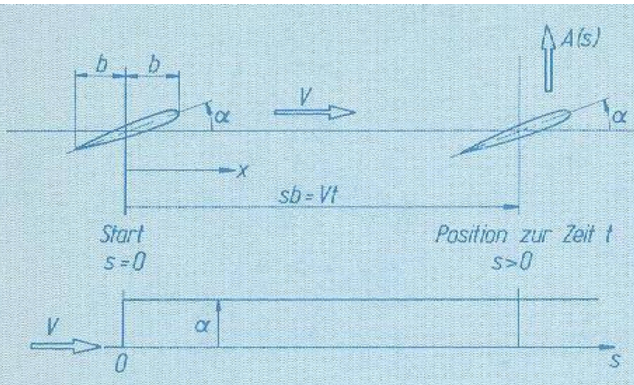
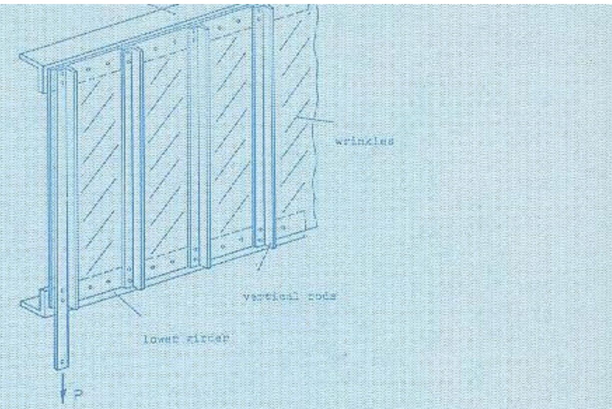
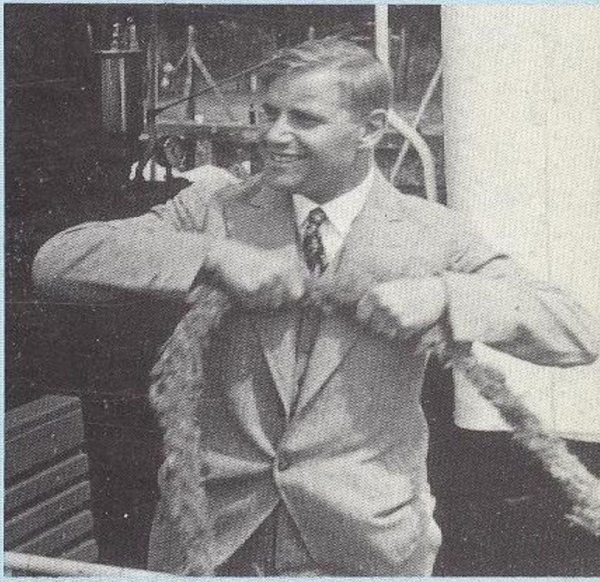


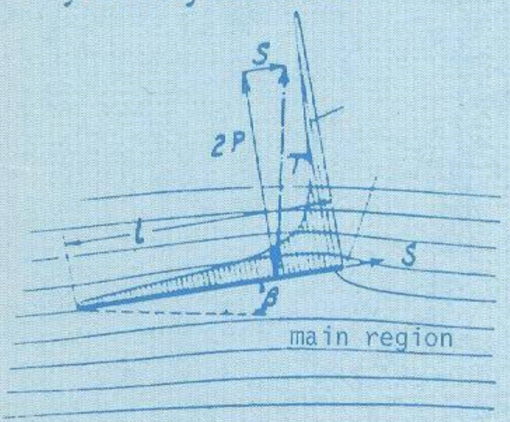


HERBERT WAGNER

His Work and Life

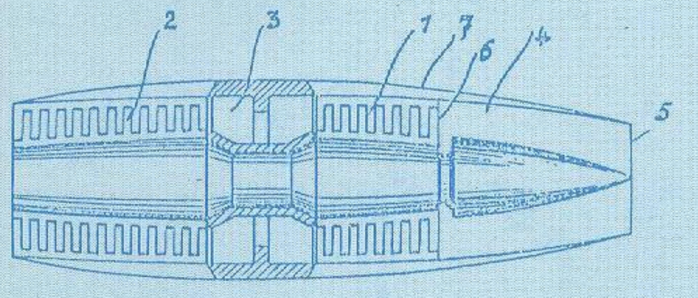


Hydrodynamics

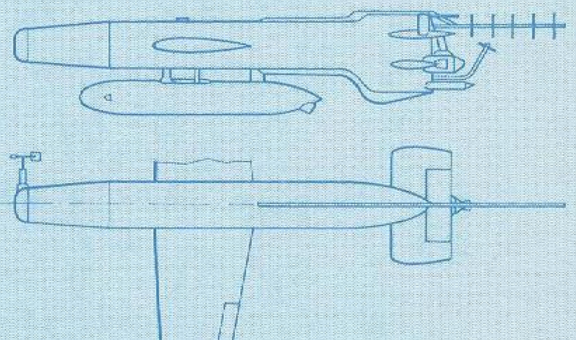


Documents

Axial Jet Engine



Guided Missiles



This is a document in memory of Dr. Herbert A. Wagner. He dedicated his life to engineering science in academe, industry, and government, especially in the area of aircraft technology and guided missiles in Germany and in the USA. This documentation contains the proceedings of a commemorative symposium held in the Hall of Fame of the Deutsches Museum in Munich on May 8, 1984, two years after his death. The papers present a lively picture of his professional career as well as personal impressions and reminiscences of colleagues, students, and friends. At the symposium it was decided to publish the papers and to establish the Herbert Wagner Archives in the Deutsches Museum in his memory and thereby to serve research in the history of technology as well. Through the cooperation of a large number of friends, helpers, and sponsors, this commemorative report was made possible, thus giving informative insight into the life and work of this versatile scientist, engineer, and teacher.

Herbert A. Wagner led an extraordinary life! With his motto "work and live", he attacked the hard problems wherever he found them and achieved outstanding advances in many areas of science and technology, in

Propulsion: axial compressor jet-engine,

Structures: lightweight aircraft structures – "web" design,

Hydrodynamics: landing impact, gliding on water surface,

Aerodynamics: nonsteady lift development,

Missile and Aircraft designs: industrial leadership and consulting,

Guidance and Control: systems and engineering,

Testing and Simulation: industrial and military problems.

He searched for the simple, most practical solutions and found them – and liked to share and teach!

HERBERT WAGNER · The Versatile Pioneer

Herbert Wagner, Berlin, 1923

HERBERT WAGNER

His Work and Life

Documents

English language edition of the German book
"Herbert Wagner,
Dokumentation zu Leben und Werk"

Editor: G. E. Knausenberger
Assoc. Editors: M. Osietzki, W. Heinzerling
Production: R. Gutmann a.o.
Translator: S. Harris a.o.

