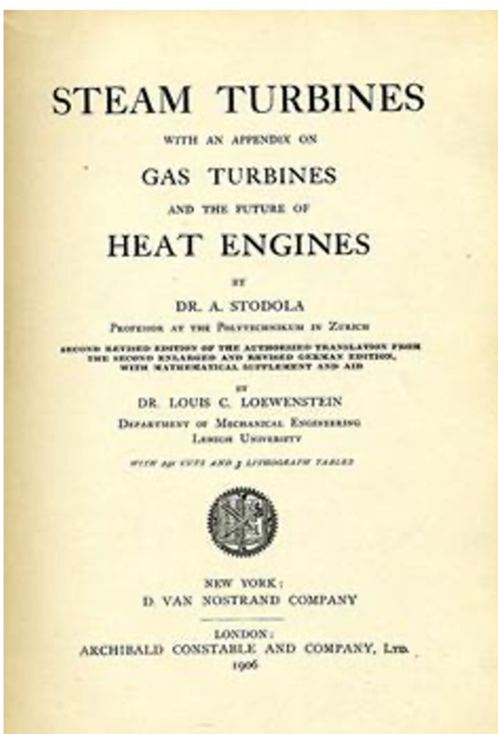
Figure 9.56: Christian Bröker filed patent applications on gas turbine engines in 1889.

Aurel Stodola
(1859–1942)





Gas turbine engines
(1890s–1930s)



STEAM TURBINES
WITH AN APPENDIX ON
GAS TURBINES
AND THE FUTURE OF
HEAT ENGINES
BY
DR. A. STODOLA
PROFESSOR AT THE POLYTECHNIKUM IN ZURICH
SECOND REVISED EDITION OF THE AUTHORIZED TRANSLATION FROM THE SECOND ENLARGED AND REVISED GERMAN EDITION, WITH MATHEMATICAL SUPPLEMENT AND AID
BY
DR. LOUIS C. LOEWENSTEIN
DEPARTMENT OF MECHANICAL ENGINEERING
LEHIGH UNIVERSITY
WITH [illegible] CUTS AND 3 LITHOGRAPH TABLES

NEW YORK:
D. VAN NOSTRAND COMPANY

LONDON:
ARCHIBALD CONSTABLE AND COMPANY, LTD.
1906

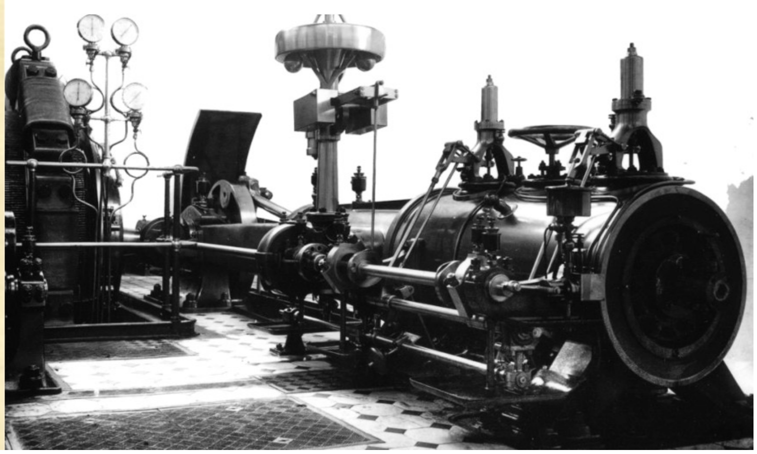


Figure 9.57: Aurel Stodola developed gas turbine engines from the 1890s through the 1930s.

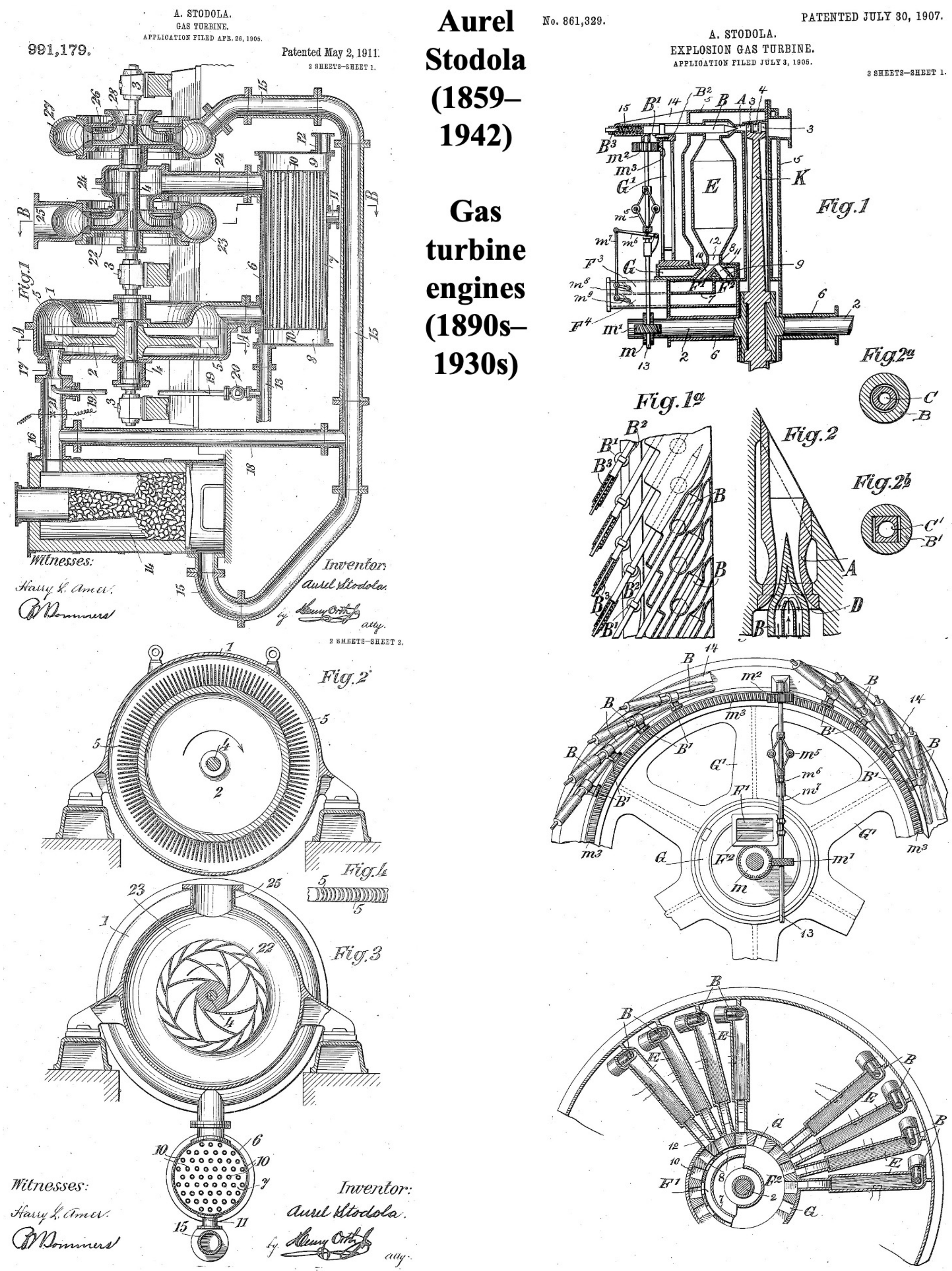


Figure 9.58: Aurel Stodola developed gas turbine engines from the 1890s through the 1930s.

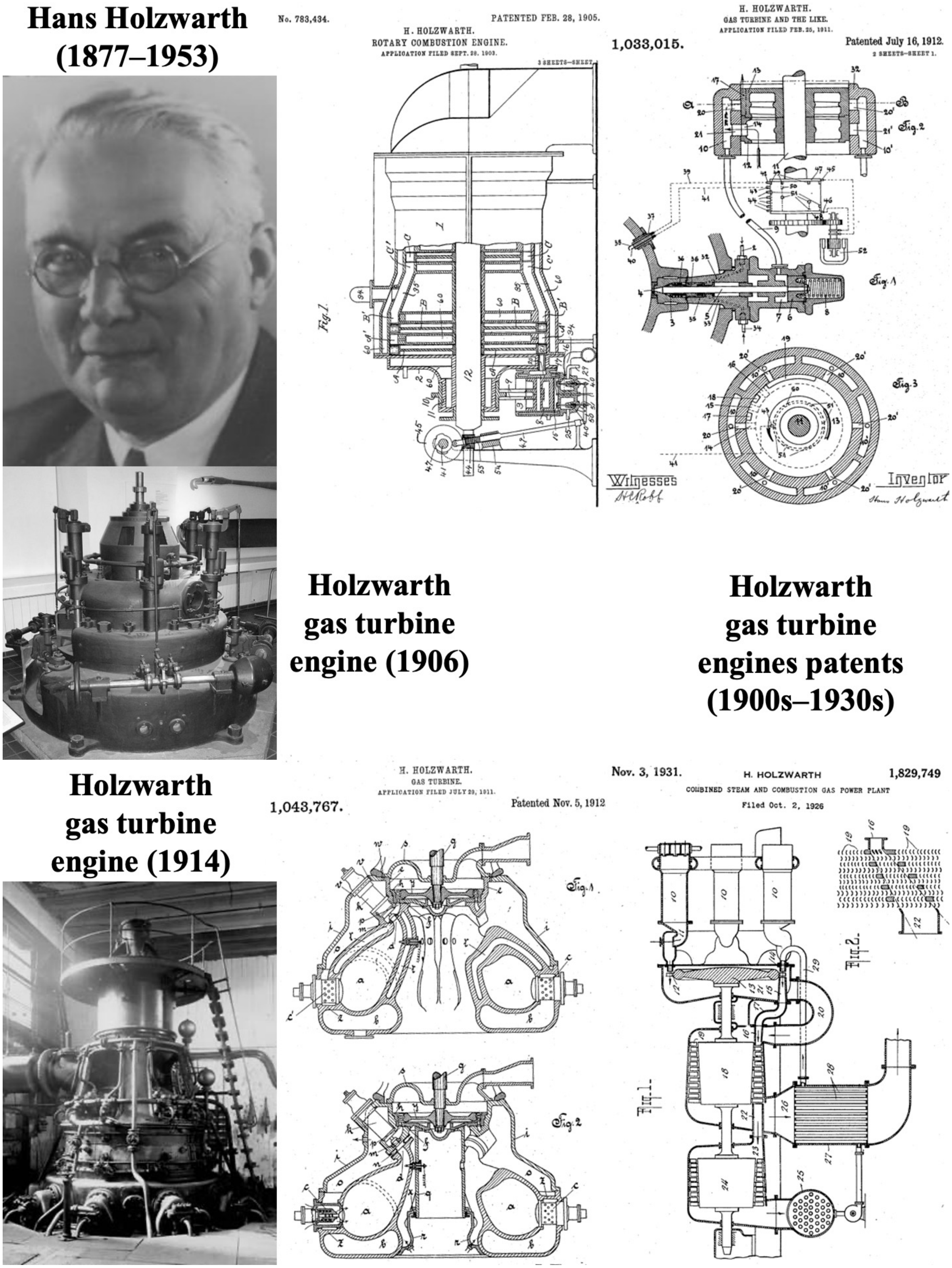
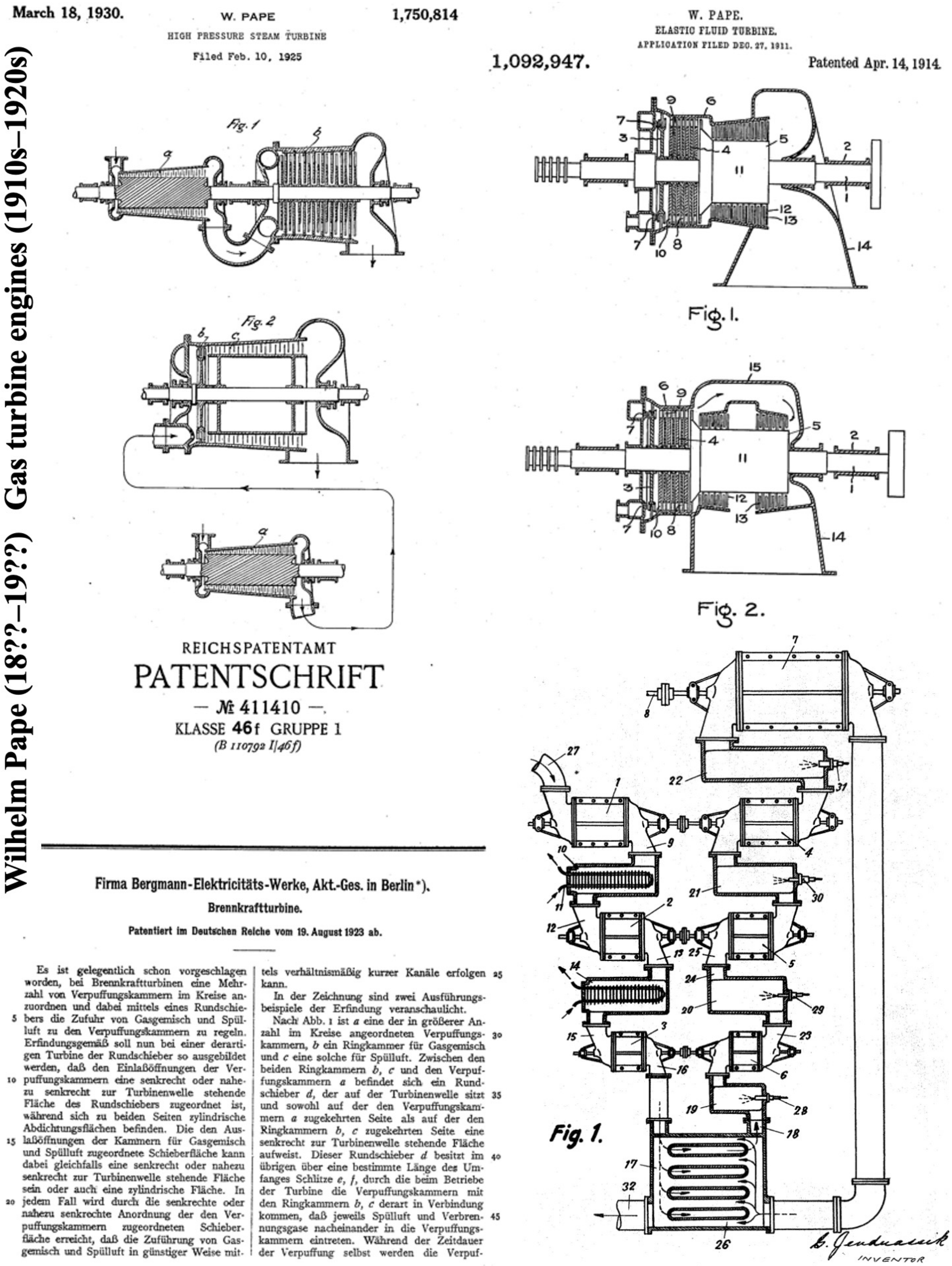


Figure 9.59: Hans Holzwarth filed a large number of patent applications on gas turbine engines from around 1900 through the 1930s.



Firma Bergmann-Elektricitäts-Werke, Akt.-Ges. in Berlin*).

Brennkraftturbine.

Patentiert im Deutschen Reiche vom 19. August 1923 ab.

Es ist gelegentlich schon vorgeschlagen worden, bei Brennkraftturbinen eine Mehrzahl von Verpuffungskammern im Kreise anzuordnen und dabei mittels eines Rundschiebers die Zufuhr von Gasgemisch und Spülluft zu den Verpuffungskammern zu regeln. Erfindungsgemäß soll nun bei einer derartigen Turbine der Rundschieber so ausgebildet werden, daß den Einlaßöffnungen der Verpuffungskammern eine senkrecht oder nahezu senkrecht zur Turbinenwelle stehende Fläche des Rundschiebers zugeordnet ist, während sich zu beiden Seiten zylindrische Abdichtungsflächen befinden. Die den Auslaßöffnungen der Kammern für Gasgemisch und Spülluft zugeordnete Schieberfläche kann dabei gleichfalls eine senkrecht oder nahezu senkrecht zur Turbinenwelle stehende Fläche sein oder auch eine zylindrische Fläche. In jedem Fall wird durch die senkrechte oder nahezu senkrechte Anordnung der den Verpuffungskammern zugeordneten Schieberfläche erreicht, daß die Zuführung von Gasgemisch und Spülluft in günstiger Weise mittels verhältnismäßig kurzer Kanäle erfolgen kann.

In der Zeichnung sind zwei Ausführungsbeispiele der Erfindung veranschaulicht.

Nach Abb. 1 ist *a* eine der in größerer Anzahl im Kreise angeordneten Verpuffungskammern, *b* ein Ringkammer für Gasgemisch und *c* eine solche für Spülluft. Zwischen den beiden Ringkammern *b*, *c* und den Verpuffungskammern *a* befindet sich ein Rundschieber *d*, der auf der Turbinenwelle sitzt und sowohl auf der den Verpuffungskammern *a* zugekehrten Seite als auf der den Ringkammern *b*, *c* zugekehrten Seite eine senkrecht zur Turbinenwelle stehende Fläche aufweist. Dieser Rundschieber *d* besitzt im übrigen über eine bestimmte Länge des Umfanges Schlitze *e*, *f*, durch die beim Betriebe der Turbine die Verpuffungskammern mit den Ringkammern *b*, *c* derart in Verbindung kommen, daß jeweils Spülluft und Verbrennungsgase nacheinander in die Verpuffungskammern eintreten. Während der Zeitdauer der Verpuffung selbst werden die Verpuf-

Figure 9.60: Wilhelm Pape filed many patent applications on gas turbine engines from the 1910s through the 1920s.

REICHSPATENTAMT

PATENTSCHRIFT

№ 493 179

KLASSE **14c** GRUPPE 5

R 59419 I/14c

Tag der Bekanntmachung über die Erteilung des Patents: 20. Februar 1930

Dr. Karl Röder in Hannover

Mehrstufige Turbine

Patentiert im Deutschen Reiche vom 22. September 1923 ab

Zur Vereinfachung und Verbilligung der Herstellung von Schaufeln ist es im Turbinenbau üblich, die gleiche Schaufelhöhe für mehrere Stufen von gleichem Beaufschlagungsdurchmesser zu verwenden. Handelt es sich um eine Gleichdruckbeschaufelung, bei der die einzelnen Räder nur teilweise, und zwar von Rad zu Rad zunehmend, beaufschlagt werden, so kann man Gruppen von Hochdruckstufen mit gleichen Schaufelhöhen ausführen. Auch für Überdruckturbinen, bei denen alle Stufen voll beaufschlagt werden, verwendet man, insbesondere im Hochdruckteil, Gruppen gleicher Schaufelhöhe bei gleichem Beaufschlagungsdurchmesser. Derartige Schaufelgruppen sind nun aber zur Erzielung eines guten Wirkungsgrades bei Dampfturbinen nicht geeignet, wie aus folgender Überlegung hervorgeht:

Wie bekannt, ist auf den Wirkungsgrad in erster Linie das Verhältnis der Dampf- zur Umfangsgeschwindigkeit von Einfluß, und zwar wird ein günstiger Wirkungsgrad bei einem bestimmten Wert dieses Verhältnisses erreicht, welches demnach für alle Stufen der Turbine vorliegen muß. Wählt man aber bei gleicher Schaufelhöhe gleichen Beaufschlagungsdurchmesser, also gleichen Durchgangsquerschnitt für die einzelnen Stufen, so nimmt die Dampfgeschwindigkeit infolge der Zunahme des spezifischen Volumens des Dampfes in jeder Stufe innerhalb der Gruppe

aller Stufen die gleiche ist, so ist das Verhältnis der Dampf- zur Umfangsgeschwindigkeit bei den einzelnen Stufen einer Gruppe verschieden groß, und zwar steigt dieses Verhältnis von der ersten bis zur letzten Stufe jeder Gruppe mit der Dampfgeschwindigkeit an.

Die Erfindung will nun einen guten Wirkungsgrad bei einer mehrstufigen Turbine mit einer oder mehreren Gruppen gleicher Schaufelhöhe und zunehmenden Beaufschlagungsdurchmessern erreichen. Sie besteht darin, daß die Beaufschlagungsdurchmesser innerhalb jeder Gruppe genau oder nahezu mit der Quadratwurzel aus dem spezifischen Volumen des Treibmittels wachsen. Es sei hierzu bemerkt, daß eine kegelige Form der einzelnen Läufer von mehrstufigen Turbinen, also ein Wachsen der Schaufelkränze in Richtung des durchströmenden Dampfes, bekannt ist. Bei dieser Anordnung bleibt aber das Verhältnis von Dampf- zur Umfangsgeschwindigkeit nicht gleich. Ein gleichbleibendes Verhältnis jener Geschwindigkeiten und damit auch ein guter Wirkungsgrad ergeben sich erst bei einer Turbine nach der Erfindung, und zwar aus folgendem Grunde:

Zwei Stufen gleicher Schaufelhöhe mit den Beaufschlagungsdurchmessern d_1 und d_2, also den Umfangsgeschwindigkeiten u_1 und u_2, verarbeiten praktisch die gleiche Dampfmenge vom spezifischen Volumen v_1 und v_2.

REICHSPATENTAMT

PATENTSCHRIFT

№ 524 426

KLASSE **14c** GRUPPE 7

R 67967 I/14c

Tag der Bekanntmachung über die Erteilung des Patents: 16. April 1931

Dr.-Ing. Karl Röder in Hannover

Gegenlaufturbine mit vorwiegend axialer Beaufschlagung

Patentiert im Deutschen Reiche vom 24. Juni 1926 ab

Zur wirtschaftlichen Verarbeitung kleiner Dampfmengen in Dampfturbinen, insbesondere in den Hochdruckstufen, ist die Verwendung kleiner Beaufschlagungsdurchmesser erforderlich, damit die Schaufelhöhe einen kleinsten Wert nicht unterschreitet. Damit ferner die Stufenzahl nicht zu groß wird, erscheint die Verwendung von zwei im Gegensinne zueinander umlaufenden Wellen vorteilhaft.

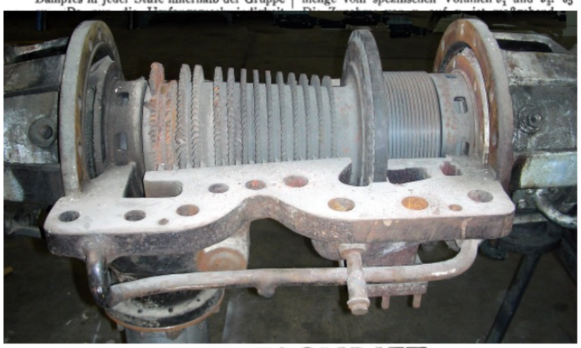
Bisher ist es nur gelungen, zweckmäßige Bauarten einer Gegenlaufturbine mit radial beaufschlagten Stufen zu schaffen. Hier steigt aber der Beaufschlagungsdurchmesser von Stufe zu Stufe so stark, daß bei Zuführung hochgespannten Dampfes ungünstige Strömungsverhältnisse entstehen.

Gegenläufige Turbinen mit axialer Beaufschlagung sind zwar auch vorgeschlagen worden, haben aber nie praktische Bedeutung erlangt, weil die bisher bekannt gewordenen Vorschläge keine Grundlage für praktische Ausführungen abgeben können. Jedenfalls sind diese Vorschläge für hochgespannten Dampf völlig ungeeignet.

Die Erfindung ermöglicht eine praktisch brauchbare Bauart einer gegenläufigen Dampf- oder Gasturbine mit vorwiegend axialer Beaufschlagung. Sie besteht darin, daß die beiden Gegenläufer vorwiegend walzenförmig aufgebaut sind, wobei der eine Teil der walzenförmigen Körper zur Lagerung, der andere Teil zur Aufnahme der Beschaufelung dient und der Dampf durch eine Mittenbohrung mindestens einer Welle zugeführt wird. Durch die neue Anordnung wird erreicht, daß Dichtungen nur auf kleinem Durchmesser vorgenommen zu werden brauchen, und daß auch die Entlastung von Axialschüben nur auf kleinem Durchmesser zu erfolgen hat. Die Walzenform der Läufer ist besonders geeignet für höhere Drücke und hohe Drehzahlen, während bisher bekannt gewordene Vorschläge für Gegenlaufturbinen trommelförmige Schaufelträger enthalten, deren Durchmesser weit größer ist als der Durchmesser der Welle. Die sich hierdurch ergebenden ungünstigen Verhältnisse machen derartige Turbinenbauarten ungeeignet für hohe Drücke.

Abb. 1 stellt ein Ausführungsbeispiel dar, in welchem mit *a* der innere, mit *b* der äußere beaufschlagte Läuferteil bezeichnet wird.

Die Lagerung erfolgt bei *d* und *d'*, die Fortleitung der mechanischen Arbeit durch die Zahnkränze *e* und *e'*. Der Dampfeintritt kann von einer oder von beiden Seiten durch die Rohre *f* und *f'* erfolgen. In den Läuferkörpern sind Rohre *g* und *g'* lediglich an den Wellenenden eingewalzt, so daß der Wärmeübergang aus dem beaufschlagten in den nicht beaufschlagten Teil jedes Läufers gering ist. Die Zwischenräume *h* und *h'* werden zu diesem Zweck mit Wärmeschutzmitteln gefüllt und gegebenenfalls auch luftleer gemacht. Die am Ende des inneren Läufers *a* untergebrachten Hochdruckstufen *c* sind in der Größe ihres Durchmessers nach innen nur durch die Größe der Dampfzuführungs-



Karl Röder
(1881–1965)

Gas turbine engines
(1910s–1930s)

PATENTSCHRIFT

№ 601 018

KLASSE **62c** GRUPPE 12₀₅

R 79484 XI/62c

Tag der Bekanntmachung über die Erteilung des Patents: 12. Juli 1934

Dr.-Ing. Karl Röder in Hannover

Turbinenantrieb für Luftfahrzeuge

Patentiert im Deutschen Reiche vom 12. Oktober 1929 ab

Bei der Ausbildung des Antriebes von Luftfahrzeugen hat sich, vor allem bei der gleichzeitigen Anwendung einer größeren Zahl von Propellern, der Vorschlag bewährt, die einzelnen Propeller nicht nebeneinander, sondern paarweise hintereinander anzuordnen. Als Antriebsmaschinen können dabei entweder Verbrennungskraftmaschinen oder Dampfturbinen verwendet werden. Die vorliegende Erfindung befaßt sich mit der Ausbildung des Turbinenantriebes. Für diesen ist bereits früher vorgeschlagen worden, jedem Propeller seine eigene Antriebsmaschine zu geben, die unabhängig von der anderen arbeitet und unabhängig von dieser geregelt wird, oder die Antriebsmaschinen gegenläufig in einem Gehäuse zu vereinigen. Die Erfindung beschreitet zur Lösung der Aufgabe, einen Dampfturbinenantrieb für Luftfahrzeuge zu entwickeln, einen grundsätzlich anderen Weg. Die gleichachsige Anordnung der beiden Propeller wird beibehalten, aber die getrennten Maschinen werden durch eine einzige Maschine, nämlich eine Gegenlaufmaschine an sich bekannter Bauart, ersetzt, nämlich eine vielstufige axiale Gegenlaufturbine ohne Leitkanäle mit ineinandergesteckten Laufkränzen, und zwar in der Weise, daß jede der Wellen selbständig und unabhängig von der anderen unmittelbar oder über Geschwindigkeitsgetriebe je einen der beiden an den entgegengesetzten Enden des Maschinensatzes angebrachten Propeller antreibt. Der wesentliche Vorteil des Antriebes gemäß der Erfindung liegt darin, daß die Gegenlaufturbine axialer Bauart mit geringen radialen Abmessungen gebaut werden kann, also den Luftstrom des Propellers praktisch nicht stört, im Gegensatz zur radial beaufschlagten Gegenlaufturbine, bei der die vorteilhafte Ausnutzung des Dampfes nur unter entsprechender Vergrößerung des Durchmessers erzielt werden kann. Aus diesem Grunde ist die Gegenlaufturbine axialer Bauart besonders wertvoll für die bewährte Propelleranordnung, bestehend aus Zug- und Druckpropeller, die wiederum für die Turbine den Vorteil einer einfachen Wellenführung ergibt, da man die baulichen Schwierigkeiten der sonst erforderlichen ineinandergesteckten Propellerwellen vermeidet.

Die Turbine kann in eine Hochdruck- und eine Niederdruckturbine in getrennten Gehäusen unterteilt werden, wobei mindestens die Hochdruckturbine als Gegenlaufturbine ausgebildet ist. Hochdruck- und Niederdruckmaschine können auf besondere Propeller arbeiten oder ihre Leistung an gemeinschaftliche Propellerwellen abgeben.

In der Abb. 1 ist ein Ausführungsbeispiel für den unmittelbaren Propellerantrieb durch eine Gegenlaufturbine axialer Bauart dargestellt. Mit *a* ist die innere, mit *b* die äußere Welle bezeichnet. Die Dampfzuführung er-

ÖSTERREICHISCHES PATENTAMT.

PATENTSCHRIFT Nr. 112287.

KARL RÖDER IN HANNOVER.

Mehrstufige Dampf- oder Gasturbine.

Angemeldet am 5. Jänner 1928; Priorität der Anmeldung im Deutschen Reiche vom 5. Jänner 1927 beansprucht.

Beginn der Patentdauer: 15. Oktober 1928.

Die Verarbeitung des Hochdruckdampfes in Turbinen bietet Schwierigkeiten, insbesondere, wenn die Aufgabe gestellt ist, den Hochdruckdampf bis herunter zum Kondensationsdruck auszunutzen. Da der Hochdruckdampf mit relativ kleinen Beaufschlagungsdurchmessern und Dampfgeschwindigkeiten verarbeitet werden soll, so entsteht eine große Anzahl von Stufen, die in mehreren Gehäusen untergebracht werden müssen. Eine weitere Erhöhung des Wärmegefälles und damit auch der Stufenzahl ist notwendig, wenn man zur Vermeidung zu großer Dampfnässe innerhalb der Schaufelung Zwischenüberhitzung anwendet.

Anderseits ist mit Rücksicht auf die Betriebssicherheit und die Länge des Maschinenaggregates eine Vermehrung der Gehäusezahl der Turbinenanlage über drei hinaus kaum zulässig.

Die vorliegende Erfindung bezieht sich auf mehrstufige Dampf- oder Gasturbinen mit mindestens zwei Wellen in derselben Achse, zwischen deren Lagerstellen in an sich bekannter Weise Teile der Turbinen, der angetriebenen Maschinen oder der Verbindungsglieder angeordnet sind. Bei diesen Maschinen werden die erwähnten Schwierigkeiten dadurch überwunden, daß beide gegenläufig zu betreibenden Wellen über ihre benachbarten Lagerstellen hinaus derart verlängert sind, daß das eine Wellenende das andere umschließt und die beiden Enden in dem hiedurch gebildeten Zwischenraum axial beaufschlagte Schaufelkränze tragen.

In der Zeichnung veranschaulicht Fig. 1 schematisch ein Ausführungsbeispiel einer mehrstufigen Turbine gemäß der Anmeldung. Das hohl ausgebildete Ende der Welle *a* umschließt das innere Wellenende *b* im beschaufelten Teil und ist mit der Welle *c* eines Stromerzeugers *d* aus einem Stück hergestellt oder starr gekuppelt. Der die Schaufeln tragende Teil *a* bildet somit eine axiale, freitragende Fortsetzung der Stromerzeugerwelle *c* und übt auf diese insofern einen günstigen Einfluß aus, als er deren größte Durchbiegung verringert und damit gegebenenfalls die kritische Drehzahl des Stromerzeugers über die Betriebsdrehzahl verlegt, so daß die kritische Drehzahl beim Anfahren und Abstellen der Maschinen nicht durchfahren zu werden braucht.

Ähnlich wie der Läufer *a* kann auch der Läufer *b* in seinem beschaufelten Teil nur den Fortsatz einer in der Figur nicht gezeichneten Welle bilden, die als Träger weiterer Schaufelkränze dient und von einem Gehäuse umschlossen ist, dessen Abdampfstutzen *g* aus der Zeichnung noch erkennbar ist.

Der Hochdruckdampf wird der gegenläufigen Beschaufelung *h* zugeführt, u. zw. durch eine Bohrung der Welle *b* oder wie dargestellt, durch die Bohrung *e* der Stromerzeugerwelle *c*. An der Einführungsstelle des Dampfes ist eine Stopfbüchse *f* angeordnet, die derart ausgebildet wird, daß die vom Dampf am beaufschlagten andern Wellenende auf die Welle ausgeübten axialen Kräfte aufgehoben und von der Lagerung ferngehalten werden.

Die Welle *b* kann auch (wie *a*) als Fortsetzung einer Stromerzeugerwelle ausgebildet sein, wobei die beiden Stromerzeuger auf dasselbe Netz arbeiten, also elektrisch gekuppelt sind.

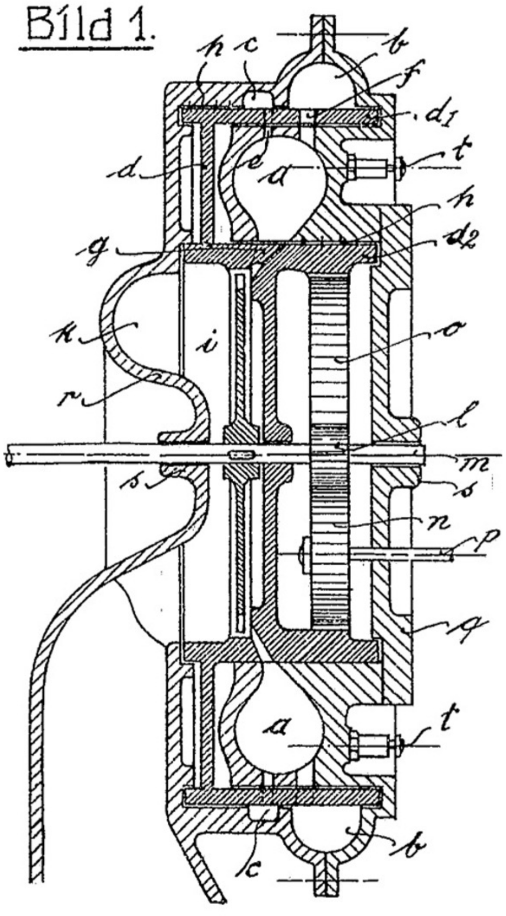
In Fig. 2 ist ein weiteres Ausführungsbeispiel dargestellt. Hier bedeuten wieder *a* und *b* den Hochdruckteil der mehrstufigen Turbine, deren Läufer durch die über das Lager *m* hinaus verlängerte Welle *h* in der Mitteldruckturbine *q* und durch die über das Lager *n* hinaus verlängerte Welle *c* der Niederdruckturbine *r* gebildet werden. Die Welle *h* ist außerdem bei *o*, die Welle *c* bei *p* gelagert. Zwischen den beiden Lagern *m* und *o* sind also die Laufkränze der Teilturbine *q*, zwischen den Lagern *p* und *n* die Laufkränze

Figure 9.61: Karl Röder filed numerous patent applications on gas turbine engines from the 1910s through the 1930s.

Karl Enders (18??–19??)

Gas turbine engines (1925)

Bild 1.



REICHSPATENTAMT

PATENTSCHRIFT

№ 451 778

KLASSE 46 f GRUPPE 1

E 33404 I/46 f

Tag der Bekanntmachung über die Erteilung des Patents: 13. Oktober 1927

Karl Enders in Dresden

Brennkraftturbine mit um die Welle liegenden Brennkammern

Patentiert im Deutschen Reiche vom 6. Dezember 1925 ab

Die Erfindung betrifft Brennkraftturbinen mit um die Welle liegenden Brennkammern, deren Ein- und Auslässe durch um die Laufradachse umlaufende Schieber geregelt werden.

Man hat bereits Turbinen vorgeschlagen, bei denen das Laufrad selbst als zylindrischer Drehschieber zur Regelung des Treibmittelaustrittes ausgebildet ist, und zwar derart, daß sich auf dem Umfange des Radkörpers Gruppen von Laufschaufeln und Steuerflächen abwechseln. Die Zahl der Gruppen wird hierbei von der Zahl der Brennkammern bestimmt. Der Gesamtwirkungsgrad solcher Anordnungen ist jedoch ein schlechter, einmal, weil eine große Zahl von Verbrennungen auf einen Umlauf des Laufrades kommt, sodann aber auch, weil bei einer großen Drehzahl und Umlaufgeschwindigkeit der Steuerflächen sich unzureichende und nicht überwachbare Verhältnisse bei der Füllung, Entspannung und Spülung ergeben. Dadurch ist die Erreichung höherer Geschwindigkeiten praktisch unmöglich.

Nun hat man weiter bereits von der Laufradachse untersetzt angetriebene und um diese umlaufende Drehschieber vorgesehen, um durch sie den Austritt der Gase zu regeln und durch eine Düse auf den im Inneren des Schiebers befindlichen Laufradkranz geleitet.

Durch die Erfindung sollen neue Vorteile erreicht werden. Sie besteht darin, daß die Steuerflächen durch einen besonderen, für Auslaßregelungen an sich bekannten, auf der Laufradachse der Turbine lose drehbaren Drehschieber, der untersetzt angetrieben wird, gebildet werden. Diese Anordnung beseitigt die Ventile an der Turbine völlig, insbesondere auch auf der Treibmitteleinlaßseite.

Ein weiterer Vorteil der Erfindung besteht darin, daß die Brennkammern nach außen gelegt sind, um so für das Gehäuse und den Drehschieber eine große Kühlfläche zu erhalten. Die Austrittsregelung der Gase aus den Kammern erfolgt erfindungsgemäß durch Gruppen von düsenförmigen Kanälen im Regelungsschlitz des Drehschiebers über einen Bereich zwischen den Austrittsöffnungen mindestens zweier benachbarter Brennkammern. Auf diese Weise wird dem Austritt der Gase ein größerer Zeitraum gelassen als bisher und gleichzeitig ihnen über die Gesamtdauer des Austrittes die gleiche Richtung gegeben.

Die in der Zeichnung dargestellte Ausführungsform stellt einen neuen Typ von Brennkraftturbinen dar, der insbesondere eine enge Bauart aufweist, die die Ausnutzung der Gase in mehreren Stufen gestattet. Die Anordnung der Innenverzahnung am Drehschieber bietet hierbei nicht unwesentliche bauliche Vorteile.

Bild 1 zeigt einen durch die Turbine mit Ausnahme der Übersetzungsräder gelegten Längsschnitt,

Bild 2 einen Querschnitt hierzu in der Richtung I zu I in Bild 1.

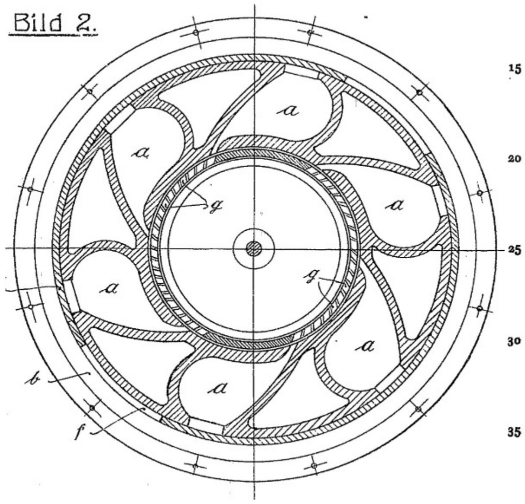
Die Brennkammern *a* sind am Umfange der Turbine angeordnet. Sie haben je eine äußere und eine innere zylindrische Begrenzungsfläche d_1 und d_2, in denen die Ein- und Austrittsöffnungen für den Betriebsstoff untergebracht sind. Äußere Ringkanäle *b* und *c* sind für die Zuführung von Gasgemisch und Spülluft vorgesehen. Der Drehschieber *d* besitzt in seinen zylindrischen Flächen d_1 und d_2 entsprechende Öffnungen *e* und *f* zur Regelung von Gemisch und Spülluft sowie düsenförmige Austrittsöffnungen *g* für die Gase, während die übrige Fläche jeweils die Brennkammern während der Verdichtungszeiten bis zur erfolgten Zündung geschlossen hält. *h* sind Labyrinthdichtungen, und *i* ist das Laufrad. Die Abgase werden im Raum *k* gesammelt und abgeführt. Zusammen mit dem Laufrad *i* ist auch ein Zahnrad *l* auf der Turbinenwelle *m* befestigt, das mit zwei Zwischenrädern *n* und *o* im Eingriff steht, von denen wenigstens *n* mit einer Achse *p* im Deckel *q* der Turbine fest gelagert ist. Dieser sowie der Gehäusedeckel *r* enthalten die Lager *s* der Welle *m*. *t* sind Zündkerzen.

Die anderen zum Betrieb der Turbine gehörigen Teile sind nicht mit eingezeichnet.

Im Ausführungsbeispiel sind sechs Brennkammern gezeichnet. Der Drehschieber ist symmetrisch mit zwei Gruppen von Ein- und Austrittsöffnungen für Gasgemisch und Spülluft und für gespannte Gase gezeichnet. Das Übersetzungsverhältnis betrage 6 : 1. Auf eine Umdrehung des Drehschiebers kommen demnach sechs Umläufe des Laufrades und zwölf Zündungen.

Bei einer größeren Zahl von Brennkammern kann man die Gruppeneinteilung noch weiter treiben, so daß beispielsweise bei 12 Kammern die 1, 4, 7, 10; 2, 5, 8, 11; 3, 6, 9, 12 gleichzeitig arbeiten.

Bild 2.



Patentansprüche:

1. Brennkraftturbine mit um die Welle liegenden Brennkammern, deren Ein- und Auslässe durch um die Laufradachse umlaufende Steuerflächen geregelt werden, dadurch gekennzeichnet, daß die Steuerflächen durch einen besonderen, für Auslaßregelungen an sich bekannten, auf der Laufradachse lose drehbaren, untersetzt angetriebenen Drehschieber gebildet werden.

2. Brennkraftturbine nach Anspruch 1, dadurch gekennzeichnet, daß von den zwei konzentrischen Zylindersteuerflächen des Drehschiebers die äußere den Einlaß der außerhalb gelegenen Gas- und Luftzuleitungen nach den zwischen beiden gelegenen Brennkammern und die innere den Auslaß aus diesen nach den Laufradschaufeln überwacht und daß die Auslaßdüsen in dem inneren Zylinder den bis dahin von außen nach innen gerichteten Weg der Arbeitsmittel in einen axial oder nahezu axial gerichteten gegen die Laufradschaufeln umlenken.

3. Brennkraftturbine nach Anspruch 1, dadurch gekennzeichnet, daß der den Auslaß der gespannten Gase freigebende Regelungsschlitz sich über einen Bereich zwischen mindestens zwei benachbarten Brennkammeraustrittsöffnungen erstreckt und in diesem düsenförmige Kanäle (*g*) vorgesehen sind, die dem Betriebsmittel über die Gesamtdauer des Austritts die gleiche Richtung geben.

4. Brennkraftturbine nach Anspruch 1 und 2, gekennzeichnet durch eine Innenverzahnung am Drehschieber.

Figure 9.62: Karl Enders filed a patent application on gas turbine engines in 1925.

Oscar Hart (18??–19??) and Joseph Hetterich (18??–19??)

Gas turbine engines (1925)

REICHSPATENTAMT

PATENTSCHRIFT

№ 476033

KLASSE 46f GRUPPE 1

H 103536 I/46f

Tag der Bekanntmachung über die Erteilung des Patents: 25. April 1929

Oscar Hart und Joseph Hetterich in München

Brennkraftturbine mit umlaufenden, auf einem Radkranz angeordneten Brennkammern

Patentiert im Deutschen Reiche vom 18. September 1925 ab

Gegenstand der Erfindung ist eine Brennkraftturbine mit umlaufenden, auf einem Radkranz angeordneten Brennkammern. Die bekannten Brennkraftturbinen dieser Art sind so beschaffen, daß die Beschickung und Entlüftung der Brennkammern sowie die Abströmung der Verbrennungsgase seitlich, also in axialer Richtung, und die Zündung des Gasgemisches gleichzeitig mit dem Abströmen in die Leitschaufeln erfolgen. Hieraus ergeben sich verschiedene Nachteile, welche die Bedienung der Maschine erschweren und deren Wirkungsgrad vermindern. Die seitliche Beschickung erfordert zwangläufig den Einbau der Steuerungsorgane, Ventile und Zündeinrichtungen im Innern der Maschine, so daß sie schwer zugänglich sind und Betriebsstörungen beim unregelmäßigen Arbeiten dieser Organe nur durch schwierige und zeitraubende Arbeiten behoben werden können. Das mit der Zündung gleichzeitig abströmende Gasgemisch verbrennt nicht gleichmäßig und unvollständig, wodurch sich ein uneinheitlicher, die Leistung der Turbine herabsetzender Verpuffungsdruck ergibt.

Mit der Erfindung wird die Beseitigung dieser Nachteile bezweckt. Die neue Erfindung besteht darin, daß die Beschickung und Entlüftung der Brennkammern radial von außen, die Abströmung der Verbrennungsgase dagegen beiderseits des Triebrades axial erfolgt, wobei die das Triebrad seitlich einschließenden Leitschaufelauslässe hinter der zugehörigen Zündstelle ansetzen.

Der Einbau der Zündmittel, Ventile und Steuerorgane in Radialkanälen ist einfach durchzuführen, ebenso lassen sich diese Organe leicht überwachen, regeln, instand halten und instand setzen, wodurch der Betrieb wesentlich gefördert wird. Die Zurücksetzung der Leitschaufelauslässe führt zur gleichmäßigen und vollständigen Verbrennung des Gemisches, so daß sich der Druck der Verbrennungsgase jeder Brennkammer zu einem gleichmäßigen Verpuffungsdruck ausgleichen kann.

Auf der Zeichnung ist eine Brennkraftturbine nach der Erfindung in einer Ausführungsform beispielsweise in Abb. 1 im Querschnitt und in Abb. 2 im Höhenschnitt dargestellt. Abb. 3 zeigt die Anordnung von einzelnen Teilen der Turbine.

Hierbei ist 1 das in der Mitte der Turbine befindliche, von der hohlen Welle 9 mitgenommene Triebrad, welches in seinem Kranz in bekannter Weise eine Anzahl. z. B. fünf, Brennkammern 2 enthält, welche gegen das Gehäuse 3 bei 4 abgedichtet sind. Aus jeder Brennkammer führen winklig zur Achse liegende Düsen 5 in die Seitenwände des Triebrades 1. Dieses ist durch eine Mittelwand 6 geteilt, welche nahe ihrem Rande Durchlässe 7 besitzt. Beide Triebradhälften stehen mittels Bohrungen 8 mit der Hohlwelle 9 zwecks Erzielung einer Umlaufkühlung in Verbindung. Beiderseits des Triebrades sitzen auf der Welle 9 ein oder mehrere am Umfange mit Schaufeln 11 besetzte Laufräder 10.

Zwischen dem Triebrad 1 und den sich anschließenden Laufrädern 10 und, wenn mehrere der letzteren vorhanden sind, auch zwischen je zwei benachbarten Laufrädern sind an ringförmigen Zwischenwänden des Gehäuses Leitschaufeln 12 vorgesehen, welche, entsprechend der Aufeinanderfolge der Verbrennungsvorgänge, nur auf einem Teil des Umfangs ihrer Träger, also absatzweise, angeordnet sind. Im Gehäuse vorgesehene Ringkanäle 13 dienen zur Ableitung der Abgase; der Gehäusemantel 14 bildet einen Teil der Kühlung.

Gemäß der Erfindung sind nun die zum Betriebe der Turbine erforderlichen, vom Triebrad 1 gesteuerten Kanalsätze, und zwar Brennstoffeinlaß 15, Zündkanal 16 und Entlüftungskanal 17, radial im Gehäuse angeordnet. Wie aus Abb. 2 ersichtlich, sind bei der gewählten Ausführungsform drei solcher Kanalsätze vorgesehen.

Die Leitschaufeln 12 setzen erfindungsgemäß etwas hinter dem zugehörigen Zündkanal 16 an und enden in der Nähe des Entlüftungskanals 17.

Die Wirkungsweise der Turbine ist folgende:

Die jeweils dem Brennstoffeinlaß 15 gegenüberliegende Brennkammer 2 wird radial von außen mit dem flüssigen oder gasförmigen Brennstoff beschickt, wozu sowohl ein gesteuertes Einlaßventil als auch ein Einlaßschlitz in Verbindung mit einem unter Druck stehenden Brennstoffgemischbehälter Verwendung finden kann.

Nach dem Anwerfen der Turbine kommt die beschickte Brennkammer 2 zum Zündkanal 16 mit Zündkerze oder Glührohr, wodurch sich das Gasgemisch entzündet, ohne jedoch sofort abströmen zu können, da die Leitschaufeln 12 erst hinter der Zündstelle 16 ansetzen. Dadurch ergibt sich einerseits eine Reihenzündung und andererseits eine Ausgleichung des Verpuffungsdrucks der Verbrennungsgase, welche dann gleichförmig und vollständig verbrannt seitlich, also axial zu den Leitschaufeln 12, abströmen und die Turbine in Bewegung halten. Die beschickte Brennkammer kommt sodann in den Bereich des Entlüftungskanals 17 und wird, z. B. mittels eines Schleudergebläses, radial entlüftet, welches auch die Leitschaufeln 12 und Laufradschaufeln 11 entlüftet und kühlt. Die neuerliche Beschickung der entleerten Brennkammern erfolgt erst dann wieder, wenn die Düse 5 gegen die Leitschaufeln 12 abgeschlossen ist.

Die Taktvorgänge spielen sich dabei in der Weise ab, daß die Zündungen nach Maßgabe der Brennkammernstellung gegenüber den Zündkanälen erfolgen.

Patentanspruch:

Brennkraftturbine mit umlaufenden, auf einem Radkranz angeordneten Brennkammern, dadurch gekennzeichnet, daß die Beschickung und Entlüftung der Brennkammern (2) radial von außen und die Abströmung der Verbrennungsgase beiderseits des Triebrades (1) axial erfolgt, wobei die das Triebrad seitlich einschließenden Leitschaufelauslässe (12) zur Erzielung einer gleichförmigen und vollständigen Verbrennung des Gemisches hinter der zugehörigen Zündstelle (16) ansetzen, so daß sich der Druck der Verbrennungsgase jeder Kammer (2) vor dem Abströmen durch die Leitschaufelauslässe (12) zu einem gleichmäßigen Verpuffungsdruck ausgleichen kann.

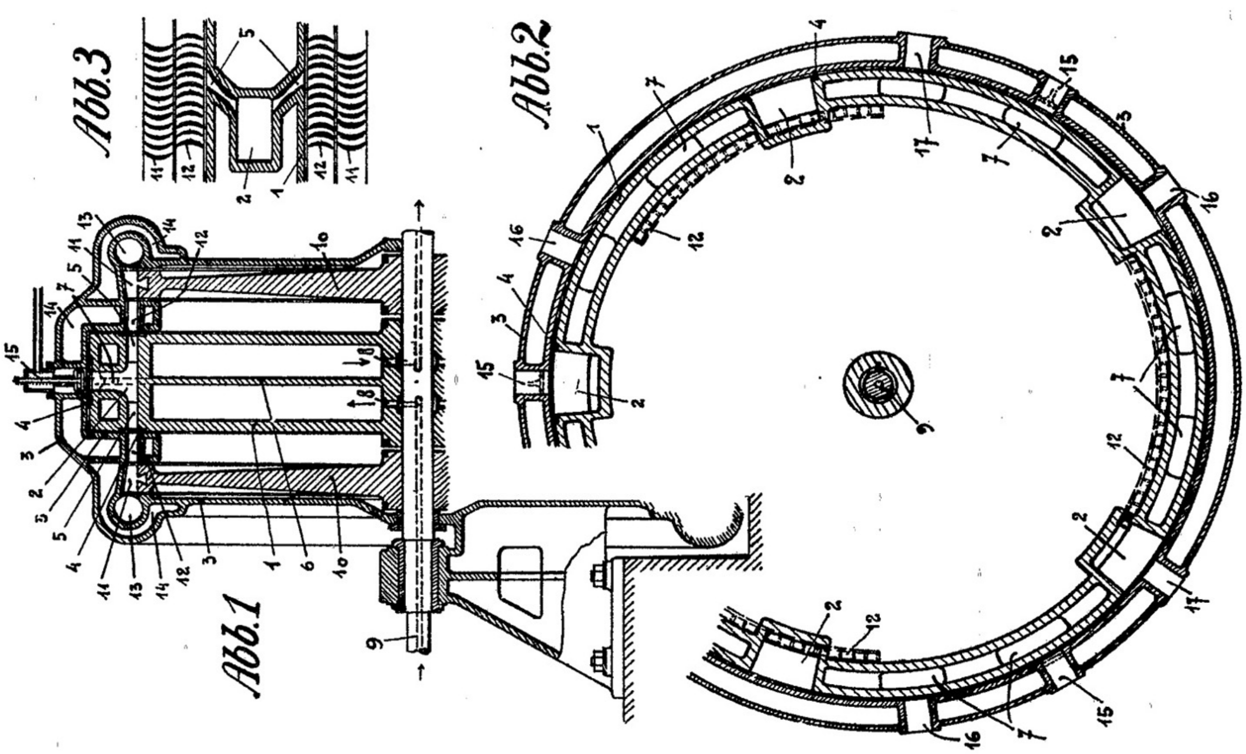
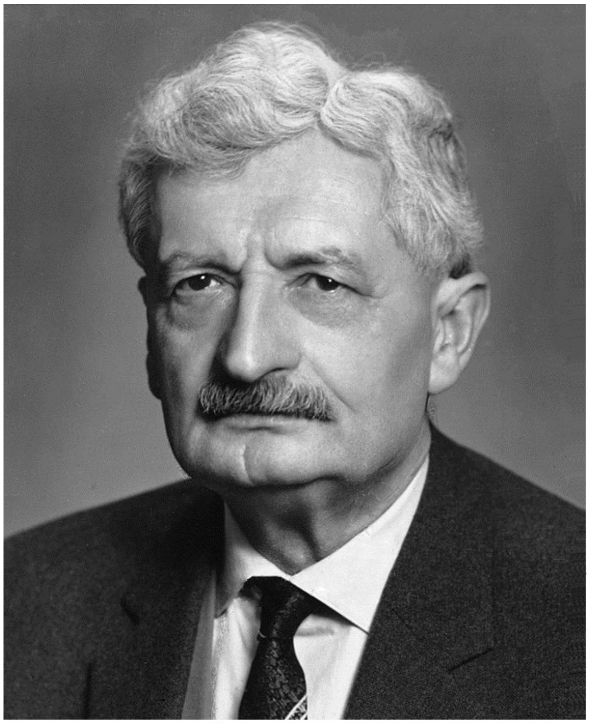


Figure 9.63: Oscar Hart and Joseph Hetterich filed a patent application on gas turbine engines in 1925.



Hermann Oberth (1894–1989)

Gas turbine engines (1925)

REICHSPATENTAMT

PATENTSCHRIFT

— № 429462 —

KLASSE 46f GRUPPE 6

(O 14748 I/46f)

Hermann Oberth in Mediasch-Medias, Rumänien.

Brennkraftturbine mit Hilfsflüssigkeit.

Patentiert im Deutschen Reiche vom 19. Februar 1925 ab.

Bei bekannten Brennkraftturbinen, bei welchen eine in einem Zylinder gestaute Flüssigkeit durch die Verbrennungsgase auf eine Turbine geeigneter Bauart getrieben wird, wird die ganze innere Zylinderoberfläche durch die Flüssigkeit benetzt und abgekühlt. Infolgedessen verliert das Gas bereits anfangs viel Wärme, was bei der hohen Anfangstemperatur einen bedeutenden Energieverlust und eine wesentliche Verschlechterung des Wirkungsgrades zur Folge hat. Wollte man die Kühlung und Benetzung des oberen Zylinders dadurch verhüten, daß man den Zylinder nur teilweise mit Flüssigkeit füllt, so entstünde ein großer schädlicher Raum, der ebenfalls den Wirkungsgrad der Maschine herabsetzen würde.

Die Erfindung will diesen Nachteil vermeiden. Sie besteht darin, daß die Flüssigkeitssäule einen Stempel trägt, welcher eine Füllung des Arbeitszylinders mit Flüssigkeit ohne Bildung eines schädlichen Raumes gestattet. Der Stempel ist mit einem Schwimmkörper fest verbunden, welcher in der oberen Totpunktlage das Einströmen von Flüssigkeit in den darüberliegenden Zylinderraum, in der unteren Totpunktlage den Ablauf der Flüssigkeit verhindert und den Stempel unmittelbar auf der Oberfläche der Flüssigkeitssäule hält. Die abdichtenden Teile des Schwimmkörpers sind zweckmäßig aus elastischem Stoff. Stempel und Schwimmkörper sind durch eine Führungsstange im Zylinder so geführt, daß sie die Zylinderwandungen nicht berühren. Die Führungsstange ist nach unten verlängert und trägt einen Schieber, welcher in der oberen Totpunktstellung die Flüssigkeitszufuhr schwächt oder ganz absperrt.

Die Zeichnung zeigt eine Ausführungsform der Erfindung, und zwar

Abb. 1 den Zylinder im Schnitt bei oberer Totpunktstellung des Stempels,

Abb. 2 desgleichen bei unterer Totpunktstellung des Stempels,

Abb. 3 einen Schnitt nach Linie *A-B* zu Abb. 1,

Abb. 4 einen Schnitt nach Linie *C-D* zu Abb. 2.

Durch die im Zylinder *a* gestaute Flüssigkeitssäule (Abb. 1), deren Spiegel durch strichpunktierte Linien angedeutet ist, wird ein Stempel *b* getragen, dessen Form der des Zylinders angepaßt und dessen Querschnitt etwas kleiner als der des Zylinders ist. Stempel *b* ist durch eine Stange *c* mit einem Schwimmkörper *d* fest verbunden, welcher in der in Abb. 1 gezeichneten Stellung mit seiner oben abgeschrägten und zweckmäßig mit Gummi belegten Kante gegen einen in den Zylinderquerschnitt ragenden Ring *e* anliegt und so das Einströmen von Flüssigkeit in den darüberliegenden Zylinderraum verhindert. Auf diese Weise ist erreicht, daß der Flüssigkeitsspiegel die durch die strichpunktierten Linien angedeutete Grenze niemals überschreiten kann. Führungsstange *c* ist nach unten verlängert und trägt einen Schieber *f* in Form eines Hohlzylinders, welcher in der oberen Totpunktstellung die Mündung des Zuleitungsrohres *g* der Flüssigkeit ganz oder teilweise abschließt. In seiner unteren Totpunktstellung (Abb. 2) schließt der Schwimmkörper *d* den Abfluß der Flüssigkeit, so daß das in dieser Abbildung ebenfalls strichpunktiert angedeutete Niveau der Flüssigkeitssäule diese Grenze nach unten nicht überschreiten kann. Die nach unten abdichtenden Flächen des Schwimmkörpers *d* sind aus geeignetem elastischen Stoff *h* zum Zweck, den Stoß aufzufangen. Die Stange *c* ist an zwei Stellen geführt (Abb. 3 und 4), so daß weder der Stempel noch der Schwimmkörper die Zylinderwandungen berührt. Hierdurch wird die Innenauskleidung des Zylinders geschont und Reibungsarbeit vermieden.

Die Arbeitsweise der in den Abb. 1 und 2 dargestellten Vorrichtung ist folgende:

Durch das Wasserzuleitungsrohr *g* wird Wasser in den Arbeitszylinder eingelassen, so lange, bis Stempel *b* seine oberste Stellung erreicht hat und Schwimmkörper *d* gegen Ring *e* anliegt. Gleichzeitig wird die Wasserzuleitung durch Schieber *f* abgeschwächt oder ganz gesperrt und mittels des bisher geschlossenen Dreiweghahnes *i* die Gaszufuhr freigegeben. Unter dem Einfluß des expandierenden Gases wird die in dem Zylinder gestaute Flüssigkeitssäule durch ein Rohr *k* der Turbine zugeführt. Durch Umstellen des Hahnes *i* wird anschließend die Auspufföffnung freigegeben, so daß durch die erneut in den Zylinder einströmende Flüssigkeit Schwimmer *d* und Stempel *b* wieder hochgehoben und die Verbrennungsgase ausgepufft werden.

PATENT-ANSPRÜCHE:

1. Brennkraftturbine, bei welcher die Verbrennungsgase eine Hilfsflüssigkeit aus einem Behälter auf eine Turbine treiben, dadurch gekennzeichnet, daß die Flüssigkeit einen Stempel (*b*) trägt, welcher eine Füllung des Arbeitszylinders (*a*) mit Flüssigkeit ohne Bildung eines schädlichen Raumes gestattet.

2. Turbine nach Anspruch 1, dadurch gekennzeichnet, daß der Stempel (*b*) mit einem Schwimmkörper (*d*) fest verbunden ist, welcher in der oberen Totpunktlage das Einströmen von Flüssigkeit in den darüberliegenden Zylinderraum, in der unteren Totpunktlage den Ablauf von Flüssigkeit verhindert und den Stempel unmittelbar auf der Oberfläche der Flüssigkeitssäule hält.

3. Turbine nach Anspruch 1 und 2, dadurch gekennzeichnet, daß die abdichtenden Teile des Schwimmkörpers aus elastischem Stoff bestehen.

4. Turbine nach Anspruch 1 bis 3, dadurch gekennzeichnet, daß Stempel und Schwimmkörper durch eine Führungsstange (*c*) im Zylinder (*a*) geführt sind, so daß sie die Zylinderwandungen nicht berühren.

5. Turbine nach Anspruch 1 bis 4, dadurch gekennzeichnet, daß die Führungsstange einen Schieber (*f*) trägt, welcher in der oberen Totpunktstellung die Flüssigkeitszuführung absperrt.

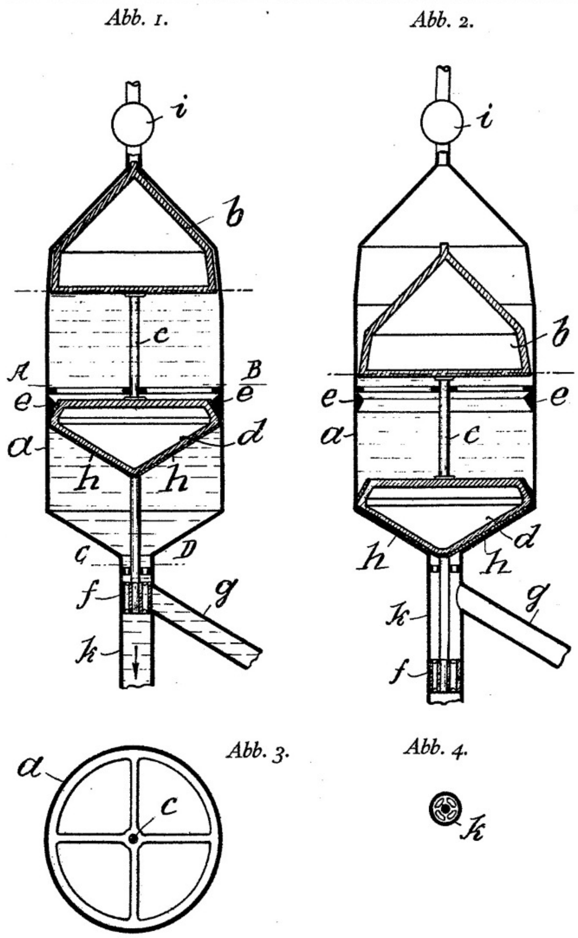


Figure 9.64: Hermann Oberth filed a patent application on gas turbine engines for aircraft in 1925.

One of the most important figures in the development of jet technology was Hans von Ohain (German, 1911–1998), a young physicist who dreamed of creating practical jet engines and aircraft. Working with the mechanic Max Hahn (German, 18??–19??), von Ohain designed his first prototype jet engine in 1933 and demonstrated it in 1935 (Fig. 9.65, top). Von Ohain's biographer Margaret Conner described the prototype [Conner 2001, pp. 38–39]:

> Von Ohain said that in a little storage room behind the shop, "We made a little model according to my own sketches. It was about three feet in diameter and about one foot wide. The blades were made of heavy sheet metal. Almost nothing was welded because Hahn was more a man for clean machining operations, and for fastening with bolts and nuts." It was a pancake engine for either vertical or horizontal thrust, a very light design. [...]
>
> Von Ohain moved his device to the back room of the Bartels and Becker garage. It was exciting to von Ohain and Hahn if the device worked at all. Each time the model was tested, long yellow flames streaked out. [...] Max Hahn, normally very stern and skeptical, seemed in this instance to be quite positive and optimistic. He conceded, in a rare glimpse of a sense of humor, "At least the flames came out of the right place," and with high velocity. The engine did not self-sustain but did result in the unloading of the starter [doing the work of the starter motor when burning]. Instead of the pounding of the conventional engine there was a smooth flow of power, and a new sound, a piercing whistle.

The 1935 prototype jet engine of von Ohain and Hahn caught the attention of Ernst Heinkel (German, 1888–1958), a politically very powerful aircraft manufacturer who hired them in 1936 and provided them with all the resources and long-term support needed to build and test improved versions such as the HeS 1 (Fig. 9.65, bottom) [Conner 2001, pp. 61–62]:

> The project engine was designated the He S 1, He S for *Heinkel-Strahltriebwerk* (Heinkel jet engine). The He S 1 engine was made essentially of sheet steel fabricated at the Marienehe works and disks created at a nearby shipyard. It consisted of a back-to-back radial compressor and a radial inflow turbine. The rotor diameter was 12 inches (300 mm). The demonstrator combustor did not present any significant problems. The engine operated at a speed of 10,000 rpm and produced a thrust of 250 lbs (1.1 kN). It performed flawlessly under design conditions and during transient acceleration and deceleration. The sound was smoothed and focused, and the size of the unit was suitable for an aircraft. [...]
>
> The He S 1 engine was completed and installed in the test bed about the end of February 1937. Von Ohain said that the first test took place in March 1937.

A further improved engine, the HeS 3 (Figs. 9.66– 9.67), was first run in March 1938. It was then installed in a Heinkel He 178 aircraft, which in August 1939 became the world's first operational jet plane. Sterling Pavelec, professor of aerospace history at the USAF Air Command and Staff College, described the first test flight [Pavelec 2007, p. 22]:

> On August 27, 1939, Heinkel test pilot Erich Warsitz lifted off the airfield at Marienehe completing the first ever jet flight. The Heinkel team had ushered in a new era of aeronautical engineering. [...]
>
> The HeS 3b turbojet that powered the Günther's He 178 V1 produced 500 kg (1,100 lbs) thrust. The plane was designed around the engine, with the air intake in the nose and a tubular frame that housed the centrifugal-flow engine. Warsitz took off for the first time in a turbojet-powered aircraft and achieved a top speed—with the wheels down—of 300 kmph (187 mph). Warsitz was also the first to suffer a jet bird strike, which cut his flight short, but without substantial damage to the airplane or engine.

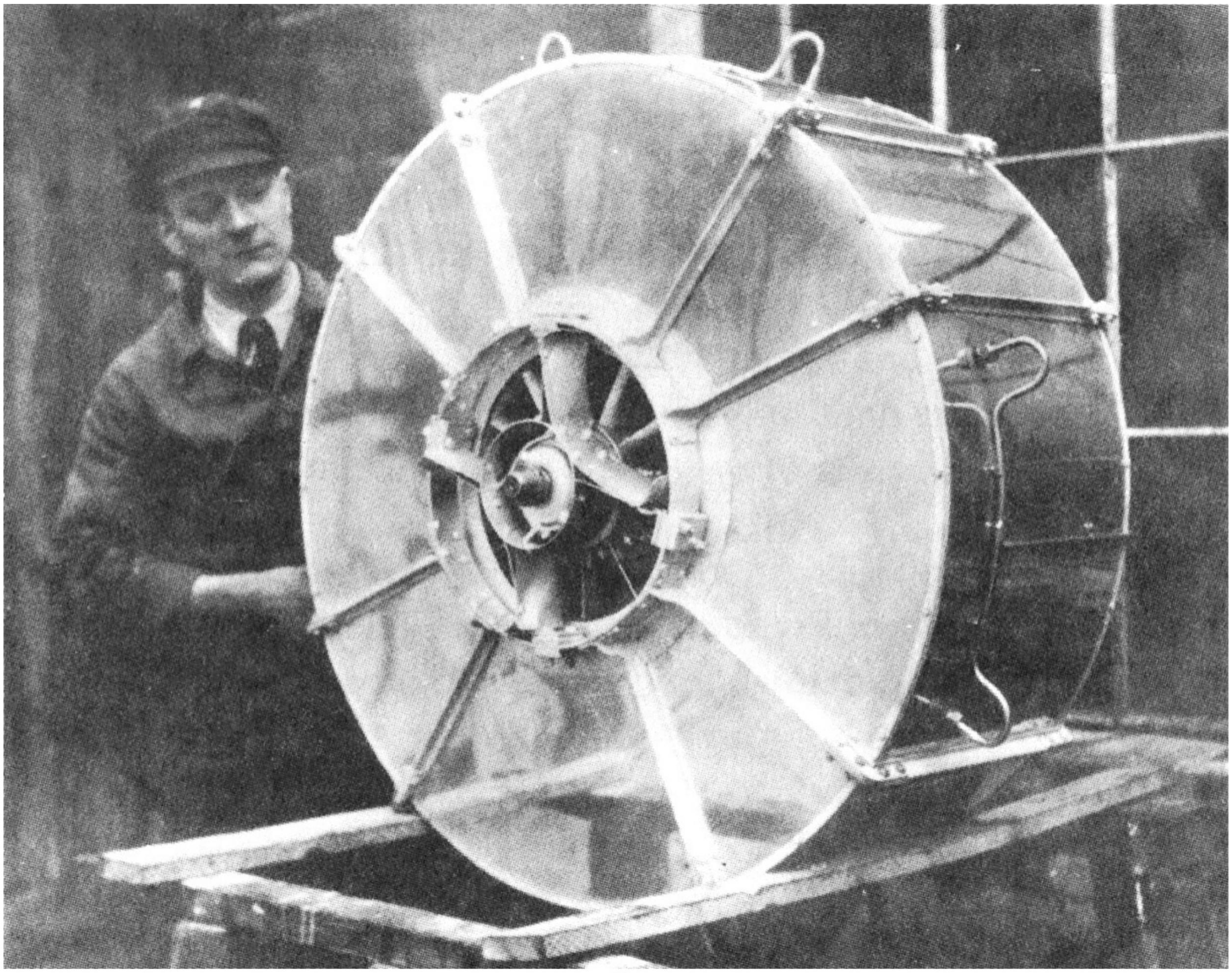
That initial single-engine jet aircraft was followed by the twin-engine He 280 jet aircraft in early 1941, using the newest HeS 8 engines (Fig. 9.68, first run September 1940) [Pavelec 2007, p. 28]:

> The He 280 airframe was prepared, and the anticipated HeS 8a engines were finally ready by March 1941. [...] The first engines were delivered, the plane was readied, and the chief test pilot Fritz Schäfer was able to make the first flight in the twin-engine He 280 on March 30, 1941. The plane tested well[....]

Von Ohain and his collaborators such as Max Hahn and Wilhelm Gundermann (German, 1904–1997) developed a long series of ever-improving jet engines in the 1930s and 1940s. Figure 9.69 shows Heinkel and von Ohain celebrating the flight of the He 178 in 1939; it also shows von Ohain's last known completed wartime engine, the He S 011, which he developed with Max Adolf Müller (German, 1901–1962) in 1943.

In addition to the He 178 and the twin-engine He 280 jet fighter, Heinkel's wartime team developed He 162 jet fighters (p. 1711) and apparently even intercontinental jet bombers (Section E.1).

After the war, von Ohain helped develop a wide range of jet and rocket engines in the United States.



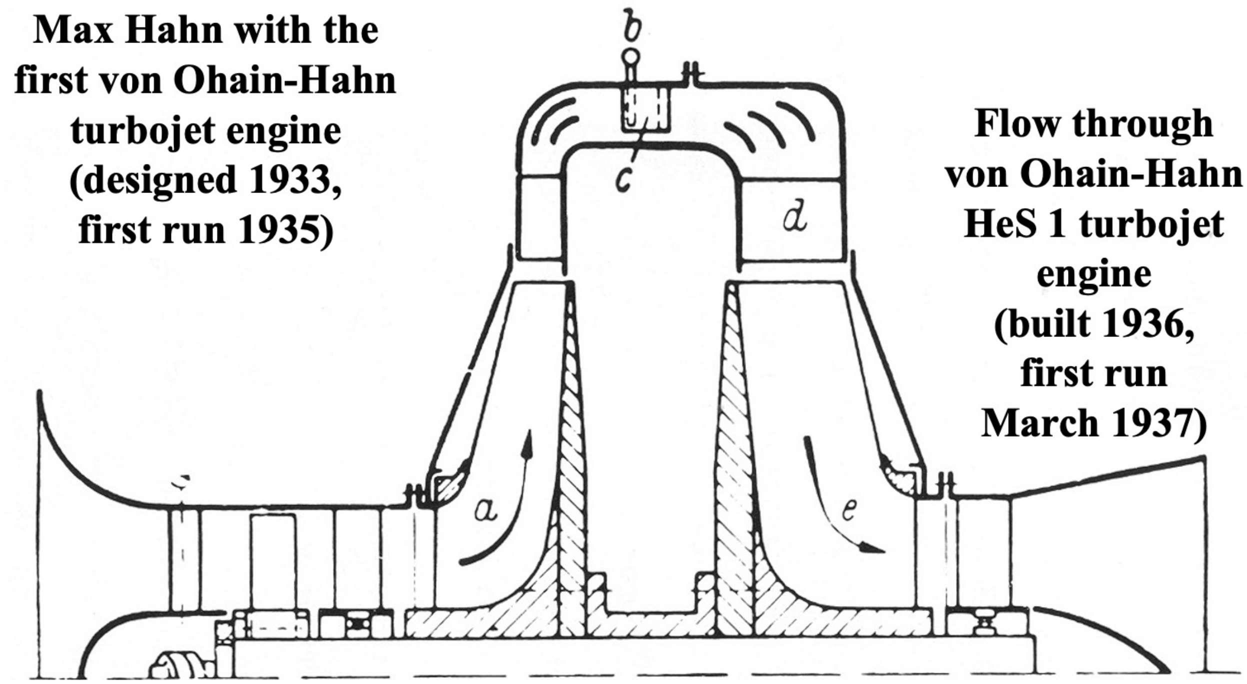


Figure 9.65: Top: Max Hahn with the first von Ohain-Hahn turbojet engine (designed 1933, first run 1935). Bottom: Flow through von Ohain-Hahn HeS 1 turbojet engine (built 1936, first run March 1937).

Patented Sept. 16, 1941 **2,256,198**

UNITED STATES PATENT OFFICE

2,256,198

AIRCRAFT POWER PLANT

Max Hahn, Seestadt Rostock, Germany, assignor to Ernst Heinkel, Warnemunde, Germany

Application May 31, 1939, Serial No. 276,572
In Germany May 27, 1938

6 Claims. (Cl. 60—35.6)

The invention relates to a power plant, especially a propulsion unit of aircraft, due to the reaction or rocket effect, with an air compressor, a combustion plant and a gas turbine driving the compressor.

Object of the invention is to provide a driving apparatus of little weight, which is compact and in which difficulties for journalling are avoided.

A further object of the invention is to provide an apparatus which is especially adapted for fast aircraft.

A further object of the invention is to reduce the frontal face of the apparatus and thereby its resistance against the flow of air by a suitable location of the combustion chamber. This feature is of great importance for manufacturing very fast aircraft.

A further object of the invention is to branch part of the air compressed by the compressor and to mix this branched air with the combustion gases of high temperature leaving the combustion chamber and thereby obtaining a low temperature at the entrance of the turbine, a good efficiency of the combustion in the combustion chamber being maintained.

A further object of the invention is to form parts of the combustion chamber detachable for the access to the interior of the combustion chamber, especially to the nozzles of the burners to interchange them.

Further features of the invention will be given in the following description and the drawings.

Fig. 1 is a longitudinal section of the apparatus, and

Fig. 2 is a vertical section according to the line II—II of Fig. 1.

Referring to the drawings, 1 designates the blower, 2 the combustion chamber and 3 the turbine. The blower 1 and the turbine 3 are encased in a common housing 4, provided with an inlet aperture 5 and an outlet aperture 6. The blower 1 and the turbine 3 are arranged upon a shaft 7, rotatably mounted in bearings 7′. The bearings 7′ are in turn supported by brackets 8, 8 which are attached to the housing 4 in the inlet aperture 5 and the outlet aperture 6. The blower 1 and the turbine 3 are not arranged directly upon the shaft 7, but upon a tube 9 held at some distance from but firmly connected to the shaft 7. Both the blower 1 and the turbine 3 possess a plurality of vanes 10, 11 arranged radially upon the tube 9, said vanes being separated from one another by a partition wall 12 attached to the tube 9, so as to form a plurality of chambers constituting U-shaped guides for the flow medium. Both at the inlet aperture of the blower as well as at the outlet aperture of the turbine the vanes 10 and 11 are bent off at 13. At the outlet aperture 6 is provided a flow element 21 which is intended to prevent the formation of eddies.

The housing 4 encasing the blower 1 and the turbine 3 carries at its front end the annular combustion chamber 2, a substantial portion of which, in the example illustrated, is constituted by a simple shell 14 which is flanged on to the housing 4 and in which fuel inlets 15 are arranged. Within the combustion chamber 2, a guide vane 16 spaced from the front portion of the housing 4 is also provided, said guide vane being adapted to guide a portion of the air conveyed by the blower as combustion air into the combustion chamber 2 and thence to the intermediate mixing chamber 17.

The guide vane 16 overlaps in a certain distance the radial outlet aperture of the compressor and is furnished at its inside with an annular air scoop with triangular cross section; that part is indicated by the reference number 22.

Spaced from the shell 14 which constitutes the outer wall of the combustion chamber 2, a further dish-shaped guide vane 18 is provided which, together with the guide vane 16, forms an annular channel 19 leading out of the combustion chamber 2. The distance between the guide vane 18 and the shell 14 is in this case smaller than the distance between the guide vane 16 and the front portion of the housing 4. The dish-shaped guide vanes 16 and 19 consist preferably of thin sheet metal having high heat-resistance whilst the remaining parts of the apparatus insofar as they are exposed to stresses, preferably consist of high-quality steel. Within the combustion chamber 2 numerous burners 20 conveniently distributed uniformly over the entire periphery of the combustion chamber 2 are provided. At the outlet end of the apparatus a flow element 21 of stream-lined form is provided.

The apparatus of the invention operates as follows:

The fuel, e. g. gasoline, is ignited at 20 by the burners distributed over the entire periphery of the combustion chamber 2. The blower 1 and turbine 2 are started in suitable manner familiar to the man skilled in the art, e. g. by means of compressed air. When the blower and the turbine are rotating, air is sucked by the blower 1 through the entrance opening 5 in an axial direction and this air is compressed. The compressed air is discharged in a radial direction from the outlets of the blower 1 into the intermediate mixing chamber 17. A portion of the compressed air is fed into the branch line terminating at the periphery of the blower 1 and this air is led through the passage formed by the guide vanes 16 and part of the walls of the housing 4. A portion of this branched air is discharged into the combustion chamber 2 and serves for completely burning the fuel fed by the fuel inlets 15. The rest part of the branched air flows between the walls 14 and 18 and is fed back to the intermediate mixing chamber 17. The hot combustion gases produced in the combustion chamber 2 leave the combustion chamber 2 through the ring channel 19 into the intermediate mixing chamber 17; in this chamber they are partly mixed with the colder air streams surrounding this hot stream inwardly and outwardly in the intermediate mixing chamber 17. Then this mixture of combustion gases and compressed air flows into the inlet openings of the radial turbine 3 and part of the energy of the gases and compressed air is absorbed in this turbine. Then the gases leave the radial turbine in an axial direction through the outlet end 6 of the apparatus.

The portion of the cold air conveyed by the blower 1 and guided by the guide vane 16 towards the front side of the apparatus cools both the portion of the housing wall which is located within the combustion chamber 2 as well as the dish-shaped external wall 14 of the combustion chamber 2 and the dish-shaped guide vanes 16 and 18.

The cold air conveyed by the blower 1 into the mixing chamber 17 is there driven outwardly owing to its gravity. Due to the fact that the hot gas of the combustion chamber entering through the passage 19 into the intermediate mixing chamber is forced through the cold air in the intermediate mixing chamber 17 a very intensive mixing of the cold air and hot gas is effected, special mixing devices not being necessary. The resultant mixture of air and combustion gases drives the turbine 3 and after passing through the turbine 3 leaves the apparatus with a certain content of energy, such that it produces a reaction force.

The energy which, by means of the blower is imparted to the flowing medium, e. g. the air which flows in, is increased by the amount of energy of the fuel introduced, so that a considerably increased energy is available for driving the turbine and for generating a reaction force.

What I claim is:

1. In an aircraft power plant operating by the effect of reaction, a housing, a channel in the housing for introducing air and a channel for discharging gas, a bearing connected to the housing and disposed in the entrance channel, another bearing connected to the housing and disposed in the discharge channel, a rotor journalled in the bearings and comprising a one-step compressor and a one-step turbine, entrance openings being provided in the compressor adjacent to the entrance channel of the housing and discharge openings being provided in the turbine adjacent to the discharge channel of said housing, said compressor having outlet ports and said turbine having inlet ports the compressor also having vanes arranged in meridian sections and simultaneously arranged axially for introducing the air and radially for the discharge of the air, the turbine likewise having vanes arranged in meridian sections and simultaneously arranged radially for the introduction of the gas and axially for the discharge of the gas and a ring-shaped combustion chamber connecting the outlet port of the compressor and the inlet port of the turbine, the said combustion chamber being arranged at the frontal surface of the housing coaxially around the entrance channel for the air.

2. An aircraft power plant according to claim 1, in which the ring-shaped combustion chamber consists of a pressure-tight housing and heat resistant inner walls, which form an air-channel between the housing and the combustion chamber.

3. An aircraft power plant according to claim 1, in which the ring-shaped combustion chamber consists of a pressure-tight housing and heat resistant inner walls, said walls forming an air-channel between the housing and the combustion chamber, said air channel having a ring shaped discharging opening arranged on the inner diameter of the combustion chamber and serving for discharging combustion air into the said combustion chamber.

4. An aircraft power plant according to claim 1, in which the ring-shaped combustion chamber consists of a pressure-tight housing and heat resistant inner walls, which form an air-channel between the housing and the combustion chamber, part of the wall overlapping the discharge opening of the compressor and having means for branching off a portion of the air emerging from the compressor.

5. An aircraft power plant according to claim 1, in which the ring-shaped combustion chamber consists at least of two stationary parts, one of which forms a front part and is detachable.

6. An aircraft power plant according to claim 1, in which the ring-shaped combustion chamber consists of a pressure-tight housing and heat resistant inner walls, which form an air channel between the housing and the combustion chamber, part of the wall over-lapping the discharge opening of the compressor and having means for branching off part of the air emerging from the compressor, said air channel having a ring-shaped discharging opening arranged on the inner diameter of the combustion chamber for discharging combustion air in the combustion chamber, and said combustion chamber consisting at least of two stationary parts, one of which forms a front part and is detachable.

MAX HAHN.

Max Hahn's patent based on the HeS 3 turbojet engine

Fig.2

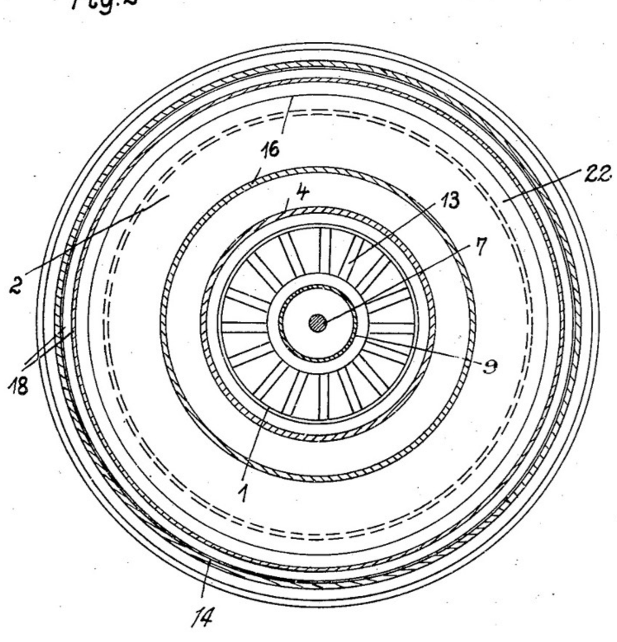


Fig.1

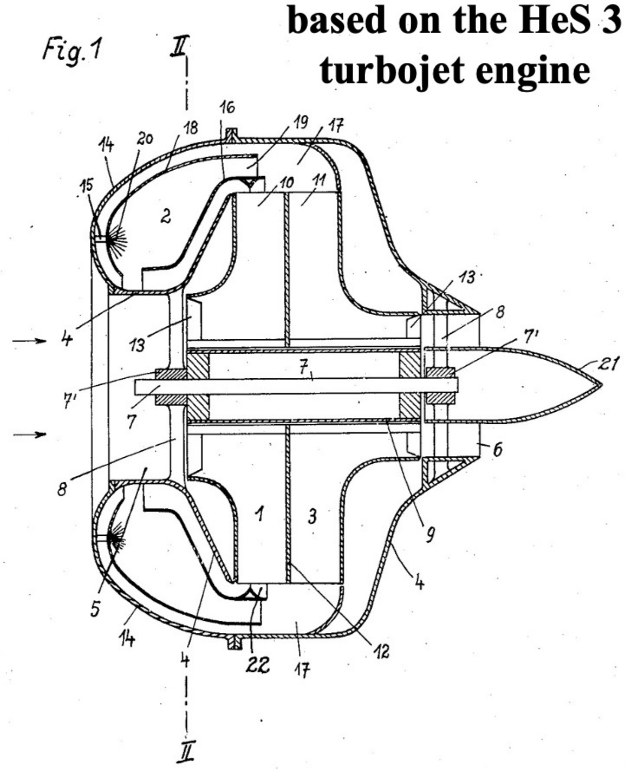
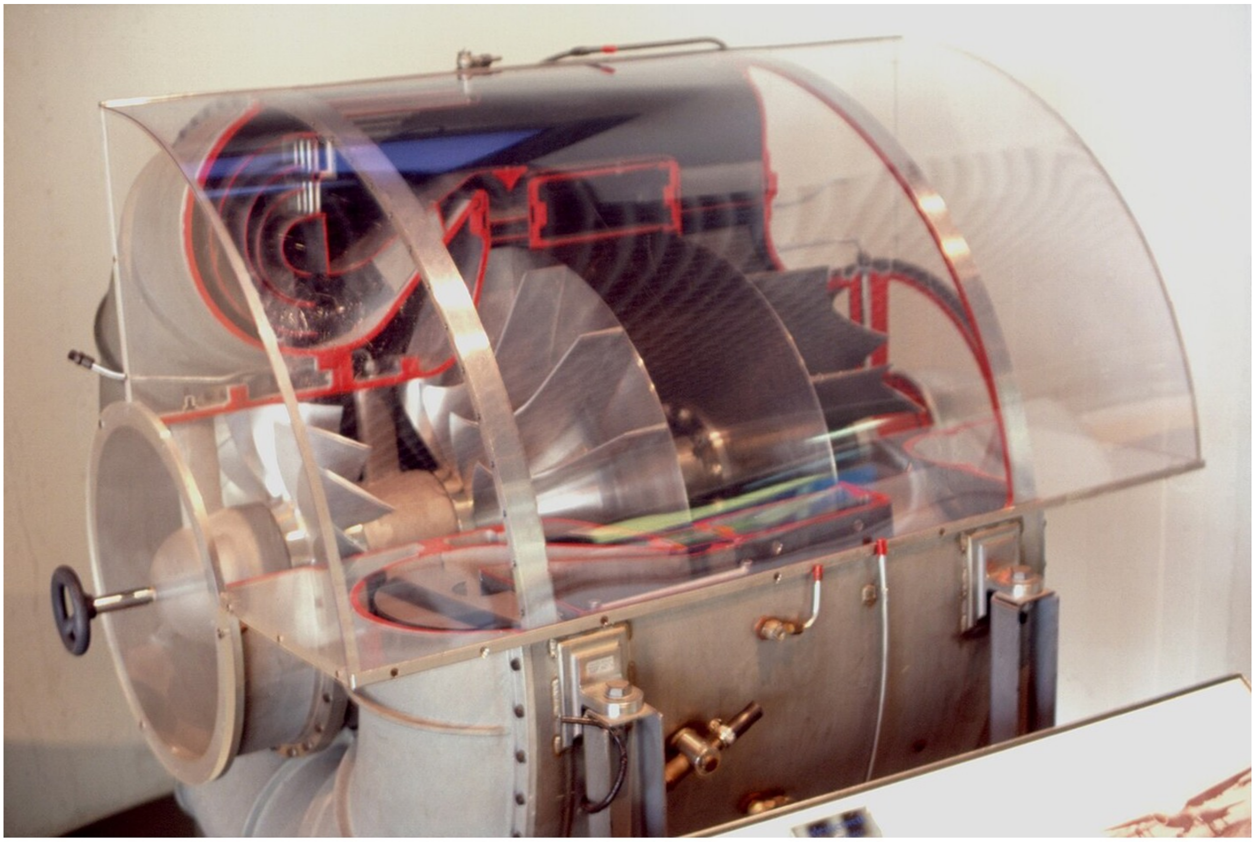


Figure 9.66: Max Hahn's patent based on the HeS 3 turbojet engine.



HeS 3 turbojet engine (first run March 1938)

First jet aircraft, Heinkel He 178 with HeS 3 engine (first flown 27 August 1939)

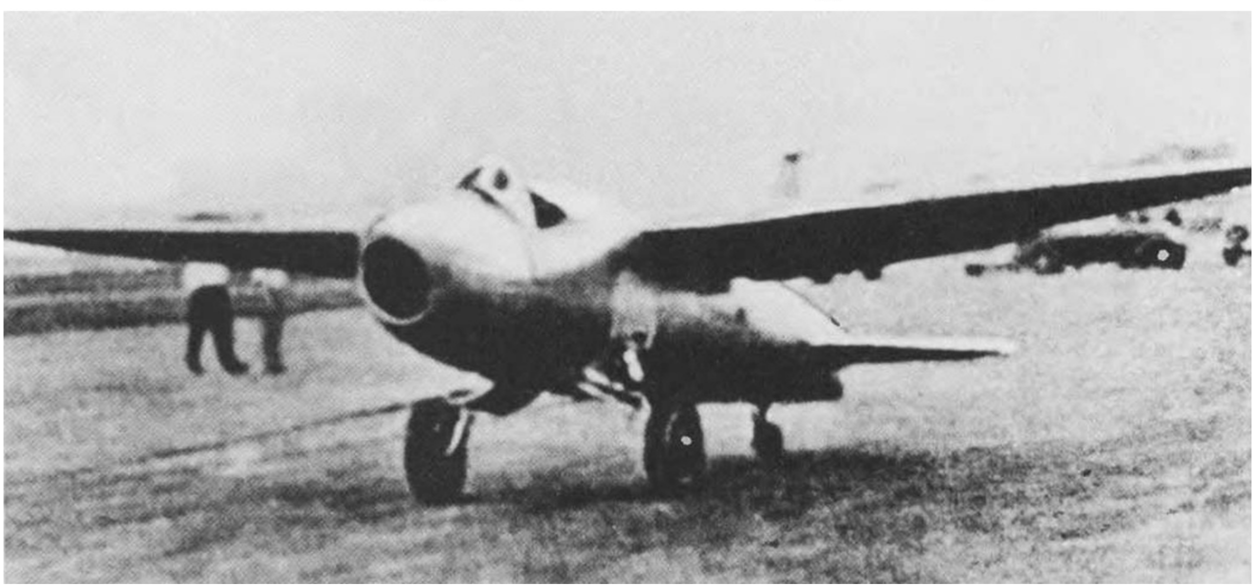


Figure 9.67: Top: HeS 3 turbojet engine (first run March 1938). Bottom: First jet aircraft, Heinkel He 178 with HeS 3 engine (first flown 27 August 1939).

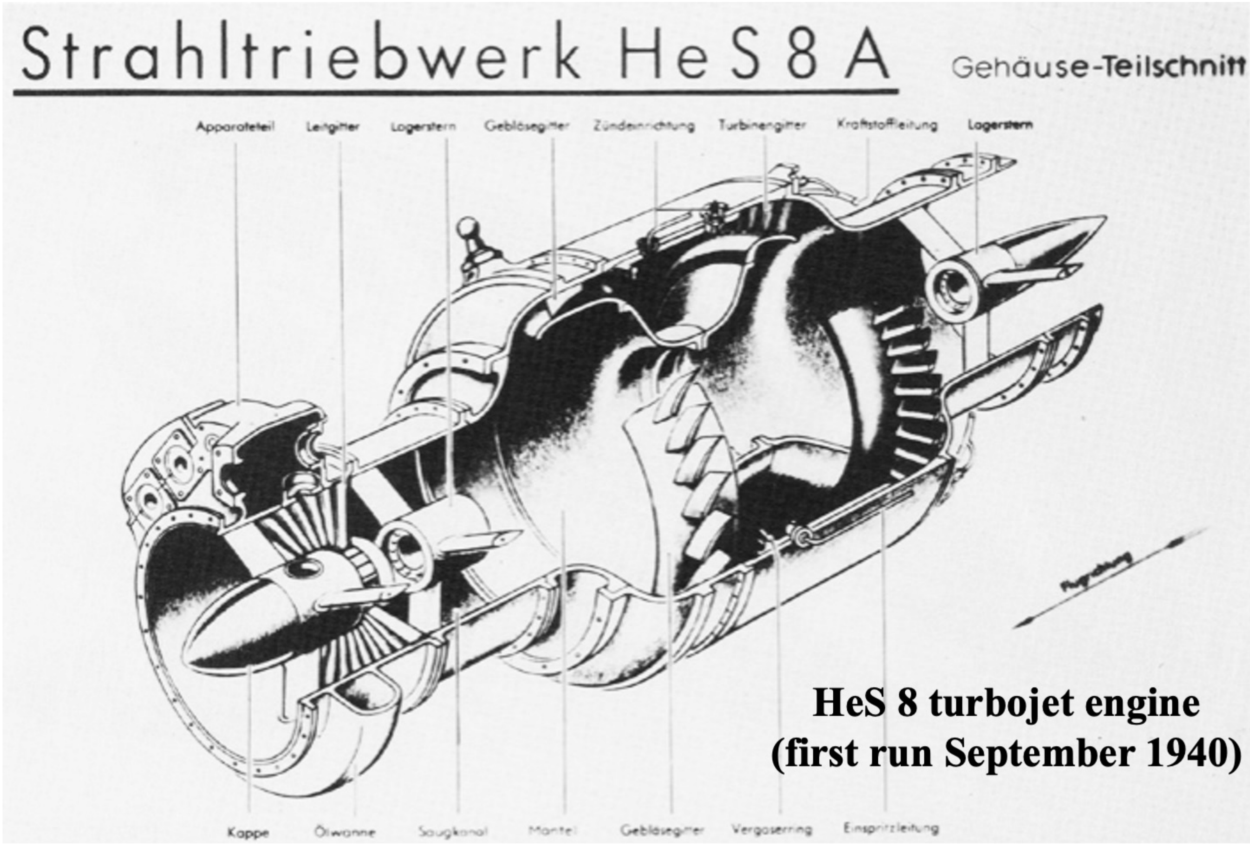


Figure 9.68: Top: HeS 8 turbojet engine (first run September 1940). Bottom: Heinkel He 280 with two HeS 8 turbojet engines (first flight 30 March 1941).