Publishers: Deutsche Gesellschaft für Luft- und Raumfahrt e.V., Bonn, Deutsches Museum München, Smithsonian Institution Washington

Contents

PART II
Documents, Sketches, Commentaries

Editorial remarks and Acknowledgements

The first part of this document contains the proceedings of the Wagner Commemorative Symposium on May 1984 held in Munich.
In the second part, the reader will find copies of original documents and a guide to the material in the "Wagner-Archives" at the Deutsches Museum in Munich.
Thus this publication has the quality of a source-book, besides offering a biography and scientific papers. In addition, it documents a valuable cooperation among members of industry, universities, the Smithsonian Institution, and the Deutsches Museum. The participants in this effort merit special acknowledgment.
Contributors of biographical material from the United States are mentioned on page 111. Their valuable encouragement is gratefully acknowledged.
Special gratitude is due to the following persons and institutions for their financial support:

Dr. L. Bölkow
Dornier GmbH
Motoren und Turbinen Union GmbH
Herbert-Schumann-Stiftung für Luft- und Raumfahrtgeschichte
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Deutsche Gesellschaft für Luft- und Raumfahrt, Bonn
Deutsches Museum, München
Smithsonian Institution, Washington, D.C.

Preface

Who was Herbert A. Wagner?
A charming man, a gifted teacher, a useful "sounding board", a "genius we are lucky to have on earth every 300 years", as one of his longtime associates says?
Was he a generator or a merchant of ideas, a bench scientist or an entrepreneur, was he just playfully responding to every challenge before him or responsibly serving a common goal?
Some may not ask such questions, but may just enjoy the stimulation from the broad spectrum of his ideas; some may want to know more of his philosophy, look into his workshop, explore his impact.
But this is not a biography and it can not be. We hope that is may be a first step toward one, a service to students and historians.

L. Bölkow

G. E. Knausenberger

Curriculum Vitae of Dr. Herbert A. Wagner (written by him probably in the early 1970s)

Personal data:

Born on May 22, 1900, at Graz, Austria.
Married to Frieda Wagner, née Quint, born on April 24, 1926, at Los Angeles.[1] I have a married daughter, Monica Lambrecht, 27 years old, a son Steven, 16, and a daughter Joan, 14.
In 1937 I was appointed a full member of the "Deutsche Akademie für Luftfahrtforschung" (German Academy for Aviation Research).
In 1960 I was awarded an Honorary Doctor's Degree by the Technical University of Berlin primarily for my work in aircraft structures and aerodynamics.
I am an American citizen.

Educational background:

1914–1917 Austrian Naval Academy.
1919–1920 Student of mechanical engineering at the Technical University of Graz.
1920–1922 Student of naval engineering at the Technical University of Berlin. I graduated in Dec. 1922 (Master's degree).
Feb. 1924 Doctor's degree in engineering from the Technical University of Berlin. The thesis subject was "Über die Entstehung des dynamischen Auftriebes von Tragflügeln" (On the Growth of Dynamic Lift on Airfoils).

Working experience:

1917–1918 Austrian Navy as a Junior Ensign.
1920–1922 Engineer and, after a few months, head of the design department of the firm "AMI Auto Motoren Industrie", a small firm in Berlin which developed a motorcycle engine.
1923–1924 Teaching assistant to the Professor of steam turbines and propellers in the department of mechanical engineering at the Technical University of Berlin.
1924–1927 Engineer at the "Rohrbach Metall Flugzeugbau" in Berlin. This factory developed and built mainly flying boats and granted licenses for their construction to foreign countries. I began as a construction engineer and was appointed in 1925 as the head of the department of fuselage and boat construction. I created a new method of sheet metal construction – Wagner beam – which was broadly used worldwide.
1927–1930 Full professor for aeronautics at the Technical University of Danzig, where I founded a research laboratory for stress investigations and an aviation club for the students.

1 update: see later Bree page 26

1930–1938 Full professor for aeronautics at the Technical University of Berlin, created the research laboratory for aircraft construction, stress analysis and wing flutter. Beginning in 1935, I took part-time leave from giving lectures in order to work in industry.

1933–1935 Consulting engineer at the Henschel Flugzeugwerke in Berlin.

1935–1939 In 1935 I entered the Junkers Flugzeugwerke in Dessau. My task was to direct all the experiment research and the design of new aircraft. I was especially interested in high altitude aircraft which resulted in the construction of a test plane for that purpose. In 1937 I was appointed officer in charge of the aircraft development department of this firm.

In 1935 I began at Junkers the development of gas turbines and turbine jet propulsion devices for aircraft. The jet engine reached the test stand in 1939. (It then became the only operational jet engine in World War II.)

In 1939 I disagreed with the president about the types of aircraft to be developed and left the firm.

1940–1945 In 1940 I started a development department for guided missiles at the Henschel Flugzeugwerke in Berlin which reached a staff of over 1100. In 1943 I was appointed director of this firm. The radio-guided air-to-surface missile, Hs 293, attained highly successful operational use in World War II. The S/A missile "Schmetterling" was in the beginning of production when the war ended.

1945–1947 I was the first German scientist brought to this country after the war. I was employed by the Institute of Aeronautical Sciences. I investigated for the United States Navy theoretical guidance problems and the stability of servo-mechanisms.

1947–1950 Employed by US Navy at the Missile Test Center, Point Mugu, California. Developed various successful guidance systems for missiles and automatic bombing systems.

1950–1952 Independent consultant to Raytheon Manufacturing Co. on problems of radar missile guidance and to Collins Radio Co. on automatic carrier landing system.

1952–1957 Chairman of the Board, president and chief engineer of the H. A. Wagner Company in Van Nuys, California. This was a research and development company for electro-mechanical-optical systems. The largest task was the semi-automatic guidance system for the DART anti-tank missile. The Company had grown to 250 employees when sold to Curtiss-Wright in 1957.

1957–1965 Full professor for Technical Mechanics – applied mechanics – at the Technical University at Aachen, Germany. I am a Professor Emeritus of this school.

1959–1962 In addition to the professorship, I was employed by Fairchild Astrionics Division, Fairchild Engine and Airplane Corporation, working both in Germany and, 40 % of the time, in the U.S.A. The main tasks were analysis of the guidance and control system for a deep-penetration, automatic reconnaissance drone and layout and analysis of an automatic, tethered helicopter.

1962–1965 In a like arrangement, I was employed by The Raytheon Company, Missile Systems Division, Bedford, Mass., for studies of radio applications to missiles and satellite systems and the satellite-borne, photographic surveillance of the moon.

1965–July 1968 Consultant to the Aeronutronics Division of Philco-Ford, Newport Beach, California, on tactical missiles.

1968–Now free-lance engineering consultant:

For Aerojet General

Analysis and loop design for automatic submarine control pilot and

Investigation of vibration problems and structural integrity of large automatic sorting system.

For L. P. Systems, Irvine, Calif.

Industrial fire protection.

For Gulton Industries

Design of automatic printer for computer terminal.

Design and program manager for Automatic Track Analyser System for Bay Aera Rapid Transit District in San Francisco.

Scientific Publications:

Numerous publications in the following fields:

Non-stationary fluid motions
Gliding and impact of bodies on the surface of a liquid
Aircraft structures
High-altitude aircraft
Missile guidance

Patents:

About 40 patents primarily in the following fields:

Thin sheet metal construction
High altitude aircraft
Jet engines for aircraft
Engine nacelles for aircraft
Increase of lift on wings
Flexible transmissions
Ricocheting bombs
Remote and automatically controlled missiles (design features, steering and control systems, aiming devices)
Torpedo bombs
Inertial platform
Aerodynamic control surfaces

Clearance:

I am cleared for "secret".

Publications and Patents

Bibliography of Wagner's Publications:

H. Wagner. *Über die Entstehung des dynamischen Auftriebes von Tragflügeln.* Dissertation TH Berlin 1924. Zeitschrift für angewandte Mathematik und Mechanik. Band 5, 1925. S. 17–35.

H. Wagner. *Einige Bemerkungen über Knickstäbe und Biegungsträger. Der Kennwert.* Zeitschrift für Flugtechnik und Motorluftschiffahrt. Band 19, 1928, Heft 11. S. 241–248.

H. Wagner. *Über die Zugdiagonalenfelder in dünnen Blechen.* Zeitschrift für angewandte Mathematik und Mechanik. Band 8, 1928, Heft 6. S. 443–446.

H. Wagner. *Über räumliche Flugzeugfachwerke. Die Längsstabkraftmethode.* Zeitschrift für Flugtechnik und Motorluftschiffahrt. Band 19, 1928, Heft 15. S. 337–347.

H. Wagner. *Über Konstruktions- und Berechnungsfragen des Blechbaues.* Jahrbuch der Wissenschaftlichen Gesellschaft für Luftfahrt. 1928. S. 113–125.

H. Wagner. *Ebene Blechwandträger mit sehr dünnem Stegblech.* Zeitschrift für Flugtechnik und Motorluftschiffahrt. Band 20, 1929, Heft 8–12. S. 200–207, 227–233; 256–262, 279–284, 306–314. Ergänzende Bemerkungen in Heft 10.

H. Wagner. *Verdrehung und Knickung von offenen Profilen.* In: Fünfundzwanzig Jahre Technische Hochschule Danzig, S. 329–344. A. W. Kafermann GmbH, Danzig 1929.

H. Wagner. *Zur Mechanik des Starts und der Landung von Seeflugzeugen.* Auszug aus einem Vortrag des Verfassers, gehalten vor dem Stuttgarter Bezirksverein des Vereins Deutscher Ingenieure am 19. März 1929. Abgedruckt in: Zeitschrift „Schiffbau", Jg. 30, 1929, Heft 14, S. 343–348.

H. Wagner. *Über den Aufschlag gekielter Flächen auf Wasser.* The 3rd International Congress for Applied Mechanics Proceedings, Stockholm, 24–29 August 1930. (Eds. C. W. Oseen and W. Weibull, Stockholm).

H. Wagner. *Über die Landung von Seeflugzeugen.* Zeitschrift für Flugtechnik und Motorluftschiffahrt. Band 22, 1931. S. 1–8. Siehe auch Jb. 1934 der Wissenschaftlichen Gesellschaft für Luftfahrt, S. 59.

H. Wagner. *Sheet-Metal Airplane Construction.* Aeronautical Engineering, 1931, Vol. 3 No. 4. S. 151–161.

H. Wagner. *Über Stoß- und Gleitvorträge an der Oberfläche von Flüssigkeiten.* In: Zeitschrift für angewandte Mathematik und Mechanik, Band 12, 1932, Heft 4. S. 193–215.

H. Wagner/Watzlawek. *Kernphysik. Technischer Stand und Anwendungsmöglichkeiten.* Bericht Henschel Flugzeug-Werke A.G., Berlin-Schönefeld, 5. August 1941.

H. Wagner/G. Kimm. *Bauelemente der Flugzeuge.* Verlag Oldenbourg, München/ Berlin 1940, 2. Aufl. 1942.

H. Wagner. *Ferngelenkte Gleitbomben.* Deutsche Akademie der Luftfahrtforschung, Schrift 1954/42, S. 83–101.

H. Wagner. *Anwendung des R-Antriebes bei Gleitbomben.* Vortrag auf der Arbeitstagung der Deutschen Akademie der Luftfahrtforschung am 5. August 1943. Abgedruckt in: Schriften der Deutschen Akademie der Luftfahrtforschung, Schrift 1071/43, 1943, S. 195–203.

H. Wagner. *Impact forces at water entry.* Proc. 8th Underwater Ballistic Conference, Part I. Iowa Institute of Hydraulic Research, Iowa City, Iowa. US Office of Naval Research, Department of the Navy, Washington, D.C., 1950.

H. Wagner. *Lenkung und Steuerung deutscher ferngelenkter Flugkörper, speziell der Henschel-Entwicklungen.* AGARD-Seminar, München, April 1956 (Advisory Group for Aeronautical Research and Development. North Atlantic Organisation, Paris).

Amerikanische Übersetzung: *Guidance and Control of the Henschel Missiles.* In: Th. Benecke and A. W. Quick (Hrsg.): History of German Guided Missiles Development, AGARDograph No. 20, S. 8–23. Verlag E. Appelhand & Co. Braunschweig 1957.

H. Wagner. *Antriebsfragen der Raumfahrt.* Haus der Technik, Essen. Technische Mitteilungen, Jg. 52. Heft 12. Dez. 1959. S. 459–468.

H. Wagner. *Über den Gültigkeitsbereich zweier alter Arbeiten: a) Auftriebsentstehung; b) Stoß- und Gleitvorgänge an der Flüssigkeitsoberfläche.* In: Jahrbuch der DGLR. 1973. S. 250–260.

List of Wagner Publications available as NACA Notes or Memoranda

a) Publications in the Structures Field
(Contributed by R. B. Katkov):

Design of Metal Box-Spar with Tension-Field-Webs

H. Wagner developed the tension field web theory and showed that once a thin web has wrinkled, it behaves approximately as a series of diagonal strips, parallel to the direction of wrinkling and subject to simple tension.

Wagner's theory was published in Zeitschrift für Flugtechnik und Motorluftschiffahrt (ZFM) in 1929. This report was translated and published by the National Advisory Committee for Aeronautics as NACA Technical Memoranda 604, 605 and 606 and summarized by P. Kuhn in NACA Technical Note 469.

Torsion on Space Frameworks

Many of the space frameworks used in aeronautical practice consist of a number of parallel transverse frames or trusses connected by members located on the boundary surfaces of the structure which may be called "Envelope Members".

Trussed fuselage structures are often of this type. In this case the transverse frames are formed by the vertical web members of the side trusses, the web members of the top and bottom trusses normal to the plane of symmetry, and the diagonal "Bulkhead Bracing" in the planes defined by those members.

The longerons and diagonal web members of the side, top and bottom trusses are envelope members.

The same type of structure is also represented by internally braced monoplane wings. In these, the transverse frames are the drag ribs; the remaining members of the spars and drag trusses are the envelope members.

Although these are normally statically indeterminate, Professor H. Wagner developed an interesting and helpful method of approximate analysis for such structures when subjected to torsion.

This method is reported in NACA Technical Memorandum 522, 1929, "The Analysis of Aircraft Structures as Space Frameworks, Method based on the Forces in the Longitudinal Members", by Herbert Wagner.

"Torsion and Buckling of Open Sections", NACA TM 807, 1936.

Nearly all methods used for the analysis of Tension Field Beams are developments of the original work of H. Wagner: "Flat Sheet Metal Girders With Very Thin Metal Web – Part III", by H. Wagner, NACA TM 606, 1931.

"Deflection of Tension Field Beams", by Wagner and Lahde, NACA TM 809.

Analysis of Buckling in Curved Sheets

Lahde and Wagner, in NACA TM 809 and 814.