Ernst Heinkel (1888–1958) **Hans von Ohain (1911–1998)**

Ohain-Müller HeS 011 turbojet engine (first run September 1943)

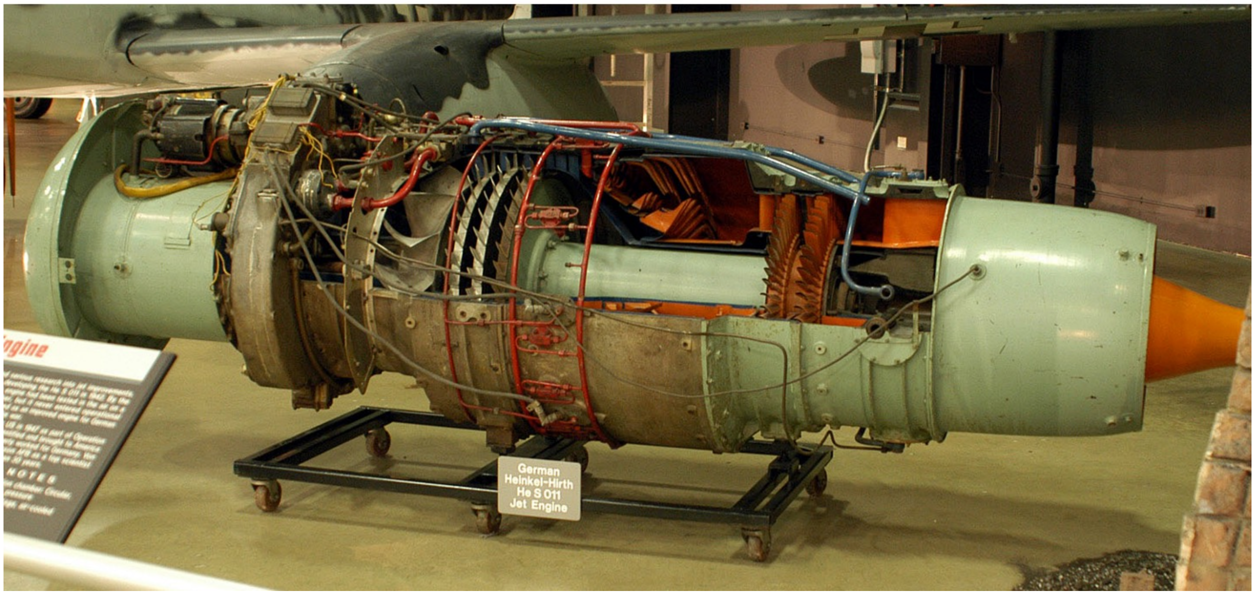


Figure 9.69: Top: Ernst Heinkel and Hans von Ohain celebrating the flight of the first jet aircraft, the Heinkel He 178, in 1939. Bottom: The HeS 011 turbojet engine, developed by von Ohain and Max Adolf Müller (first run September 1943).

Albert Betz (German, 1885–1968) and Walter Encke (German, 1888–1982), shown in Fig. 9.70, developed axial-flow compressors, which were utilized in most wartime German jet engines and virtually all modern jet engines. Betz also developed highly efficient wind turbine designs that are now used worldwide (p. 1677).

Herbert Wagner (Austrian, 1900–1982) and Max Adolf Müller (German, 1901–1962) led a team that was working to develop axial-flow compressors and prototype turbojet, turbofan, and turboprop engines at Junkers in the 1930s, as shown in Figs. 9.71–9.75. Due to management difficulties at Junkers, in 1939 Wagner left Junkers to create guided missiles and smart bombs at Henschel (see Section 9.6). Müller and most of the rest of Wagner's jet engine team (such as Rudolf Friedrich, German, 1909–1998) joined von Ohain's jet engine development program at Heinkel. Wagner also worked on German nuclear weapons programs during the war (p. 4203). After the war, Wagner developed a wide range of guided missiles and smart bombs in the United States, and Müller designed jet engines and related technologies in the United Kingdom.

After Wagner and Müller left the Junkers company, Anselm Franz (Austrian, 1900–1994) quickly rebuilt the jet engine program and engineering team at Junkers in 1939. Franz and his team designed and demonstrated the Jumo (Junkers Motors) 004 axial-flow turbojet engine (first run in 1940, Fig. 9.76); at least 8000 Jumo 004 engines were produced during the war. Franz and his team also developed other engines such as the Jumo 022 turboprop engine (Fig. 9.84).

After the war, Anselm Franz moved to the United States and joined the Lycoming company, along with many members of his Junkers jet engine team, including Heinrich Adenstedt (German, 1910–1991), Hans Berkner (German, 19??–19??), Friedrick Bielitz (German, 19??–19??), Siegfried Decher (German, 19??–19??), Heinz Moellmann (German, 19??–19??), and Wolfgang Stein (German, 19??–19??). At Lycoming, they produced the T53 and T55 turboshaft engines (which became widely used in helicopters and turboprop planes), PLF1 turbofan engine (the first high-bipass turbofan engine, important for jet airliners), AGT1500 turboshaft engine (for tanks and other land and sea vehicles, as well as stationary power plants, p. 1391), and other jet and gas turbine engines (pp. 1752–1755).

Early turbojet engines were challenged by overheating of the central components, especially the turbine blades, which shortened the operational lifetime of an engine before it needed to be rebuilt or replaced. That challenge arose both because of the extremely high temperatures achieved inside the engines and also because of the shortage of major high-temperature metals due to Allied blockades and bombing. In response, engineers such as Hermann Hagen (German, 19??–19??), Karl Leist (for his DB 007 engine), Paul Leistritz (German, 18??–1957), and Christian Lorenzen (German, 19??–19??) developed methods of directly cooling the blades inside a turbine. Many other scientists and engineers developed novel high-temperature ceramics (p. 673) and new high-temperature metal alloys (p. 695) that could be fabricated into turbine blades. For example, both in Germany during the war and in the United States after the war, Anselm Franz collaborated very closely with Heinrich Adenstedt (German, 1910–1991, pp. 703–704), an expert on high-temperature metal alloys. Such high-temperature ceramics and alloys are still widely used in a variety of modern engine types.

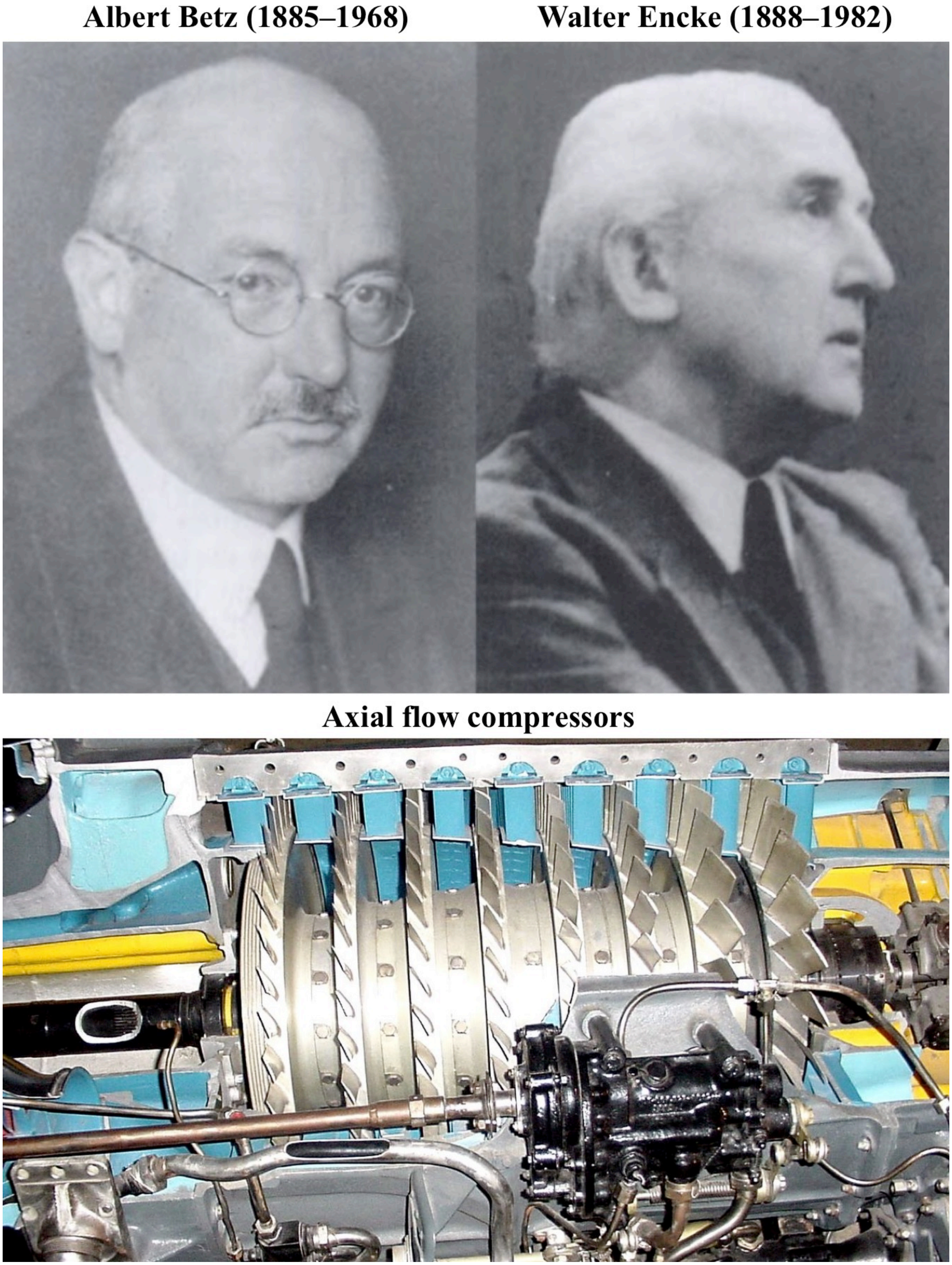


Figure 9.70: Albert Betz and Walter Encke developed axial flow compressors.

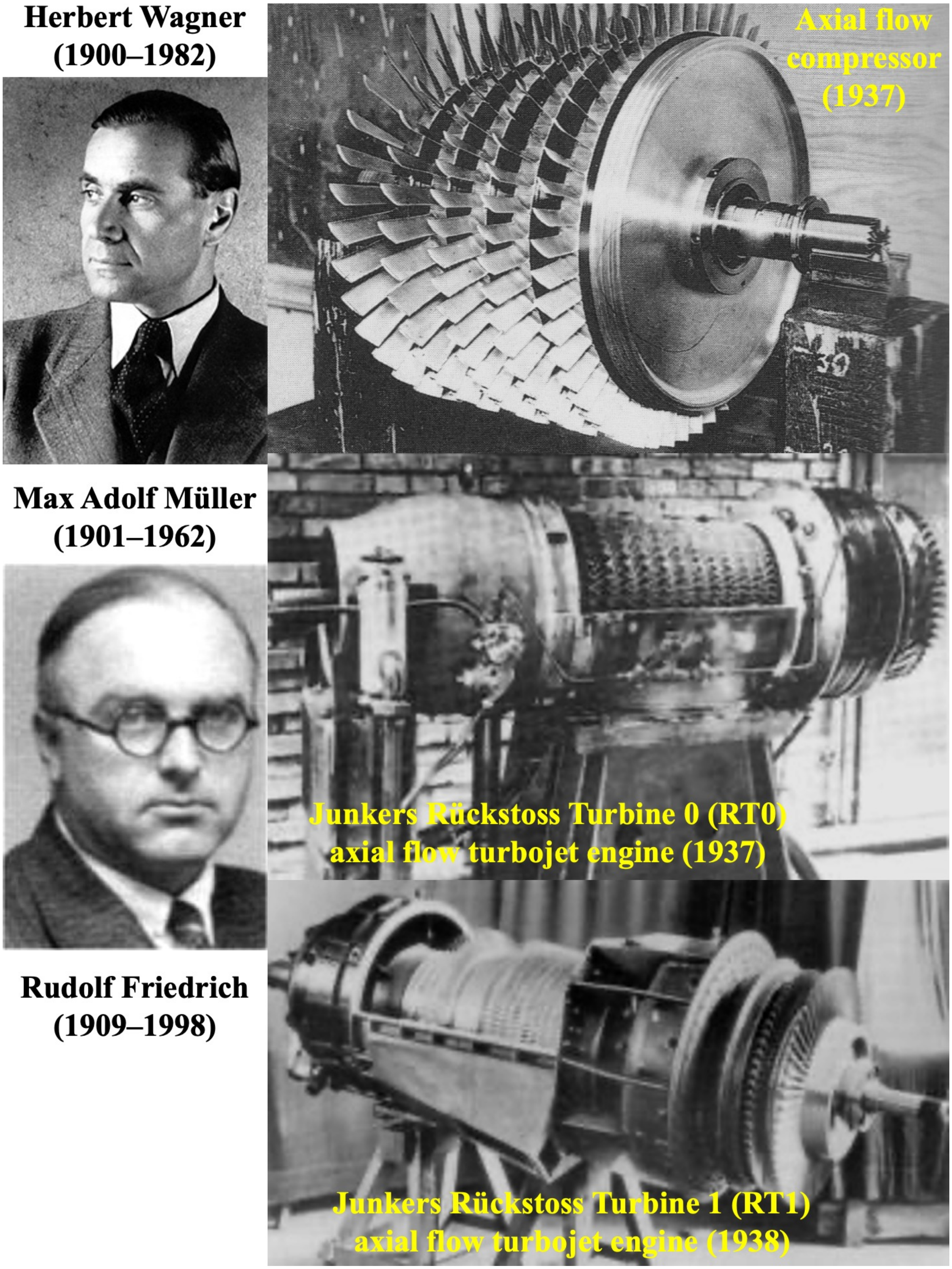


Figure 9.71: Herbert Wagner, Max Adolf Müller, and Rudolf Friedrich led a team that was working to develop prototype turbojet, turbofan, and turboprop engines at Junkers in the 1930s.

Herbert Wagner's turboprop and turboshaft patent application (February 1936)

PATENT SPECIFICATION **495,469**

Convention Date (Germany): Feb. 8, 1936. No. 3682/37.
Feb. 8, 1936. No. 3683/37.

Application Date (in United Kingdom): Feb. 8, 1937.

Specification not Accepted

COMPLETE SPECIFICATION

An Improved Method of and Means for Propelling Aircraft

I, Prof. Dr. HERBERT WAGNER, a German citizen, of Cunostrasse 67b, Schmargendorf, Berlin, Germany, do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In order in the case of combustion engines of the piston type, which are employed, for example, for driving the airscrews of aircraft, to maintain the output substantially constant at high altitudes despite the decreased density of the air at these heights it is usual to provide compressors which supply compressed air to the engine.

It has also been proposed to provide between the engine and the propeller a gear having a variable transmission. This gear has the object of varying the circumferential velocity of the airscrew as compared with the substantially constant velocity of the engine, in order to be able to adapt the running conditions of the airscrew to the different altitudes concerned. These variable speed gears have not been adopted in practice owing to the fact that the variable airscrew (airscrew having a variable pitch), which was introduced in the meantime, largely eliminated any necessity for varying the speed of the airscrew.

There have also been proposed for the propulsion of aircraft gas turbines comprising in substance a compressor, a combustion chamber, and a turbine driven by the burnt gases. It is known to employ these turbines as reaction or "rocket" device, in which case they eject the combustion gases towards the rear, or for driving the conventional type of propeller.

In order to maintain the output of these gas turbines substantially constant at different altitudes it has also been proposed, in adaptation to the practice adopted in respect of internal combustion engines, to furnish special compressors for supplying the turbine with compressed air, so that the circumferential velocity of the turbine will remain substantially the same irrespective of the particular height.

The provision of these compressors is accompanied by the disadvantage of considerably increased weight and a much more complicated design of the entire power aggregate.

The invention provides a new method of diminishing, or entirely eliminating, a drop in output at comparatively high altitudes in the case of gas turbines. According to the invention, the circumferential velocity of the gas turbine is increased with increasing altitude. In this way there is obtained in face of the existing art a considerably simplified construction. There may be obtained at higher altitudes a greater compression ratio of the turbine, and accordingly a higher output and an improved efficiency, without the use of special compressors.

In gas turbines employed for driving airscrews it is proposed in accordance with the invention to provide a reducing gear between the turbine and the propeller, in such fashion that, with a substantially constant velocity of the propeller, the gas turbine at higher altitudes will run at a greater speed than at lower altitudes. The airscrew may be adapted to the particular conditions prevailing by varying the pitch of the blades of the screw.

A particularly simple means of reducing to practice the idea according to the invention of increasing the circumferential velocity of the gas turbine with increasing height consists in providing between the gas turbine and the propeller a reducing gear having an invariable transmission ratio for driving the propeller at low altitudes, for example for starting purposes or for gaining height,

[Price 1/-]

and also to furnish a clutch device in order, after disengagement of the propeller, to allow the gas turbine at higher altitudes to run at a greater speed, in which case the gas turbine will then act as a pure "rocket" device.

In the case of piston engines an increase in the circumferential velocity would not only fail to improve the compression ratio, but would also represent an increase of the mechanical load on the engine. On the other hand in the case of the highly loaded low-pressure blades of a gas turbine the reduced bending strain on the blades owing to the decrease in the pressure of the air permits at high altitudes of an increase in the load imparted by the centrifugal force and according of an increased circumferential velocity.

The invention will now be described more particularly with reference to the accompanying drawing, which illustrates two possible forms of embodiment.

Fig. 1 is a vertical section taken through a gas turbine aggregate, which in accordance with the invention is furnished with a variable speed gear between the gas turbine and the propeller.

Fig. 2 is a vertical section taken through a gas turbine aggregate, which in accordance with the invention is furnished with an invariable reducing gear and a clutch.

Referring to Fig. 1, the compressor is shown in the form of an axial compressor 1, 2 being the combustion chamber and 3 the turbine. The air enters the compressor 1 at 4 and is heated by the burnt fuel in the combustion chamber 2. The burnt gases drive the turbine 3 and are ejected towards the rear through the diffuser 5. The gas turbine is mounted on the fuselage 16, 17 being the wing of the aircraft.

Connected with the compressor 1 is a gear 6. The shaft 7, on which there are firmly mounted the gear wheels 8 and 9, is connected with the compressor 1. On the key shaft 10, on which is mounted the propeller 11, which is preferably constructed as a variable-pitch propeller, there are mounted to be shiftable the two gear wheels 12 and 13. The gear wheels 12 and 13 may be displaced by means of the fork 14 and the lever mechanism 15 leading to the pilot's seat (not shown), so that the reduced transmission between gas turbine and propeller may be varied. If the shiftable gear wheels 12 and 13 are situated in an intermediate position between the wheels 8 and 9, so that no wheel is in engagement, the gas turbine and the propeller are not connected. The displacement may be effected by hand; it may, however, also be performed by means of a servo-motor. If desired, the variation in the reduced ratio may also take place automatically, for example dependent on the altitude. In the present example a two-speed gear has been shown; there is, however, no limitation with regard to the number of speeds which may be provided. It is also possible to employ a gear in which there is no break in the variation of the speed, for example a hydraulic gear or the like.

Fig. 2 shows a possible embodiment of the invention making use of an invariable reducing gear and a clutch. In the drawing there has been shown a dog clutch. This, however, may also be a spring-controlled friction clutch, an electro-magnetic clutch or a clutch of any other design.

With the compressor 1 there is connected the smaller gear wheel 18, which meshes with the larger gear wheel 19. To the wheel 19 there is firmly connected the disc 20 of the clutch. On the shaft 21 carrying the propeller 11 there is mounted the shiftable clutch plate 22, which may be moved into engagement with the plate 20. The plate 22 may be shifted by means of the fork 23 and the lever mechanism 24.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

1. A method of adapting the output of gas turbines for propelling aircraft and comprising in substance a compressor, a combustion chamber and a turbine to different altitudes, characterised in that the gas turbine is driven at high altitudes at a greater circumferential velocity than at low altitudes.

2. A gas turbine propelling means for aircraft adapted to drive at least one propeller, characterised in that between the gas turbine and the propeller means are provided which permit of a reduced transmission of any desired ratio, the said transmission being capable of being varied automatically or manually or by combined automatic and manually operable control means.

3. A gas turbine propelling means according to Claim 2, characterised in that an invariable reducing gear and a clutch are fitted between the gas turbine and the propeller.

4. A gas turbine propelling means according to Claim 2, characterised in that between the gas turbine and the propeller there are provided a reducing gear, which is variable automatically or manually or by combined automatic and manual control, and a clutch.

5. A method of adapting the output of gas turbines for propelling aircraft to different altitudes, substantially as hereinbefore described with reference to the accompanying drawing.

6. A gas turbine propelling means for aircraft, substantially as hereinbefore described with reference to the accompanying drawing.

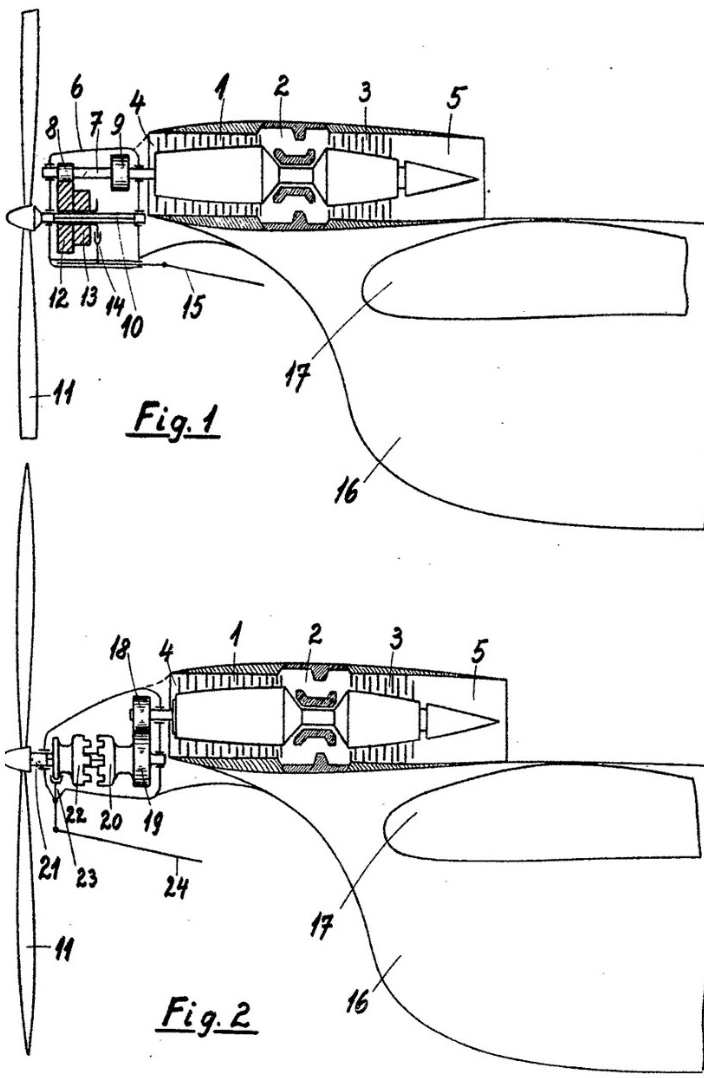


Figure 9.72: Herbert Wagner's turboprop and turboshaft patent application (February 1936).

REICHSPATENTAMT

PATENTSCHRIFT

№ 768 103

KLASSE **46f** GRUPPE 7**03**

J 58734 Ia/46f

Nachträglich gedruckt durch das Deutsche Patentamt in München

(§ 20 des Ersten Gesetzes zur Änderung und Überleitung von Vorschriften auf dem Gebiet des gewerblichen Rechtsschutzes vom 8. Juli 1949)

Junkers Flugzeug- und Motorenwerke A. G., Dessau*)

Verbrennungskammer für mit Gleichdruckverbrennung arbeitende Gasturbinen

Patentiert im Deutschen Reich vom 5. März 1936 an
Patenterteilung bekanntgemacht am 18. Mai 1955

Die Erfindung betrifft eine Verbrennungskammer für mit Gleichdruckverbrennung arbeitende Gasturbinenanlagen, die je aus einem Luftverdichter, einer Turbine und der unmittelbar zwischen diesen angeordneten Verbrennungskammer bestehen und die insbesondere zum Antrieb von Luftfahrzeugen verwendet werden sollen. Der Luftverdichter, der als axial oder radial durchströmtes Gebläse ausgebildet sein kann, speist die Verbrennungskammer mit verdichteter Luft, die hier unter Zutritt von Brennstoff verbrennt; die Verbrennungsgase gelangen aus der Verbrennungskammer in die Turbine, beaufschlagen deren Beschaufelung und versetzen den Turbinenläufer in Drehung.

Es ist an sich bekannt, die metallischen Wände der Verbrennungskammer einer Gasturbine mit feuerfestem Baustoff auszukleiden, um so die sonst unter der unmittelbaren Einwirkung der heißen Verbrennungsgase stehenden Wände der Verbrennungskammer vor Zerstörung zu schützen. Es ist ferner vorgeschlagen worden, insbesondere bei Anordnung einer axial durchströmten Turbine und eines unmittelbar von der Turbine angetriebenen axial durchströmten Verdichters, die Verbrennungskammer unmittelbar zwischen der letzten Stufe des Verdichters und der ersten Stufe der Gasturbine anzuordnen. Eine solche Anordnung hat jedoch den Nachteil, daß die Beschaufelung der letzten Stufe des Verdichters und die Beschaufelung der ersten Stufe der Gasturbine unter der unmittelbaren Einwirkung der Wärmestrahlung aus dem Verbrennungsraum stehen. Diese Strahlung ist so groß, daß eine solche Turbinenanlage bisher nicht betriebsfähig war, da die Beschaufelungen des Verdichters als auch der Gasturbine in kürzester Zeit unter der zusätzlichen Einwirkung der Wärmestrahlung aus dem Verbrennungsraum zerstört wurden.

Es ist Aufgabe der Erfindung, eine unmittelbar zwischen Luftverdichter und Turbine einer mit Gleichdruckverbrennung arbeitenden Gasturbine angeordnete Verbrennungskammer zu schaffen, die die schädliche Einwirkung der Wärmestrahlung auf die unmittelbar anschließenden Beschaufelungen vermeidet. Dies wird gemäß der Erfindung dadurch erreicht, daß in den Verbrennungsraum ein Vorsprung oder mehrere Vorsprünge so weit hineinragen, daß sie die wärmeempfindlichen Teile, insbesondere die Beschaufelungen des Luftverdichters und der Turbine, gegen Wärmestrahlung aus dem Verbrennungsraum decken. Hat die Kammer die Form eines Ringes, dann werden die Vorsprünge als ringförmige Rippen oder Wülste ausgebildet, deren radiale Erhebung über die ursprünglichen Mantellinien der äußeren oder inneren Brennraumauskleidung mindestens gleich der Kopfhöhe der letzten Schaufel des Luftverdichters oder der Kopfhöhe der ersten Schaufel der Turbine ist.

In der Zeichnung ist ein Ausführungsbeispiel des Erfindungsgegenstandes im mittleren Längsschnitt durch den Mittelteil einer mit Gleichdruckverbrennung arbeitenden Gasturbine mit ringförmiger Verbrennungskammer veranschaulicht.

Der Luftverdichter 1 ist mit der Gasturbine 2 durch eine Welle 3 verbunden. Um die Welle 3 herum ist innerhalb eines Gehäuses 4 eine ringförmige Verbrennungskammer 5 angeordnet. Die aus der letzten Schaufelreihe 6 des Verdichters 1 austretende verdichtete Luft strömt durch eine ringförmige Öffnung 7 der Verbrennungskammer 5 zu, wo ihr durch eine Düse oder mehrere Düsen 8 Brennstoff zugeführt wird; das Gemisch verbrennt, und die Brenngase strömen durch eine ringförmige Öffnung 9 der Brennkammer 5 zu der ersten Laufschaufelreihe 10 der Turbine 2. Der Verbrennungsraum 5 ist mit Schamotteauskleidungen 11 und 12 versehen, die von Blechen 13 und 14 gestützt werden. Die innere Auskleidung 12 besitzt an ihrem dem Luftverdichter 1 zugewandten Ende eine in den Verbrennungsraum 5 hineinragende ringförmige Rippe 15 und an ihrem der Turbine 2 zugewandten Ende eine entsprechende Rippe 16, während die äußere Auskleidung 11 mit einer ebenfalls ringförmigen wulstartigen Rippe 17 in den mittleren Teil des Verbrennungsraumes 5 hineinragt. Die Querschnittsform der Rippen 15, 16, 17 sowie ihre radiale Erhebung h_1, h_2, h_3 über die ursprünglichen Mantellinien a und i der äußeren oder inneren Brennraumauskleidung sind im Verhältnis zur Lage und zur Kopfhöhe der Schaufeln 6 und 10 so gewählt, daß sie diese vor der Wärmeanstrahlung aus dem Verbrennungsraum 5 schützen. Durch die wulstartige Formgebung, insbesondere der mittleren Rippe 17, wird gleichzeitig die Durchwirbelung der Brenngase und damit der Verbrennungsvorgang gefördert.

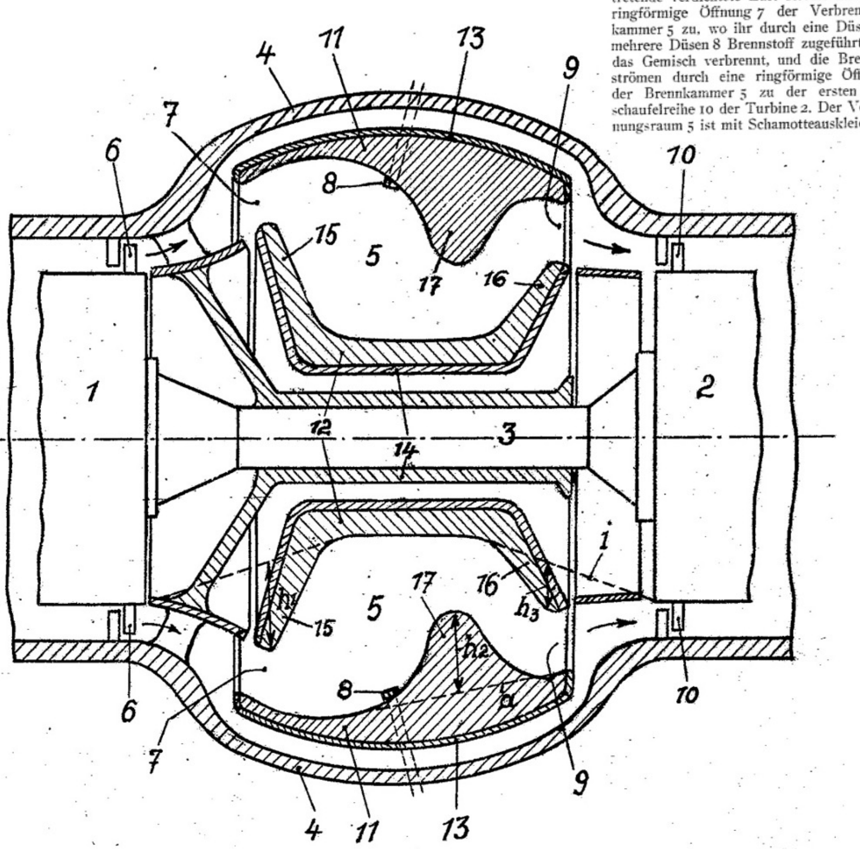
PATENTANSPRÜCHE:

1. Unmittelbar zwischen Luftverdichter und einer mit Gleichdruckverbrennung arbeitenden Gasturbine angeordnete Verbrennungskammer, dadurch gekennzeichnet, daß in den Verbrennungsraum (5) ein Vorsprung oder mehrere Vorsprünge (15, 16, 17) so weit hineinragen, daß sie die wärmeempfindlichen Teile, insbesondere die Beschaufelungen des Luftverdichters und der Turbine gegen Wärmeanstrahlung aus dem Verbrennungsraum decken.

2. Verbrennungskammer nach Anspruch 1, dadurch gekennzeichnet, daß die Kammer (5) die Form eines Ringes hat und die Vorsprünge (15, 16, 17) als ringförmige Rippen oder Wülste ausgebildet sind, deren radiale Erhebung (h_1, h_2, h_3) über die ursprünglichen Mantellinien (a und i) der äußeren oder inneren Brennraumauskleidung hinaus mindestens gleich der Kopfhöhe der letzten Schaufel (6) des Luftverdichters oder der Kopfhöhe der ersten Schaufel (10) der Turbine ist.

Zur Abgrenzung des Erfindungsgegenstands vom Stand der Technik sind im Erteilungsverfahren folgende Druckschriften in Betracht gezogen worden:

Deutsche Patentschrift Nr. 255 499;
französische Patentschrift Nr. 741 433;
USA.-Patentschriften Nr. 985 793,
1 418 444, 1 960 810.



One of Herbert Wagner's turbofan patent applications (March 1936)

Figure 9.73: One of Herbert Wagner's turbofan patent applications (March 1936).

REICHSPATENTAMT

PATENTSCHRIFT

№ 768 034

KLASSE **46f** GRUPPE ~~3~~ 4/02

W 98278 Ia/46f

Nachträglich gedruckt durch das Deutsche Patentamt in München

(§ 20 des Ersten Gesetzes zur Änderung und Überleitung von Vorschriften auf dem Gebiet des gewerblichen Rechtsschutzes vom 8. Juli 1949)

Junkers Flugzeug- und Motorenwerke A. G., Dessau*)

Gasturbinenanlage mit Gleichdruckverbrennung

Patentiert im Deutschen Reich vom 5. März 1936 an
Patenterteilung bekanntgemacht am 21. April 1955

Die Erfindung bezieht sich auf eine insbesondere zum Antrieb von Luftfahrzeugen bestimmte Gasturbinenanlage mit Gleichdruckverbrennung, die im wesentlichen aus einem Luftverdichter, einem Brennraum und der eigentlichen Turbine besteht und bei der diese Bestandteile unmittelbar hintereinander angeordnet sind. Diese Anordnung bringt es mit sich, daß der Brennraum der Gasturbine, in dem während des Betriebes ständig hohe Temperaturen herrschen, in nächster Nähe von wärmeempfindlichen Teilen der Turbinenanlage liegt. Die Erfindung bezweckt, eine solche Gasturbine so auszubilden, daß diese wärmeempfindlichen Teile vor der von dem Brennraum ausgehenden Wärmewirkung geschützt werden und hierbei die Verbindungen des Luftverdichters und der Turbine eine ihren erheblichen Festigkeitsbeanspruchungen gerecht werdende Gestalt und Anordnung erhalten.

Es ist bereits bei Gasturbinen der erwähnten Bauart bekannt, zwischen einer ringförmigen Brennkammer und der leistungsübertragenden Verbindung von Turbine und Verdichter einen mit Luft angefüllten Raum anzuordnen, der einen kleinen, aber angesichts der erheblichen Wärmeeinwirkung des Verbrennungsvorganges unzureichenden Schutz für Turbinenteile, und zwar in erster Linie für die Laufräder der Turbine und des Verdichters und die sie verbindende Welle, bietet. Die diesen Raum anfüllende Luft unterliegt aber selbst einer erheblichen Temperaturerhöhung, da sie die aufgenommene Wärme nicht ableiten kann. Demgegenüber wird die hier vorliegende Aufgabe von der Erfindung in wirksamer Weise dadurch gelöst, daß der die leistungsübertragenden Verbindungen des Verdichters und der Turbine umgebende ringförmige Brennraum innerhalb der Verbindung der Leitvorrichtungen des als umlaufendes Gebläse ausgebildeten Verdichters und der Turbine liegt und diese letztere sowie jene leistungsübertragende Verbindung durch einen Luftstrom gegen die von dem Brennraum ausgehende Wärmeeinwirkung geschützt sind.

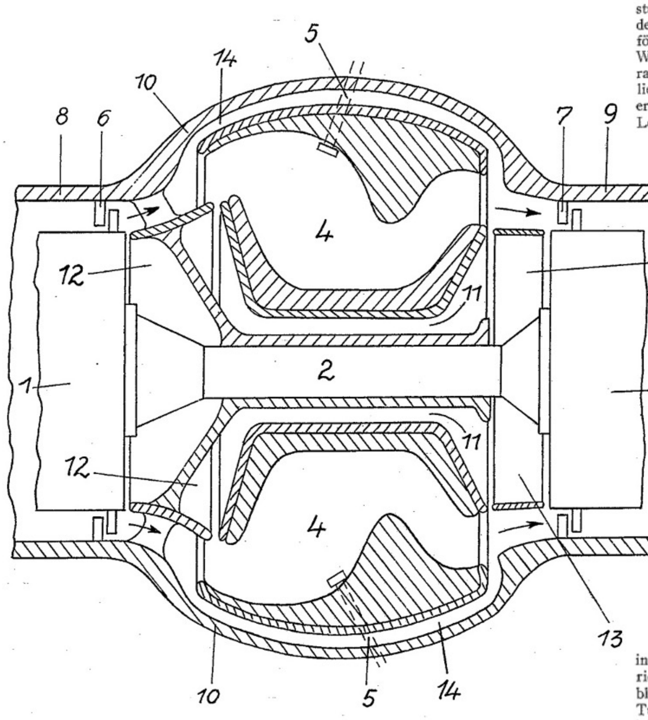
Der mit der Erfindung erzielte Wärmeschutz ist also besonders wirksam bei einer solchen Gasturbinenbauart, deren Brennraum ringförmig ausgebildet ist und die leistungsübertragende Verbindung von Luftverdichter und Turbine vollständig umschließt sowie seinerseits innerhalb eines Gehäuses angeordnet ist, das die Leitvorrichtungen des als umlaufendes Gebläse ausgebildeten Verdichters und der Turbine miteinander verbindet. Bei diesem Aufbau der Gasturbine sind in der Hauptsache nur die erwähnten Verbindungen von Verdichter und Turbine gegen die Wärmeeinwirkung des Brennraumes zu schützen. Dies gelingt im vorliegenden Falle um so besser, als die luftdurchströmten Räume sich infolge des Aufbaues der Turbinenanlage unmittelbar an den Verdichter anschließen und daher die Luft ihre Kühlwirkung bei günstigen niedrigen Temperaturen ausüben kann. Außerdem ermöglicht es die Erfindung, den Verbindungen des Verdichters und der Turbine eine Gestalt zu geben, die auch ihre Festigkeit wesentlich steigert.

Die Erfindung ist im nachstehenden an Hand eines Ausführungsbeispieles näher erläutert, welches in der Zeichnung in einem Axialschnitt durch eine Gasturbinenanlage mit Gleichdruckverbrennung dargestellt ist.

Der Läufer des Verdichters 1 ist mit dem Läufer der Turbine 3 durch eine zur Leistungsübertragung dienende Welle 2 verbunden. Zwischen den Teilen 1 und 3 ist ein ringförmiger Brennraum 4 angeordnet, der die Welle 2 vollständig umschließt. Dem Brennraum 4 wird die von dem Verdichter 1 gelieferte Luft sowie der zu ihrer Verbrennung erforderliche Kraftstoff, letzterer durch Leitungen 5, zugeführt; die heißen Brenngase strömen aus dem Brennraum zu der Turbine 3 und versetzen deren Laufrad in Drehung. Die die Leitvorrichtungen 6 und 7 des Verdichters und der Turbine tragenden Teile 8 und 9 sind durch ein tonnenförmiges Gehäuse 10 miteinander verbunden, welches den Brennraum 4 ringförmig umschließt. Zwischen dem Brennraum 4 und der Verbindungswelle 2 ist ein ringförmiger Raum 11 angeordnet, der durch im wesentlichen kegelförmige Räume 12 und 13 mit der Austrittsöffnung der Luft aus dem Verdichter und der Eintrittsöffnung des Brenngasgemisches in die Turbine in Verdung steht. Ferner ist zwischen der Außenseite des ringförmigen Brennraumes 4 und der Innenwand des Gehäuses 10 ein ebenfalls ringförmiger Raum 14 angeordnet, der gleichfalls mit dem Austritt der Luft aus dem Verdichter und dem Eintritt des Brenngasgemisches in die Turbine in Verbindung steht. Die beiden ringförmigen Räume 11 und 14 werden somit von einem Teil der aus dem Verdichter 1 austretenden Luft durchströmt, die von hier aus den den Brennraum verlassenden Brenngasen vor ihrem Eintritt in die Turbine zugesetzt wird. Auf diese Weise entstehen in den ringförmigen Räumen 11 und 14 während des Betriebes der Gasturbine Ströme von ständig aus dem Verdichter zugeführter kalter Frischluft, welche die vom Brennraum ausgehende Wärmeeinwirkung von den die Läufer und die Leitvorrichtungen des Verdichters und der Turbine verbindenden Teile 2 und 10 fernhalten. Durch entsprechende Bemessung der Ein- und Austrittsquerschnitte dieser beiden Luftströme läßt sich die Strömungsgeschwindigkeit der Kühlluft durch die Räume 11 und 14 derart regeln, daß die günstigste Wärmeschutzwirkung der Welle 2 und des Gehäuses 10 erzielt wird. Die ringförmige Ausbildung des Brennraumes 4 und seine unmittelbare Anordnung zwischen Verdichter und Turbine ermöglichen es, dem Gehäuse 10 ebenfalls eine Ringform zu geben, welche den Brennraum völlig umschließt, so daß das Gehäuse der Turbinenanlage gerade in seinem besonders beanspruchten Teil eine einfache und kräftige Gestalt erhält, die ihm eine erhöhte Festigkeit auch gegenüber den mechanischen Beanspruchungen verleiht.

Patentanspruch:

Gasturbinenanlage mit Gleichdruckverbrennung, in deren Längsrichtung ein Luftverdichter, ein Brennraum und eine Turbine hintereinander angeordnet sind, dadurch gekennzeichnet, daß der die leistungsübertragende Verbindung (2) des Verdichters (1) und der Turbine (3) umgebende ringförmige Brennraum (4) innerhalb der Verbindung der Leitvorrichtungen (10) des als umlaufendes Gebläse ausgebildeten Verdichters und der Turbine liegt und diese letztere sowie jene leistungsübertragende Verbindung (2) durch einen Luftstrom gegen die von dem Brennraum ausgehende Wärmeeinwirkung geschützt sind.



Another of Herbert Wagner's turbofan patent applications (March 1936)

Zur Abgrenzung des Erfindungsgegenstands vom Stand der Technik sind im Erteilungsverfahren folgende Druckschriften in Betracht gezogen worden:
Deutsche Patentschrift Nr. 106 586;
österreichische Patentschrift Nr. 57 682;
französische Patentschrift Nr. 346 713;
USA.-Patentschrift Nr. 1 418 444.

Figure 9.74: Another of Herbert Wagner's turbofan patent applications (March 1936).

Herbert Wagner's axial flow turbojet patent application (August 1938)

Patentiert im Deutschen Reich vom 14. August 1938 an

Patenterteilung bekanntgemacht am 9. Juli 1942

724091

Junkers Flugzeug- und -Motorenwerke AG. in Dessau

Vortriebseinrichtung für Luftfahrzeuge

Die Erfindung bezieht sich auf für Luftfahrzeuge bestimmte Vortriebseinrichtungen, die aus einer Gasturbine, einem von dieser angetriebenen Verdichter für die Verbrennungsluft und einer an die Gasturbine sich anschließenden Rückstoßdüse bestehen.

Es sind Ausführungsformen von Strahlantrieben der angeführten Art bekannt, bei welchen der Austrittsquerschnitt der Rückstoßdüse größer ist als der freie Querschnitt der letzten Turbinenschaufelreihe. Eine solche Ausführung hat zwar den Vorteil, daß die Abmessungen der Gasturbine gering sind; der sich ständig erweiternde Querschnitt der Rückstoßdüse hat aber eine Treibmittelaustrittsgeschwindigkeit zur Folge, die weit über den jetzt üblichen Höchstgeschwindigkeiten von Luftfahrzeugen (etwa 170 m pro Sekunde) liegt. Der Nachteil einer solchen Anlage liegt in dem außerordentlich schlechten Wirkungsgrad, da bekanntlich der Wirkungsgrad einer Rückstoßdüse um so besser wird, je mehr sich Treibmittelgeschwindigkeit und Fahrzeuggeschwindigkeit einander nähern.

Es ist auch schon vorgeschlagen worden, die Rückstoßdüse gegen ihren Austritt zu allmählich zu verengen, so daß der Austrittsquerschnitt der Düse kleiner als der freie Durchtrittsquerschnitt der letzten Beschaufelungsreihe der Gasturbine wird. Die Folge dieser Maßnahme war zwar eine geringere Austrittsgeschwindigkeit des Treibmittels aus der Rückstoßdüse, aber es trat als nicht zu vermeidende Rückwirkung ebenfalls eine durchaus unerwünschte Verringerung der Treibmittelgeschwindigkeit innerhalb der Gasturbine auf. Die Folge war, daß man bei gleicher Leistung den freien Durchtrittsquerschnitt der Gasturbine vergrößern mußte, d. h. daß das Baugewicht der Turbine erhöht und damit das gesamte Triebwerk für die Verwendung im Luftfahrzeug ungeeignet wurde.

Es ist Aufgabe der Erfindung, eine Vortriebseinrichtung für Luftfahrzeuge zu schaffen, welche die Vorteile der bekannten Ausführungsformen besitzt, deren Nachteile jedoch vermeidet.

Gemäß der Erfindung wird diese Aufgabe dadurch gelöst, daß der Austrittsquerschnitt der Rückstoßdüse etwa die gleiche Größe wie der Austrittsquerschnitt der Gasturbine hat.

Ein Strahlantrieb gemäß der Erfindung hat den Vorteil, daß es möglich ist, auch bei Flugzeuggeschwindigkeiten, die etwa in der Größenordnung von 170 m pro Sekunde liegen, einen wirtschaftlichen Wirkungsgrad mit Sicherheit zu erreichen.

Auf der Zeichnung ist ein Ausführungsbeispiel des Erfindungsgegenstandes im Längsschnitt veranschaulicht. Mit 1 ist eine Gasturbine bezeichnet, die einen Verdichter 2 antreibt. Die von diesem verdichtete Luft wird zu einer Brennkammer 3 geleitet, wo sie in Mischung mit dem der Brennkammer zugeführten Brennstoffe zur Verbrennung des letzteren dient. Die aus der Gasturbine 1 austretenden Verbrennungsgase durchströmen ein ringförmig ausgebildetes Rohr 4, und zwar mit einer nahe unterhalb der Schallgeschwindigkeit liegenden Geschwindigkeit. Das ringförmige Rohr 4 dient als Rückstoßer und läßt die Verbrennungsgase durch seinen Querschnitt 5 ins Freie austreten. Der kreisförmige Austrittsquerschnitt 5 ist so bemessen, daß er etwa gleich dem Austrittsquerschnitt 6 der Gasturbine ist und daß zugleich der Umhüllung 7 der gesamten Anordnung eine strömungstechnisch günstige Gestalt gegeben wird.

PATENTANSPRUCH:

Vortriebseinrichtung für Luftfahrzeuge, bestehend aus einer Gasturbine, einem von dieser angetriebenen Verdichter für die Verbrennungsluft und einer an die Gasturbine sich anschließenden Rückstoßdüse, dadurch gekennzeichnet, daß der Austrittsquerschnitt der Rückstoßdüse etwa die gleiche Größe wie der Austrittsquerschnitt (6) der Gasturbine (1) hat.

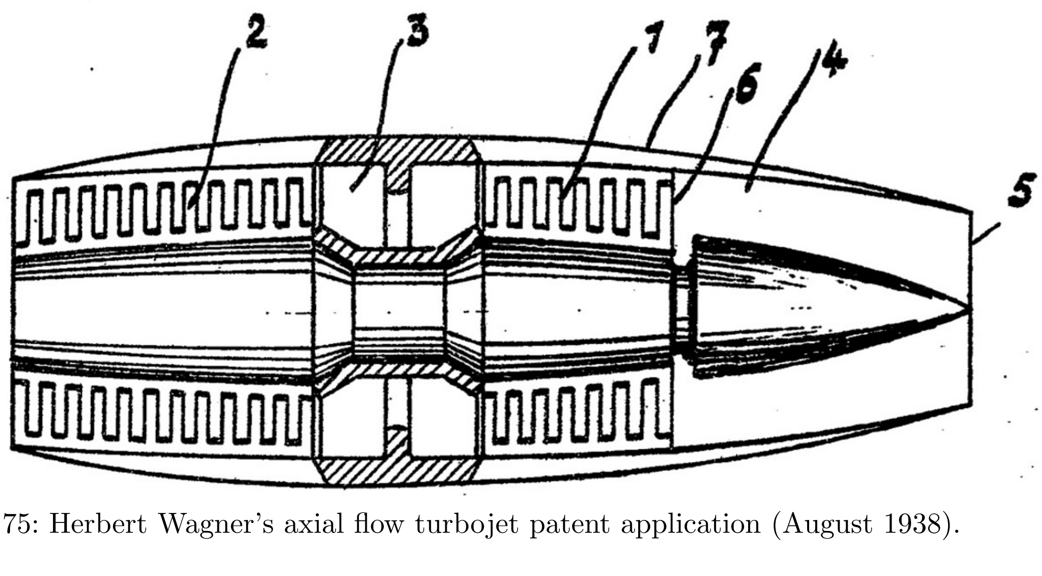


Figure 9.75: Herbert Wagner's axial flow turbojet patent application (August 1938).

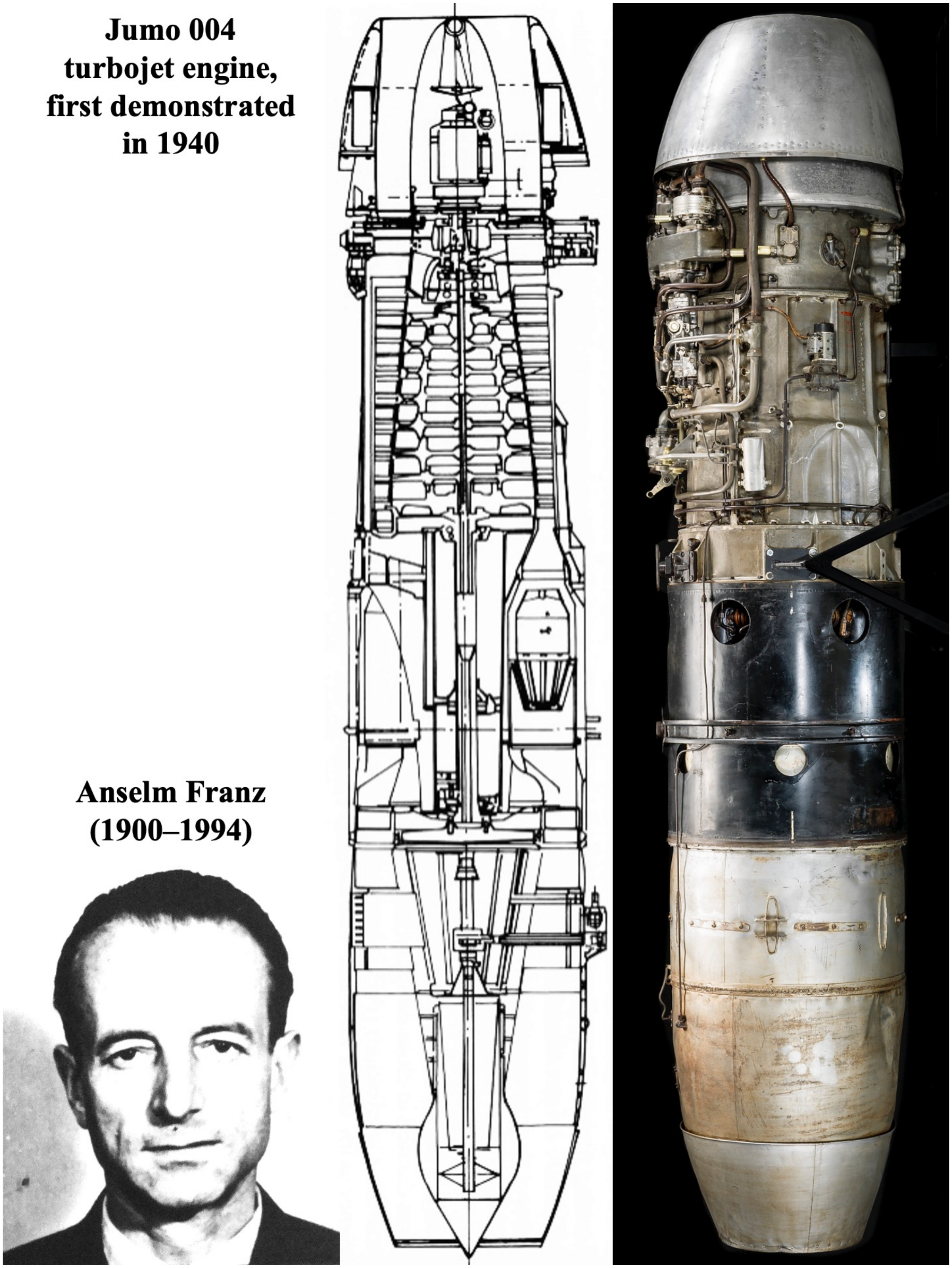


Figure 9.76: During the war, Anselm Franz led a team that developed and mass-produced the Jumo (Junkers Motors) 004 turbojet engine and also developed other engines such as the Jumo 022 turboprop engine (p. 1760).

Heinz Moellmann, Siegfried Decher, Wolfgang Stein, Anselm Franz

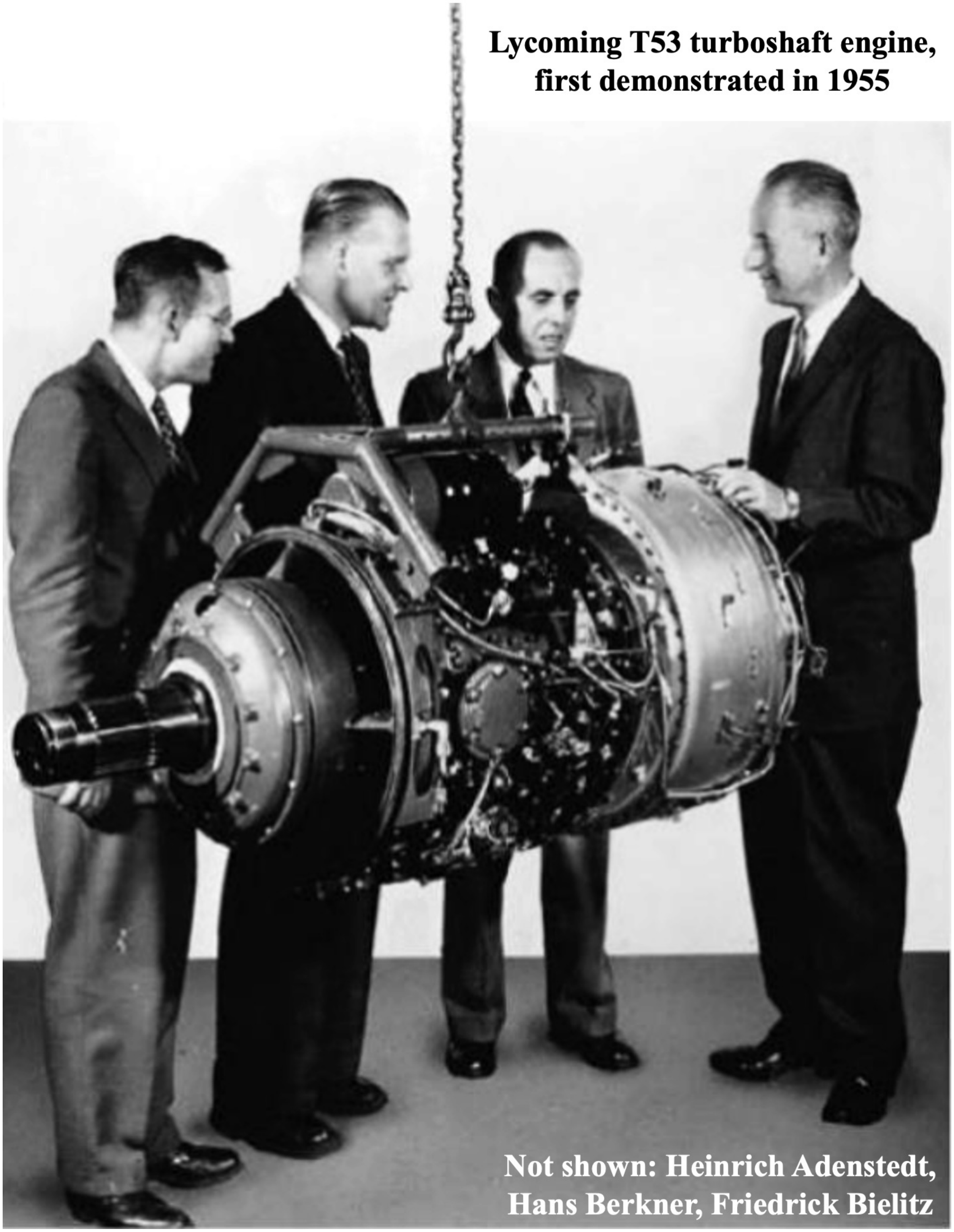
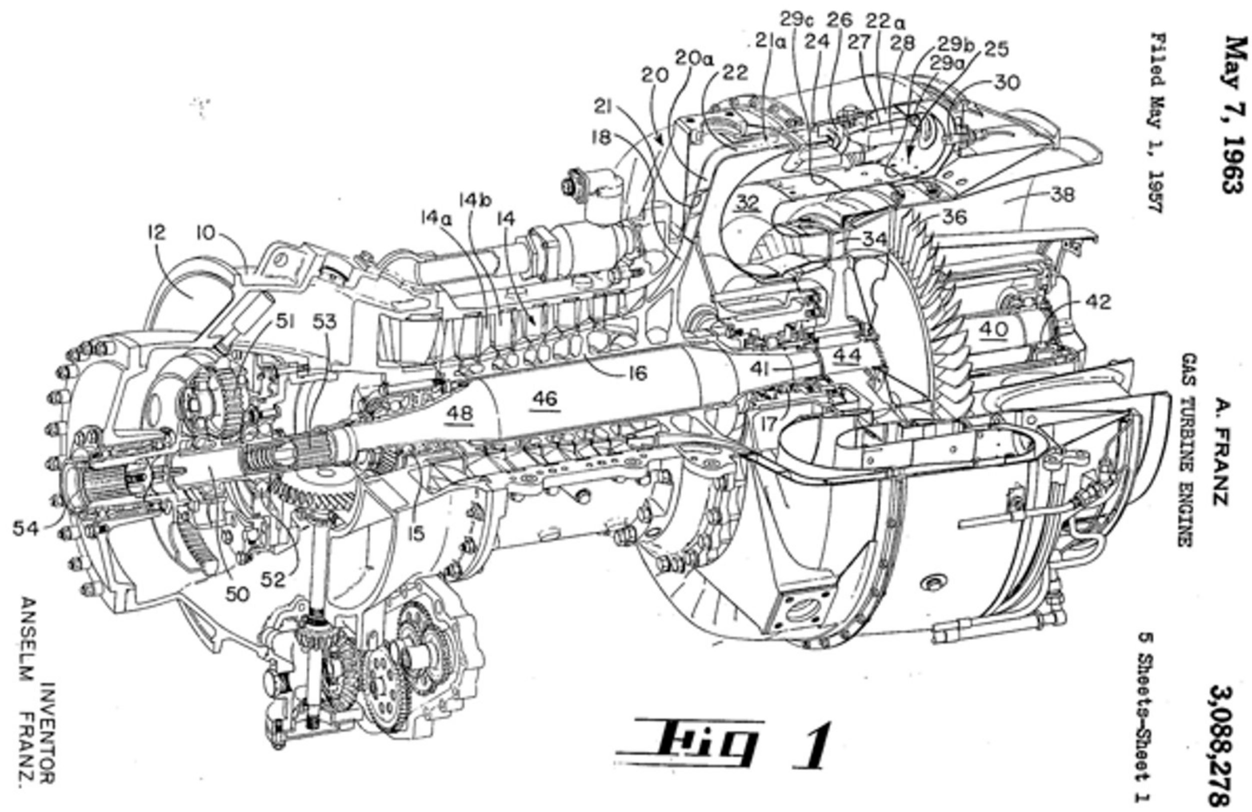
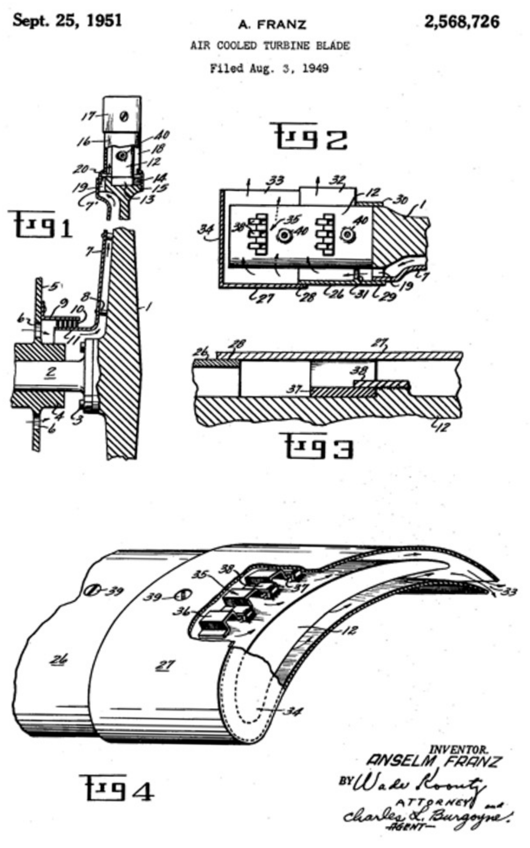


Figure 9.77: After the war, Anselm Franz led a team including Heinrich Adenstedt, Hans Berkner, Friedrick Bielitz, Siegfried Decher, Heinz Moellmann, and Wolfgang Stein to produce the Lycoming T53 and T55 turboshaft engines, PLF1 high-bypass turbofan engine, AGT1500 turboshaft tank engine (p. 1391), and other engines.





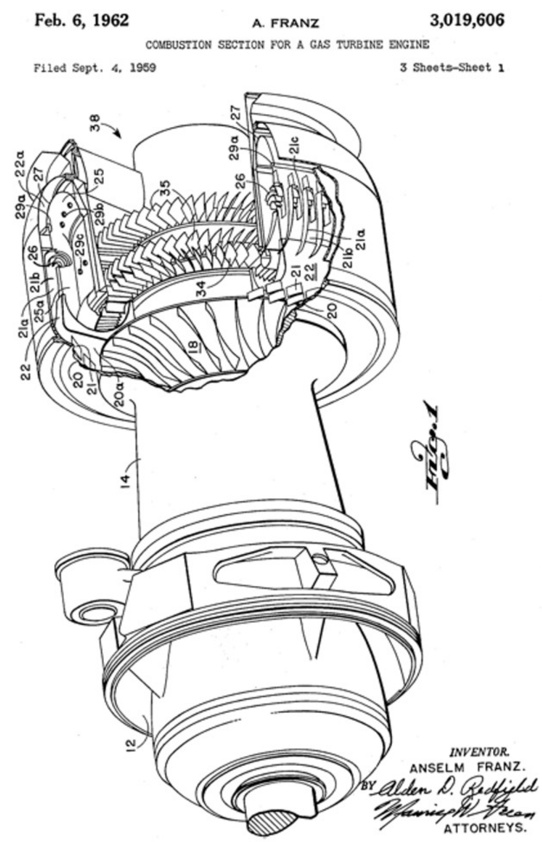


Figure 9.78: Examples of jet engine patents by Anselm Franz.

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
3. DEZEMBER 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 898 699

KLASSE 46g GRUPPE 8 10

J 5016 I a/46g

Dipl.-Ing. Siegfried Decher, Décize, Nièvre (Frankreich) und
Heinz Möllmann, Indiana, Ohio (V. St. A.)
sind als Erfinder genannt worden

Junkers Flugzeug- und Motorenwerke AG., Dessau

Heißstrahltriebwerk zum Vortrieb von Luftfahrzeugen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 6. März 1943 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Patentanmeldung bekanntgemacht am 19. März 1953
Patenterteilung bekanntgemacht am 22. Oktober 1953

Die Erfindung bezieht sich auf Heißstrahltriebwerke zum Vortrieb von Luftfahrzeugen, bestehend aus einem Verdichter, Brennkammern und einer den Verdichter antreibenden Gasturbine mit anschließender Rückstoßdüse, bei welchem die Kraftstoffzuteilung in Abhängigkeit von der Drehzahl gesteuert wird, und betrifft ein Verfahren zur Regelung.

Die bei Dampfturbinen bekannte Regelung in Abhängigkeit von der Drehzahl läßt sich zweckmäßig auf Gasturbinen übertragen, welche in Heißstrahltriebwerken der obengenannten Art eingebaut sind. Jedoch ist hierbei zu berücksichtigen, daß das Treibmittel für diese Gasturbinen (im Gegensatz zu dem Treibmittel der Dampfturbinen, das aus dem Kesselhaus in stets gleicher Beschaffenheit anfällt) im Heißstrahltriebwerk selbst aufbereitet wird und daß daher die Höchsttemperatur des Treibmittels mit Rücksicht auf die Turbinenbeschaufelung durch eine zusätzliche Regeleinrichtung begrenzt werden muß.

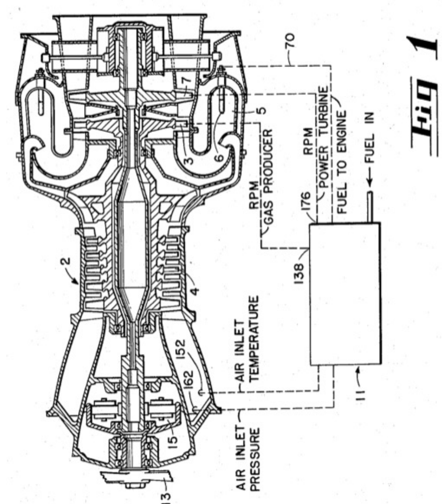
Regelungseingriffe für die Temperatur sind aber, wie die Erfahrung zeigt, in Heißstrahltriebwerken praktisch schwierig durchzuführen, weil der Fühlverzug eines vor der Gasturbine angeordneten Temperaturfühlers im Verhältnis zu den Anforderungen des Triebwerkes sehr groß ist.

Die geschilderten Schwierigkeiten können gemäß der Erfindung dadurch behoben werden, daß die Rückstoßdüse so ausgelegt ist, daß im oberen Leistungsbereich des Triebwerkes das Druckverhältnis des Treibmittels in der Ausströmdüse

Dec. 1, 1964 H. F. MOELLMANN 3,159,001

FUEL CONTROL AIR PRESSURE MULTIPLIER AND MAIN METERING VALVE

Original Filed May 20, 1959 3 Sheets-Sheet 1

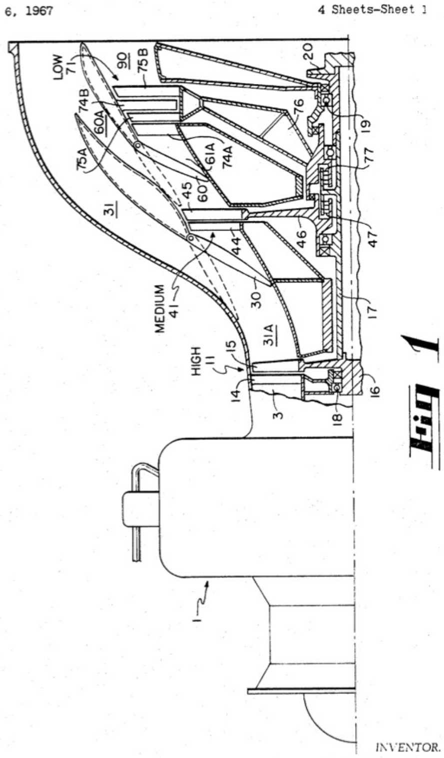


INVENTOR.
HEINZ F. MOELLMANN.
BY Alden D. Redfield
Maurice W. Green
ATTORNEYS.

Oct. 14, 1969 H. MOELLMANN 3,472,487

WIDE SPEED RANGE GAS POWER CONVERTER

Filed Oct. 6, 1967 4 Sheets-Sheet 1



INVENTOR.
HEINZ MOELLMANN

United States Patent [19] [11] **4,147,024**

Moellmann [45] **Apr. 3, 1979**

[54] **DUAL CYCLE GAS TURBINE ENGINE SYSTEM**

[75] Inventor: **Heinz F. Moellmann**, New Haven, Conn.

[73] Assignee: **Avco Corporation**, Stratford, Conn.

[21] Appl. No.: **833,532**

[22] Filed: **Sep. 15, 1977**

[51] **Int. Cl.**[2] **F02C 7/00; F02C 7/08**

[52] **U.S. Cl.** .... **60/39.15**; 60/34.16 R; 60/34.51 R

[58] **Field of Search** .... 60/39.15, 39.16 S, 39.51 R, 60/39.51 H, 39.16 R

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,814,181	11/1957	Schwartz	60/39.51 R
2,930,190	3/1960	Rogers	60/39.51 R
2,981,063	4/1961	Wickmann	60/39.16 S

Primary Examiner—Louis J. Casaregola
Attorney, Agent, or Firm—Irwin P. Garfinkle; Robert J. McNair, Jr.; Ralph D. Gelling

[57] **ABSTRACT**

A dual cycle turbine system is presented which includes a combination of two engines with different cycle pressure ratios. The two engines are cross connected by a common regenerator that enables low specific fuel consumption under partial load conditions.

8 Claims, 4 Drawing Figures

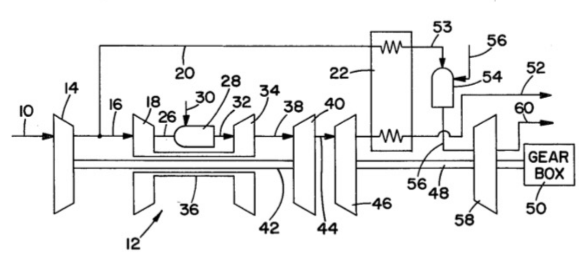
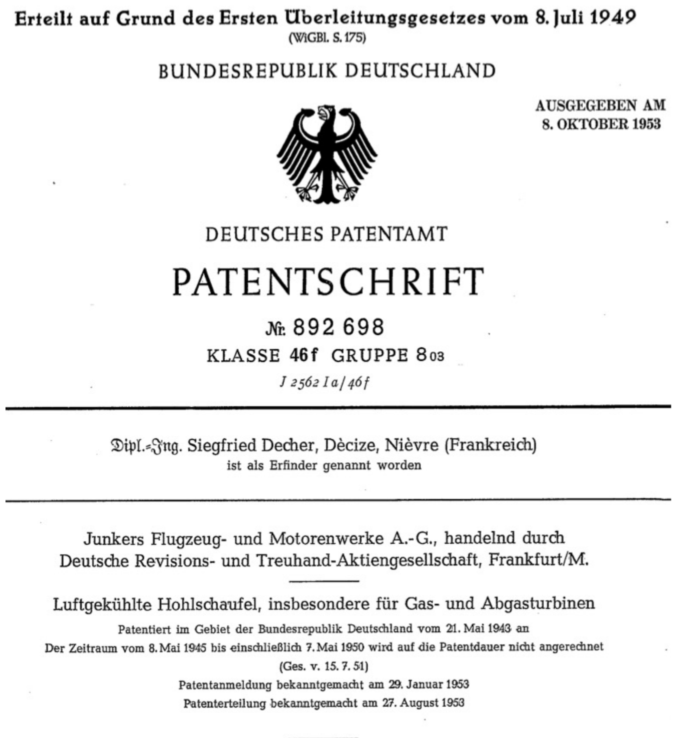


Figure 9.79: Examples of jet engine patents by Heinz Moellmann.



Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
8. OKTOBER 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 892 698

KLASSE 46f GRUPPE 8 03

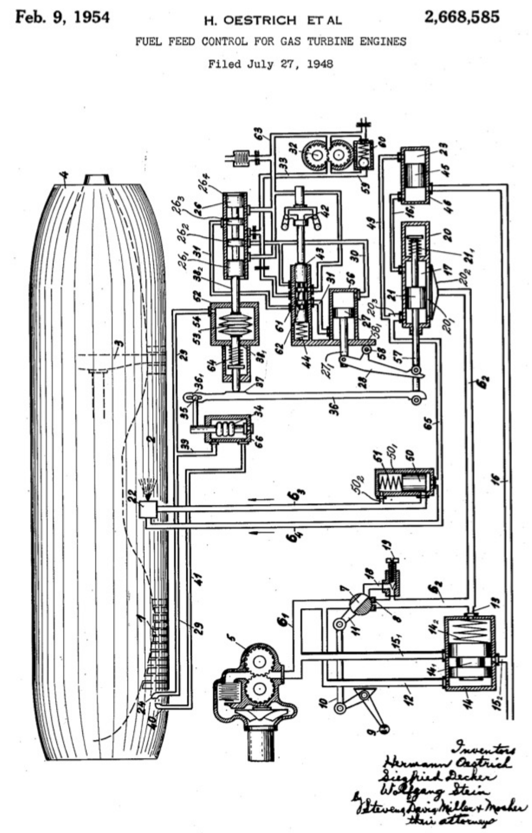
J 2562 I a / 46 f

Dipl.-Ing. Siegfried Decher, Dècize, Nièvre (Frankreich)
ist als Erfinder genannt worden

Junkers Flugzeug- und Motorenwerke A.-G., handelnd durch
Deutsche Revisions- und Treuhand-Aktiengesellschaft, Frankfurt/M.

Luftgekühlte Hohlschaufel, insbesondere für Gas- und Abgasturbinen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 21. Mai 1943 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Patentanmeldung bekanntgemacht am 29. Januar 1953
Patenterteilung bekanntgemacht am 27. August 1953



Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
25. OKTOBER 1956

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 951 160

KLASSE 27c GRUPPE 7 05
INTERNAT. KLASSE F 04 d

J 2369 I a / 27 c

Dipl.-Ing. Siegfried Decher, Décize, Nièvre (Frankreich)
ist als Erfinder genannt worden

Junkers Flugzeug- und Motorenwerke A. G., Dessau

Einrichtung zum Vermeiden des Abreißens der Strömung
in Axialverdichtern

Patentiert im Gebiet der Bundesrepublik Deutschland vom 2. März 1943 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 1951)
Patentanmeldung bekanntgemacht am 7. Mai 1953
Patenterteilung bekanntgemacht am 4. Oktober 1956

Die Erfindung bezieht sich auf eine Einrichtung zum Vermeiden des Abreißens der Strömung in axial durchströmten Verdichtern.

Bekanntlich können in axial durchströmten Verdichtern große Mengen bei im Verhältnis zu radial durchströmten oder gar zu Kolbenverdichtern wesentlich kleineren Maschinenabmessungen verarbeitet und dabei günstige Wirkungsgrade erzielt werden. Diesen Vorzügen steht nachteilig die Tatsache entgegen, daß sich günstige Wirkungsgrade nur in einem verhältnismäßig schmalen Betriebsbereich erreichen lassen; ein Nachteil, der sich mit der Anzahl der Stufen steigert.

Fördert nämlich ein axial durchströmter Verdichter eine größere Menge, als seinem günstigsten Betriebspunkt entspricht, d. h. als der Menge entspricht, für welche er ausgelegt ist, dann sinken Förderdruck und Wirkungsgrad zunächst langsam, dann immer schneller ab. Dieses Absinken ist zwar energiemäßig unerwünscht, führt aber noch zu keinen Betriebsschwierigkeiten, wenn eine genügend große Arbeitsleistung zum Antrieb des Verdichters zur Verfügung steht und die geringere Verdichtung in Kauf genommen werden kann. Wesentlich ungünstiger liegen jedoch die Verhältnisse, wenn der Verdichter eine zu kleine Menge verarbeiten soll.

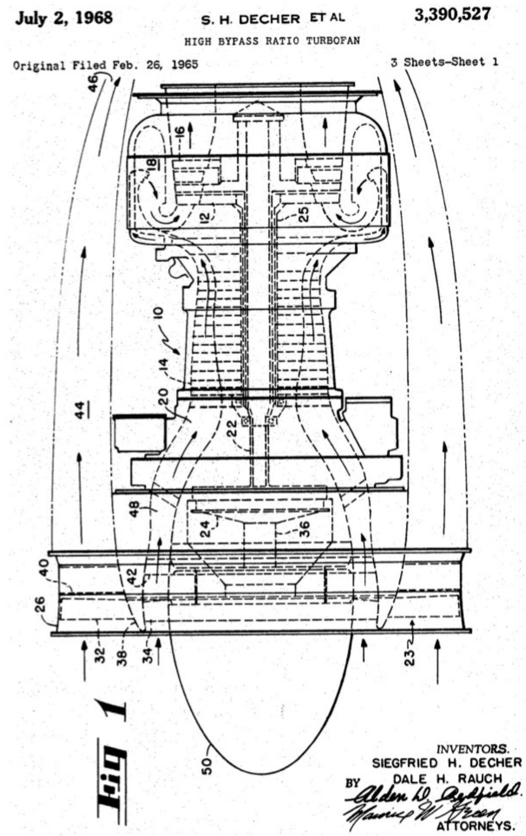


Figure 9.80: Examples of jet engine patents by Siegfried Decher.

Bruno Bruckmann (Austrian, 1902–1997), Peter Kappus (German, 1910–2008), Hermann Östrich (German, 1903–1973), R. Walter Brisken (German, 1914–2011), and others developed the BMW 003 axial-flow turbojet engine (first run in 1940, Fig. 9.81). At least 3500 BMW 003 engines were produced during the war. The BMW team also built prototypes of the larger, more advanced BMW 018 axial-flow turbojet engine, and they were developing the BMW 028 turboprop engine (p. 1760).

Norbert Riedel (Austrian, 1912–1963) built turbojet starter motors and also motorcycles.

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. 1758, 5287–5295. At least three DB 007 turbofan engines were produced. The Heinkel company was also developing turbofan engines.

György Jendrassik (Austro-Hungarian, 1898–1954) designed the Jendrassik Cs-1 turboprop engine in 1937 and first ran it in a test stand in 1940 (Fig. 9.83).

During the war, there were several notable turboprop engine development projects, including the Jumo 022 (p. 1760), BMW 028 (p. 1760), and Heinkel He S 021 (a turboprop version of the He S 011, p. 1743).

Ferdinand Brandner (Austrian, 1903–1986) worked at Junkers during the war developing engines such as the Jumo 012 turbojet and Jumo 022 turboprop. After the war, he built copies (NK-12) of the Jumo 022 turboprop in Russia and then developed jet engines (such as the Egyptian E-300) in several other countries. See Fig. 9.85.

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.

For more information on wartime programs to develop intercontinental jet bombers, see Sections E.1 and E.6.

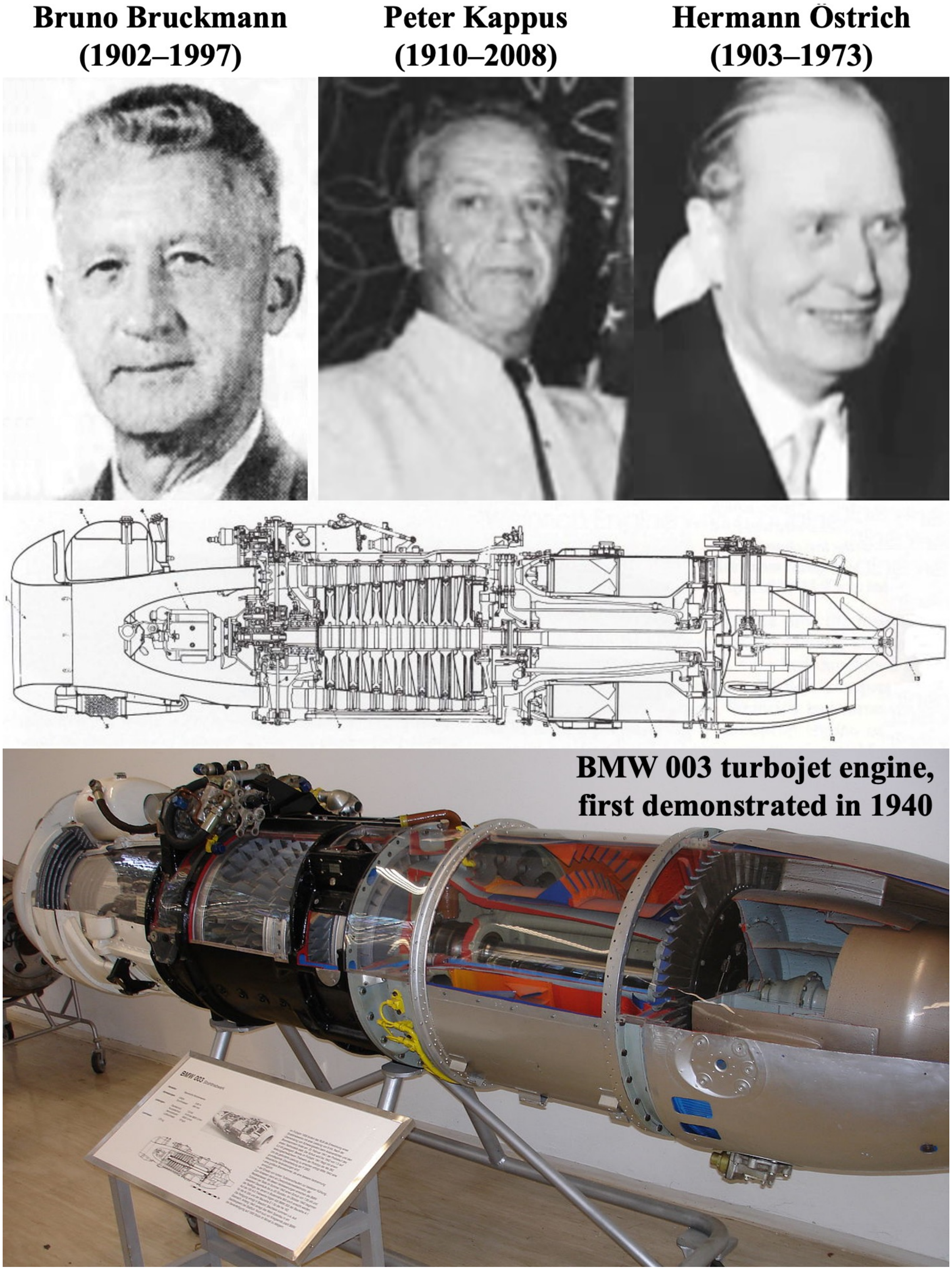


Figure 9.81: Bruno Bruckmann, Peter Kappus, and Hermann Östrich led the team that developed and mass-produced the BMW 003 turbojet engine.

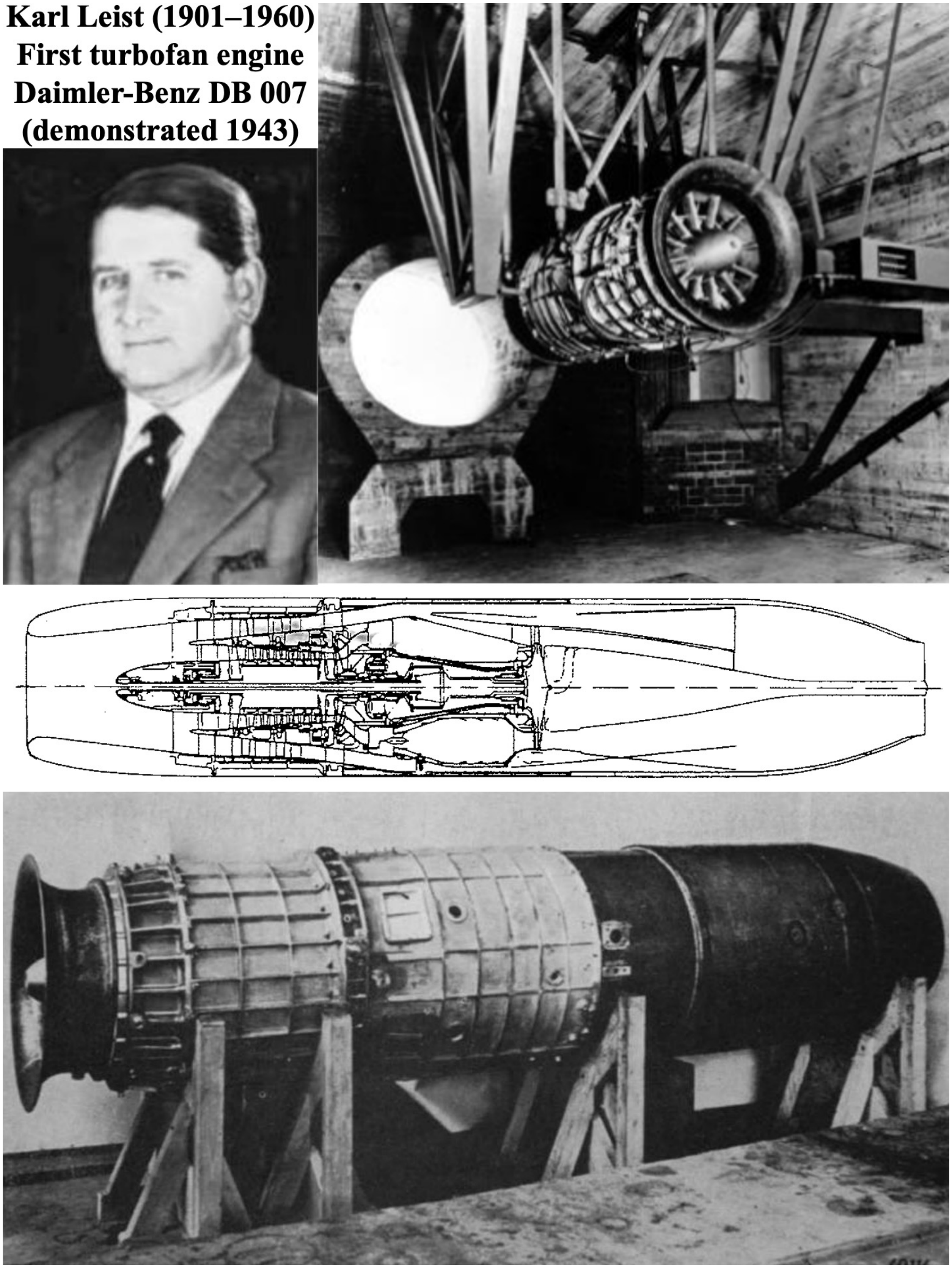


Figure 9.82: Karl Leist built and demonstrated the first fully functional turbofan engine, the Daimler-Benz DB 007, in 1943.

György Jendrassik
(1898–1954)

Jendrassik Cs-1 turboprop engine
(designed 1937, first run 1940)

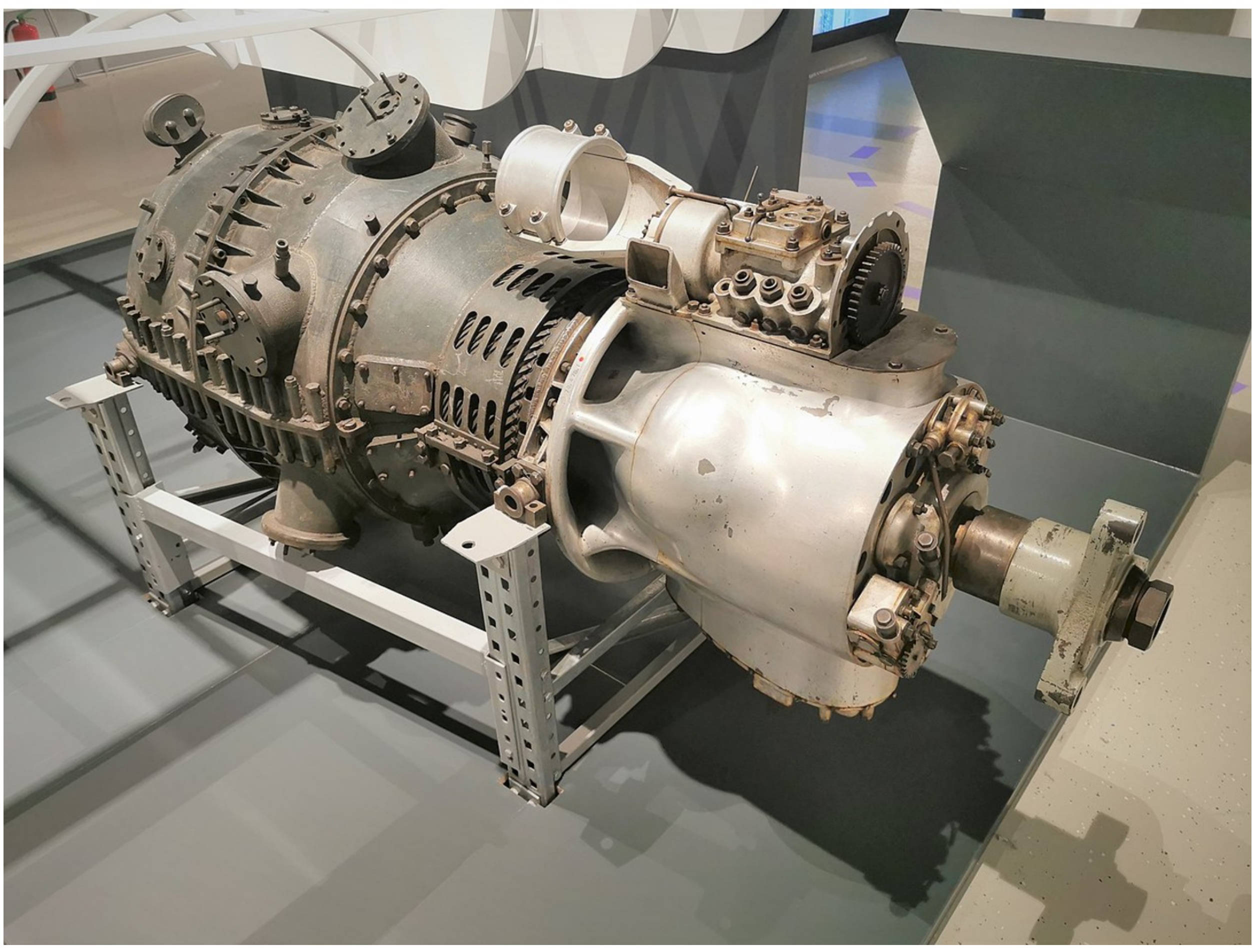
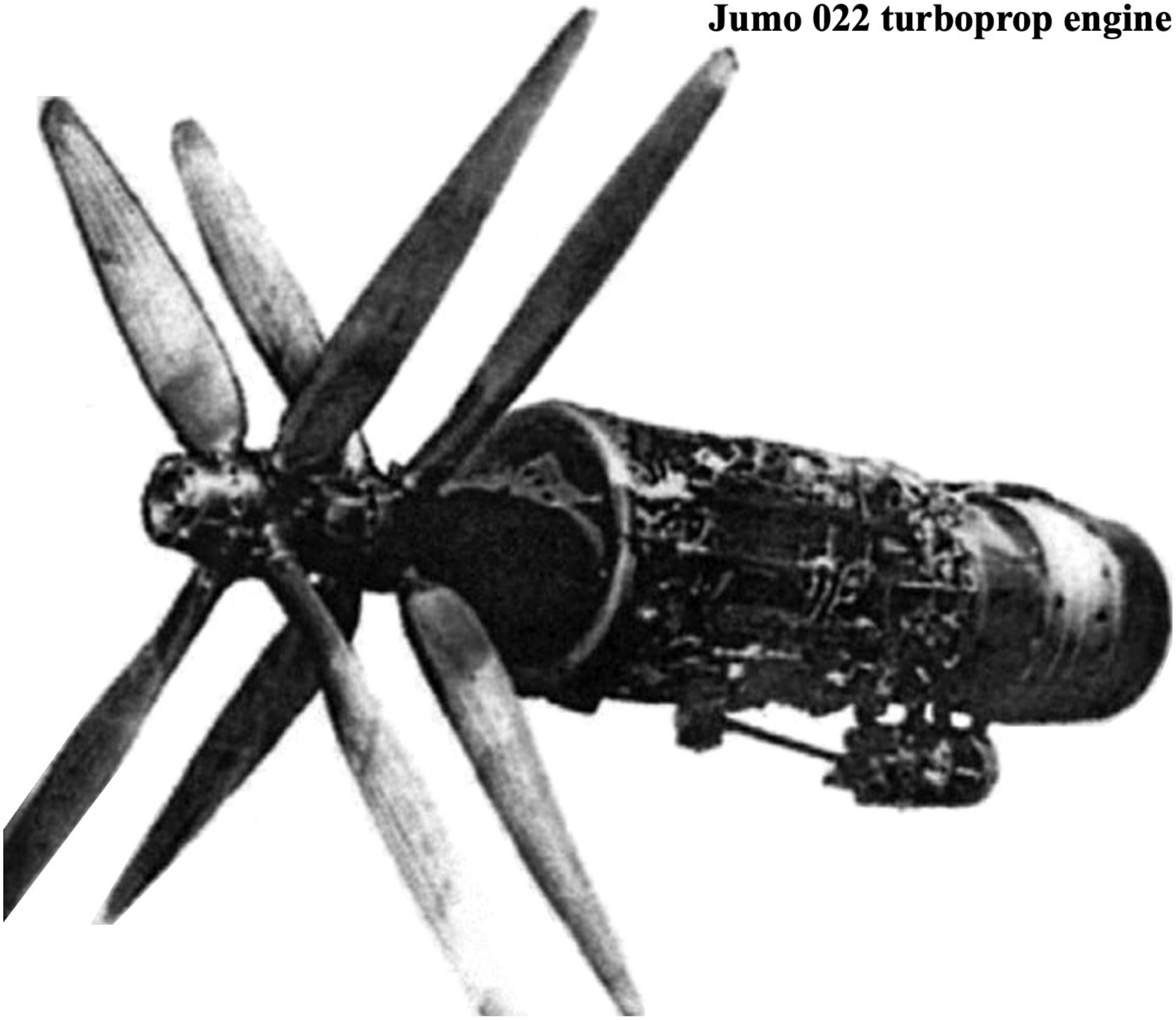


Figure 9.83: György Jendrassik designed the Jendrassik Cs-1 turboprop engine in 1937 and first ran it in a test stand in 1940.

Jumo 022 turboprop engine



BMW 028 turboprop engine

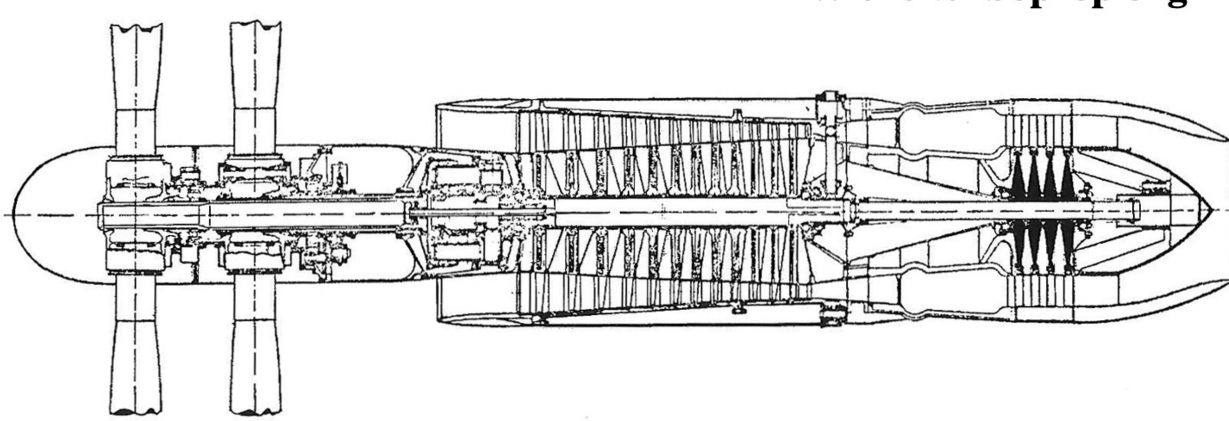


Figure 9.84: Turboprop engines under development during the war included the Junkers Jumo 022 (a postwar Soviet copy, NK-12, is shown), the BMW 028, and a turboprop version of the Heinkel He S 011 (p. 1743) dubbed the He S 021.

Figure 9.85: Ferdinand Brandner worked at Junkers during the war developing engines such as the Jumo 012 turbojet and Jumo 022 turboprop. After the war, he built copies (NK-12) of the Jumo 022 turboprop in Russia and then developed jet engines (such as the Egyptian E-300) in several other countries.

After the war, Bruno Bruckmann and Peter Kappus from the BMW group moved to the United States and designed jet engines for General Electric. See Figs. 9.86–9.97. Some of their postwar GE engines included the J47 turbojet engine (first run 1947, while Bruckmann and Kappus were still officially based at Wright Field but working with GE in nearby Evendale, Ohio), J73 turbojet engine (first run 1953), J79 or CJ805 turbojet engine (first run 1954), and TF35 or CJ805-23 turbofan engine (first run 1956). One of the most impressive projects by Bruckmann and Kappus was the YJ-93 engines for the Mach 3+ XB-70 Valkyrie (Figs. 9.89–9.90). The XB-70 made its first flight in 1964, and *Life* magazine highlighted Bruckmann's accomplishments [Wheeler 1965]:

> Bruno Bruckmann. G.E. assigned him to build the engines for the B-70. Bruckmann was born in 1902, the son of a pulp mill director, in the village of Mühlbach in the Italian-Austrian Alps. With an engineering degree from the Technische Hochschule of Munich he eventually went to work at the Bayerische Motoren Werke designing aircraft engines. He started building primitive jets for Hitler in 1939 and, by 1941, hitched his first two practicable engines to a Messerschmitt. The jets were so feeble that a standard piston engine had to be glued on for insurance.
>
> When the war ended, B.M.W. had been bombed out of four different plants and the jet works had been moved for safekeeping into salt mines 2,000 feet underground. In 1946 the U.S. Air Force "invited" Bruckmann to come for a lengthy visit to the U.S. He is tall, precise, silver-haired and looks and sounds like a casting director's dream of a Prussian nobleman.
>
> "It wasn't a social invitation. Perhaps I could have refused it—although that might have made the Air Force unhappy," Bruckmann said recently, "But I was not going to refuse. After all, I was aware the Russians might *invite* me." [...]
>
> Most of the other revolutions Bruckmann wrought are classified Pentagon secrets. They include such exotic concepts as the internal use of rare new alloys, or using fuel to soak the heat out of lubricating oils, or an exacting process of tuning lengths of pipe like a violin to cut out sympathetic vibrations. The results add up to a monster engine, doubling the output of its predecessor and delivering 30,000 pounds of thrust, or six pounds of push for every pound it weighs, capable of sustained operation in ferocious temperatures of more than 2,500^o F in the afterburners. They called it the YJ-93.

Bruckmann and Kappus even designed jet engines that heated the air via nuclear fission instead of chemical combustion reactions. For example, they developed the GE X211 nuclear turbojet engine, which was first demonstrated in 1958 (Fig. 9.91). Two GE X211 engines would have powered the proposed Convair NX-2 bomber, which was cancelled before it could be completed [Carpenter 2003].

Kappus was also a longtime designer and proponent of vertical takeoff and landing (VTOL) aircraft. In September 1957 (before Sputnik!), he filed a patent application on a VTOL vehicle that was ultimately implemented as the Lunar Landing Research Vehicle to train astronauts to land the Apollo Lunar Module (first flight 1964, with the vehicle's legs and pilot's position modified to resemble the final Lunar Module design, Fig. 9.95). Beginning in 1957, he filed several patent applications on VTOL aircraft with downward-pointing ducted fans in the wings and/or body (Figs. 9.96–9.97). That approach was successfully implemented in aircraft such as the Ryan XV-5 Vertifan (first flight 1964) and the Lockheed Martin F-35B (first flight 2008).

After the war, R. Walter Brisken from the wartime BMW jet engine group also moved to General Electric, where he developed the GE LM2500 gas turbine power plant that has been widely employed in ships and industrial applications since the 1960s (Fig. 9.98).

Bruno Bruckmann was jet expert

Austrian native was GE manager

BY L. PATRICE SANDERS
The Cincinnati Enquirer

Bruno W. Bruckmann, a former jet expert at GE Aircraft Engines in Evendale, died Tuesday at his Phoenix home. The former Greenhills man was 94.

Mr. Bruckmann worked at GE for 17 years. During that time, he managed the engineering development of major engine programs including the J47 fighter engine, the Mach 3 J93, the X211 engine for a nuclear-powered experimental bomber and the SST, the first large and technically difficult engine for the U.S. Supersonic Transport, according to friends.

Born in Austria in 1902, he was graduated from the University of Munich in Bavaria, Germany, receiving a master's degree in engineering. After graduation, aircraft engines became the center of his professional career.


Mr. Bruckmann

He worked as vice president of engineering at Bavarian Motor Works in Germany. In 1945, he began fours years of work for the United States Air Force.

Then he went to work for General Electric in Cincinnati.

He lived in Cincinnati for the 17 years he worked for GE. After retirement in 1967, Mr. Bruckmann moved to Phoenix with his wife of 56 years, Johanna.

The airplane engine pioneer was respected in his field. Known to GE employees as a "warm and inspiring manager," according to a 1967 *Enquirer* article, he was inducted into the GE Aircraft Engine Business Propulsion Hall of Fame.

He was known as an excellent manager of people and outstanding engineer by all who knew him, said his friend, M.C. Hemsworth of Springdale.

Mr. Hemsworth also called him an unusually fine gentleman.

Other survivors include five children; Antje Bruckmann Hirt of Munich, Germany, Albert Narath of Albuquerque, New Mexico, Helmar Narath of Boston, and Wolf Bruckmann and Dieter Bruckmann, both of Spittal, Austria; 11 grandchildren and four great-grandchildren.

Services were held in Phoenix. Memorials should be directed to the Arizona Humane Society, 9226 N. 13th Ave., Phoenix, Ariz. 85021.

Figure 9.86: Top: Bruno Bruckmann in Allied custody, 1945. Bottom: Bruckmann's obituary [*Cincinnati Enquirer*, 15 June 1997, p. 32].

Examples of jet engines developed for General Electric by Bruno Bruckmann and Peter Kappus

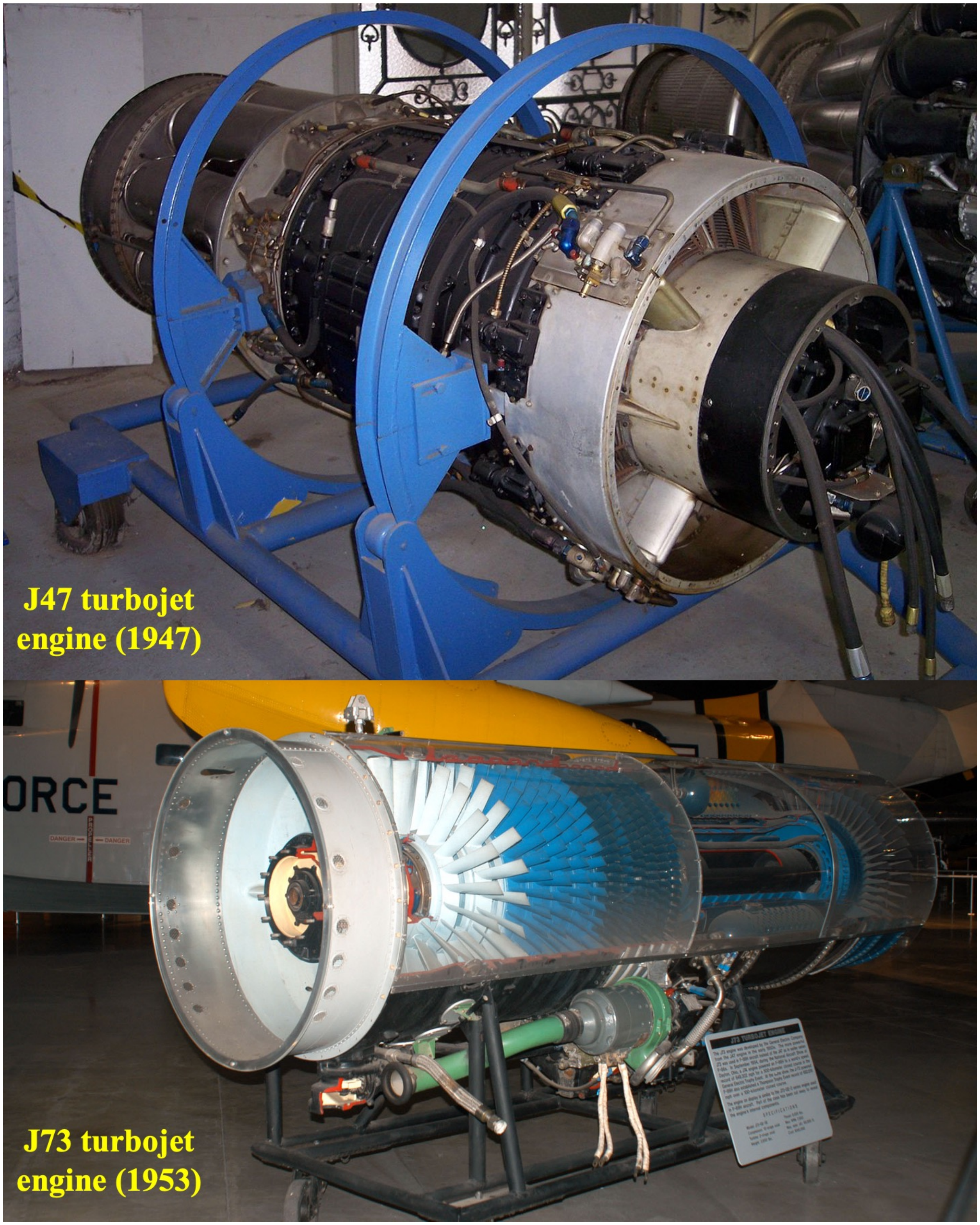


Figure 9.87: Some examples of postwar jet engines developed for General Electric by Bruno Bruckmann and Peter Kappus include the J47 turbojet engine (first run 1947) and the J73 turbojet engine (first run 1953).

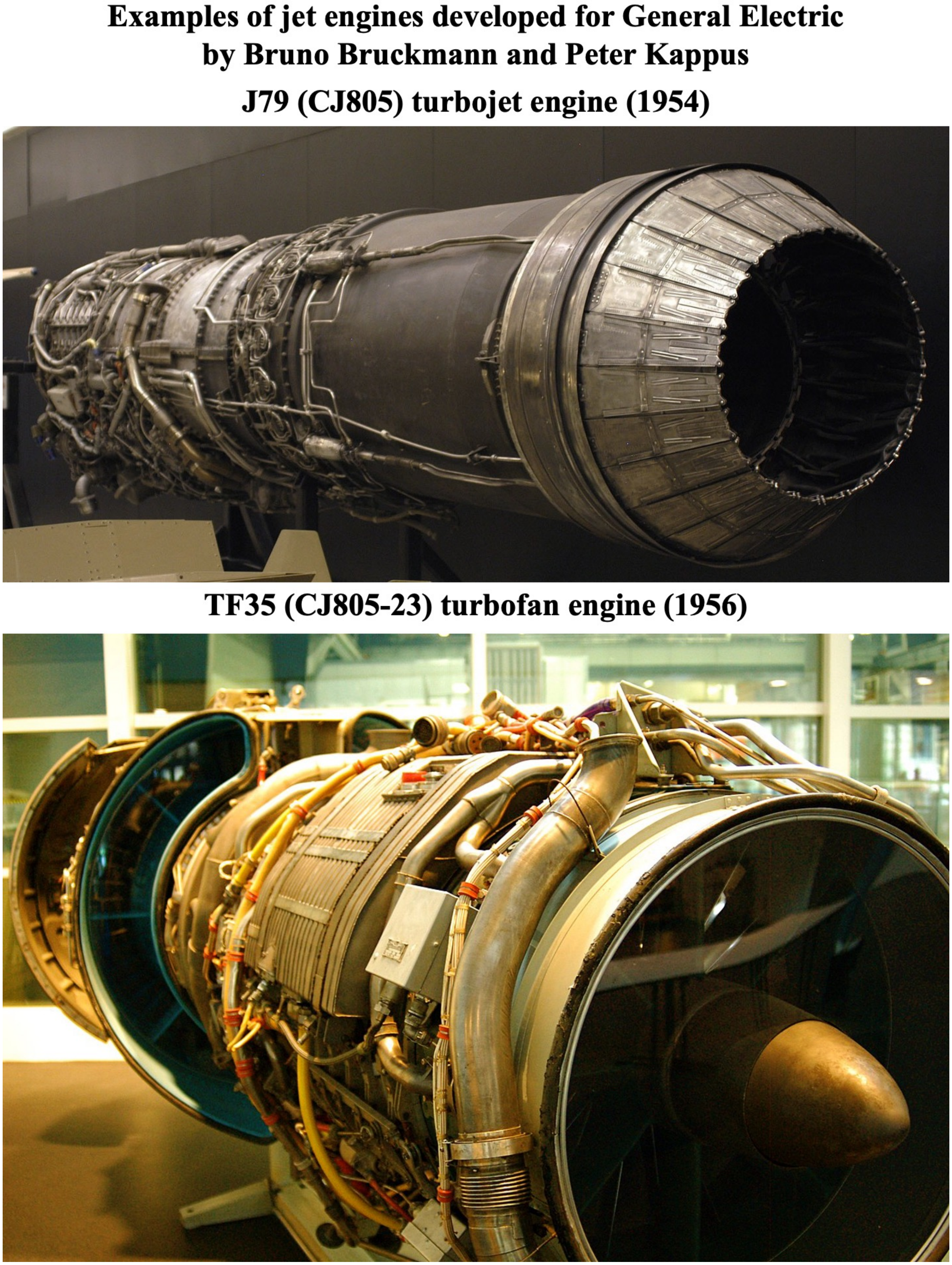


Figure 9.88: Other examples of postwar jet engines developed for General Electric by Bruno Bruckmann and Peter Kappus include the J79 or CJ805 turbojet engine (first run 1954) and the TF35 or CJ805-23 turbofan engine (first run 1956).

Bruno Bruckmann designed the YJ-93 engines for the Mach 3+ XB-70 Valkyrie (first flight 1964)

Figure 9.89: Bruno Bruckmann designed the engines for the Mach 3+ XB-70 Valkyrie (first flight 1964).

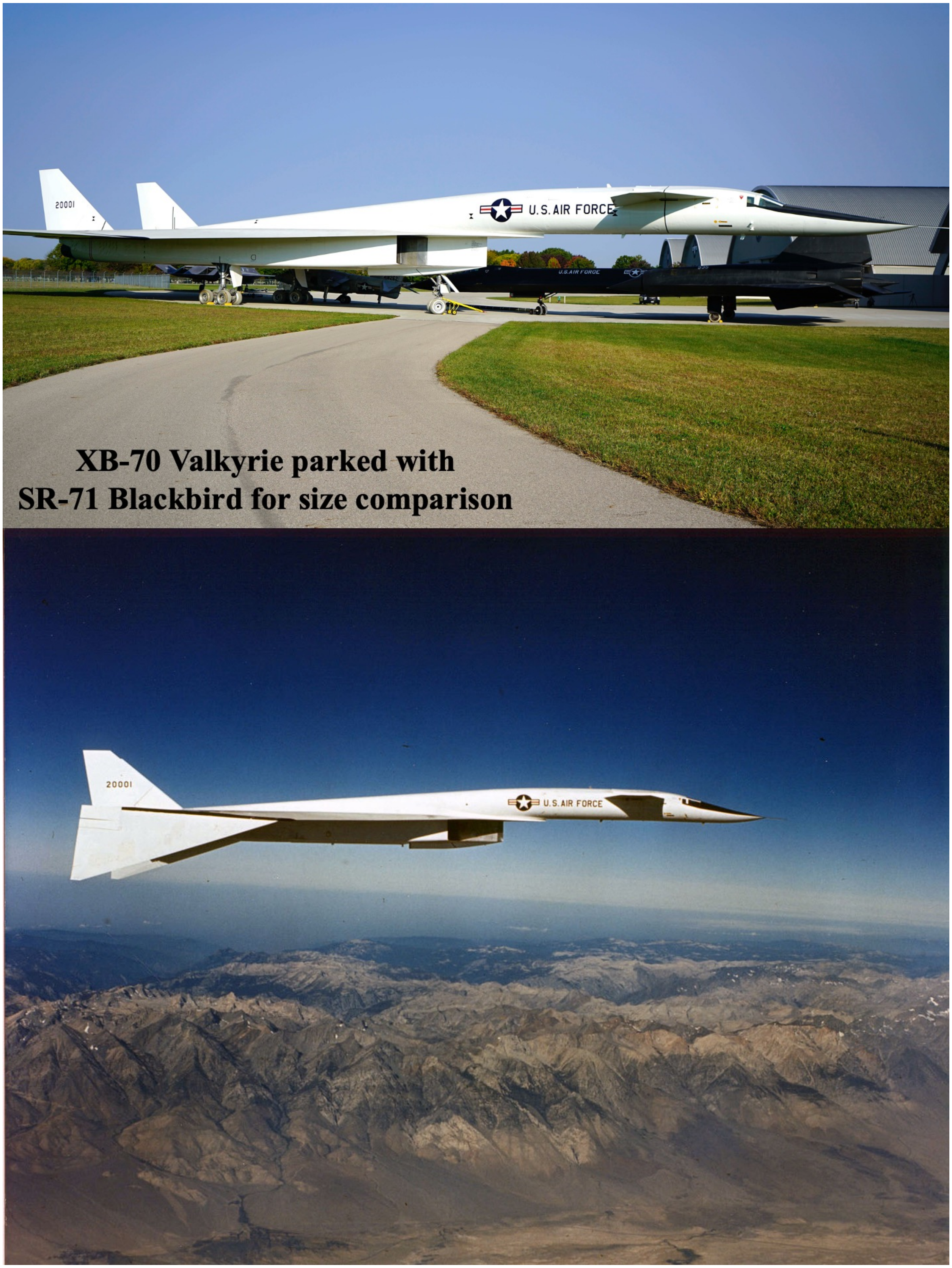
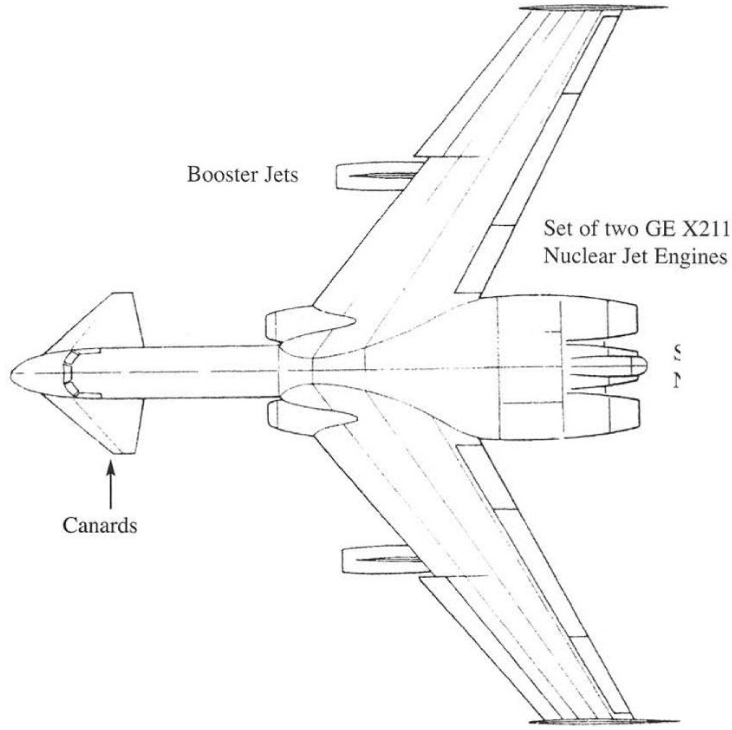
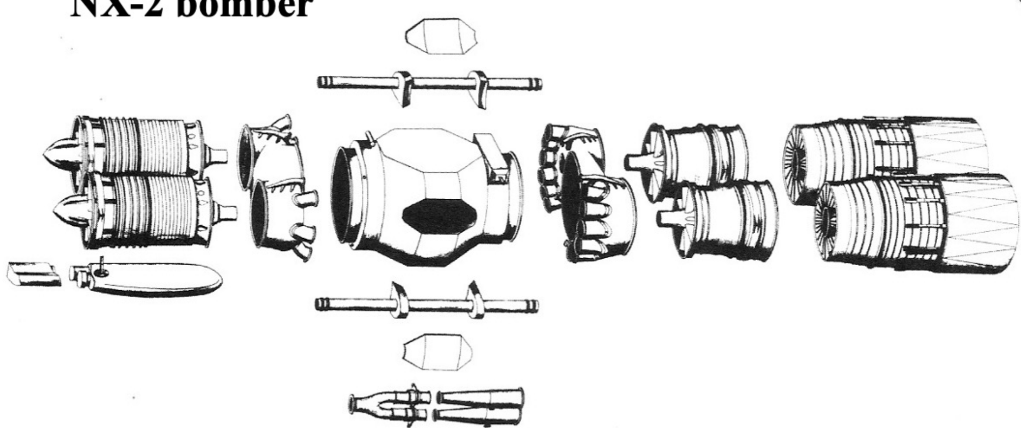


Figure 9.90: Bruno Bruckmann designed the engines for the Mach 3+ XB-70 Valkyrie (first flight 1964).

Bruno Bruckmann designed the GE X211 nuclear turbojet engine (first demonstrated in 1958)



Two GE X211 engines would have powered the proposed Convair NX-2 bomber



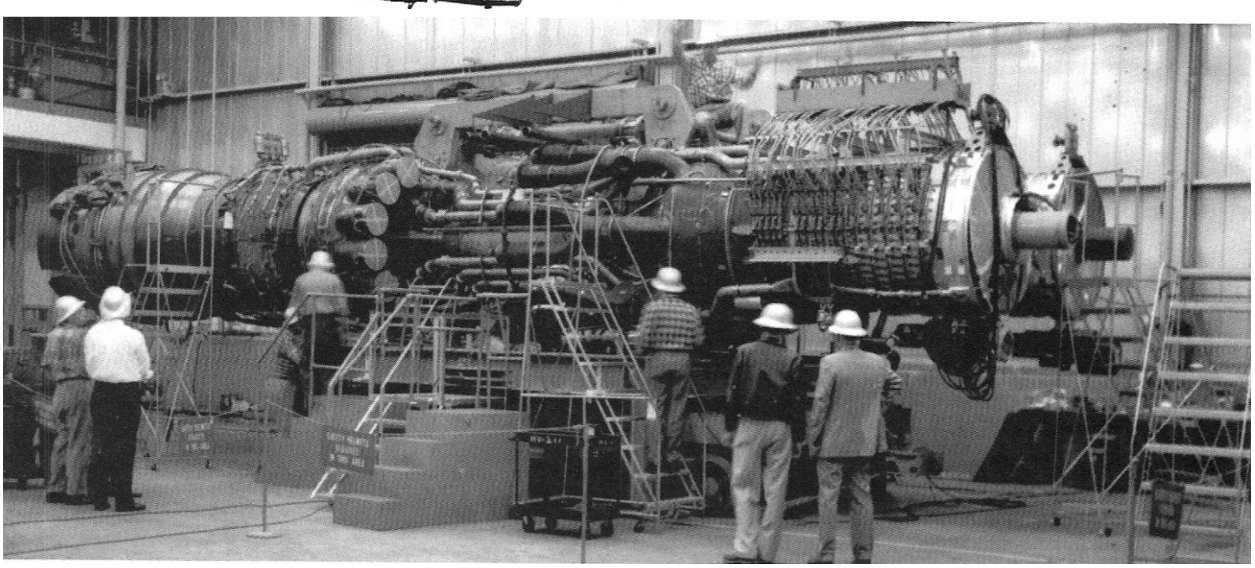
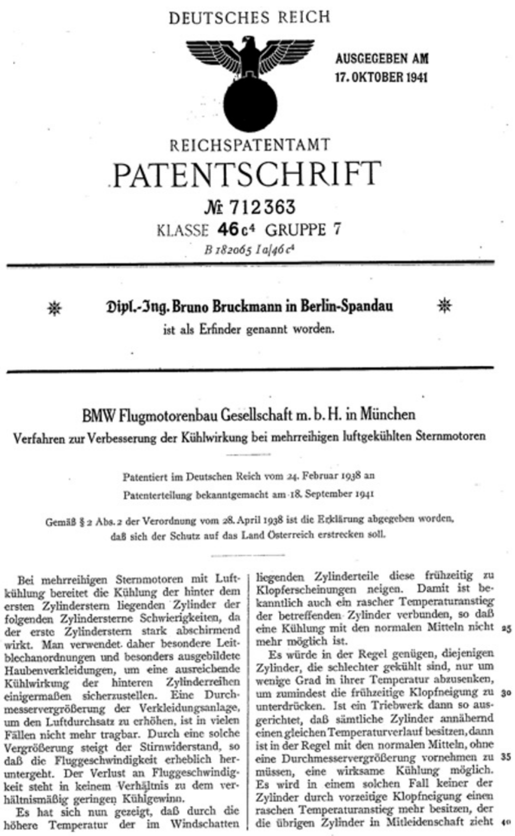


Figure 9.91: Bruno Bruckmann designed the GE X211 nuclear turbojet engine (first demonstrated in 1958). Two GE X211 engines would have powered the proposed Convair NX-2 bomber [Carpenter 2003].



DEUTSCHES REICH

AUSGEGEBEN AM 17. OKTOBER 1941

REICHSPATENTAMT

PATENTSCHRIFT

№ 712363

KLASSE 46c⁴ GRUPPE 7

B 182065 Ia/46c⁴

Dipl.-Ing. Bruno Bruckmann in Berlin-Spandau
ist als Erfinder genannt worden.

BMW Flugmotorenbau Gesellschaft m. b. H. in München

Verfahren zur Verbesserung der Kühlwirkung bei mehrreihigen luftgekühlten Sternmotoren

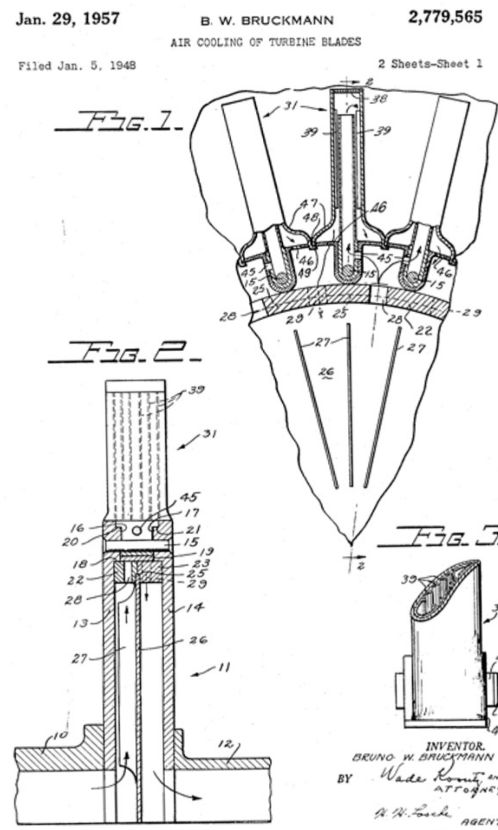
Patentiert im Deutschen Reich vom 24. Februar 1938 an
Patenterteilung bekanntgemacht am 18. September 1941

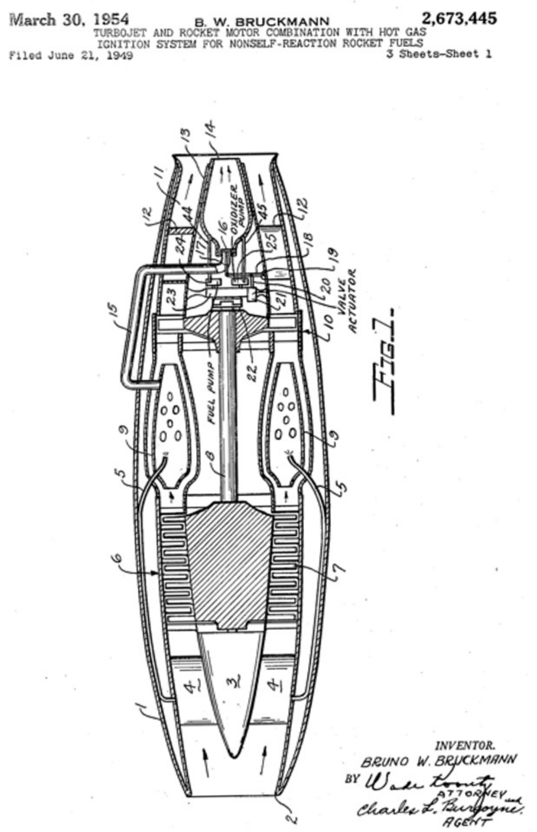
Gemäß § 2 Abs. 2 der Verordnung vom 28. April 1938 ist die Erklärung abgegeben worden, daß sich der Schutz auf das Land Österreich erstrecken soll.

Bei mehrreihigen Sternmotoren mit Luftkühlung bereitet die Kühlung der hinter dem ersten Zylinderstern liegenden Zylinder der folgenden Zylindersterne Schwierigkeiten, da der erste Zylinderstern stark abschirmend wirkt. Man verwendet daher besondere Leitblechanordnungen und besonders ausgebildete Haubenverkleidungen, um eine ausreichende Kühlwirkung der hinteren Zylinderreihen einigermaßen sicherzustellen. Eine Durchmesservergrößerung der Verkleidungsanlage, um den Luftdurchsatz zu erhöhen, ist in vielen Fällen nicht mehr tragbar. Durch eine solche Vergrößerung steigt der Stirnwiderstand, so daß die Fluggeschwindigkeit erheblich heruntergeht. Der Verlust an Fluggeschwindigkeit steht in keinem Verhältnis zu dem verhältnismäßig geringen Kühlgewinn.

Es hat sich nun gezeigt, daß durch die höhere Temperatur der im Windschatten liegenden Zylinderteile diese frühzeitig zu Klopferscheinungen neigen. Damit ist bekanntlich auch ein rascher Temperaturanstieg der betreffenden Zylinder verbunden, so daß eine Kühlung mit den normalen Mitteln nicht mehr möglich ist.

Es würde in der Regel genügen, diejenigen Zylinder, die schlechter gekühlt sind, nur um wenige Grad in ihrer Temperatur abzusenken, um zumindest die frühzeitige Klopfneigung zu unterdrücken. Ist ein Triebwerk dann so ausgerichtet, daß sämtliche Zylinder annähernd einen gleichen Temperaturverlauf besitzen, dann ist in der Regel mit den normalen Mitteln, ohne eine Durchmesservergrößerung vornehmen zu müssen, eine wirksame Kühlung möglich. Es wird in einem solchen Fall keiner der Zylinder durch vorzeitige Klopfneigung einen raschen Temperaturanstieg mehr besitzen, der die übrigen Zylinder in Mitleidenschaft zieht





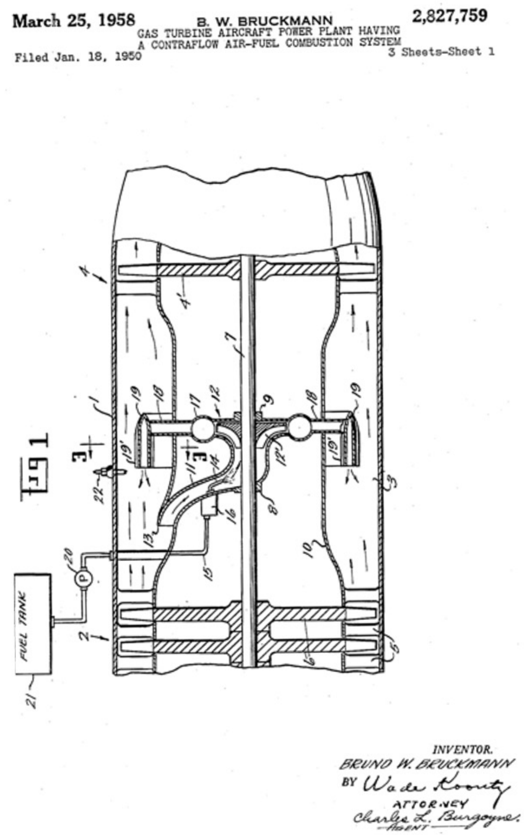


Figure 9.92: Examples of jet engine patents by Bruno Bruckmann.

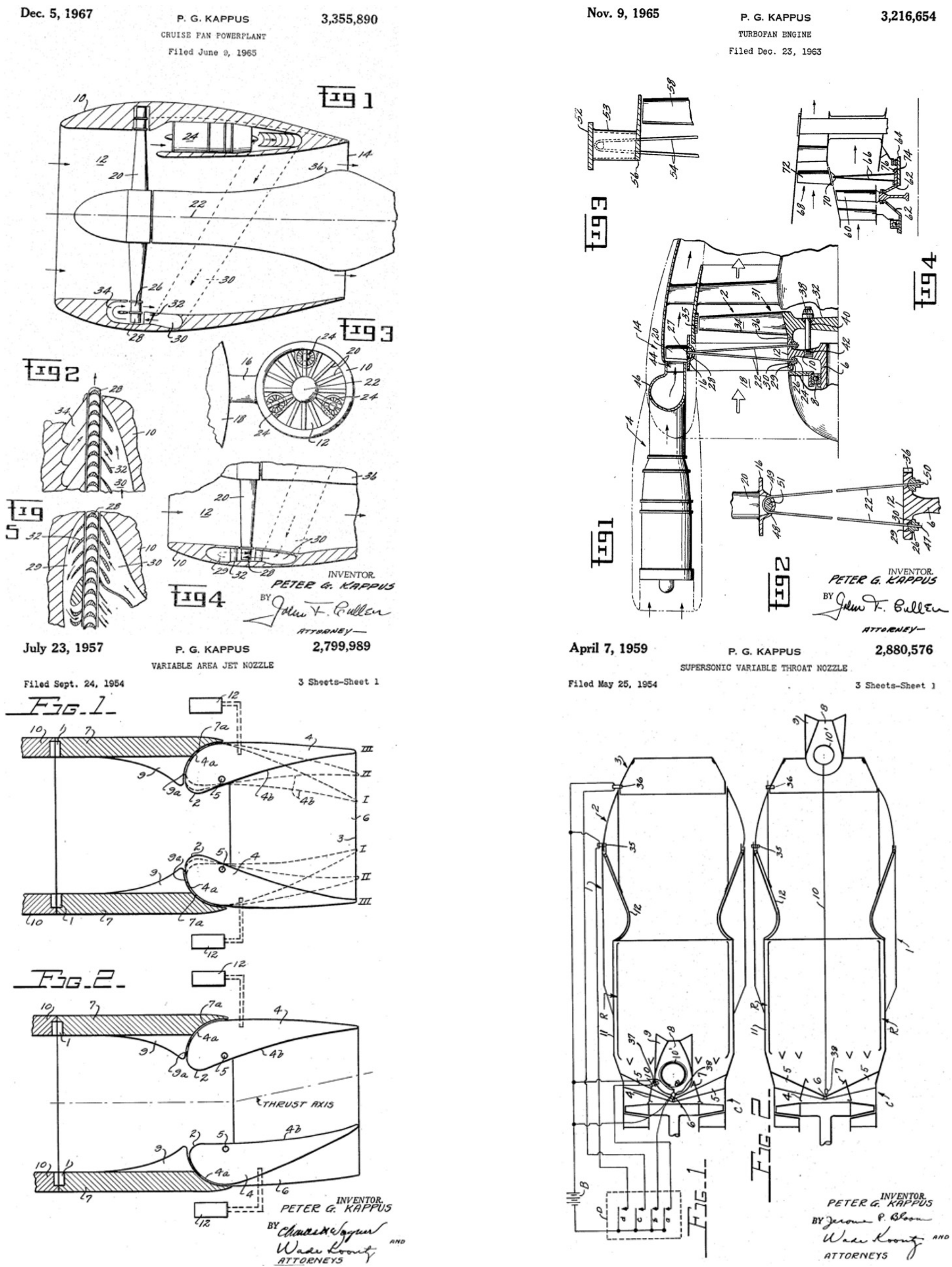
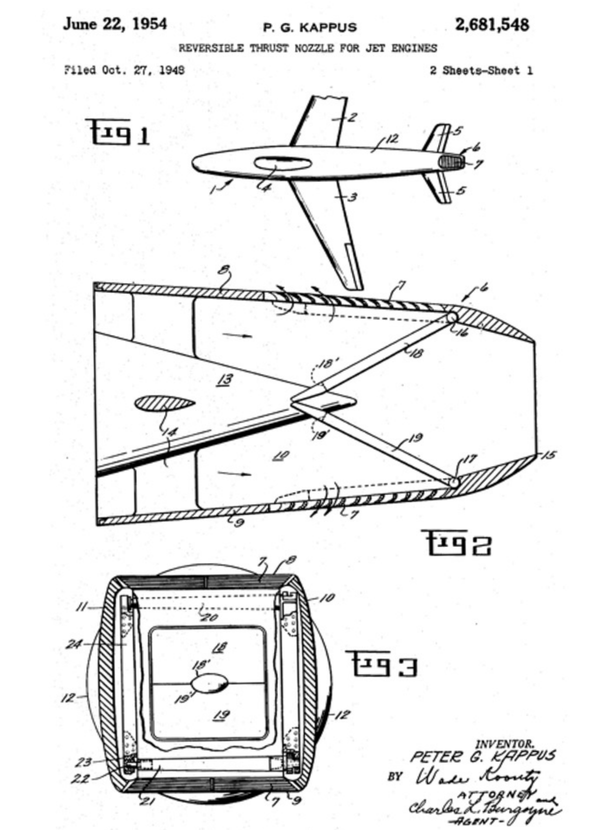
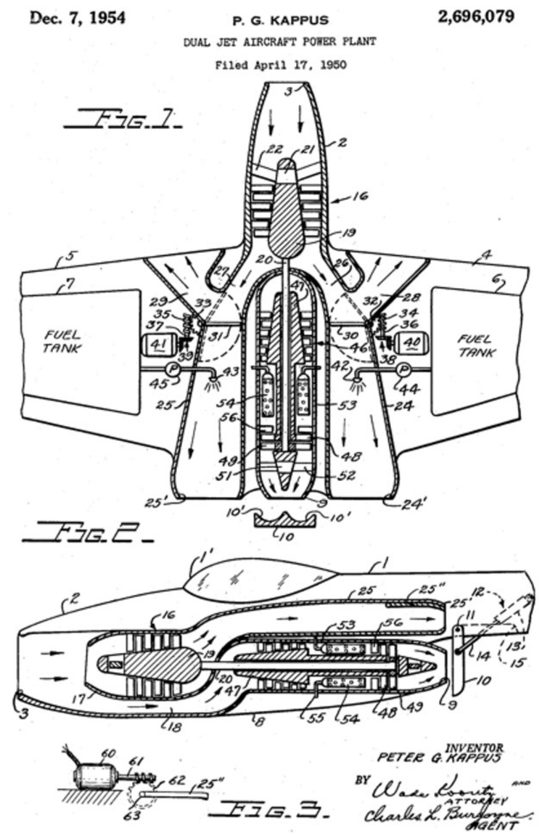


Figure 9.93: Examples of jet engine patents by Peter Kappus.





United States Patent [11] **3,547,379**

[72] Inventors **Peter G. Kappus; William H. Long, Cincinnati, Ohio**
[21] Appl. No. **668,436**
[22] Filed **Sept. 18, 1967**
[45] Patented **Dec. 15, 1970**
[73] Assignee **General Electric Company a corporation of New York**

[54] **AIRCRAFT NUCLEAR PROPULSION SYSTEM HAVING AN ALTERNATIVE POWER SOURCE**
8 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **244/55,** 60/59, 60/203, 176/52
[51] **Int. Cl.** **B64d 27/22**
[50] **Field of Search** 244/53, 55, 58, 62, 73, 15; 60/203, 226, 244, 36, 39.19, 39.18, 59, 224; 176/52, 60

[56] **References Cited**

UNITED STATES PATENTS

2,604,277	7/1952	Anxionnaz et al.	244/15
3,068,647	12/1962	Santamaria et al.	244/55
3,229,933	1/1966	Kutney	244/55
3,235,205	2/1966	Newcomb	244/54
3,368,352	2/1968	Hewson	60/224

FOREIGN PATENTS

1,178,646	12/1958	France	60/226

Primary Examiner—Milton Buchler
Assistant Examiner—James E. Pittenger
Attorneys—Frank L. Neuhauser, Oscar B. Waddell, Loren W. Peters and Derek P. Lawrence

ABSTRACT: An aircraft propulsion system includes a fuselage mounted, primary gas generator powered by nuclear energy for supplying motive fluid to wing mounted propulsion units capable of converting the energy of the motive fluid into useful thrust, the propulsion system also including secondary gas generators mounted on the wings for supplying hot products of combustion to the propulsion units as an alternative or additional motive fluid.

United States Patent [11] **3,547,380**

[72] Inventors **Peter G. Kappus; William H. Long, Cincinnati, Ohio**
[21] Appl. No. **668,581**
[22] Filed **Sept. 18, 1967**
[45] Patented **Dec. 15, 1970**
[73] Assignee **General Electric Company a corporation of New York**

[54] **AIRCRAFT NUCLEAR PROPULSION SYSTEM**
9 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** **244/55;** 176/52; 60/59, 60/203
[51] **Int. Cl.** **B64d 27/22**
[50] **Field of Search** 244/53, 55, 58, 62, 73, 15; 176/52; 60/39.19, 39.18, 36, 59, 203, 226, 244

[56] **References Cited**

UNITED STATES PATENTS

2,604,277	7/1952	Anxionnaz et al.	244/15
3,229,933	1/1966	Kutney	244/55
3,235,205	2/1966	Newcomb	244/54

FOREIGN PATENTS

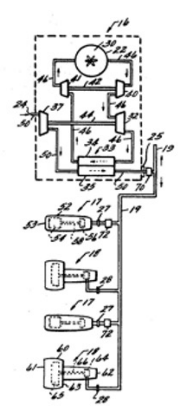
1,178,646	12/1958	France	60/226

OTHER REFERENCES

Nuclear-Chemical Hybrids, G.N. Nesterenko et al. Space/Aeronautics, April 1959, pp. 47—49

Primary Examiner—Fergus S. Middleton
Assistant Examiner—James E. Pittenger
Attorneys—Derek P. Lawrence, Frank L. Neuhauser, Oscar B. Waddell and Loren W. Peters

ABSTRACT: A nuclear power plant includes a closed reactor circuit within which a medium heated by the nuclear reactor transfers energy to a propulsion fluid in a two-step process, the first step being a mechanical transformation and the second step being a thermal transformation of energy.



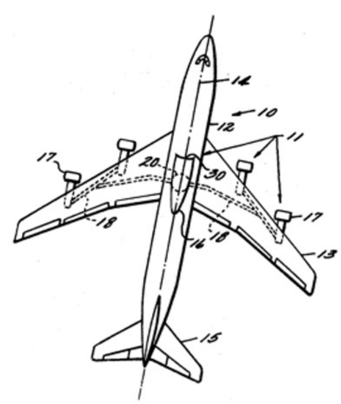
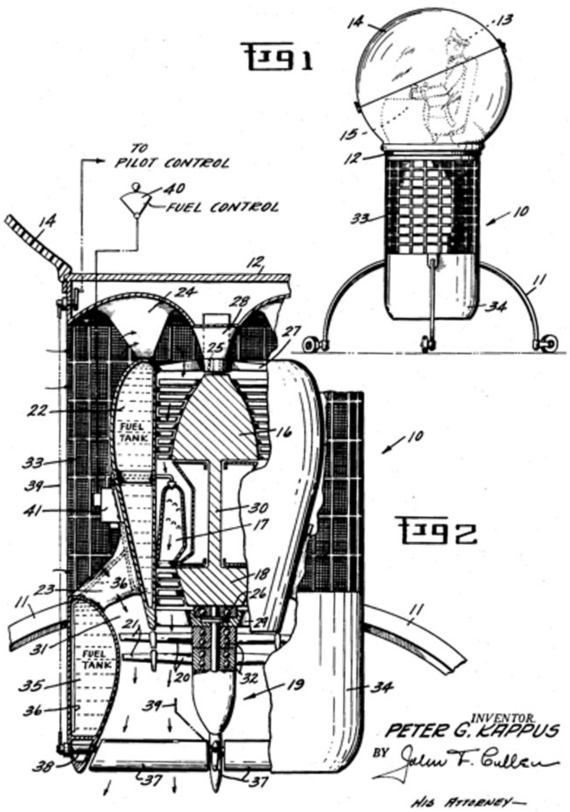


Figure 9.94: Examples of jet engine patents by Peter Kappus.

May 17, 1960 P. G. KAPPUS **2,936,973**

VTOL AIRCRAFT

Filed Sept. 6, 1957



United States Patent Office

2,936,973
Patented May 17, 1960

1

2,936,973

VTOL AIRCRAFT

Peter Gottfried Kappus, Cincinnati, Ohio, assignor to General Electric Company, a corporation of New York

Application September 6, 1957, Serial No. 682,328

6 Claims. (Cl. 244—23)

The present invention relates to a VTOL aircraft and, more particularly, to a vertical take-off and landing aircraft using a ducted-fan engine in which a smooth external vehicle surface completely encloses all the rotating and control elements.

In recent years, much emphasis has been placed on the development and perfection of the so called VTOL or vertical take-off and landing type of aircraft. This is an aircraft that requires no runway and takes off directly upward or substantially so and is then directed forwardly by either shifting weight or by suitable control surfaces to provide a horizontal component of force. In some propeller driven types of VTOL aircraft, the whole vehicle or engine is tilted for horizontal flight. The advent of the jet engine has indicated it to be a desirable powerplant for such an aircraft if suitable control means and size can be obtained in an efficient vehicle to make the project feasible. As is well known, the jet engine consumes relatively high quantities of fuel which can be a distinct disadvantage in VTOL aircraft which are designed for subsonic or low subsonic forward operations in that the vehicles have a very short range of operation. Another disadvantage is that such vehicles are inherently unstable in flight. Consequently, there is a need for a vehicle of this type which will have a clean outward appearance within practical size limits and be capable of sustained flight at high subsonic operation with a practical specific fuel consumption.

Many of the VTOL aircraft of the type discussed here are nothing more than flying engines with a load platform to carry the pilot. Devices of this type, which have thus far been perfected, have been either propeller operated or, in those employing jet engines, have been limited by very short flight duration, time, and relatively low speeds.

It is a primary object of the present invention to provide a VTOL aircraft which will have a much higher sustained operation time with economy of operation in fuel consumption and which is capable of higher flight speeds than similar aircrafts heretofore known.

Another object of the invention is to provide such a vehicle which has a high ratio of fuel load to gross weight and is self contained in that all the rotating parts and controls are completely enclosed within the vehicle itself to prevent external drag and provide completely flexible control.

A further object is to provide such a vehicle which attains these objectives by the use of a ducted fan engine in combination with enclosed control surfaces in the nozzle or exhaust stream within the confines of the vehicle.

Briefly stated, in accordance with my invention, I provide a vehicle housing which carries a load sustaining platform at one end and has a nozzle at the opposite end. Within the housing, there is provided a gas generator with a ducted fan which is separate from the generator and provides for a larger mass flow and economy of op-

2

eration. This is attained within a vehicle of relatively small diameter for its thrust capabilities.

My invention will be better understood from the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing:

Figure 1 is an elevation view of the VTOL aircraft of the instant invention as it would appear on the ground and,

Figure 2 is a cross sectional view illustrating the internals of such an aircraft.

Referring first to Figure 1, a VTOL aircraft of the type described in the instant invention, may be termed a flying engine, since, in effect, it consists of nothing more than a barrel-like housing generally indicated at **10**, which is supported at one end in a vertical position on the ground by suitable supporting means **11** and carries at the other or upper end a load carrying platform **12** which may accommodate the pilot **13**. The pilot may or may not be enclosed by a suitable protecting canopy **14**. In order to pilot the aircraft, a suitable control panel **15** is provided.

As shown in Figure 2, housing **10** may be a tubular housing of generally cylindrical shape although it is not limited to the cylindrical form. Coaxially arranged within the housing is a powerplant of the jet engine type. This may preferably comprise a gas generator engine of the axial flow type including a compressor section **16**, a combustion section **17** which may be annular or cannular as shown, and a turbine section **18**. This structure which, in effect, is a turbojet engine minus the nozzle is generally referred to as the main engine.

In order to provide for economical operation with relatively low specific fuel consumption within a vehicle of much smaller diameter than heretofore believed necessary, I employ a powerplant of the ducted fan type. This may comprise a free rotating turbine **20** having fan blades **21** on the extremity thereof.

For compactness of operation and high ratio of fuel load to gross load, fuel tanks **22** may form the outer casing of the gas generator or main engine. The fuel tanks are supported within housing **10** by means of struts **23** and **24**. In order to provide for aligned rotation of the turbine and compressor, bearing **25** is supported from the fuel tanks by struts **27** and from the housing by strut **28** and bearing **26** is supported from the fuel tank by strut **29**. The engine shaft **30** is supported in these bearings.

The increased mass flow obtained by the use of the ducted fan engine is obtained by the provision of the bypass duct **31** between the housing and the engine in which ducted fan blades **21** compress additional air for increased mass flow. Fan blades **21** are driven by free turbine or turbines **20** which are supported in bearing **32** separate from bearing **26**. Thus the turbine **20** is disconnected from and freely rotatable with respect to the main engine. It is to be noted that the free fan may comprise a single stage, or plurality of stages as shown which stages may rotate in the same direction as the main engine or in the opposite direction. In addition, if a plurality of stages is provided, the stages may rotate in opposite directions relative to one another. The direction of rotation will be determined by the characteristics desired of the particular powerplant.

In order to provide air for the powerplant as thus far described, the periphery of the housing **10** is supplied with a plurality of openings preferably in the upper portion thereof which openings may be covered by screen member **33**. Thus, substantially the whole periphery of the housing member **10** is an air intake surface. The air for the main engine flows upwardly around struts **24**

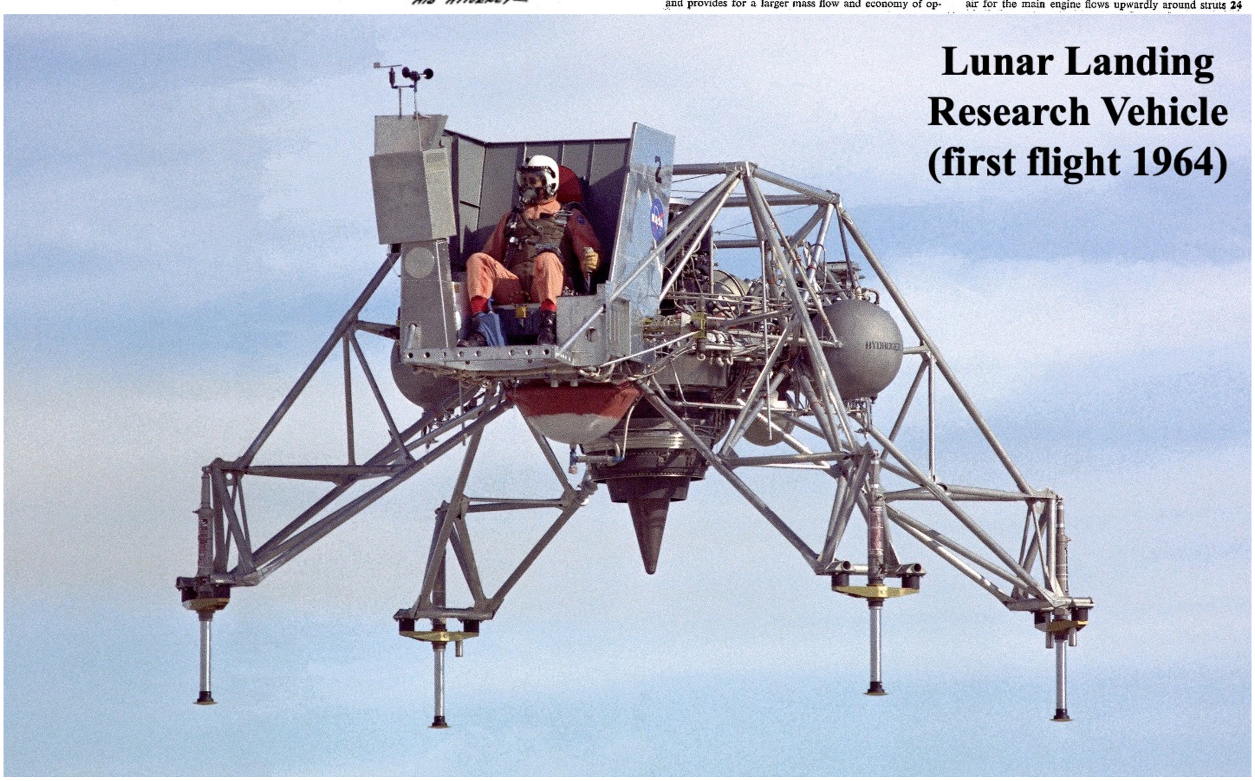


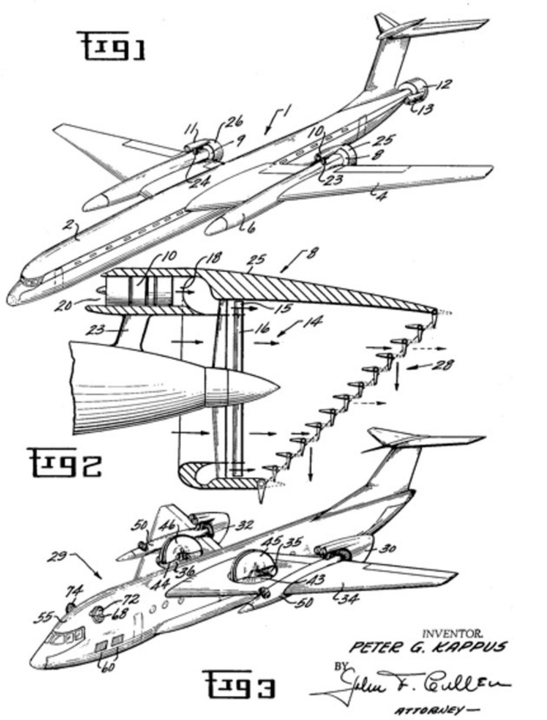
Figure 9.95: In September 1957 (before Sputnik!), Peter Kappus filed a patent application on a VTOL vehicle that was ultimately implemented as the Lunar Landing Research Vehicle to train astronauts to land the Apollo Lunar Module (first flight 1964, with the vehicle's legs and pilot's position modified to resemble the final Lunar Module design).

Figure 9.96: Beginning in 1957, Peter Kappus filed several patent applications on VTOL aircraft with downward-pointing fans in the wings and/or body (see also Fig. 9.97). That approach was successfully implemented in aircraft such as the Ryan XV-5 Vertifan (first flight 1964) and the Lockheed Martin F-35B (first flight 2008).

Oct. 19, 1965 P. G. KAPPUS 3,212,731

FAN POWERED AIRCRAFT

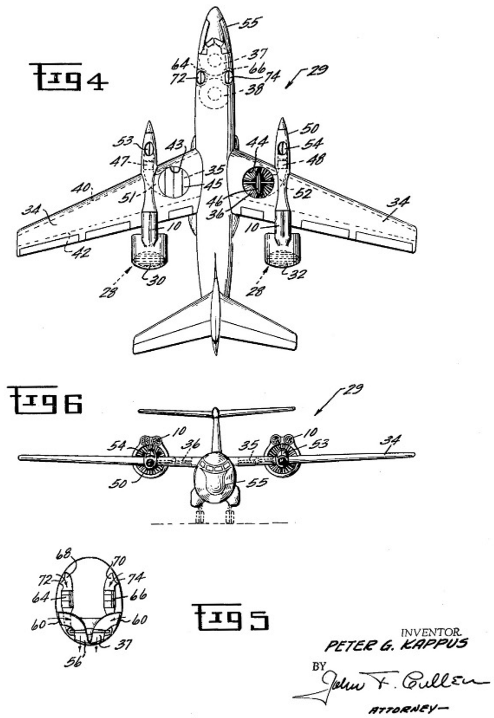
Filed Sept. 9, 1963 2 Sheets-Sheet 1



Oct. 19, 1965 P. G. KAPPUS 3,212,731

FAN POWERED AIRCRAFT

Filed Sept. 9, 1963 2 Sheets-Sheet 2



United States Patent [11] 3,618,875

[72] Inventor Peter G. Kappus
Cincinnati, Ohio
[21] Appl. No. 801,293
[22] Filed Feb. 24, 1969
[45] Patented Nov. 9, 1971
[73] Assignee General Electric Company

[54] **V/STOL AIRCRAFT**
14 Claims, 8 Drawing Figs.

[52] U.S. Cl. 244/12 B, 244/23 B
[51] Int. Cl. B61c 29/04
[50] Field of Search 244/12, 15, 23

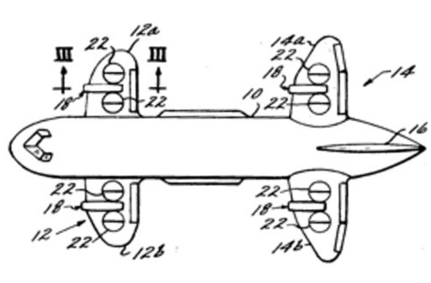
[56] **References Cited**

UNITED STATES PATENTS

2,973,166	2/1961	Stahmer	244/23
3,161,374	12/1964	Allred et al.	244/12
3,289,975	12/1966	Hall	244/55
3,131,873	5/1964	Sanders	244/12
3,267,667	8/1966	Erwin	244/23

Primary Examiner—Milton Buchler
Assistant Examiner—Steven W. Weinrieb
Attorneys—Derek P. Lawrence, E. S. Lee, III, Lee H. Sachs, Frank L. Neuhauser and Oscar B. Waddell

ABSTRACT: A V/STOL aircraft comprises a fuselage having tandem wings which are offset lengthwise and vertically. Identical propulsion units are provided in each wing half. Each power unit comprises a pair of gas generators mounted respectively above and below the wing half and a pair of lift fans mounted within the wing structure on opposite sides of the engines. A valve system diverts the hot gas stream of the engines into a plenum chamber formed integrally with the wing structure. The hot gas streams are then directed from the plenum chamber to a tip turbine which powers the lift fans when vertical thrust is desired in operation of the aircraft. When forward speed of the aircraft is great enough for the aircraft wings to have sufficient lift, the hot gas streams are directed through propulsive nozzles providing a forward thrust component. In cruise, one engine of each power unit could be shut down. Each engine and each lift fan has emergency capacity which is automatically brought into play in the event of a failure of a lift fan or engine, with proper adjustments being made to the other power units to maintain balance and controlled operation of the aircraft in the lift mode.



April 12, 1960 P. G. KAPPUS 2,932,468

VTOL AIRCRAFT

Filed Dec. 6, 1957

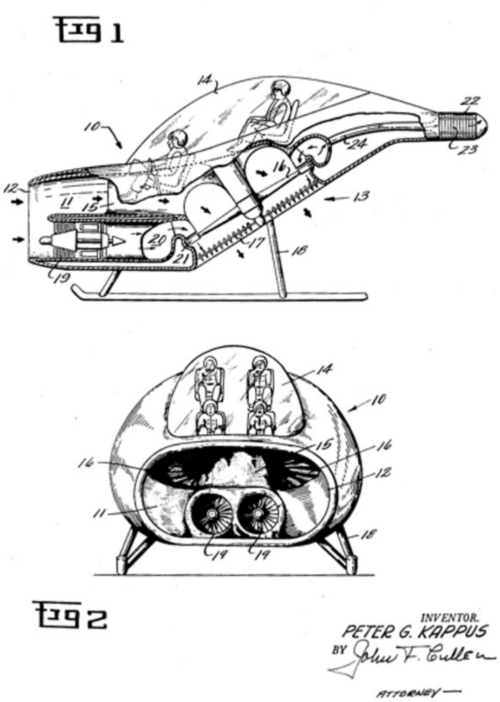


Figure 9.97: Other examples of VTOL jet vehicle patents by Peter Kappus.

R. WALTER BRISKEN

August 8, 1986
1356 SHIPWATCH
AMELIA ISLAND PLANTATION
FLORIDA, 32034

R. Walter Brisken (1914–2011) developed the GE LM2500 gas turbine power plant for ships and industrial applications

Officer in Charge of Construction, TRIDENT
Attention: Code 09XE3
293 Point Peter Road
St. Marys, Georgia 31558

Subject: Public Hearing for Draft Third Supplement Environmental Impact Statement "St. Marys Entrance Channel Dredging", held at Fernandina Beach High School, Fernandina Beach, Florida on July 31, 1986.

Dear Sir!

The following is my written statement concerning the above subject.

After 41 years of research, engineering development, project leadership and management I retired six and a half years ago as Program General Manager, Marine Projects, General Electric Co. in which position I had the full responsibility for the LM 2500 marine engine which now powers all the non-nuclear powered destroyers, frigates and hydrofoils of the US Navy built since 1970 and currently being built. When I retired at the end of 1979 Vice Admiral, US Navy C. R. Bryan, Commander Naval Sea Systems Command wrote me a letter in which he said "I can not help but think that the Navy is losing a very good friend".

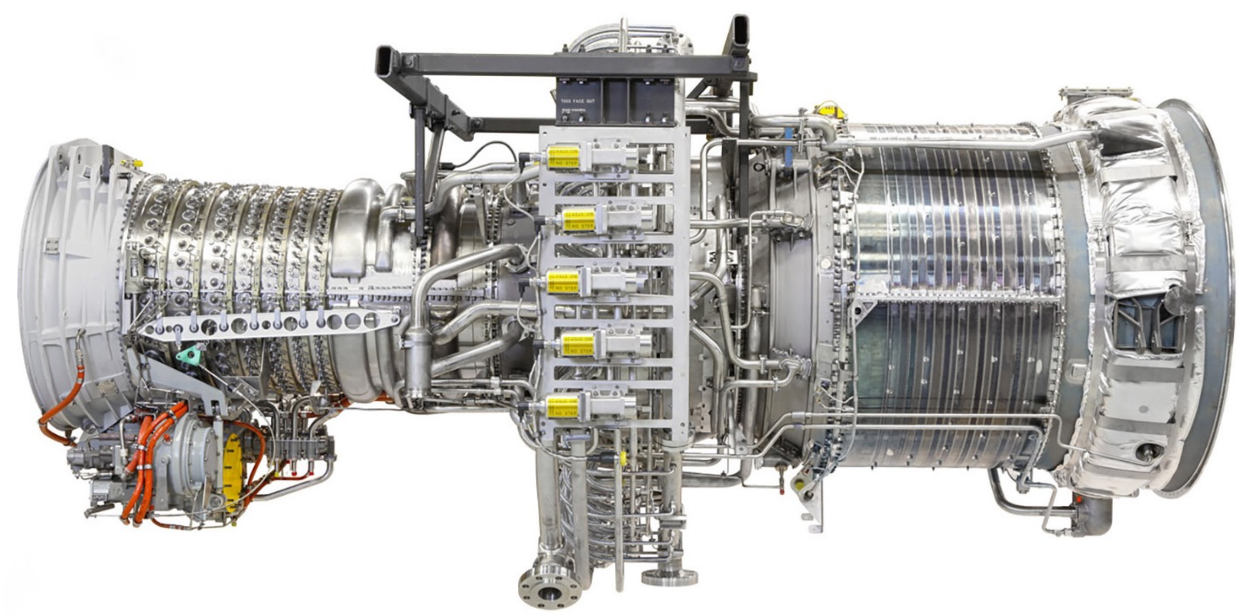


Figure 9.98: R. Walter Brisken developed the GE LM2500 gas turbine power plant for ships and industrial applications.

Other BMW aircraft engine experts who moved to the United Stated included Rudolf Ammann (German, 19??–19??, an expert on piston aircraft engines and on wind turbines) and Christoph Soestmeyer (German, 19??–19??, an expert on jet engine testbeds to simulate high altitudes, such as the wartime BMW Herbitus facility in Munich).

Some other BMW jet experts, such as Hermann Östrich, Hans-Georg Münzberg (Austrian/German, 1916–2000), August Wilhelm Quick (German, 19??–19??), Otto David (German, 19??–19??), and others, developed jet engines and jet aircraft in France after the war (Fig. 9.99).

René Lorin (French, 1877–1933) proposed the general notion of a ramjet in 1913 but did not have the resources to pursue the topic; ramjets are sometimes called Lorin tubes after him. In Germany, separate, well-funded teams led by Otto Pabst (German, 19??–19??), Eugen Sänger (Austrian, 1905–1964), and Hellmuth Walter (German, 1900–1980) developed and demonstrated fully functional ramjets during World War II. Figure 9.100 shows Sänger's ramjet being successfully tested in 1942. In the United States, Fritz Zwicky (Swiss, 1898–1974) designed and proposed ramjets, but was unable to find any financial or political support for such an innovative concept.

Just as ramjets work best at supersonic speeds but can be modified to operate at hypersonic speeds as scramjets, they can also be modified to work at subsonic speeds as pulsejets, as shown in Fig. 9.53. With no active compressor and only minimal compression from stagnation effects, the combustion products could easily escape through the front diffuser of the engine instead of through the rear nozzle as intended. To avoid this problem, the diffuser must be open when taking in air, but closed when combustion occurs. This means that combustion must occur in a pulsed rather than continuous fashion, and the front air inlet must cycle open and closed at the appropriate times during each pulse. In order to imitate continuous combustion, the pulses must occur at fairly high frequency, typically ∼40–50 cycles per second (or Hertz, Hz). The air intake generally uses mechanical shutters or valves that can be opened and closed at such a high frequency.

Paul Schmidt (German, 1898–1976) created the first major pulsejet engine of note—the Argus As 014 engine that ended up being used in the V-1 missile, which is discussed in Section 9.6. Figure 9.101 shows an Argus engine with one side cut open. The engine used mechanical shutters and a pulse frequency of 43 Hz to produce 3.3 kN (750 lb) of thrust during flight. Since there was no active compressor, a steam-driven catapult was used to rapidly accelerate the V-1 to an airspeed where its engine could achieve self-sustaining flight (p. 5339). The V-1 was essentially the world's first cruise (non-ballistic) missile, and became known as the "buzz bomb" because of its engine's very loud and distinctive frequency. The engine's low energy efficiency (due to its minimal compression of the intake air) and inherent problems with vibration were offset by its very simple design and attendant low cost and high thrust-to-weight ratio.

During the Third Reich, many of the jet engine and jet aircraft development programs were funded by the Reichsluftfahrtministerium (Reich Ministry of Aviation). Two individuals there who were especially important in championing and guiding the jet programs were Helmut Schelp (German, 19??–19??) and Hans Mauch (German, 1906–1984). After the war, Helmut Schelp went to the United Kingdom, and Mauch went to the United States. Ultimately Mauch became much better known for his wartime and long postwar work developing prosthetic limbs, rather than for his earlier work on jets; see Sections 2.7.2 and A.2.

 AFHRA A2055 Frame 1257

[redacted]

[redacted] AUTH [redacted] DATE

EXPLOITATION OF GERMAN SCIENTISTS BY
FRANCE AND RUSSIA

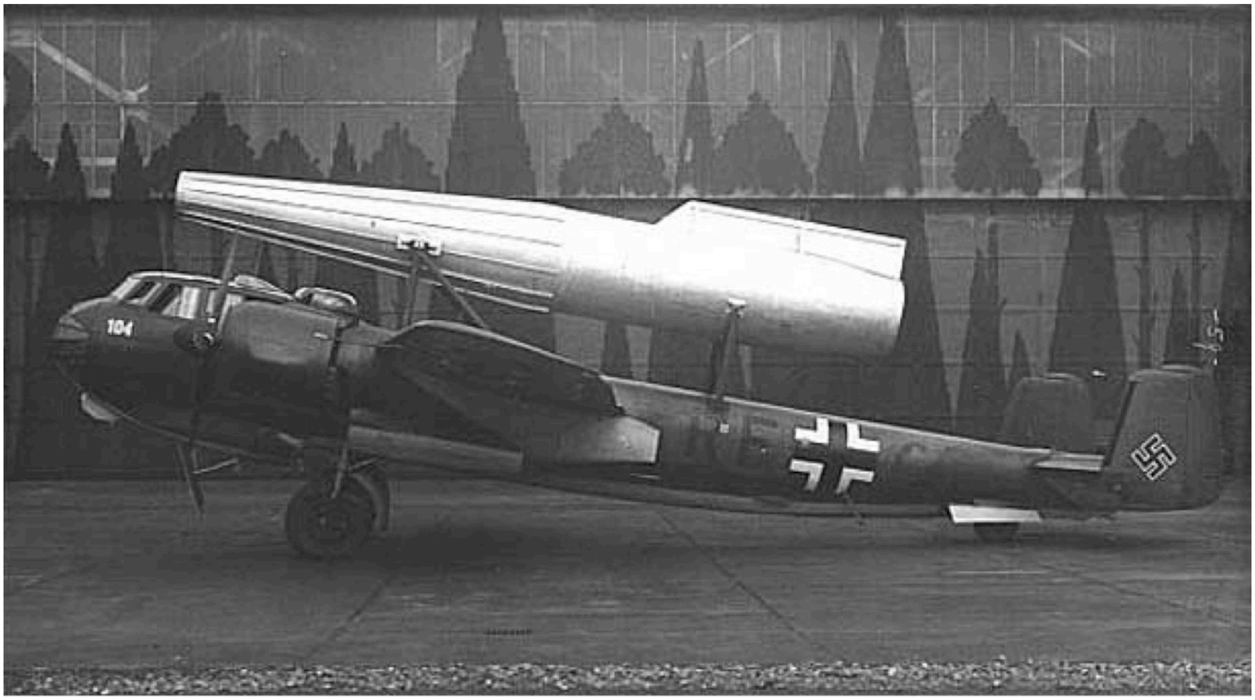
The following typical cases are presented as evidence of French-Russian efforts and successes and American failures in contracting top ranking German scientists and technicians.

1. Case "Oestrich" (France)

a. Dr. Oestrich has been in charge of jet development at BMW. Shortly before the Russian invasion he was taken to Munich by American authorities. After a long and fruitless waiting period during which Oestrich hoped for an American contract, he entered into negotiations with France. Dr. Oestrich had secured the cooperation of his best collaborators by private contracts in advance. In November 1945 Oestrich and these collaborators, first class specialists throughout, went as a group of 25 to Lindau in the French occupied zone. Previously, Oestrich had shown his French contract to one of the scientists now at Wright Field. According to this contract, the French government made the most generous arrangements to immediately accomodate these scientists and their families. The contract runs for a period of 4 years, during which time Oestrich expects to employ approximately 1,000 people. Dr. Oestrich is sole chief of the undertaking and directly responsible to the respective French Ministry. He receives the same salary as in Germany, shares substantially in the profits derived from his designs and patents, and has full authority to hire and fire as he pleases. According to latest reports, Oestrich already has gathered a staff of 500, is traveling freely throughout the American Zone and has succeeded in contracting some of BMW's and Daimler-Benz's top ranking engineers. It may be safely assumed that it is Oestrich's intention and immediate aim to gather all leading German jet engineers still in Germany under French contracts in France.

b. One of the scientists now at Wright Field is Dr. Anselm Franz, former chief of jet development at Junkers, and designer of the Junkers 004. In view of long term future projects in this country, Dr. Franz is in need of some of his top ranking specialist collaborators. Some of the people who fall in this category, particularly Dr. Siegfried Decher, have been officially requested by Dr. Franz some time ago. Due to the lack of any notification by American authorities upon this request, or by Dr. Franz himself -- Franz is unable to write because of present restrictions -- Decher has meanwhile accepted a French contract with Dr. Oestrich. A few days ago Dr. Decher informed Dr. Franz via Mrs. Franz by wire that France intends very shortly to move all German scientists to the interior of France (Pyrenees), and

Figure 9.99: Many German and Austrian experts such as Hermann Östrich developed jet engines and jet aircraft in France after the war. Donald L. Putt. 13 June 1946. Exploitation of German Scientists by France and Russia [AFHRA A2055 Frame 1257].



Eugen Sänger's ramjet being tested on a Dornier Do 217 aircraft (1942)

Figure 9.100: Eugen Sänger's ramjet being tested on a Dornier Do 217 aircraft (1942).

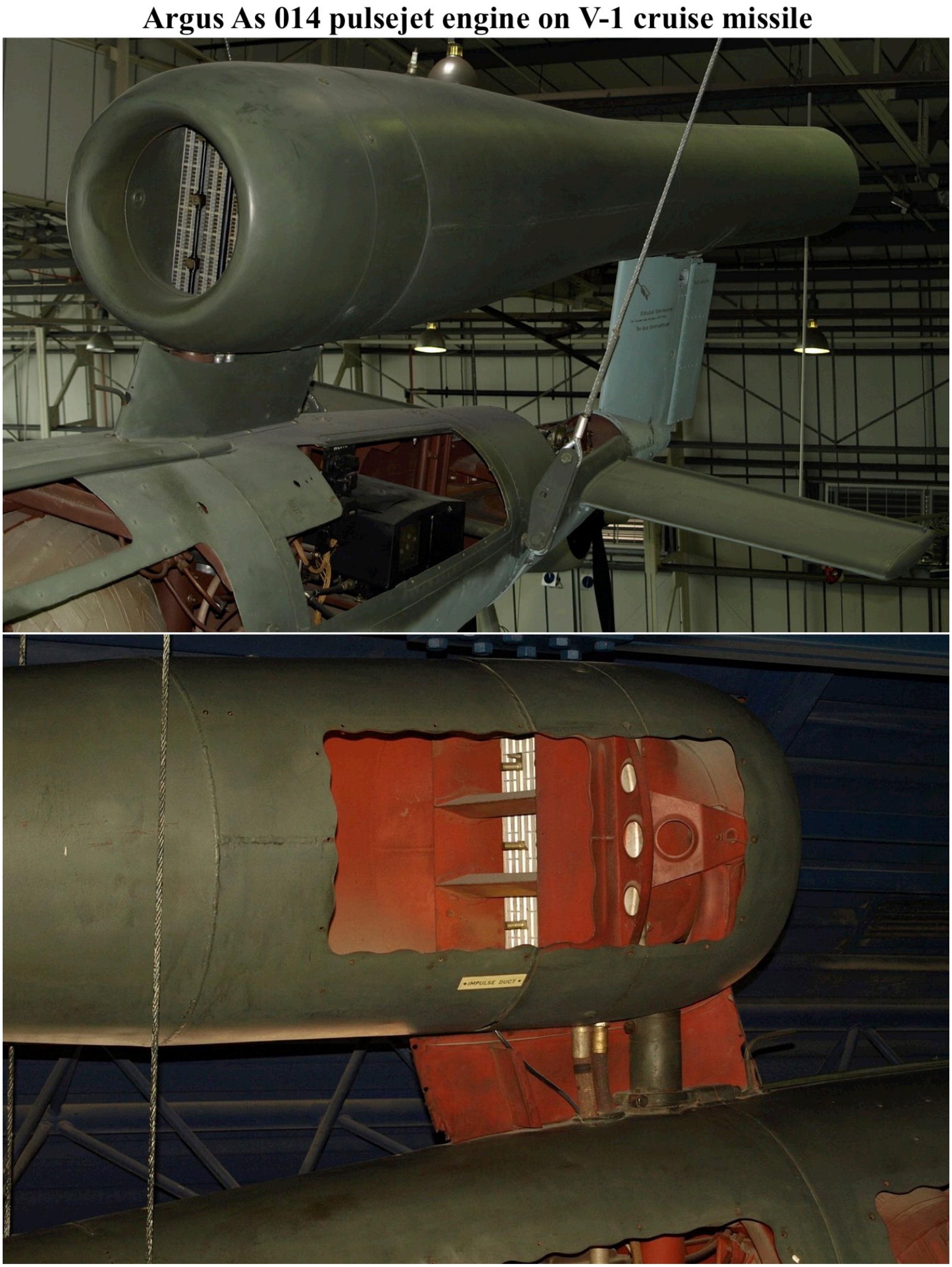


Figure 9.101: Argus As 014 pulsejet engine on V-1 cruise missile.

9.3.2 Jet Aircraft

Willy Messerschmitt (German, 1898–1978), Ludwig Bölkow (German, 1912–2003), and Woldemar Voigt (German, 1907–1980) headed the team that developed and mass-produced the Messerschmitt Me 262 Schwalbe (Swallow) twin-engine jet fighter, which was first flown in 1942; see Fig. 9.102. By the end of the war, there were highly sophisticated underground plants for mass-producing Me 262 fighters despite Allied bombing, such as those at St. Georgen/Gusen and Kahla (pp. 5013–5015, 5268–5271). An upgraded version of the Schwalbe with integrated jet engines and a two-person cockpit, Me 262 HG III, was designed but apparently not built before the end of the war (Fig. 9.103). After the war, Messerschmitt developed jet aircraft for Spain, Egypt, and West Germany; Bölkow created jets and missiles in West Germany; and Voigt worked in the United States.

Walter Blume (German, 1896–1964) led the team that developed and mass-produced the Arado Ar 234 Blitz (Lightning) twin-engine jet bomber, which was first flown in 1943; see Fig. 9.104. After the war, he played a critical role in developing jet fighters and bombers in the Soviet Union.

The German brothers Walter Horten (1913–1998) and Reimar Horten (1915–1994) developed advanced flying wing jet aircraft, as shown in Figs. 9.105–9.106.[9] Their earliest prototypes were sailplanes, before they were able to obtain jet engines from Jumo or BMW. They designed and built the twin-engine Horten Ho 229 stealth fighter, which they first demonstrated in 1944. They also designed the six-engine Horten H.XVIII intercontinental stealth bomber in 1944; there is some evidence that it may have been built or under construction when the war ended—see pp. 5281–5285. After the war, Reimar Horten developed aircraft in Argentina while Walter Horten developed aircraft in West Germany. In addition to the all-wing approach, an important feature of the Horten brothers' designs was their stealthy reduced radar cross sections, due to vehicle shapes that minimized direct radar returns, buried engines, minimization of metal components, and use of special coatings. (For more information on the German creation of stealth technology, see Section 6.8.2.) The strong influence of the Horten brothers' designs was felt even many decades later in the U.S. stealth fighter and stealth bomber.

As shown in Fig. 9.107, postwar jet fighters such as the U.S. F-86 Sabre and Soviet MiG-15 were directly derived from wartime German designs such as the Messerschmitt Me P.1101 (designed by Woldemar Voigt and Ludwig Bölkow) and Focke-Wulf Ta 183 (designed by Hans Multhopp and Kurt Tank).

In fact, the F-86 was developed by Edgar Schmüd (German, 1899–1985), an aircraft designer who immigrated to the United States before World War II (pp. 1691, 1700). In addition to the Me P.1101 and Focke-Wulf Ta 183, Schmüd drew upon other German-developed technologies. As just one example, in 1952, *Life* magazine reported [Campion 1952]:

> In the summer of 1945 two peculiarly interesting objects, sent by air force intelligence, arrived at the North American Aviation Co.'s Los Angeles plant. One was the wing of the latest German jet fighter, a Messerschmitt 262, and its batlike design was startling to the company's engineers who had never seen anything like it on a plane before. The other, of even greater interest, was a secret record of German wind-tunnel experiments

[9] Horten and Selliger 2012; Jorgensen 2009; Myhra 1998b; Shepelev and Ottens 2015.

> on the aerodynamic behavior of radically swept-back wings. Conclusive and exhaustingly thorough, the data (which the Russians also lifted from the files of the Luftwaffe) saved North American three laborious years of research in designing the Air Force's fastest fighter now in operation, the F-86 Sabre jet. As sketched out on the company's drawing boards, the F-86 was to be equipped with the conventional straight wing. But by adapting the German innovations, North American was able to convert its design from straight to swept-back in only four weeks.

Edgar Schmüd also created the North American P-51 Mustang (1940, based on the 1935 Messerschmitt Bf 109), the North American F-100 Super Sabre (1953), the Northrop F-5 Freedom Fighter (1959), and the Northrop T-38 Talon trainer (1959, widely used by NASA for astronaut training) [Ray Wagner 2000].

Brunolf Baade (German, 1904–1969) and Günther Bock (German, 1898–1970) designed jet aircraft such as Ju 287 bomber prototype (with forward-sweeping wings, first flown in 1944) at Junkers in Germany during the war, and others such as the Tu-95 "Bear" bomber (with back-swept wings, first flown in 1952) at Tupolev in the Soviet Union after the war. They also designed a civilian airliner version of the Tu-95, the Tupolev Tu-114. In those wartime and postwar projects, they collaborated with engine designer Ferdinand Brandner. See Fig. 9.108.

Figure 9.102: Willy Messerschmitt, Ludwig Bölkow, and Woldemar Voigt headed the team that developed and mass-produced the Messerschmitt Me 262 Schwalbe (Swallow) twin-engine jet fighter, which was first flown in 1942.

Figure 9.103: An upgraded version of the Messerschmitt Schwalbe with integrated jet engines and a two-person cockpit, Me 262 HG III, was designed but apparently not built before the end of the war.

Walter Blume (1896–1964)

Arado Ar 234 Blitz (Lightning) twin-engine jet bomber, first flown in 1943

Figure 9.104: Walter Blume led the team that developed and mass-produced the Arado Ar 234 Blitz (Lightning) twin-engine jet bomber, which was first flown in 1943.

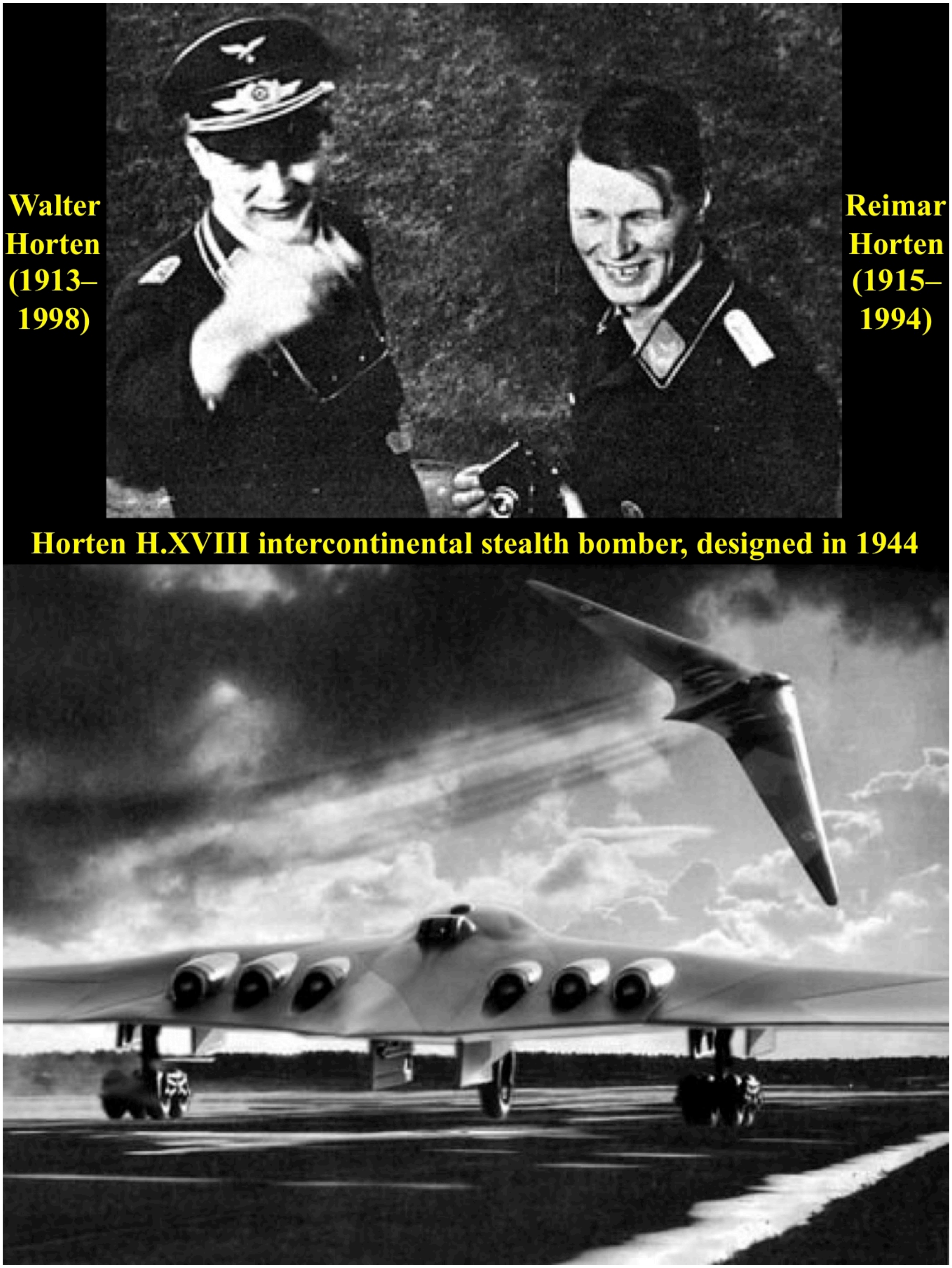


Figure 9.105: The brothers Walter and Reimar Horten developed advanced flying wing jet aircraft, such as the twin-engine Horten Ho 229 stealth fighter (demonstrated in 1944) and the six-engine Horten H.XVIII intercontinental stealth bomber (designed in 1944 and possibly built or under construction when the war ended—see pp. 5281–5285).

Figure 9.106: The brothers Walter and Reimar Horten developed advanced flying wing jet aircraft, such as the twin-engine Horten Ho 229 stealth fighter, which they first demonstrated in 1944.

Messerschmitt Me P.1101 (1944–1945)

Focke-Wulf Ta 183 (designed 1944; model shown)

U.S. F-86 Sabre (1947)

Soviet MiG-15 (1947)

Figure 9.107: Postwar jet fighters such as the U.S. F-86 Sabre and Soviet MiG-15 were directly derived from wartime German jets such as the Messerschmitt Me P.1101 and Focke-Wulf Ta 183.

Figure 9.108: Brunolf Baade and Günther Bock (shown with engine designer Ferdinand Brandner, with whom they collaborated) designed jet aircraft such as Ju 287 at Junkers in Germany during the war, and others such as Tu-95 at Tupolev in the Soviet Union after the war.

Sterling Pavelec, professor of aerospace history at the USAF Air Command and Staff College, explained the fundamental motivation and the ultimate impact of the German jet programs [Pavelec 2007, pp. 148, 154–156]:

> Even before the end of the war the Allies realized that the Germans had had an enormous impact on the evolution of military technology. In the final year of the war in Europe, the Germans led in nearly all fields of military technology, industrial capability, and theoretical knowledge. Some of the most impressive gains were in the fields of rocket technology (both manned and unmanned), turbojet aircraft, submarine technology[....] By the end of the war each of the major Allies—the British, the Americans, and the Soviets—were poised to capture German technology for future considerations. [...]
>
> Turbojets were devised, designed, and developed for their revolutionary potential. The Germans were the first—and in the end the best—in developing turbojet technology during the war for a number of reasons. Initially, turbojet development was a natural evolution of German academic predisposition. The advanced theoretical knowledge in the institutes of higher learning in Germany translated directly into conditions for developing nontraditional aircraft and power plants. The "shackles" of Versailles actually forced the Germans to start fresh without technological baggage. The young Doctor of Physics, Hans von Ohain, searching for "elegance" in flight, wanted to develop an alternative to the dirty, noisy, and rough propeller engine. Fortunately, for Germany, his ideas were accepted by an aviation industrialist who was searching for speed and efficiency. German aircraft designers were looking for revolutionary technology at the exact time it was becoming available. And that is not all; Dr. Franz, responsible for the development of the German axial-flow designs, also found the right time and climate for acceptance. His theories were proven correct; the Germans were the first to develop working, efficient axial-flow turbojets. Further, the Germans were devoted to increasingly higher theoretical advancement. In all forms of military hardware, the Germans were dedicated to developing the highest quality weapons by pursuing the boundaries of theoretical knowledge. [...]
>
> What held up the development of German turbojet aircraft was the lack of raw materials—chrome, nickel, and molybdenum—in Germany. Substitutes were found; the machines were built. [...] The Germans made do with what they had because they had to. There were no other alternatives. And still the Me 262—and later Ar 234 and He 162—were better than any Allied turbojet aircraft built during the same period.
>
> The longevity of the German turbojet program is evident in the impact on postwar military and civilian applications. The Americans virtually copied most German theoretical data and applied it directly to experimental programs. Further, German aeronautical engineers, designers, and technicians were brought to the United States to advance theoretical knowledge for their new bosses. The impact of German turbojet engineering was substantial.
>
> During World War II, the Americans and British were content to continue testing and with the development of conservative designs. Neither of the Western Allies felt the pressing need for turbojet aircraft throughout the war. [...]
>
> The Allies did not need turbojet aircraft to beat the Germans; the Germans needed their turbojet aircraft to have any hope of combatting the Allied bombers over Germany. The Germans did it first and did it right; and after the war, the Germans kept doing it for the powers that combined to defeat them in World War II.

For evidence that appears to demonstrate the development of even more advanced jet aircraft, including intercontinental jet bombers, in wartime Germany, see Appendix E.

Whether Whittle?

In the English-speaking world, the British engineer Frank Whittle is widely considered the inventor of the jet engine, or at the very least the co-inventor before or in parallel with the German engineers. For example, Oxford's *Biographical Dictionary of Scientists* says of Frank Whittle: "British engineer and inventor of the jet engine. The developments from his original designs were used first in the Gloster Meteor at the end of World War II. Direct descendents of these engines are now the sources of power for all kinds of military and civil aircraft" [Porter 1994, pp. 721–722]. The biographical dictionary never mentions Hans von Ohain or any other German-speaking inventors of jet engines and jet aircraft, apart from briefly remarking that "the Germans had produced the Messerschmitt Me 262 slightly earlier" than the British. The Oxford scholars do not even attempt to explain why all of the modern engines that are "now the sources of power for all kinds of military and civil aircraft" look absolutely nothing like Whittle's engines of which they are allegedly "direct descendents," yet instead bear an uncanny resemblance to the German engines.

Hill and Peterson's *Mechanics and Thermodynamics of Propulsion*, which has been the gold standard textbook of aerospace propulsion since its first edition in 1965, accurately summarized Whittle's jet milestones [Hill and Peterson 1991, p. 17]:

> [...A] company called Power Jets was formed in March 1936 that set to work on the development of a new engine while Whittle was still finishing his degree program. After enormous technical, financial, and bureaucratic difficulties, Whittle was able to run the engine for 20 minutes at 16,000 rpm on June 30, 1939, in a demonstration that at last convinced the authorities that his concept was valid and worthy of substantial support. On May 15, 1941, the first British jet aircraft, the Gloster Meteor, powered by the Whittle engine, flew from Cranwell in Lincolnshire.

After Whittle had demonstrated his engine, the older and very experienced British piston engine designer Frank Halford (1894–1955) stepped in and streamlined Whittle's engine as much as he could, leading to the Halford H-1 or de Havilland Goblin turbojet engine.

The United States actually produced a wartime jet, the Bell P-59 Airacomet, that used Whittle's jet engine design. Because of the engine's weight and inefficiency, the P-59 had a slower top speed and shorter range than even the piston-propeller P-51 Mustang. An improved U.S. jet, the Lockheed P-80 or F-80 Shooting Star, was also under development during the war but did not really come into much use until the postwar period.

Whereas all of Whittle's and Halford's engines and the earliest von Ohain prototype engines used centrifugal flow, most of the wartime German-produced engines employed axial flow and thus looked far more similar to jet engines used today.

U.K. and U.S. jets produced during or soon after the war used the Whittle or Halford engine designs. However, the German jet engineers, designs, and prototypes were scooped up by Allied countries in 1945 and rapidly became the basis for turbojet, turbofan, turboprop, turboshaft, and ramjet engine designs that have been used worldwide ever since.

Kelly Johnson, the lead designer of the Lockheed P-80/F-80, compared wartime German and U.S./U.K. jets [Johnson and Smith 1989, pp. 95–96, 102–104]:

> The Air Corps commissioned use of the [Whittle jet] engine in the Bell P-59, originally designed as a propeller-driven airplane. When the jet-powered version flew in 1943, the performance was hardly better than that of the piston-powered P-38 and P-51. [...]
>
> The Germans by this time already had a number of jet-powered Me-262s in combat, and these planes were much faster than anything we had. They were well into the jet age while we were just starting. The Me-262 was a very good airplane, designed by Willy Messerschmitt, whose talent I respected. [...]
>
> The main concern turned out to be attack from the rear quadrant, where the German jets could overtake our aircraft, fly at any matching speed, and have considerably more time to aim and fire. [...]
>
> The war in Europe ended before the F-80 could be proved in combat there. But development, testing, and production continued.
>
> When the Air Corps team went to Germany after the war to inspect military capabilities, we at Lockheed were invited. [...]
>
> We found that the Germans had been flying the only axial flow jet engine in the world, fundamentally more efficient than the centrifugal compressors of the British jets because it was of simpler design. The flow went straight into the inlet and progressed in a straight line through the engine and out the exhaust. In centrifugal flow, the air goes in two sides of a rotor, flows perpendicular to the flight path of the airplane, enters the burner cans, then goes through the rest of the machine; so that it changes flow 90 degrees at least twice.

As explained by Kelly Johnson, Whittle's engine was very heavy, complex, and inefficient compared to the German designs, which were both earlier and more advanced. In the years following the war, even the British military and British companies abandoned Whittle's design and adopted the German designs (see for example Fig. 9.109).

It appears that the early U.K./U.S. jet engines were hampered not only by an inferior design, but also by a wartime research system that provided far less financial and political support than jet creators received in Germany. Moreover, during the war, the United States simply copied the British engine designs without even really trying to significantly innovate and improve upon them, as the German engineers were constantly doing with their own designs. U.S./U.K. support for jet innovation drastically increased after the war, once the performance of the German jets and the rising Cold War tensions with the Soviet Union became clear.