Wagner and Ballerstedt, in NACA TM 774.

Torsional Column Failure

The pioneer in the field was H. Wagner in Germany.

H. Wagner and W. Pretschner (in NACA TM 784, 1936) have shown how to allow for the effect of section thickness in computing the various constants.

Paper by H. Wagner in: Jahrbuch der Wissenschaftlichen Gesellschaft für Luftfahrt (WGL), 1928, pp. 113–125.

Tension Field Beams

The first and most important single paper on the analysis of tensionfield beams is still that of H. Wagner on the "Flat Sheet Metal Girder with very thin Metal Web", NACA TM 604, 605 and 606, 1929.

One of the most important problems has been that of determining the degree of completeness of the tension field and the effects of the residual compression.

This has been studied by R. Lahde and H. Wagner in "Tests for the Determination of the Stress Condition in Tension Fields", NACA TM 809, 1936.

Shells

A number of important reports on shells have been translated from the German.

The earliest of these is "The Stress Distribution in Shell Bodies and Wings as an Equilibrium Problem", by H. Wagner, NACA TM 817, 1937.

Stiffened Panels

"Experimental Studies of the Effective Width of Buckled Sheet", by R. H. Lahde and H. Wagner, NACA TM 814, 1936.

"Remarks on Airplane Struts and Girders under Compressiv and Bending Stresses. Index values", NACA TM 500, 1292.

b) Publications on File at NASA,
   Ames Research Center
   (contributed by R. Lahde)

"Remarks on Airplane Struts and Girders under Compressive and Bending Stresses. Index values", (including tabulations and 9 figures), NACA TM 500, 1929 (from ZFM, June 14, 1928, pp. 241–247).

"Remarks on Controlled Glide Bombs", Sept. 1946, 23 pp. AAF AirMatCom. Wright Field Technical Intelligence Translation, F-TS-588-RE (from Deutsche Akademie der Luftfahrtforschung, Schriften, 1054/42, Nov. 5, 1942).

"Report on the Construction of High Altitude Aircraft", Aug. 1946, 22 pp. AAF AirMatCom. Wright Field, Technical Intelligence Translation, F-TS-590-RE (from Deutsche Akademie der Luftfahrtforschung, Schriften, 29 Oct. 1928, 1937).

"The Stress Distribution in Shell Bodies and Wings as an Equilibrium Problem", (23 pp. with 29 Diagrams), NACA TM 817, Feb. 1939 (from Luftfahrtforschung, Sept. 20, 1936, Vol. 13, No. 9, pp. 281–292).

"Torsion and Buckling of Open Sections", (17 pp. with 1 tabulation and 7 diagrams), NACA TM 807, Oct. 1936 (from 25 Jahre Technische Hochschule Danzig, 1904–1929, pp. 329–343).

"Landing of Seaplanes", (15 pp. with 18 figures), NACA TM 622, May 1931 (from ZFM, Vol. 22, No. 1, Jan. 14, 1931. pp. 1–8). See also: Preprint from WGL Report, pp. 120–130D (incl. 1191, 3–59 tabs. and figures).

"Of the Gliding of Bodies on the Water Surface", photostat from International Congress for Applied Mechanics, July 3–4, 1934, pp. 264–265 (German text).

"Phenomena associated with Impact and Gliding on Liquid Surfaces", (60 pp. with illustrations), by H. A. Wagner, Aeronautical Research Council (ARC), July 1936, S. 302. Photostat and translation from Zeitschrift für Angewandte Mathematik und Mechanik (ZAMM), Vol. 12, No. 4, August 1932, pp. 193–215, illustrations 76 pp.

"Planing of Watercraft", (41 pp. with approx. 28 figures, graphs, and photos), NACA TM 1139, (from Jahrbuch der Schiffbautechnischen Gesellschaft, Vol. 34, 1933, pp. 205–227).

"The Analysis of Aircraft Structures as Space-Frameworks. Method based on the forces in the longitudinal members", (35 pp. with 17 figures), NACA TM 522, (from ZFM, August 14, 1928, pp. 337–347).

"Applications of the Rocket Propulsion of Gliding Bombs", (9 pp. with illustrations), Ministry of Supply, Völkenrode, LF 83H (Vol. 397H) GDC 697 T(H) (from Deutsche Akademie der Luftfahrtforschung, Schriften, Heft 1071/43, August 5, 1943, pp. 194–203).

"Flat Sheet Metal Girders With Very Thin Metal Web":
Part 1 "General Theory and Assumptions", (38 pp. with figures 1–13), NACA TM 604;
Part 2 "Sheet Metal Girders with Spars Resistant to Bending, Oblique Uprights, Stiffness", (38 pp. incl. tabulations, figures 14–32), NACA TM 605;
Part 3 "Sheet Metal Girders with Spars Resistant to Bending, the Stresses in Uprights, Diagonal Tension Fields", (39 pp., figures 33–50), NACA TM 606
(from ZFM, Vol. 20, April, May, June 1929).

"Translation of a report prepared by Dr. H. Wagner of Henschel AG with regard to flying bombs", May 25, 1945. 2 pp., Illustrations. Confidential. AAF Strategic Forces in Europe. Technical Intelligence I–2B.

"Tension Fields in Originally Curved, Thin Sheets During Shearing Stresses", (11 pp. and 8 figures) by H. Wagner and W. Ballerstedt, NACA TM 774, August 1935 (from Luftfahrtforschung, Vol. 12, No. 2, May 16, 1935, pp. 70–74).

"Experimental Studies of the Effective Width of Buckled Sheets", (23 pp. with 22 figures, graphs, and photos, appendix), NACA TM 814, Dec. 1936 (from Luftfahrtforschung, July 1936, Vol. 13, No. 77, pp. 214–223).

"Tests for the Determination of the Stress Condition in Tension Fields", (13 pp. with 21 figures, graphs, and photos), by H. Wagner and R. Lahde, NACA TM 809, Nov. 1936 (from Luftfahrtforschung, Vol. 11, No. 6, December 5, 1934, pp. 174–180).

"Bars as Trailing Edge Control Surfaces", (24 illustrations), October 1951 (III), Naval Air Missile Test Center (NAMTC), Point Mugu, California, N-13239.

"Decoys On or Near a Target", (49 pp. with illustrations), (GSR Navy NAMTC, No. 5). October 11, 1948 (III), Confidential NAMTC, Point Mugu, California, Technical Report 33.

"Impact Forces at Water Entry", (pp. 3–13, with illustrations). Proceedings of the 8th Underwater Ballistics N-9683 Conference, Part I, October 2–3, 1950 (Office of Naval Research, Navy Department)

Note also that in the Part II of this book the following can be found:

Various notes concerning DART, RADOTT, visual guidance and patents.