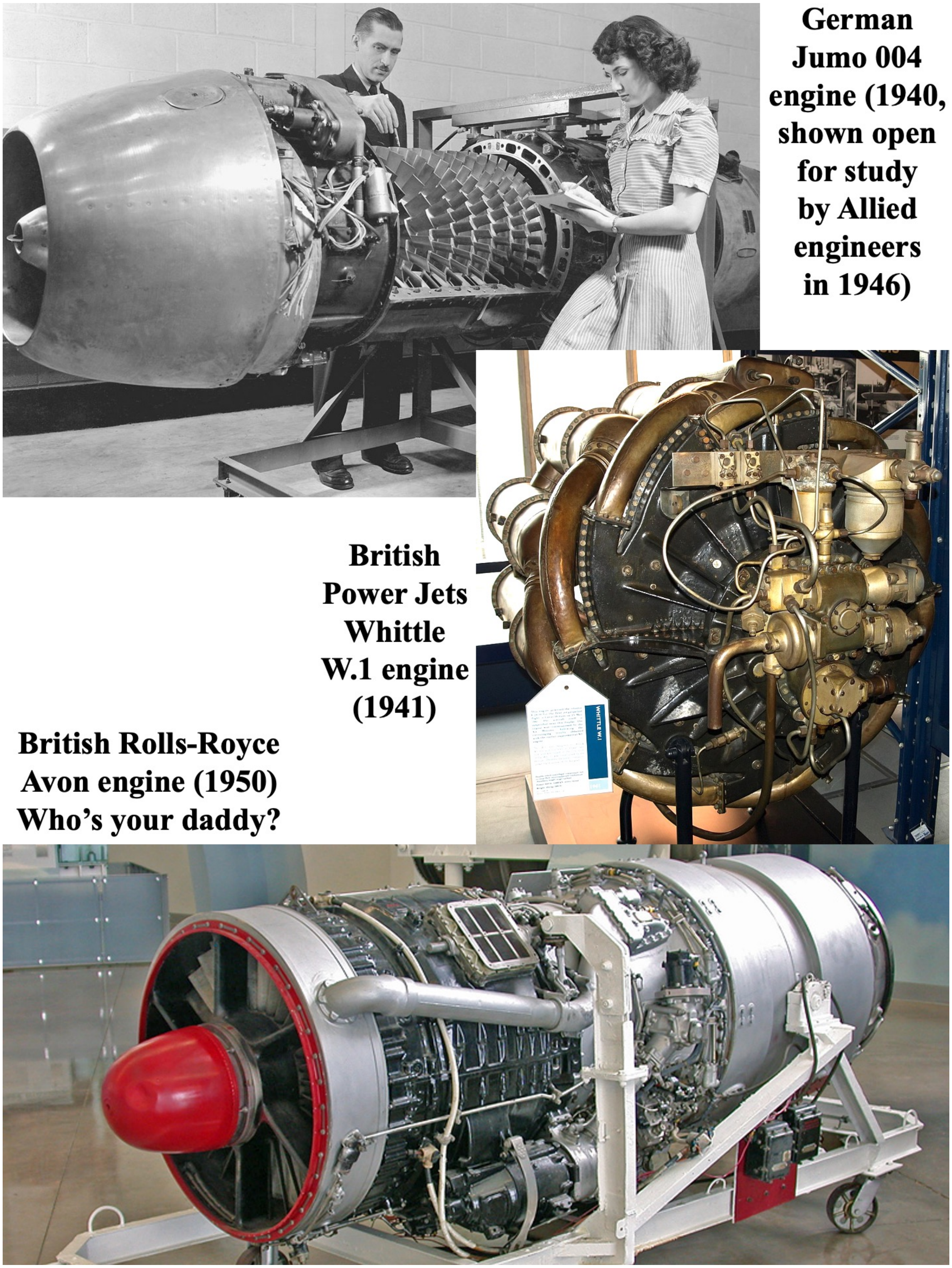


Figure 9.109: The British Rolls-Royce Avon turbojet engine began as a design project in 1945 and entered production in 1950. Does this postwar British engine look like wartime German engines such as the Jumo 004 or wartime British engines such as the Whittle W.1? Hint: What engines, information, and engine designers suddenly became available to British companies in 1945?

As shown in this section and summarized in Table 9.1, Whittle's British team was at least two years behind the German engineers at every step along the way in the development of jet engines and jet aircraft. In addition to these obvious differences in dates, the historical evidence shows that the German jet engines and jet aircraft were more sophisticated, more capable, and produced in greater numbers and greater varieties than their British counterparts.

If runners A and B are in a race, and runner B crosses the finish line two years after runner A, it would not be even remotely accurate or honest to say that runner B was the winner of the race, or even the co-winner. The evidence for the development of jets is clear, and historians must be clear as well. Frank Whittle was a talented engineer, but he was just one among countless engineers who worked on jet engines in the years following their invention and development by Hans von Ohain and the other German pioneers of the field.

The skies around the world today are filled with jet engines and jet aircraft that are directly descended from those created by the German engineers. Whittle's engines are evolutionary dead ends that can only be found in museums (Fig. 9.109).

Jet milestone	**German engineers**	**Whittle team**
First patent application	1925	1930
First proof-of-concept turbojet engine	1935	1938
First practical turbojet engine	1937	1939
First jet-powered flight	1939	1941
First twin-engine jet fighter	1941	1943

Table 9.1: Major milestones in the development of jet engines and jet aircraft, comparing the German engineers and Whittle's British team.

9.4 Parachutes and Ejection Seats

German-speaking scientists and engineers developed and demonstrated application-specific parachutes (Section 9.4.1) as well as ejection seats (Section 9.4.2) [Harsch 2006a, 2017, 2018; Hirschel et al. 2004; BIOS 466; FIAT 465; NavTecMisEu 247-45].

9.4.1 Parachutes

Hermann Lattemann (German, 1852–1894) and Katharina Paulus (German, 1868–1935) developed collapsible parachutes and backpack parachutes beginning in 1890 (Fig. 9.110). Lattemann died testing one of the parachutes in 1894, and Paulus continued to perfect the invention, producing a final product in 1910.

The parachute designers Gerhard Sedlmayr and Holger Hansen described the contributions of several other creators to parachute development; see Figs. 9.111–9.117 [Hirschel et al. 2004, pp. 309–315]:

> The second procedure—a stepwise deceleration—was developed by Waldemar Müller in 1924; here, a small auxiliary parachute is applied (free bag deployment), which, after being exposed to the flow, deploys and pulls the main parachute from the packing case and stretches it. The auxiliary parachute is connected to the apex of the main parachute by a short interconnecting cord. To improve the automatic procedures, the auxiliary parachute is, for instance, equipped with a steel spring so that it opens immediately after being released from the packing case. [...]
>
> Spherical canopies tend to oscillations if they are excited by small disturbances. At especially unfavourable circumstances, spherical canopies may even amplify these movements. To let air escape from the parachute canopy, an opening was placed at the apex of the parachute canopy, which resulted in a reduction of the pendulum-like oscillations. [...]
>
> Two essential brake parachutes originated which are still widely applied today. In 1933, Theodor W. Knacke started his theoretical and practical investigations to achieve the most effective deceleration of an aircraft in the air and during landing. In 1938, the development of the FIST [Flugtechnisches Institut der Technischen Hochschule Stuttgart] ribbon parachute was carried out by Georg Madelung and Theodor W. Knacke (first landing in 1939), and in 1941, the development of the guide-surface parachute by Helmut Heinrich. For the first time, parachutes became technically very efficient due to extensive theoretical research and numerous systematic experimental developments. [...]
>
> During 1933 and 1945, practical investigations of about 10,000 parachute drops were performed at the test center Rechlin from aircraft. More than half of these drops were filmed by high-speed cameras and documented. [...]
>
> In about 1937, the employees of the FIST (Georg Madelung, Theodor W. Knacke, Rudolf

> Isermann and Albert Keller) had the idea to build a parachute whose canopy consisted only of ribbons. [...] It still bears the name of the institute where it was developed, viz., "FIST ribbon parachute"; it is still being utilised today as recovery parachute, e.g., for reconnaissance drones, and as brake parachute for aircraft, landing space capsules and the Space Shuttle.
>
> After development work on a parachute canopy that consisted only of ribbons, the first trials started in 1938. [...]
>
> Under the supervision of Theodor W. Knacke, the FIST ribbon parachutes were further developed after 1946 in the USA, and various versions of the ribbon parachute resulted and were employed as brake and recovery parachutes. Probably the most attention-getting application of the further advanced ribbon parachute was the combination of several such chutes to a landing system for manned space flight up to the Apollo program of NASA. [...]
>
> The guide surface parachute of Helmut Heinrich was utilised in the unmanned spaceflight programs in conjunction with the Mars probe Viking and the Venus probe. [...]
>
> Based on the experiences with ribbon parachutes, the concept was again revised at FIST, and in 1940, Georg Pirzer and Friedrich Weinig started with the development of an entirely new ribbon parachute, the so-called "Great-circle Ribbon Parachute (Wako Canopy Parachute)". This design exhibits an up to now unprecedented performance.

After World War II, German designs for parachutes were widely adopted by other countries and used in a variety of aerospace projects, including the U.S. Apollo and Space Shuttle programs [Hirschel et al. 2004; BIOS 466; FIAT 465]. See Figs. 9.112–9.117.

Hermann Lattemann
(1852–1894)

Katharina Paulus
(1868–1935)

Collapsible parachute (1890–1910)

Figure 9.110: Hermann Lattemann and Katharina Paulus developed collapsible parachutes and backpack parachutes during the period 1890–1910.

Parachutes optimized for specific applications

Rudolf Isermann (18??–19??)	Albert Keller (18??–19??)	Georg Madelung (1889–1972)
Waldemar Müller (18??–19??)	**Georg Pirzer (18??–19??)**	**Friedrich Weinig (18??–19??)**

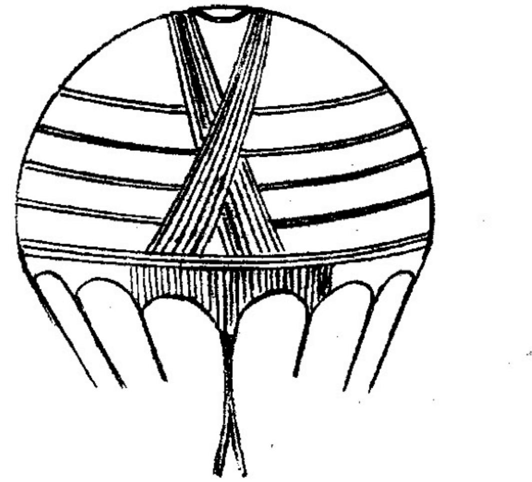
Figure 9.111: Creators who developed parachutes optimized for specific applications included Helmut Heinrich (Fig. 9.116), Rudolf Isermann, Albert Keller, Theodor Knacke (Fig. 9.116), Georg Madelung, Waldemar Müller, Georg Pirzer, and Friedrich Weinig.

B.I.O.S.—FINAL REPORT No. 466
ITEM No. 27

GERMAN PARACHUTE DESIGN AND MANUFACTURE

This report is issued with the warning that, if the subject matter should be protected by British Patents or Patent applications, this publication cannot be held to give any protection against action for infringement.

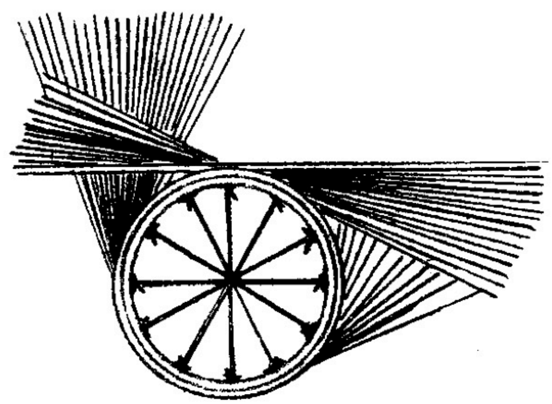
BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE



Field Information Agency, Technical

Parachutes and Parachute Materials Used in Germany

Final Report No. 465



Office of Military Government for Germany (U.S.)

Figure 9.112: Allied countries studied and copied parachute designs from Germany after World War II [BIOS 466; FIAT 465].

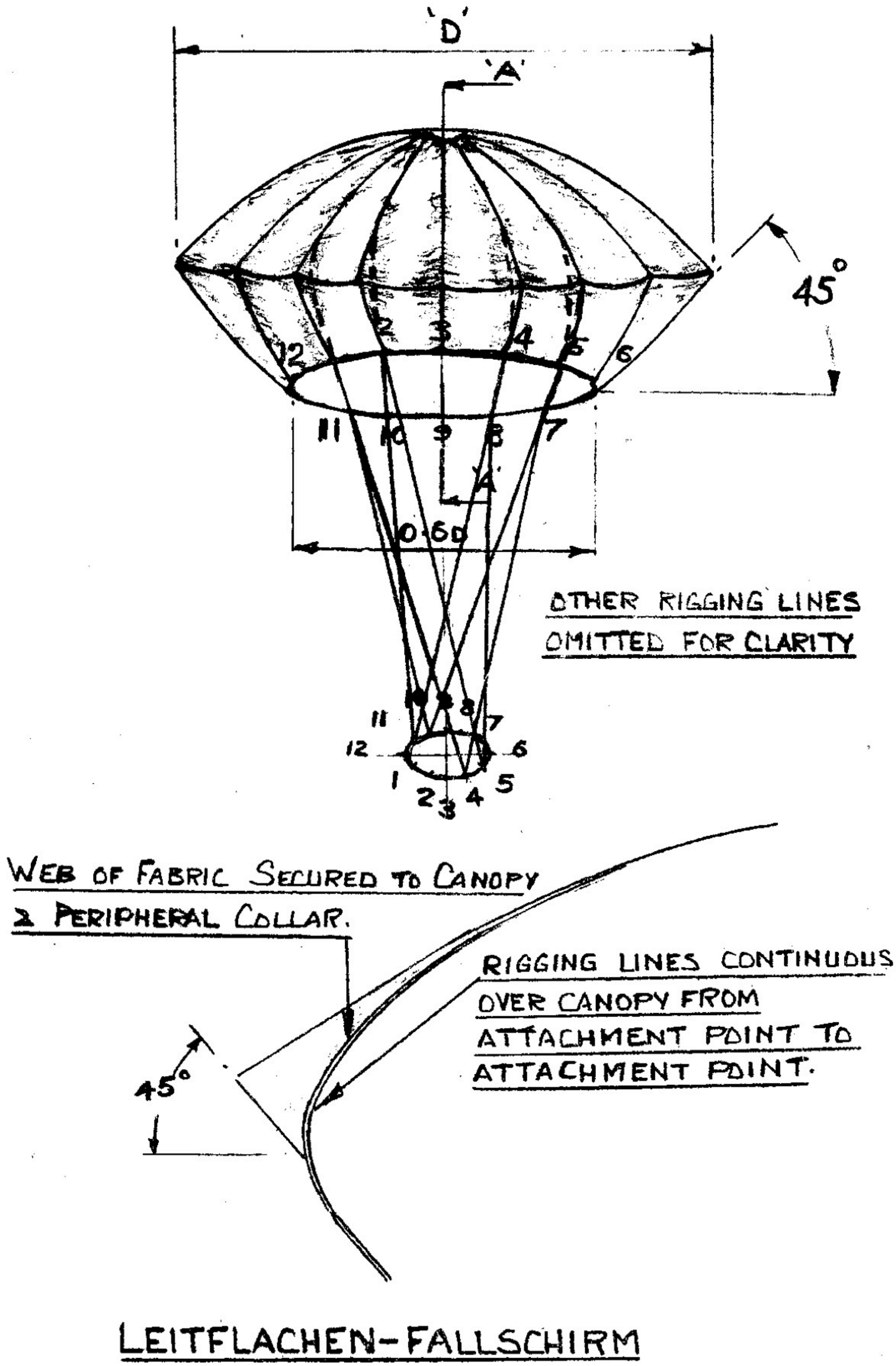


Figure 9.113: Allied countries studied and copied parachute designs from Germany after World War II [BIOS 466].

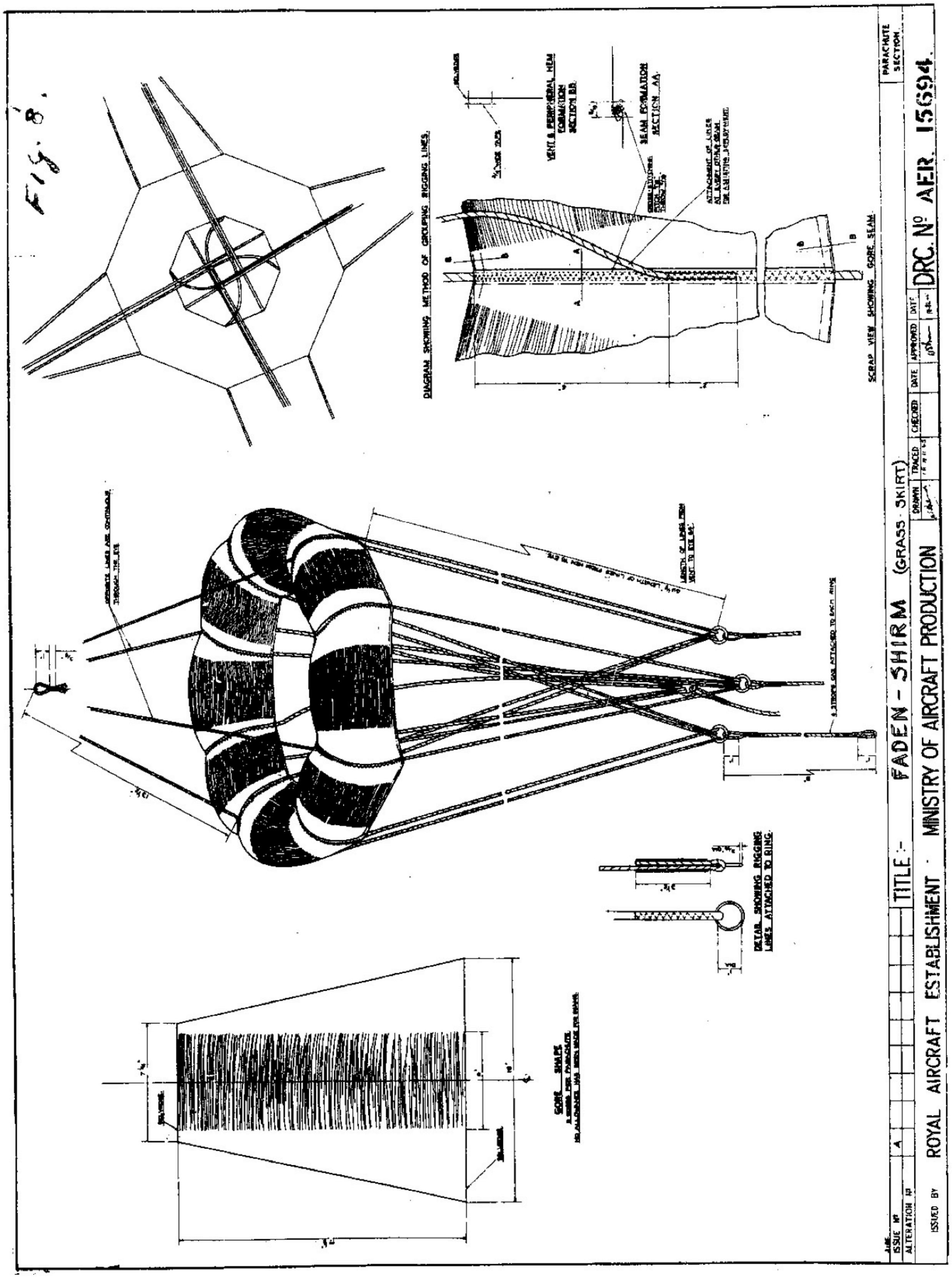
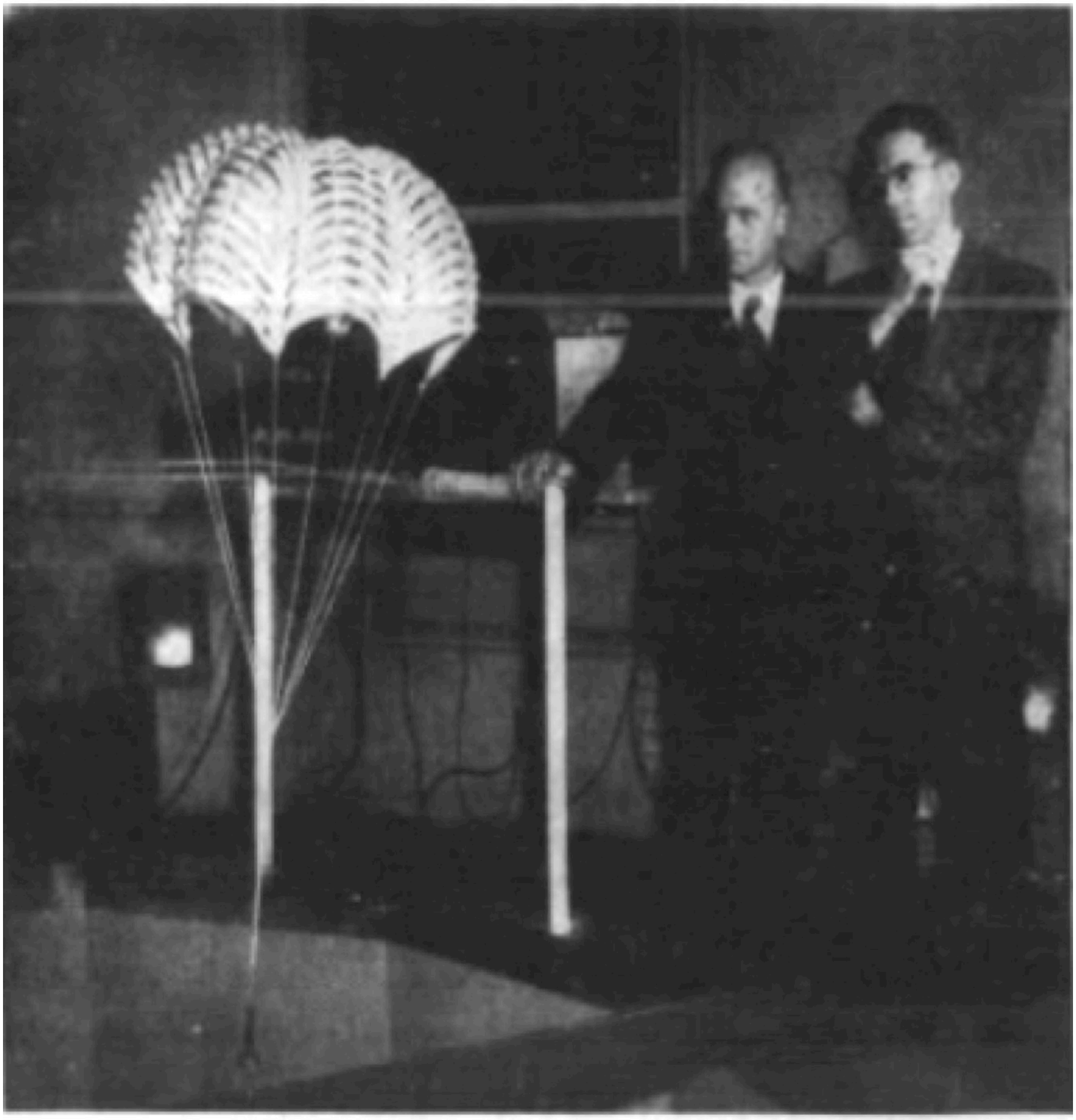


Figure 9.114: Allied countries studied and copied parachute designs from Germany after World War II [BIOS 466].

Figure 9.115: Demonstration of a ribbon braking parachute deployed by a German aircraft, ca. 1940 [Deutsches Museum Archive, photo 39529].

Helmut Heinrich (18??–19??) **Theodor Knacke (1910–2001)**



Dr. Helmut Heinrich, left, and Dr. Theodor Knacke, right, demonstrate one model of German ribbon parachute in field wind tunnel.

Figure 9.116: Demonstration of a ribbon braking parachute at Wright Field, Ohio, by parachute designers Helmut Heinrich and Theodor Knacke in 1946 [*Dayton Daily News*, 8 December 1946, p. 55].

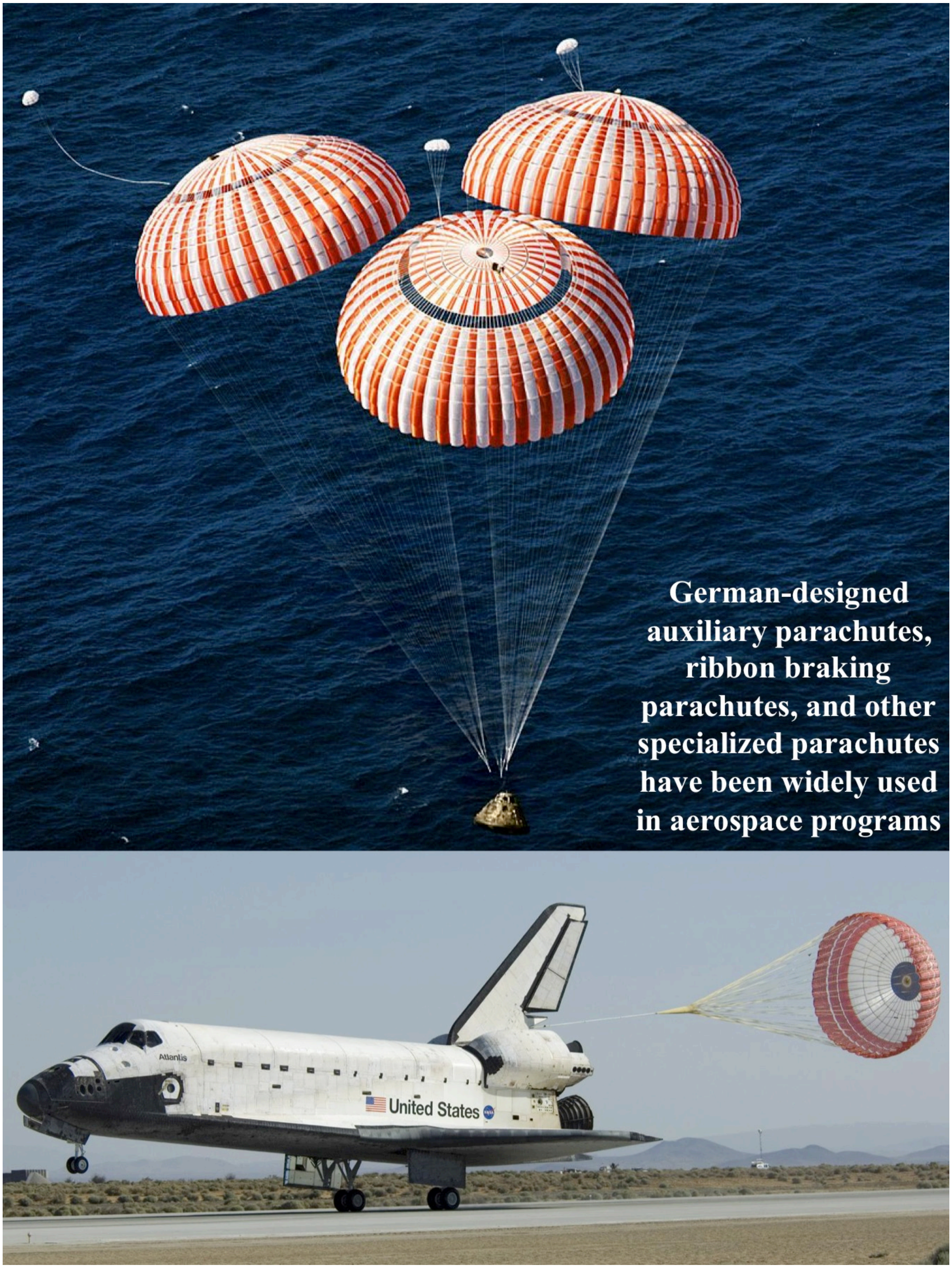


Figure 9.117: German-designed auxiliary parachutes, ribbon braking parachutes, and other specialized parachutes have been widely used in aerospace applications ranging from Apollo capsules to the Space Shuttle.

9.4.2 Ejection Seats

Whereas pilots could simply grab a parachute and jump out of a malfunctioning lower-speed airplane, the advent of jet aircraft meant that a pilot attempting to bail out might be pinned inside the opened cockpit or blown into the tail of the aircraft by the very high-speed airflow. Thus higher flying speeds necessitated the development of a method to automatically, forcefully, and safely propel the pilot and parachute away from a malfunctioning aircraft.

At the Junkers aircraft company, Karl Arnhold (German, 19??–19??), Oscar Nissen (German, 19??–19??), Reinhold Preuschen (German, 19??–19??), and Otto Schwarz (German, 19??–19??) invented and patented aircraft ejection seats in 1938; see Figs. 9.118–9.119. In 1943, Erich Dietz (German, 19??–19??) filed a further patent application on improvements to ejection seats, as illustrated in Fig. 9.120.

Under the leadership of Ernst Heinkel (German, 1888–1958), engineers at the Heinkel aircraft company also developed ejection seats and made them standard equipment on a number of wartime aircraft. Figure 9.121 shows an ejection seat for a Heinkel 162 jet fighter, as well as an ejection seat in action in 1941.

After the war, the Junkers and Heinkel ejection seat technology was eagerly adopted by other countries, and such ejection seats have been used worldwide ever since.

In September 1945, R. P. Linstead and T. J. Betts, the British and American chairs of the Combined Intelligence Objectives Subcommittee (CIOS), listed a number of important German innovations for ejection seats and parachutes [AFHRA A5186 electronic version pp. 904–1026, Ch. 4, pp. 58–59]:

> The field of German aero-medical research was the subject of energetic investigation by United States and British specialists. The emergency oxygen bail-out system employed by the Luftwaffe in high altitude flying was regarded as of particular interest. This system permitted the use of the same oxygen mask by the pilot after leaving the plane. The device consisted of eight tubular bottles of oxygen connected in series by means of high pressure tubing. A three-way switch was employed which provided for normal supply, automatic disconnection prior to bail-out, and switching to the bail-out or emergency supply prior to parachute descent. As a result of this method, delays and complications arising from the necessity of changing masks prior to leaving the plane are eliminated.
>
> The Germans had developed ejection seats to permit pilots to leave high speed aircraft without injury. This equipment operated with a cordite charge which expelled the pilot from the cockpit so that his body was prevented from coming in contact with the tail surface or vertical fin of the plane.
>
> Much information was obtained concerning new types of parachutes developed by the enemy. These types included the non-pendulating parachute which was designed to equalize air turbulence on either side of the 'chute and thus avoid the possibility of accidental collapse and failures which characterize conventional types. Another development was the shock-free parachute consisting of a small pilot 'chute of air permeable construction to cushion the initial shock of release prior to opening of the main 'chute. A third type of parachute is known as the ribbon 'chute; this design provided for variable air orifices so that the rate of descent can be controlled. [...]
>
> Samples of froth clothing were obtained, i.e., flying clothing, treated with a chemical compound which generated heat by chemical reaction when placed in contact with cold water.

DEUTSCHES REICH

AUSGEGEBEN AM 25. SEPTEMBER 1941

REICHSPATENTAMT

PATENTSCHRIFT

№ 711 045

KLASSE 62c GRUPPE 23 02

J 63271 XI/62c

Karl Arnhold, Dipl.-Ing. Oscar Nissen, Dipl.-Ing. Reinhold Preuschen und Dipl.-Ing. Otto Schwarz in Dessau sind als Erfinder genannt worden.

Junkers Flugzeug- und -Motorenwerke Akt.-Ges. in Dessau

Aus dem Innenraum eines Luftfahrzeuges durch einen Kraftspeicher entfernbarer, mit einem Fallschirm ausgerüsteter Sitz

Patentiert im Deutschen Reich vom 23. Dezember 1938 an

Patenterteilung bekanntgemacht am 21. August 1941

Gemäß § 2 Abs. 1 der Verordnung vom 20. Juli 1940 ist die Erklärung abgegeben worden, daß sich der Schutz auf das Protektorat Böhmen und Mähren erstrecken soll.

Es ist insbesondere bei Flugversuchen vorteilhaft, Einrichtungen vorzusehen, um den Insassen des Luftfahrzeuges während des Fluges und besonders bei außergewöhnlichen Flugzuständen, insbesondere beim Trudeln, ein Verlassen des Innenraumes des Luftfahrzeuges zu ermöglichen. Zu diesem Zweck hat man bereits die Sitze für die Insassen an Führungsgliedern lösbar in der Weise festgelegt, daß nach Lösen der Befestigung der Stuhl mitsamt dem daraufsitzenden Insassen, sei es infolge Massenwirkung oder sei es unter Einwirkung eines besonderen Kraftspeichers, aus dem Innenraum herausbewegt wurde. Bei den bekannten Einrichtungen wird dann nach Verlassen des Luftfahrzeuges der am Sitz befestigte Fallschirm ausgelöst, und es gelangt der Insasse zusammen mit dem Sitz zum Erdboden. Die bekannten Einrichtungen haben aber den Nachteil, daß der Sitz in solcher Weise ausgestaltet sein muß, daß der Insasse den Landestoß mit den Beinen abfangen kann, wozu eine erhebliche Bewegungsfreiheit erforderlich ist. Diese Forderung ist aber mit der Gewährung eines ausreichenden Schutzes für den Insassen beim Verlassen des Flugzeuges durch den Sitz bei den bekannten Einrichtungen nicht vereinbar.

Gemäß der Erfindung ist nun die Ausgestaltung derart getroffen, daß der Insasse mit einem Fallschirm ausgerüstet und lösbar mit einem gehäuseartig gestalteten, aus dem Innenraum des Luftfahrzeuges bewegbaren Sitz verbunden ist, welcher seinerseits einen zweiten Fallschirm aufweist zur Beeinflussung der Fallbewegung des Gehäusesitzes. Die gehäuseartige Gestaltung des Sitzes gewährleistet dabei einen wirksamen Schutz für den Insassen in Fällen, in denen beim oder nach Verlassen des Innenraumes des Luftfahrzeuges Teile des Flugzeuges, z. B. das Leitwerk, in die Bewegungsbahn des Sitzes bzw. des Insassen geraten. Bei der erfindungsgemäßen Ausgestaltung kommt dann nicht der Insasse, sondern der gehäuseartige Sitz, welcher den Insassen zweckmäßig von drei Seiten umgibt, mit den Flugzeugteilen in Berührung. Auch erfolgt beim Verlassen des Flugzeuges die erste Abbremsung von dem hohen Flugstaudruck auf den Staudruck des freien Falles, während der Insasse noch fest mit seinem gehäuseartigen Sitz verbunden und dadurch gegen Verletzungen durch gewaltsame Körperbewegungen geschützt ist. Dies bedeutet gleichzeitig einen Schutz für den Insassenfallschirm gegen Überbeanspruchungen, da dieser erst bei verringerter Geschwindigkeit betätigt werden kann.

Ist nach der Trennung vom Luftfahrzeug die Gefahr der Berührung mit Flugzeugteilen behoben und der hohe Anfangsstaudruck durch den Eigenwiderstand des Stizes verringert, so wird der am Gehäuse angeordnete Fallschirm zur Entfaltung gebracht und anschließend die Verbindung des Insassen mit dem Gehäusesitz gelöst. Durch die Entfaltung des am Gehäuse angebrachten Fallschirms erfolgt die sichere Trennung des Gehäusesitzes von dem Insassen. Nach erfolgter Trennung löst dann der Insasse den an ihm befestigten Fallschirm aus und gelangt vom Sitz befreit in der üblichen Weise zum Erdboden.

Es wird demnach bei der erfindungsgemäßen Ausgestaltung einesteils ein Schutz für den Insassen nach Verlassen des Luftfahrzeuges und anderenteils eine ausreichende Bewegungsfreiheit zum Abfangen des Landestoßes gewährleistet, da der Insasse örtlich weit getrennt von dem Sitz zu Boden kommt.

Im weiteren Ausbau der Erfindung können noch Mittel vorgesehen sein, um im Falle des Versagens der Sitzschleudereinrichtung dem Insassen den Hinausstieg aus dem gehäuseartigen Sitz zu erleichtern, indem insbesondere der obere Teil des gehäuseartigen Sitzes aufklappbar oder entfernbar an den übrigen Teilen befestigt ist.

Der Erfindungsgegenstand ist in den Abbildungen in einem Ausführungsbeispiel veranschaulicht, und zwar zeigen

Abb. 1 den vorderen Teil eines Flugzeugrumpfes im Längsschnitt und den eingebauten, in gesperrter Lage befindlichen gehäuseartigen Schleudersitz in Seitenansicht,

Abb. 2 den aus dem Flugzeug hinausgeschleuderten, vom Insassen befreiten Gehäusesitz am Fallschirm hängend; desgleichen den Insassen mit in Wirkung getretenem Fallschirm und das abstürzende Flugzeug mit entferntem Zellendach.

Der den Insassen zweckmäßig von drei Seiten umhüllende Gehäusesitz 1 ist in an sich bekannter Weise in einer Führung 2 lösbar derart festgelegt, daß nach Lösen der Befestigung durch Betätigen des Handhebels 3 unter voraufgehender Lösung und Entfernung des Zellendaches 4 der gehäuseartige Sitz 1 mitsamt dem daraufsitzenden Insassen unter Einwirkung eines besonderen Kraftspeichers, beispielsweise eines Gummizuges 5, aus dem Innenraum des Flugzeugrumpfes hinausbewegt wird. Der Insasse sitzt auf einem an seinem Körper mittels üblicher Gurte befestigten zusammengefalteten Fallschirm 6, der in Tätigkeit tritt, sobald der Insasse sich vom gehäuseartigen Sitz 1 befreit hat. Der Sitz 1 ist ebenfalls mit einem Fallschirm 7 versehen, der beim Lösen des Insassen vom Sitz 1 in Wirkung tritt, wobei der Insasse aus dem Gehäusestuhl 1 hinausfällt. Wie aus Abb. 2 ersichtlich, gelangen dann Insasse und Gehäusesitz getrennt zum Boden.

Um im Falle des Versagens der Sitzschleudereinrichtung dem Insassen das Hinaussteigen aus einem weitgehend geschlossenen gehäuseartigen Sitz zu ermöglichen, sind obere Teile des Gehäusesitzes, beispielsweise eine Kappe 9, entfernbar an den übrigen Teilen befestigt. In diesem Fall veranlaßt die Handhabe zum Lösen des Insassen vom Gehäusesitz zweckmäßig gleichzeitig das Lösen und Entfernen der Gehäusekappe 9. Die auf diese Weise vergrößerte Gehäuseöffnung dient dem Insassen dann zum Aussteigen.

PATENTANSPRÜCHE:

1. Aus dem Innenraum eines Luftfahrzeuges durch einen Kraftspeicher entfernbarer, mit einem Fallschirm ausgerüsteter Sitz, gekennzeichnet durch die Anwendung eines mit dem Insassen verbundenen besonderen Fallschirmes und eines gehäuseartig gestalteten Sitzes, mit welchem der Insasse lösbar verbunden ist.

2. Sitz nach Anspruch 1, dadurch gekennzeichnet, daß Teile, insbesondere der obere Teil, des gehäuseartigen Sitzes aufklappbar oder entfernbar an den übrigen Teilen befestigt sind.

Hierzu 1 Blatt Zeichnungen

BERLIN. GEDRUCKT IN DER REICHSDRUCKEREI

Karl Arnhold (19??–19??) **Oscar Nissen (19??–19??)**

Reinhold Preuschen (19??–19??) **Otto Schwarz (19??–19??)**

Figure 9.118: Karl Arnhold, Oscar Nissen, Reinhold Preuschen, and Otto Schwarz at Junkers filed a patent application on aircraft ejection seats in 1938.

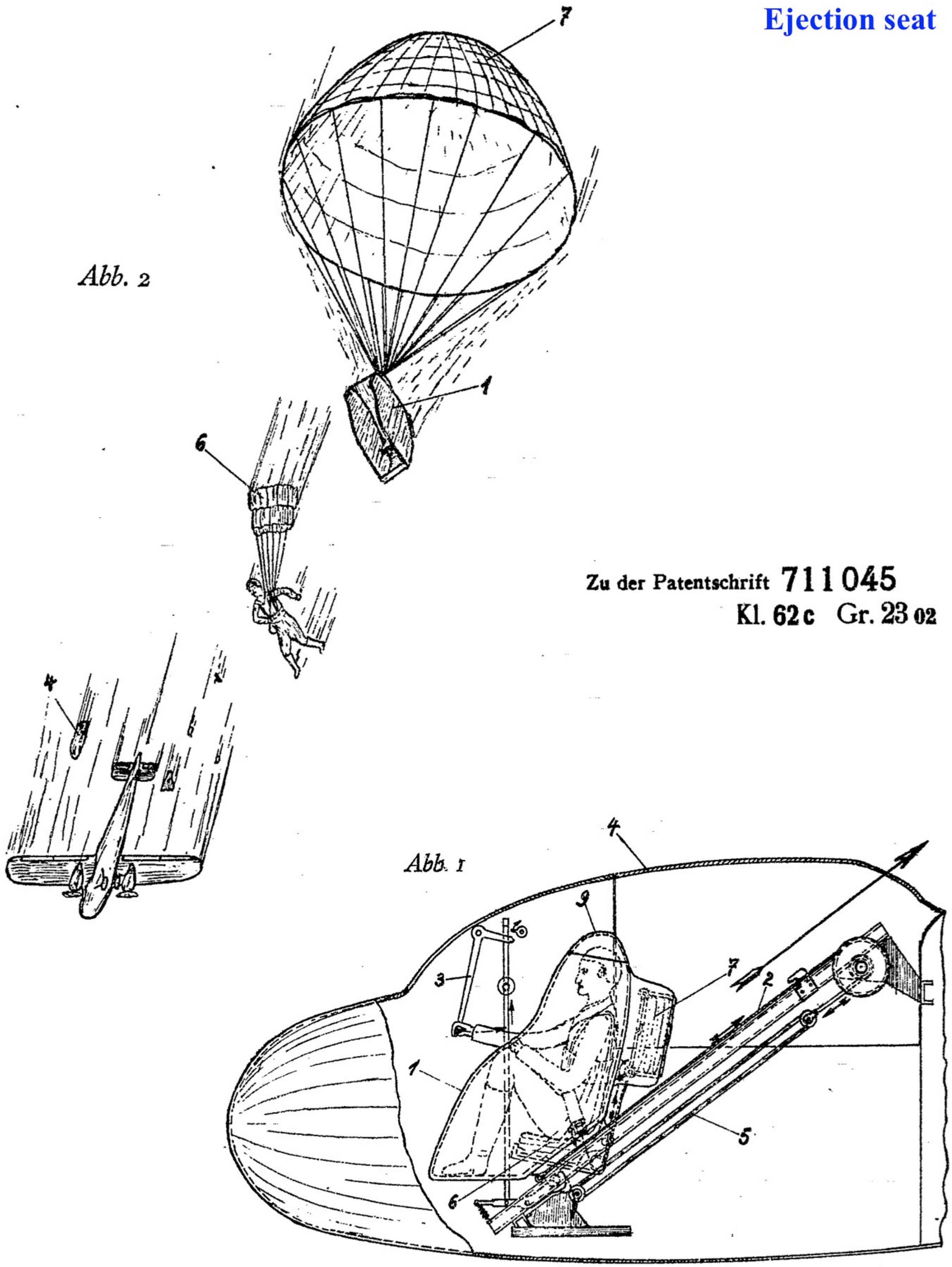


Figure 9.119: Karl Arnhold, Oscar Nissen, Reinhold Preuschen, and Otto Schwarz at Junkers filed a patent application on aircraft ejection seats in 1938.

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 20. SEPTEMBER 1954

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 918 006

KLASSE **62c** GRUPPE 23 04

J 5022 XI / 62 c

Dr.-Ing. Erich Dietz, Dessau
ist als Erfinder genannt worden

Junkers Flugzeug- und Motorenwerke AG., Dessau

Aus dem Innenraum eines Flugzeuges durch einen Kraftspeicher herausschleuderbarer Sitz

Patentiert im Gebiet der Bundesrepublik Deutschland vom 1. Juni 1943 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Patentanmeldung bekanntgemacht am 11. Februar 1954
Patenterteilung bekanntgemacht am 5. August 1954

Die Erfindung bezieht sich auf Flugzeugsitze, die während des Fluges vermittels eines Kraftspeichers samt dem darauf sitzenden Besatzungsmitglied aus dem Flugzeuginnenraum herausschleuderbar sind. Solche Schleudersitze sind bekannt. Sie wurden bisher beim Einfliegen von Flugzeugen sowie bei Versuchsflügen mit besonders großer Absturzgefahr, z. B. bei Schwingungs- und Höchstgeschwindigkeitsflügen, benutzt, um der Flugzeugbesatzung die Möglichkeit zu geben, bei Gefahr aus dem Flugzeug rasch und ungehindert auszusteigen.

Mit dem Anwachsen der Fluggeschwindigkeiten hat sich das Bedürfnis herausgestellt, solche Schleudersitze nicht nur in Versuchsmaschinen, sondern auch serienmäßig als Normalsitze einzubauen, weil bei den durch die großen Fluggeschwindigkeiten bedingten außerordentlich hohen Staudrücken und Beschleunigungen ein Aussteigen der Besatzung mit eigener Kraft in der im Gefahrenfalle zur Verfügung stehenden kurzen Zeitspanne in der Regel nicht möglich ist. Der Befriedigung dieses Bedürfnisses steht jedoch entgegen, daß die bei den bekannten Schleudersitzen angewendeten Kraftspeicher in Form von gespannten Federn, Gummisträngen, Preßluft od. dgl. wegen der hierfür erforderlichen konstruktiven Einrichtungen verhältnismäßig viel freien Raum beanspruchen, der zwar in größeren Flugzeugen beispielsweise bei Schwingungsflügen zur Verfügung steht, solange die für den normalen Flugbetrieb erforderlichen Einbauten und Geräte noch fortgelassen sind, der aber in einer für ihren Einsatzzweck freigegebenen Maschine, insbesondere in kleineren Maschinen, beispielsweise in Jagdflugzeugen, nicht vorhanden ist. In solchen Maschinen sind daher Schleudersitze der bekannten Art unzweckmäßig.

Es wäre an und für sich denkbar, den Raumbedarf und Gewichtsaufwand solcher Schleudersitze

2 918 006

dadurch in tragbaren Grenzen zu halten, daß sie mit einer unter dem Sitz angebrachten Pulverladung als Schleuderkraftspeicher ausgerüstet werden. Dem steht jedoch entgegen, daß durch die schlagartige volle Entfaltung der Schleuderkraft das Besatzungsmitglied eine Beschleunigung erfahren würde, welcher der menschliche Organismus nicht gewachsen ist. Da außerdem eine Treibladung nach Art von Kartuschen nur schußartig wirkt, ist die Zeit der Krafteinwirkung äußerst gering gegenüber Kraftspeichern in Form von Federn, Preßluft od. dgl.

Die Erfindung beseitigt die erwähnten Mängel und Gefahrenquellen von Schleudersitzen der bekannten Art dadurch, daß als Kraftspeicher des in bekannter Weise längs flugzeugfester Führungen herausschleuderbaren Sitzes an dem Sitz eine oder mehrere Treibkammern mit Rückstoßdüsen nach dem Raketenprinzip angeordnet sind. Ein solcher Kraftspeicher ergibt eine weiche Rückstoßwirkung und ein allmähliches Anwachsen der Sitzbeschleunigung, was sich noch durch entsprechende Gestaltung der Düsen sowie durch die Dosierung und Zusammensetzung der Treibladung weitgehend beeinflussen läßt, so daß ein herausgeschleudertes Besatzungsmitglied selbst von vorübergehenden gesundheitlichen Störungen verschont bleibt. Da sich die Treibkraft der Rückstoßdüse so regeln läßt, daß sie ihren Höchstwert im Augenblick des Austretens des Sitzes in die freie Luftströmung erreicht und sodann noch kurze Zeit vorhält, ist es auch möglich, den Sitz genügend weit vom Flugzeug wegzuschleudern, so daß die Bedingungen für ein einwandfreies Katapultieren des Sitzes gewährleistet sind.

Ein weiterer, insbesondere vom militärischen Standpunkt aus bedeutsamer Vorteil eines erfindungsgemäßen Schleudersitzes besteht auch darin, daß die aus den Sitzrückstoßdüsen austretenden Stichflammen zur Erzeugung eines Brandherdes am Boden des Besatzungsraumes herangezogen werden können, dessen Verbreitung gegebenenfalls durch im Flugzeugboden eingebaute besondere Brandsätze noch begünstigt werden kann. Das von der Besatzung beim Absturz verlassene Flugzeug wird daher schon brennend am Boden aufschlagen und so rasch vernichtet, daß eine feindseitige Untersuchung auf technische Einzelheiten nicht mehr möglich ist. Sollte die Vernichtung des Flugzeuges durch Brandentfachung dagegen nicht erwünscht sein, so läßt sich die Brandwirkung der aus den Düsen austretenden Schwaden beispielsweise durch Klappen im Flugzeugboden vermeiden.

In weiterer Ausgestaltung der Erfindung wird die Anordnung der Rückstoßdüsen zum Gesamtschwerpunkt des belasteten Sitzes so getroffen, daß das beim Herausschleudern des Sitzes mit dem Besatzungsmitglied von der Luftströmung auf letztere ausgeübte Moment von dem aus der resultierenden Treibkraft herrührenden Moment bezüglich des Gesamtschwerpunktes im Hinblick auf die Lage oder Drehbewegung des Besatzungsmitgliedes vorbestimmbar ist.

Es ist selbstverständlich, daß der in der Schleuderrichtung des Sitzes befindliche Teil der Flugzeugbegrenzungswände vor oder beim Auslösen des Schleuderkraftspeichers, was beispielsweise auf elektrischem Wege über das Bordnetz und/oder eine Notbatterie erfolgen kann, abgeworfen wird. Hierfür geeignete Abwurfeinrichtungen sind bekannt. Es ist zweckmäßig, die benutzte Abwurfeinrichtung mit der Auslösung des Sitzkraftspeichers funktionsmäßig so zu kuppeln, daß beide durch einen einzigen Handgriff zur Wirkung gebracht werden können, was z. B. bei Absprengung des Daches durch eine gemeinsame elektrische Zündung erreicht werden kann.

Die Erfindung ist in der Zeichnung an Hand eines Ausführungsbeispiels in vereinfachter schematischer Darstellung näher erläutert. Es bedeutet 1 den im Besatzungsraum 2 eines kleinen, schnellen Flugzeuges, beispielsweise eines Jagdflugzeuges, angeordneten Führersitz, der mit Hilfe von Rollen 3 an seinem Unterteil sowie an seiner Rückenlehne in flugzeugfesten Führungen 4 derart beweglich geführt ist, daß ein Ecken und Hängenbleiben mit Sicherheit vermieden ist. An der Unterseite des Sitzes 1 ist ein Kraftspeicher in Form von Rückstoßdüsen 5 angebracht, durch deren Zündung der Sitz 1 samt dem darauf sitzenden Flugzeugführer im Sinne des eingezeichneten Pfeiles, wie gestrichelt dargestellt, aus dem Flugzeuginnern herausgeschleudert wird. Die oberhalb des Führersitzes befindliche Überdachung 6 ist zu diesem Zweck mit einer nicht dargestellten geeigneten Abwurfeinrichtung bekannter Art versehen, die unmittelbar vor oder bei der Zündung der Treibladung zur Wirkung gebracht wird.

PATENTANSPRÜCHE:

1. Aus dem Innenraum eines Flugzeuges durch einen Kraftspeicher längs flugzeugfester Führungen herausschleuderbarer Sitz, dadurch gekennzeichnet, daß als Kraftspeicher am Sitz eine oder mehrere Treibkammern mit nach dem Raketenprinzip arbeitenden Rückstoßdüsen angeordnet sind.

2. Schleudersitz nach Anspruch 1, gekennzeichnet durch eine derartige Anordnung der Treibkammern zum Gesamtschwerpunkt des belasteten Sitzes, daß das beim Herausschleudern des Sitzes mit dem Besatzungsmitglied von der Luftströmung auf letztere ausgeübte Moment von dem aus der resultierenden Treibkraft herrührenden Moment bezüglich des Gesamtschwerpunktes im Hinblick auf die Lage oder Drehbewegung des Besatzungsmitgliedes nach dem Verlassen des Flugzeuges vorbestimmbar ist.

3. Schleudersitz nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß der Sitzkraftspeicher zu benachbarten Flugzeugteilen oder besonderen Brandsätzen so angeordnet ist, daß diese Teile durch die aus den Speicherdüsen austretenden Flammen in Brand gesetzt werden.

Erich Dietz
(19??–19??)

Ejection seat

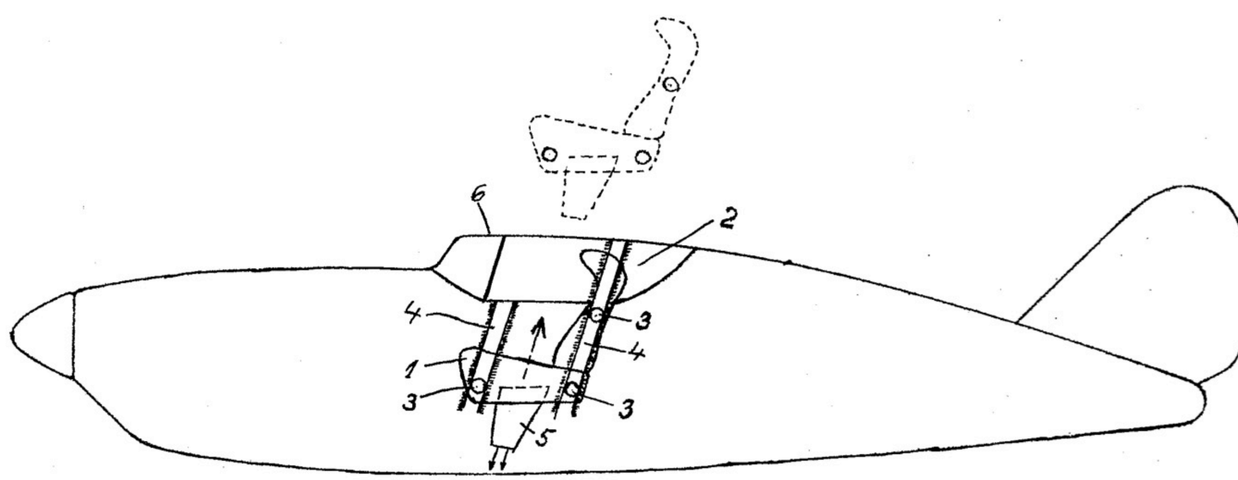


Figure 9.120: Erich Dietz at Junkers filed a patent application on improved aircraft ejection seats in 1943.

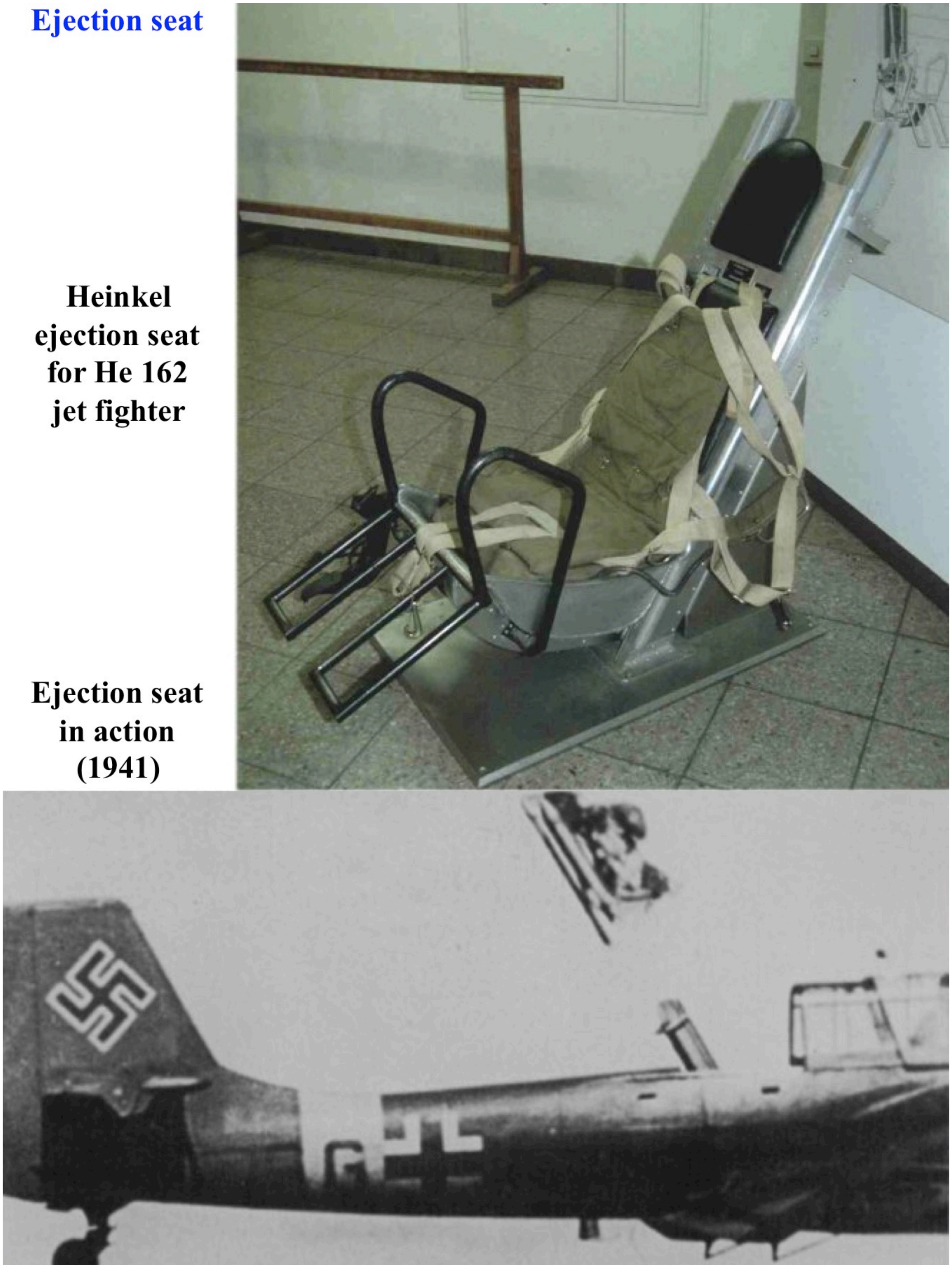


Figure 9.121: Under the leadership of Ernst Heinkel, engineers at the Heinkel aircraft company also developed ejection seats. Above: an ejection seat for a Heinkel He 162 jet fighter. Below: an ejection seat in action in 1941.

9.5 Helicopters

German-speaking creators dominated the development of helicopters. They labored in the late nineteenth and early twentieth centuries to develop proto-helicopters, finally produced the world's first fully functional helicopters in 1936, mass-produced and fielded state-of-the-art helicopters during World War II, and played critical roles in the worldwide helicopter industry after the war.[10]

This section covers:

9.5.1 Proto-Helicopters and Autogyros

The general idea of helicopters had been around since at least Leonardo da Vinci's designs for a cloth aerial screw, but the practical implementation of that idea was long hindered by two challenges: (1) making the helicopter powerful enough to support its own weight, and (2) making the helicopter stable enough that it would not rapidly spin out of control if it did lift off. With the advent of sufficiently powerful engines by the late nineteenth century, engineers worldwide began trying to build a functional helicopter.

Helicopters behave quite differently than other aircraft. In particular, a helicopter's main rotor may be regarded as a rotating wing that is always moving forward and thus can generate lift even if the helicopter itself is motionless. This confers on helicopters both their advantages, such as their ability to hover or even fly backwards, and their disadvantages, such as their high fuel consumption and limited speed relative to fixed-wing aircraft.

[10] See for example: Coats and Carbonel 2002; Hirschel et al. 2004; Jackson 2014; Johnston 1996; Leishman 2006; Myhra 2003; Nowarra 1990; NYT 1946-05-13 p. 4; BIOS Overall 8; CIOS XXXI-5; CIOS XXXI-11; FIAT 176; FIAT 177; FIAT 178; FIAT 604.

Figure 9.122 shows the airflow through a helicopter rotor. As shown in the upper half of the figure, the forces involved are less complex for purely vertical flight, and therefore it was less challenging for prototype helicopters to simply hover than for them to travel horizontally. To move forward or in another horizontal direction, a helicopter must tilt slightly toward the chosen direction, so that the rotor thrust has components causing both vertical lift and horizontal propulsion. Airflow to and from the rotor is then altered as shown in the lower half of the figure. The velocity of air far upstream from the rotor is inclined at an angle of attack α relative to the rotor.

Of course, a helicopter must have some method of counteracting the rotor torque so that the helicopter body will not spin wildly in the opposite direction from the rotor's rotation. Often a tail fin and tail rotor aimed to the side serve this purpose, though some helicopters simply avoid the problem by having two counter-rotating rotors on top.

The autogyro, another predecessor of true helicopters, should also be considered. This was an airplane with an unpowered, free-spinning rotor on top that was tilted slightly toward the rear of the craft. As the autogyro flew forward with its primary aircraft engine, the airflow spun the rotor, creating extra lift. This effect made the autogyro virtually stall proof at low forward speeds, although it could not hover completely motionless like a true helicopter with a powered rotor.

Almost all of the important early helicopter experimenters came from the greater German-speaking world. In general, prior to 1936, their early prototype helicopters could hover but not move forward without becoming unstable, and their closely related autogyro prototypes from the same period could move forward but not hover in place.

Early helicopter experimenters included:

- Hermann Ganswindt (German, 1856–1934) had many aerospace ideas that were far ahead of their time, designed a helicopter in 1884, and may have tested a prototype helicopter in 1901. See Fig. 9.123.

- Ján Bahýl' (Austro-Hungarian Slovak, 1856–1916) patented a helicopter design in 1895 and briefly flew a prototype in 1905, as shown in Fig. 9.124.

- István Petróczy (Hungarian, 1874–1957), Theodore von Kármán (Hugarian, 1881–1963), and Vilém Žurovec (Czech, 1883–1935) created proto-helicopters such as the electric-powered PKZ-1 (1918) and gasoline-powered PKZ-2 (1918). See Fig. 9.125.

- Emil(e) Berliner (German, 1851–1929) moved to the United States, where he built and tested prototype helicopters and autogyros 1909–1929, as illustrated in Fig. 9.126. Toward the end of his life, he was also assisted by one of his sons, Henry Berliner (1895–1970).

- Engelbert Zaschka (German, 1895–1955) built and patented a prototype helicopter, which he dubbed Rotary Wing, in 1927. See Fig. 9.127.

- Albert Gillis von Baumhauer (Dutch, 1891–1939) experimented with a helicopter prototype 1924–1930 (Fig. 9.128) but never could overcome its instability problems, which ultimately destroyed the prototype.

- In the 1920s and early 1930s, Oskár von Asboth (Hungarian, 1891–1960) built several helicopter prototypes that could hover but that became unstable when they tried to move. See Fig. 9.129.

- Raoul Hafner (Austrian, 1905–1980) built prototype autogyros in the 1920s and 1930s, first in Austria and then in the United Kingdom. While in Austria, he collaborated with Bruno Nagler (Austrian, 1901–1979) to create proto-helicopters such as the Hafner-Nagler R.I Revoplane (1929), shown in Fig. 9.130.

- Walter Rieseler (German, 1890–1937) built prototype autogyros and helicopters in the 1920s and 1930s but died in 1937, just as helicopter technology was finally coming to fruition. See Fig. 9.131.

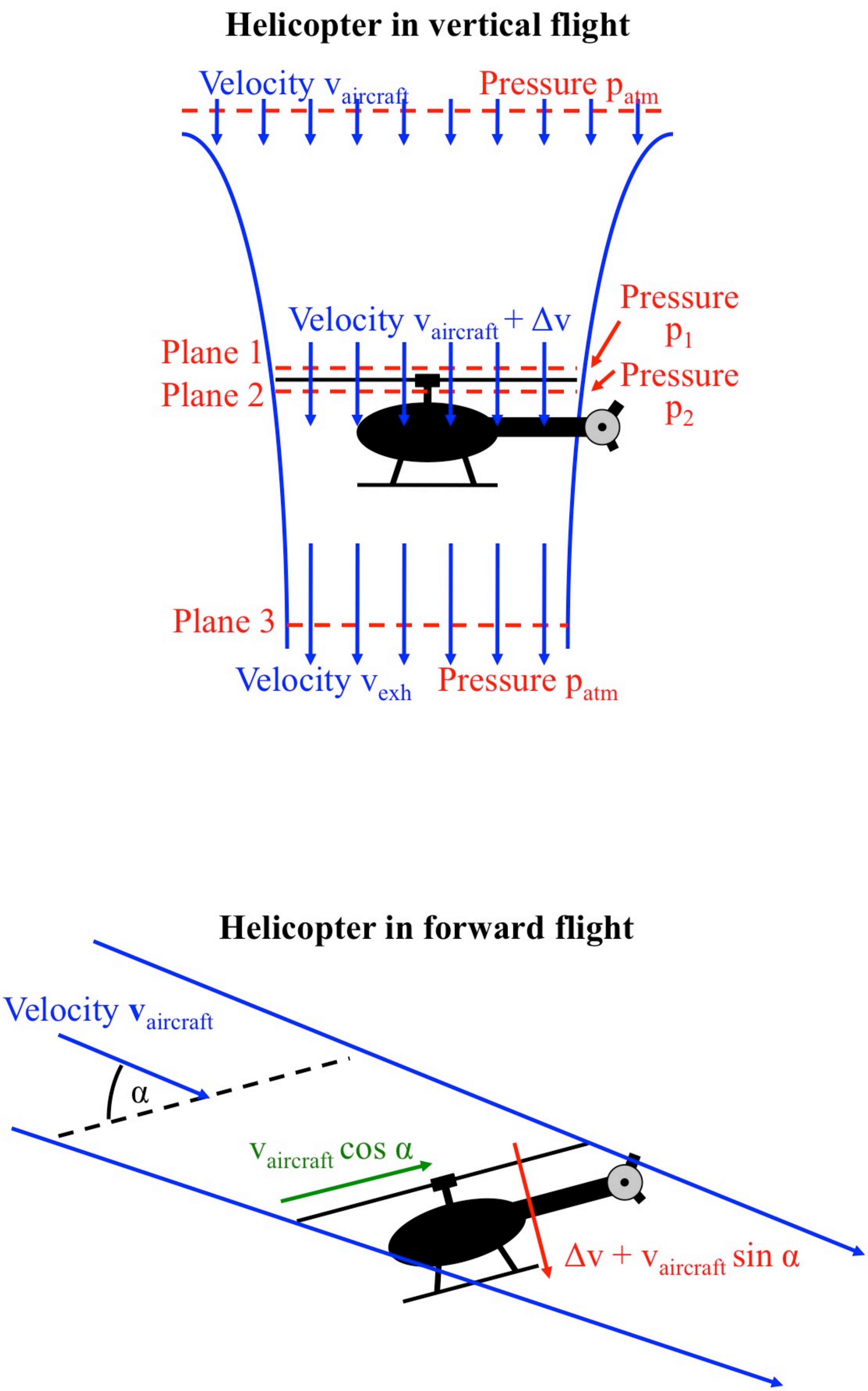
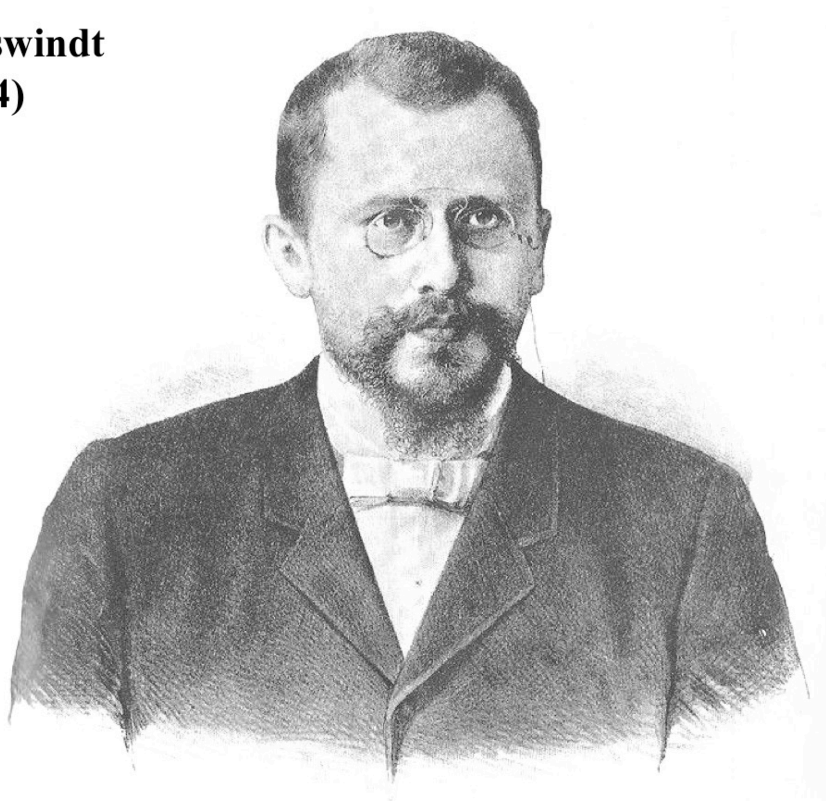


Figure 9.122: Airflow through a helicopter rotor for a helicopter in vertical flight (above) and a helicopter in forward flight (below).

Hermann Ganswindt (1856–1934)



Ganswindt proto-helicopter design (1884)

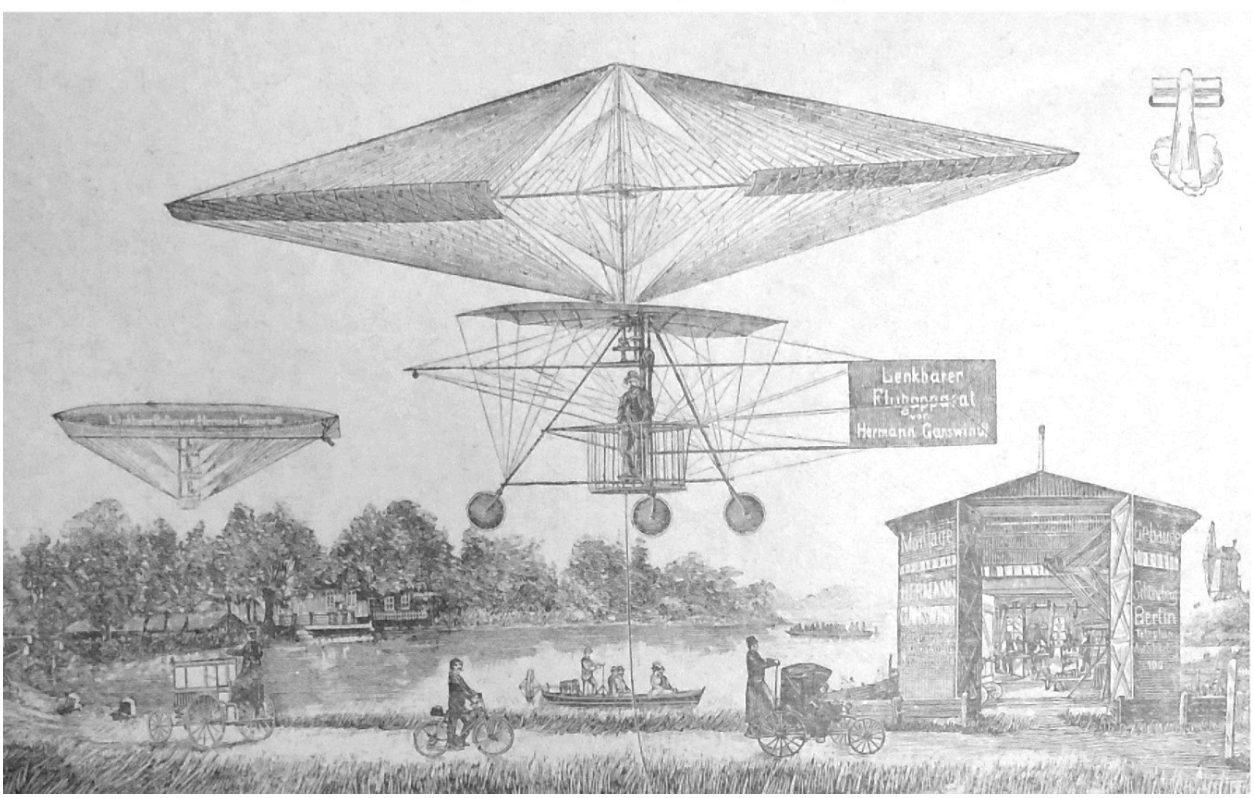


Figure 9.123: Hermann Ganswindt designed proto-helicopters such as this 1884 design.

Ján Bahyl’
(1856–1916)

Bahyl’
proto-helicopter
(1905)

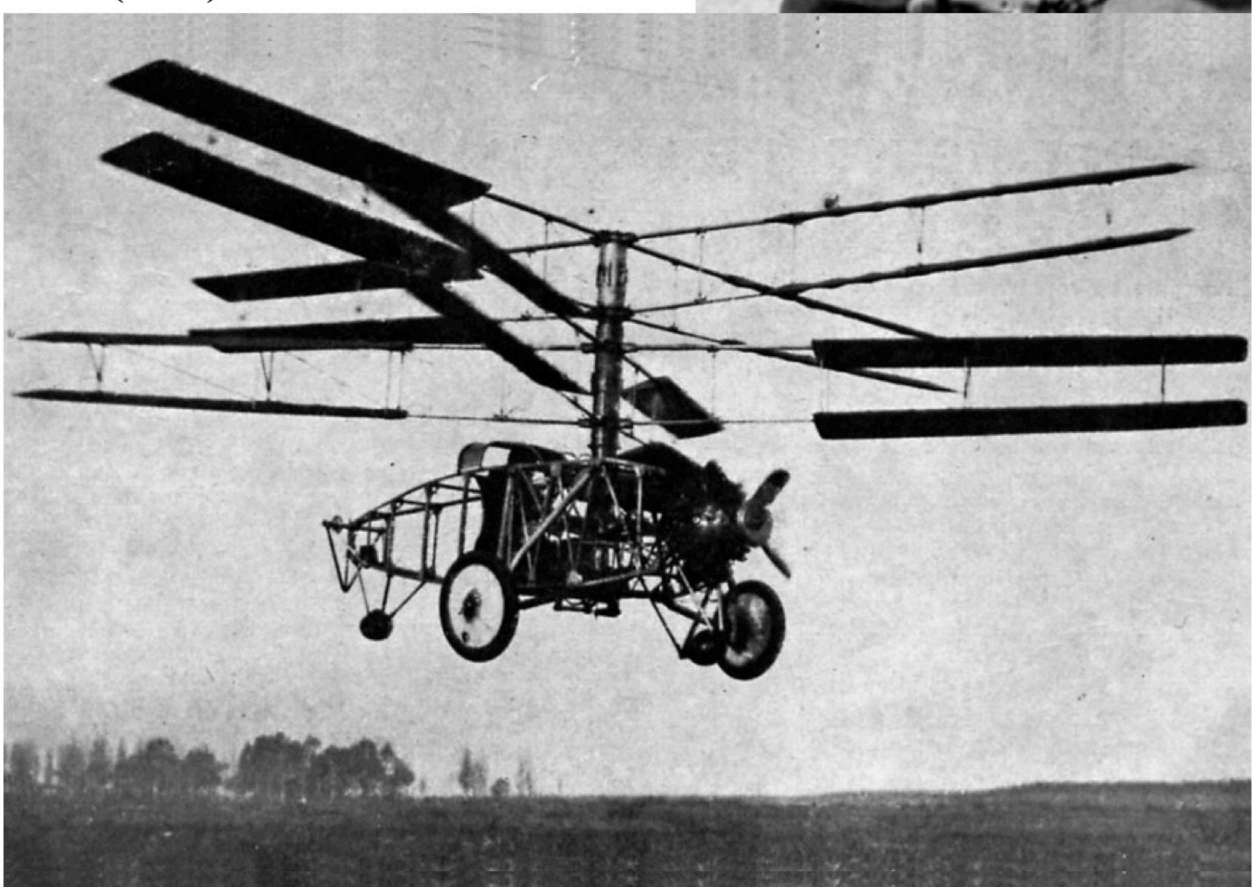


Figure 9.124: Ján Bahyl’ created proto-helicopters such as this 1905 prototype.

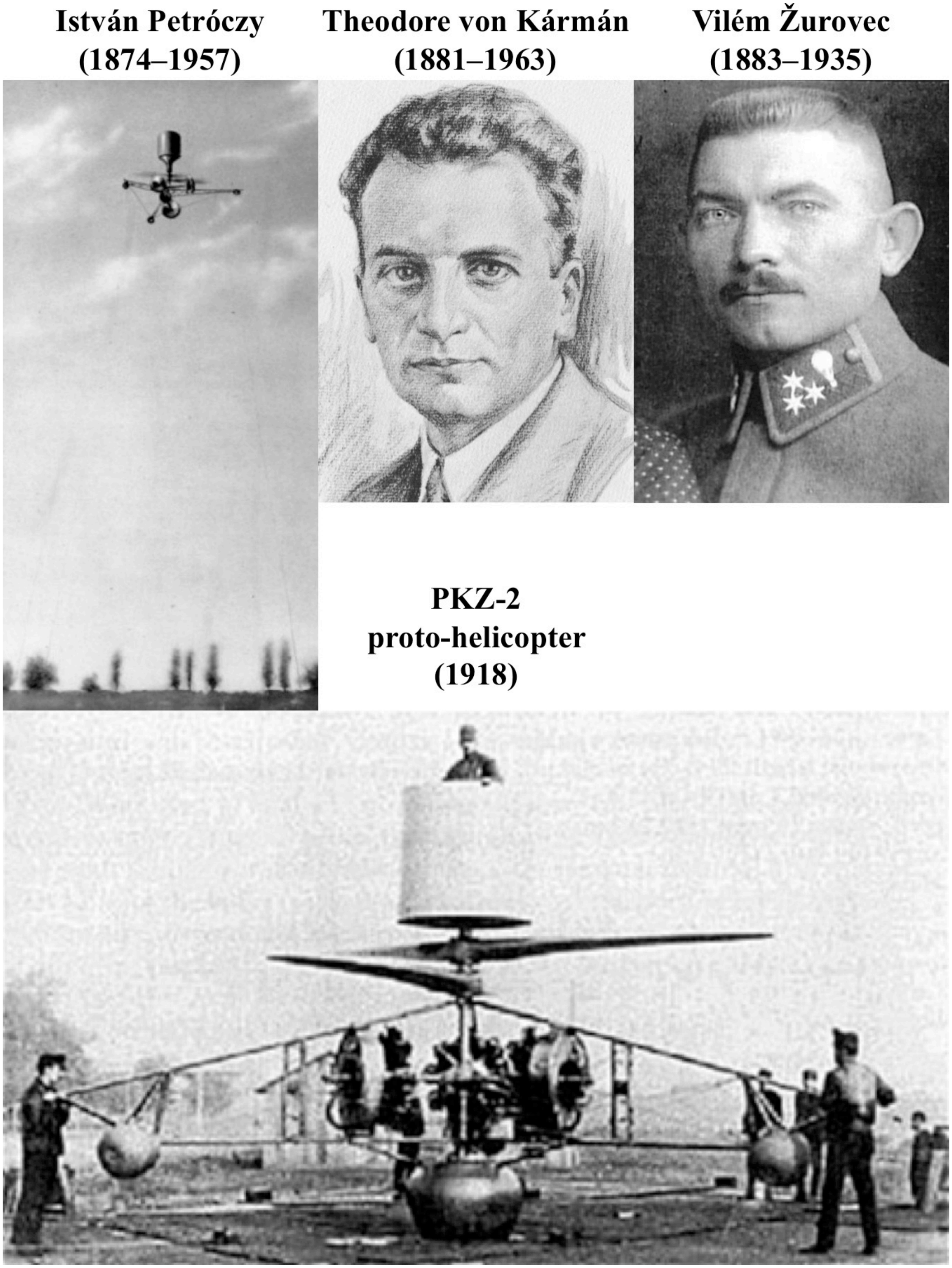


Figure 9.125: István Petróczy, Theodore von Kármán, and Vilém Žurovec created proto-helicopters such as the electric-powered PKZ-1 (1918) and gasoline-powered PKZ-2 (1918).

Emil Berliner (1851–1929)

Berliner Helicopter No. 5 autogyro (1923)

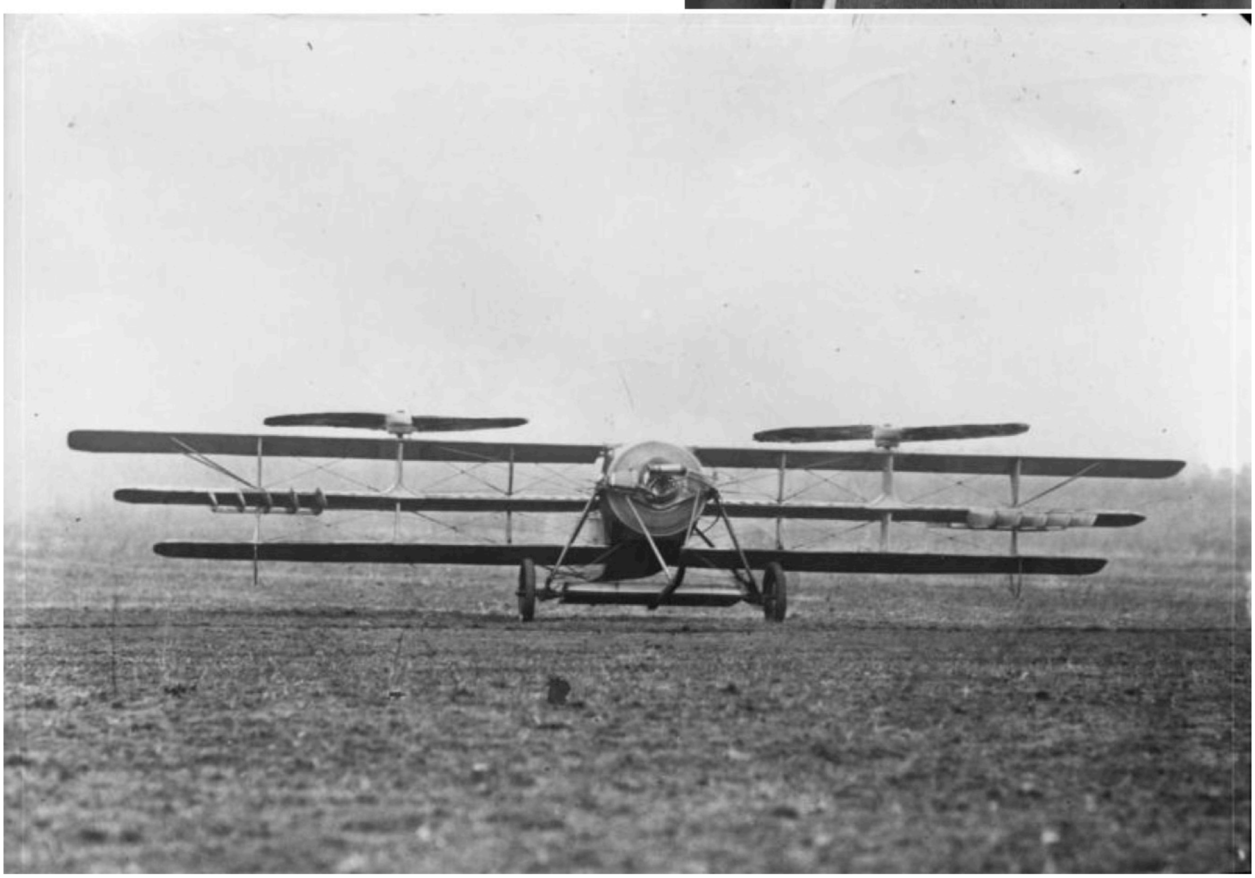


Figure 9.126: Emil Berliner created proto-helicopters and autogyros such as the Berliner Helicopter No. 5 (1923).

Figure 9.127: Engelbert Zaschka created proto-helicopters such as the Rotary Wing (1927).

Albert Gillis von Baumhauer (1891–1939)

Von Baumhauer proto-helicopter (1924–1930)

Figure 9.128: Albert Gillis von Baumhauer created proto-helicopters such as this 1925 test model.

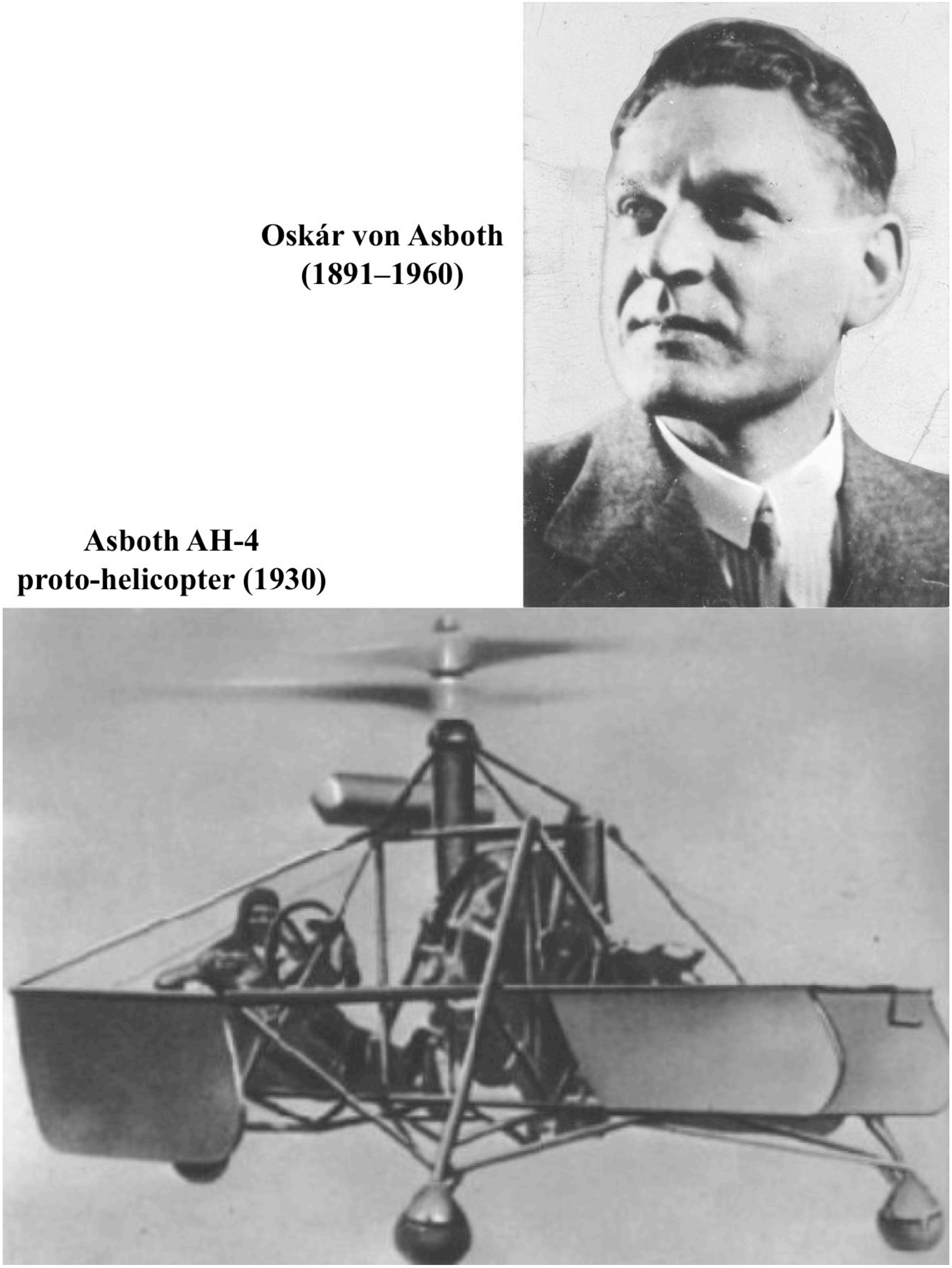


Figure 9.129: Oskár von Asboth created proto-helicopters such as the Asboth AH-4 (1930).

Raoul Hafner (1905–1980) **Bruno Nagler (1901–1979)**

Hafner-Nagler R.I Revoplane proto-helicopter (1929)

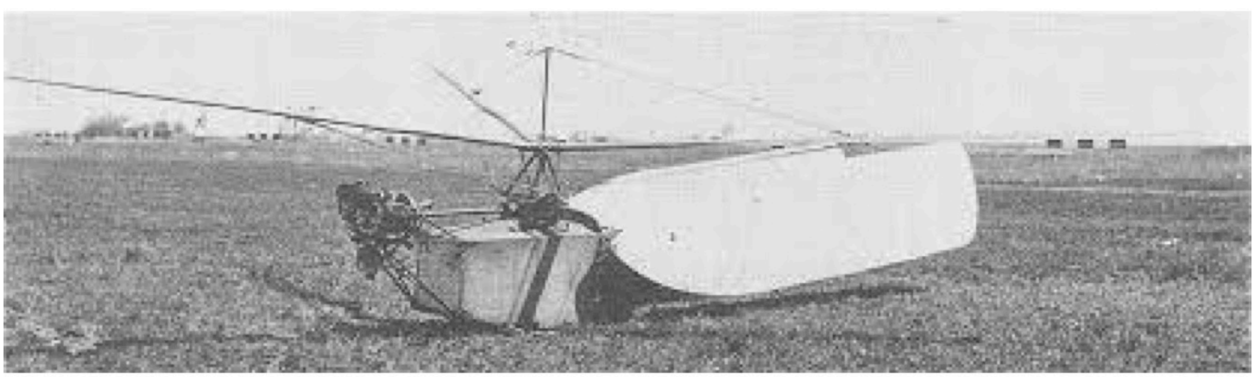


Figure 9.130: Raoul Hafner and Bruno Nagler created proto-helicopters such as the Hafner-Nagler R.I Revoplane (1929).

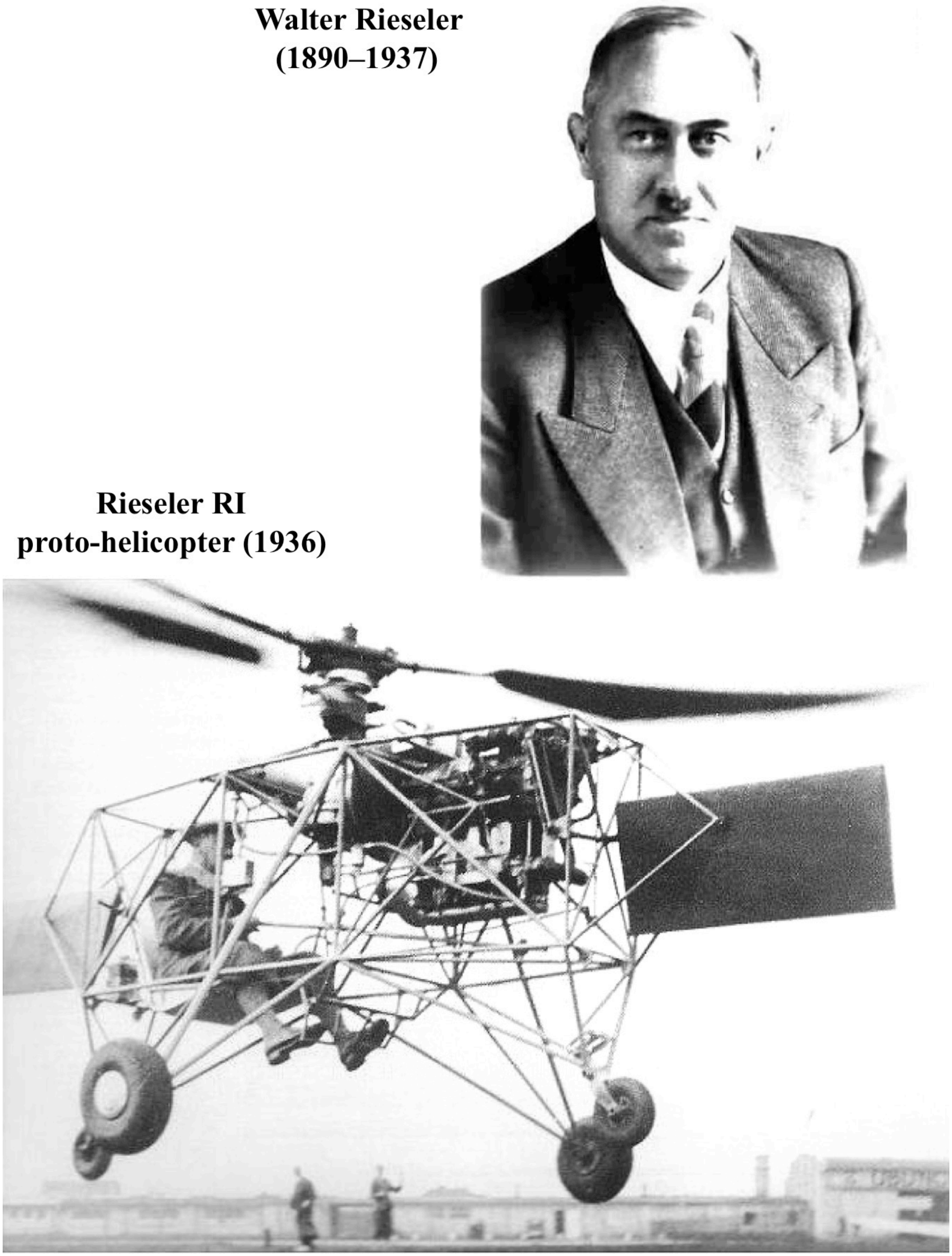


Figure 9.131: Walter Rieseler created proto-helicopters such as the Rieseler RI (1936).

In the 1930s and early 1940s, at least three German-speaking teams—led by Henrich Focke, Anton Flettner, and Friedrich von Doblhoff—finally developed fully functional large helicopters that were able to both hover and move in a stable fashion.

9.5.2 Henrich Focke's Helicopter Team

In 1936, Henrich Focke (German, 1890–1979) created the Focke-Wulf Fw 61, the world's first fully functional helicopter, as shown in Fig. 9.132.

His engineering team included:

- Harry Duda (German, 19??–19??, mechanical design and manufacturing)
- Hans Gerd Eyting (German, 19??–19??, mechanical design and manufacturing)
- Reinhold Gensel (German, 19??–19??, design)
- ?? Helme (German, 19??–19??, mechanical design and control)
- K. Jäckel (German, 19??–19??, aerodynamics and stability)
- Walter Just (German, 1909–1980, aerodynamics and stability)
- Paul Klages (German, 1899–1959, mechanical design and overall development)
- Heinrich Papenhausen (German, 19??–19??, statics and material testing)
- Friedrich Schaper (German, 19??–19??, statics)
- Erich Schweym (German, 19??–19??, aerodynamics and stability)
- Herbert Spranger (German, 19??–19??, development and aerodynamics)
- Enno Springmann (German, 19??–19??, mechanical design)

The Fw 61's development also involved several test pilots, the first of whom was Ewald Rohlfs (German, 1911–1984). In February 1938, the famous pilot Hanna Reitsch (German, 1912–1979, Fig. 9.217) demonstrated the Fw 61 in a crowded indoor sports arena in Berlin every day for three weeks to show the public how controllable and reliable the newly invented helicopter was (Fig. 9.132).

The Focke team subsequently developed other helicopters such as the Focke-Achgelis Fa 223 Drache (Dragon) twin-rotor cargo helicopter (Fig. 9.133). The Fa 223 was first flown in 1940, went into series production, and was used in the war.

In 1942, they designed the larger Focke-Achgelis Fa 284 heavy cargo helicopter (Fig. 9.134) and the four-rotor Fa 325 Krabbe heavy cargo helicopter (Fig. 9.135), but Allied attacks halted construction on those projects.

Focke's team produced a prototype of the Fa 269 tilt-rotor VTOL (vertical takeoff and landing) aircraft that was actually rather similar to the modern U.S. V-22 Osprey (Fig. 9.136). However, it was destroyed by Allied bombing in 1944.