Correspondence, publications and recollections from former associates and friends of H. A. Wagner.

c) A List of known Wagner Patents

Patent application H. Wagner: Blechwandträger mit quer zu seinen Gurten angeordneten Stäben, insbesondere für Flugzeuge. Patented on July 10th, 1926, published on March 17th, 1932. (DRP 547 624)

Patent application H. Wagner: Winkeltrieb. Patented on June 1933, published on April 16th, 1936. (DRP 629 625)

Patent application H. Wagner and J. Muttray: Selbsttragender Schalenkörper aus durchsichtigem Werkstoff bei Flugzeugen. Patented on December 29th, 1936, published on June 6th, 1940. (DRP 693 159)

Patent application H. Wagner: Tragflügel, Flossen oder Ruder für Luftfahrzeuge. Patented on February 9th, 1937, published on September 14th, 1939. (DRP 681 864)

Patent application H. Wagner and Ph. v. Doepp: Einrichtung zum Ausgleich der von Strömungskräften herrührenden, an Rudern auftretenden Drehmomente. Patented on March 2nd, 1937, published on August 11th, 1938. (DRP 664 509)

Patent application H. Wagner, J. Muttray and L. Wagenseil: Kuppelartige Scheibe. Patented on May 8th, 1937, published on December 22nd, 1938. (DRP 670 223)

Patent application H. Wagner: Belüftungseinrichtung für gegenüber der Außenluft unter Überdruck stehende Höhenkammern in Luftfahrzeugen. Patented on October 29th, 1937, published on April 25th, 1940. (DRP 691 285)

Patent application H. Wagner: Flugzeugtragwerk. Patented on October 29th, 1937, published on September 19th, 1940. (DRP 697 606)

Patent application H. Wagner and F. Villinger: Flugzeugtragwerk. Patented on October 29th, 1937, published on October 19th, 1939. (DRP 683 504)

Patent application H. Wagner and O. Bohlmann: Tragflügel mit Spaltklappe. Patented on October 29th, 1937, published on October 29th, 1941. (DRP 714 000)

Patent application H. Wagner and B. v. Schlippe: Kraftgetriebene Einrichtung zur Beeinflussung der Strömungsgrenzschicht an Tragwerken von Luftfahrzeugen. Patented on July 9th, 1938, published on June 20th, 1940. (DRP 693 898)

Patent application H. Wagner: An Tragflügeln angeordnete Abreißleisten. Patented on July 9th, 1938, published on October 8th, 1942. (DRP 727 732)

Patent application H. Wagner and H. Gropler: Luftfahrzeug mit Einrichtungen zur Beeinflussung der Strömungsgrenzschicht. Patented on July 12th, 1938, published on August 15th, 1940. (DRP 696 300)

Patent application H. Wagner: Vortriebseinrichtung für Luftfahrzeuge. Patented on August 14th, 1938, published on July 9th, 1942. (DRP 724 091)

Patent application H. Wagner: Spannvorrichtung zum Aufbau von aus Außenhaut und Versteifungen bestehenden schußartigen Flugzeugschalenteilen. Patented on March 14th, 1939, published on September 25th, 1941. (DRP 712 525)

US Patent 3 161 846: Dec. 15, 1964, H. Wagner "Head Motion Sensing System"

US Patent 3 935 913: Oct. 1974, H. Wagner, R. B. Katkov, Aerojet General "Industrial Weighing Machine"

Remark:

Let conclude with an appeal to readers to assist in complementing this biographical effort; i.e. anyone in a position to add or correct this account, please do so by writing to:

Dipl.-Ing. W. Heinzerling
Deutsches Museum
Postfach 26 01 02
Museums-Insel
8000 München 26
Bundesrepublik Deutschland

Abt. Luft- und Raumfahrt
Subject: H. A. Wagner Archiv

Telephone: (089) 2179-265

Commemorative Symposium on May 8, 1984 in Munich

EINLADUNG

Die
DEUTSCHE GESELLSCHAFT FÜR LUFT- UND RAUMFAHRT E.V.
veranstaltet gemeinsam mit dem
AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS
eine

Gedächtnisvorlesung

zu Ehren von

Prof. Dr.-Ing. Dr.-Ing. E.h. Herbert Wagner

im Deutschen Museum in München,
am Dienstag, dem 8. Mai 1984.

Die Veranstaltung folgt auf die am 6. Mai 1984 stattfindende Neueröffnung der Halle für Luft- und Raumfahrt des Deutschen Museums.

Der Vorstand der Deutschen Gesellschaft für Luft- und Raumfahrt e.V. beehrt sich, Sie zu dieser Gemeinschaftsveranstaltung einzuladen.

Für den Vorstand der DGLR:

Prof. Dipl.-Ing. Gero Madelung — Dr. phil. Theodor Benecke

U.A.w.g. – Einsendeschluß für die Antwortkarte: 27. April 1984

Programm

10.30 - 12.00 Uhr	Ehrensaal – Sammlungsgebäude	
	Dr. rer. nat. Otto Mayr, Generaldirektor des Deutschen Museums **Begrüßung**	
	Dr.-Ing. E.h. Ludwig Bölkow, Träger des Ludwig-Prandtl-Ringes und Ehrenmitglied der DGLR, **Einführung**	
	MinDirig a.D. Ing. Rudolf Brée, **Lebensbild**	
12.00 - 13.30 Uhr	Mittagspause (Gelegenheit zum Mittagessen im Restaurant des Deutschen Museums und zur Besichtigung der Halle für Luft- und Raumfahrt)	
13.30 - 17.00 Uhr	Filmsaal des Deutschen Museums	
	Fachvorträge Sitzungsleitung: Prof. Dipl.-Ing. G. Madelung	
	1. Aerodynamik	Prof. Dr.-Ing. H. Försching
	2. Erste Arbeiten am axial durchströmten Strahltriebwerk	Prof. Dr.-Ing. R. Friedrich
	3. Hydrodynamik (in Englisch)	Dr. Th. Y. Wu, Caltech, Pasadena
15.00 Uhr	Kaffeepause	
	4. Festigkeit	Prof. Dr.-Ing. M. Esslinger
	5. Flugkörper (Henschel)	Dipl.-Ing. C. Diederich
	6. Arbeiten in USA	Prof. Dr.-Ing. G.E. Knausenberger
	Schlußwort	Dr.-Ing. E.h. L. Bölkow

Welcoming Address

Professor Gero Madelung
Chairman of the Deutsche Gesellschaft für Luft- und Raumfahrt DGLR (German Society for Aeronautics and Astronautics)

The German Society for Aeronautics and Astronautics (DGLR) recognized Herbert Wagner as an honorary member over a number of years. Today we wish to remember with thanks his productive efforts in this joint conference of the German Society for Aeronautics and Astronautics (DGLR) and the American Institute for Aeronautics and Astronautics (AIAA) along with several of his prominent students and colleagues.

Our thanks are due today especially to those of our members who took the initiative in arranging this conference. I may mention especially Dr. Ludwig Bölkow and Professor Georg Knausenberger.

Gero Madelung

Welcome

by Dr. rer. nat. Otto Mayr
General Director of the Deutsches Museum

Ladies and Gentlemen,
If someone today, interested in the history of aeronautics, wants to get information about the distinguished airplane designer Herbert A. Wagner, his source would have to be the latter's family, students, co-workers and colleagues. For Herbert Wagner has hardly been in the spotlight of the history of technology research, which of course is due also to the generally insufficient illumination of German air and space flight history.
Sufficient source material is the precondition for any historical work. I therefore welcome your initiative for this symposium in memory of Herbert Wagner and your intention to publish the proceedings.
Similarly, I thank you for your readiness to provide the archives of the Deutsches Museum with the documents and source material in your possession.
Surely the new Air and Space Hall inaugurated recently will render suitable countenance for this commemorative event. I cordially welcome you here and wish the symposium good success.