In 1942, Focke and his team developed the novel and useful Focke-Achgelis Fa 330 Bachstelze rotor kite, which could be deployed and towed by a submarine (via a 150-meter cable) as an aerial lookout. (Fig. 9.137).

In 1939, Focke's team designed the Rochen, a winged VTOL aircraft with counter-rotating rotors in a ducted fan (Fig. 9.138). Focke's design lives on in examples such as the Sikorsky Cypher II or Dragon Warrior drone (2000).

They also designed the even more radical Focke-Wulf Triebflügel jet-powered rotary-wing VTOL aircraft (Figs. 9.139–9.140). It had wing-tip ramjets and was designed to take off and land vertically but fly horizontally. The Triebflügel was designed in 1944; it is unclear how far experimental work got by the end of the war.

Closely related to the Focke-Wulf Triebflügel were the Heinkel Wespe and Heinkel Lerche (Fig. 9.141 shows the Lerche; the Wespe was highly similar but somewhat smaller), which were also designed but apparently not completed during the war. After the war, the Triebflügel and Lerche/Wespe designs (and perhaps some of the engineers who worked on them?) directly inspired similar projects such as the Lockheed XFV Salmon (1954) and Convair XFY Pogo (1954). While the Lockheed XFV could fly vertically or horizontally but could not make the transition between those two modes, the Convair XFY was completely successful at demonstrating the feasibility of taking off vertically, transitioning from vertical to horizontal flight, flying horizontally, transitioning from horizontal to vertical flight, and landing vertically.

As shown in Fig. 9.142, the wartime German Lerche/Wespe- and Triebflügel-type designs (for aircraft that could take off and land on their tails but pitch over by 90^o to fly horizontally) still live on in modern unmanned aerial vehicles (UAVs) such as the University of Kansas XQ-138 drone and the Martin UAV V-BAT drone.

After the war, Henrich Focke and other members of his team produced helicopters for France, the Netherlands, Brazil, and West Germany.

Henrich Focke (1890–1979) **Walter Just (1909–1980)** **Paul Klages (1899–1959)**

Focke-Wulf Fw 61 helicopter, first flown in 1936

Fw 61 demonstrated in crowded indoor arena in Berlin by test pilot Hanna Reitsch (1938)

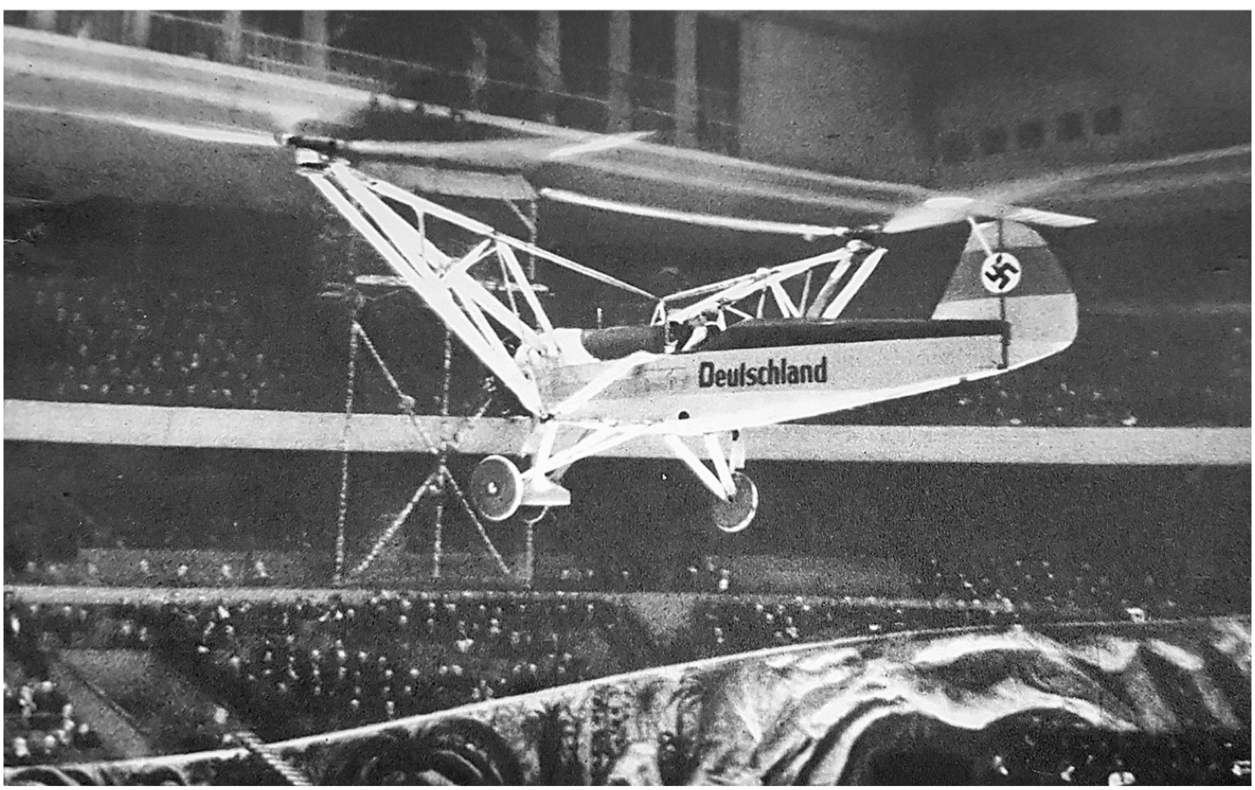


Figure 9.132: Henrich Focke and his team, including Walter Just and Paul Klages, created the world's first fully functional helicopter, the Focke-Wulf Fw 61, in 1936. In 1938, test pilot Hanna Reitsch (Fig. 9.217) demonstrated the Fw 61 in a crowded indoor arena in Berlin.

Figure 9.133: Henrich Focke and his team created the much more advanced Focke-Achgelis Fa 223 Drache (Dragon) dual-rotor cargo helicopter in 1940.

Focke-Achgelis Fa 284 heavy cargo helicopter
(designed in 1942 but Allied attacks halted its construction)

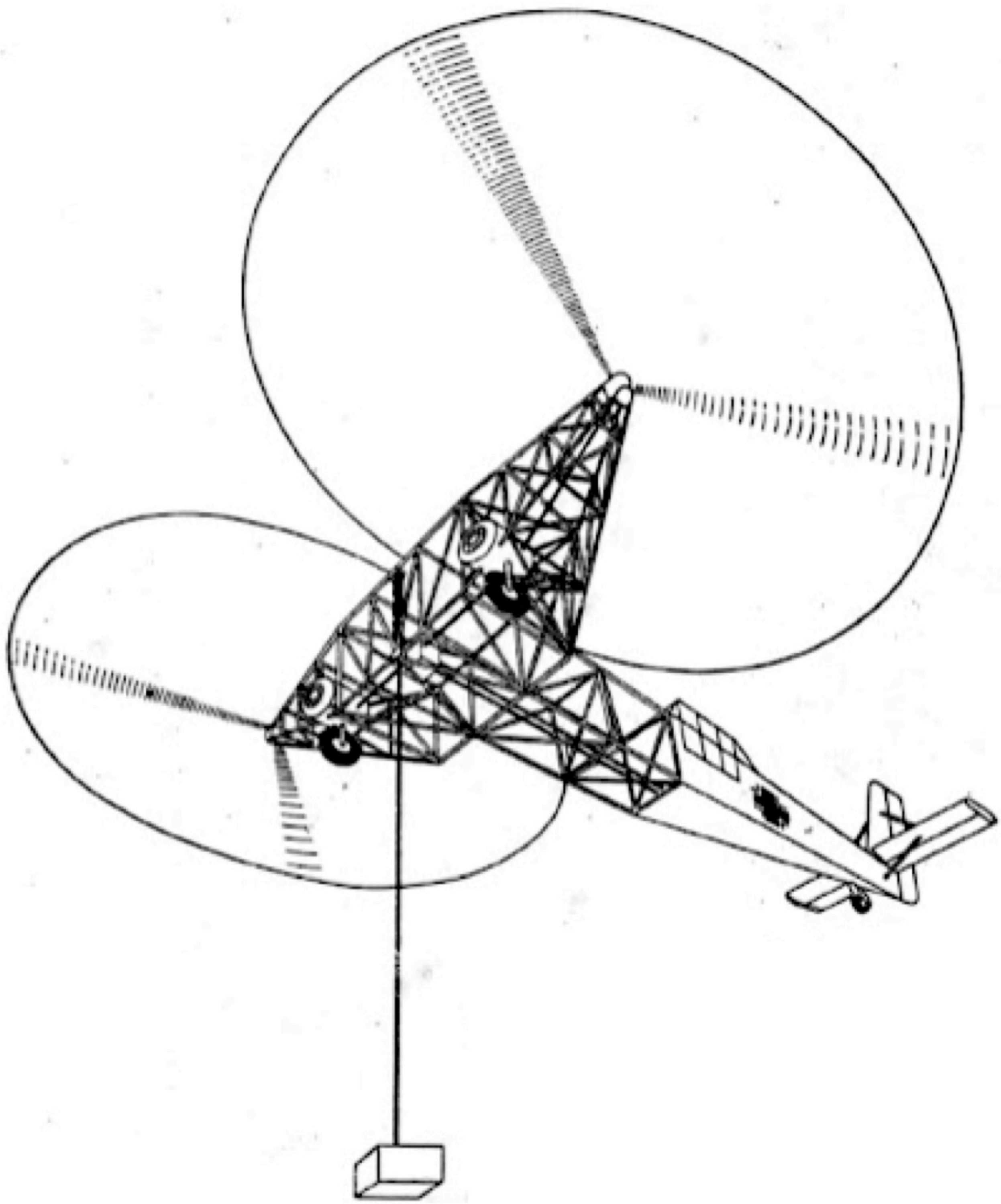


Figure 9.134: Henrich Focke and his team designed the Focke-Achgelis Fa 284 heavy cargo helicopter in 1942, but Allied attacks halted its construction.

Focke-Achgelis Fa 325 Krabbe heavy cargo helicopter
(designed in 1942 but Allied attacks halted its construction)

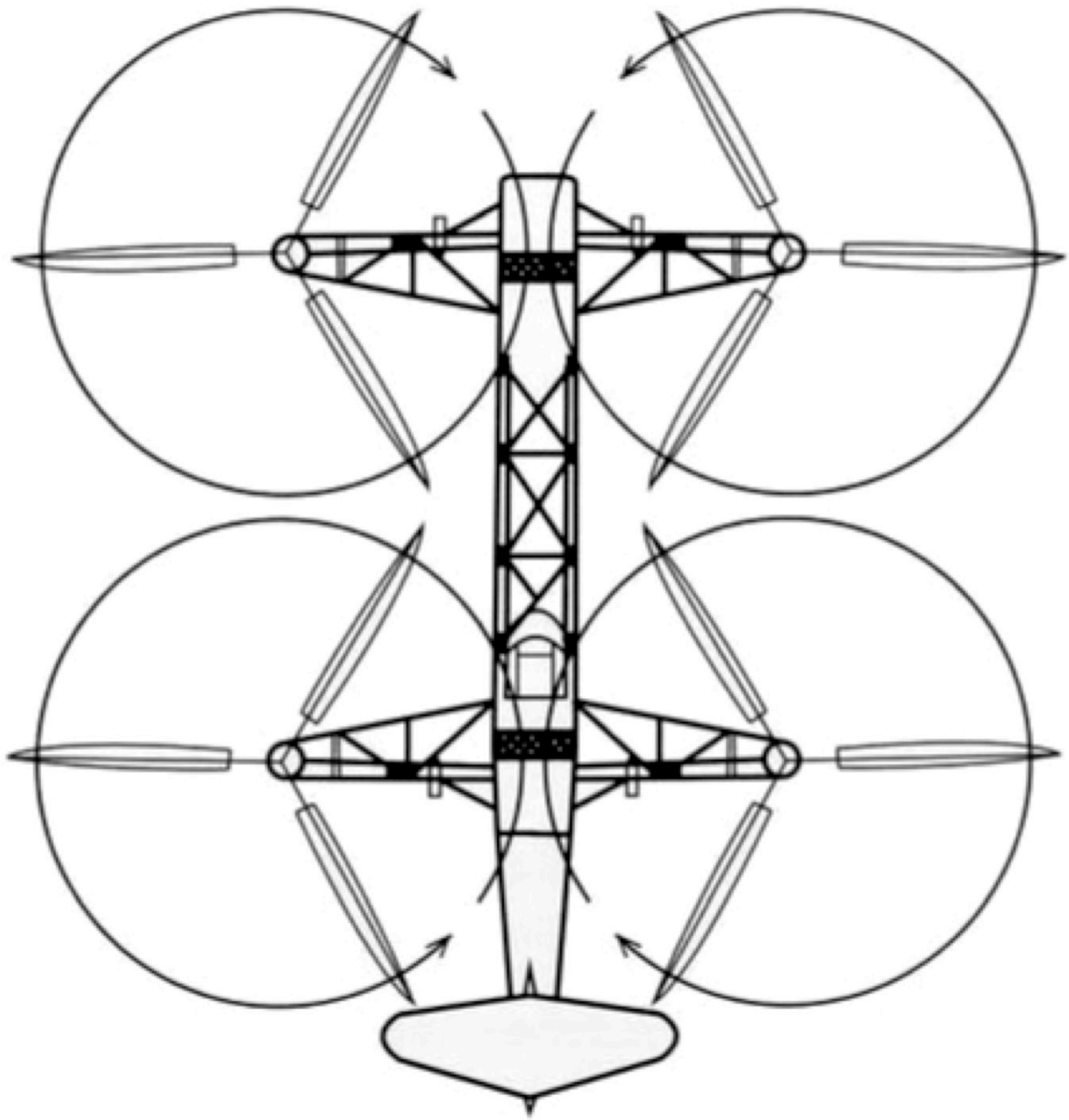


Figure 9.135: Henrich Focke and his team designed the Focke-Achgelis Fa 325 Krabbe heavy cargo helicopter in 1942, but Allied attacks halted its construction.

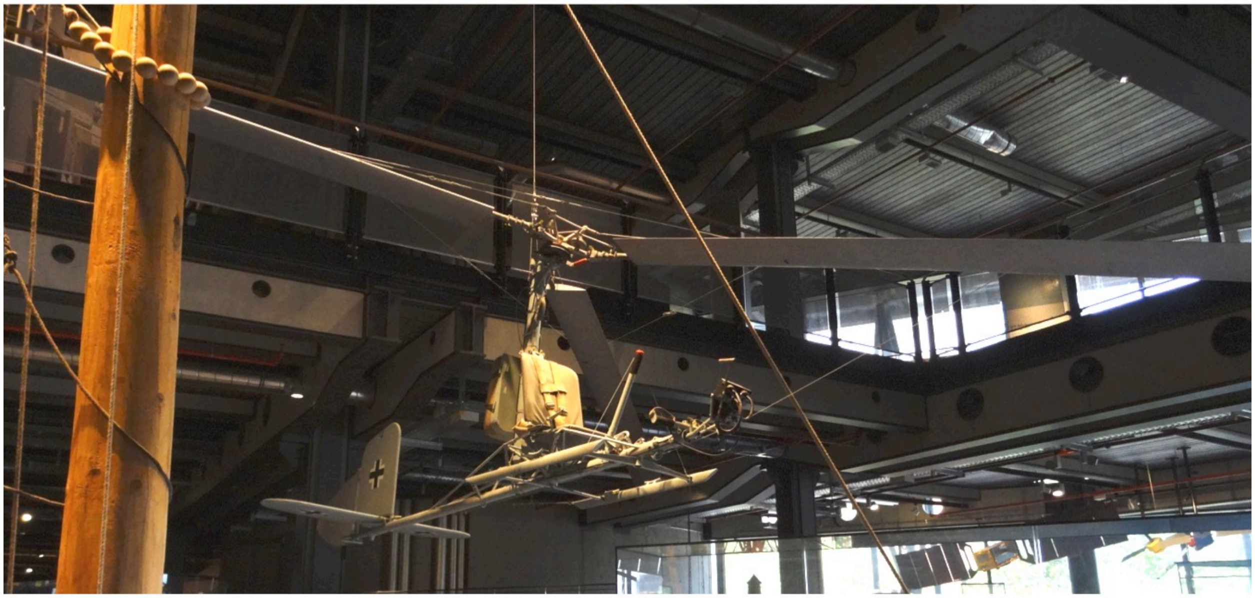
Focke-Achgelis Fa 269 tilt-rotor VTOL aircraft, designed in 1943 but destroyed by Allied bombing in 1944 (model above, drawing below)

Figure 9.136: Henrich Focke and his team were developing a prototype tilt-rotor VTOL aircraft, the Focke-Achgelis Fa 269, that was destroyed by Allied bombing in 1944.

Focke-Achgelis Fa 330 Bachstelze rotor kite

Could be deployed and towed by a submarine as an aerial lookout

First flown in 1942



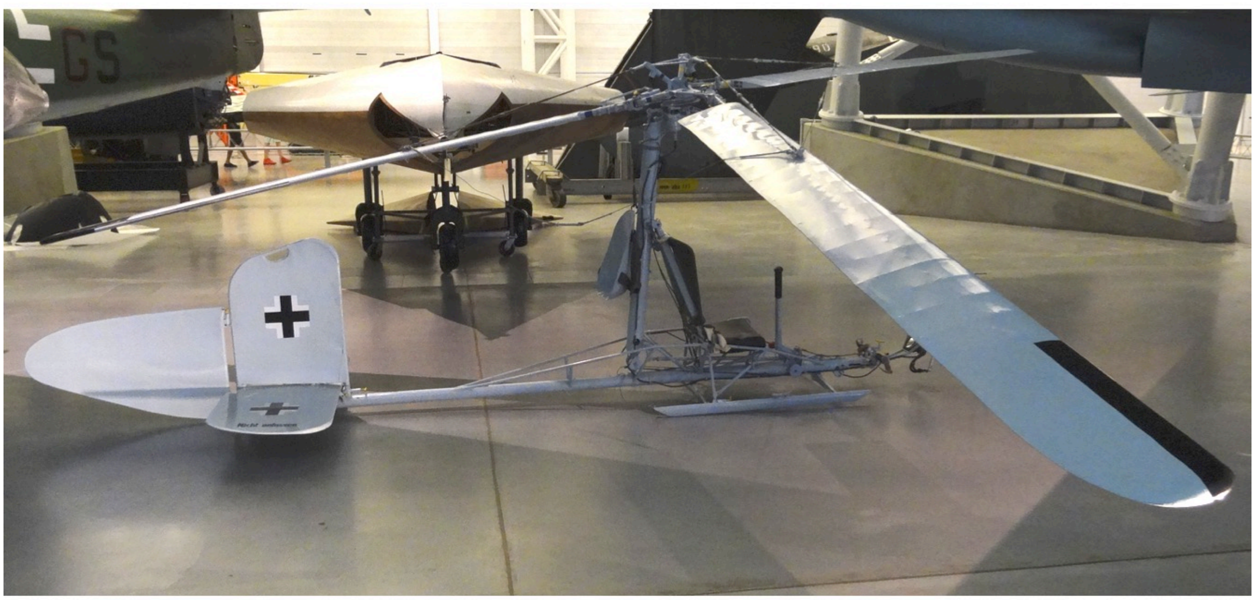


Figure 9.137: In 1942, Henrich Focke and his team developed the Focke-Achgelis Fa 330 Bachstelze rotor kite, which could be deployed and towed by a submarine (via a 150-meter cable) as an aerial lookout.

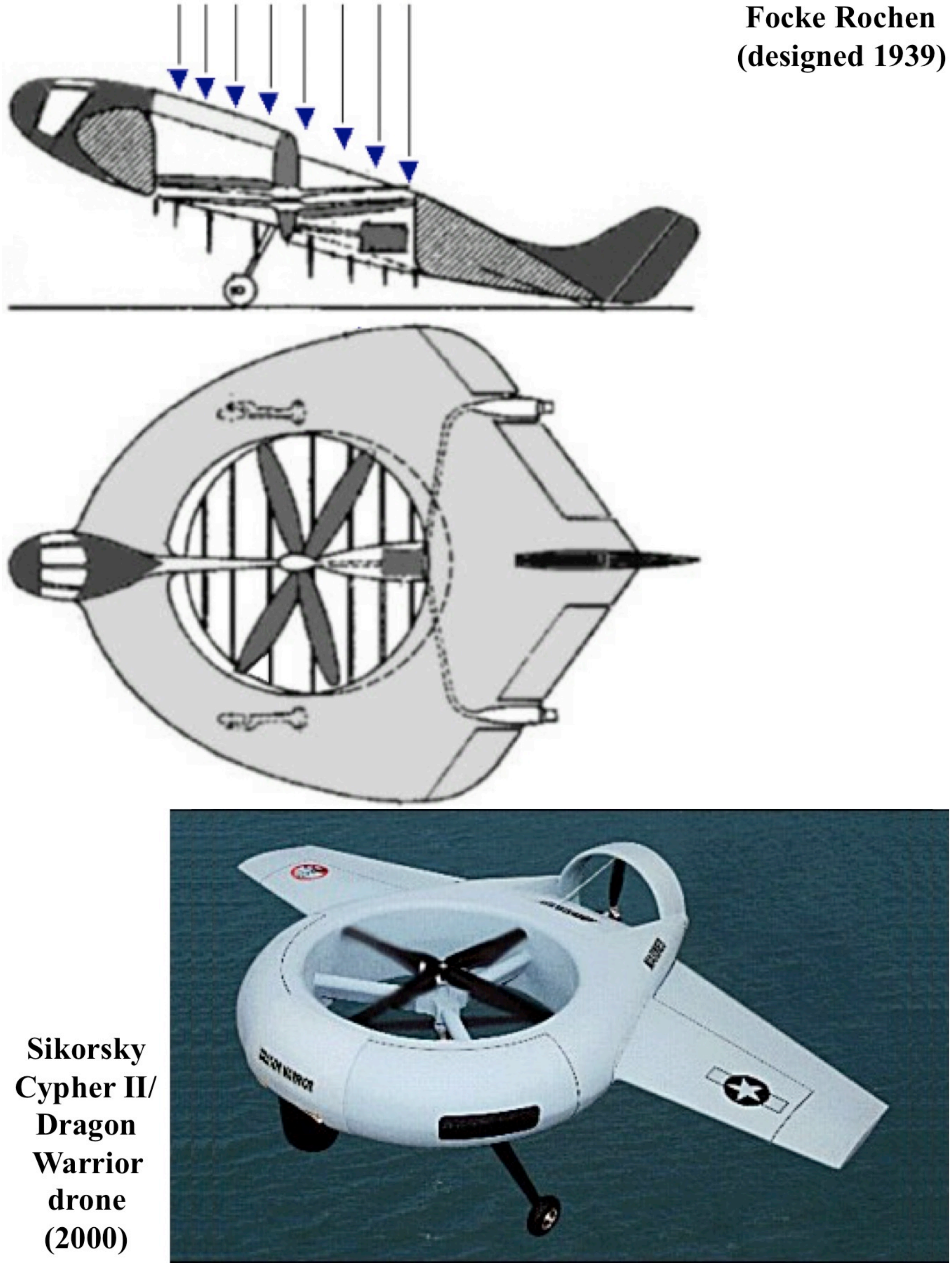


Figure 9.138: In 1939, Henrich Focke and his team designed the Rochen, a winged VTOL aircraft with counter-rotating rotors in a ducted fan. Focke's design lives on in examples such as the Sikorsky Cypher II or Dragon Warrior drone (2000).

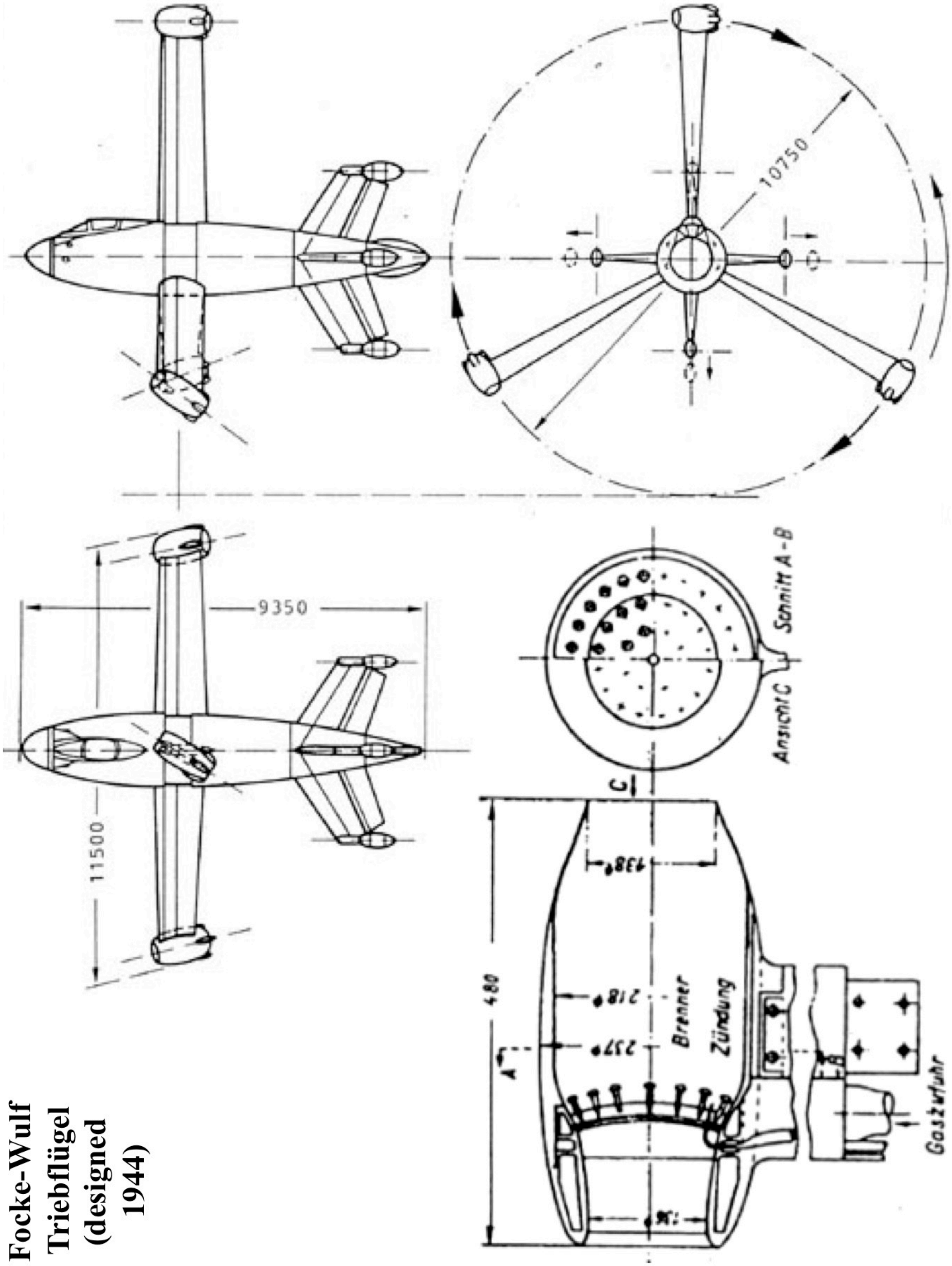


Figure 9.139: The Focke-Wulf Triebflügel was a highly innovative rotary-wing aircraft powered by wing-tip ramjets that was designed to take off and land vertically but fly horizontally. It was designed in 1944; it is unclear how far experimental work got by the end of the war.

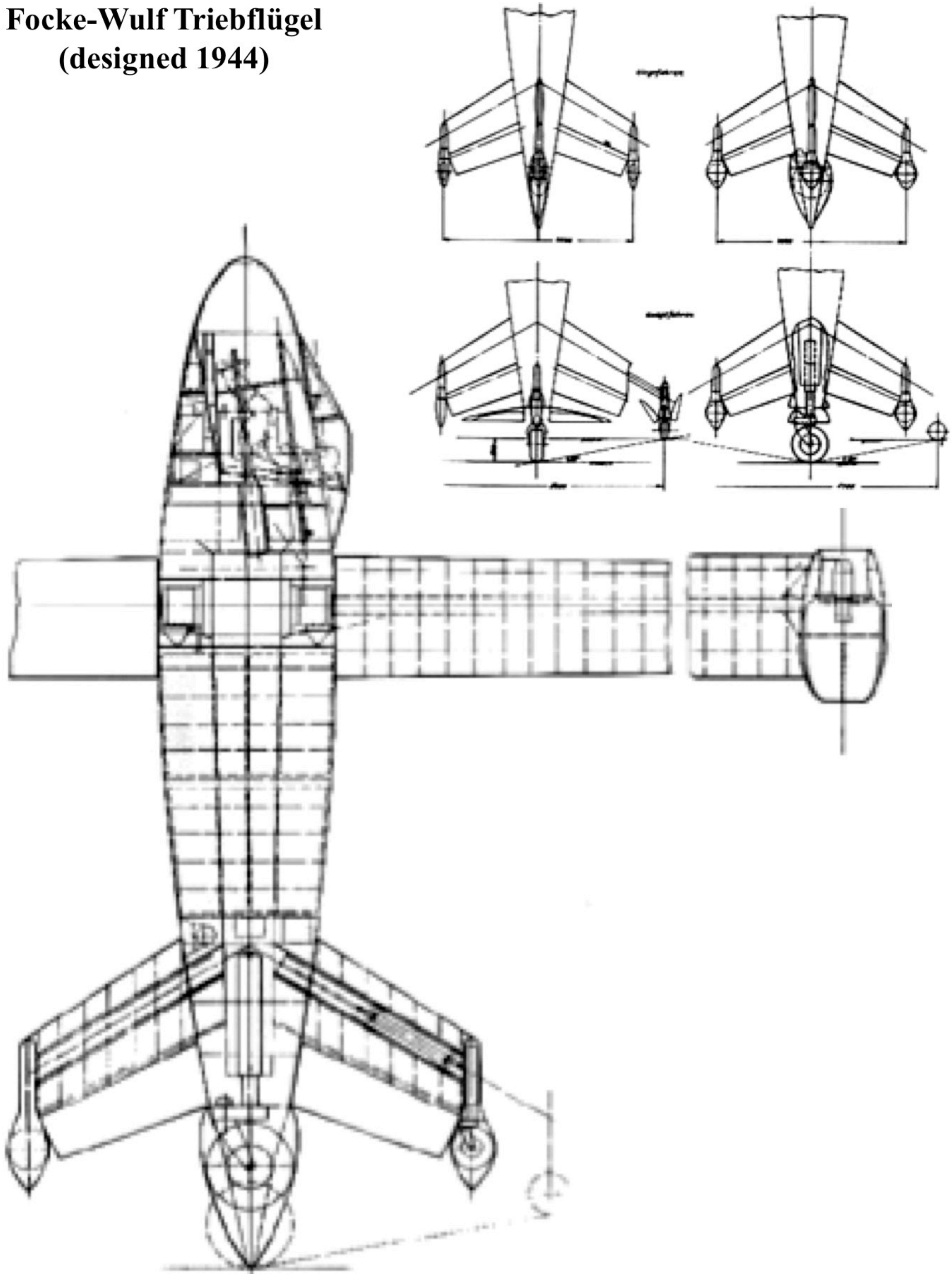


Figure 9.140: The Focke-Wulf Triebflügel was a highly innovative rotary-wing aircraft powered by wing-tip ramjets that was designed to take off and land vertically but fly horizontally. It was designed in 1944; it is unclear how far experimental work got by the end of the war.

Figure 9.141: Closely related to the Focke-Wulf Triebflügel were the wartime Heinkel Lerche (model, 1945, larger than but otherwise highly similar to the proposed 1944 Heinkel Wespe) and the postwar Lockheed XFV Salmon (1954) and Convair XFY Pogo (1954).

University of Kansas XQ-138 drone

Martin UAV V-BAT drone

Figure 9.142: The wartime German Lerche/Wespe- and Triebflügel-type designs (for aircraft that could take off and land on their tails but pitch over by 90^o to fly horizontally) still live on in modern unmanned aerial vehicles (UAVs) such as the University of Kansas XQ-138 drone and the Martin UAV V-BAT drone.

9.5.3 Anton Flettner's Helicopter Team

As shown in Fig. 9.143, Anton Flettner (German, 1885-1961) also demonstrated his own fully functional helicopter, the Flettner Fl 185, in 1936 very soon after Focke. Previously Flettner had invented battlefield robots (p. 1217) and rotor ships (p. 1494).

In addition to several test pilots, his engineering team included:

- Emil Arnold (German, 19??–19??, chief designer)
- Willi Deilitz (German, 19??–19??, test facilities)
- Heinz Gundlach (German, 19??–19??, designer)
- Kurt Hohenemser (German, 1906–2001, aerodynamics and stability)
- ?? Küchler (German, 19??–19??, transmissions)
- Oskar Nagel (German, 19??–19??, project designer)
- Xaver Schleicher (German, 19??–19??, flight mechanics)
- Joseph Schmidt (German, 19??–19??, flight-test engineer)
- Gerhard Siegel (German, 19??–19??, statics)
- Gerhard Sissingh (German, 1907–2002, aerodynamics)

Flettner's team went on to create other helicopters such as the much more advanced Fl 282 Kolibri (Humming Bird) reconnaissance helicopter. The Fl 282 was first flown in 1941, went into series production, and was used in the war. See Fig. 9.144.

Flettner and his team also developed the Fl 265 helicopter/autogyro (1938), the improved Fl 285 reconnaissance helicopter (1944, Fig. 9.145 top), and the large Fl 339 passenger/cargo helicopter prototype, which apparently was not completed before the end of the war (Fig. 9.145 bottom).

After the war, Flettner, Hohenemser, and Sissingh produced helicopters in the United States.

Anton Flettner (1885–1961) **Kurt Hohenemser (1906–2001)** **Gerhard Sissingh (1907–2002)**

Flettner Fl 185 helicopter, first flown in 1936

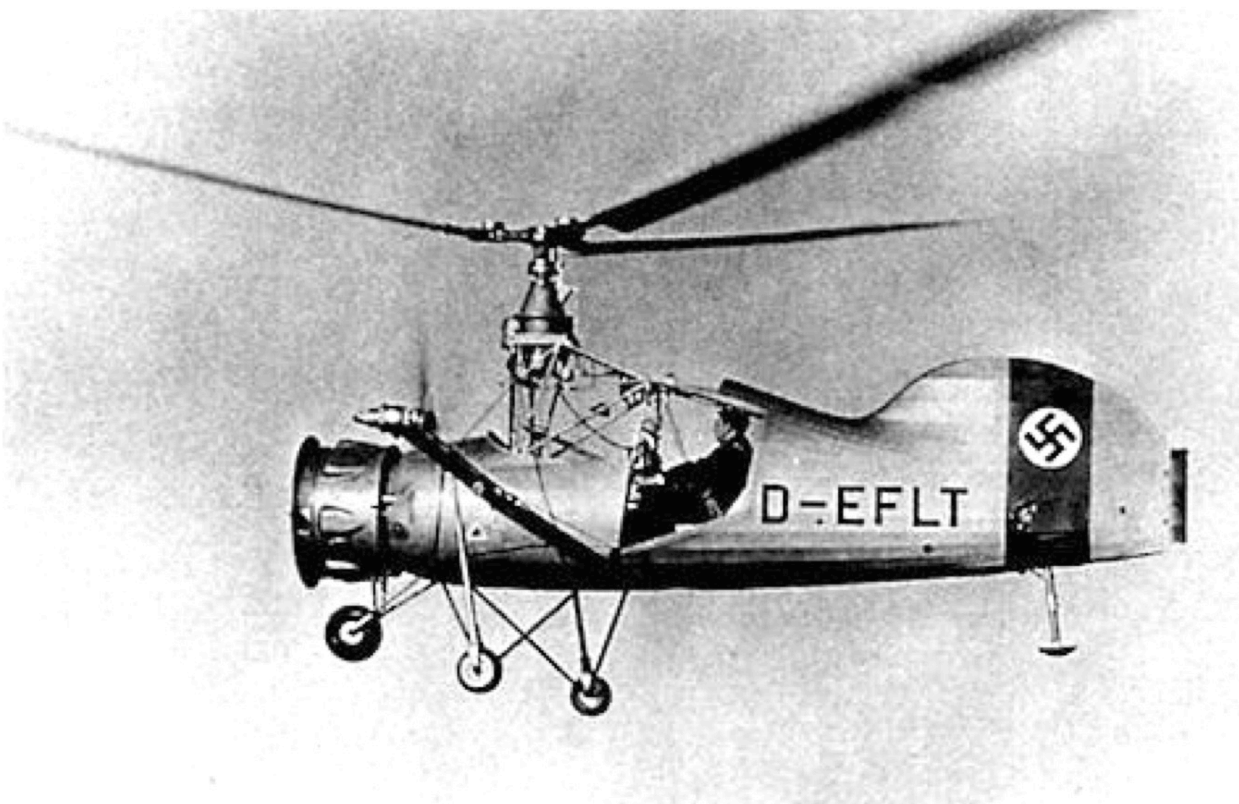


Figure 9.143: Anton Flettner and his team including Kurt Hohenemser and Gerhard Sissingh created their first fully functional helicopter, the Fl 185, in 1936.

Figure 9.144: Anton Flettner and his team produced the much more advanced Fl 282 Kolibri (Humming Bird) reconnaissance helicopter in 1941.

Flettner Fl 285 reconnaissance helicopter (1944)

Flettner Fl 339 passenger/cargo helicopter (designed in 1944 but not completed before the end of the war)

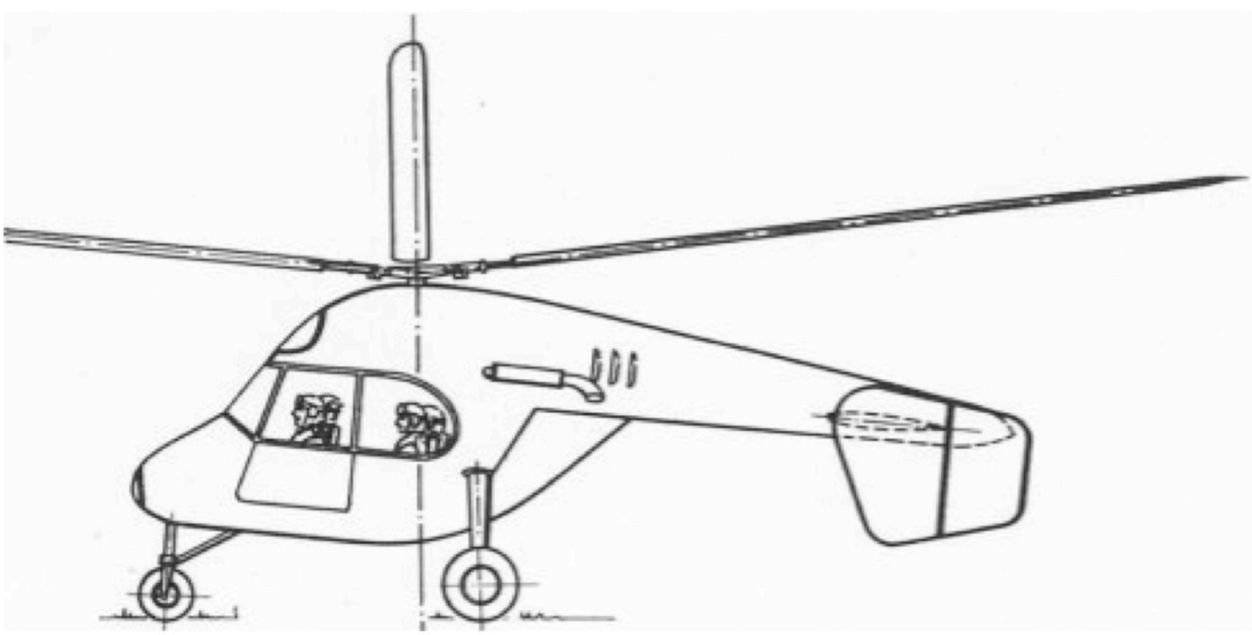


Figure 9.145: By the end of the war, Flettner's team had produced the improved Flettner Fl 285 reconnaissance helicopter and was building the much larger Fl 339 passenger/cargo helicopter.

9.5.4 Friedrich von Doblhoff's Helicopter Team

In 1943, Friedrich von Doblhoff (Austrian, 1916–2000) demonstrated the prototype WNF 342 submarine-launched helicopter, which featured a rotor that was directly powered by small jet engines at the rotor tips; see Fig. 9.146.

Some of the other members of his engineering team were:

- Alexander Czernin (Austrian, 19??–19??, mechanical design)
- Theodor Laufer (Austrian, 1875–1951, aerodynamics and stability)
- Kurt Löffler (Austrian, 19??–19??, detailed design)
- August Stepan (Austrian, 1915–2003, structural design)
- M. Vordren (Austrian, 19??–19??, detailed design)

After the war, von Doblhoff developed helicopters in the United States, Czernin and Stepan built helicopters in the United Kingdom, Stepan later developed helicopters in West Germany (including the revolutionary MBB Bo 105), and Laufer built helicopters in France. Several of the postwar helicopters designed by former von Doblhoff team members were propelled by the same tip-jet rotor approach as the wartime WNF 342, including the McDonnell XV-1 military helicopter, Fairey Jet Gyrodyne test prototype, and Fairey Rotodyne passenger vehicle (Fig. 9.147).

9.5.5 Backpack Helicopters

Special mention should go to three innovators who created and successfully demonstrated prototype "backpack" helicopters during the war:

- Paul Baumgärtl (Austrian, 1920–2012) produced and tested a series of one-person helicopters that he called Heliofly (Fig. 9.148). Baumgärtl's prototypes included Heliofly I (1941), which attached directly to the back of the pilot, and Heliofly III (1943), which was essentially a flying chair for the pilot.

- Beginning in 1940, Bruno Nagler (Austrian, 1901–1979) and Franz Rolz (Austrian, 19??–19??) demonstrated the NR 54 and NR 55 prototype helicopters, which could be folded up and carried as a backpack, or unfolded into a helicopter for use by a seated pilot (Fig. 9.149). After the war, Nagler moved to the United States, where he continued to develop and demonstrate portable helicopters such as the strap-on backpack Heliglider (1952).

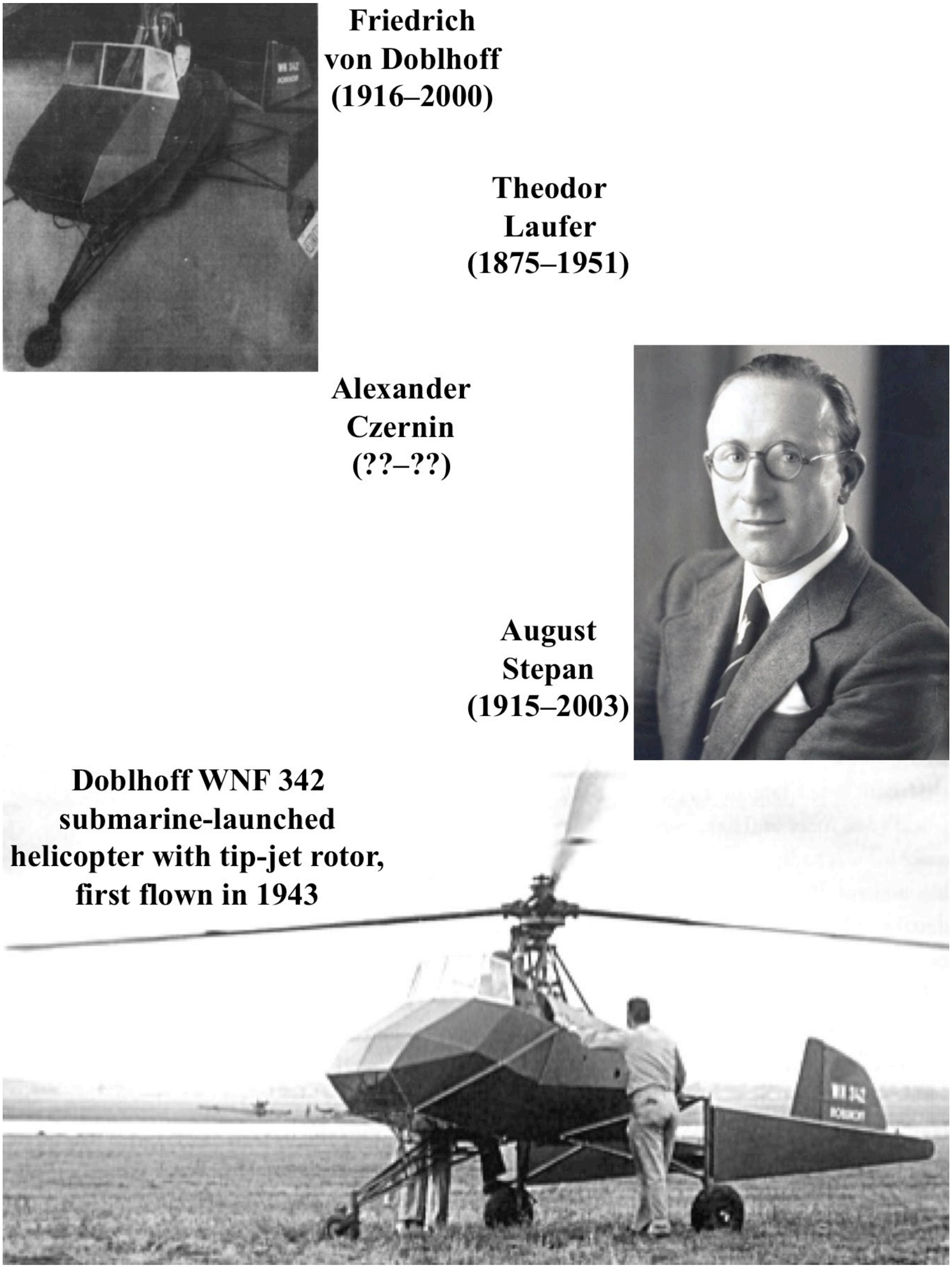


Figure 9.146: Friedrich von Doblhoff and his team including Theodor Laufer, Alexander Czernin, and August Stepan created helicopters propelled by tip-jet rotors, such as the Doblhoff WNF 342 submarine-launched jet helicopter, which was first flown in 1943.

Fairey Jet Gyrodyne with tip-jet rotor (1954) designed by August Stepan and Alexander Czernin

Fairey Rotodyne with tip-jet rotor (1957) designed by August Stepan and Alexander Czernin

Figure 9.147: After the war, members of Friedrich von Doblhoff's team continued to develop helicopters propelled by tip-jet rotors, such as the McDonnell XV-1 military helicopter, Fairey Jet Gyrodyne test prototype, and Fairey Rotodyne passenger vehicle.

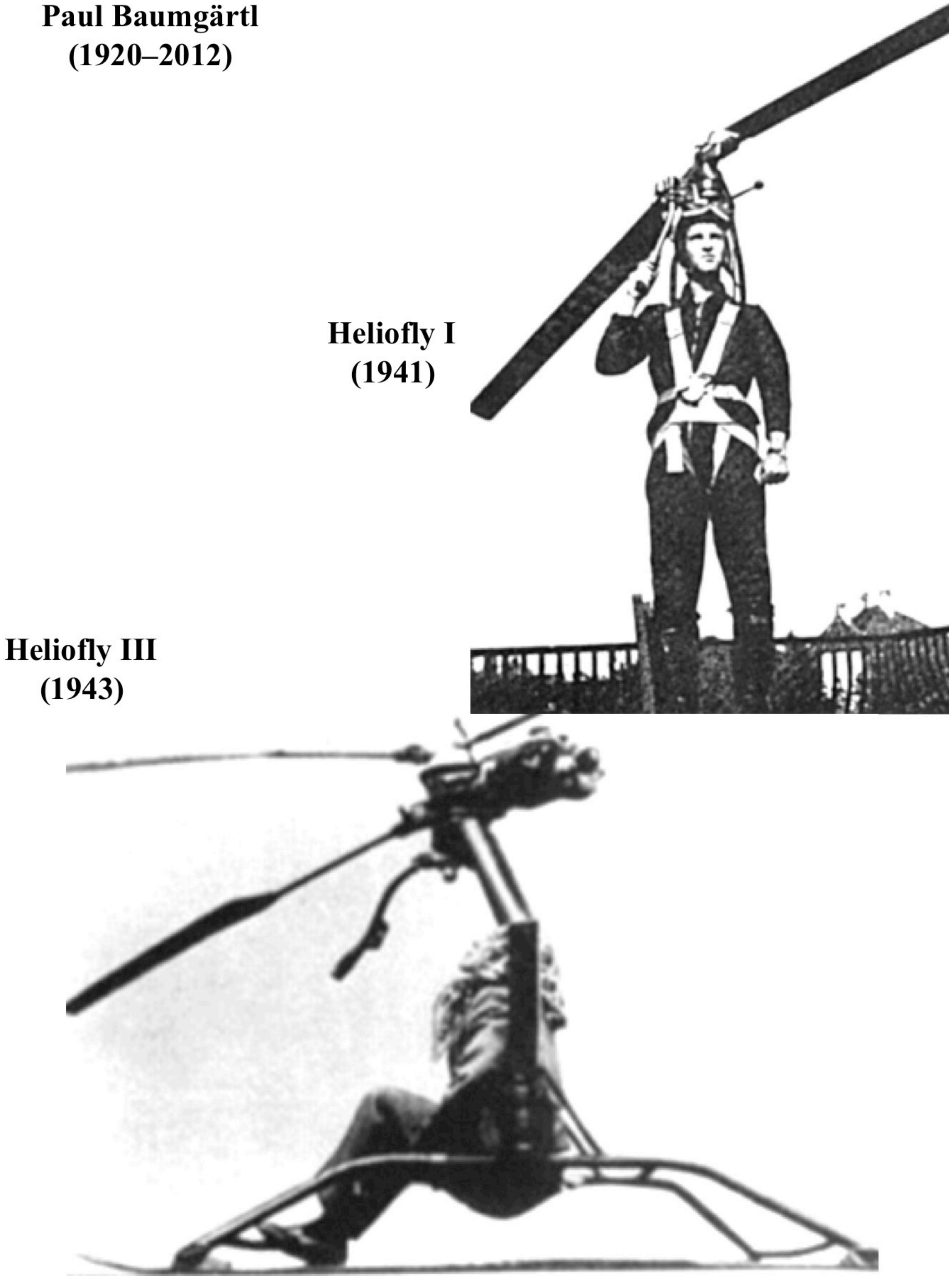
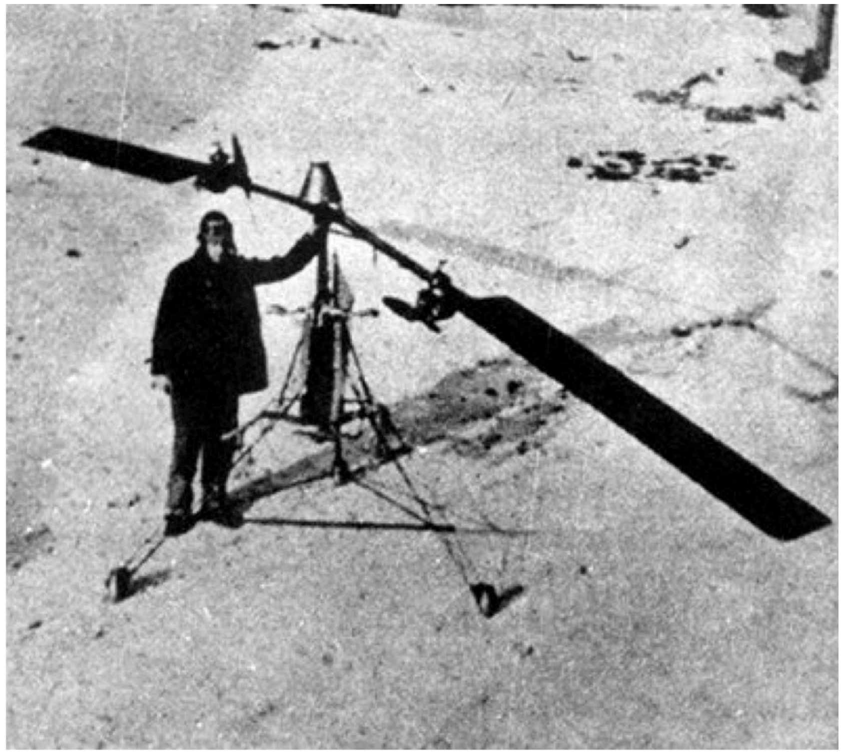


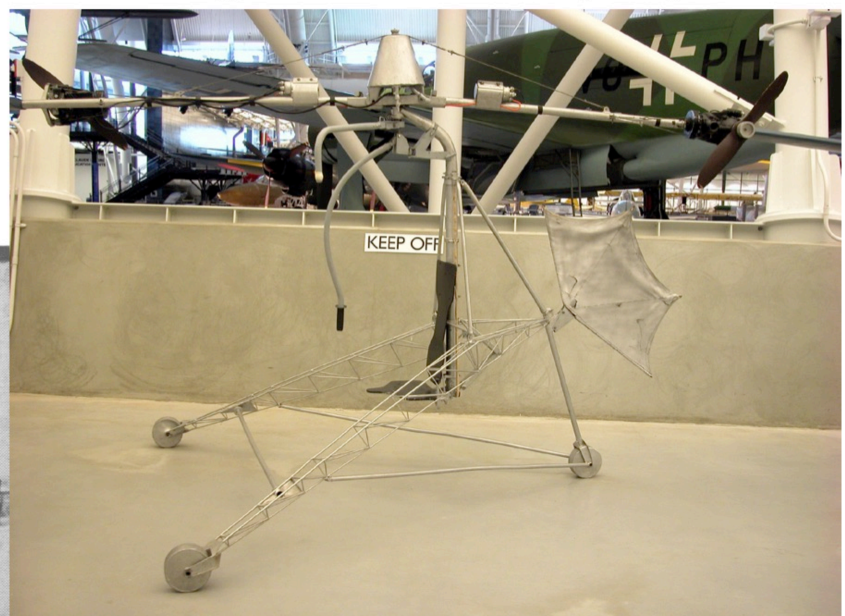
Figure 9.148: Paul Baumgärtl designed and successfully demonstrated several portable, single-person helicopters during the war.

Bruno Nagler (1901–1979)

Franz Rolz (??–??)



Nagler-Rolz NR 54 V2 (1941)



Nagler Heliglider (1952)

Figure 9.149: Bruno Nagler and Franz Rolz designed and successfully demonstrated several portable, single-person helicopters during and shortly after the war.

9.5.6 Electric Helicopters

The PKZ-1 proto-helicopter that was built by István Petróczy, Theodore von Kármán, and Vilém Žurovec (Fig. 9.125) in 1918 demonstrated the potential of electric-powered helicopters.

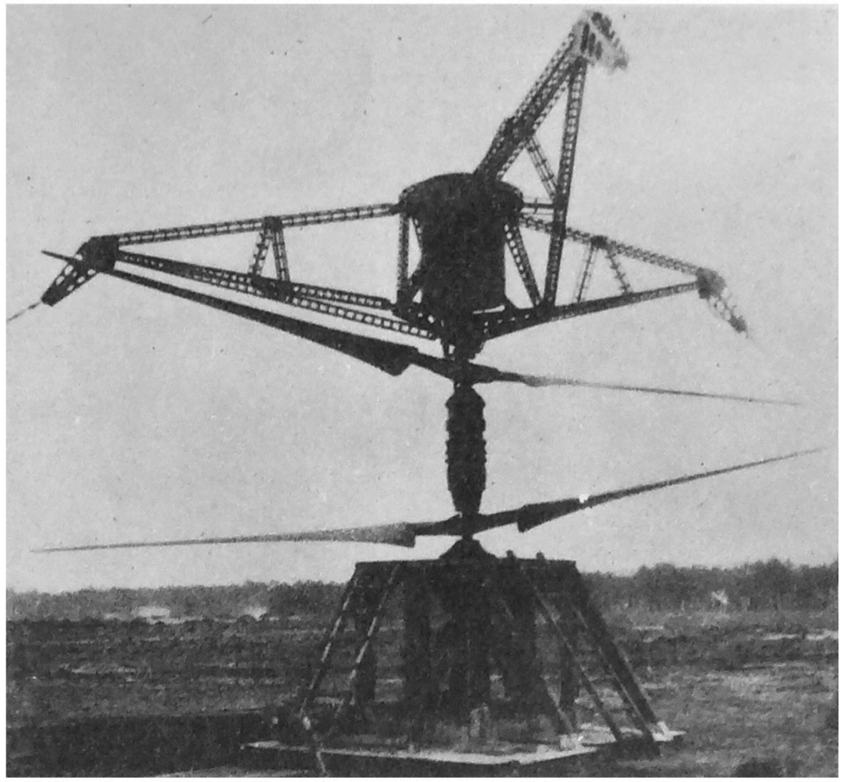
While most helicopters focused on fuel-burning engines of various types, R. Schmidt (German, ??–??) and G. Kirchberg (German?, ??–??), engineers working at the electrical equipment company AEG, continued the development of electric helicopters. Beginning in 1933, they built and demonstrated a series of increasingly sophisticated electric helicopters that could be launched from a truck and that remained tethered by power cables to a ground-based electric generator. Figure 9.150 shows the final (1945) version of the helicopter, in which the hovering vehicle and its attached cables could function as a large radio antenna. By sending the helicopter aloft from the truck, the system could act as a portable radio tower [FIAT 604].

Electric helicopter/quad-copter drones are now quite common, and they are deeply indebted to these first electric helicopters.

R. Schmidt (19??–19??)

G. Kirchberg (19??–19??)

Electric helicopter launched from a truck and connected via power cables to a ground-based generator (1933–1945)



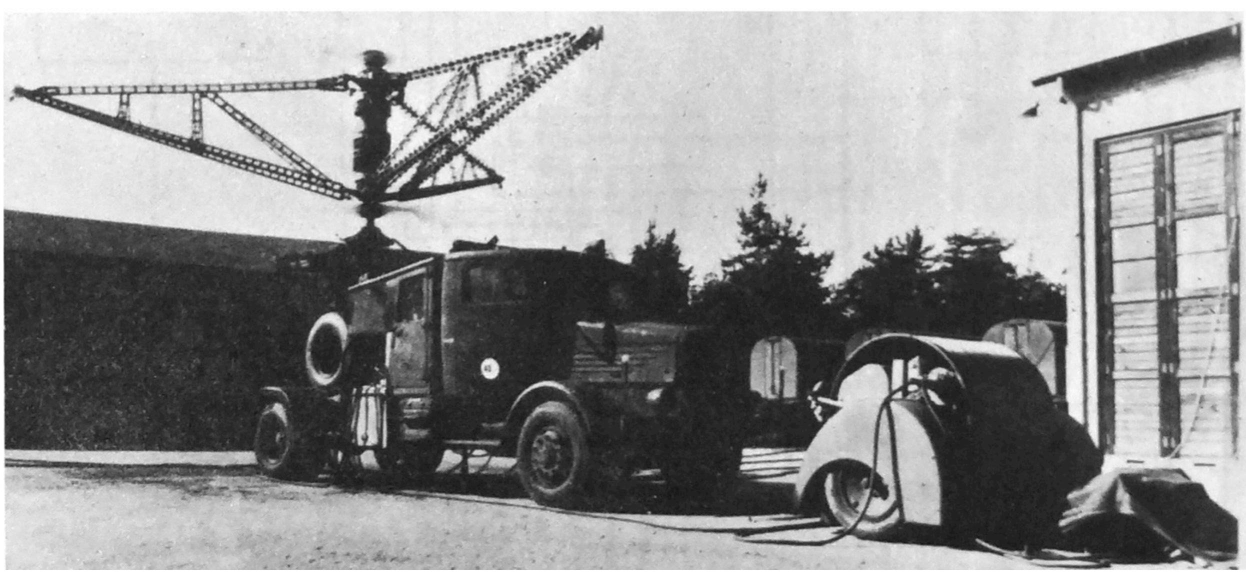


Figure 9.150: R. Schmidt and G. Kirchberg developed an electric helicopter launched from a truck and connected via power cables to a ground-based generator. The helicopter and its attached cables were designed to function as a giant radio antenna, effectively making the whole system a portable radio tower [FIAT 604].

9.5.7 Transfer of Helicopter Technologies to Other Countries

Outside the German-speaking world, the closest competitor in helicopter development was probably Igor Sikorski (1889–1972), a Russian engineer who emigrated to the United States. By May 1940, he had created a prototype helicopter (VS-300) that could hover but became unstable if it tried to move forward, the same problem that had plagued German prototypes of earlier decades. A version that could both hover and move forward, the R-4, was first demonstrated in 1942, six years after the first fully functional Focke and Flettner helicopters, and presumably after the details of the various Focke and Flettner designs would have become available in the West to aid Sikorski's experiments. However, the early R-4 versions still had a number of issues, and in order to resolve those, the R-4 design had to go through a series of further modifications, prototypes, and tests for two more years. The first actually useful versions of R-4 helicopters were finally fielded in the war in small numbers by the United States in 1944 and the United Kingdom in 1945, 4–5 years after Germany's first fully operational helicopters had been mass-produced and deployed.

Not only were the German helicopters produced many years earlier than U.S. helicopters, but they were technically superior, according to U.S. officials. Even compared to U.S.-built helicopters of 1946, the *New York Times* practically gushed about the performance of the 1940 Fa 223 Drache (Dragon) twin-rotor cargo helicopter [NYT 1946-05-13 p. 4]:

> The Germans built ten big helicopters able to climb eighteen feet a second with ten passengers aboard and a full load of fuel before the Allies bombed out the manufacturing plant at Bremen, the Commerce Department disclosed tonight.
>
> The Department made available a report giving specifications of the helicopter which has many unusual features, including a different method for suspending the engine in the craft, which can fly up, down, forward, backward, or sideways.

In the United States after the war, German-speaking helicopter engineers collaborated with German-speaking turbojet engine designers such as Anselm Franz to produce more energy-efficient helicopters powered by turboshaft engines such as the Lycoming T53 and T55 engines (see p. 1752). Such turboshaft-powered helicopters are still the standard helicopter design. By the Korean War, helicopters were routinely used for medical evacuations, and by the Vietnam War, helicopters were the preferred platform for virtually all aerial tasks except bombing.

As already noted, several key engineers from the original Focke, Flettner, and von Doblhoff helicopter teams also developed helicopters in the United Kingdom, France, and other countries after the war. The Soviet Union was late to field fully functional helicopters, but (apparently) with the help of captured German designs and engineers, it began serial production of the small Mi-1 Hare helicopter in 1950, followed by more advanced helicopters in the 1950s and beyond.

9.6 Small Missiles and Smart Bombs

German-speaking engineers developed precision-guided missiles and smart bombs that were the direct forerunners of modern guided weapons.[11] The wartime (Section 9.6.1) and postwar (Section 9.6.2) missile programs were so numerous and so large, and employed so many German-speaking engineers, that only a few examples are mentioned here.

9.6.1 Wartime Missiles and Smart Bombs

While many of the most important and best known advances in missiles and smart bombs occurred just before and during World War II, some remarkable work was actually conducted just before and during World War I [Everett 2015; Trenkle 1987]. As shown in Fig. 9.151, Siemens-Halske engineers developed and successfully demonstrated the first wire-guided glide bombs in 1914. Siemens-Halske also worked with Mannesmann-Mulag to create and demonstrate the even more ambitious Fledermaus radio-controlled explosive airplane in 1916. Those nearly forgotten programs deserve greater recognition and more archival research by military and aerospace historians.

Paul Schmidt (German, 1898–1976, designer of the Argus As 014 pulsejet engine), Fritz Gosslau (German, 1898–1965, missile designer), and Robert Lusser (German, 1899–1969, missile designer) led teams that created the V-1 or Fieseler Fi 103 cruise missile, first flown in 1942, which was powered by a novel pulsejet engine (Figs. 9.101 and 9.152).[12] During the war, versions of the V-1 cruise missile that were piloted and/or air-launched were also produced and demonstrated (Fig. 9.153). After the war, Schmidt, Gosslau, and Lusser worked for the United States to produce missiles and other technologies.

As shown in Fig. 9.154, Herbert Wagner (Austrian, 1900–1982) led a team that created precision-guided weapons such as the Henschel Hs 293 smart bomb, guided by a miniaturized onboard camera and first demonstrated in 1942, and the Henschel Hs 117 Schmetterling (Butterfly) surface-to-air and air-to-air missile, also guided by a miniaturized onboard camera and first demonstrated in 1944. The miniaturized camera and television system are shown on pp. 1017–1019. Wagner was an extremely versatile and prolific inventor. In the 1930s, he created some of the first jet engines, and his designs strongly influenced subsequent jet engine developers (pp. 1746–1750). He also worked on German nuclear weapons programs during the war (p. 4203). After the war, Wagner developed a wide range of guided missiles and smart bombs in the United States.

[11] See for example: Griehl 2003; Miranda and Mercado 1996; Putt 1946a, 1946b; Stüwe 1999; Stüwe 2014; Stüwe 2015; Zaloga and Laurier 2019; NYT 1944-12-05; CIOS XXVII-66; CIOS XXVIII-56; CIOS XXIX-55; CIOS XXXII-125; AFHRA A5729 electronic version p. 255ff.

[12] Hellmold 1999; Hölsken 1994; Irving 1965; Jackson 2014; Jones 1978; King and Kutta 1998; Lommel 2005; Myhra 2001.

Max Kramer (German, 1903–1986) created precision-guided weapons such as the Ruhrstahl SD 1400 X (Fritz X) radio-guided or wire-guided (to avoid radio jamming) smart bomb, first operational in 1943, and the Ruhrstahl X-4 air-to-air guided missile in 1944, as well as the Ruhrstahl X-7 anti-tank missile; see Fig. 9.155. After the war, Kramer worked in the United States to develop additional missiles and aircraft and to reduce drag on submarines. Kramer's wartime missiles also had a profound influence on the development of postwar missiles in other countries; for example, the French SS.10 anti-tank missile was directly based on the Ruhrstahl X-7.

Note that Wagner's and Kramer's smart bombs were developed and deployed nearly a half century before U.S. smart bombs directly based on that technology were first widely publicized in the 1990 Gulf War.

Heinrich Klein (German, 19??–19??) led the Rheinmetall-Borsig team that created the Rheintochter two-stage, radio-guided, surface-to-air missile, which was first demonstrated in 1943 (p. 1924). Klein's team also created the larger Rheinbote four-stage missile, first launched in 1943 (p. 1925) [Klein 1977; Margry 2001; Mills 2020, 2022]. In fact, according to a 1947 French military document, during the war Klein was even personally involved in "the construction of flying rockets... capable of crossing the Atlantic in 40 minutes" (p. 5534).

Ludwig Roth (German, 1909–1967) led the team at Peenemünde that developed the Wasserfall surface-to-air missile, which was essentially a miniature version of the A-4 (V-2) rocket. See Fig. 9.156. The Wasserfall was first demonstrated in 1944, and was designed to be either radio- or radar-guided. After the war, Roth moved to the United States to continue developing missiles and rockets. The Wasserfall was copied and became the Hermes series of U.S. missiles, and its technologies were incorporated into other postwar missiles [Mills 2020, 2022].

Messerschmitt's Oberbayerische Forschungsanstalt in Oberammergau developed the Enzian surface-to-air missile, which was first demonstrated in 1944. See Fig. 9.157. It was designed to use either radio guidance or infrared homing to find its target.

A team led by Klaus Scheufelen (German, 1913–2008) developed the Taifun surface-to-air missile, which was first demonstrated in January 1945 (Fig. 9.158). Scheufelen continued to develop missiles and rockets in the United States after the war.

U.S. Army Air Forces Colonel (later General) Donald Putt, who recruited many of these German-speaking engineers at the end of World War II and supervised their postwar work in the United States, gave an unclassified public overview of their wartime accomplishments in 1946 [Putt 1946b]:

> The Germans were preparing rocket surprises for the whole world in general and England in particular, which would have, it is believed, changed the course of the war if the invasion had been postponed for so short a time as six months. Many of Germany's research laboratories and several large commercial firms concentrated on this field of endeavor. This tremendous effort resulted in 138 guided missiles and assorted devices, including their modifications. [...]
>
> The stupendous effort in basic research expended by the Germans in the guided missile field was designed to cover the complete field of potentialities for such weapons. The losses incurred in Germany by heavy bomber raids can in no way be charged to lack

of preliminary research on missiles. Weapons of this category were divided into the following classifications:

A. Ground to air.

B. Air to air.

C. Air to ground.

D. Ground to ground.

E. Underwater to underwater.

F. Underwater to ground.

G. Underwater to air.

Moreover, every known type of remote control and fusing means was exploited. These included radio control, wire control, radar, continuous wave, acoustics, infrared, light beams, and magnetics.

Likewise, all methods of employing jet propulsion for subsonic and supersonic speeds were exploited.

In all, it was estimated that one-third of the aerodynamics research in Germany was devoted to problems of guided missiles. [...]

Some of the classes of German missiles based on intended use are:

A. The Beethoven [...] was an air-to-ground missile. [...]

B. The Enzian [...] was a ground-to-air missile. [...]

C. The Wasserfall was a ground-to-air missile. [...]

D. The X-4 was an air-to-air missile. [...]

E. The Fitz X [...] was an air-to-ground missile. This German bomb was released from aircraft flying at a minimum altitude of 22,000 ft. It was gyrostabilized and visibly guided into the target by radio. The Fritz X was ready for operational use in January, 1943, and was first employed successfully against our shipping and assault forces at Salerno. The warhead on this bomb was armor-piercing and carried a charge of 2530 lb of standard explosive.

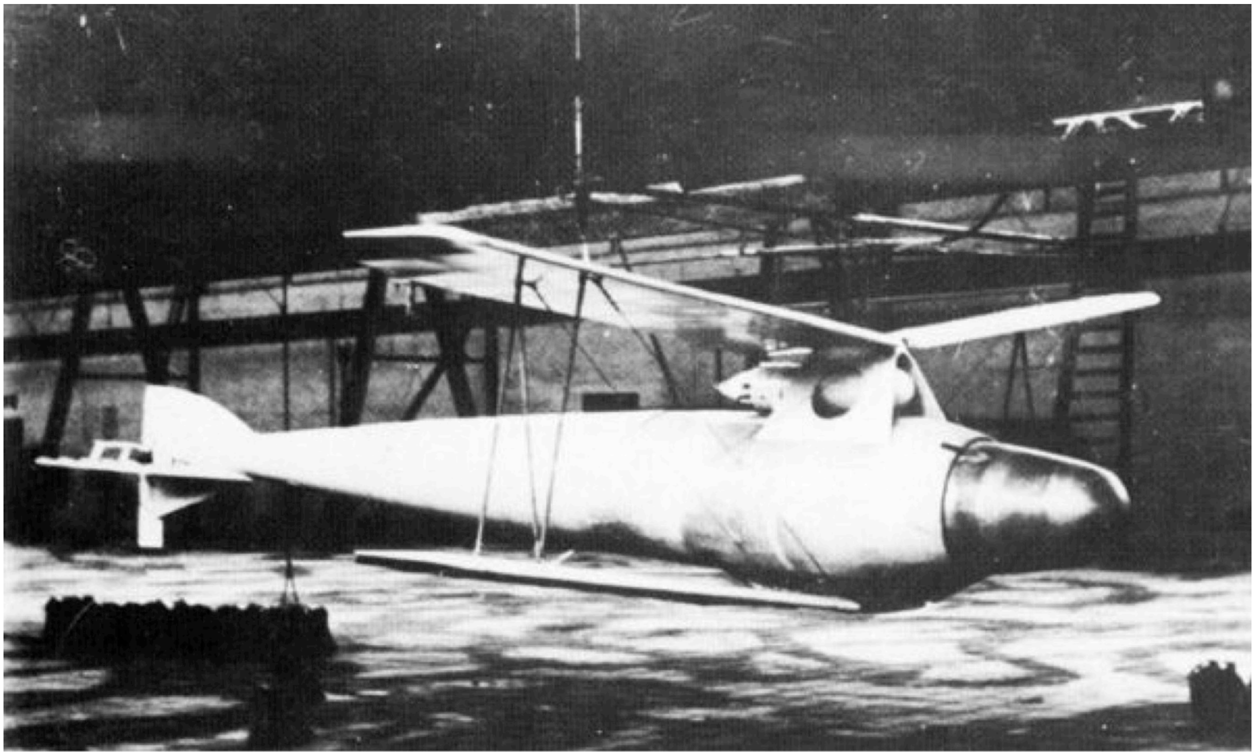
F. The Hs-298 [...] was an air-to-air missile. [...]

G. The Hs-117 [...] was a ground-to-air missile. It was named Schmetterling or butterfly, and was a rocket-propelled, radio-controlled missile to be launched from

> the ground against bomber formations. It accelerated to a speed of 560 mph, and was steadied in flight by a pendulum device. The take-off rocket burned out and were jettisoned; the main propulsion unit then drove the missile until it was detonated by a proximity fuse. Large-scale production began January, 1945, in an underground factory in Nordhausen.
>
> H. The Rheintochter [...] was a ground-to-air missile. It was a rocket-propelled anti-aircraft weapon and was controlled in flight by radio. It traveled at a speed of 1100 mph and carried an explosive charge of 330 lb, equipped with a proximity fuse, to a ceiling of 48,000 ft. The starting rocket, attached to the base, was blown off after combustion was completed. Development did not go beyond the test firing stage, but experiments were still being conducted as late as February, 1945. The code name Rheintochter means daughter of the Rhine.
>
> I. The FZG-76 [...] was a ground-to-ground missile. [...]
>
> In conclusion may I state that the Germans in the guided missile field were 10 years in advance of similar American development.

As just one more example of countless statements from the U.S. military about the effectiveness of German missiles, consider: Says Nazis Had New Rocket, *New York Times* 1946-01-18 p. 6:

> Germany developed a new rocket a month before V-E Day which proved so accurate that it almost ended Allied bombing attacks, Col. Leslie Simon, director of the Aberdeen Ballistics Research Laboratory, said today before 300 scientists and engineers meeting here. He declared that the weapon enabled the Germans to bring down our bombers "almost at will." The new rockets were mounted in groups of twenty-four on fast German interceptor planes.



Siemens-Halske wire-guided glide bomb (1914)

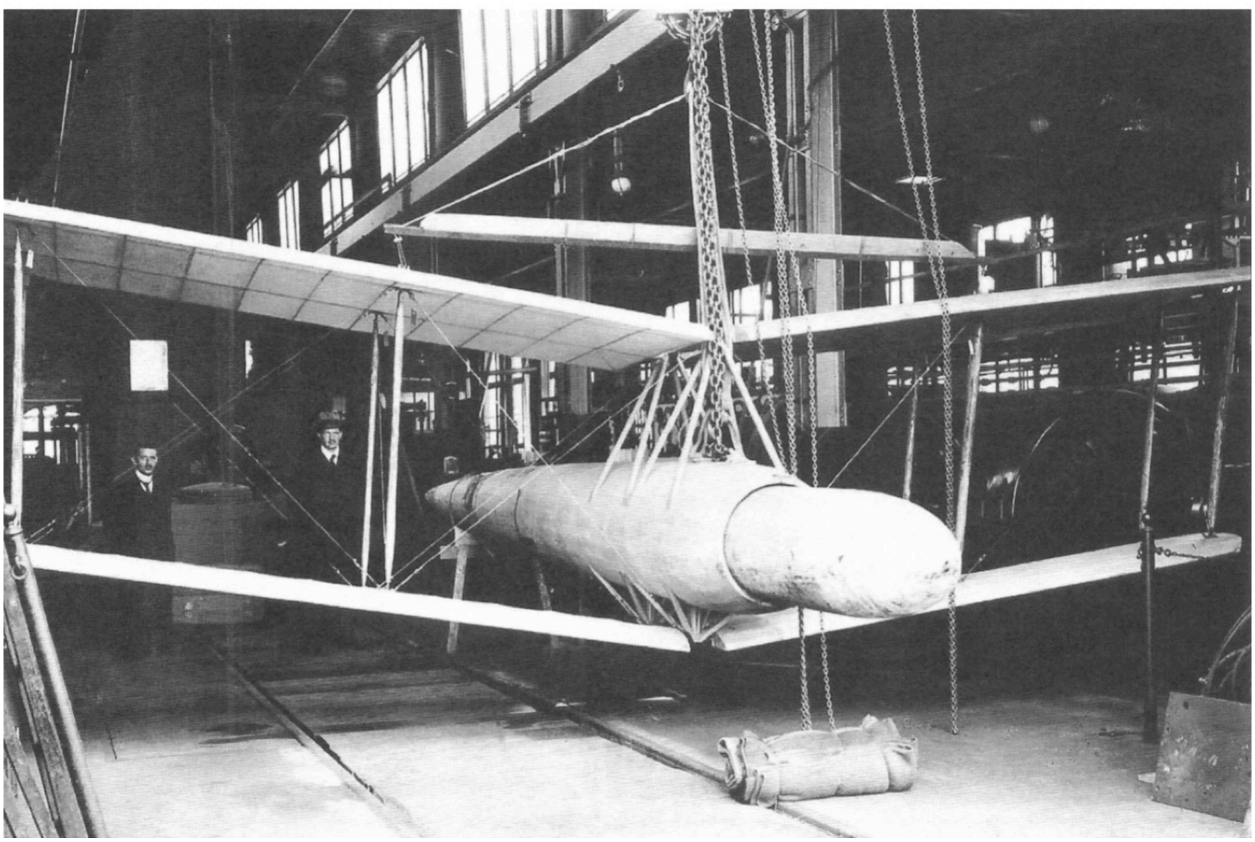


Figure 9.151: Siemens-Halske engineers developed the first wire-guided glide bombs in 1914.

Fritz Gosslau (1898–1965)

Robert Lusser (1899–1969)

Paul Schmidt (1898–1976)

Fieseler Fi 103 (V-1) cruise missile, first flown in 1942

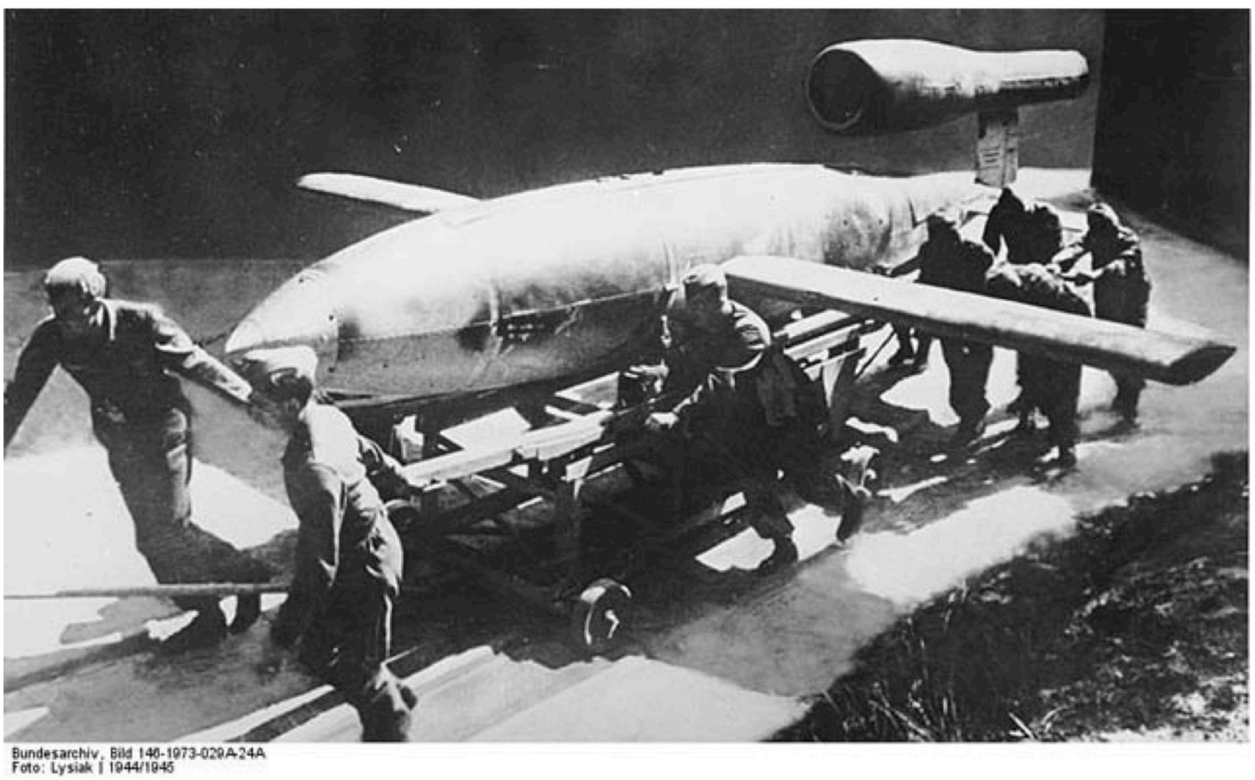
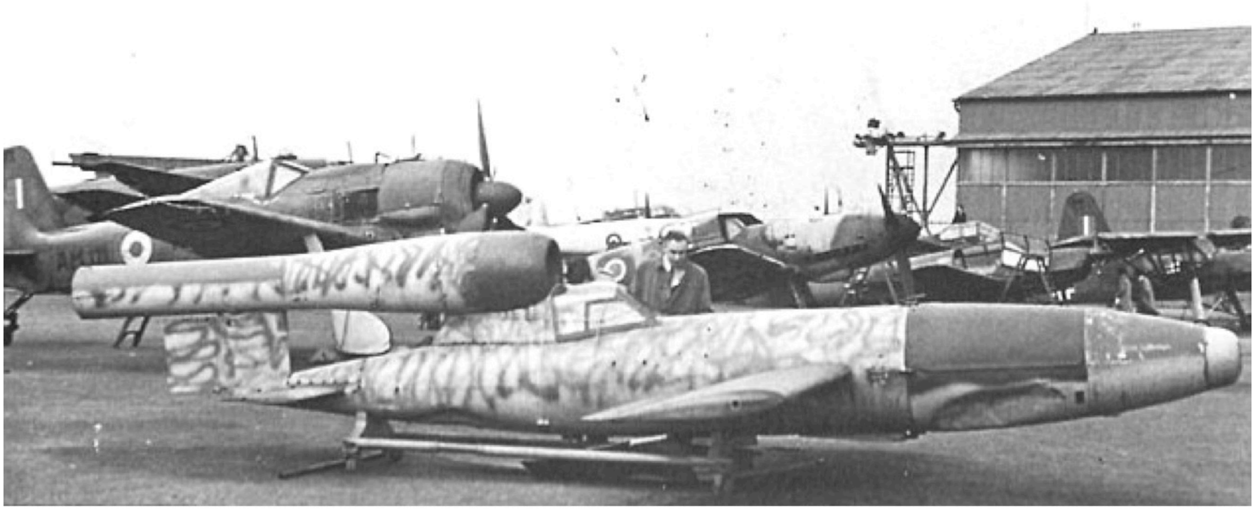


Figure 9.152: Paul Schmidt, Fritz Gosslau, and Robert Lusser created the V-1 or Fieseler Fi 103 cruise missile, first flown in 1942, which was powered by a novel pulsejet engine.

Piloted V-1 (1945)

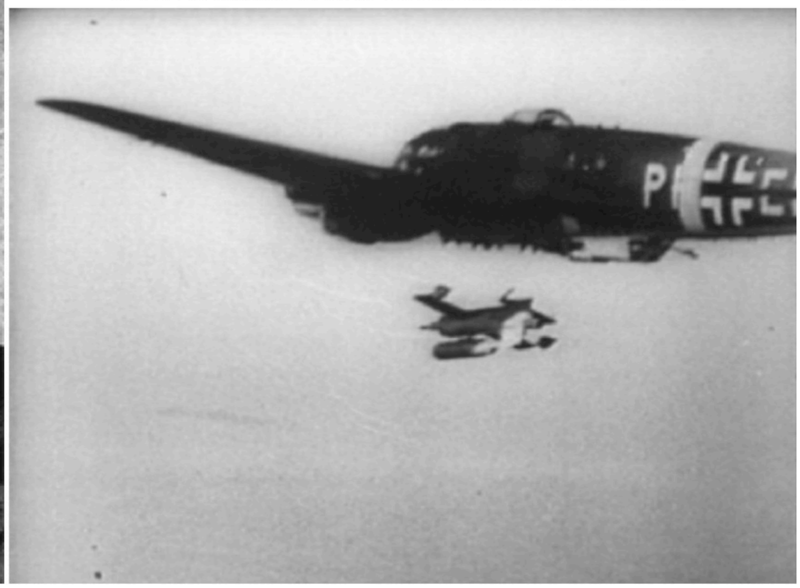


Heinkel He 111 with unpiloted V-1 under the wing as an air-launched cruise missile

Figure 9.153: During the war, versions of the V-1 cruise missile that were piloted and/or air-launched were also produced and demonstrated.

Herbert Wagner (1900–1982)

Henschel Hs 293 smart bomb, first demonstrated in 1942. Some versions could be guided using a miniaturized onboard camera.



Henschel Hs 117 Schmetterling (Butterfly) surface-to-air and air-to-air missile, first demonstrated in 1944. Some versions could also be guided by a miniaturized onboard camera.

Figure 9.154: Herbert Wagner created precision guided weapons such as the Henschel Hs 293 smart bomb, first demonstrated in 1942, and the Henschel Hs 117 Schmetterling (Butterfly) surface-to-air and air-to-air missile, first demonstrated in 1944. Some versions of these weapons were guided by a miniaturized onboard camera (pp. 1017–1019).

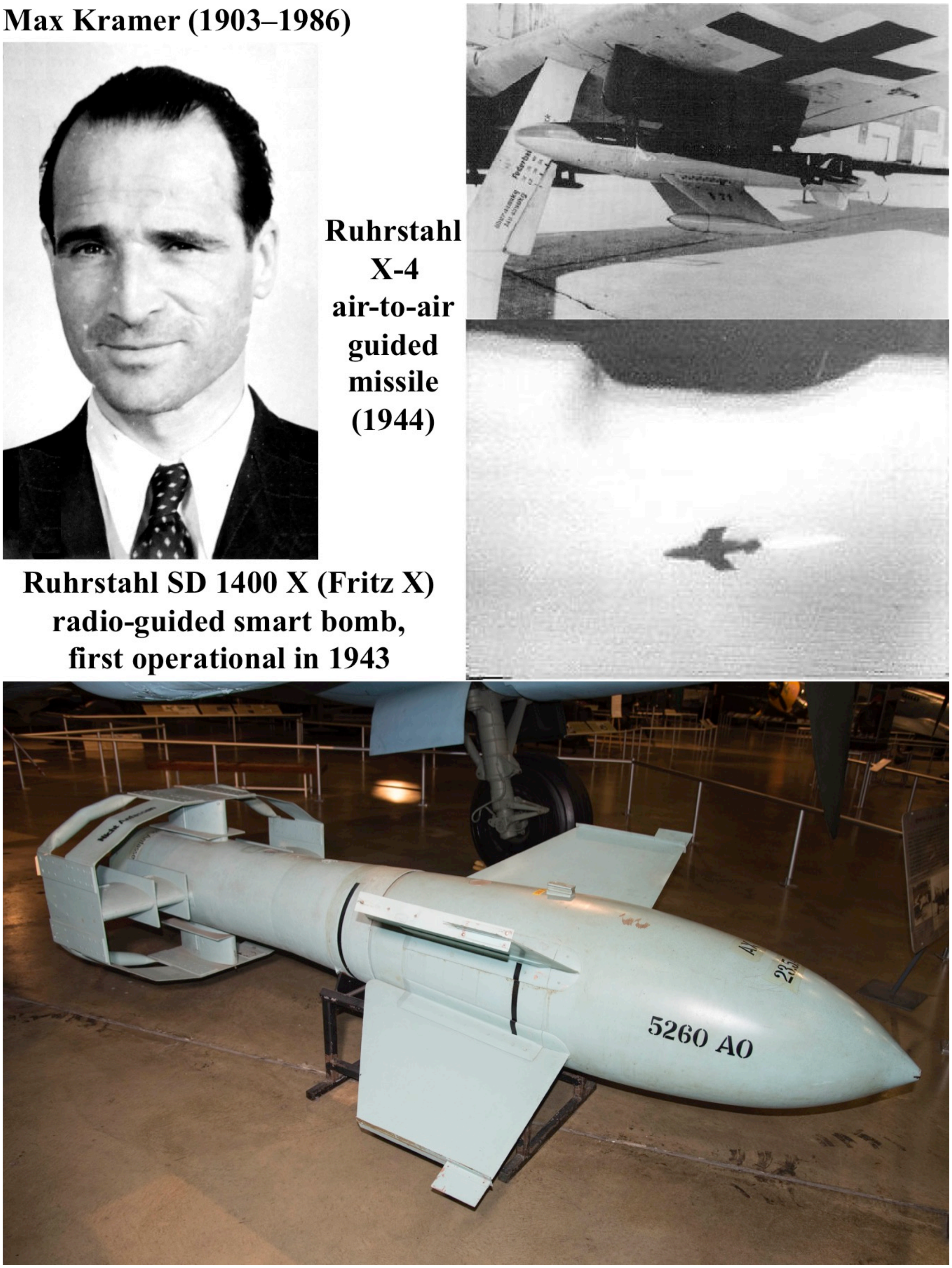


Figure 9.155: Max Kramer created precision guided weapons such as the Ruhrstahl SD 1400 X (Fritz X) radio-guided smart bomb, first operational in 1943, and the Ruhrstahl X-4 air-to-air guided missile in 1944.

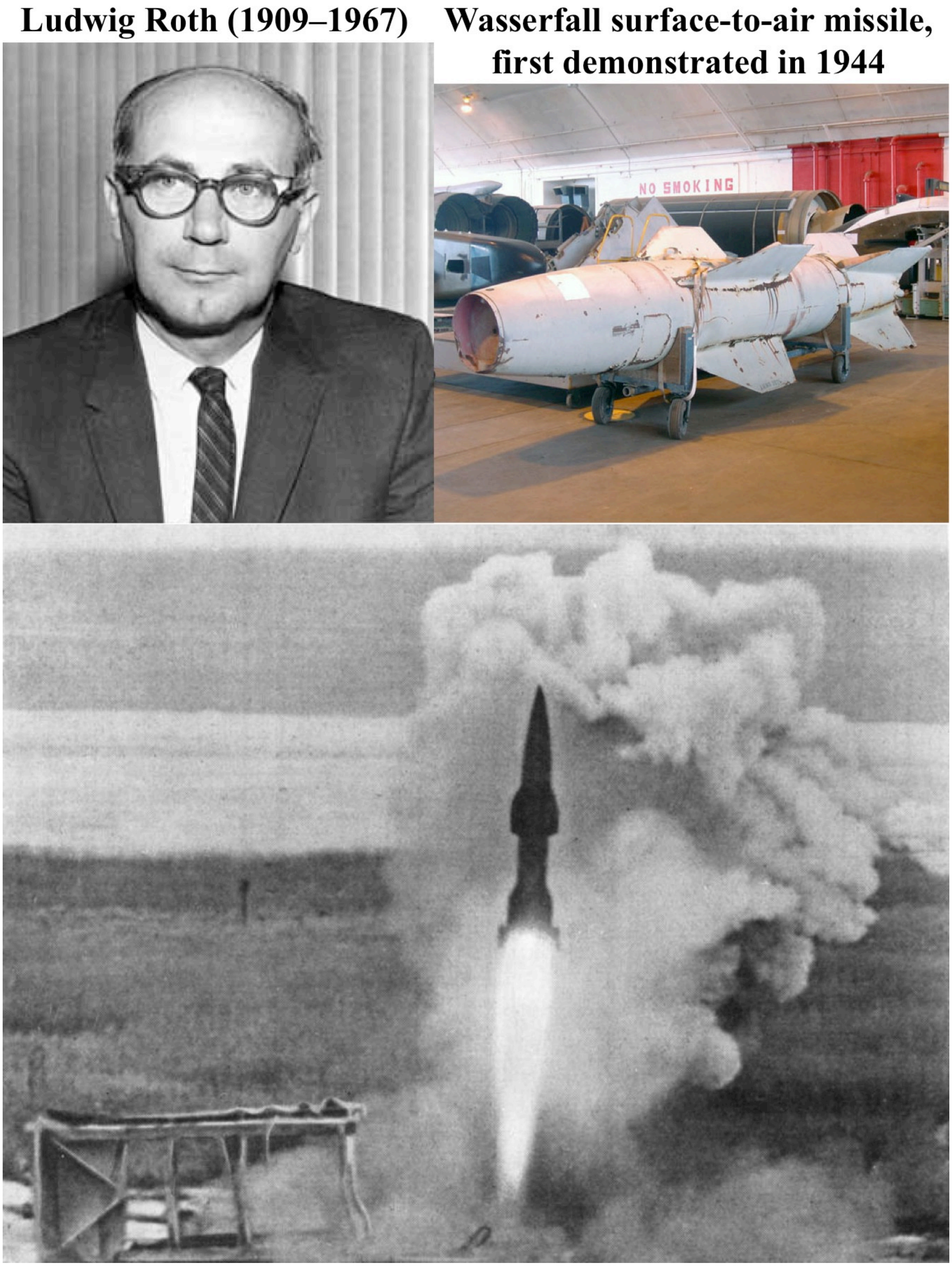


Figure 9.156: A team led by Ludwig Roth developed the Wasserfall surface-to-air missile, which was first demonstrated in 1944.

Enzian surface-to-air missile,
first demonstrated in 1944

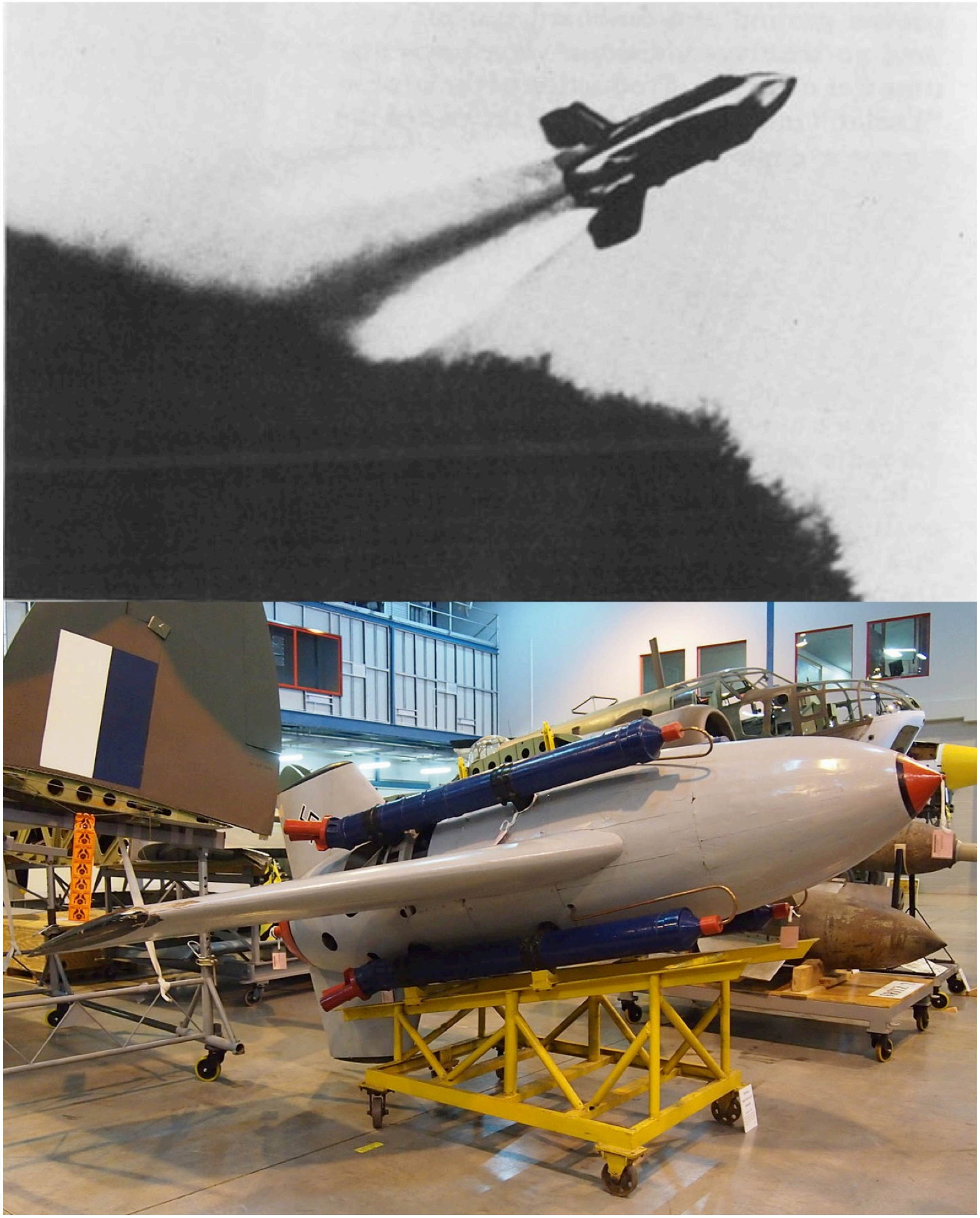
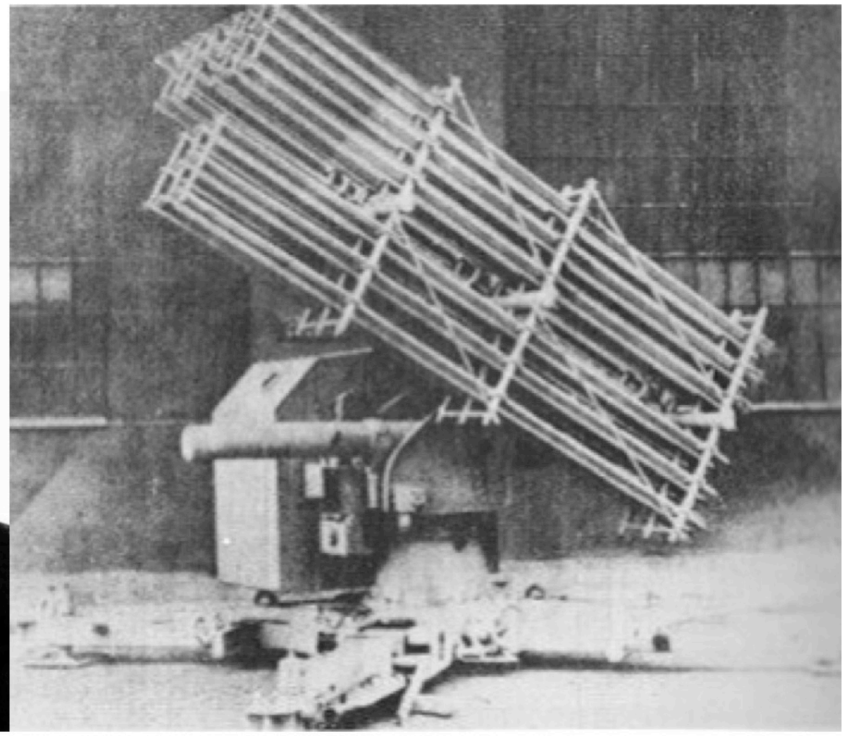


Figure 9.157: Enzian surface-to-air missile, first demonstrated in 1944.

Klaus Scheufelen (1913–2008)

Taifun surface-to-air missile, first demonstrated in January 1945



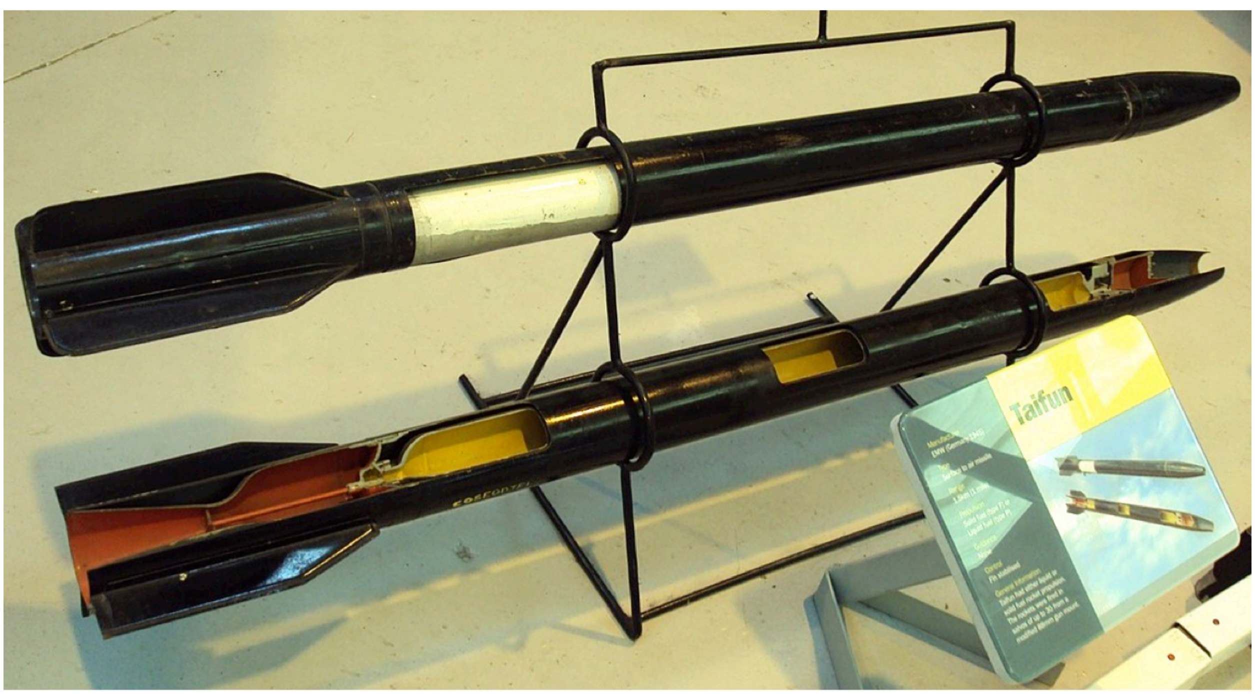


Figure 9.158: A team led by Klaus Scheufelen developed the Taifun surface-to-air missile, which was first demonstrated in January 1945.

NARA Still Pictures, RG 111 SCA---Records of the Chief Signal Officer. Prints: U.S. Army Signal Corps Photographs of Military Activity During WW II and the Korean Conflict, 1941-1954. Captured German Equipment, German, Box 3347, Book 8, SC 231474.

Figure 9.159: "Sections of new German F.X.3 experimental, self-propelled radio rockets, awaiting assembly, are stacked in a small factory in Hövelhof, Germany. The factory where these rockets were being manufactured was discovered by Antiaircraft Artillery Brigade, XVIth Corps, U.S. Ninth Army. 5/12/45" [NARA Still Pictures, RG 111 SCA—Records of the Chief Signal Officer. Prints: U.S. Army Signal Corps Photographs of Military Activity During WW II and the Korean Conflict, 1941–1954. Captured German Equipment, German, Box 3347, Book 8, SC 231474.]

9.6.2 Postwar Missiles and Smart Bombs

The wartime missiles shown in this section are among the better-known German technological accomplishments. What is less well known is that those wartime missiles were not an engineering dead end. The scientists, engineers, prototypes, designs, methods, and experience from those programs were all used to create a wide variety of missiles that have been used around the world ever since [Mills 2020, 2022].

Figures 9.160–9.162 show just one example—some of the German-speaking scientists who developed U.S. missiles at the Naval Air Missile Test Center, Point Mugu, California. They included:

Alexis Dember (German, 1912–2002)

Willy Fiedler (German, 1908–1998)

Ernst Friedrich (German, 19??–19??)

Wilfried Hell (German, 1914–2010)

Werner Hohenner (German, 1907–2000)

Hans Hollmann (German, 1899–1960)

Edgar Kutzscher (German, 1906–19??)

Reinhard Lahde (German, 1908–1999)

Johann Ludloff (German, 19??–19??)

Robert Lusser (German, 1899–1969)

Otto Schwede (German, 1912–2005)

Theodore Sturm (German, 19??–19??)

Herbert Wagner (Austrian, 1900–1982)

Etc.

These and other German-speaking scientists were responsible for the postwar development of cruise missiles in the United States and other countries. As a starting point, the V-1 was directly copied and deployed by the United States, renamed as the Loon missile [p. 1908; Quigg 2014]. Using captured German prototypes, factories, and engineers, the Soviet Union also copied and deployed the V-1, designating it as the 10Kh missile. The German-speaking scientists then created a long line of more advanced cruise missiles, ranging from late 1940s–1950s examples (e.g., U.S. SM-62 Snark, SM-64 Navaho, MGM-1 Matador, SSM-N-6 Rigel, and SSM-N-8 Regulus; Soviet P-5 Pyatyorka) to modern cruise missiles (e.g., U.S. BGM-109 Tomahawk and AGM-86 Air-Launched Cruise Missile (ALCM); Russian Kh-55 and Kh-101).

As another example of direct technology transfer from the German-speaking world, the Bell GAM-63 RASCAL (RAdar SCAnning Link) air-launched cruise missile was designed by Walter Dornberger (German, 1895–1980, Fig. 9.223) in 1946 and first launched in 1953; see Fig. 9.164. Essentially it was a German-derived liquid propellant rocket that was intermediate in size between the Wasserfall (p. 1856) and A-4/V-2 (p. 1872) and was deployed like the air-launched V-1 (p. 1853). There was also a British version of the RASCAL, the Avro Blue Steel (Fig. 9.165), which was deployed in 1963. (Dornberger had worked for the British immediately after the war, before going to the United States.)

The German-speaking scientists also developed a wide range of other postwar missile types, including for example:

- AGM-12 Bullpup air-to-ground missile
- SSM-A-23 Dart anti-tank missile
- AIM-4 Falcon air-to-air missile (p. 1164)
- AGM-84/RGM-84/UGM-84 Harpoon anti-ship missile
- MIM-23 Hawk surface-to-air missile
- AAM-N-4 Oriole air-to-air missile
- MGM-51 Shillelagh anti-tank missile
- AIM-9 Sidewinder air-to-air missile (p. 1164)
- AIM-7 Sparrow air-to-air missile

Furthermore, German-speaking scientists and engineers created a wide variety of missile guidance, tracking, and homing systems during the war, and continued to develop those technologies in other countries after the war. For infrared and heat-seeking targeting systems for missiles, see pp. 1140–1164. For radio and acoustic proximity fuses and homing devices, see pp. 1263–1267, 5481.

For German-speaking contributions to larger rockets, see Sections 9.7–9.8 and Appendix E.

Naval Air Missile Test Center, Point Mugu, California (ca. 1950)

Wilfried Hell (1914–2010) Herbert Wagner (1900–1982) Werner Hohenner (1907–2000) Edgar Kutzscher (1906–19??)

Reinhard Lahde (1908–1999) Ernst Friedrich (19??–19??) Hans Hollmann (1899–1960) Theodore Sturm (19??–19??)

Not shown: Alexis Dember (1912–2002),
Willy Fiedler (1908–1998), Johann Ludloff (19??–19??),
Robert Lusser (1899–1969), Otto Schwede (1912–2005), etc.

Figure 9.160: Examples of German-speaking scientists who developed U.S. missiles at the Naval Air Missile Test Center, Point Mugu, California.

Figure 9.161: Alexis Dember inspecting the remains of a missile test at the Naval Ordnance Test Station at China Lake, California in 1953.

Los Angeles Times (1947)

Nazi Weapon Experts Now Aiding Navy

Seven of Germany's Scientists Working at Point Mugu Center

Seven German scientists—experts on Nazi secret weapons in World War II—today are working at the Navy's Guided Missile Test Center, Point Mugu, under voluntary government contracts, The Times learned yesterday.

They are Dr. Herbert Alois Wagner, Dr. Reinhard Natanael Lahde, Dr. Wilfred Hermann Hell, Dr. Theodore Friedrich Sturm, Dr. Ernest O. Freiderich, Dr. Edgar R. Kutsscher and Dr. Hane Erich Holman.

While they are not permitted to work on new Navy developments in the mysterious field of "push-button" warfare, their research parallels that of American scientists at the test center in that they are completing wartime projects begun for Hitler.

Their Work for Nazis

Exact nature of their studies was not disclosed, but it was learned Dr. Wagner directed Germany's program for development of air-to-ground and ground-to-air missiles, with Dr. Lahde and Dr. Hell as associates, while Dr. Sturm was in charge of remote control and guidance for rockets, bombs and other missiles.

Dr. Hell is said to be an authority on remote-control mechanisms while Dr. Lahde specializes in gas turbine and bombsight equipment.

All reportedly have applied for U.S. citizenship, and three of the scientists—Dr. Wagner, Dr. Lahde and Dr. Hell—have their families with them in nearby Oxnard.

Bid for Their Families

The others have asked that their families be brought to the United States, including some relatives who were in Russian-occupied territory at the war's end—when the scientists themselves were being questioned by U.S. intelligence officers.

The Point Mugu center is regarded as one of the Navy's top projects, and the House Armed Services Committee recently approved a $34,520,000 allocation for construction work at the base.

Primary purpose of the installation is to test and evaluate the many secret remote-controlled "birds" now being developed by the Navy to keep America abreast of similar weapons-of-the-future also sought by other nations.

SECTION A, PAGE TEN — OXNARD PRESS-COURIER—PHONE HU 3-1101 — TUESDAY, OCTOBER 4, 1955

Former German Scientists Aid Defense Effort at Mugu

Top Missile Guidance Man under Hitler Escaped Nazi Troops to Join Americans

Theodore F. Sturm ... guidance his specialty.

A former German scientist, who during World War II was coordinator and director of all electronic work on guided missiles in his homeland excepting the V-2 rocket, is now head of one of the important divisions at the Naval Air Missile Test Center.

Sitting at his desk in one of the sparsely-furnished offices in an unprepossessing temporary wooden barracks near the missile launching area, Theodore F. Sturm, head of the Component Tests Guidance Division, spoke quietly and deliberately about his life in Germany.

Saw Germany Fall Twice

The speaker was a man who as a student remembered vividly Germany's defeat in World War I, who had gone through the economic tragedies of the 20's and early 30's, who had seen the arrogant Hitler and enslaving Naziism rise to power, who had been appointed to one of the most sensitive scientific posts during World War II, and who, in 1945, "escaped" from a fanatic group of German soldiers to a little town occupied by American troops.

The broad-shouldered, middle-aged bachelor, who lives with his widowed sister in Port Hueneme, smoked one filter cigaret after another with deliberation as he related his life and replied to questions.

A native of little Kaiserslautern, 60 miles west of Heidelberg, Sturm attended grammar and high schools in his home town before going to Maximillian University in Munich from which he received a degree in science.

After graduation, he went to Berlin as a member of the scientific staff at Heinrich Hertz Institute Technical University. From 1937 to 1945 he worked for various electric companies as project engineer in guided missile research and development.

Developed Glide Bombs

In that period of 1937-45, he that period of 1937-45, he developed the first guided missiles which really worked in being able to pinpoint and bomb a small target. These missiles were called the FX and Henschel 293 glide bombs. They became, unfortunately, too familiar to Allied fleets operating in the Atlantic. Not as spectacular as the V-1 and V-2 rocket bombs, the glide bombs nevertheless had three major successes in World War II, according to Sturm.

1. Henschel 293 missiles sank two British destroyers in the Bay of Biscay in 1943. The destroyers had German submarines bottled up. After the sinkings, the destroyers moved out and German subs began operating again.

2. The bombs delayed success of the Allies at the Anzio beach-head.

3. The bombs deterred the British plan of recapturing islands off of Greece and Greece itself until the war's end.

Also, it was an FX which sank the Italian battleship Roma in 1943. The Roma was part of the Italian fleet which was on its way to surrender to Allied forces.

Of course, Sturm said, if the Allies had wanted to badly enough, they could have prevented submarines from operating again and could have taken Greece. However, it would have taken considerable more time plus expenditure of equipment and men than contemplated.

Working on a radio-controlled beam, the missiles were guided to their targets by a pilot flying an airplane approximately eight miles away from the target. Later effective counter-measures by the Allies included sending up radio frequency barriers which gave false commands to the bomb, and a tremendous amount of ack-ack which made it practically impossible for the German pilot to keep the missile in sight.

Sturm said glide bombs were not used more because their tactical use was geared to air supremacy. When development of the bombs began, the Germans did have this supremacy. However, by late 1943, it was almost impossible to get a German plane aloft.

Reached Americans

Sturm was working at hidden laboratories in the Harz mountains when American troops occupied the nearby town of Stassfurt. A german general and several hundred men had come to the mountains to fight a last ditch, suicidal battle.

"It was ridiculous," Sturm said. "Nothing was to be gained but more loss of life. But the general's adjutant thought I should be one of the men to rally around the crumbling bulwark. The only thing that saved me was a paper I had from high authorities in the party which gave me free access to any part of Germany. I commandeered a car, drove into Stassfurt, and waited for American officers to come."

Brought to America

Sturm was picked up and interrogated by Signal Corps Officers attached to Ninth Army Headquarters in Brunswick. Further interrogation was held in Paris. He was then given a contract to work for the American government and was sent to Boston as one of 16 German scientists, including Dr. Wernher Von Braun who was head of V-2 rocket development.

After two years, he was given a government job at Point Mugu. He arrived at this base shortly after it was opened in 1946. Here, as in Germany, he is concerned with developing guidance systems for use in missiles.

On Dec. 10, 1954, he became an American citizen.

He described Hitler as a supreme egotist, a little mad, and a man with absolutely no sense of humor. He said Hitler managed to achieve power in 1933 because the German people were ready to accept anyone who promised a way out of their economic miseries.

'Operation Paper Clip'

Shortly after World War II, the United States began a race with Russia to recruit top German scientists—men who had contributed much in both the technical and productive ends of the German war effort.

America termed its program "Operation Paper Clip." It succeeded in bringing many of the experts from Germany to our country, several of whom were put under contract by the Navy and assigned to Point Mugu. The stories on this page reveal the backgrounds and personalities of four "Operation Paper Clip" scientists who still work at the Naval Air Misile Test Center.

Willy Fiedler ... piloted buzz bomb.

Buzz Bomb Test Supervisor Flew in Desperation Missile

It was a cold, bleak day in November of 1944 when 36-year-old Willy Fiedler, now a Point Mugu scientist, stepped confidently into a tiny cockpit mounted atop a cigar-shaped missile. Fiedler was going to test a suicide-designed modification of the V-1 buzz bomb — a weapon for which 15,000 fanatical German youths had volunteered to fly to their deaths if the test was successful.

Fiedler's development of the suicide bomb was a desperation measure, but most Germans realized in November of 1944 that only desperation measures might clutch victory for the Nazis from apparent defeat.

The scientist and pilot, who during most of the war had been in charge of testing the V-1 at Peenemunde, strapped himself in the cockpit of the "Reichenberg" bomb attached to the belly of the mother bomber. The plane and its weird-looking "leech" with stubby wings and pulse jet engine that resembled

(Continued on page A-12)

New Ideas in Radar Come from Man Who Headed Lab Developing German Methods

Dr. Otto G. Schwede, technical director of the Range Instrumentation Department at Point Mugu, headed the laboratories of the company which developed German radar and produced pratically all long-range radar and sonar equipment in Germany during the war.

As an American scientist, he is still developing new ideas in radar and other instrumentation. Only now his theoretical and practical genius channels itself into the scientific flow of American research.

At Technical University in Munich, Dr. Schwede took one of the toughest academic courses possible. Besides his natural interests in the fields of science and mathematics, he studied French, English, Latin, Spanish and German. In 1936 he graduated summa cum laude with a degree comparable to our Master of Applied Physics, and then in 1938, he took his doctorate degree summa cum laude in natural sciences.

Microwave Research

Research for his doctorate in microwave was done while working at the Institute of Wireless Telegraph and Telephony in Munich. He continued at this institute as a research scientist until 1940 when he took a position with the GEMA company in Berlin.

The GEMA company was given the responsibility for development and production of ground-based early warning radars, ship radars, and airborne radars. The company also worked on sonar and infra-red equipment. Dr. Schwede was in charge of the development laboratories.

Although some research in radar had been done as early as 1935, it wasn't until the war that mass-scale development and production began. Dr. Schwede emphasizes that Germany wasn't the only pioneer in radar, but that he and his staff had to work as if they were the only scientists developing ideas and methods.

Studied Captured Equipment

Naturally, interchange of information among countries was at a minimum although studies of captured enemy equipment became common as the war progressed.

Otto G. Schwede ... microwave expert.

In 1943 the GEMA company moved its labs out of Berlin into Silesia to escape Allied bombings. When the Russians began moving on Silesia in 1945, the labs were moved again, this time to Tyrol. The company's personnel and equipment were evacuated with the Russians less than 10 miles away.

After Germany's surrender, Dr. Schwede and his wife went back to Munich where they had a home prior to the war. They found the house almost completely gutted by bombs. Dr. Schwede went to work. He chopped down trees from a nearby forest for lumber. Authorities allowed him to take bricks from demolished houses. He begged and borrowed mortar, pipe, and everything else necessary to rebuild his home. It was livable again before winter.

Repaired Army Radios

Meanwhile, Dr Schwede worked as a radio repairman for the United States Army Signal Corps in Munich. In 1946-47, he was a radio instructor in a displaced person's camp near Munich. In August, 1947, the United States government offered him a job. He accepted the position and before the year was over he was permanently settled at Point Mugu.

Author of several scientific papers dealing with highly classified material, Dr. Schwede also has been active in the patent field. In Germany, both before and during the war, he had 40 patents approved, or pending, fates of which are unknown. Since coming to Mugu, one patent application on a new electronic tube has been approved and several other applications are in the mill.

Dr. Schwede, with his wife and two children, lives in Ventura. He became an American citizen Nov. 11 of last year.

Oxnard Press-Courier (1955)

Figure 9.162: Examples of German-speaking scientists who developed U.S. missiles at the Naval Air Missile Test Center, Point Mugu, California.

Figure 9.163: German hardware and knowledge and German-speaking scientists led to the development of the U.S. Air Force Matador cruise missile (first flight 1949), U.S. Navy Regulus cruise missile (first flight 1951), and other postwar cruise missiles.

Figure 9.164: The Bell GAM-63 RASCAL air-launched cruise missile was designed by Walter Dornberger in 1946 and first launched in 1953. Essentially it was a German-derived liquid propellant rocket that was intermediate in size between the Wasserfall (p. 1856) and A-4/V-2 (p. 1872) and was deployed like the air-launched V-1 (p. 1853).

Figure 9.165: The Avro Blue Steel air-launched cruise missile carried by Vulcan and Victor bombers (deployed in 1963) was essentially the British version of Walter Dornberger's Bell GAM-63 RASCAL (p. 1866).

9.7 Large Liquid Propellant Rockets

Perhaps the best-known contributions (though dimming with time as the memories become more distant) of German-speaking scientists were the development of large rockets and spacecraft. German-speaking creators led the development of all types of rocket-related technologies in Germany during World War II and in countries around the world after the war.

Probably the most publicly visible rocket-related technology is liquid propellant rockets, which carry a liquid fuel and liquid oxidizer and burn them together to produce thrust, as shown in Fig. 9.166 [Hill and Peterson 1991; Huzel and Huang 1992; George Sutton 1992]. As illustrated in the upper part of the figure, the fuel and oxidizer are burned in a special combustion chamber, generating a gas that initially has a very high temperature (thermal energy) and high pressure (potential energy) but little velocity (kinetic energy). That gas then expands as it flows out through a nozzle, converting much of the initial thermal and potential energy into kinetic energy of a high-velocity exhaust stream. As shown in the lower part of the figure, it is necessary to pressurize the oxidizer and fuel from the storage tanks before they can be injected into the combustion chamber, since the gas pressure inside the combustion chamber is so high. Smaller, simpler liquid propellant rockets use high-pressure gas to pressurize the propellant in the tanks, but larger liquid propellant rockets usually use a turbopump to raise the pressure of the fuel and oxidizer just before they are injected into the combustion chamber. Small amounts of fuel and oxidizer are diverted to power the turbopump, or sometimes the turbopump is powered by an entirely separate supply of propellant. In order to cool the engine and to preheat the fuel, usually fuel first detours through coils wrapping the combustion chamber and nozzle.

This section covers the development of liquid propellant rockets by German-speaking creators who worked in:

9.7.1. Pre-war and wartime German rocket programs

9.7.2. Postwar U.S. and U.K. rocket programs

9.7.3. Postwar Soviet rocket programs

9.7.4. Postwar French rocket programs

German-speaking scientists also made important contributions to postwar rocket programs in many other countries around the world, but those are not covered here.

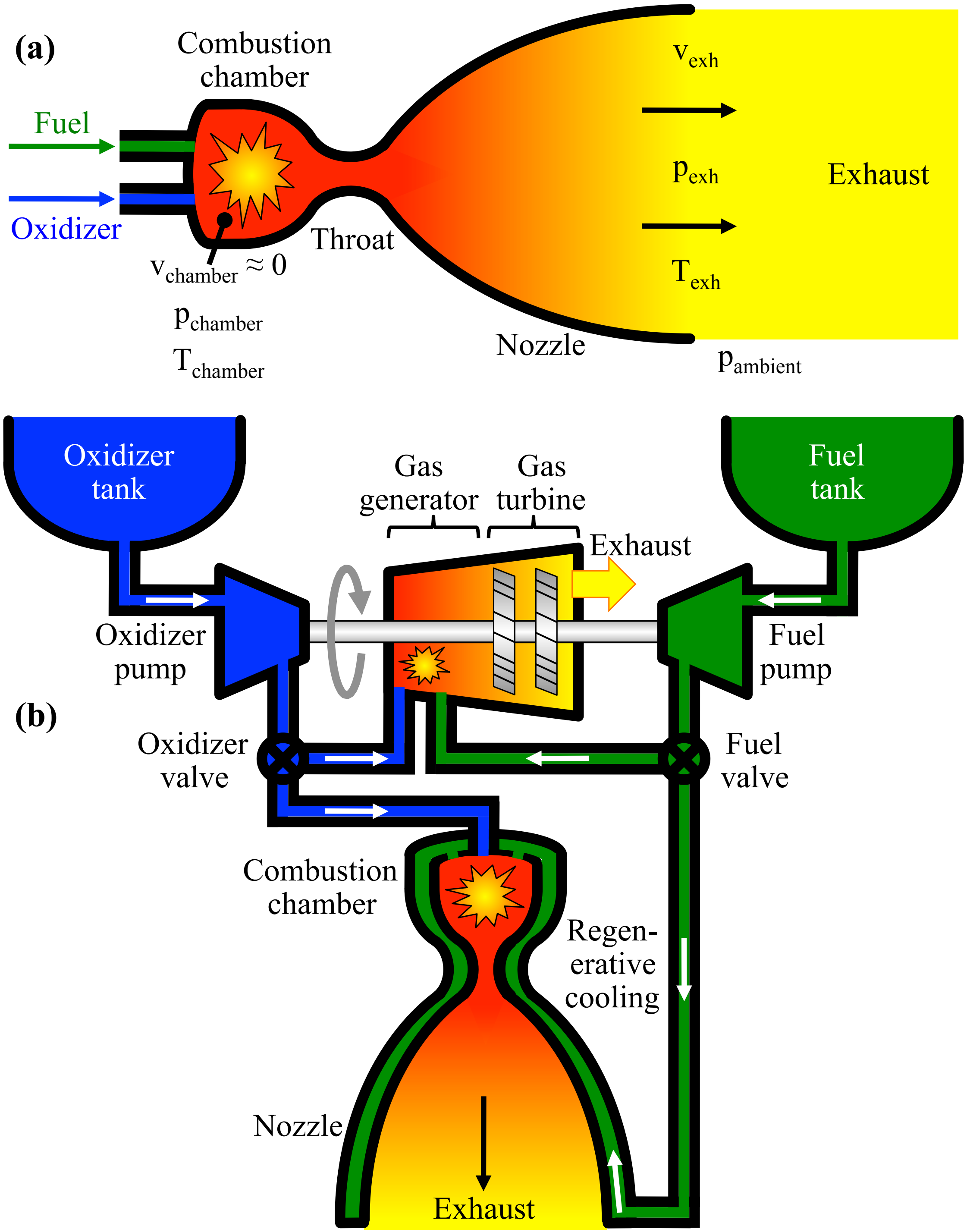


Figure 9.166: Liquid propellant rocket design. (a) Burning of fuel and oxidizer in the combustion chamber generates hot gas with velocity $v_{\text{chamber}} \approx 0$, pressure p_{chamber}, and temperature T_{chamber}, which expands in the nozzle until it has exhaust values v_{exh}, p_{exh}, and T_{exh}. (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.

9.7.1 Pre-War and Wartime German Rocket Programs

Hermann Oberth (Austro-Hungarian, 1894–1989), shown in Fig. 9.167, began experimenting with rockets in 1908 when he was only 14. By the early 1920s, he was publishing detailed and highly influential designs and analyses of rockets [Oberth 1929, 1984].

Oberth was the scientific consultant for Fritz Lang's 1929 film, *Frau im Mond* (*Woman in the Moon*, p. 1983),[13] which depicted how astronauts could use a rocket to travel to the moon, and which profoundly influenced a whole generation of young German rocket engineers such as Werner von Braun (German, 1912–1977). Among other prophetic details, the film showed the construction of the rocket in a large vehicle assembly building, the transport of the rocket to a launch pad, a countdown to the launch, horizontal couches for the astronauts during launch, the use and ejection of multiple rocket stages during the ascent, the effects of zero gravity in space, etc.

Oberth advised and assisted the younger rocket engineers during the 1930s and 1940s, and continued to promote spaceflight in Europe and the United States after the war.

In the early development of liquid propellant rockets, the closest competitor outside the German-speaking world was probably Robert Goddard (American, 1882–1945) [Lehman 1988]. Despite Goddard's promising ideas and experiments, he never was able to obtain much U.S. political and financial support for his research, in stark contrast to the enormous support that the German-speaking engineers received. By the time of Goddard's death in 1945, German rockets were many years ahead of anything that Goddard had been able to accomplish with his limited support.

From 1933 to 1945, Wernher von Braun (German, 1912–1977) led a team that developed a series of increasingly sophisticated liquid propellant rockets, initially at Kummersdorf, then at Peenemünde. Von Braun was closely backed by the strong political support of Walter Dornberger (German, 1895–1980, Fig. 9.223), a general in the German army. By far their most famous creation was the A-4 or V-2 rocket, which was first launched in 1942 and was capable of reaching altitudes over 200 km (beyond the earth's atmosphere and well into outer space). See Fig. 9.168.[14]

Although German-designed rockets certainly went all the way to the moon after the war, there is considerable evidence that even wartime German rockets may have advanced significantly beyond the single-stage A-4 or V-2 rocket. As presented in Appendix E, there is documentation reporting wartime research, development, and even testing of larger rockets with longer ranges and larger payloads, two-stage intercontinental ballistic missiles, submarine-launched missiles, advanced solid propellant rockets, prototype manned space planes (A-9 and Silbervogel), and advanced rocket engines (hydrogen/oxygen, ion, and fission thermal). Appendix E gives an overview of currently known evidence for these wartime advanced rocket developments, but this is clearly another area where much more archival research is needed to clarify exactly what work was done and by whom, and precisely how it guided postwar missile, rocket, and space programs in the United States, the Soviet Union, and other countries.

[13] Bogdanovich 1967; Eisenschitz and Bertetto 1994; Eisner 1977; Jenkins 1981; McGilligan 1997.

[14] The history of the Peenemünde A-4 rocket program has already been so well documented that it will not be covered in any detail here. For much more information, see for example: Bode and Kaiser 2013; Dornberger 1958, 1994; Erichsen and Hoppe 2011; Gildenhaar and Gildenhaar 2013a; Hölsken 1994; Irving 1965; Jones 1978; King and Kutta 1998; Klee and Merk 1963; Knight 1946; Ley 1968; McGovern 1964; Jürgen Michels 1997; Miranda and Mercado 1996; Neufeld 1995; Ordway and Sharpe 1979; Putt 1946a, 1946b; CIOS XXXII-125; digipeer.de; v2rocket.com.

Hermann Oberth (1894–1989)

Figure 9.167: Hermann Oberth began experimenting with rockets in 1908 and published detailed and highly influential designs and analyses of rockets in the 1920s.

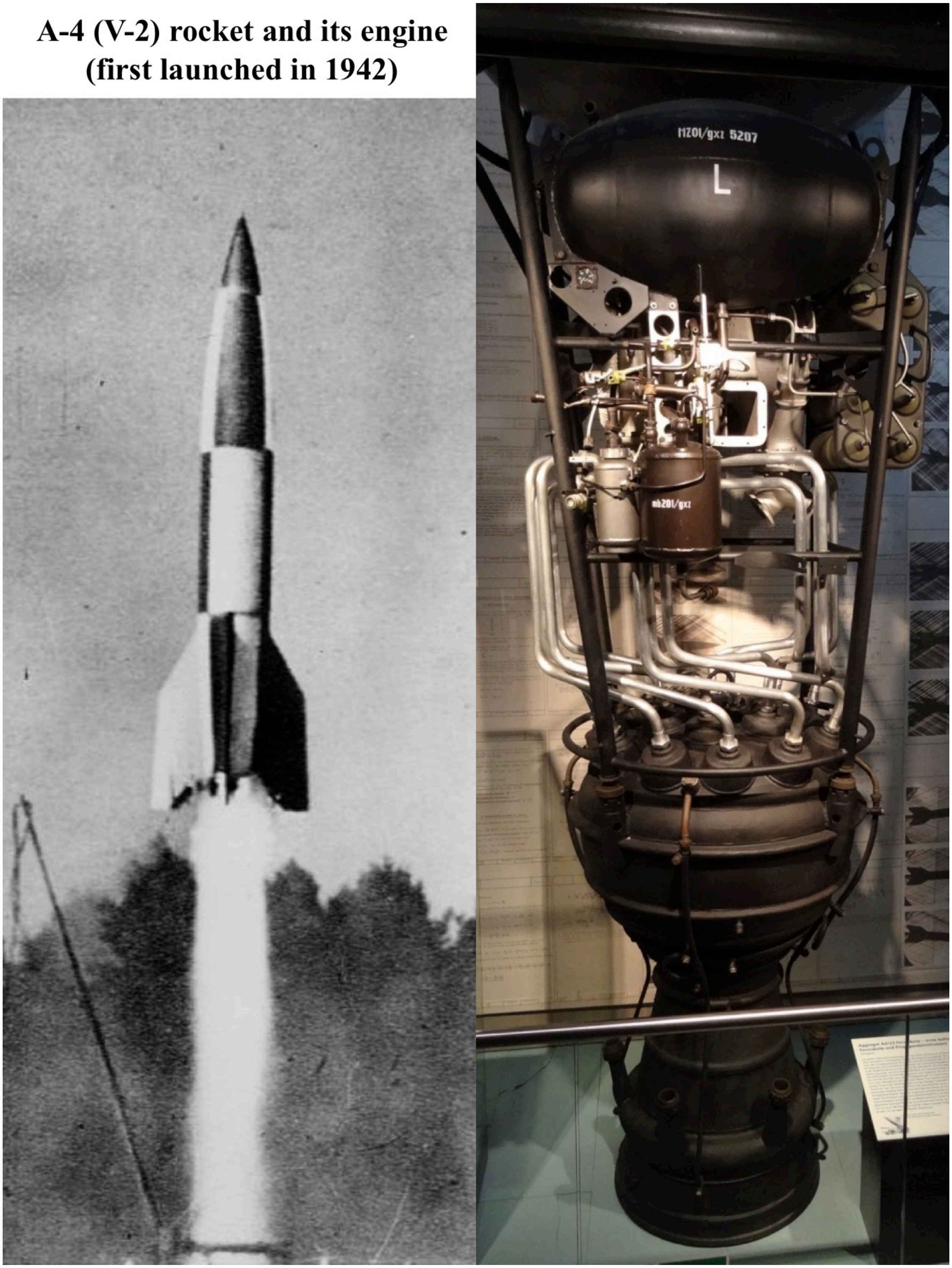


Figure 9.168: The A-4 (V-2) rocket, first launched in 1942 and capable of reaching altitudes over 200 km, was designed and developed by a team led by Wernher von Braun.

9.7.2 Postwar U.S. and U.K. Rocket Programs

At the end of the war, von Braun and much of his team moved to the United States, where they spent a quarter-century developing a series of even larger rockets, both for ballistic missile programs (Fig. 9.169) and also for the space program. Their work culminated in the Saturn V rocket that carried the Apollo missions to the moon in 1968–1972 (Figs. 9.170–9.171). Dornberger also moved to the United States and worked separately on a series of rocket planes, culminating in the U.S. Space Shuttle (pp. 1866 and 1939–1944).[15]

U.S. Army Lt. Colonel William E. Winterstein worked very closely with von Braun immediately after his arrival in the United States, and he later emphasized how long von Braun had planned and lobbied for manned missions to the moon [Winterstein 2005, pp. 34–35]:

> Among the many discussions I had with Wernher [von Braun] during those days was the theme of space exploration. The first step, naturally, was a voyage to the Moon. This was his lifelong ambition. At that time, the outlook for any rocket research for such a project was unfavorable. [...]
>
> In the summer of 1946, I asked Wernher "If we could give you all of the money you wanted, how much, and how long, would it take you to put Man on the Moon?" Several weeks later, he said: "Give us three billion dollars, and ten years, and we will go to the moon and back." At the time, I thought it was merely very interesting information, never dreaming of their importance.
>
> It was fifteen years later that similar words, concerning the time frame at least, were uttered by President Kennedy to a joint session of Congress on May 25th 1961. "Before this decade is out," described the time frame. Prior to President Kennedy's address to Congress, Dr. von Braun had convinced the President that the trip to the Moon was technologically possible. This further convinced me that Wernher must have done a lot of planning for a Moon mission, years before he gave me the same information concerning the time element in 1946.

Of course, von Braun and his team ultimately did exactly what they had long envisioned, once the United States finally committed the necessary amount of funding after many years of bureaucratic indecision and delays. Yet if von Braun's team had had the full financial and political support of the United States from 1945 onward, how soon might the United States have sent the first astronaut into space, or sent the first astronauts to the Moon? How much further into space might the United States have progressed after that? (And what did von Braun's apparently very knowledgeable 1946 statement to Winterstein suggest about how far the development of rockets more advanced than the A-4 had progressed in wartime Germany? See Sections E.2, E.5, and E.7.)

[15] Likewise, the history of postwar liquid propellant rockets has been so well documented that it will not be covered in any detail here. For more information, see: Bilstein 1980; von Braun et al. 1985; Franklin 1987; Freeman 1993; Huzel 1962; Huzel and Huang 1992; Koelle 1961; Kurowski 2001; Ley 1968; Mader 1963; Jürgen Michels 1997; Neufeld 2007; Powell-Willhite 2007; Stuhlinger and Ordway 1994a, 1994b; NYT 1945-05-23 p. 4, 1946-04-12 p. 11, 1946-04-22 p. 6, 1946-05-07 p. 3, 1946-06-29 p. 11, 1947-03-02 p. 17, 1947-06-22 p. E-7, 1948-04-03 p. 27.

When Wernher von Braun died in 1977, President Jimmy Carter issued a public statement [Carter 1977, p. 1125]:

> To millions of Americans, Wernher von Braun's name was inextricably linked to our exploration of space and to the creative application of technology. He was not only a skillful engineer but also a man of bold vision; his inspirational leadership helped mobilize and maintain the effort we needed to reach the Moon and beyond.
>
> Not just the people of our Nation but all the people of the world have profited by his work. We will continue to profit from his example.

Of course, von Braun was only one person, but President Carter's statement demonstrates how critical the German-speaking scientists had been for the space and ballistic missile programs in the United States. John Becklake, a historian of science at London's Science Museum, described the contributions of the German-speaking scientists in more detail [Becklake 1994]:

> Twenty-five years ago, in July 1969, the first men landed on the Moon. These pioneering spacefarers, Neil Armstrong and Buzz Aldrin, were launched on this mission by America's massive Saturn V rocket. Twenty-five years before this, on 8 September 1944, the first operational V2 missile was fired at Paris from a mobile launch site in the Ardennes region of France. Both of these rockets were developed by the same team of German engineers, led by Wernher von Braun. [...]
>
> The accomplishments of this US-based team, now expanded to include local engineers, are legendary—they developed the US's first long range missile (Redstone), provided the launch vehicle that orbited America's first satellite and later, under the auspices of the civil space agency, NASA, developed the Saturn family of rockets. This included the Saturn V rocket that sent the Apollo astronauts to the Moon. So influential were von Braun and his team in almost every major rocket activity in Germany and the US between 1930 and 1970, that this volume [a biography of von Braun] effectively represents a history of rocketry in the Western world.

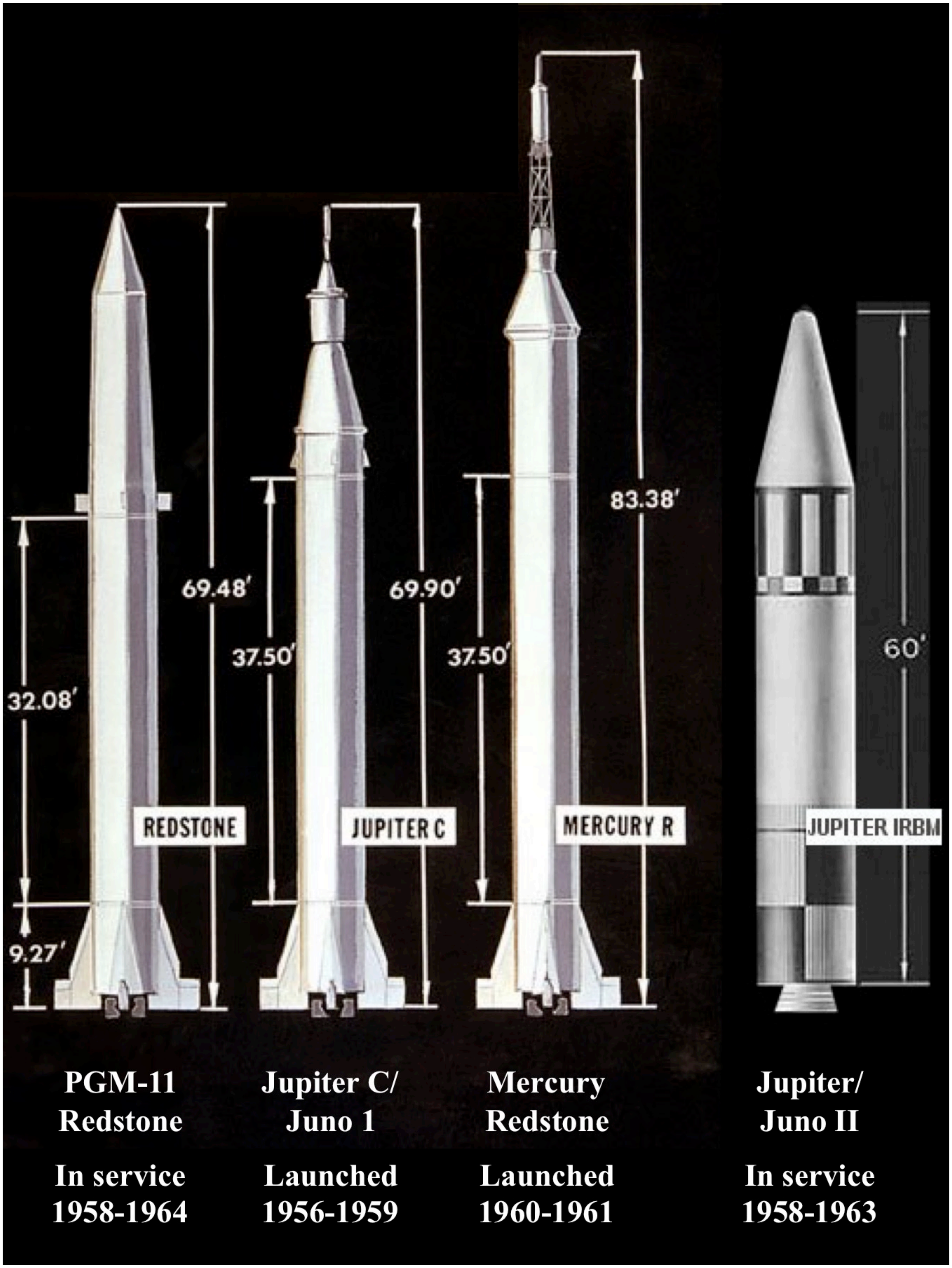


Figure 9.169: Examples of early U.S. ballistic missiles derived directly from German creators and creations.

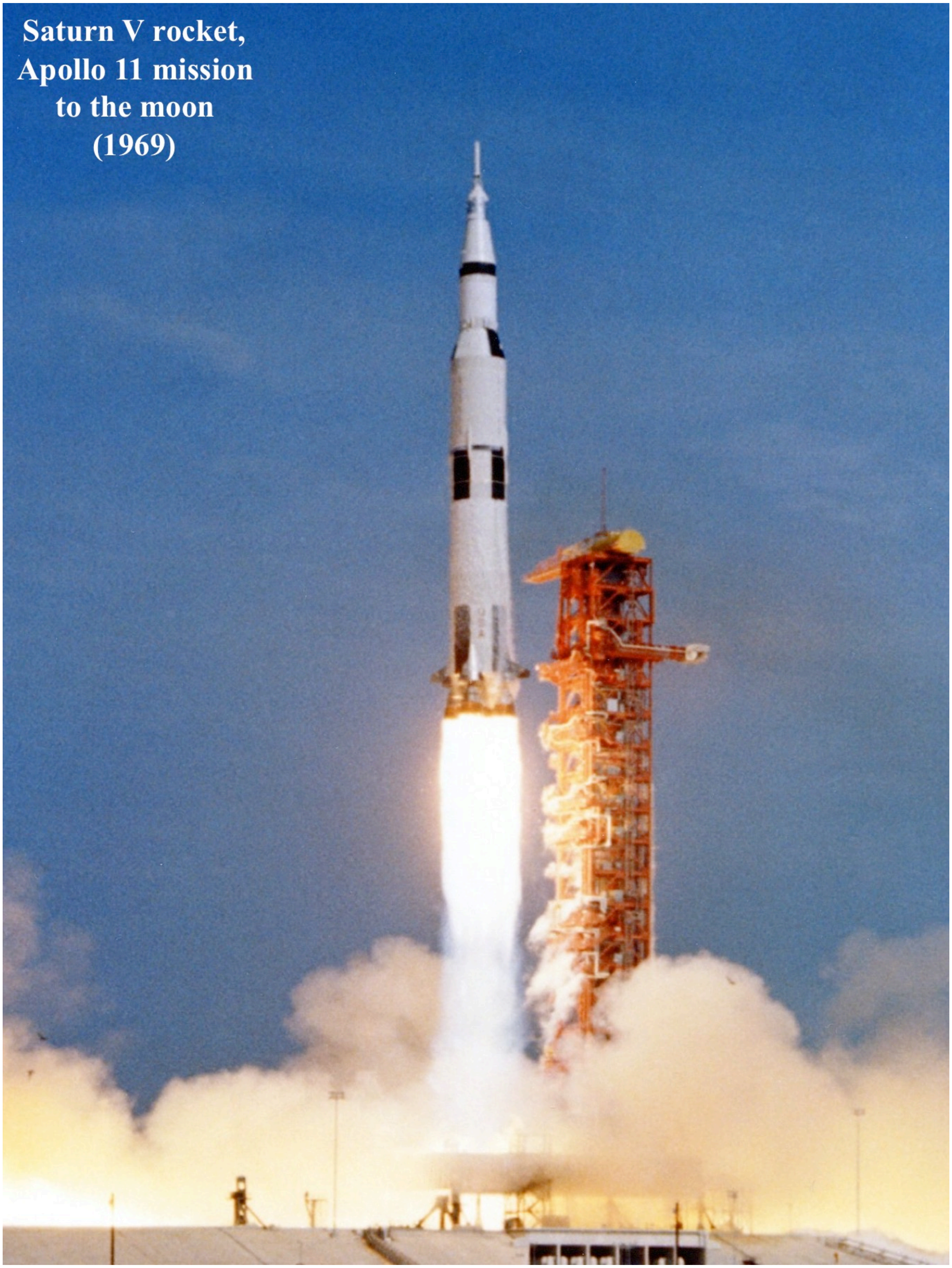


Figure 9.170: The Saturn V rocket, which carried the Apollo 11 mission to the moon in 1969, was also designed and developed by Wernher von Braun's team.

Wernher von Braun with F-1 engines for Saturn V rocket

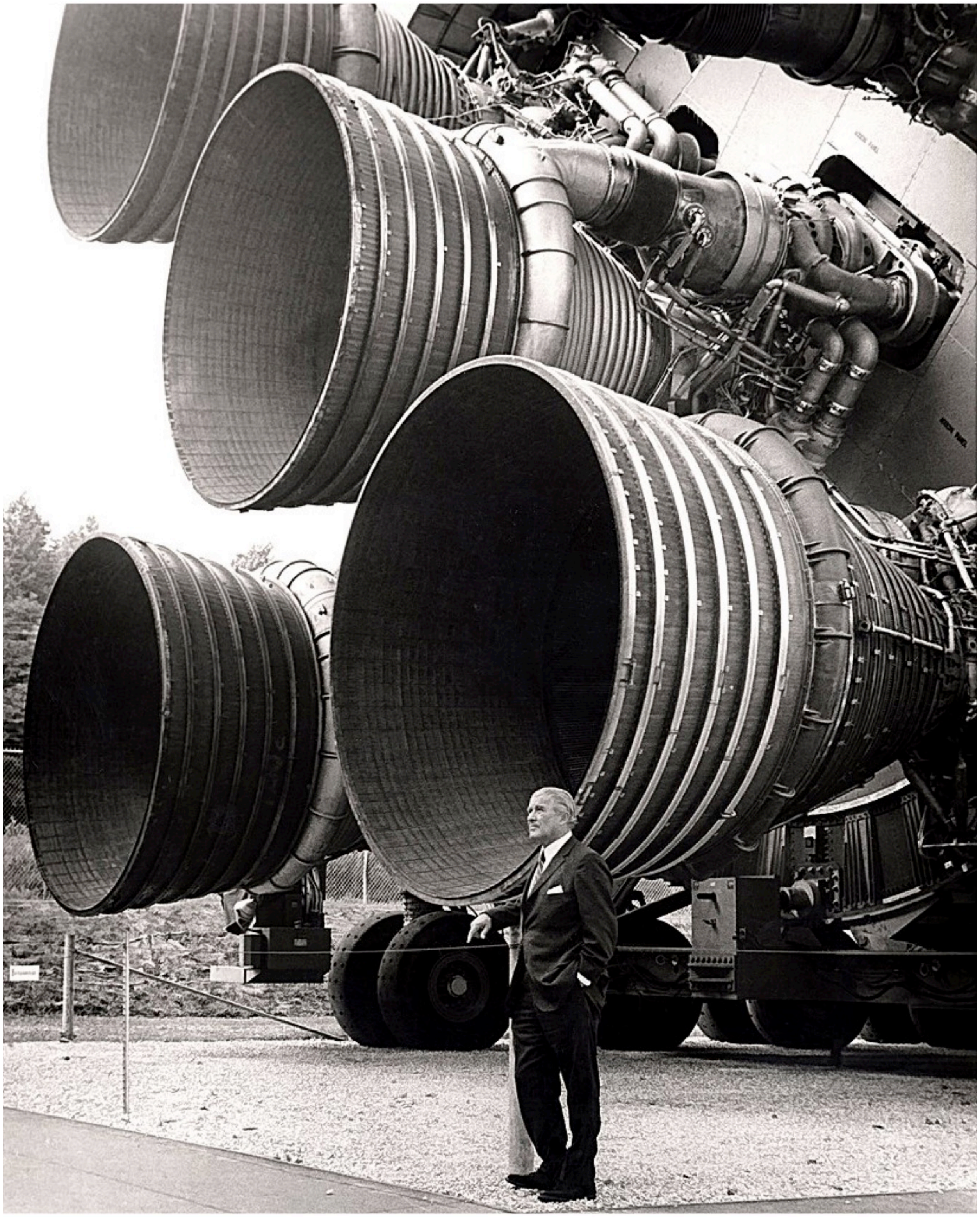


Figure 9.171: Wernher von Braun with the F-1 engines for the Saturn V rocket.

The two photographs in Fig. 9.172 illustrate how numerous and influential German-speaking creators were in the U.S. ballistic missile and space programs.

The upper photograph in Fig. 9.172 shows the attendees of a 1959 meeting at the Army Ballistic Missile Agency. From left to right, they were:

Name	Born	Lived	Role
Ernst Stuhlinger	German	1913–2008	
Frederick von Saurma	German	1908–1961	
Fritz Mueller	German	1907–2001	
Hermann Weidner	German	1912–2008	
Erich Neubert (in back)	German	1910–1999	
William Mrazek	German	1911–1992	
Karl Heimburg	German	1910–1997	
Arthur Rudolph	German	1906–1996	
Otto Hoberg	German	1912–1991	
Wernher von Braun	German	1912–1977	
Oswald Lange	German	1912–2000	
Bruce Medaris	American	1902–1990	U.S. Army General
Helmut Hölzer	German	1912–1996	
Hans Maus	German	1905–1999	
Ernst Geissler	German	1915–1989	
Hans Hueter	German	1906–1970	
George Constan	American	1909–1986	Manager, Michoud Assembly Facility

The lower photograph in Fig. 9.172 shows the attendees of a 1961 meeting at NASA. From left to right, they were:

Name	Born	Lived	Role
Werner Kuers	German	1907–1983	Director, Manufacturing Engineering Division
Walter Häussermann	German	1914–2010	Director of the Astrionics Division
William Mrazek	German	1911–1992	Propulsion and Vehicle Engineering Division
Wernher von Braun	German	1912–1977	Director of Marshall Space Flight Center
Dieter Grau	German	1913–2014	Director of the Quality Assurance Division
Oswald Lange	German	1912–2000	Director of the Saturn Systems Office
Erich W. Neubert	German	1910–1999	Assoc. Deputy Director, Research/Development

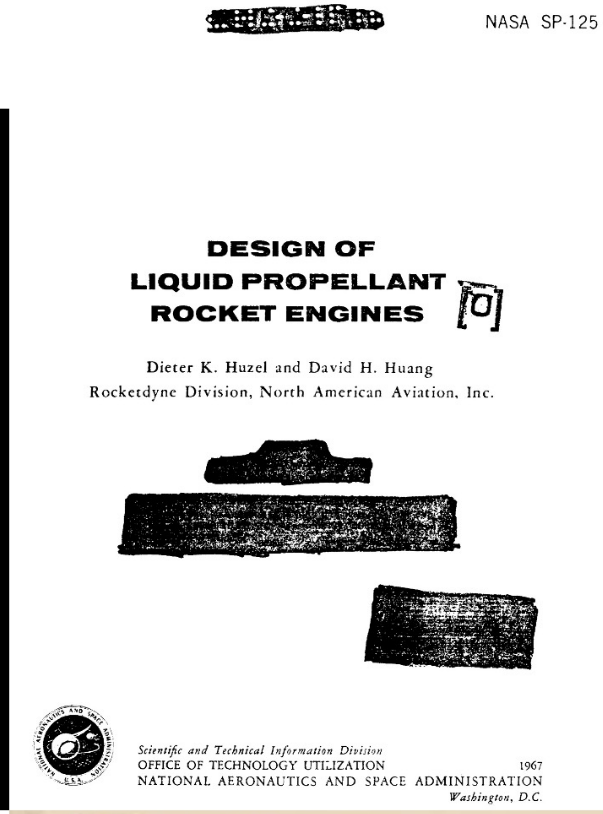
For a more extensive list of German-speaking scientists/engineers who worked in postwar U.S. and U.K. rocket and missile programs, see Table 9.2. (There was a relatively free exchange of German-speaking scientists and information between the U.S. and U.K. programs, so they are treated together here.) Even this list represents only a fraction of the many hundreds of German-speaking scientists and engineers who worked in all parts of NASA, military research centers, and aerospace and electronics companies to make the U.S. and U.K. missile, rocket, and space programs possible.

For examples of U.K. rockets designed by German-speaking scientists, including Black Knight, Blue Streak, Europa, and Black Arrow, see pp. 1882–1884 and p. 5670.

The German-speaking creators developed these revolutionary inventions from scratch to fully mature technologies during their careers. Even now, many decades later, these same German creations are still repackaged by others as “new” inventions (Fig. 9.177).

Figure 9.172: Examples of German-speaking designers and managers in the U.S. rocket programs. Above: 1959 meeting at the Army Ballistic Missile Agency. Below: 1961 meeting at NASA.

Dieter Huzel
(1912–1994)


[redacted] NASA SP-125

DESIGN OF
LIQUID PROPELLANT
ROCKET ENGINES

Dieter K. Huzel and David H. Huang
Rocketdyne Division, North American Aviation, Inc.

[redacted]

[redacted]

Scientific and Technical Information Division
OFFICE OF TECHNOLOGY UTILIZATION 1967
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

Georg Paul Schulhof, a.k.a.
George P. Sutton (1920–2020)

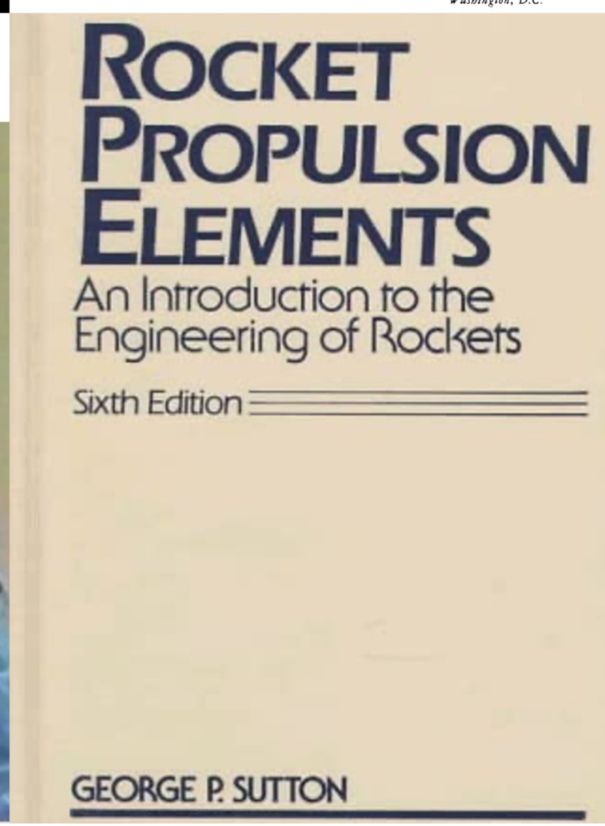


Figure 9.173: Two prominent figures (among many others) in transferring rocket engine technology from the German-speaking world to the United States were: (1) Dieter Huzel, who had been part of von Braun's team since Peenemünde and led postwar rocket engine development at North American Aviation Rocketdyne. (2) Georg Paul Schulhof, a.k.a. George P. Sutton, who moved from Austria to the United States in 1938 and worked with Huzel, Theodore von Kármán, Fritz Zwicky, and others to transfer German-speaking scientists, documents, information, and technologies to North American Aviation Rocketdyne, Aerojet, and other organizations. See pp. 5580–5582.

Andreas Alexandrakis
Wilhelm Angele
Herbert Axter
Erich Ball
Oscar Bauschinger
Gerd de Beek
Rudolf Beichel
Anton Beier
Herbert Bergeler
Hermann Beuderftig
Josef Boehm
Gerhard Braun
Magnus von Braun
Wernher von Braun
Erhardt Bruenecke
Theodor Buchhold
Walter Burose
Rudolf Buschmann
Werner Dahm
Konrad Dannenberg
Kurt Debus
Heinrich Determann
Friedrich Dhom
Herbert Dobrick
Walter Dornberger
Gerhard Drawe
Friedrich Duerr
Ernst Eckert
Rudolf Edse
Krafft Ehricke
Otto Eisenhardt
Willy Fiedler
Hans Fichtner
Alfred Finzel
Edward Fischel
Karl Fleischer
Hans Friedrich
Herbert Fuhrmann
Ernst Geissler
Werner Gengelbach
Dieter Grau
Hans Gruene
Herbert Guendel
Johann Gustav
Karl Hager
Guenther Haukohl
Walter Häussermann
Karl Heimburg
Emil Hellebrand
Gerhard Heller
Bruno Helm
Alfred Henning
Rudolf Hermann
Bruno Heusinger
Guenther Hintze
Otto Hirschler
Otto Hoberg
Rudolf Hoelker
Helmut Hoelzer
Oscar Holderer
Helmut Horn
Hans Hosenthien
Hans Hueter
Dieter Huzel
Walter Jacobi
Wilhelm Jungert
Hans Kammler
Erich Kaschig
Karl Klager
Ernst Klauss
Johann Klein
Georg E. Knausenberger
Heinz-Hermann Koelle
Max Kramer
Hubert Kroh
Werner Kuers
Joachim Kuettner
Hermann Kurzweg
Hermann Lange
Oswald Lange
Willy Ley[†]
Hans Lindenberg
Hans Lindenmayr
Kurt Lindner
Hannes Luehersen
Carl Mandel
Hans Maus
Helmut Merk
Joseph Michel
Hans Milde
Heinz Millinger
Rudolf Minning
William Mrazek
J. W. Muehlner
Fritz Mueller
Heinz E. Mueller
Rudolf Nebel
Erich Neubert
Kurt Neuhoefer
Wolfgang Noeggerath
Max Novak
Adolf Oberth
Hermann Oberth
Robert Paetz
Hans Palaoro
Kurt Patt
Hans Paul
Karl Pohlhausen
Theodor Poppel
Willibald P. Prasthofer
Jesco von Puttkamer
Eberhard Rees
Gerhard Reisig
Georg Rickhey
Walther Johannes Riedel
Werner Rosinski
Ludwig Roth
Heinrich Rothe
Arthur Rudolph
Harry Ruppe
Friedrich von Saurma
Heinz Schnarowski
Klaus Scheufelen
Martin Schilling
Rudolf Schlidt
Helmuth Schlitt
Helmut H. Schmidt
Albert Schuler
Georg Paul Schulhof,
a.k.a. George P. Sutton[††]
William August Schulze
Friedrich Schwarz
Walter Schwidetzky
Karl Sendler
Eberhard Spohn
Werner Sieber
Fridtjof Speer
Ernst Steinhoff
Hermann Steuding?
Wolfgang Steurur
Ernst Stuhlinger
Johann Tschinkel
Bernhard Tessmann
Adolf Thiel
Georg von Tiesenhausen
Werner Tiller
Arthur Urbanski
Fritz Vandersee
Werner Voss
Theodor Vowe
Herbert Wagner
Hermann Weidner
Günter Wendt
Walter Wiesman
Albin Wittmann
Hugo Woerdemann
Albert Zeiler
Helmut Zoike

Table 9.2: Some German-speaking scientists and engineers in postwar U.S. and U.K. rocket and missile programs. [†]Willy Ley came to the United States in 1935. [††]Georg Paul Schulhof, later and much better known as George P. Sutton, came to the United States in 1938.

Figure 9.174: German-speaking rocket engineers designed the British Black Knight, which was first launched in 1958. See also p. 5670.

Blue Streak (1964)

Renamed Europa with upper stages (1968)

Figure 9.175: German-speaking rocket engineers designed the British Blue Streak, which was first launched in 1964. With upper stages mounted on top, it was renamed Europa and launched in 1968. See also p. 5670.

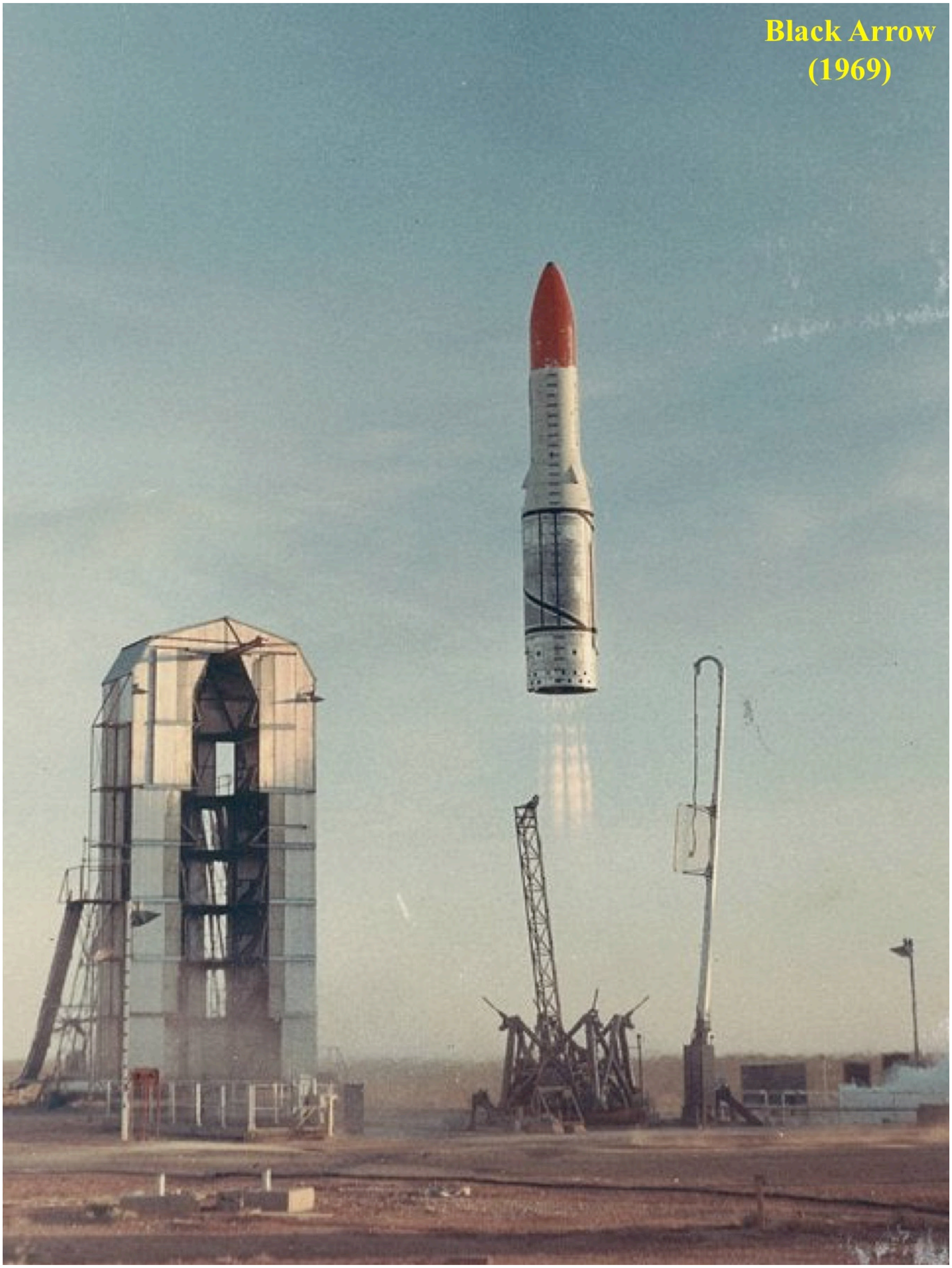


Figure 9.176: German-speaking rocket engineers designed the British Black Arrow, which was first launched in 1969. See also p. 5670.

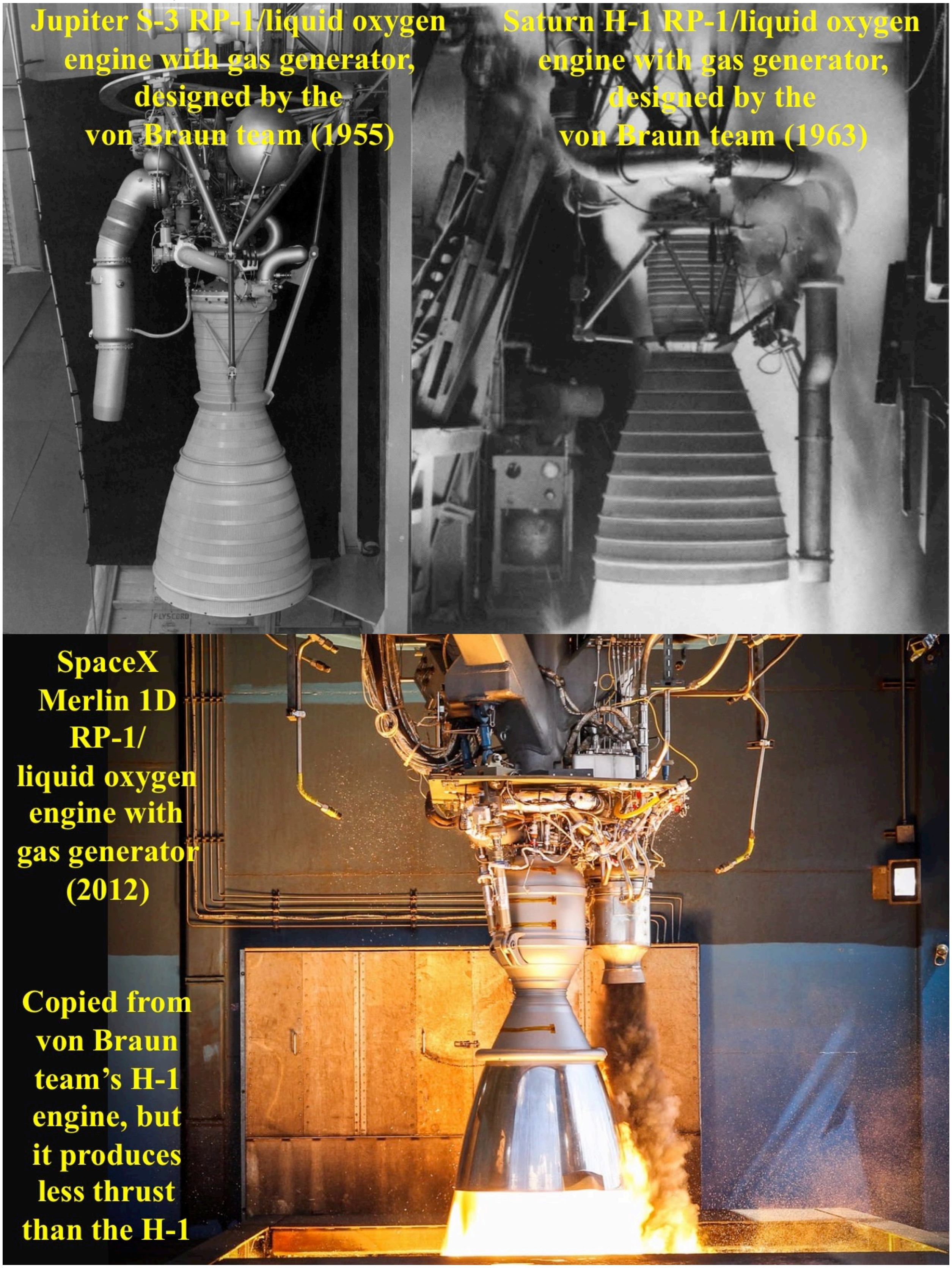


Figure 9.177: Based on their earlier A-4 and Redstone engines, Wernher von Braun's team designed RP-1/liquid oxygen engines with gas generators: the Jupiter S-3 (first operational in 1955) and the Saturn H-1 (first operational in 1963). The much-hyped SpaceX Merlin 1D engine (first operational in 2012) was directly copied from the H-1 engine yet produces less thrust than the H-1.

9.7.3 Postwar Soviet Rocket Programs

German-speaking engineers, designs, and materials also greatly contributed to the development of missiles, rockets, and spacecraft in the Soviet Union.[16]

Huge numbers of German-speaking scientists and engineers were employed (willingly or otherwise) in postwar Soviet rocket and missile programs (p. 2076). Table 9.3 lists some examples. Helmut Gröttrup (German, 1916–1981) was the most prominent scientific leader and coordinator among the German-speaking engineers. Figure 9.178 shows an October 1947 photo at the Kapustin Yar rocket testing site, where Gröttrup posed with Karl Viktor Stahl, Johannes Hoch, Fritz Viebach, and Hans-Albert Vilter.

Figure 9.179 presents the first three major types of Soviet ballistic missiles (see also p. 5899):

- The SS-1 or R-1 Scunner was basically just an A-4/V-2 rocket (14 meters long) that was manufactured by Germans under Soviet control and used 1950–1953.

- The SS-2 or R-2 Sibling was a longer, upgraded A-4 (18 meters long) that was in service 1953–1956. Not only was it produced by German engineers, but it appears to have been copied from 18-meter extended A-4 rockets that were secretly developed and tested in Germany during the war (p. 5895).

- The SS-3 or R-5M Shyster, also shown in Fig. 9.180, was an even longer upgraded A-4 (21 meters long) that was in service 1956–1967. It was again created by German engineers, also apparently based on wartime work (p. 5895). In fact, with its 1200 km range, capable of delivering a nuclear warhead to anywhere in the United Kingdom from dedicated launch sites near Peenemünde, the SS-3 appears to have been the very embodiment of wartime German plans (p. 5669).

Later Soviet rockets, including those still used by Russia today, were also the product of German-speaking engineers working in the Soviet Union:

- The clustered design of the R-7 or SS-6 Sapwood and all later Russian rockets was directly derived from Helmut Gröttrup's G-5 design, as illustrated in Fig. 9.181 [http://www.astronautix.com/g/g-5.html].

- The RD-107/RD-108 engines of the R-7 and all later Russian rockets were directly derived from engine designs by Werner Baum (German, 1918–20??), as shown in Fig. 9.182 [Przybilski 2002a].

- Figure 9.183 illustrates how Helmut Gröttrup's rocket designs and Werner Baum's engines were used for the R-7, Sputnik, Vostok, Voshkod, and Soyuz launchers.

- Soyuz rockets are still used by Russia for launches to the International Space Station (Fig. 9.184).

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[16] For much more information, see: Chertok 2005–2012; Robert Godwin 2001; Harford 1997; Oberg 1981; Phelan 2013; Przybilski 1999, 2002a; Reinke 2007, pp. 36–37; Siddiqi 2000; Uhl 2001; *Scientific Intelligence Review* 1946; NYT 1947-05-18 p. 45.

Albert Adolf	Karl Held	Max Pole
Werner Albring	Bruno Henning	Hans Prost
Helmut Anders	Walter Hensch	Oswald Putze
Erich Apel	Anton Herr	Siegfried Reinhard
Willi Aporius	Rudolf Herrman	Helmut Ritter
Herbert Auler	Johannes Hoch	Fritz Rockstuhl
Gerhard Bart	Heinz Jaffke	Erwin Rossler
Werner Baum	Alois Jasper	Paul Rothe
Heinz Bauschke	Anton Kahler	Walter Rüdiger
Karl Begel	Heinrich Kindler	Ferdinand Rule
Siegfried Bergemann	Alfred Kirchner	Franz Schadt
Erich Bischof	Alfred Klippel	Waldemar Schellhorn
Kurt Blasig	Alfred Klose	Konrad Schidlo
Josef Blass	Wilhelm Knack	Walter Schierhorn
Friedrich Bönisch	Heinz Knittel	Walter Scholz
Karl Borkmann	G. Kraut	Heribert Schröder
Kurt Briese	Hans Kuhl	Werner Schulz
Hugo Brötler	Gerhard Lange	Wilhelm Schütz
Bernhard Buckdolf	Erich Langenbach	Willi Schwarz
Günter Bujak	Ernst Lehmann	Gerhard Siegmund
Wilhelm Burchard	Ludwig Leihfeld	Willi Sommer
Alfons Busselt	Werner Lessing	Karl Viktor Stahl
Gerhardt Butke	Josef Linke	Felix/Ferdinand Stolpe
Heinz Büttner	Kurt Magnus	Heinrich Strützing
Rudolf Chwalczyk	Fritz Mattheis	Hubert Tacke
Erich Drews	Franz Matthes	Rosemarie Tannhäuser
Hans Eiseler	Otto Meier	Paul Täubert
Josef Eitzenberger	Emil Mende	H. Tellmann
Fritz Engelmann	Heinz Moser	Wolf Trommsdorff
Helmut Faulstick	Rudolf Müller	Robert Tschechner
Georg Gasch	Werner Müller	Joachim Umpfenbach
Bernhardt Gerhardt	Herbert Mummert	Harmm Verger
Paul Gerold	Horst Nehrkorn	Fritz Viebach
Alfred Grevesmühl	Peter Neidhardt	Hans-Albert Vilter
Helmut Gröttrup	Lisa Neumeister	Willi Vredl
Alfred Grünert	Friedrich Nikolaus	Karl Wilhelm
Micheslaw Gudakovskij	Friedrich Otto	Henrik Winskowski
Heinz Hasse	Walter Pauer	Waldemar Wolff
Werner Haase	Max Pehle	Kurt Wohlfahrt
Erich Habann	Arthur Pilz	Willi Zeleskij
Karl Harnisch	Bertold Podeschva	Heinz Zershinskij
Alfred Hecker	Josef Poitner	Herman Zimpe

Table 9.3: Some German-speaking scientists and engineers in postwar Soviet rocket and missile programs.

**Kapustin Yar rocket testing site
(October 1947)**

Karl Viktor Stahl (19??–19??)

Johannes Hoch (1913–1955)

Helmut Gröttrup (1916–1981)

Fritz Viebach (1907–1961)

Hans-Albert Vilter (19??–19??)

Figure 9.178: Helmut Gröttrup led the team of German-speaking engineers that designed and developed postwar Soviet rockets. In this October 1947 photo at the Kapustin Yar rocket testing site, he posed with Karl Viktor Stahl, Johannes Hoch, Fritz Viebach, and Hans-Albert Vilter.

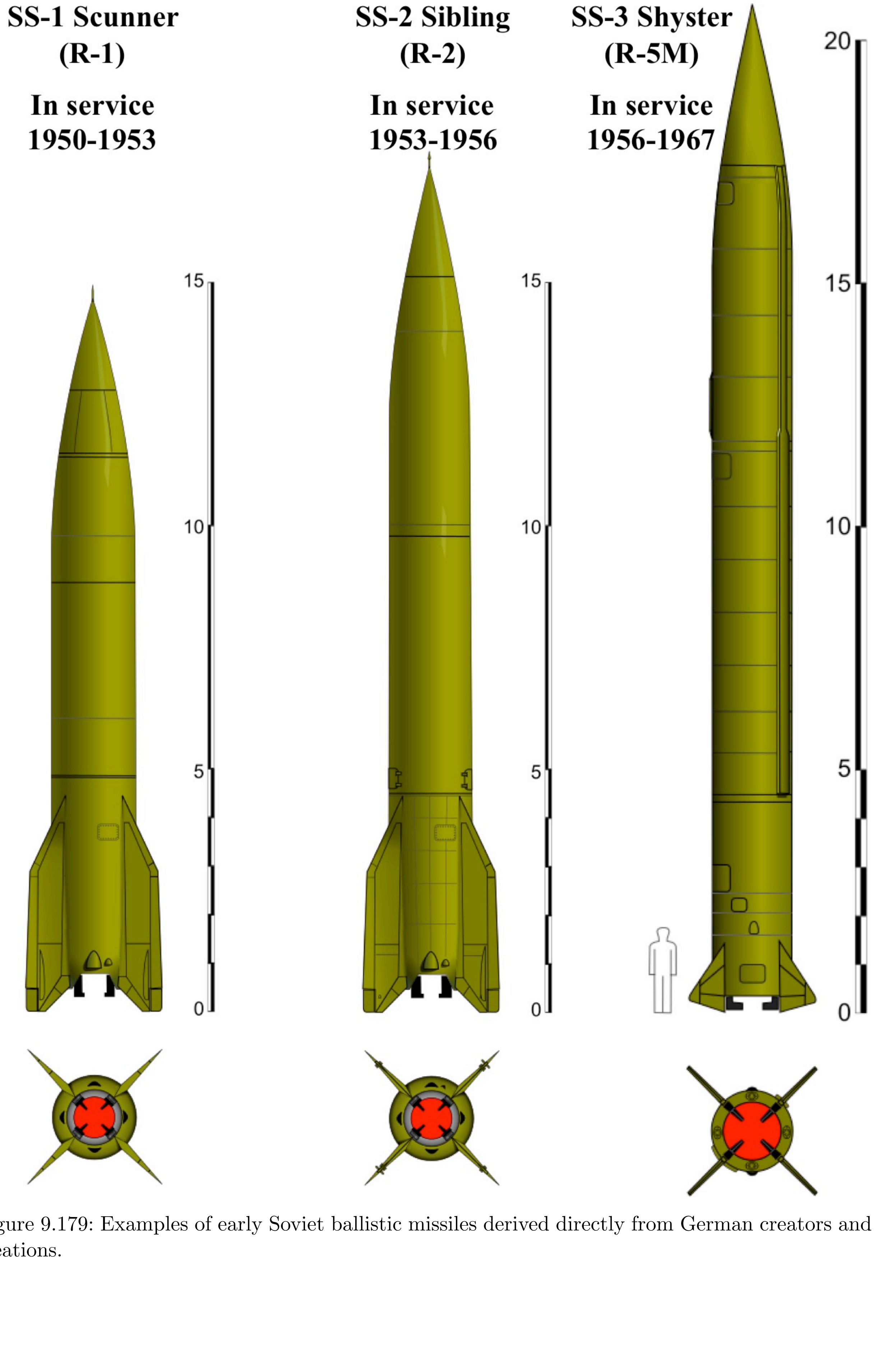


Figure 9.179: Examples of early Soviet ballistic missiles derived directly from German creators and creations.

SS-3 Shyster (R-5M)

Figure 9.180: The SS-3 Shyster (R-5M) ballistic missile was derived directly from German creators and creations.

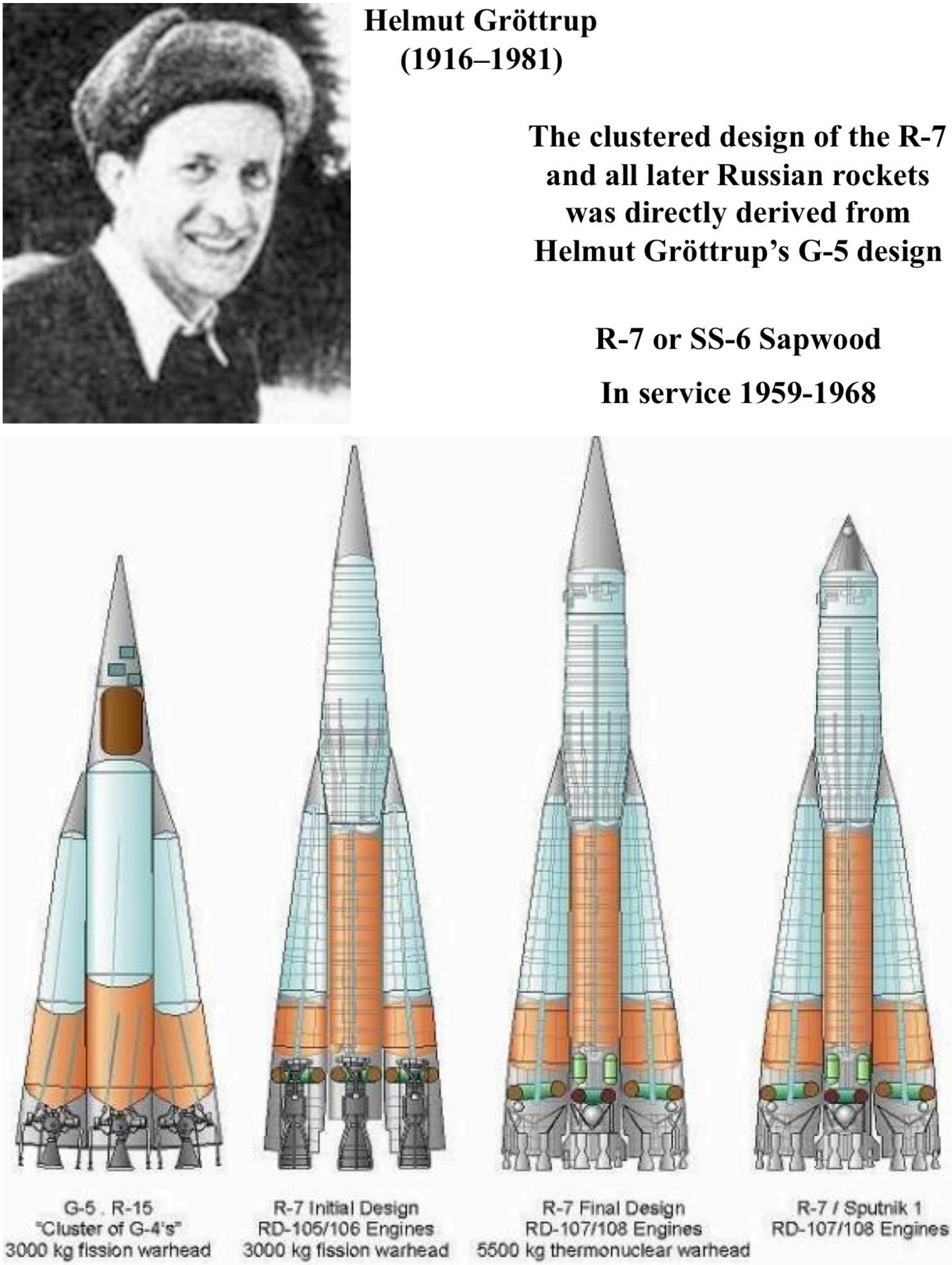


Figure 9.181: The clustered design of the R-7 and all later Russian rockets was directly derived from Helmut Gröttrup's G-5 design [http://www.astronautix.com/g/g-5.html].

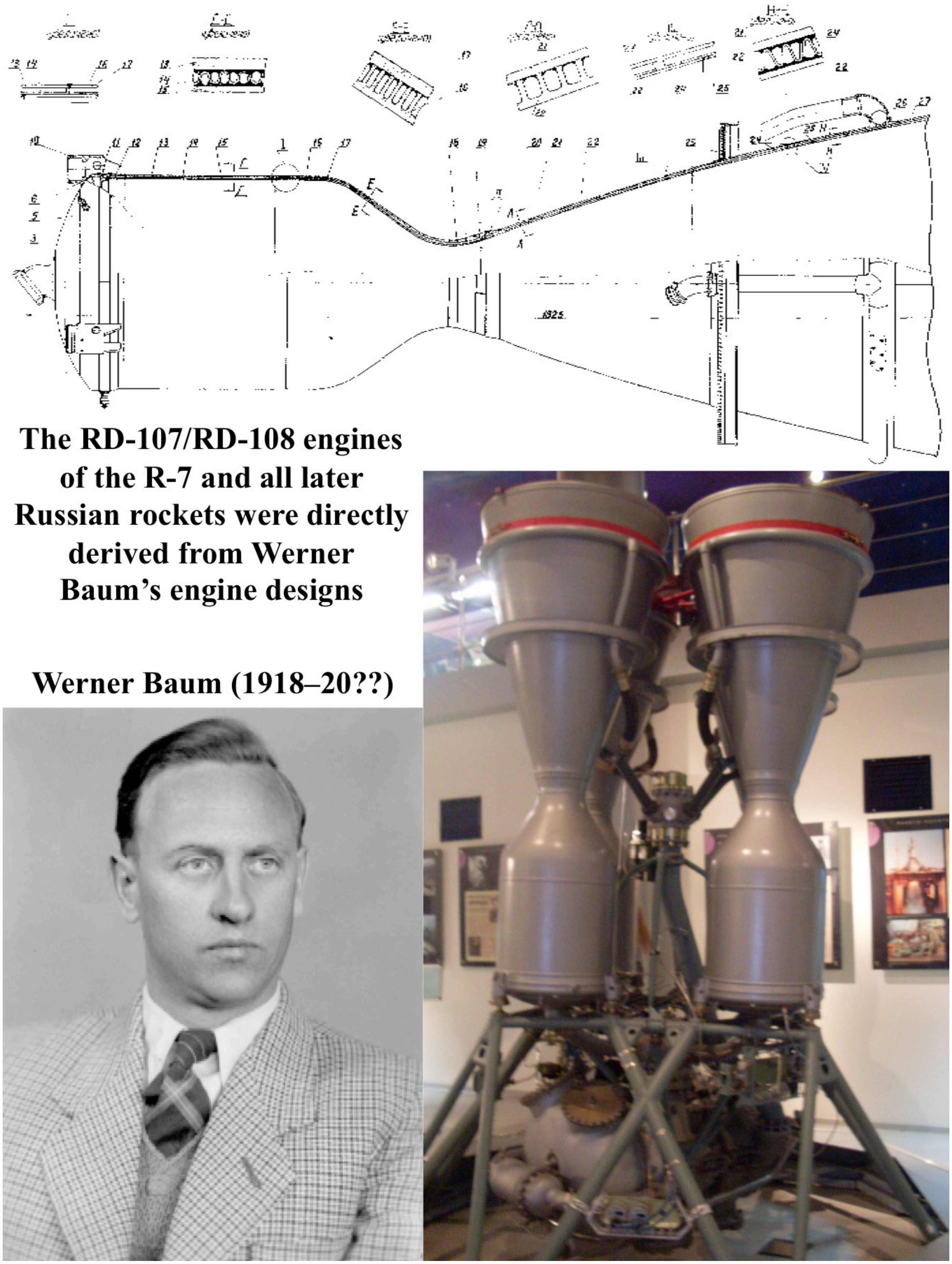


Figure 9.182: The RD-107/RD-108 engines of the R-7 and all later Russian rockets were directly derived from Werner Baum's engine designs [Przybilski 2002a].

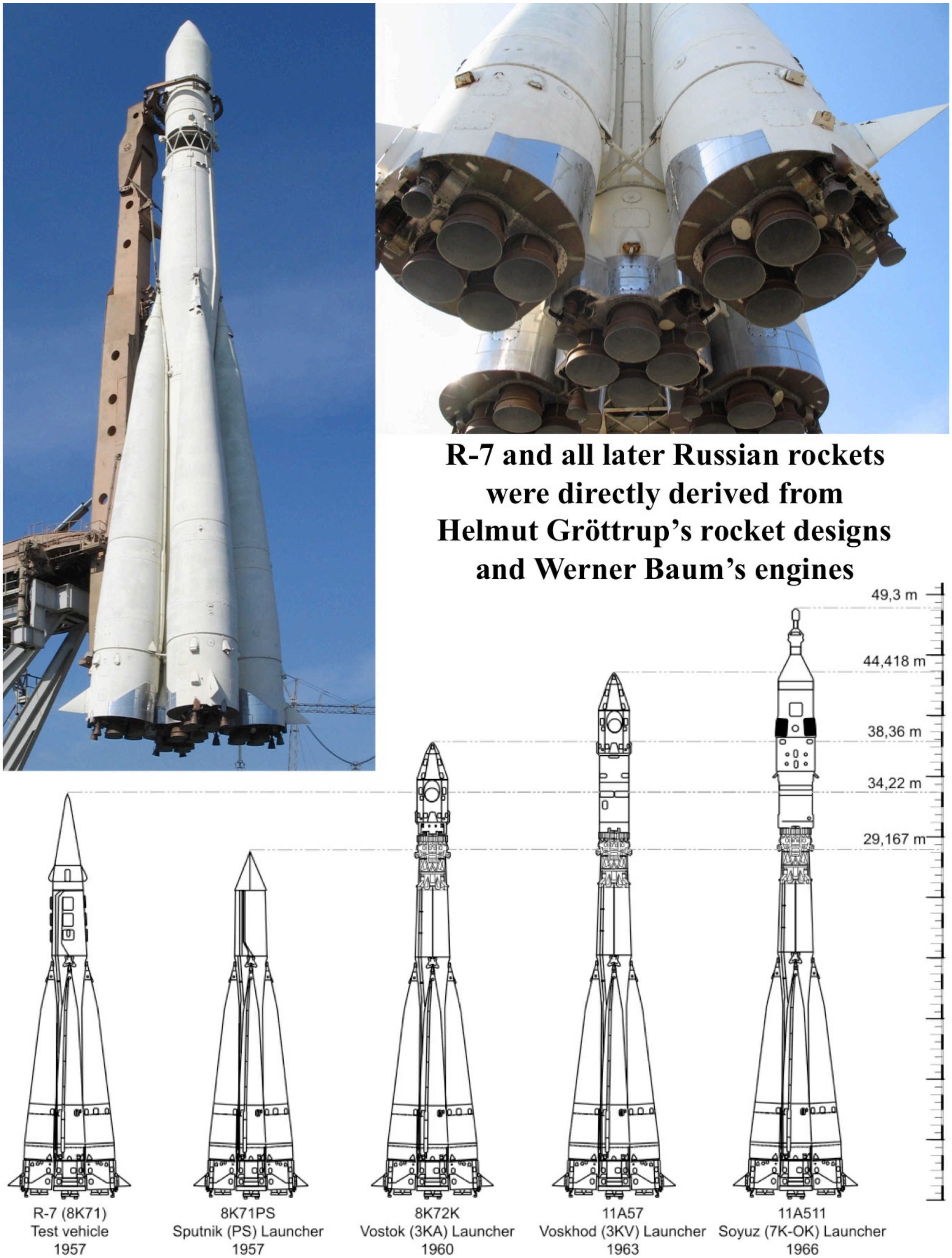


Figure 9.183: R-7 and later Russian rockets through current Soyuz launchers were directly derived from Helmut Gröttrup’s rocket designs and Werner Baum’s engines.

Figure 9.184: Even the most recent Russian rockets such as Soyuz (1966–present) are directly based on German rocket designs and German rocket engines. For more information, see pp. 1887–1893.

9.7.4 Postwar French Rocket Programs

Similarly, German-speaking scientists and engineers made major contributions to postwar programs in France. Writing for *L'Express*, investigative journalists Vincent Nouzille and Olivier Huwart researched unclassified French government records and described the recruitment and ultimate technological impact of over 1000 German and Austrian scientists and engineers in France after the war, especially with regard to missiles and other aerospace technologies [Nouzille and Huwart 1999].

For some examples of German-speaking contributions to postwar French rockets, including Véronique, Diamant, and Ariane, see Table 9.4 and Figs. 9.185–9.189 [Jürgen Michels 1997]. Later the German-designed Viking engine and other Ariane technologies were licensed to India, which built copies for its space program (p. 1901).

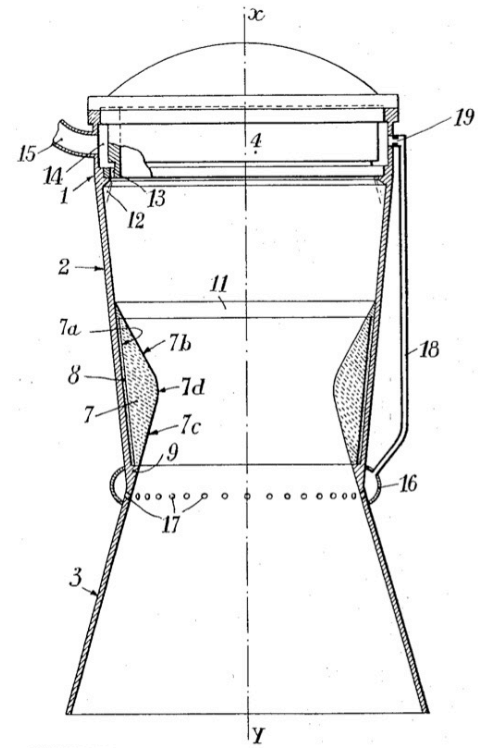
For more information on German-designed rockets in France, see pp. 5670–5678.