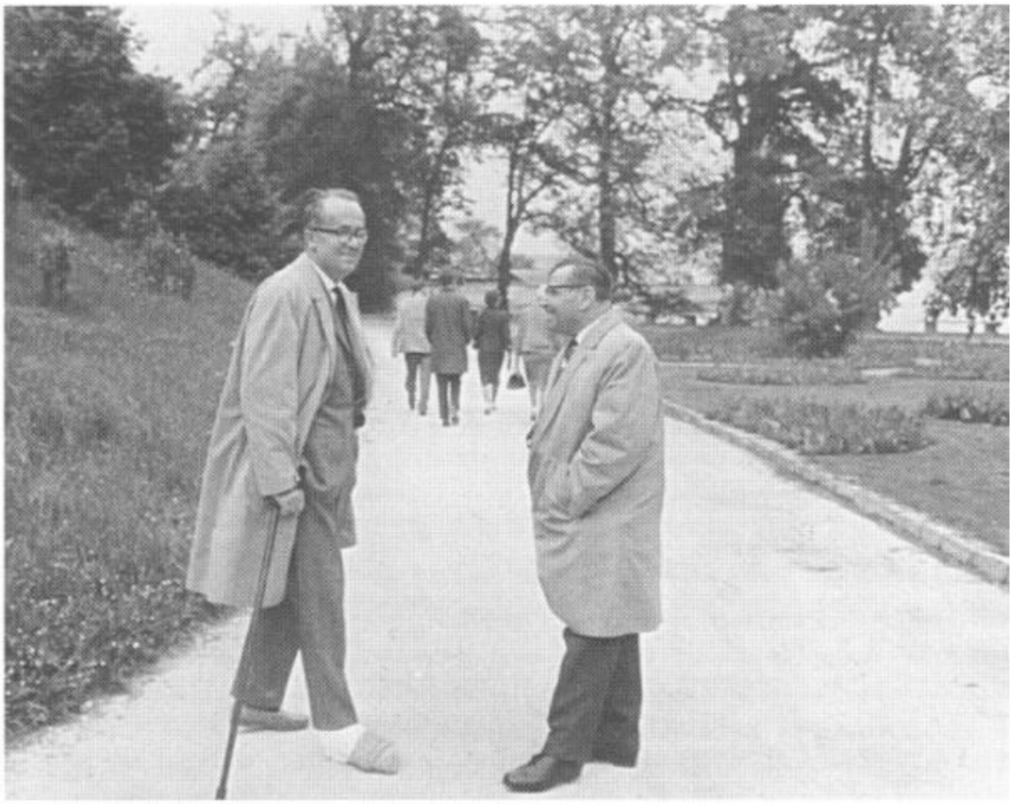
Otto Mayr

Introduction

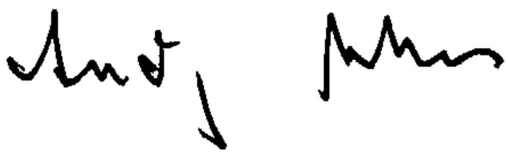
Dr.-Ing. E. h. Ludwig Bölkow

My dear Mrs. Wagner,
Mr. Mayr,
honored guests and friends.

As former students and co-workers of Professor Herbert Wagner, we welcome you here today in the Ehrenhalle (Hall of Fame) of the Deutsches Museum. At the same time, we thank the Generaldirektor of the Deutsches Museum for making available to us these facilities for the commemorative symposium.
Having been students of Herbert Wagner only in a narrow field of aeronautics and astronautics, or having worked with him in development, one fact came as a surprise to us during the preparation of this event. We discovered his creative scientific and technical achievements in areas which we had not been aware of earlier during our own busy occupation in our specific activities – be it in industry or in research.
These were accomplishments of originality, depth and versatility – accomplishments which have been attained only by a very few inspired scientists.
For me, as student and friend – if you will excuse the personal remark – Herbert Wagner reigns side by side with Ludwig Prandtl, from the lonely heights in the technical realm of aero- and astronautics.
What was he like as a teacher? I shall never forget how he introduced us to the particulars of the science of statics and structures – at first a somewhat difficult science for us – by asking the question: "Have you ever seen a force?". And then, in his deformation lectures, the configurations which we were composing and calculating gained shape and life. He took away our inhibitions about formulating for ourselves differential equations for the problems of structures.
For the normal shortcomings of the student of general mechanics, he gave each of us the three volumes of Wittenbauer's problems of mechanical engineering – he always kept some copies in store with the advice to solve 200 problems! Preliminary to design problems, there was a little examination – the famous "Colloquium" – most of the time with three tasks. As long as he was in Berlin, this test was given by him personally.
If one succeeded at the first try, one could be sure of his personal interest in one's future. Repetitions were granted; but if there were too many, he could be very biting in casual remarks.



During our later professional years, one heard again and again from colleagues that we students had acquired from him a particular way of thought and approach to technical-scientific problems. It differed from the usual approach and enabled us to find surprising new methods and solutions.
A final word about the man Herbert Wagner. Once he recognized you as part of his circle of friends, you became a friend for life. When he met you again after years, it was as if he had seen you just yesterday.
Certainly the close personal cooperation with such a genius – which he was in the truest sense of the word – was not easy; but in many respects it was a privilege.
Ladies and gentlemen, we hope that today's commemorative lectures may acquaint all of us with Herbert Wagner and the worldwide significance of his work.

Ludwig Bölkow 

Portrait of Herbert A. Wagner

by Rudolf Brée*

Translation of a talk given at the Herbert Wagner commemorative symposium on May 8th, 1984 at the Deutsches Museum in Munich.

Herbert Wagner as I saw him

Thirty nine years ago to the day I camped on a clover field as a prisoner of war. Among the thoughts that preoccupied me then was the question, "where might Herbert Wagner be at this moment". Four weeks earlier, we had said farewell to each other. At that time he, like myself, was supposed to follow orders to report to Oberammergau as soon as possible. However, he had decided that, whatever might happen, he would stay with his family in the Harz mountains.

Before saying goodbye, we agreed to destroy all the papers, designs, and material related to our common effort during the war years in the field of guided missiles development. We had not the slightest idea whether we would ever see each other again.

But this happened much earlier than anticipated, only seven months later, at Sands Point, Long Island in the U.S.A., on the outskirts of New York City. From then on, I had unforgettable eight months, during which we met daily, within the boundaries of our "gilded cage" on the Guggenheim estate. Including the war years, I witnessed the life of this outstanding personality for only about five years. This, of course, is rather slim basis for my attempt to supplement the following scientific papers by my reflection on Wagner's life.

Three friends facilitated my task: Mrs. B. Wagner, to whom I am indebted for a fascinating, very personal report of the life of her late husband; Walther Ballerstedt, former assistant to Herbert Wagner during his years at the Technical University of Danzig, who has been critic and mentor to me; and the third, Georg Knausenberger, who cannot be with us today – regrettably so, since he has contributed significantly to bring about this event. However, the summary of Wagner's years in the U.S.A. will be presented to this assembly. I must acknowledge the invaluable assistance these three friends of mine have offered me. Similarly, I would also like to extend my deep felt thanks to all who made this commemorative symposium possible.