Bachmann	Höhne	Irene Sänger-Bredt
F. Bayer	Hüttenberger	Schabert
Behnke	Rolf Jauernick	Karl Scheidt
Bernkopf	Just	Schlotzer
Billig	Kauba	C. Schmidt
Bodenstein	Keiner	W. Schmidt
Uwe Bödewadt	Kieffer	Schmoll
Boese	Klar	Schnapper
Bornscheuer	Hans Kleinwächter	Oskar Scholze
Karl-Heinz Bringer	Kohl	Schossig
Büchner	König	Schubert
Buhl	Otto Kraehe	Schuran
Deucker	Krämer	Joachim Seidel
Dollhopf	Laebe	Sohn
Rolf Engel	Lammerhirt	Störk
Fabian	Lang	Strobel
Fölster	Liesegang	Stumke
Frey	Lörtsch	Hermann Teichmann
Gardian	Menke	Voigt
Görtz	Mosch	Walther
Grater	Otto Müller	Helmut Weiss
I. Gross	Netterscheim	Weissenborn
Martin Haas	Wolfgang Pilz	Woytech
Helmut Habermann	Willibald P. Prasthofer	Wüterich
Rudolf Hackh	Rudolf Reichel	Wolfgang Zangl
Heine	Ernst Runge	Helmut von Zborowski
Joseph Himpan	Eugen Sänger	

Table 9.4: Some German-speaking scientists and engineers in postwar French rocket and missile programs.

Karl-Heinz Bringer (1908–1999)
Rocket engines in wartime Germany and postwar France

Feb. 14, 1967 H. BRINGER 3,303,654
COMBUSTION CHAMBER FOR RAM-JETS OR ROCKET POWER UNITS EMPLOYING A COOLING FILM OF LIQUID FUEL
Filed Nov. 5, 1964



United States Patent [11] **3,601,993**

[72] Inventor **Henri Bringer**
26 Allee des Penitents, Vernon 27, France
[21] Appl. No. **24,993**
[22] Filed **Apr. 2, 1970**
[45] Patented **Aug. 31, 1971**
[32] Priority **Apr. 3, 1969**
[33] **France**
[31] **PV 6910190**

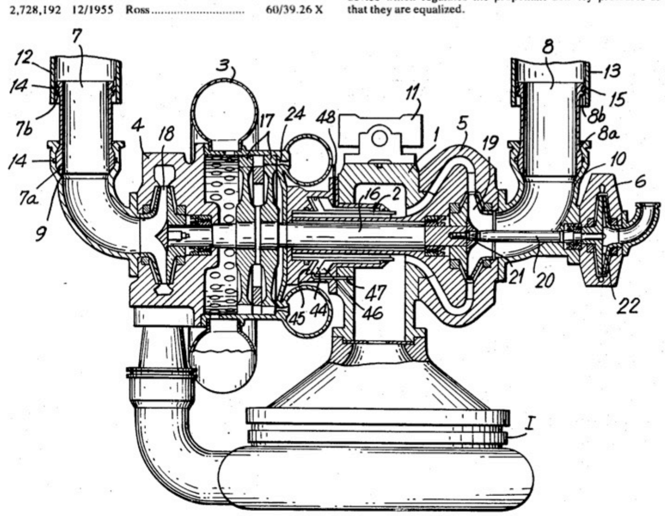
[54] **TURBOPUMP FOR ROCKET ENGINES**
10 Claims, 3 Drawing Figs.
[52] **U.S. Cl.** **60/240,** 60/39.26, 60/39.27, 60/39.3
[51] **Int. Cl.** **F02k 3/00**
[50] **Field of Search** 60/240, 39.26, 39.27, 39.3

[56] **References Cited**
UNITED STATES PATENTS

2,728,192	12/1955	Ross	60/39.26 X
3,137,128	6/1964	Francais	60/240 X
3,215,352	11/1965	Meraz	60/240 UX
3,433,022	3/1969	Lovingham	60/240 X
3,527,056	9/1970	Hoffman	60/240 X

Primary Examiner—Clarence R. Gordon
Attorney—Waters, Roditi, Schwartz & Nissen

ABSTRACT: A turbopump is provided for a liquid-fuel rocket engine using two power propellants, namely a noncryogenic oxidizer and a noncryogenic fuel. The turbopump feeds the rocket engine at high pressure. The pump-driving turbine of the turbopump is fed by gases from a generator produced by the combustion of the two propellants and cooled by the injection of water. A regulator is connected between the generator and the propellant pumps of the turbopump to control the speed of the turbine in accordance with engine combustion pressure to maintain a substantially constant pressure. The propellants are fed to the engine injection via a balancing device which regulates the propellant delivery pressures so that they are equalized.



Sept. 24, 1968 H. BRINGER 3,402,552
LIQUID INJECTION DEVICE
Filed Nov. 5, 1964

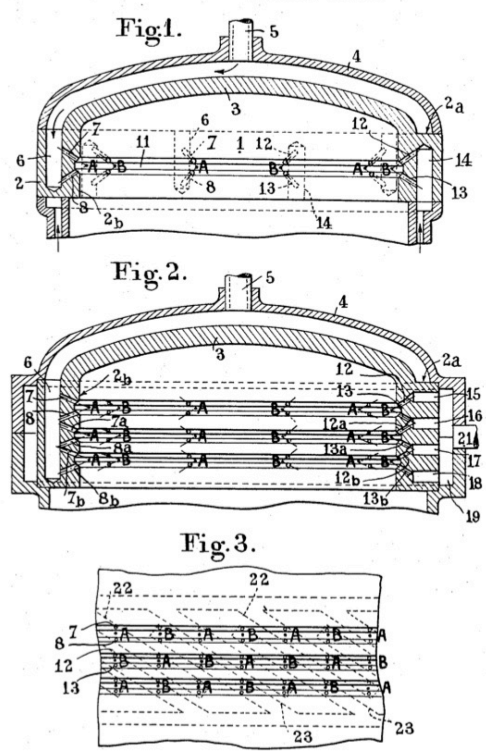


Figure 9.185: Karl-Heinz Bringer designed and demonstrated a long series of sophisticated rocket engines in wartime Germany and postwar France, culminating in the Viking engine for the Ariane rockets.

Karl-Heinz Bringer (1908–1999)

Viking rocket engine (developed in 1965, used in Ariane rockets)

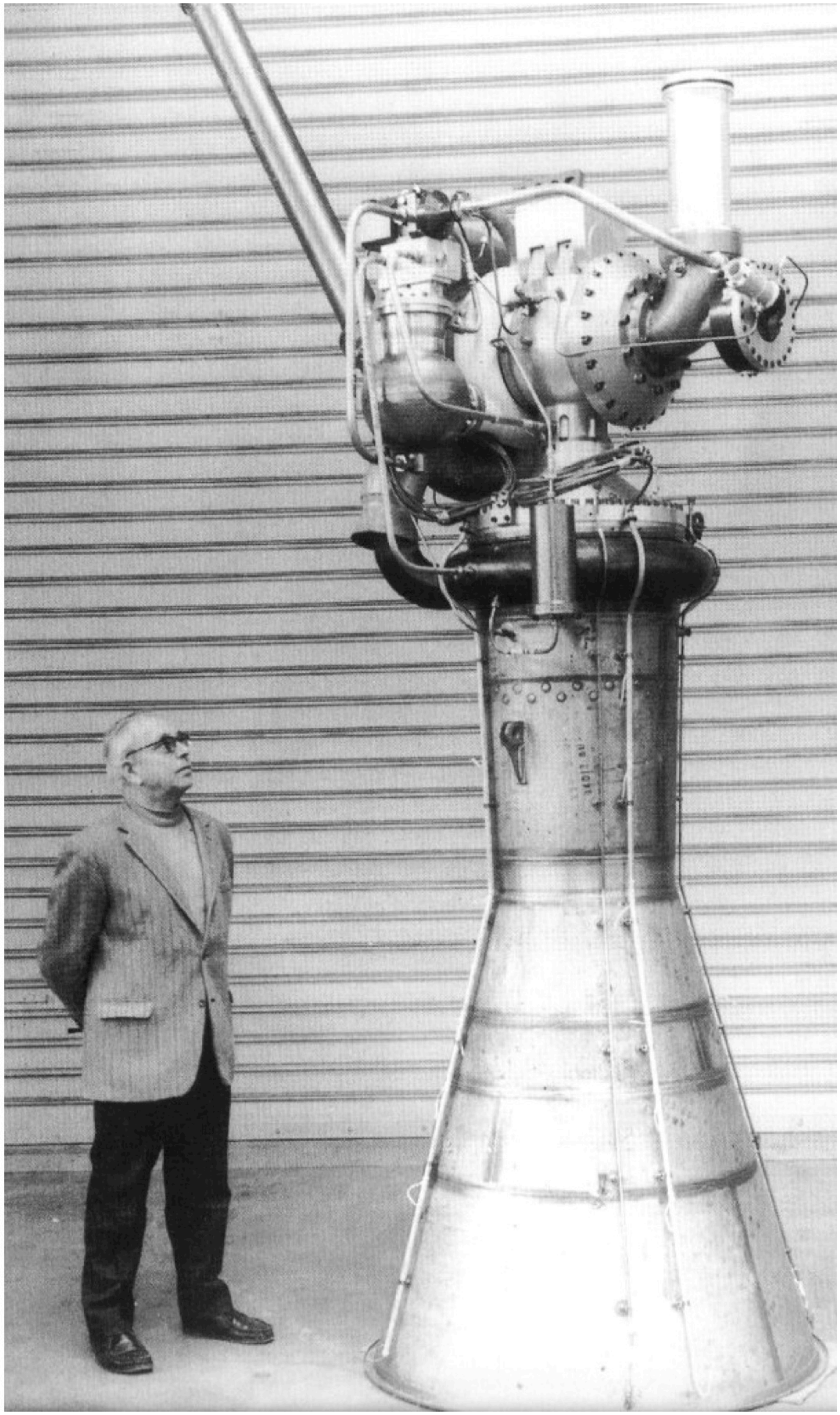


Figure 9.186: Karl-Heinz Bringer led a team of German-speaking engineers that designed and developed postwar French rocket engines, such as the Viking engine for the Ariane rockets. Later the Viking engine and other Ariane technologies were licensed to India, which built copies for its space program (p. 1901).

Figure 9.187: German-speaking rocket engineers designed the French Véronique, an A-4/V-2-like rocket that was first launched in 1954.

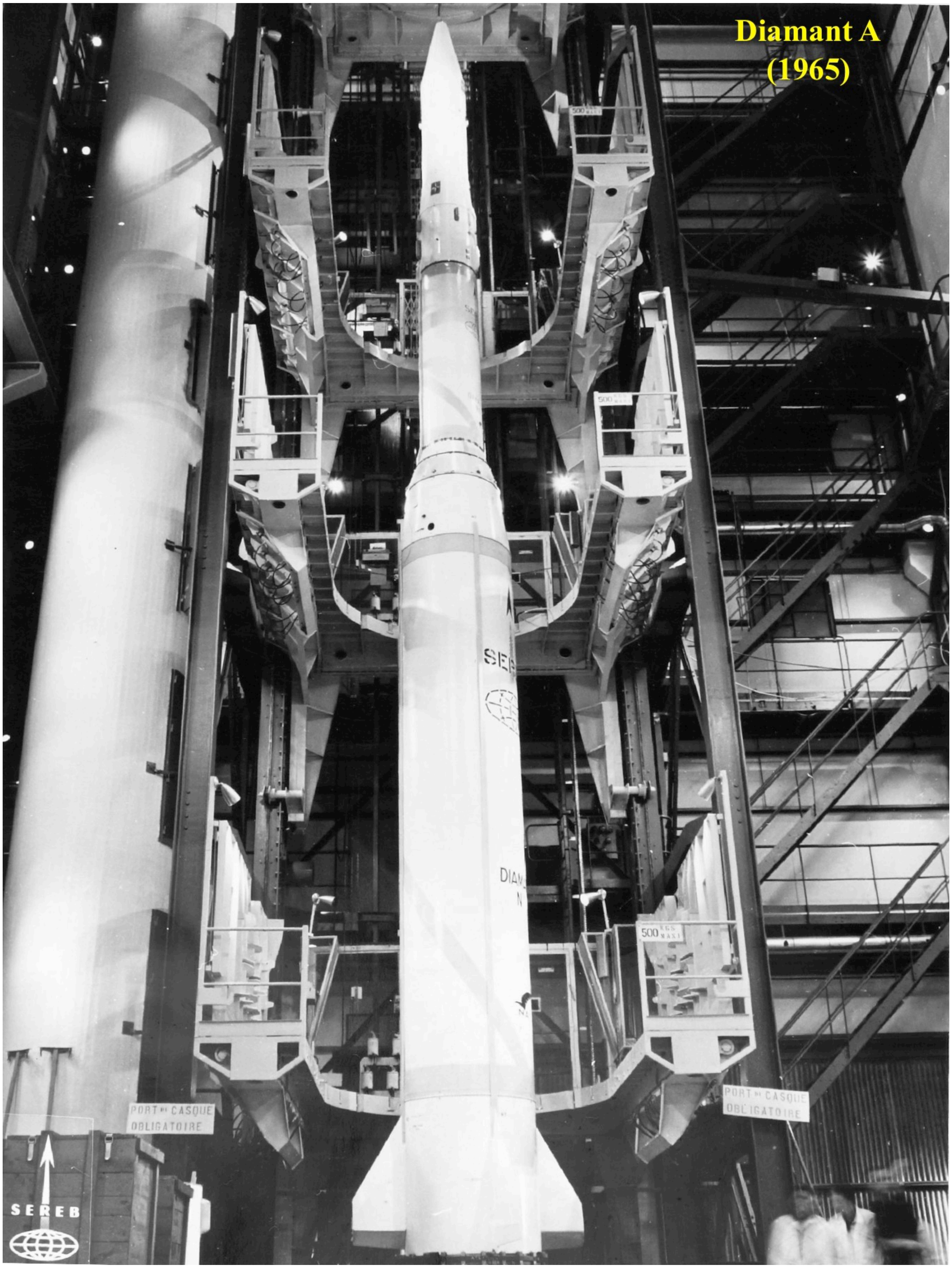


Figure 9.188: German-speaking rocket engineers designed the French Diamant, which was first launched in 1965.

Figure 9.189: German-speaking rocket engineers designed the French Ariane, which was first launched in 1979.

Figure 9.190: Preparation for the 2020 launch of India's Polar Satellite Launch Vehicle using the Vikas rocket engine, a licensed copy of Karl-Heinz Bringer's Viking rocket engine, as well as other German-designed Ariane technologies. See also: https://www.b14643.de/Spacerockets/Specials/VIKAS_engines/Vikas.htm

9.8 Submarine-Launched and Solid Propellant Rockets

Section 9.8.1 concerns submarine-launched missiles that were developed or were under development during the war, as well as the postwar influence of such projects and German-speaking scientific experts.

Section 9.8.2 covers 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 together here.

A number of supporting documents are presented in Appendix E.

9.8.1 Submarine-Launched Missiles

Several submarine-launched missile prototypes and designs were developed in wartime Germany:

- 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. 1904 and 5725–5733.

- 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. 1905 and 5734–5739.

- 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. 1906 and 5740–5748. 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.

- There were also wartime programs to launch modified V-1 cruise missiles from German submarines (pp. 5712–5721).

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:

- 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. 1907).
- 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. That program was even marketed as a great American achievement in magazines (e.g., p. 1908) and in a fictionalized Hollywood film (*The Flying Missile*, 1950, Columbia Pictures). See also p. 5721.
- German-speaking scientists and technologies were used to develop a series of more advanced U.S. cruise missiles beginning in the late 1940s (pp. 1862–1866).
- 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. 1909).
- 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. 1914–1916 and 5798–5834).
- 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. 5749).
- The Soviet Union also investigated versions of the "Prüfstand XII" approach as part of its postwar Golem program to develop SLBMs.[17]
- The first 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. 1910–1911.
- 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. 1912).
- German-speaking scientists and technologies likely also had a great impact on the postwar submarine-launched missile programs of other countries (e.g., p. 5754).

[17] www.globalsecurity.org/wmd/world/russia/golem.htm

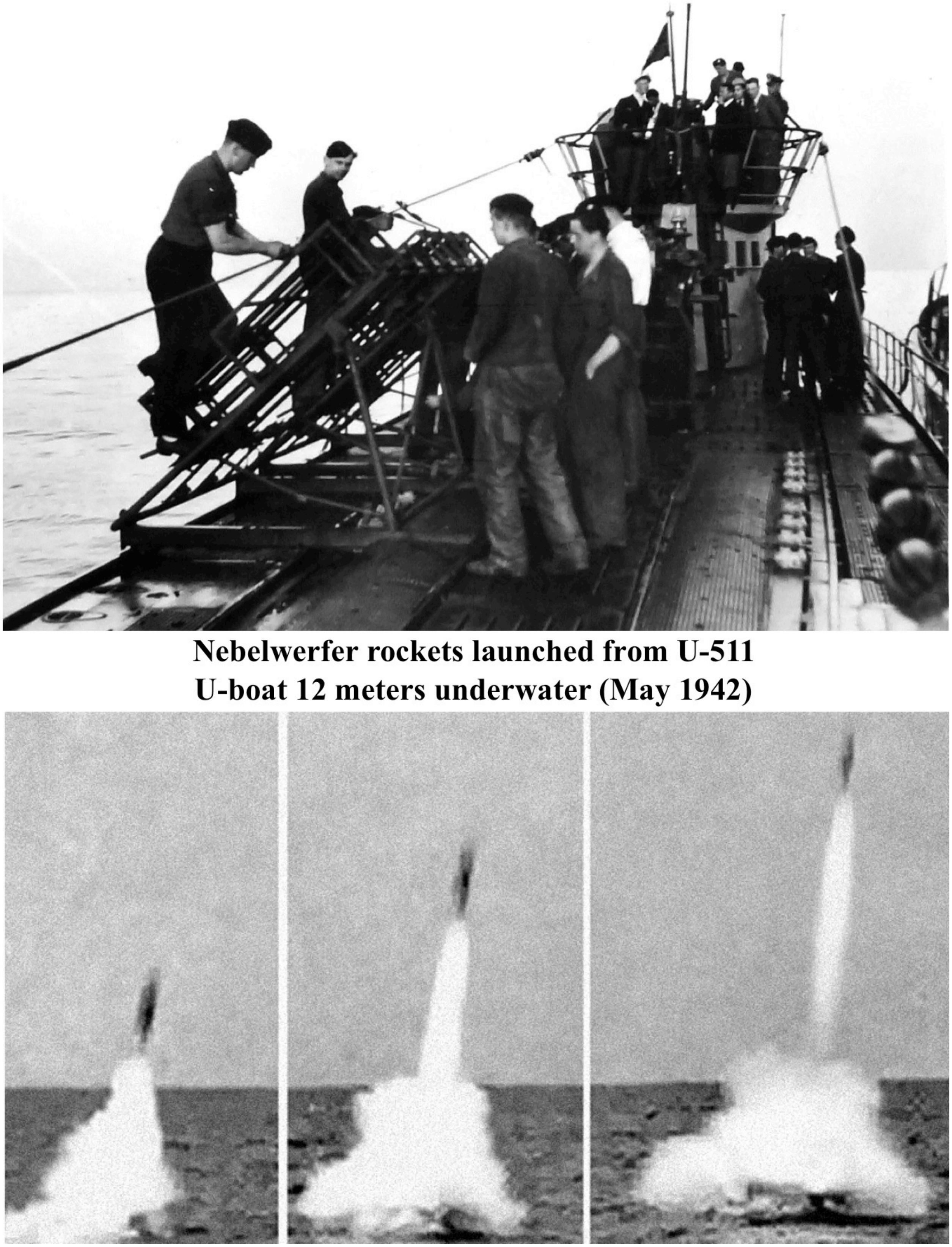


Figure 9.191: Photographs from a 1942 report describing a series of successful tests to launch small rockets from a submerged submarine [Bundesarchiv Militärarchiv Freiburg RH 8/369].

A long series of increasingly sophisticated submarine-launched rockets were developed and successfully demonstrated at Toplitz See, Austria (1942–1945)

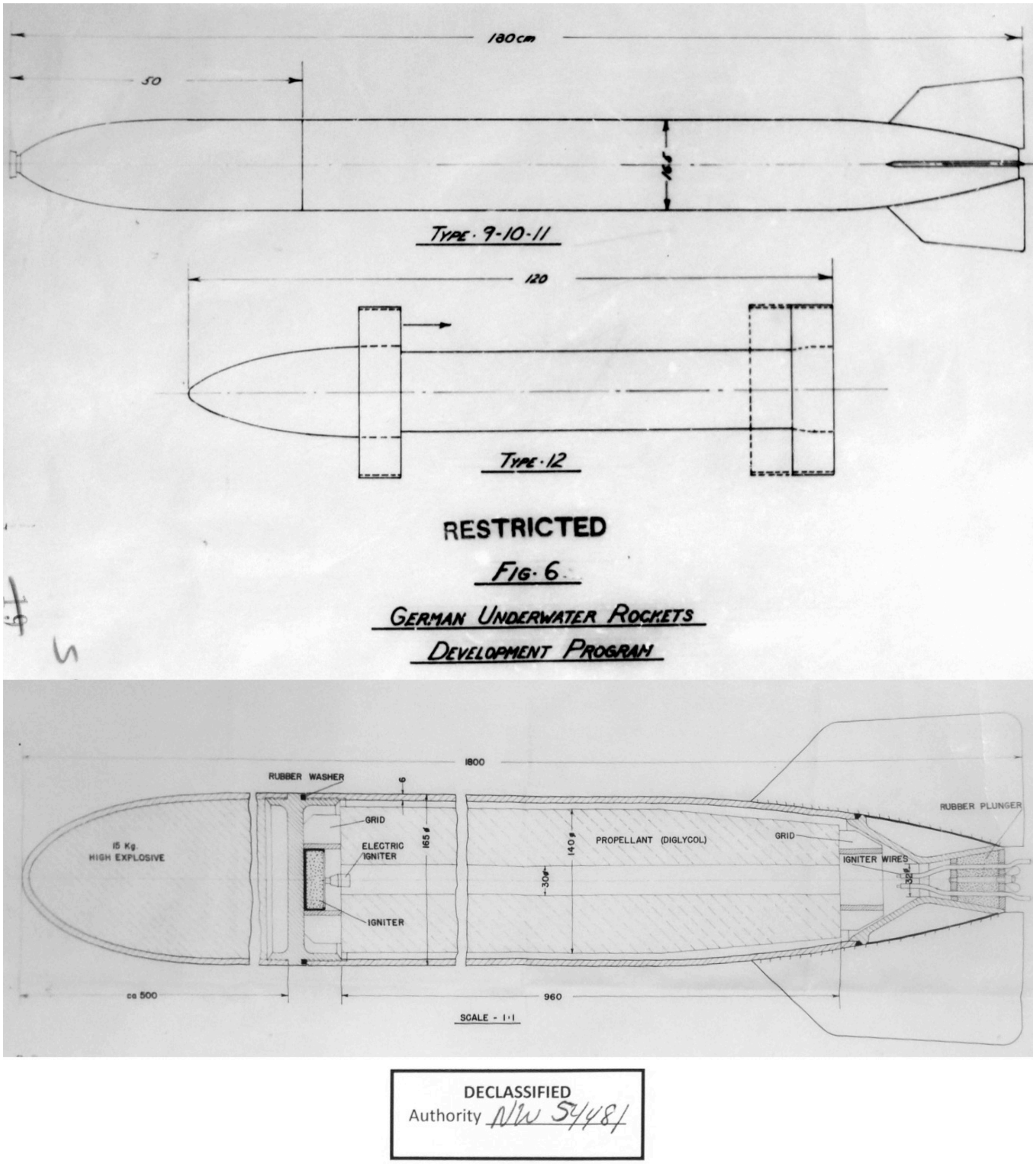


Figure 9.192: Drawings from a postwar report on a long series of increasingly sophisticated submarine-launched rockets that were developed 1942–1945 and successfully demonstrated at Toplitz See, Austria [NavTecMisEu 500-45].

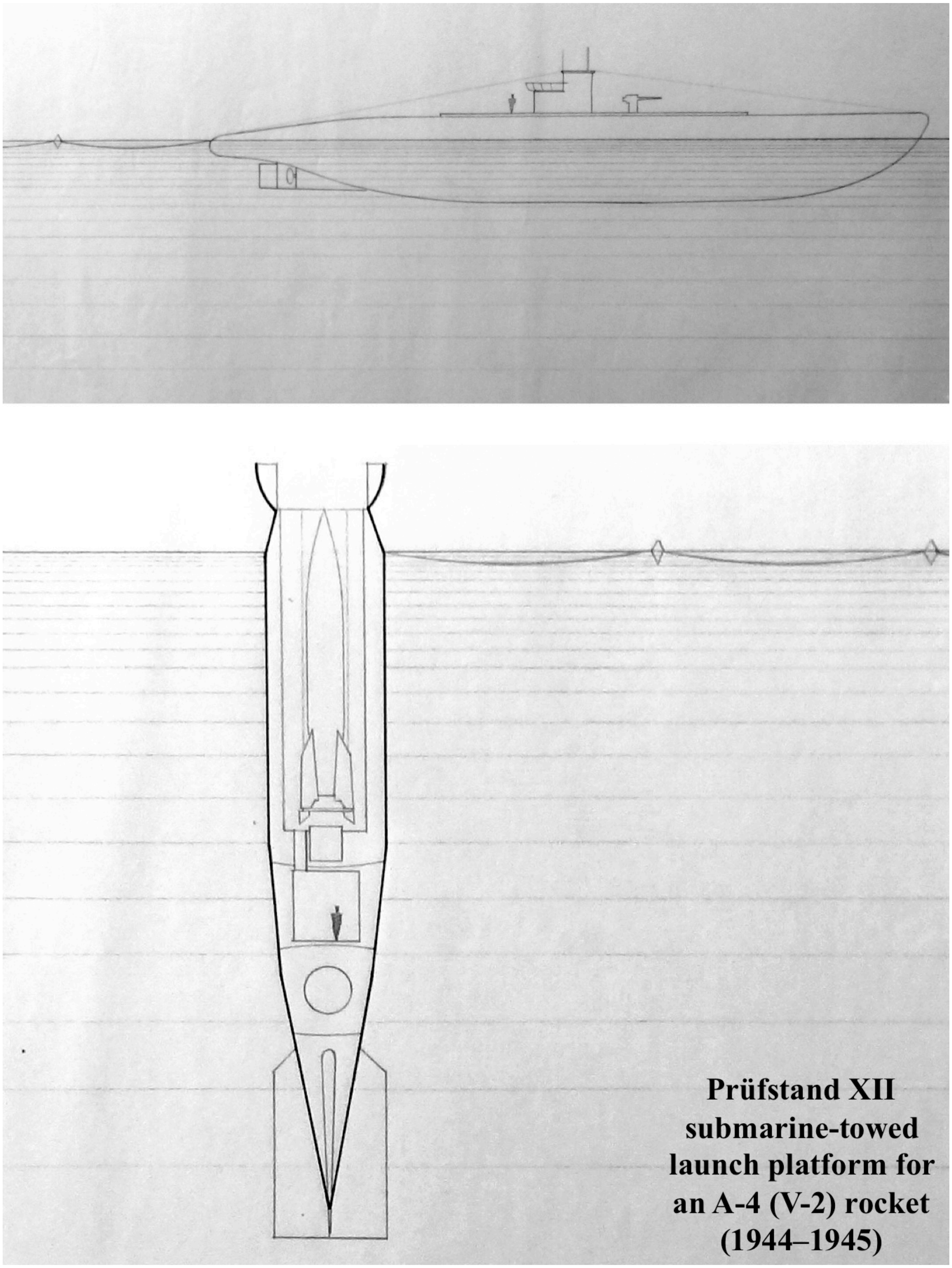


Figure 9.193: 1944 drawings from the "Prüfstand XII" project to transport and launch A-4 (V-2) rockets from specially designed underwater cargo containers that could be towed by submarines [Bundesarchiv Militärarchiv Freiburg RH 8/4067K].

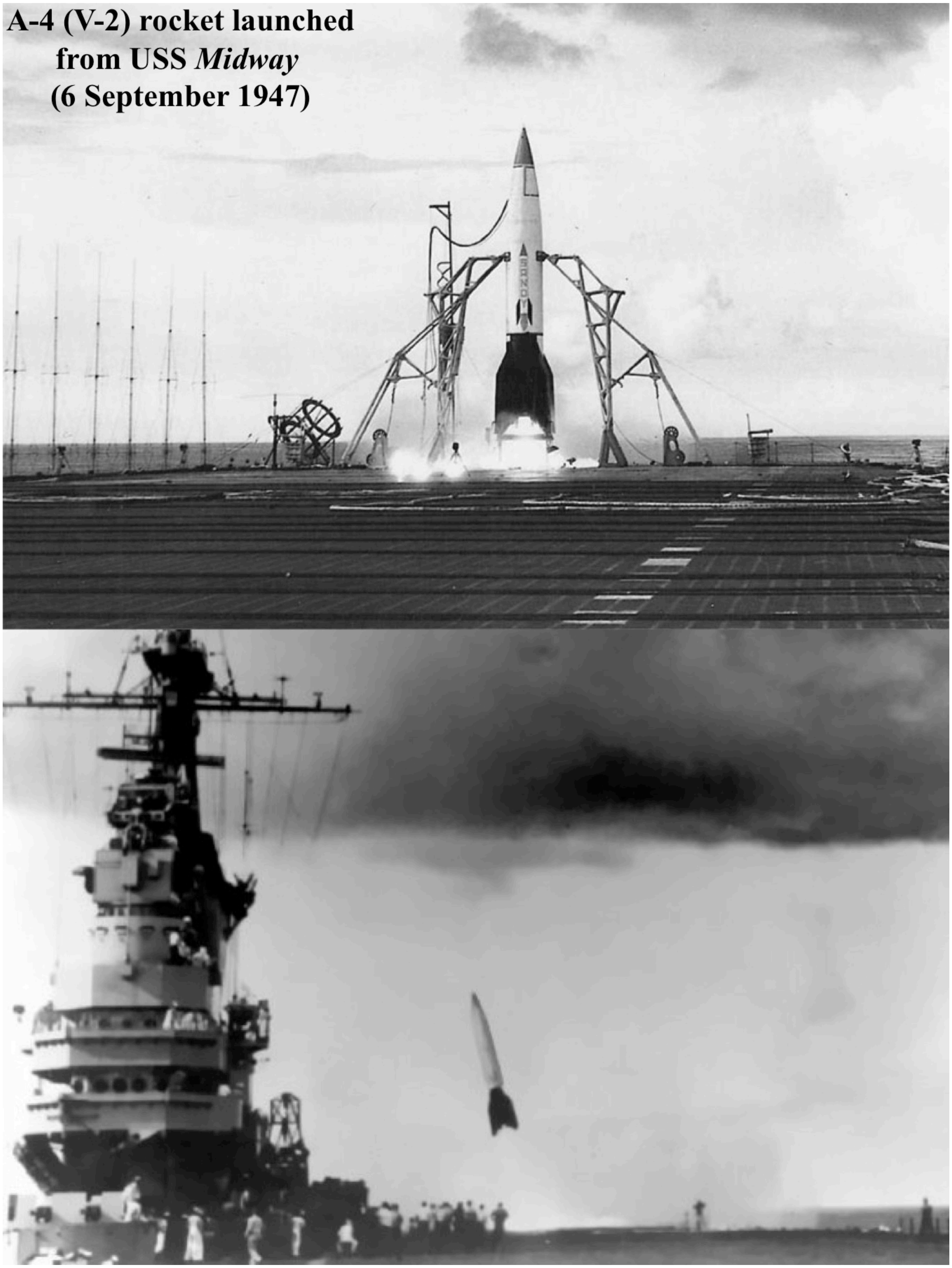


Figure 9.194: As part of Operation Sandy, the U.S. Navy launched an A-4 (V-2) rocket from the deck of the USS Midway on 6 September 1947 [http://www.cv41.org/photos/gallery/main.php?g2_itemId=17451].

U.S. copies of V-1 cruise missile ("Loon") launched from U.S. submarine USS *Cusk* (first launched 12 February 1947)

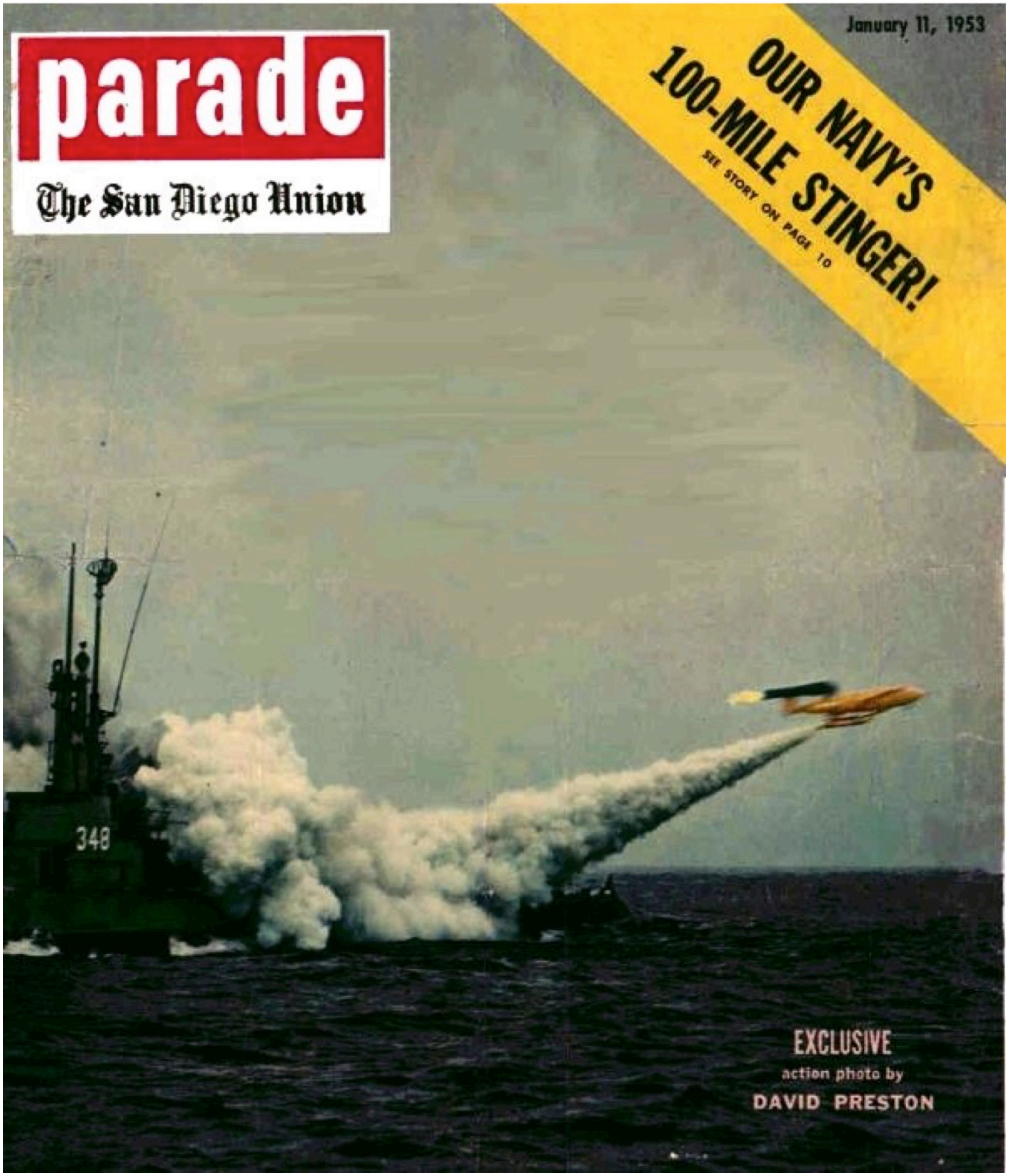


Figure 9.195: Loon, a U.S. copy of the V-1 cruise missile, launched from the USS *Cusk* submarine, based on wartime German developments and implemented by German-speaking scientists at Point Mugu Naval Air Missile Test Center [http://www.usscusk.com/1953.htm].

Figure 9.196: The U.S. PGM-19 Jupiter, first launched in 1957, was developed to be a liquid propellant SLBM. Ultimately it was only launched from land.

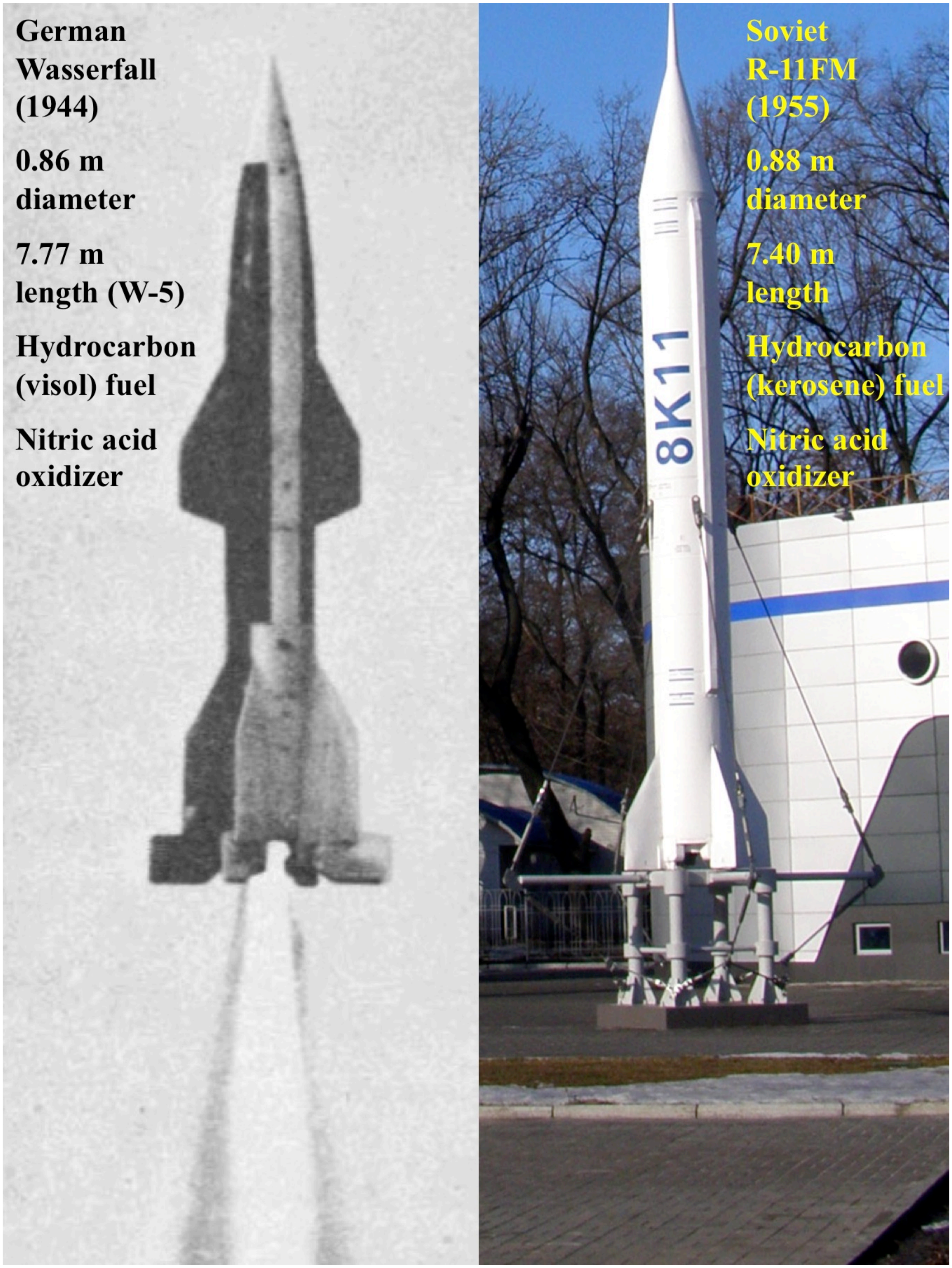


Figure 9.197: The first Soviet SLBM, the R-11FM Zemlya (SS-1B SCUD-A, first launched in 1955), was directly based on the German Wasserfall (first launched in 1944). Like the Wasserfall, it used storable liquid propellants.

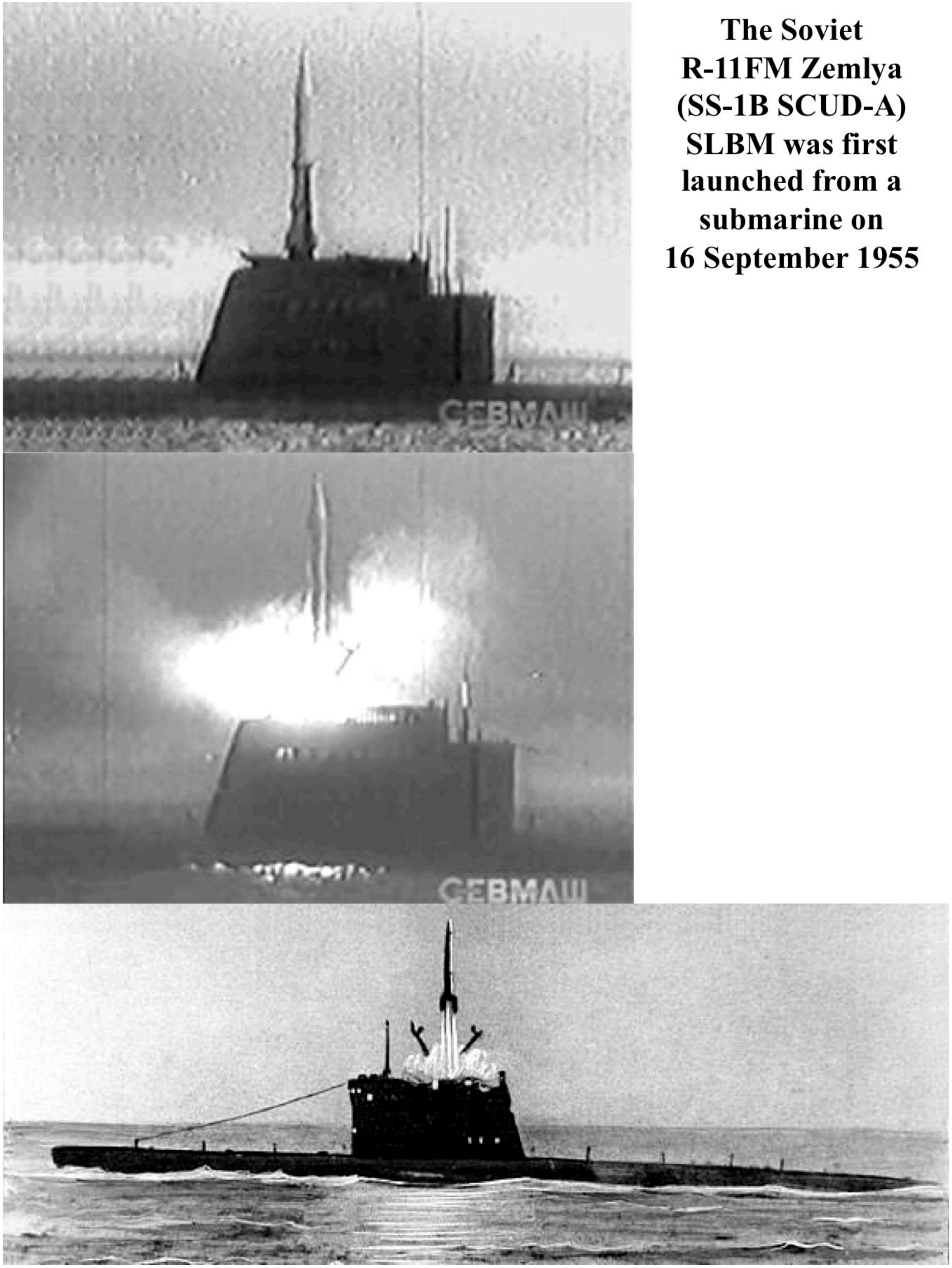


Figure 9.198: The Soviet R-11FM Zemlya (SS-1B SCUD-A) SLBM was first launched from a submarine on 16 September 1955.

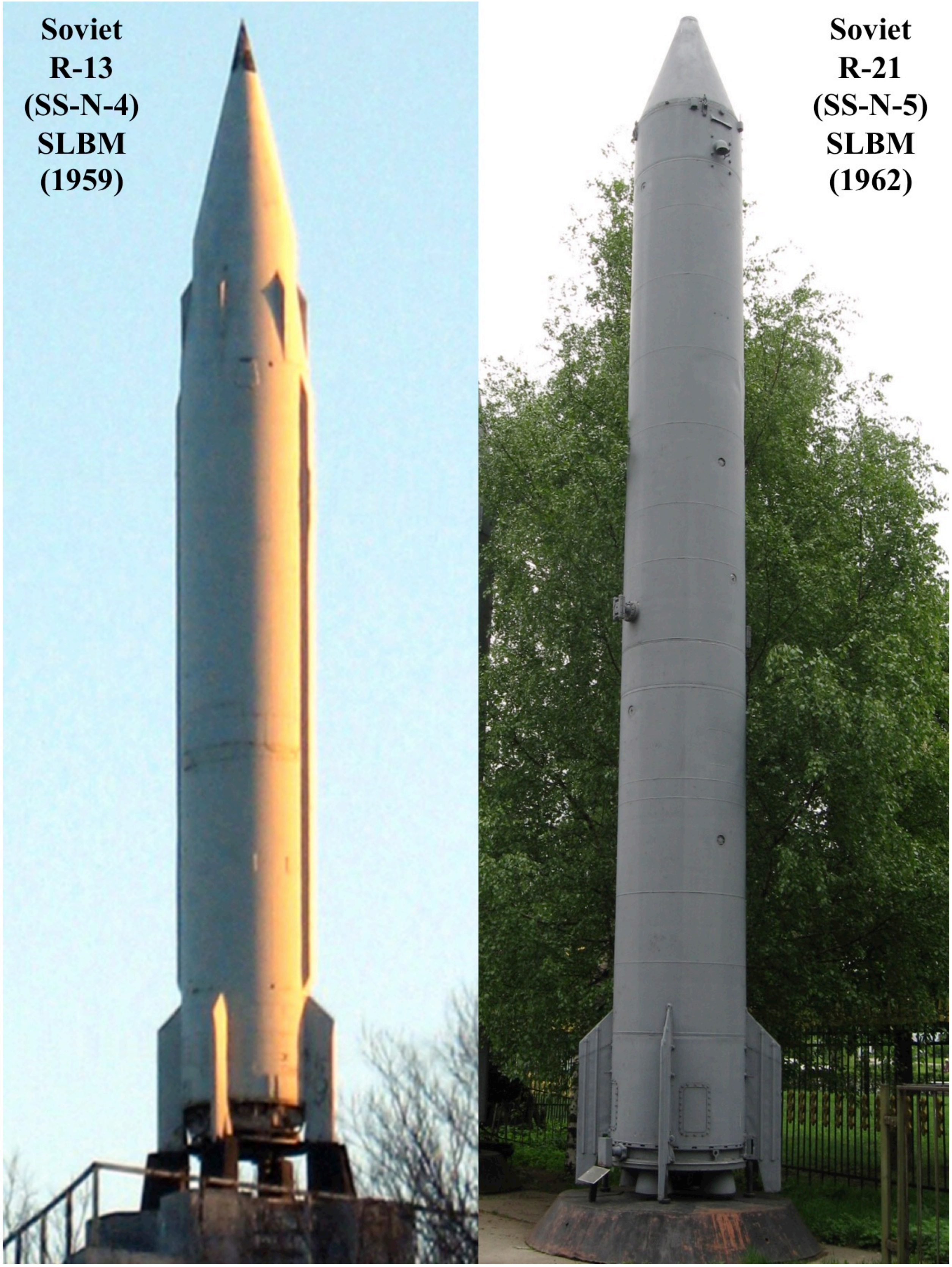


Figure 9.199: Later generations of Soviet SLBMs, such as the R-13 (SS-N-4, first launched in 1959) and R-21 (SS-N-5, first launched in 1962) were scaled up from the R-11FM and again were directly based on German-developed technologies and propellants.

9.8.2 Solid Propellant Rockets

German-speaking creators made huge contributions to large solid propellant rockets.[18] 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.

Most large solid propellant rockets typically contain a mixture of:[19]

$\sim$ 70% (by mass) powdered crystalline oxidizer, usually ammonium perchlorate but sometimes potassium perchlorate, ammonium nitrate, potassium nitrate, cyclotrimethylene trinitramine (RDX), or cyclotetramethylene tetranitramine (HMX).

$\sim$ 15% powdered metal fuel, usually aluminum but sometimes magnesium, zinc, or zirconium.

$\sim$ 15% binder, a polymer that both holds the powdered oxidizer and metal fuel in place (while withstanding high thermal and mechanical stresses) and also serves as additional fuel that can react with the oxidizer. Binders are usually derivatives of polybutadiene (buna synthetic rubber), polyurethane, polyalkylene, or polyvinyl chloride.

$\sim$ 1% or less of other ingredients that may act as curing agents (to cross-link the polymer binder), plasticizers (to make the propellant more flexible and therefore less likely to crack), stabilizers (to slow chemical degradation of the propellant during years of storage), etc.

Instead of the above propellant mixture, missiles that must minimize their smoke (e.g., so it is harder to see them coming) tend to use double-base propellants such as a mixture of nitroglycerin and nitrocellulose.

As shown in Fig. 9.200, solid propellant burns along its exposed surfaces, releasing hot exhaust gases through the nozzle until the propellant is used up or the thrust termination port is opened. An igniter (not shown) initiates the combustion. For all practical purposes, solid propellant rockets cannot be shut down and restarted later, unlike liquid propellant rockets.

The exposed surfaces in a solid propellant rocket may be molded into different patterns or propellant grain designs (Fig. 9.200). Progressive solid propellant grain designs have cross-sectional patterns of exposed surfaces (e.g., tubular or perforated) such that the exposed surface area and hence the thrust increase as the rocket burns. Neutral grain designs (e.g., rod and tube or star) have approximately the same exposed surface area and thrust during most of their burn time. Regressive grain designs (e.g., slotted or double anchor) have a decreasing exposed surface area and thrust as the rocket burns. For more complicated thrust profiles, solid propellant rockets may even change

[18] Benecke and Quick 1957; Christopher 2013; Hahn 1998; Nagel 2011, 2012a; BIOS 27; BIOS 31; BIOS 100; BIOS 571; BIOS 1261; NavTecMisEu 327-45.

[19] [Brooks 1972; Scortia and Cutforth 1971; Hill and Peterson 1991; George Sutton 1992.

the grain design along the length of the rocket, or use different solid propellants that are exposed at different times during the engine burn.

Like liquid propellant rockets, solid rockets may be steered by any of several mechanisms during their burn, including tilting the nozzle (if it is connected to the propellant case by a flexible yet heat-resistant seal or joint), injecting fluid into one side of the exhaust to divert the rest of the hot exhaust gas, or moving heat-resistant rudders or vanes that protrude into the exhaust stream.

During World War II, a number of nearly forgotten German-speaking chemists and engineers, such as those shown in Figs. 9.201–9.205, successfully developed and demonstrated advanced solid propellant rockets, including for example:

- The Rochen ammonium perchlorate/polybutadiene short-range missile, first fired in 1944 (Fig. 9.206).
- The Rheintochter two-stage surface-to-air missile, first launched in 1943 (Fig. 9.207).
- The Rheinbote four-stage long-range rocket, first launched in 1943 (Fig. 9.208).
- 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 (Fig. 9.209).

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].

As illustrated in Figs. 9.210–9.212, 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.

Although aerospace historian J.D. Hunley focused mainly on the work of American engineers, he could not avoid discussing the important contributions of Karl Klager (Austrian, 1908–2002) to the development of large solid-propellant rockets in the United States after the war [Hunley 1999]:

> 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.

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 [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 *Baltimore Sun* reported the death of Werner Hohenner (1907–2000) another German scientist who played an important role in the development of the Polaris missile [*Baltimore Sun* 2000-11-29]:

> 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.

Grayson Merrill, a retired Navy Captain, also emphasized the central role of German-speaking scientists in the missile programs [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.

Rolf Engel, Uwe Bödewadt, and Hermann Teichmann (all of whom developed and demonstrated ammonium perchlorate/polybutadiene solid rocket propellants during the war) all went to work for France after the war (p. 1895). 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 as well.

For much more detailed information on the contributions of German-speaking scientists and engineers to the development of large solid propellant rockets, see Section E.4.

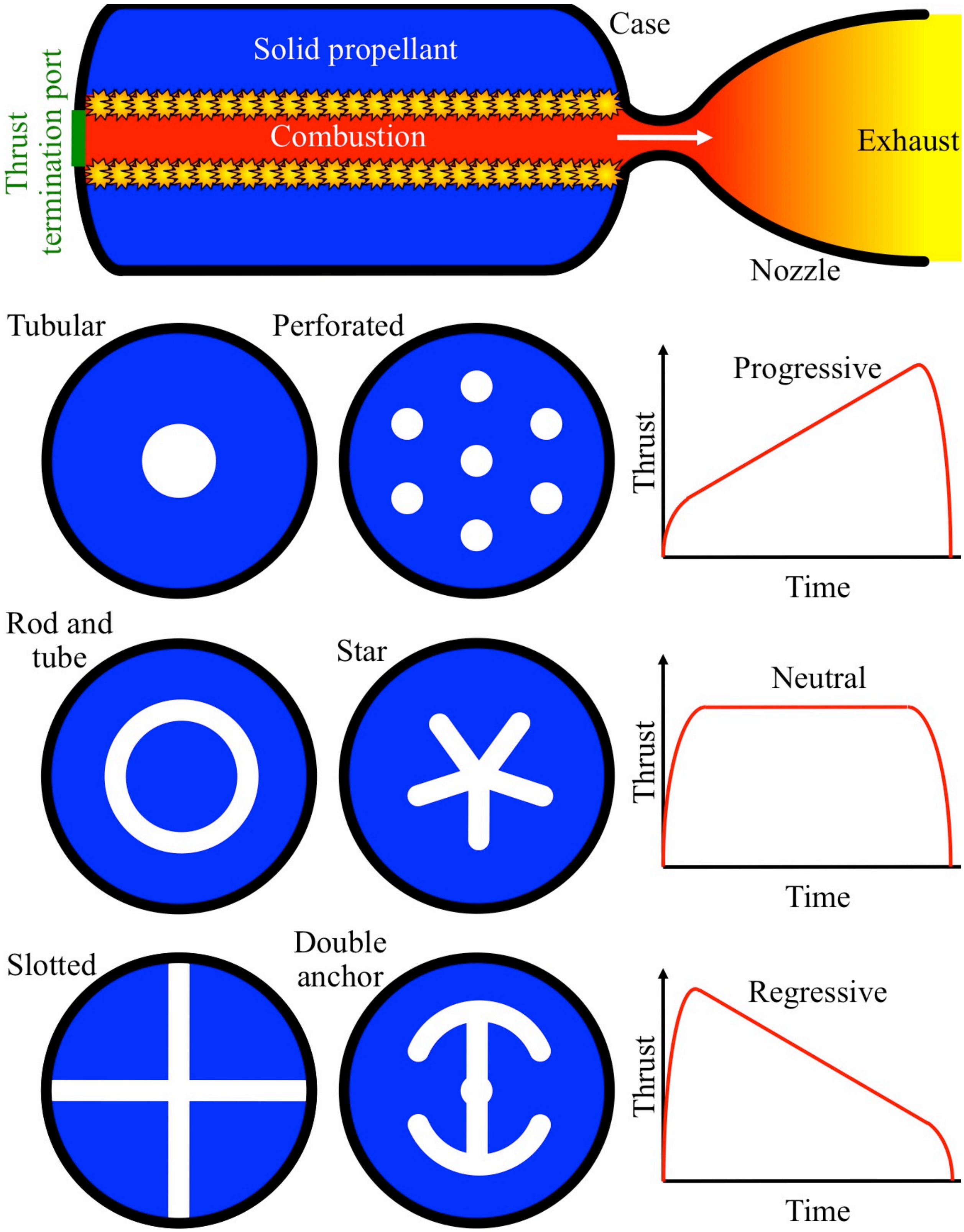


Figure 9.200: In a solid propellant rocket, the propellant burns along its exposed surfaces, releasing hot exhaust gases through the nozzle unless the thrust termination port is opened. Different solid propellant grain designs have different cross-sectional patterns of exposed surfaces such that the exposed surface area and hence the thrust changes in some desired way (increasing, remaining constant, or decreasing) as the rocket burns.

Uwe Bödewadt (1911–2003) **Gerhard Braun (19??–19??)** **Rudolf Buschmann (19??–19??)**

Rudolf Edse (1913–1998) **Rolf Engel (1912–1993)** **Willy Fiedler (1908–1998)**

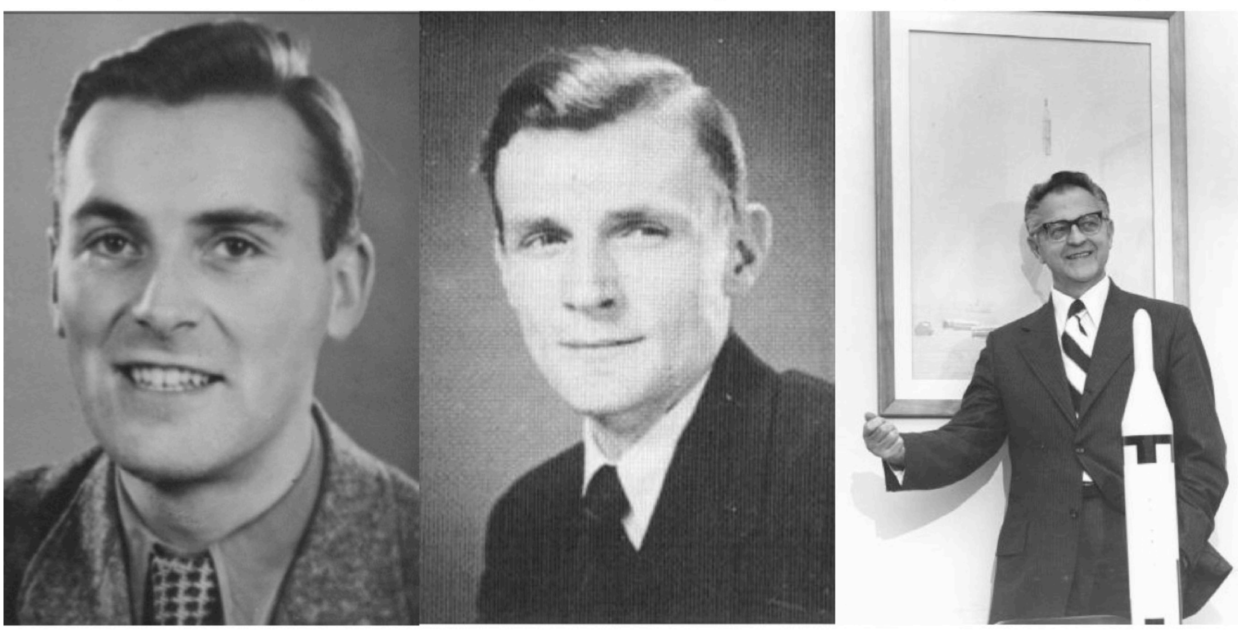


Figure 9.201: Some German-speaking creators of large solid propellant rockets.

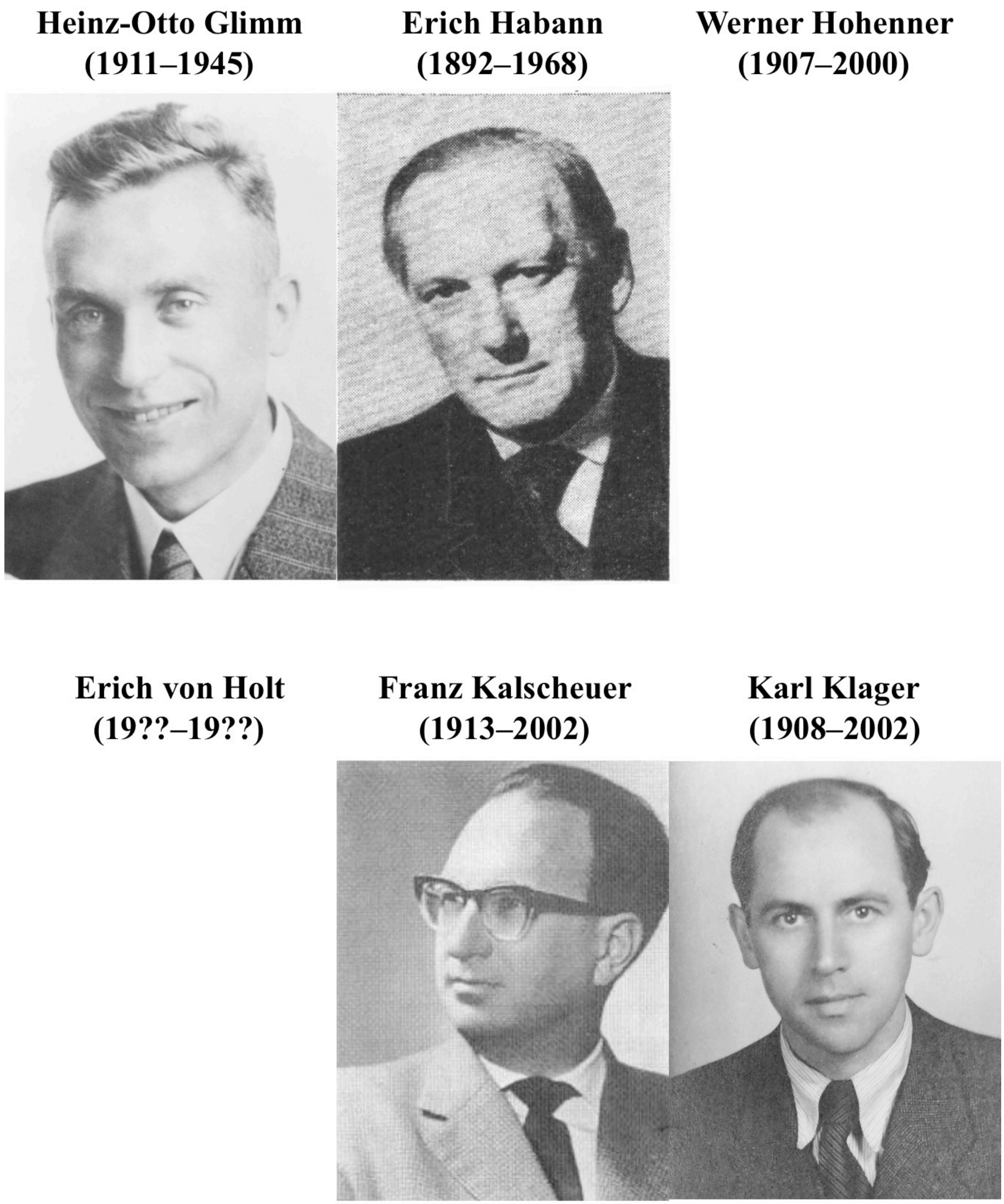


Figure 9.202: More German-speaking creators of large solid propellant rockets.

Heinrich Klein
(19??–19??)

Ernst Knust
(19??–19??)

Heinz Langweiler
(19??–19??)

?? Moßmann
(19??–19??)

Helmut Müller
(19??–19??)

Wolfgang Noeggerath
(1908–1973)

Figure 9.203: More German-speaking creators of large solid propellant rockets.

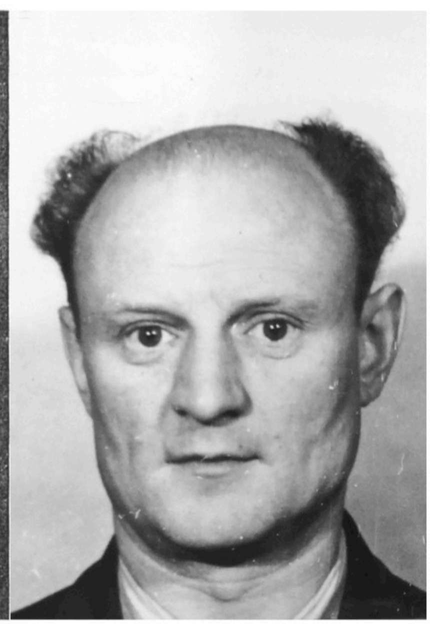
Alfred Nordt
(19??–19??)

Adolf Oberth
(1928–2007)

Wilhelm Orthmann
(1901–1945)

Otto Poppenberg
(1876–1956)

Arthur Rudolph
(1906–1996)



Martin Schilling
(1911–2000)

Figure 9.204: More German-speaking creators of large solid propellant rockets.

Gustav Schweikert (1890–19??)

Hermann Teichmann (1913–1976)

Richard Tilling (1890–1960)

Hermann Vüllers (19??–19??)

Albert Wolff (19??–19??)

Wilhelm Zeyss (1908–20??)

Figure 9.205: More German-speaking creators of large solid propellant rockets.

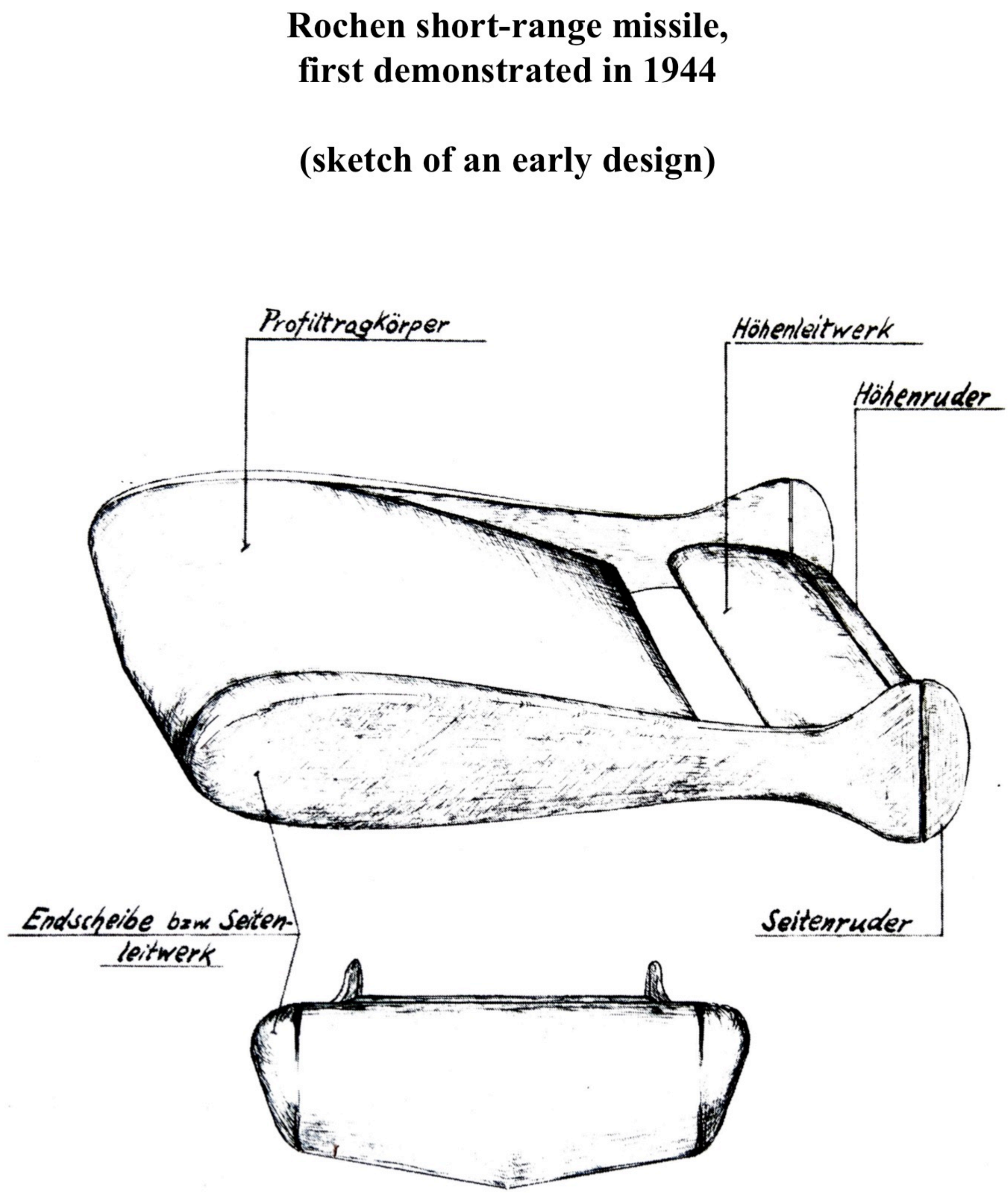


Figure 9.206: The Rochen short-range missile (first fired in 1944) successfully demonstrated ammonium perchlorate/polybutadiene solid rocket propellant.

Rheintochter R1 surface-to-air missile, first demonstrated in 1943

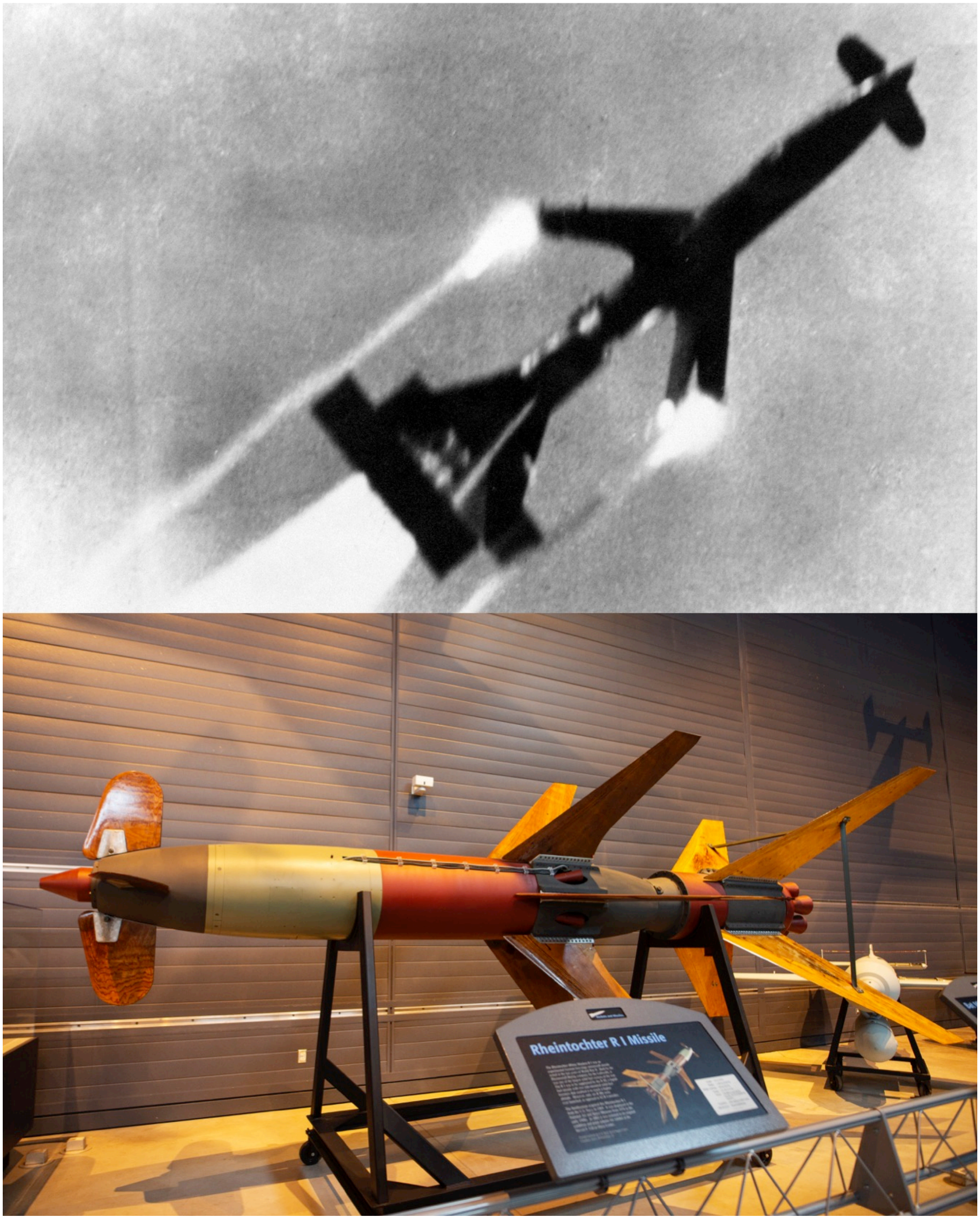


Figure 9.207: Heinrich Klein led the Rheinmetall-Borsig team that created the Rheintochter solid propellant, two-stage, surface-to-air missile, which was first launched in 1943.

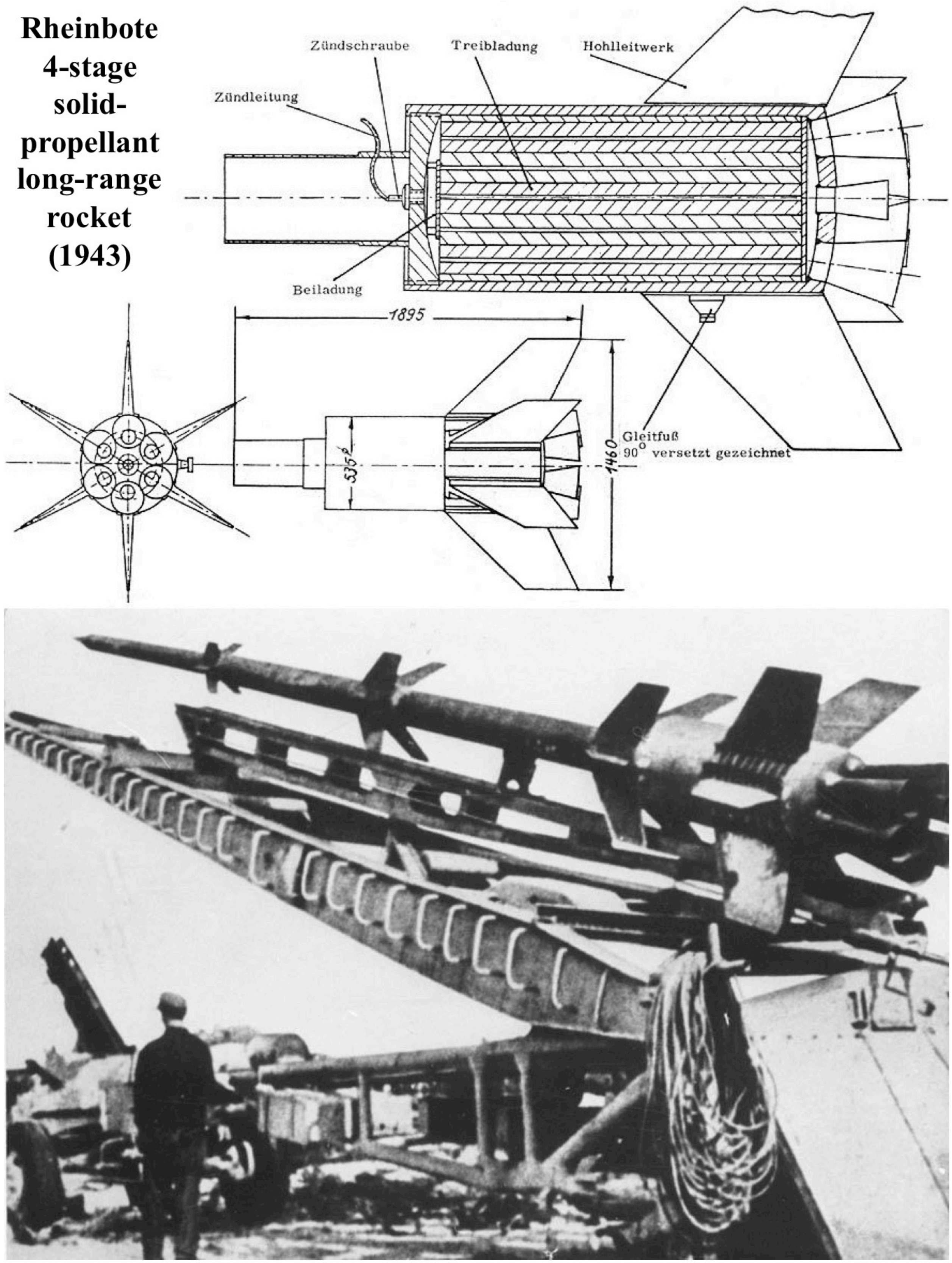


Figure 9.208: Heinrich Klein and his Rheinmetall-Borsig team also created the Rheinbote solid propellant, four-stage, long-range rocket, which was first launched in 1943.

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 perchlotate.

HEC 5787/22

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.

Figure 9.209: Hermann Teichmann and his collaborators invented and optimized ammonium perchlorate/polybutadiene solid rocket propellants, successfully demonstrated them in the Rochen short-range missile, and were using those propellants to develop a 140-ton, 30-meter-tall, long-range ballistic missile, the Skoda V-101, when the war ended [top: BIOS 571; bottom: HEC 5787].

Figure 9.210: German-speaking scientists played major roles in the development of postwar large solid propellant rockets such as the Polaris missiles.

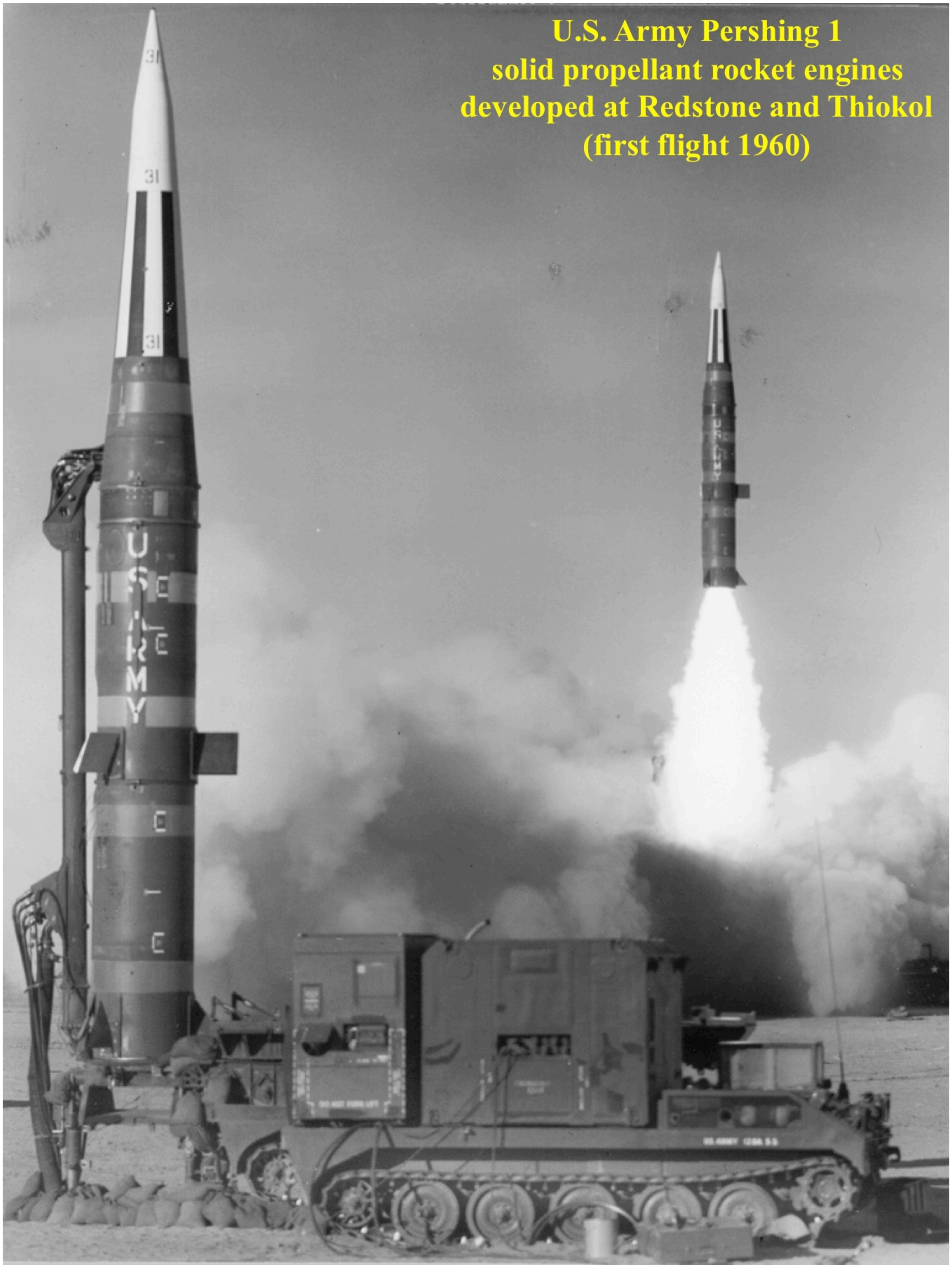


Figure 9.211: German-speaking scientists played major roles in the development of postwar large solid propellant rockets such as the Pershing missiles.

Figure 9.212: German-speaking scientists played major roles in the development of postwar large solid propellant rockets such as the Minuteman missiles.

9.9 Rocket Planes and Space Planes

German-speaking creators also led the way in the development of rocket planes (Section 9.9.1) and space planes (Section 9.9.2), from the first rocket plane in 1928 to the U.S. Space Shuttle.[20]

9.9.1 Rocket Planes

German-speaking scientists and engineers designed and tested numerous rocket planes from the 1920s to 1945:[21]

- Alexander Lippisch (German, 1894–1976) designed the first rocket plane, the Lippisch Ente, which was powered by two solid propellant rockets and test flown in 1928. See Fig. 9.213.

- In 1929, Fritz von Opel (German, 1899–1971) funded and piloted the second rocket plane. The Opel RAK.1 was designed and built by Julius Hatry (German, 1906–2000), with solid propellant rockets by Friedrich Sander (German, 1885–1938). See Fig. 9.213.

- In the late 1930s, engineers under Ernst Heinkel began developing and testing rocket planes using liquid propellant rocket engines, provided first by Wernher von Braun and then by Hellmuth Walter (German, 1900–1980). The culmination of that work was the Heinkel He 176, which was successfully test flown in 1939, powered by a Walter rocket engine. See Fig. 9.214.

- Shortly after that, Hellmuth Walter produced the liquid rocket engine, and Alexander Lippisch and Friedrich Otto Ringleb (German, 1900–1966) created the aircraft, for the Messerschmitt Me 163 Komet (Comet) rocket plane, the best-known German rocket plane. The Me 163 was first demonstrated in 1941, and several hundred were produced by the end of the war; see Figs. 9.215–9.216.

- In 1944, Erich Bachem (German, 1906–1960) designed the Bachem Ba 349 Natter rocket plane for vertical take-off. Several dozen were built, but they were still undergoing testing at the end of the war. See Fig. 9.217.

- Felix Kracht (German, 1912–2002) created the DFS (Deutsche Forschungsanstalt für Segelflug) 228, which was designed to be launched from a Dornier Do 217 bomber, then use a Walter rocket to climb to an altitude of up to 25 km. Two prototypes were built in 1944 but were still being tested at the end of the war. Nonetheless, the DFS 228 designs that were captured by the Allies appear to have had an enormous influence on the design of the postwar U.S. U-2 high-altitude spy plane. See Fig. 9.218.

[20] Chertok 2005–2012, Vol. 1, pp. 262–265; Robert Godwin 2003, pp. 38–51; Myhra 2002; Putt 1946b; R. Dale Reed 1997, pp. 129–130, 136; Eugen Sänger and Bredt 1944; Hartmut Sänger 2006; Frank Winter 1990; NYT 1986-11-05.

[21] Dressel and Griehl 1995; Lommel 2002; Miller 2001; Myhra 2000b; Ranson and Cammann 2003; Späte 1983; CIOS XXVII-67, XXX-81.

- Kracht also created the DFS 346, which was again designed to be launched from a Do 217 bomber but would then have used its streamlined design and its Walter rocket engine to break the sound barrier. A prototype was constructed but not tested before the end of the war. Captured designs for the DFS 346 appear to have had a tremendous influence on the designs for the Bell X-1 and X-1A through X-1E rocket planes that were built and tested in the U.S. after the war. See Fig. 9.218.

- Alexander Lippisch designed and built the DM-1 rocket plane in 1944, and continued to work on the prototype until spring 1945. It was designed for flight at several times the speed of sound, although a suitable propulsion system was not installed before the war ended. (Lippisch considered various propulsion systems, including Walter liquid rocket engines and a ramjet.) Among other influences it exerted, the DM-1 may be regarded as a direct forerunner of lifting bodies that the United States began testing in the 1960s. See Fig. 9.219.

After the war, Lippisch moved to the United States, where he developed a wide range of aerospace technologies at the White Sands Missile Range, Convair, Collins Radio, and his own Lippisch Research Corporation. Walter developed submarines and other technologies in the United Kingdom, United States, and West Germany. Felix Kracht worked on many aerospace projects in France and West Germany, eventually finishing his career as the Senior Vice President of Airbus.

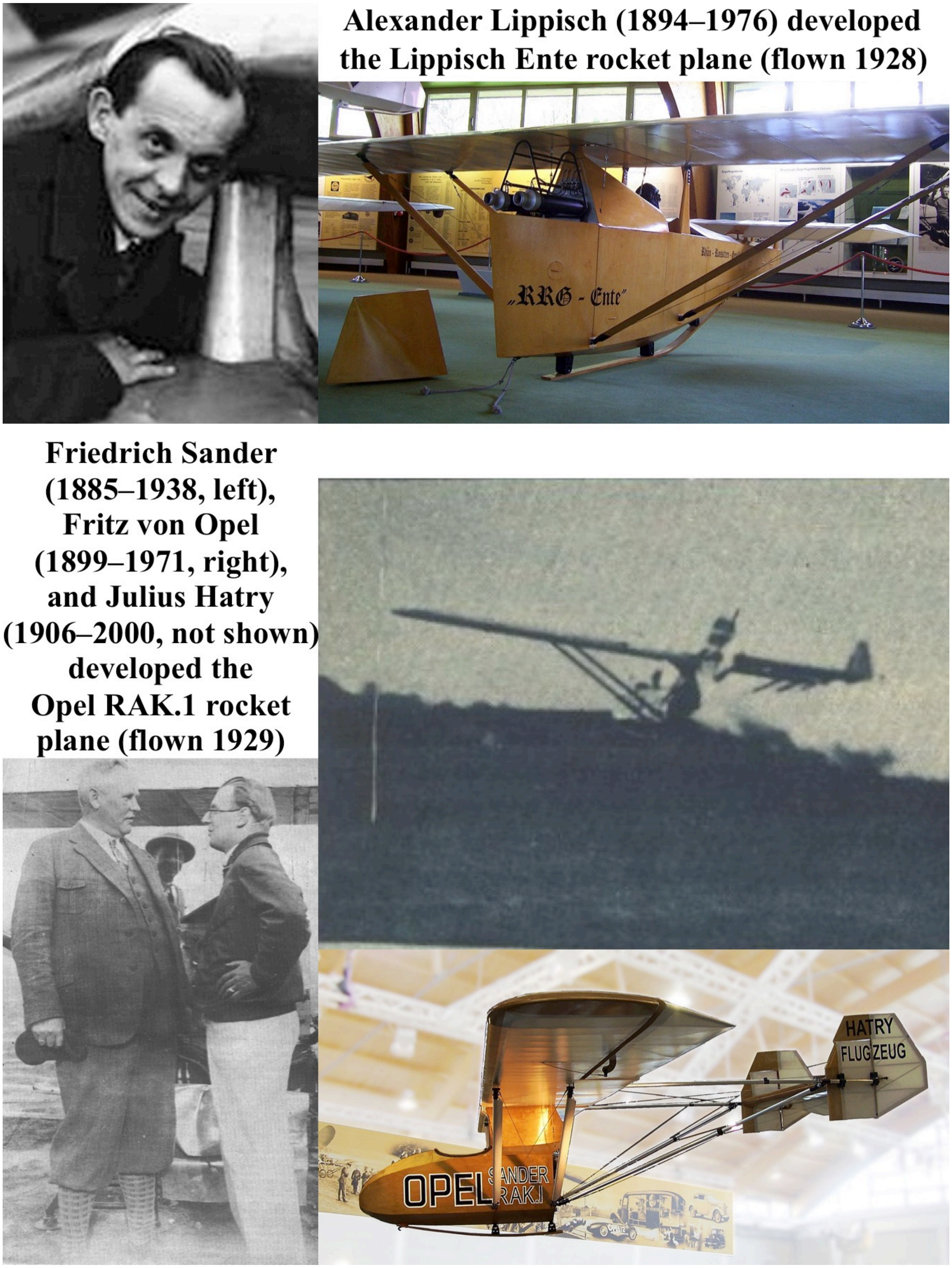


Figure 9.213: Alexander Lippisch developed the Lippisch Ente rocket plane. Friedrich Sander, Fritz von Opel, and Julius Hatry developed the Opel RAK.1 rocket plane.

Hellmuth Walter (1900–1980)

Walter HWK 109-509 engine

Heinkel He 176 rocket plane (flown 1939)

Figure 9.214: Hellmuth Walter designed most German rocket plane engines, such as the HWK 109-509 engine. The Heinkel He 176 rocket plane successfully demonstrated an earlier version of a Walter rocket engine in 1939.

Alexander Lippisch, Friedrich Ringleb, and Hellmuth Walter created the Messerschmitt Me 163 Komet (Comet) rocket plane (1941)

Me 163 in flight

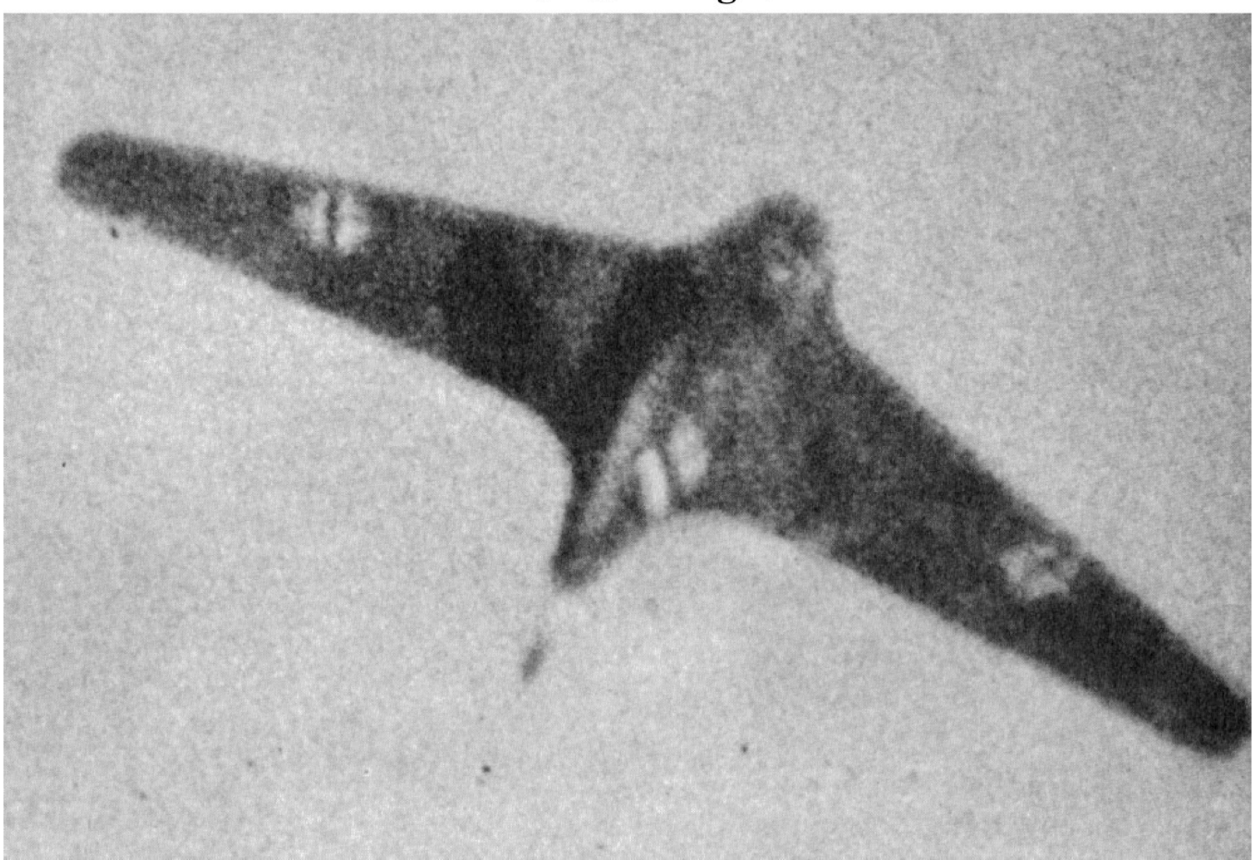


Figure 9.215: Alexander Lippisch and Friedrich Otto Ringleb created the aircraft, and Hellmuth Walter created the rocket engine, for the Messerschmitt Me 163 Komet (Comet) rocket plane, first flown in 1941.

Alexander Lippisch (1894–1976) Friedrich Otto Ringleb (1900–1966)

Me 163 Komet (Comet) rocket plane (1941)
and numerous postwar U.S. aerospace projects

Figure 9.216: Alexander Lippisch and Friedrich Otto Ringleb designed the Messerschmitt Me 163 Komet (Comet) rocket plane (1941) and numerous postwar U.S. aerospace projects [*Dayton Daily News*, 8 December 1946, p. 55].

Erich Bachem (1906–1960)
Hanna Reitsch (1912–1979)

Bachem Ba 349 Natter rocket plane

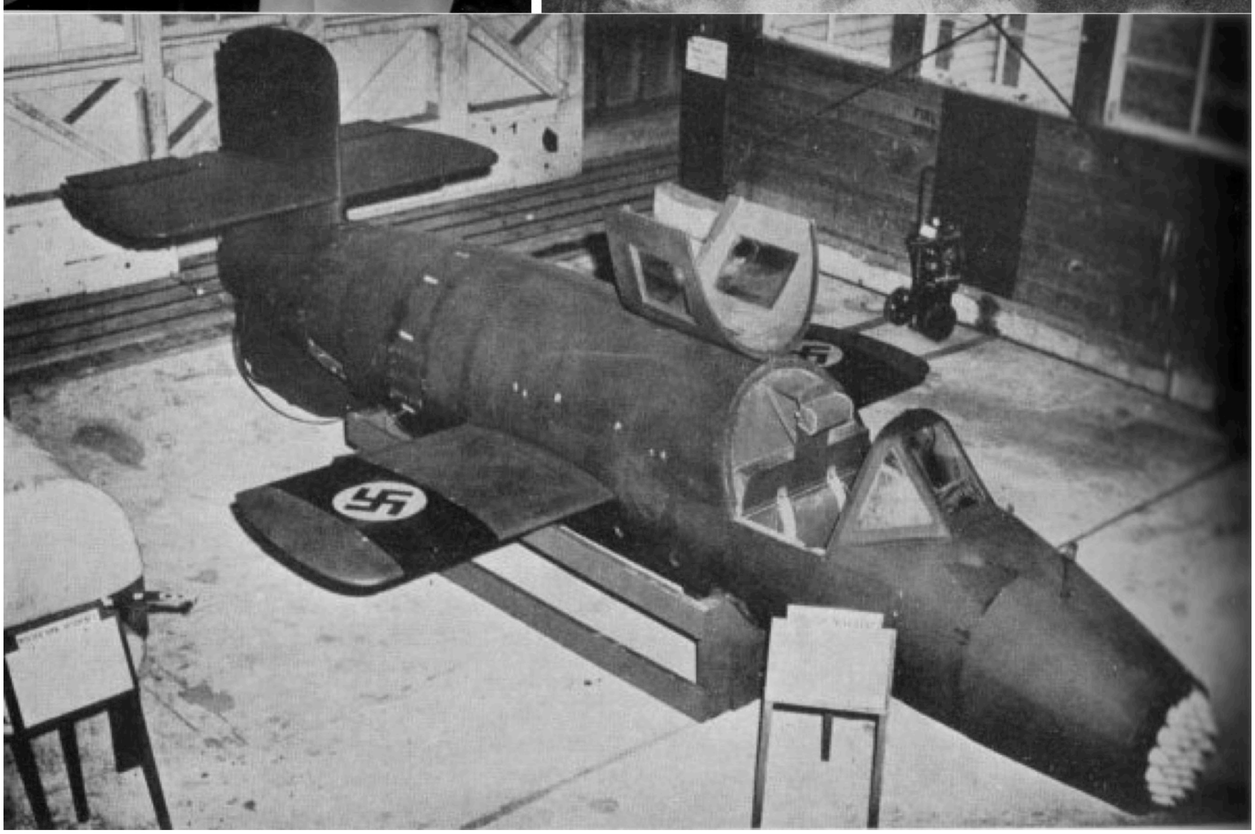
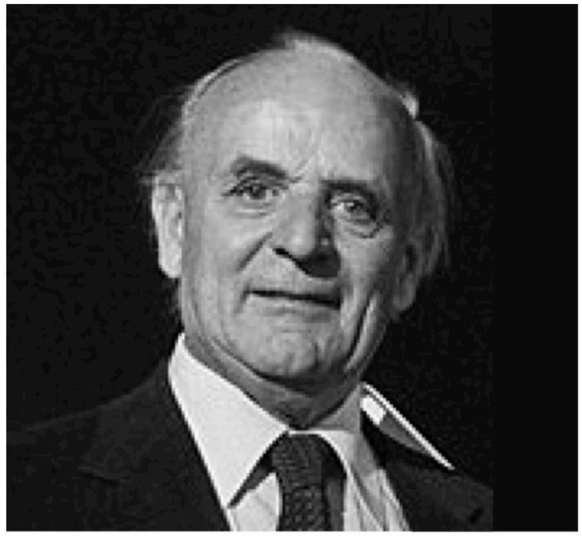


Figure 9.217: Erich Bachem (shown here with famous test pilot Hanna Reitsch) designed and built the Ba 349 Natter, a vertically launched rocket plane.

Felix Kracht (1912–2002)



DFS 228 rocket plane prototype carried on Do 217 bomber

DFS 346 rocket plane prototype

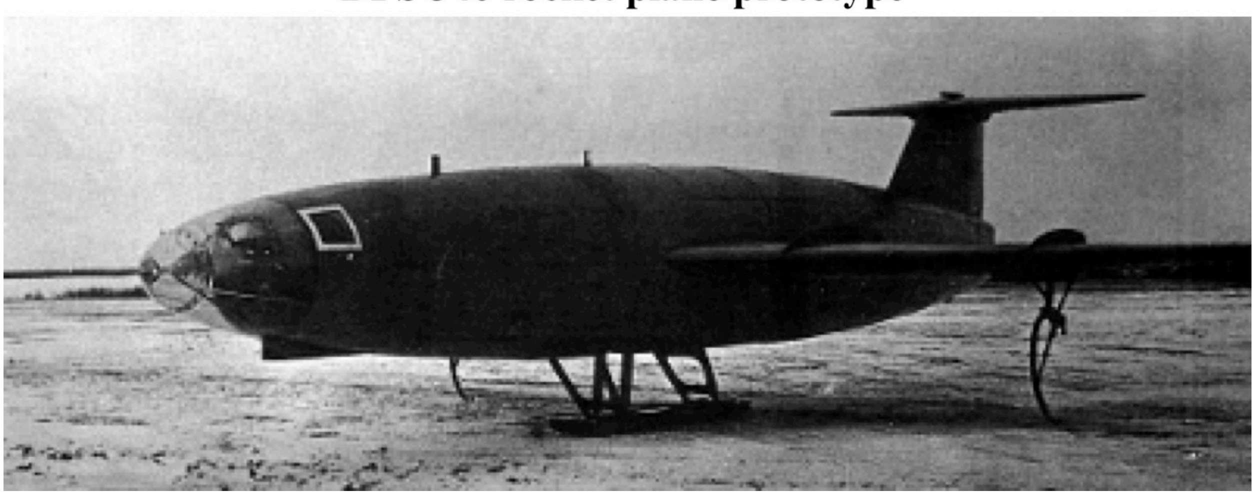


Figure 9.218: Felix Kracht designed rocket planes such as the DFS 228 (predecessor of the U-2 spy plane) and the DFS 346 (predecessor of the Bell X-1 rocket plane).

Alexander Lippisch designed and built the DM-1 rocket plane prototype (1944–1945)

Figure 9.219: Alexander Lippisch created the DM-1 rocket plane prototype, which was designed to travel at several times the speed of sound.

9.9.2 Space Planes

As shown in Fig. 9.220, different types of vehicles can employ different trajectories for reentering the earth's atmosphere from space. In a ballistic reentry, the vehicle cannot generate aerodynamic lift to stay aloft, so it quickly plunges into denser and denser layers of atmosphere, rapidly decelerating due to the large aerodynamic drag force. Ballistic reentry trajectories involve decelerations of at least 8–9 times earth's normal gravity, as well as tremendous heating from atmospheric friction. Ballistic reentry is used by most warheads and was used by the Vostok and Mercury space capsules.

In contrast, lifting reentry trajectories apply to the case in which the vehicle generates aerodynamic lift, which allows the decelerating vehicle to remain much higher, in the thinner parts of the atmosphere, much longer than is possible for a ballistic vehicle with no lift. As a result, vehicles using lifting reentry trajectories experience much smaller decelerations and heating loads, which is why space plane designs are especially attractive. They can also maximize the distance travelled, which was of great interest for long-range bombing during World War II.

As shown in Fig. 9.221, Ludwig Roth (German, 1909–1967), with backing from Wernher von Braun and Walter Dornberger (German, 1895–1980), led the team that developed the A-4b or A-9 winged rocket and launched it in 1945. For evidence that versions of the A-9 designed to accommodate two astronauts may have actually been manufactured during the war, see Section E.2.

As illustrated in Fig. 9.222, Eugen Sänger (1905–1964) and Irene Bredt (1911–1983) designed the Silbervogel space plane, which would have accommodated one astronaut and was even larger than the A-9. They made detailed designs and trajectory calculations for the Silbervogel from the 1930s until 1945. For evidence that prototype hardware for the Silbervogel may have actually been constructed during the war, see Section E.3.

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 (Fig. 9.220). Both the A-9 and Silbervogel would have used rocket power to achieve a suborbital flight, and then could have repeatedly skipped off the atmosphere to travel part of the way around the Earth before reentering for a final time and bombing a target.[22]

Building upon the wartime work on the manned winged A-9 and Silbervogel, many creators and creations from the German-speaking world played critical roles in postwar programs to develop space planes, including the U.S. Space Shuttle:

- 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].

[22] A more complex reentry trajectory that is closely related to the skip reentry is the double-dip reentry. If a spacecraft is returning from deep space with a huge amount of kinetic energy, its deceleration and aerodynamic heating would be too great if all of its kinetic energy were expended during just one pass into the earth's atmosphere. For this reason, the U.S. Apollo and Soviet Zond capsules that returned from the moon executed a double-dip reentry, making two passes into the atmosphere before landing. The wartime calculations for the A-9 and Silbervogel pioneered this area of reentry trajectory methods, and then German-speaking scientists who went to the United States and Soviet Union after the war helped to implement those methods.

- 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. 1866). 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 (p. 1944). 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, p. 1717) designed the Martin Marietta X-24 lifting body, which first flew in 1969 [R. Dale Reed 1997, pp. 129–130, 136]; see pp. 1945 and 5706.

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

- The U.S. Space Shuttle (Fig. 9.225) incorporated design features, experience, and personnel from the earlier A-9, Silbervogel, Bomi, Dyna-Soar, and X-24 space plane programs [Frank Winter 1990, pp. 42–44, 113–122]; see pp. 5702 and 5704.

- 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. 5705.

- 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. 5707–5711).

- 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. 9.225), the Soviet Buran (first launched in 1988, Fig. 9.227), and other space planes such as Dream Chaser (Fig. 9.228) [Chertok 2005–2012, Vol. 1, pp. 262–265; Frank Winter 1990, pp. 42–44, 113–122].

For more information on wartime and postwar space plane programs, see Section E.3.

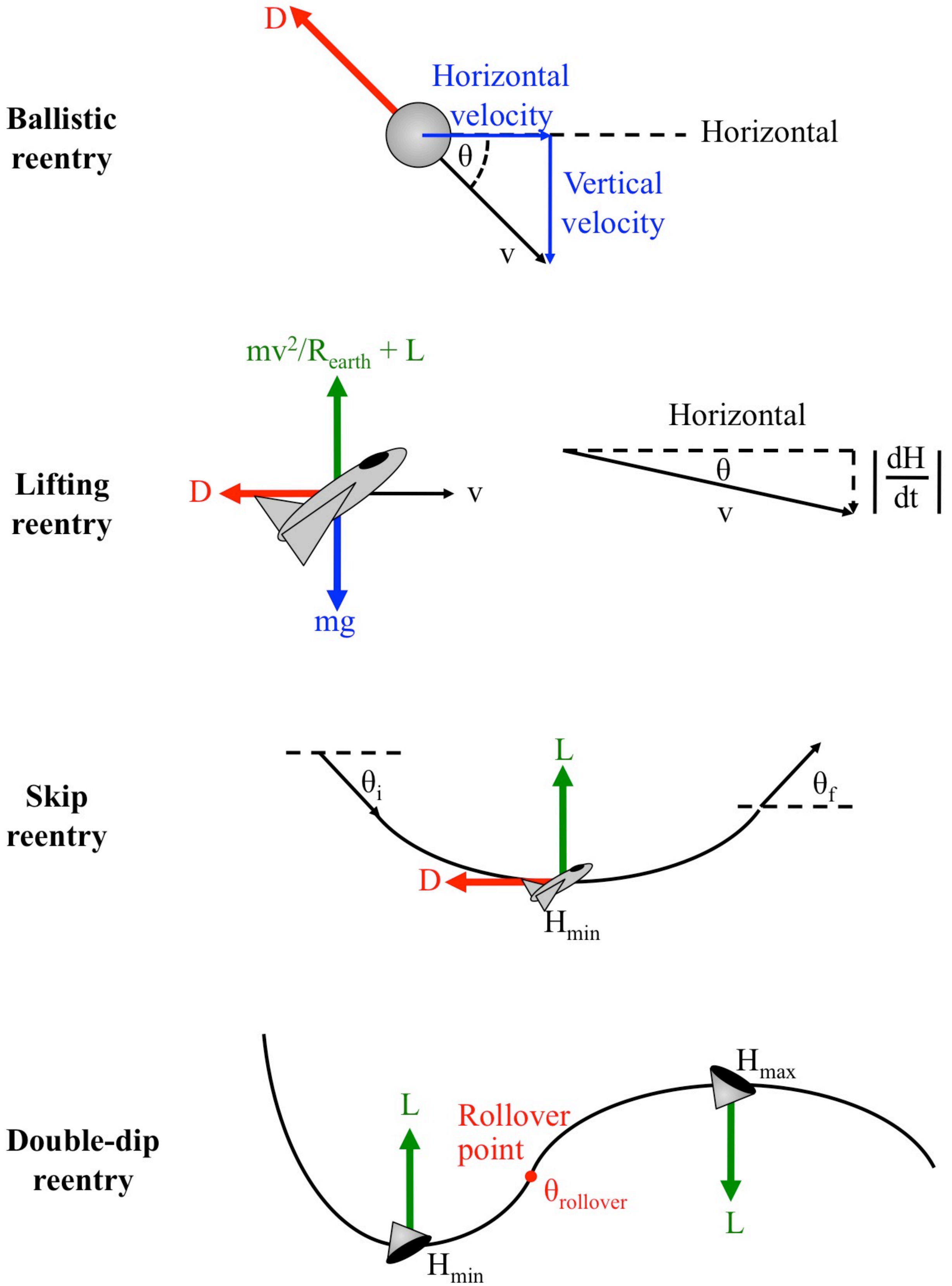
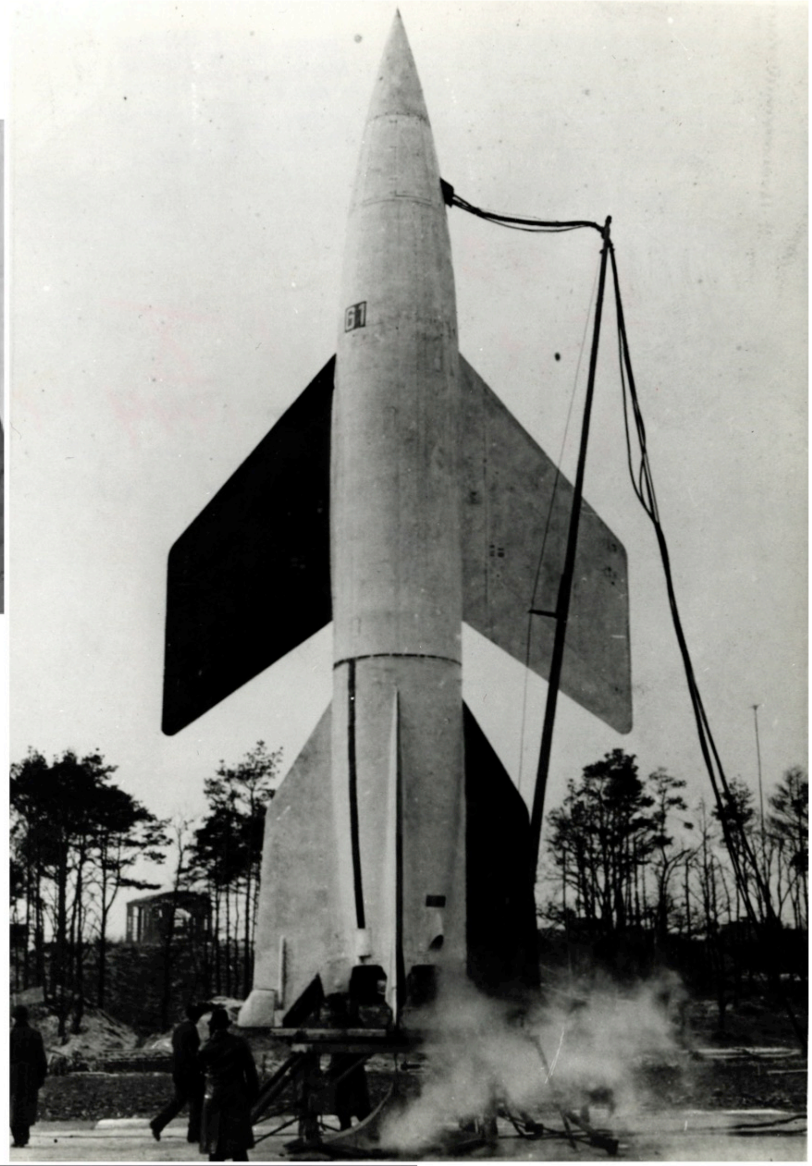


Figure 9.220: Atmospheric reentry approaches include ballistic reentry, lifting-body reentry, skip reentry, and double-dip reentry.

Ludwig Roth (1909–1967)



A-4b (A-9) in flight (1945)

Figure 9.221: Ludwig Roth led the team that developed the A-4b or A-9 winged rocket and launched it in 1945.

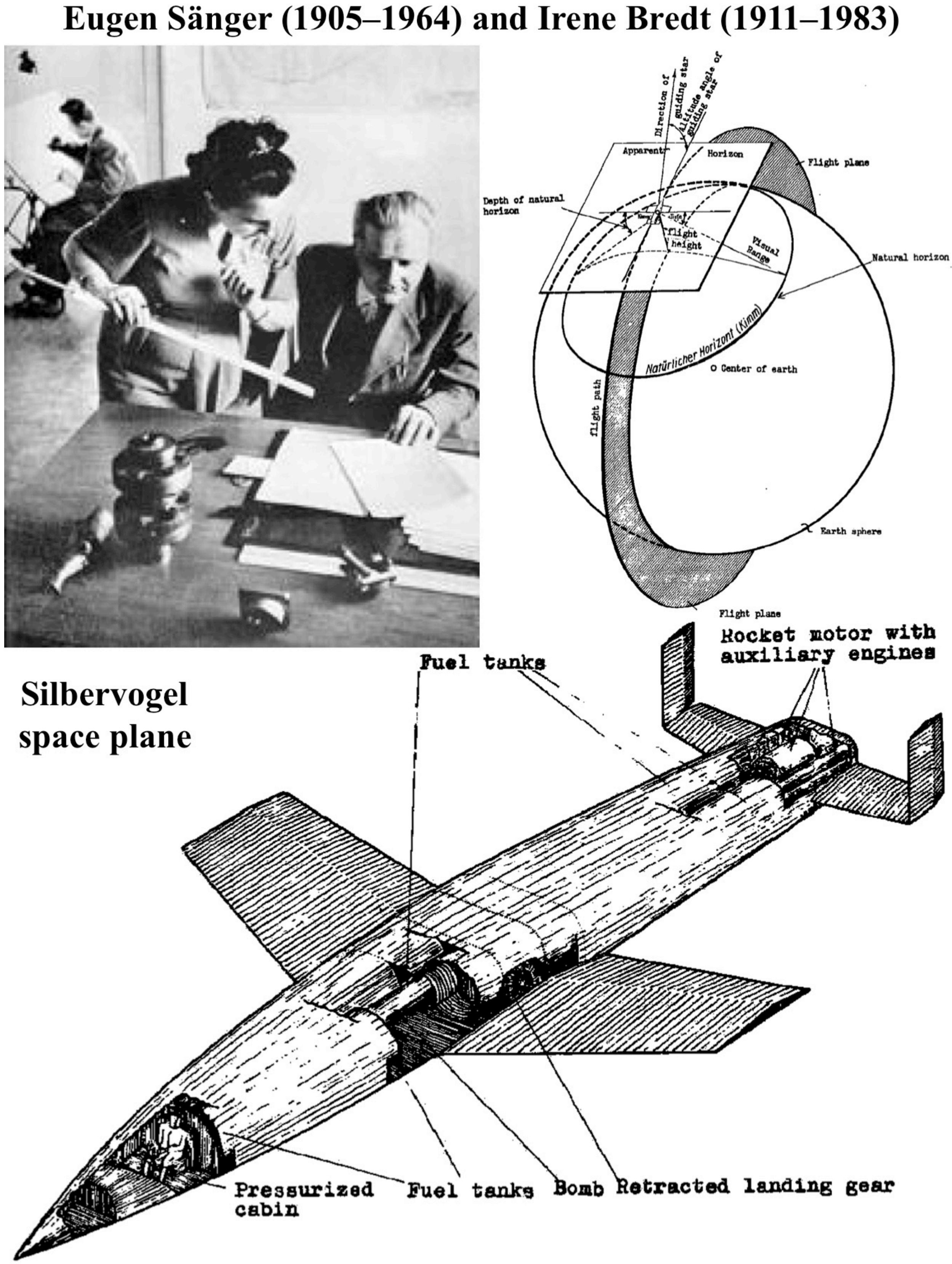
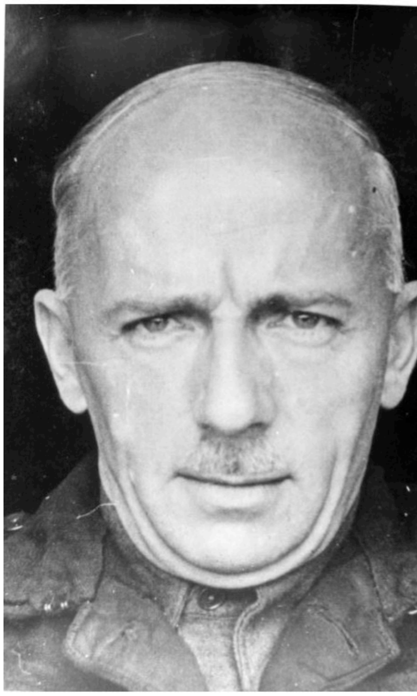


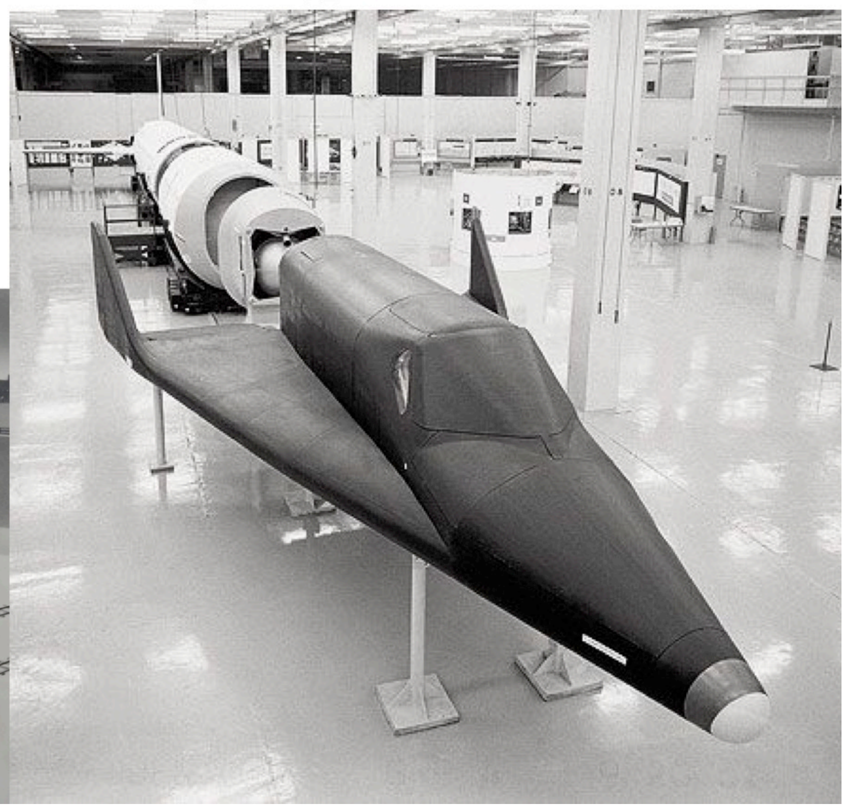
Figure 9.222: Eugen Sänger and Irene Bredt designed the larger Silbervogel space plane and constructed prototype hardware for it during World War II.

Walter Dornberger (1895–1980)



X-15 rocket plane (first flight 1959)

X-20 Dyna-Soar space plane prototype (cancelled 1963)



Bell Aerospace Bomi (Bomber Missile, proposed 1952)

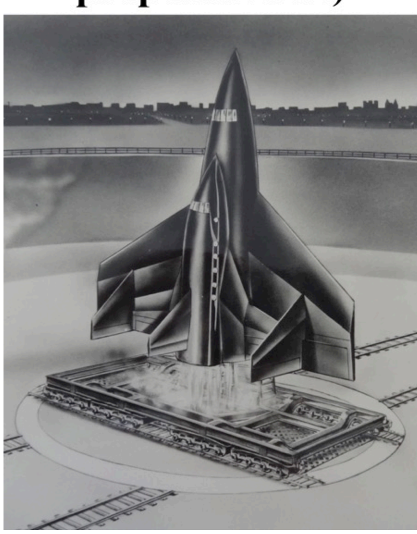


Figure 9.223: Walter Dornberger led the design of the several highly influential postwar rocket planes and space planes, such as the Bomi (Bomber Missile) space plane, the X-15 rocket plane, and the X-20 space plane. He also named NASA's space plane program the Space Shuttle.

Hans Multhopp (1913–1972) **X-24 lifting body (1969)**

Figure 9.224: Hans Multhopp designed the Martin Marietta X-24 lifting body, which first flew in 1969. The modern Sierra Nevada Dream Chaser (p. 1949) is essentially a larger version of Multhopp's design.

Figure 9.225: First launch of a U.S. Space Shuttle, *Columbia* STS-1, on 12 April 1981.

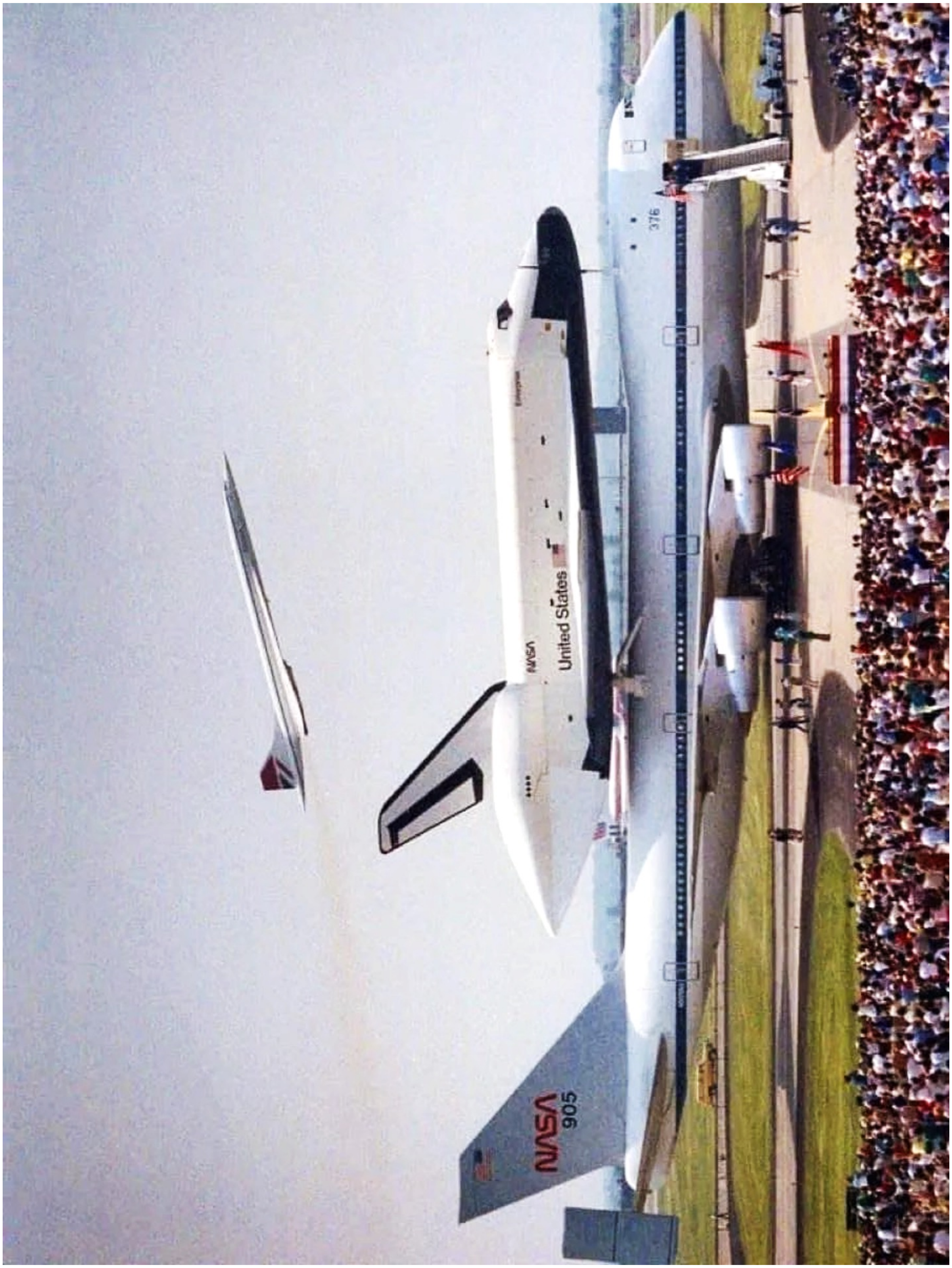


Figure 9.226: A Concorde, Space Shuttle, and 747 together at Washington Dulles International Airport in 1986. These three vehicles were made possible by the work of many German-speaking creators, as shown in this chapter and Appendix E.

Figure 9.227: First and only launch of the Soviet space shuttle, Buran OK-1K1, on 15 November 1988.

**The Sierra Nevada Corporation's Dream Chaser,
aiming for a first launch in 2022, is one of
the latest vehicles to recycle the designs
of Eugen Sänger, Irene Bredt,
Walter Dornberger, Hans Multhopp,
and the other German-speaking creators**

Figure 9.228: The Sierra Nevada Corporation's Dream Chaser, aiming for a first launch in 2022, is one of the latest vehicles to recycle the designs of Eugen Sänger, Irene Bredt, Walter Dornberger, Hans Multhopp, and the other German-speaking creators. Especially note the striking resemblance to Multhopp's X-24 design (p. 1945); it has simply been made larger to accommodate more people.

9.10 Space Exploration

On top of their work on liquid and solid rocket propulsion and space shuttles, German-speaking creators led the way with regard to other aspects of long-term space exploration, including designing:

9.10.1. Interplanetary trajectories

9.10.2. Space stations

9.10.3. Non-chemical rockets

9.10.1 Interplanetary Trajectories

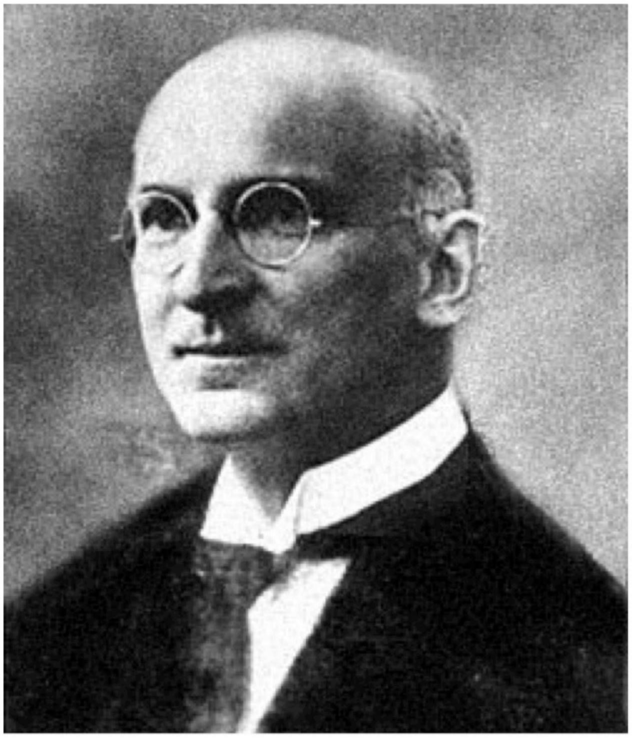
Walter Hohmann (German, 1880–1945) published a detailed textbook of calculations for spacecraft trajectories and orbits in 1925 [Hohmann 1925]. Figures 9.229–9.230 show illustrations from his book for calculations regarding atmospheric reentry, aerobraking, and what are now called Hohmann transfer ellipses—elliptical 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.

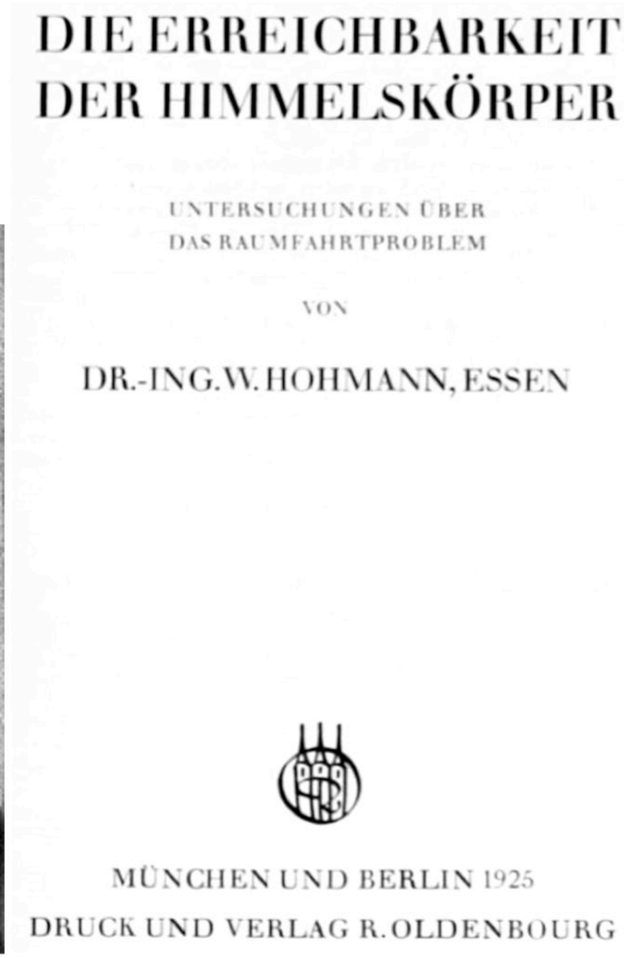
In 1928, Franz von Hoefft (Austrian, 1882–1954, Fig. 9.231) laid out the first systematic plan for steadily progressing from small initial test rockets to very large rockets capable of carrying people to the moon and to other planets [Ley 1928]. Although von Hoefft did not have the opportunity to realize his vision, Wernher von Braun's team did, with their long series of rockets in Germany in the 1930s and 1940s and then in the United States through the 1960s.

Willy Ley (German, 1906–1969, Fig. 9.231) studied earth science at the University of Berlin but spent the rest of his life promoting rockets and space exploration, writing a large number of highly influential books in that area between 1926 (when he was only 20) and his death in 1969. Ley's activities and his books directly inspired, brought together, and publicized the work of many other scientists and engineers involved with rockets and space exploration.

For information on the contributions of German-speaking scientists to planetary science and astrophysics, see Sections 4.5–4.6.

Walter Hohmann (1880–1945) published a detailed textbook of calculations for spacecraft trajectories and orbits (1925)





DIE ERREICHBARKEIT DER HIMMELSKÖRPER

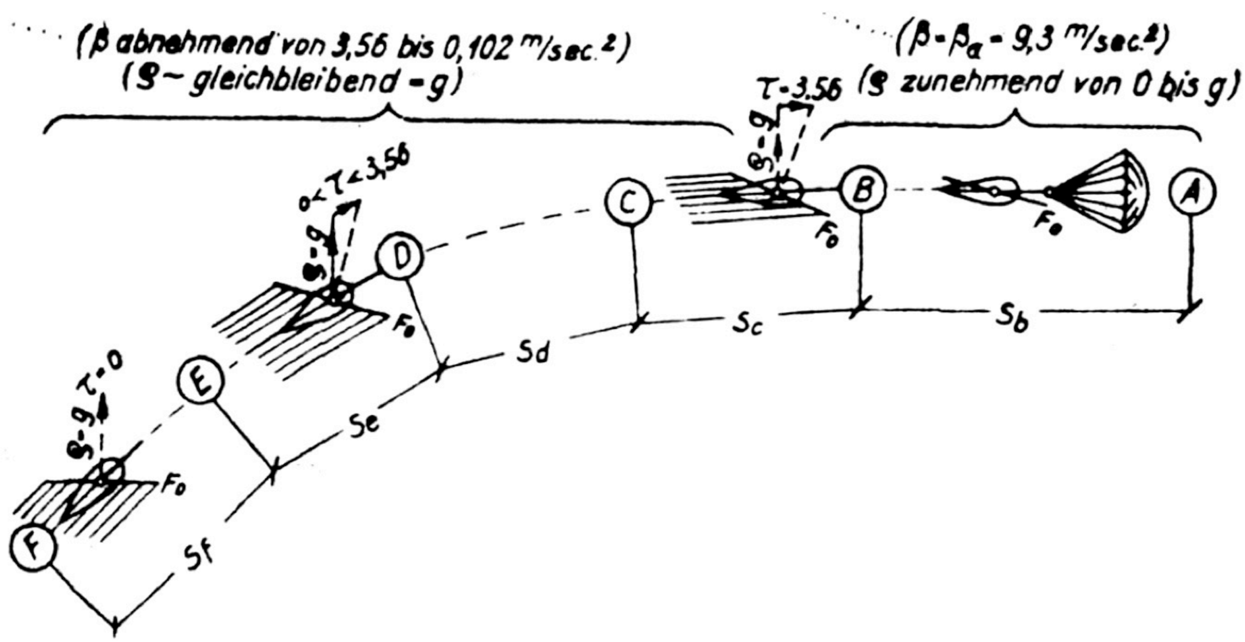
UNTERSUCHUNGEN ÜBER DAS RAUMFAHRTPROBLEM

VON

DR.-ING. W. HOHMANN, ESSEN

MÜNCHEN UND BERLIN 1925

DRUCK UND VERLAG R. OLDENBOURG



Atmospheric reentry trajectory

Figure 9.229: Walter Hohmann published a detailed textbook of calculations for spacecraft trajectories and orbits in 1925.

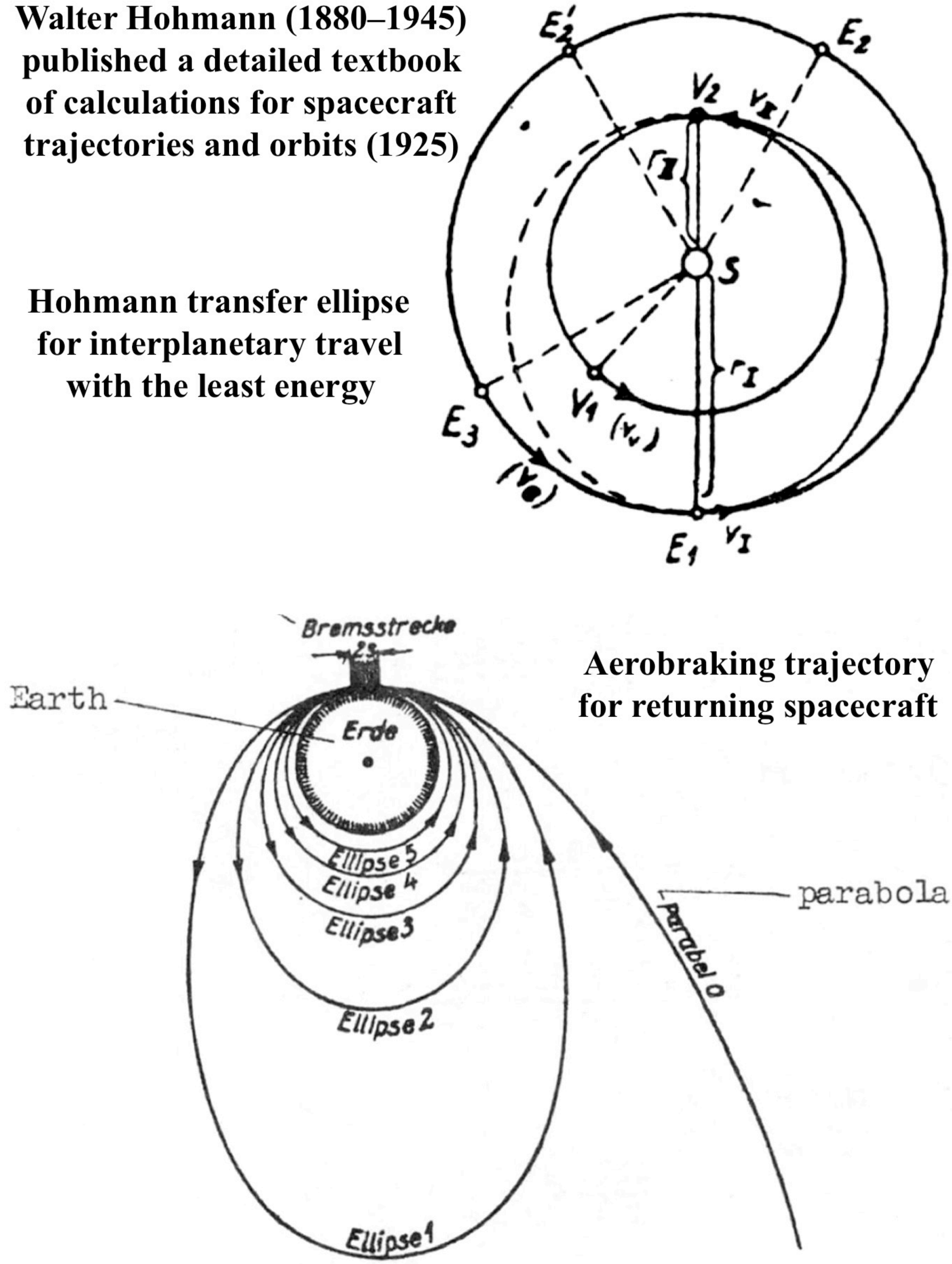


Figure 9.230: Walter Hohmann published a detailed textbook of calculations for spacecraft trajectories and orbits in 1925.

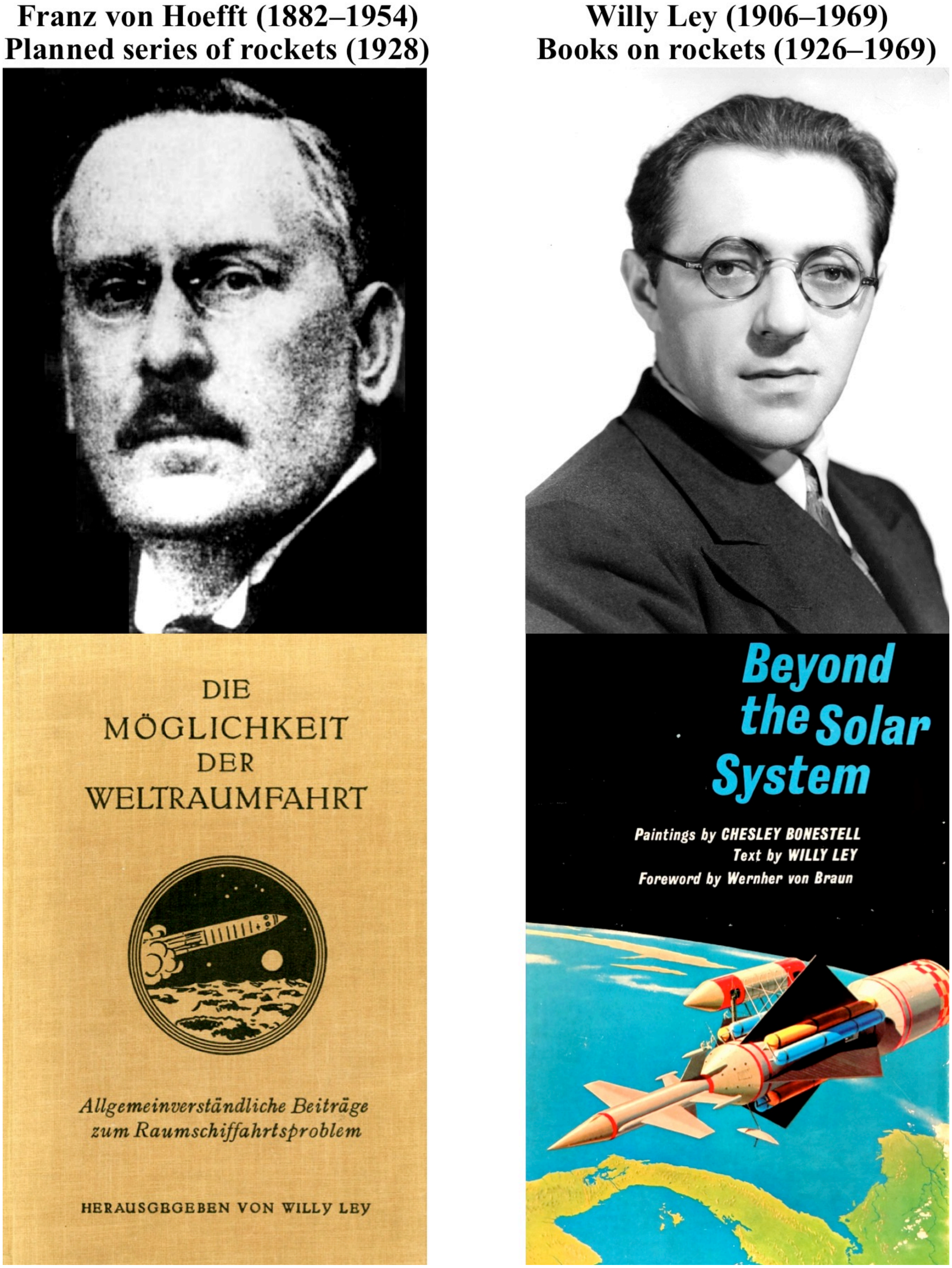


Figure 9.231: In 1928, Franz von Hoefft published papers describing a planned series of rockets ranging from small test rockets to large rockets capable of carrying people to the moon and to other planets. Between 1926 and his death in 1969, Willy Ley published a large number of popular books advocating for rockets and space exploration.

9.10.2 Space Stations

German-speaking scientists led the development of space stations from their initial conception through Skylab to the International Space Station.

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 Fig. 9.232 [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. He described and correctly calculated a geosynchronous orbit for the space station. Potočnik's 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 and 1929 [Ley 1928; Oberth 1929]. See Fig. 9.233. 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. Von Pirquet explained in detail how a space station could be used to refuel spacecraft for interplanetary missions.

Krafft Ehricke (German, 1917–1984), one of the later pioneers of space exploration and advanced rocket propulsion (p. 1969), paid credit to these creators who first worked out the mathematical and physical details of space travel [Ehricke 1960, pp. 19–25]:

> In Germany the most theoretical book on space flight, aside from Oberth's book, was written by Walter Hohmann and published in 1925 under the title, *Die Erreichbarkeit der Himmelskörper* (The Accessibility of the Celestial Bodies). It consisted of a systematic treatment of the departure from the Earth, return to the Earth (re-entry), free coasting in space, circumnavigation of other celestial bodies, and landing on these. Hohmann's departure from the Earth was accomplished by means of vertical ascent. Lateral motion, for instance to enter a circular orbit or another cosmic orbit, was to be given after the vehicle had reached its summit point outside the atmosphere. In his discussion of the return to the Earth, Hohmann proposed to use the atmosphere as a brake. [...]
>
> Hohmann was fully aware of the aerodynamic heating problem. He stated that it is important to transform as much of the kinetic energy of the vehicle as possible into vortex motion of the air. [...] For free coasting in space and the circumnavigation of other celestial bodies *transfer ellipses* were considered; Hohmann showed that the *cotangential* ellipse would be the most economical, but would require an increasingly long transfer time when applied to the outer planets of the solar system. He, therefore, also considered "fast" ellipses which intersect the orbit of the target planet at an angle and require, upon arrival, not only a change in scalar velocity, but also in direction. Hohmann was the first to discuss analytically the landing on other celestial bodies, specifically Venus and Mars. However, he believed that the atmospheric conditions on Mars may not be adequate for an exclusively aerodynamic descent, and that retrothrust must be employed. [...]

> Austria contributed two outstanding space flight pioneers of the early 20th century, Guido von Pirquet and Franz von Hoefft. Von Pirquet was the first to investigate systematically the significance of a terrestrial satellite station for interplanetary flight. While Oberth had only mentioned in passing that such satellites could be used as propellant depots, von Pirquet became convinced that, for the realization of space flight with chemical vehicles, refueling on a satellite would be a necessary condition. [...] Although Pirquet's analyses, like Hohmann's, extended as far as to include circumnavigation of Jupiter, his development approach was quite realistic. [...]
>
> Von Hoefft [...] contributed three fundamental thoughts: The balloon-launched, high-altitude rocket; the flat-bottom glide rocket; and the non-aerodynamic configuration of satellite-launched space ships. Von Hoefft visualized eight development steps, each characterized by a particular project. In a sense he is, therefore, the first to present an organic plan for the development of space flight, from a simple balloon-launched sounding rocket RH I to the interstellar vehicle RH VIII. [...]
>
> With this development plan, von Hoefft displayed a remarkable combination of practical sense and vision. Together with his sincere enthusiasm for the cause of space flight, this makes him one of the outstanding pioneers in this field.
>
> In this era of the thinkers, another interesting idea was contributed by H. Noordung. [...] Here Noordung contributed the first engineering concept of such a space station, or rather what he called its "living unit". He introduced the rotating wheel shape in order to provide centrifugal force as a sort of artificial gravity for the crew. [...] He placed his space station into a very high orbit, about 20,000 n. mi. out where it would complete one revolution in 24 hr.
>
> Thus, when the remarkable 1920's drew to a close, the foundations of the new science of rocket flight and astronautics were established.

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, as illustrated in Fig. 9.234 [NYT 1945-06-29 p. 1, 1945-06-30 p. 3; *Life* 1945-07-23 p. 78; *Time* 1946-09-02 p. 52].

After the war, Hermann Oberth, Wernher von Braun, Willy Ley, and many other German-speaking scientists continued to design and advocate for space stations in the United States [e.g., *Collier's* 1952-03-22]. Figure 9.235 shows a 1952 space station design from von Braun's team, drawn by Chesley Bonestell, based on earlier designs by Potočnik, von Pirquet, and Oberth.

In addition to the large wheel designs, the German-speaking scientists also proposed simpler space station designs as a starting point. Wernher von Braun, Heinz-Hermann Koelle (German, 1925–2011), and others proposed converting the empty upper stage of a Saturn-class rocket into a space station no later than 1959 for the U.S. Army's Project Horizon project. When von Braun's group was transferred from the Army to the recently formed NASA, the project for converting the upper stage of a Saturn V into a space station first became part of NASA's Future Projects Office, then part of the Apollo Applications Program. That project resulted in Skylab, the first U.S. space station, which was launched in 1973 (Figs. 9.236–9.238).[23]

[23] Belew 1977; Benson and Compton 1983; Heppenheimer 1997; Michael Neufeld 2007; Newkirk et al. 1977; Shayler et al. 2018; Frank Winter 2019; https://www.nasa.gov/centers/marshall/history/skylab.html

The Skylab design was actually capable of far more than the United States did with it; von Braun's team envisioned it to transport and house astronauts during manned flybys of Venus and Mars in the 1970s [Portree 2012].

Oberth, von Braun, Krafft Ehricke, and other creators also produced many other detailed designs for manned missions to or bases on the moon, Mars, and elsewhere [e.g., von Braun 1991; Freeman 2008]. While those ideas have not been utilized yet, perhaps they will be in the future.

Even the current International Space Station came about largely because of the longtime political advocacy of Hans Mark (Austrian/German, 1929–), one of the sons of the chemist Herman(n) Mark (p. 661) [Hans Mark 1987]. See Fig. 9.239. (Herman Mark's other son, Peter Mark, 1931–1979, conducted important research on electronics at Polaroid and Princeton until his early death.)

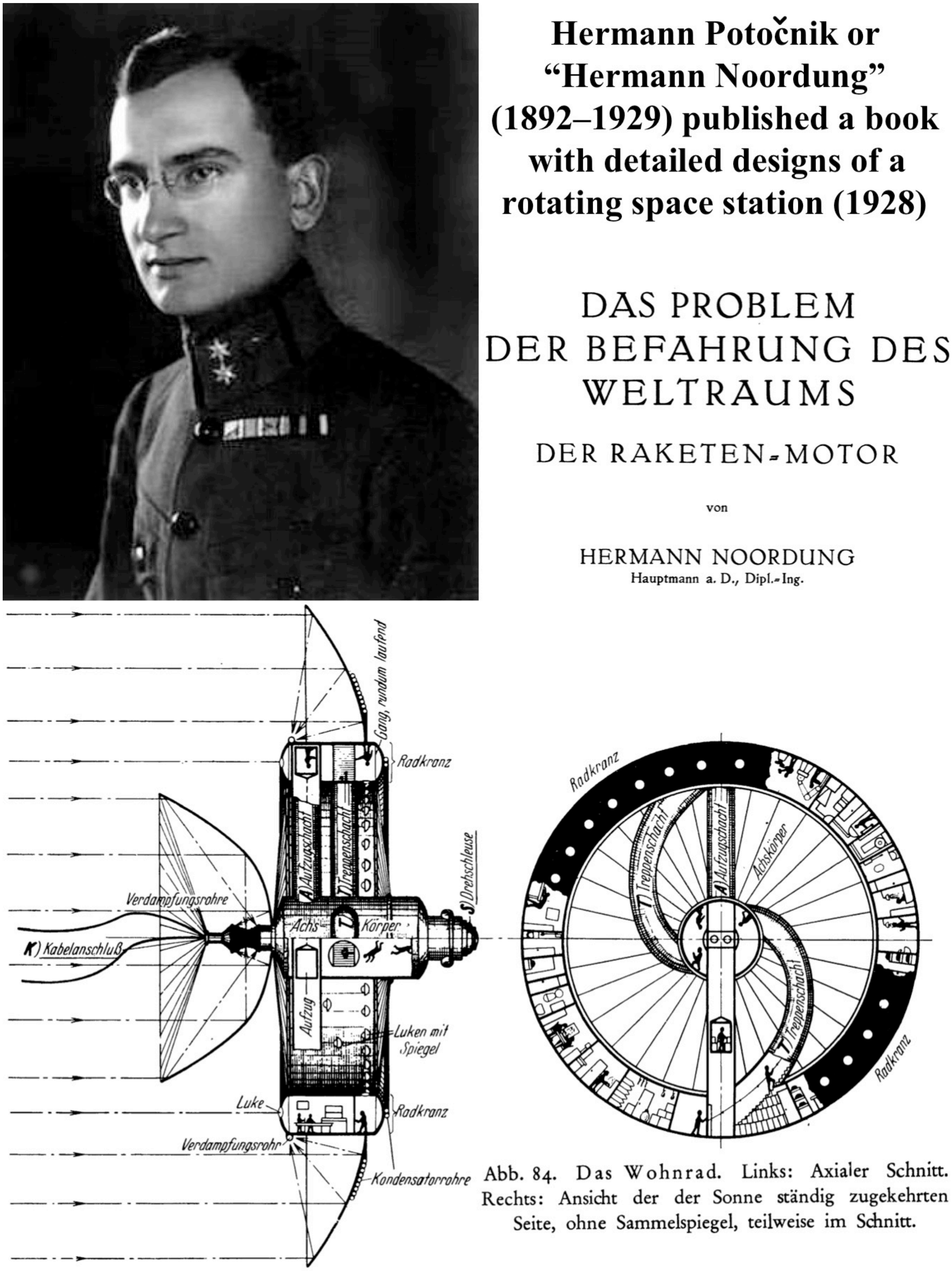
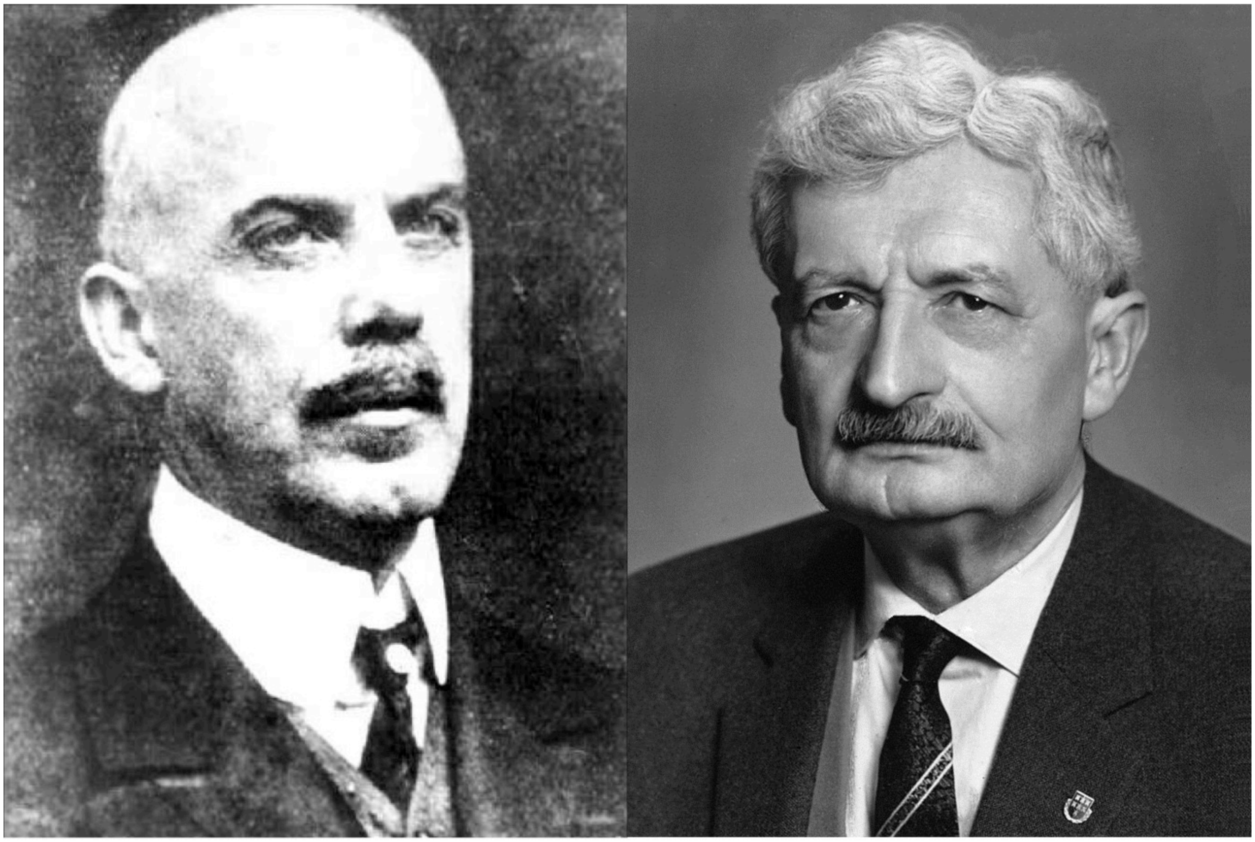


Figure 9.232: Hermann Potočnik, under the pen name of "Hermann Noordung," published a book with detailed designs of a large, circular, rotating space station in 1928.

Guido von Pirquet (1880–1966) Hermann Oberth (1894–1989)



Detailed designs for an orbiting space station and mirror (1929)

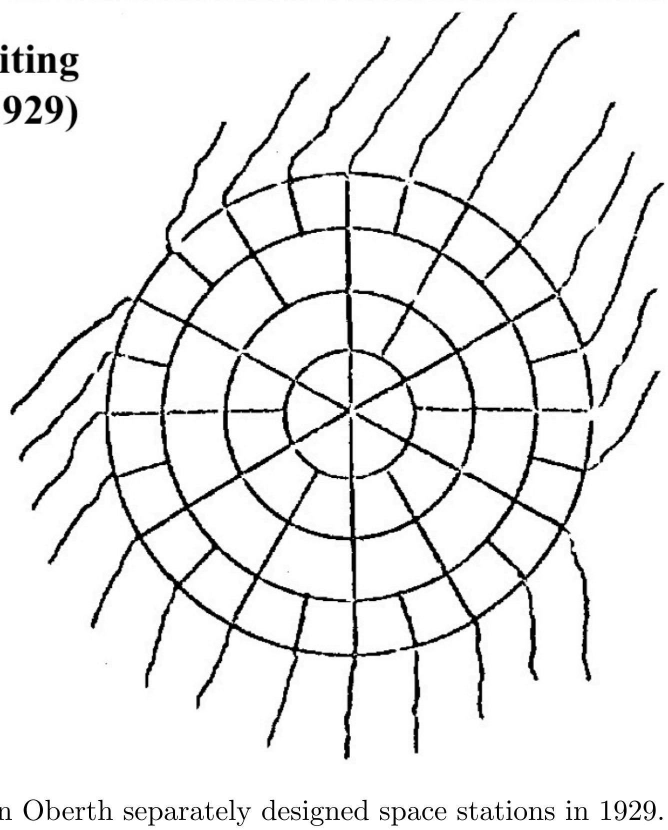
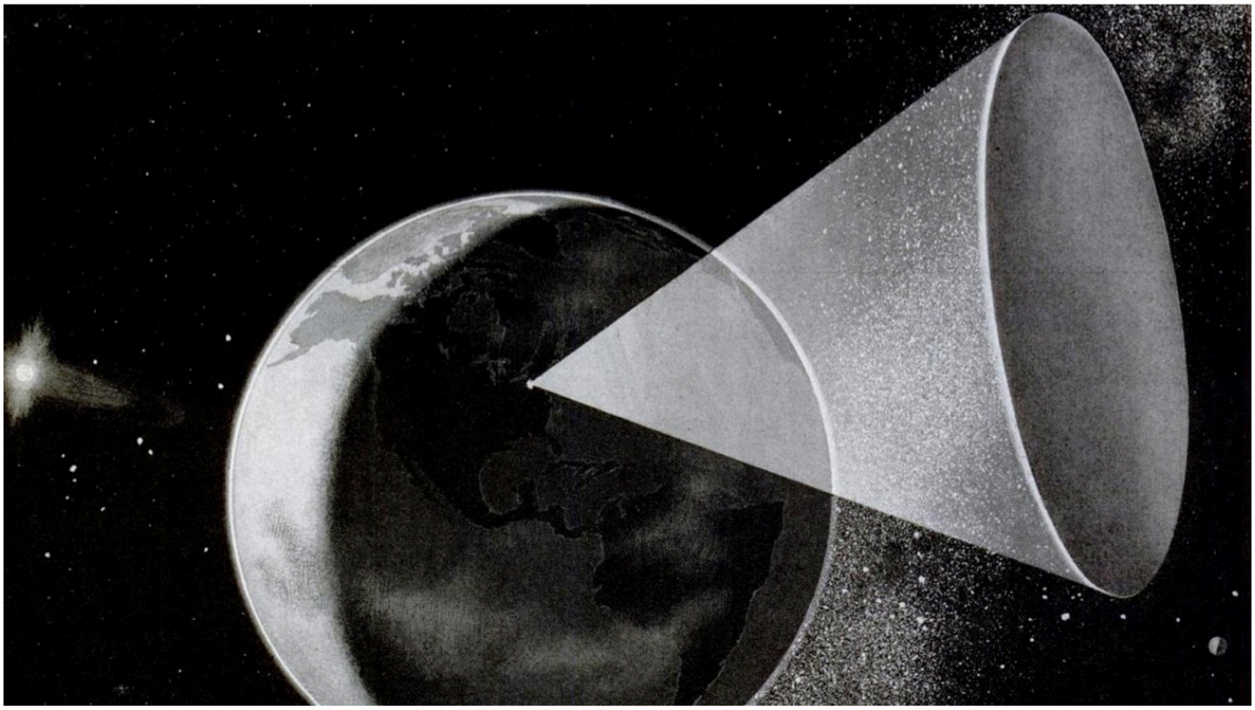


Figure 9.233: Guido von Pirquet and Hermann Oberth separately designed space stations in 1929. Oberth's station featured a kilometers-wide mirror to focus sunlight on areas of the Earth for either peaceful or military applications.

Plans for orbiting space station and mirror (1939–1945)



Nazis' Scientists Planned Sun 'Gun' 5,100 Miles Up

By GLADWIN HILL
By Wireless to THE NEW YORK TIMES.

PARIS, June 28—German scientists, a high United States Army ordnance officer declared 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.

Figure 9.234: Plans for an orbiting space station and space mirror were seriously studied during World War II.

1952 space station design from Wernher von Braun's team, drawn by Chesley Bonestell

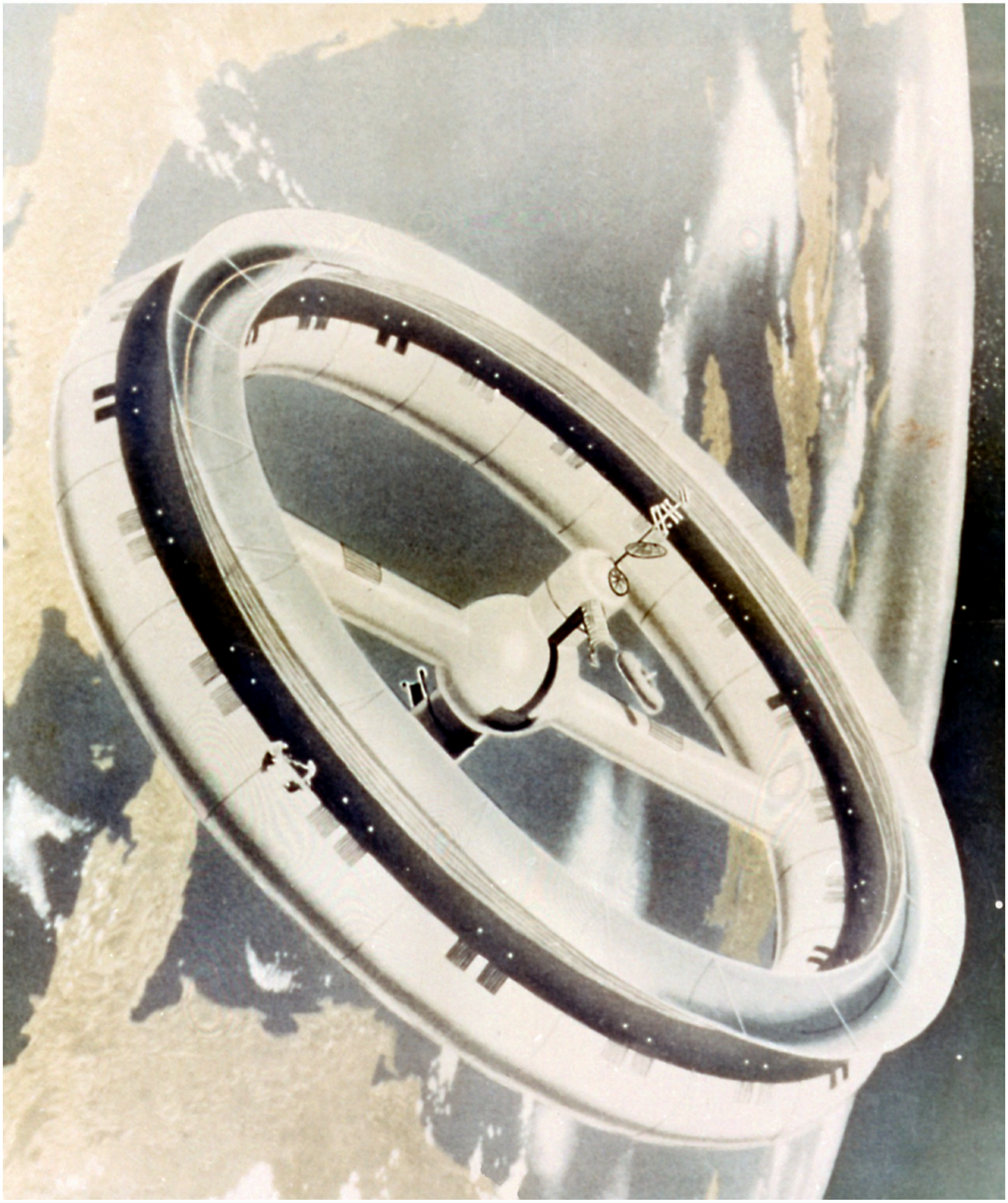
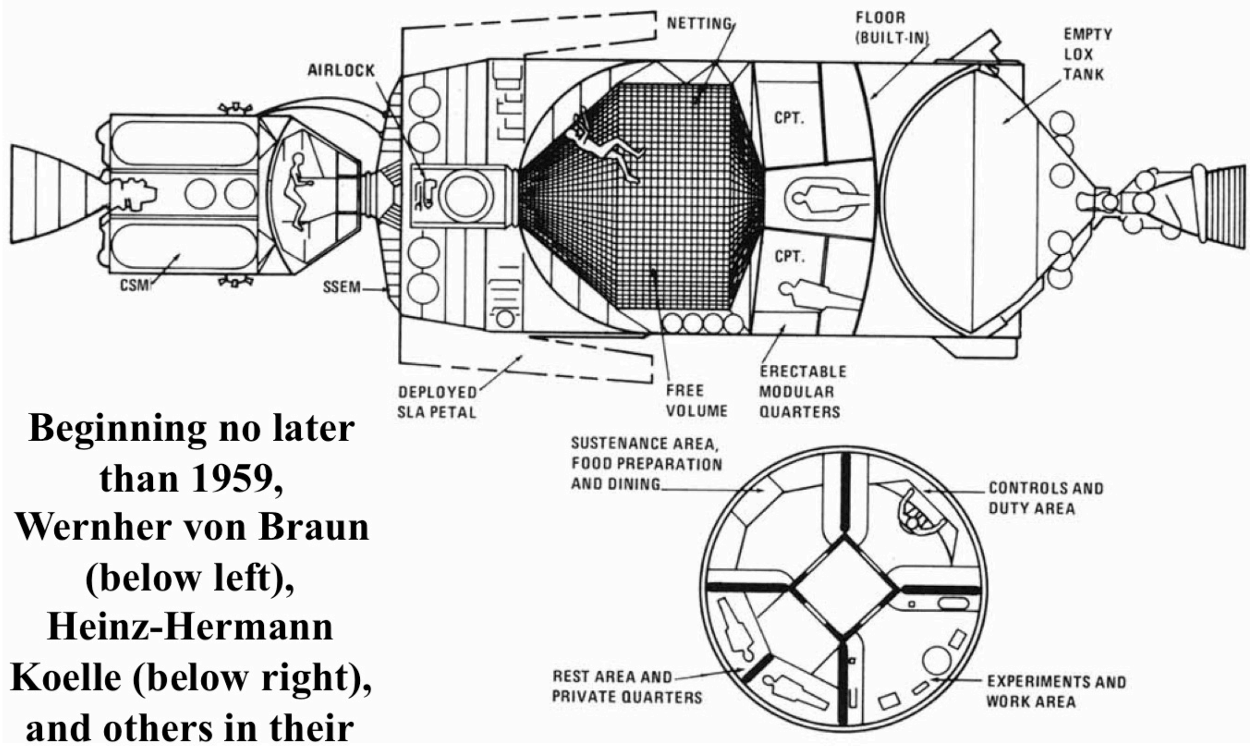


Figure 9.235: A 1952 space station design from Wernher von Braun's team, drawn by Chesley Bonestell, based on earlier designs by Hermann Potočnik, Guido von Pirquet, and Hermann Oberth.



Beginning no later than 1959, Wernher von Braun (below left), Heinz-Hermann Koelle (below right), and others in their group designed space stations converted from the empty upper stage of a Saturn rocket

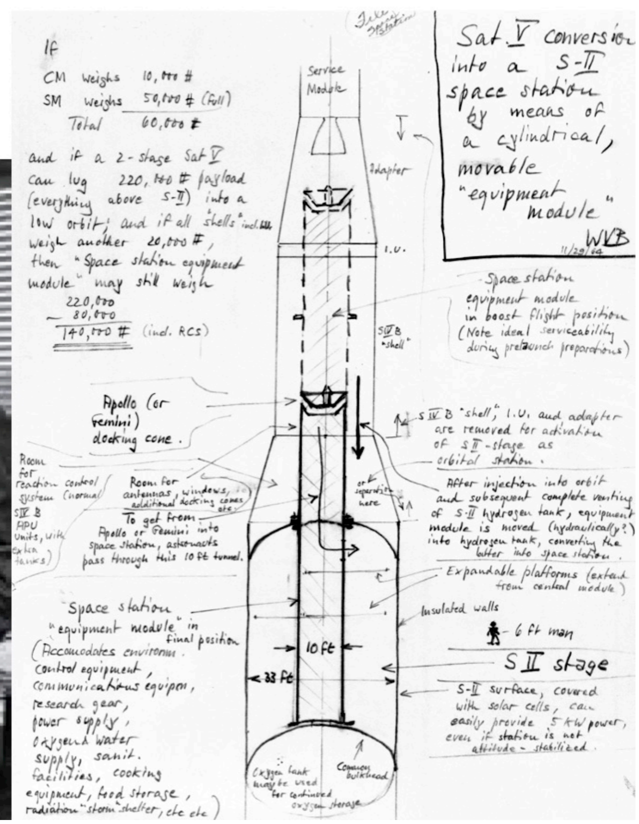


Figure 9.236: Beginning no later than 1959, Wernher von Braun, Heinz-Hermann Koelle, and others in their group designed space stations converted from the empty upper stage of a Saturn rocket.

Wernher von Braun (left) and Walter Häussermann (back) with Skylab mockup (October 1968)

Wernher von Braun (left) and Ernst Stuhlinger (right) with Skylab model (March 1969)

Eberhard Rees (left) and Kurt Debus (right) with Skylab hardware (April 1971)

Figure 9.237: NASA photographs illustrate the central role that German-speaking scientists such as Wernher von Braun, Walter Häussermann, Ernst Stuhlinger, Eberhard Rees, and Kurt Debus played in the design and development of the Skylab space station [Belew 1977].

Skylab space station, the converted upper stage of a Saturn V (launched in 1973)

Figure 9.238: Skylab, the first U.S. space station, was built from the converted upper stage of a Saturn V rocket, and was launched in 1973.

**Hans Mark (1929–,
son of Herman(n) Mark)
was largely responsible for
getting the U.S. government
to approve what became the
International Space Station**

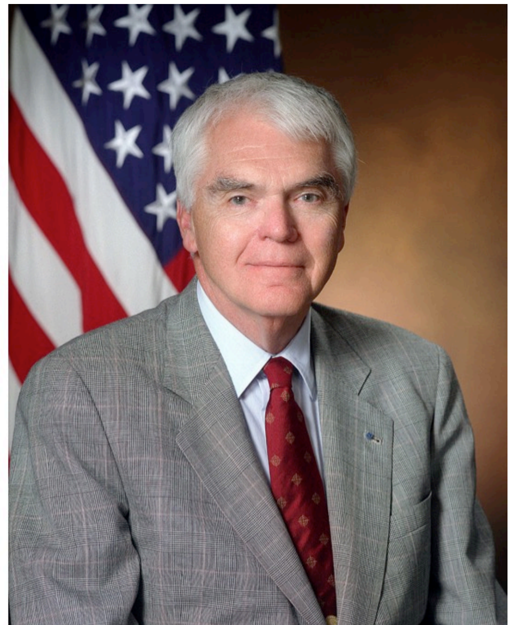


Figure 9.239: Hans Mark, the son of the chemist Herman(n) Mark, was largely responsible for getting the U.S. government to approve what became the International Space Station.

9.10.3 Non-Chemical Rockets

Whereas most rockets employ chemical reactions, non-chemical (i.e., nuclear) rockets could deliver much higher performance for deep space missions (Figs. 9.240–9.241). 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. 9.240. 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.

The upper part of Fig. 9.242 shows that scientists at Peenemünde and the Reichspost began programs on nuclear rocket propulsion no later than 1942. Manfred von Ardenne (German, 1907–1997), Wernher von Braun, Krafft Ehricke (German, 1917–1984), Werner Heisenberg (1901–1976), Franz Josef Neugebauer (German, 1897–1983), Hans von Ohain (German, 1911–1998), Ernst Stuhlinger (German, 1913–2008), and others worked on fission thermal propulsion during the war (pp. 5855–5873). After the war, von Braun, Ehricke, Neugebauer, Stuhlinger, and others continued to seriously develop fission thermal propulsion in the United States, as shown in Figs. 9.242–9.243.

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. 9.240 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 quite 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 sources on p. 5871 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 to the public. 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 postwar work ever progressed in the United States before the U.S. program was cancelled.

Electric rocket propulsion, or an ion-electron thruster, uses energy (heat, electric voltage, 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. 9.241. 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 negative 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 (p. 5872). Experimental development of electric propulsion in Germany began no later than 1937 and continued until at least 1944 (p. 5371). Ernst Stuhlinger, Wernher von Braun, and other German-speaking scientists continued to develop and promote electric propulsion after the war (pp. 1970, 5872). Currently very few documents on the wartime electric propulsion program are publicly available, but it seems likely that Oberth, Stuhlinger, and von Braun were involved in it as well.

Antimatter rockets, first proposed by Eugen Sänger, would store matter and antimatter propellant, then carefully combine them to create very high-energy exhaust (Figs. 9.241 and 9.243). 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. For maximum density, the antimatter could be stored as anti-atoms such as anti-hydrogen (an antiproton plus a positron, or antimatter electron), safely isolated from any matter by electric and/or magnetic fields. Annihilation of an antiproton with a proton creates $\sim 2/3$ charged and $\sim 1/3$ uncharged pions; the charged pions can be directed out a magnetic nozzle before they decay into gamma rays, although the neutral pions would be nearly impossible to direct.

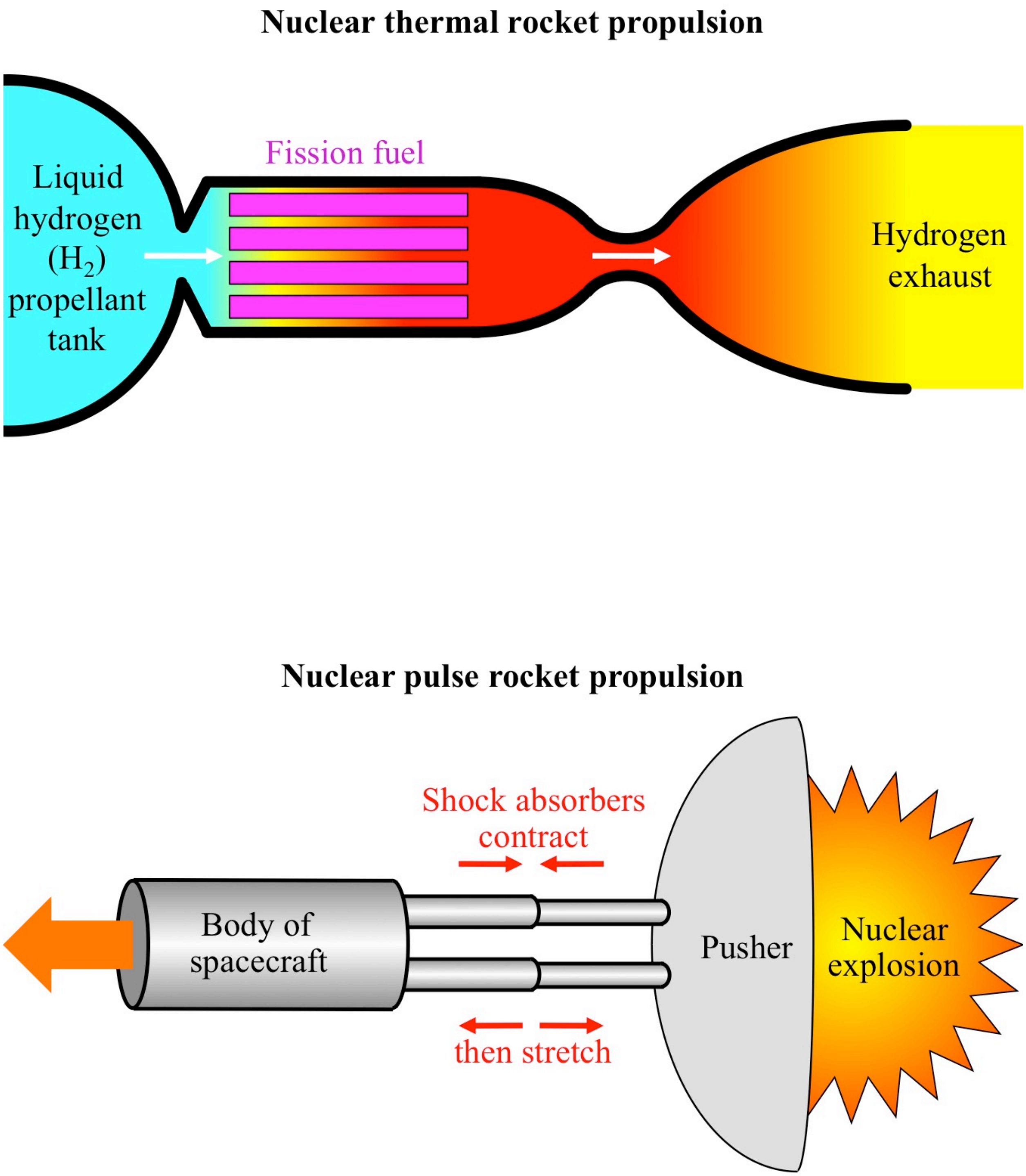


Figure 9.240: Nuclear rocket propulsion approaches. Above: fission thermal rocket propulsion, in which hydrogen propellant is heated by an internal fission reactor. Below: nuclear pulse propulsion, in which small nuclear bombs are ejected from a spacecraft and explode outside the spacecraft, pushing the spacecraft.

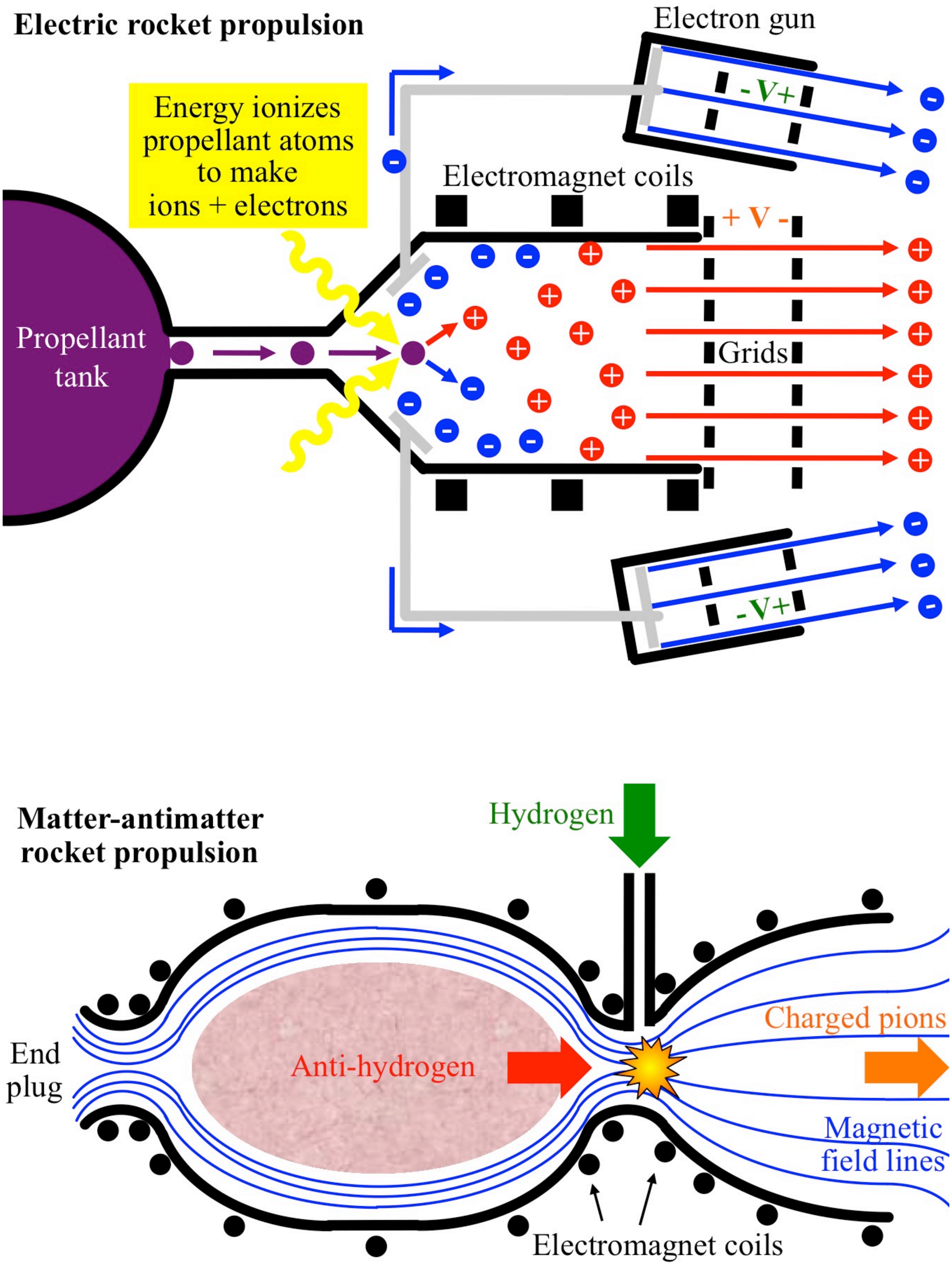
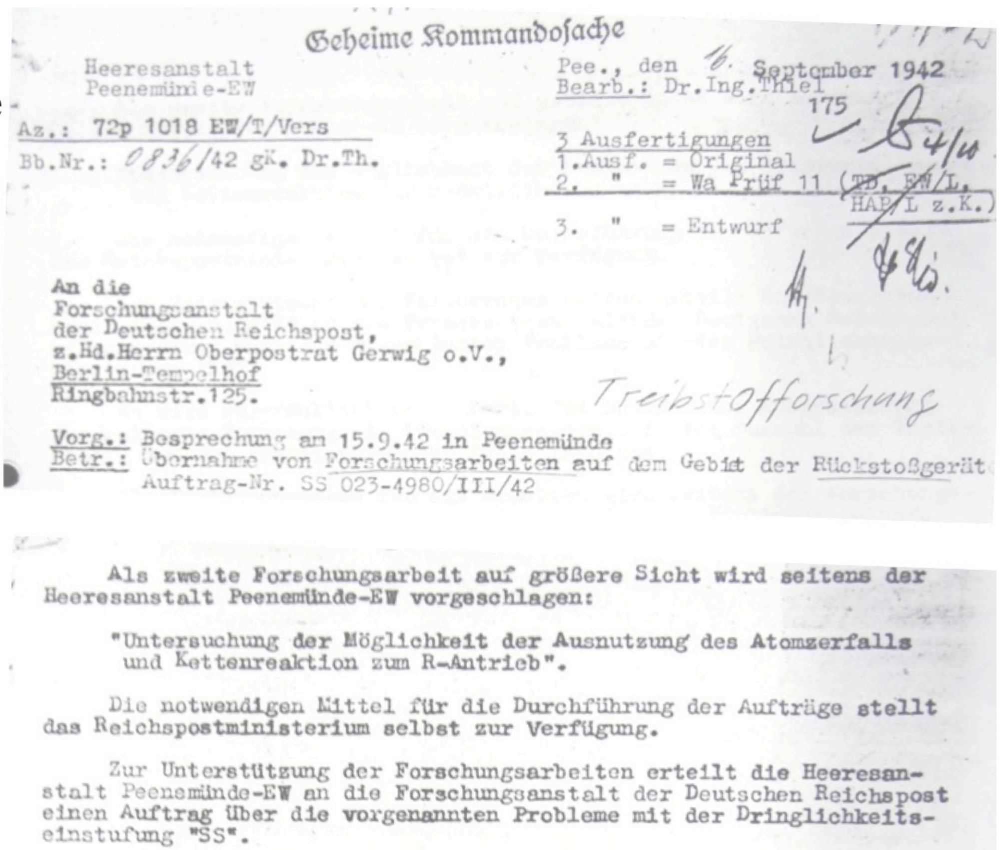


Figure 9.241: Rocket propulsion by an ion-electron thruster (above, also called electric rocket propulsion) and matter-antimatter annihilation (below).

Scientists at Peenemünde and the Reichspost began a program on nuclear rocket propulsion no later than 1942



Geheime Kommandosache

Heeresanstalt Peenemünde-EW

Pee., den 16. September 1942
Bearb.: Dr.Ing.Thiel

Az.: 72p 1018 EW/T/Vers
Bb.Nr.: 0836/42 gK. Dr.Th.

3 Ausfertigungen
1.Ausf. = Original
2. " = Wa Prüf 11 (TD, 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 Rückstoßgerät
Auftrag-Nr. SS 023-4980/III/42

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".

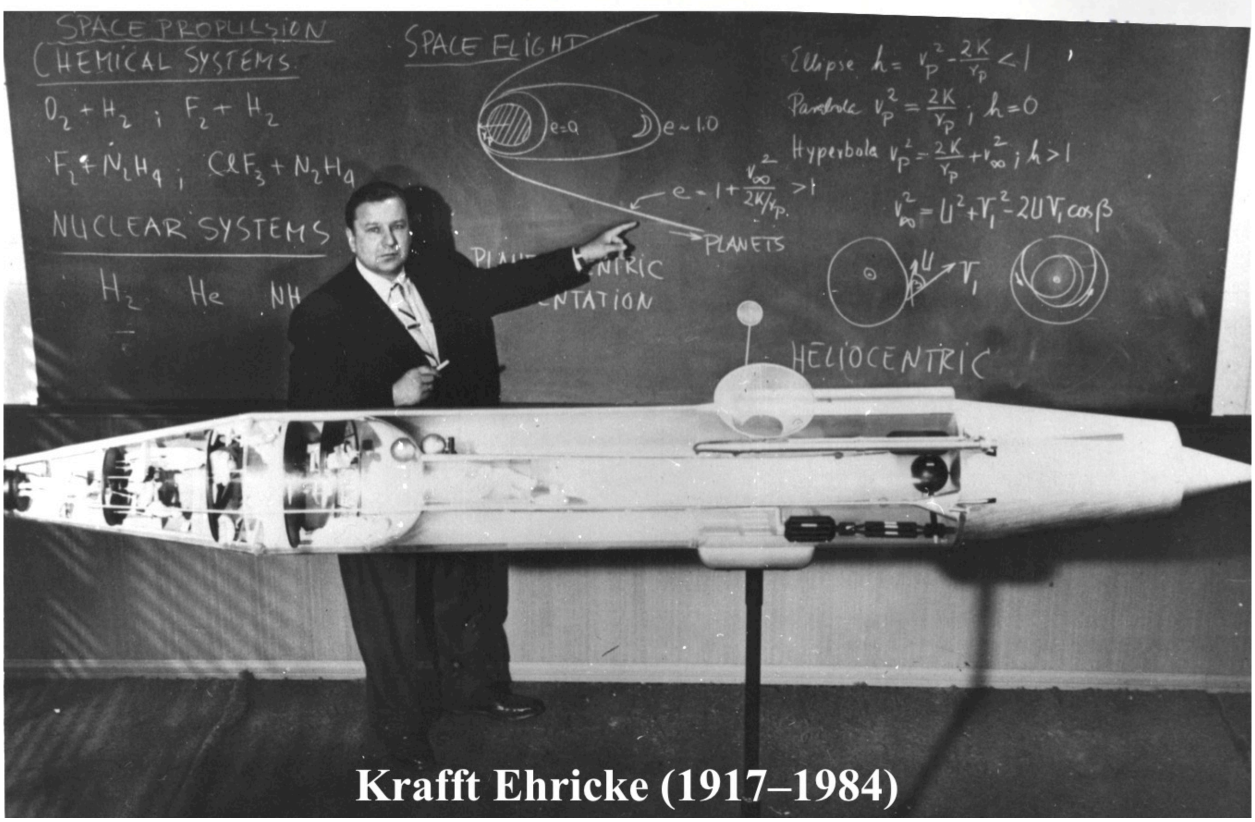


Figure 9.242: Scientists such as Krafft Ehricke at Peenemünde and the Reichspost began programs on nuclear rocket propulsion no later than 1942, and continued their work in the United States.

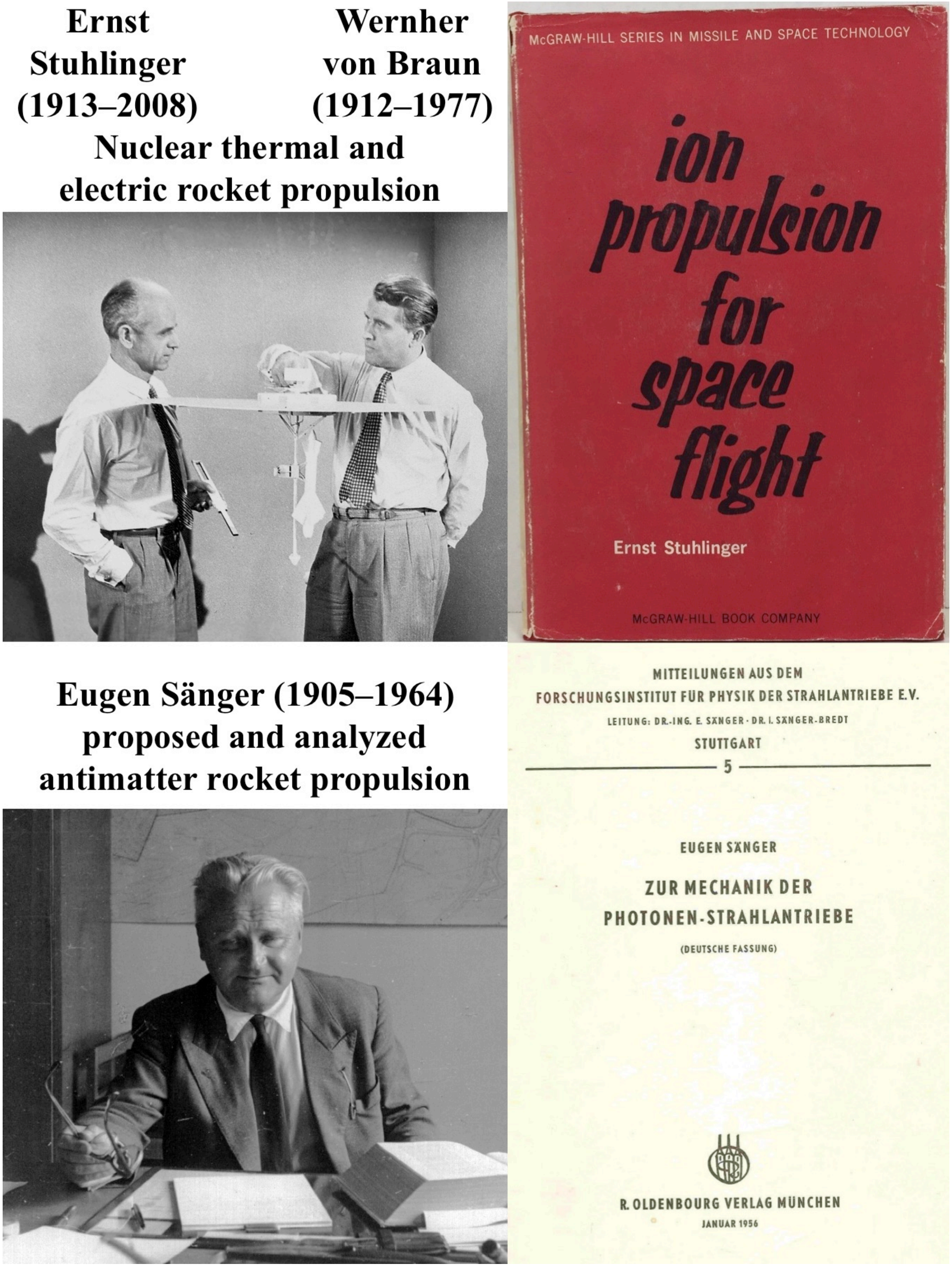


Figure 9.243: Ernst Stuhlinger, Wernher von Braun, and others worked on both nuclear thermal and nuclear electric propulsion in Germany during the war and in the United States after the war. Eugen Sänger was the first scientist to propose and analyze antimatter rocket propulsion systems.