I was neither a student of, nor an assistent to Herbert Wagner. It was in 1939/40, during my time in the German Air Ministry (Reichsluftfahrtministerium) that I became his ministerial counterpart. I made an effort however to become his partner in this work.

Of all the outstanding people I met during my ten years of service, Herbert Wagner

* Biographical sketch see page 33

was undoubtedly the most ingenious and amiable, although perhaps the least patient, and in some ways, the most difficult.

My own first encounter, not with him but with his achievements, happened in 1933. At that time I worked as a design engineer at the firm of Heinkel/Rostock on the wing for the Heinkel "He 111". I had been told that the spars of the wing should be so-called "Wagner-Beams". At that time, I did not yet have much of an idea about aircraft design, so this did not mean anything to me. But I remember being horrified, when told that this meant, parts of the structure of the wing would be elastically deformed under full loads. This, of course, was directly contrary to the basic concepts of a machine-tool designer, which I had been previous to my ministerial position.

A second encounter – this time a much more immediate one – happened a few years later during my time with the Air Ministry. A group of us had witnessed a demonstration of auxiliary boosters of the Walter-type for assisting the take-off of the "He 111", and we were on our way back to Berlin. A few seats behind me a gentleman was speaking vehemently – with a rather broad Austrian accent – which did not allow the rest of the passengers to miss his very outspoken views. He spiced all he said with explosive salvos of laughter. As I was leaving the bus, someone told me that this man was Herbert Wagner and that this laughter was his mark.

The third encounter was serious. Toward the end of 1939 or the beginning of 1940, Herbert Wagner paid a visit to my office in order to introduce himself. He was accompanied by Mr. Hormel and Mr. Frydag, both directors of the Henschel-Flugzeugwerke (Henschel Aircraft Company). Herbert Wagner had joined this firm, having previously been a member of the Junkers Flugzeugwerke (Junkers Aircraft Company). I had been informed of this change by Roluf Lucht, at that time the chief engineer of the Air Ministry. He had entrusted me with the responsibility for the development of guided missiles. When Lucht saw that I was somewhat alarmed about this new task, he tried to console me by pointing out that I had a very capable partner for this job, the Henschel-Flugzeugwerke, and inside the firm I had the very best man I could wish for this task: Professor Herbert Wagner.

When I met him personally, he was just 40 years old. Five years earlier, he had switched from university to the aircraft industry. This was virgin territory for him! He was given responsibility for the development of an aircraft for very high altitudes, the experimental Junkers "EF 61" (Experimental-Flugzeug 61). Along with this development, he laid the foundation for a jet engine, which later became known under the designation Junkers "Jumo 004" (Junkers-Motorenwerke 004). Now, with Henschel, he would again face fully unexplored terrain.

Our first meeting was by no means love at first sight. Wagner must have had misgivings about this connection to the almighty ministry, and if he was not completely distrustful, he was at least very cautious. Compared to him and his experience, I was a very young man. Very soon I came to recognize his overwhelming abilities; although his lack of patience, his aversion to diplomacy, and his explosive temper often made him a difficult partner. One had to come to terms with this side of his character. For me it was relatively easy because of my fast growing admiration and sympathy for him.

These were war years. We collaborated on a classified project. The longer the war continued, the more doubtful its outcome, and the stricter the surveillance – to which everyone was subject – became. Outside the matters of our projects we avoided any confidences; any wrongly chosen communication was liable to endanger human beings. These were years of mental isolation. We learned to understand each other without words.

The impatience of Herbert Wagner with the authorities had its source in his understandable desire to have his concepts realized as soon as possible. His own certainty about his proposals and their justification often stood very much in contrast to the lack of understanding on the part of those on whom he was dependent. He was superior to any and all in the analysis of complex technical relations. As only few had, he had the totality of the engineering sciences and mathematics at his fingertips. Thus he was often able to offer surprisingly simple solutions – many of them quite unconventional. In order to grasp the full impact of the solutions, his counterpart had to have two faculties: a sufficiently high degree of sympathetic understanding, and the courage to present and defend the proposed solutions to the higher authorities. The lack of these faculties resulted, as a rule, in the loss of much time.

Eminent talent together with discipline made Herbert Wagner what he was. He pursued his career with utmost purpose. Born in 1900 in Graz (Austria) to a family whose ancestors were linenweavers from Silesia, he enjoyed a pleasent childhood. This may be concluded from his close relationship with and attachment to his mother and brother. His mother must have made a very strong impression on him, and the influence of her personality lasted up to her death. At the age of fourteen, he became an Ensign in the Imperial Austrian Navy and was drafted for war service in 1918. When the warship on which he served was torpedoed by the Italian navy and began to sink, he survived by running for his life onto the hull of the capsizing ship, an act of utmost presence of mind. After the war, during the difficult times between 1918 and 1922, he finished school and went to the university, first at Graz and later at Berlin, to study engineering. In 1924, he received the degree of Dr.-Ing. (Doctor of Engineering), and for three years he worked in the aircraft industry at Berlin (Rohrbach). When he was only 27 years old he accepted a call to the chair at the University (Technische Hochschule) of Danzig and received a full professorship one year later. This technical university won prominence as one of the strongholds of aeronautical sciences, not the least thanks to Wagner's presence and performance.

During this time of teaching aeronautics, Wagner encouraged his students to join the academic aviation group to which he belonged – thus fostering contacts with his students. Moreover, he wanted his students to become broadly educated instead of merely specialists.

In 1930, he received a call to Berlin, taking over a full professorship and the direction of the attached institute. In 1935, probably disgusted by the circumstances and consequences of the political turmoil even in the field of teaching, he lost interest in staying with the University and changed to the aircraft industry, accepting an offer from the firm of Junkers in Dessau. There he had a most challenging task of developing an aircraft for flight at very high altitudes. However, when he found that this project was doomed to failure (e.g. by the lack of suitable engines) he left Junkers, where in the meantime he had become member of the board, and in 1940 accepted the task of developing guided missiles at the firm Henschel-Flugzeugbau.

This change had been favored by the Chief Engineer of the Air Ministry, who held Herbert Wagner in very high esteem. This trust was well founded, for Wagner soon developed his ideas for the creation of a family of guided missiles of very high accuracy. The prototype was released from an aircraft less than 12 months after the beginning of development. Unfortunately faulty connection of the ailerons caused its failure. The second test one day later, however, was a brilliant success. The missile, controlled from the aircraft, flew exactly over the middle of the barn serving as the target. This happened on December 17, 1940. The same day Wagner's first child, a daughter, was born. He radiated sheer joy and pride as he informed me of this remarkable coincidence.

Despite the fact that I have never been a student of Wagner, I have learned very much from him. Thus I share the feeling of all of his students and also their life-long attachment to him.

Walther Ballerstedt, one of his students and later one of his assistants, wrote in this context:

"Herbert Wagner was born a teacher, and he did all he could to foster and promote his gift. Once, when developing a formula for describing the forces during the landing of a flying-boat on water he stated: 'If one has analysed a problem correctly and exhaustively, the solution turns out to be simple. Therefore, one should be able to present the result in plain words. If you are not able to express your findings in simple and plain words, it should be a warning to you. Whenever you want to teach somebody anything, you must avoid pompous expressions. You can never guarantee that your student will be able to follow you. Therefore, stick to the principle of never forgetting your elementary school education. That means state everything in plain words and develop your ideas in simple common-sense terms. This way everybody, except, of course the stupid, will understand you.'"

Wagner must have excelled in this faculty. It shows distinctly what linguistic clarity meant to him. His postulate of plain phrasing of ideas is significant. He knew how to handle language perfectly. I remember him speaking on official occasions. One listened for quite a while to presentations in wordy "officialese" and then it was his turn. When he spoke, he did it in a most refreshing, natural way. His words came from his heart and reached the hearts of the listeners.

Herbert Wagner always felt that the first twenty-five years of his professional life had been the most satisfactory ones, especially those at Berlin. A span of time of at least equal length followed in the U.S.A., interrupted from 1957 to 1965 by a new period of teaching in Germany (Aachen). His years in the U.S.A. as well were full of success. He earned much respect and admiration and he was able to found his own industrial company already in 1952. He sold this firm five years later, before he left the U.S.A. to assume a chair at the Technical University in Aachen. But even during this period he remained in permanent contact with American friends and with companies as a consultant. In Aachen he once paid a visit to my home and brought his family along. At that time he considered staying in Europe after retirement.

The transfer to and the settling in the U.S.A. later on was an important caesura in his personal as well as in his professional life. In preparing this presentation, I was privileged to read a series of accounts on the life of Herbert Wagner, thereby filling many gaps in my own image of his personality. In doing so, I found an excellent appreciation of his professional, as well as of his scientific achievements, but it closed with a rather unexpected and succinct remark: "Four wifes, three children." This remark reminded me that the life of Herbert Wagner cannot be presented from its professional side only.

I had the favour of meeting all the wives of Herbert Wagner, except his first wife, the daughter of his erstwhile teacher, Professor Krainer in Berlin, whose assistant he had been. The first marriage occurred in 1924. One year earlier, he had proposed to Hely Raschka, an earlier love from his home town in Graz. This young lady had just finished school at the time and considered the marriage proposal premature. So she turned Herbert Wagner down. His first marriage lasted fourteen years. It was dissolved by mutual consent, and Herbert Wagner supported his first wife substantially up to his own end.

Following his divorce he married, in 1939, Hely Raschka to whom he had proposed unsuccessfully 15 years earlier. She was as beautiful as she was lively, and had become an actress in the meantime. The oldest of his children came from this marriage. Neither in Berlin during the war nor in the Harz Mountains where we were transferred to after the war, did I have more than fleeting contact with Mrs. Hely Wagner.

After my release from captivity, Mrs. Wagner was one of the first persons I sought out after returning to Germany. I had promised Herbert Wagner to contact her as soon as possible. At that time, I cared for some families of German scientists and engineers, who had been transferred to the U.S.A. and who had left their relatives behind. During my first visit with her, I found out that Mrs. Wagner had always suspected that I was a member of the Nazi party because of my position in the ministry. Now that we could talk freely, I was thoroughly interrogated: above all of course about her husband. She could not overcome her shock that on April 8, 1945 her husband had been taken away from her. She had been given the solemn promise that he would return in a few weeks time. However, she almost never saw him again. The separation was no less difficult for him, as I witnessed in Sands Point. His distress was aggravated by the fact that at that time there was no regular mail and the letters he did receive were often censured. I recall his violent fits of rage. He viewed all of this as unworthy and spiteful.

In 1946 in Steina in the Harz mountains, I saw that Hely Wagner was even more distressed than her husband. In an outburst of temper, fully the equal of her husband's best, she reviled the dishonesty of those who had taken her husband from her. Because she was deeply convinced that he would fit better into European life, she had contacted French authorities and had discovered for him what she considered to be excellent opportunities. It might well be that she mentioned these contacts in her letters. Thus the American authorities were informed and did not hesitate to destroy the respective parts of her letters before passing them on to her husband. Her distress and her wrath led finally to tragic consequences. She had to undergo an operation, because she suffered from dropsy. The surgeon found that the dropsy was caused by cancer and tumors were discovered throughout her body. She had only a short time to live. Both Mrs. Wagner and her doctor entreated me to try to arrange for her husband to see her as soon as possible. Under the conditions prevailing at that time, such a request was almost certainly unrealizable. Contrary to my expectations, however, the request was granted, and they were able to share at least a few weeks together. Upon his arrival, at first I only saw Herbert Wagner in the escort of American officers. Only in the evening, after he had met his wife, did we have a short time to speak privately. Immediately after this meeting, I lost my freedom. Six months later Herbert Wagner was back in the U.S.A. and his wife buried in Europe.

Herbert Wagner was permitted to take both his young daughter and his old father back to America. Three years later, he married again, this time an American lady, Frieda Quint. He had two children with her.

In the late fifties he paid a visit to us with his wife and small children. His conversation at that time led me to conclude that he had come to Aachen hoping that his wife might be able to adjust to, and feel comfortable in Europe, so they could eventually live in Austria. This did not happen. His wife preferred to return to California. Herbert Wagner had kept his connections in the United States while teaching in Aachen, and he did not stop working for projects in American firms. So he returned to the U.S.A. Later, when his wife Frieda became incurably ill, he cared most faithfully for her for many years until her death in 1977; she was a fine, warm-hearted woman, who after many years of happy marriage, left her husband and two children, Steven and Joan, in deep sorrow.

Two years later, he again married a Raschka, the niece of his second wife. It was only for a span of a few happy years. He knew already that he too suffered from a fatal illness.

One is tempted to speculate what might have happened had his wifes not been taken away from him so. However, such speculation has no purpose. One can only say that the end of the war, his transfer to the U.S.A. and the death of Hely and Frieda made a very deep impact on the life of Herbert Wagner.

He became a very loyal citizen of the U.S.A. and gave this country the best of what he had to offer.

Herbert Wagner was an eminent scientist and engineer. Was he a happy and a successful man? Did his life reflect his extraordinary gifts? The answer might be yes *and* no. In any case he was not only a scientist and an enthusiastic and creative engineer. He was also a friend and lover of the arts. He also enjoyed participating in every kind of game with a characteristic intensity – whether it was tennis or volleyball, chess or bridge. He was a man who radiated a joy of life.

Only then in the "gilded cage" of the Guggenheim estate at Sands Point, where we lived in a kind of fools' paradise, were we free to talk to each other without restraint. And that we did, about God and the world. Herbert Wagner made it quite clear that for him there was absolutely no doubt that only the here and now mattered. Whatever happened before or after our earthly existence was a matter beyound discussion and reliable clarification; it lay beyond concrete experience for him. He considered himself an agnostic, and distanced himself from ideas of transcendence. At the same time, in practice, he did not live the life of an extreme agnostic. He did not lead a solely material life, nor did he in any way give in to nihilism. Quite the contrary, he accepted fully his own existence. He felt obliged to lead a life in balance with his powers, and he did this with a devotion and vigor that I have never witnessed in any other human being. It might well be that the concepts and values of the old Austrian empire had influenced him, for he never discarded them – in contrast to most of his contemporaries. He stuck to a few simple rules: Obligations were to be honored. Fellow-human beings who tried honestly to do their best were to be respected. Effort beyond personal benefit was important. Amassing a fortune was not an end in itself. One cares for one's own, and does not let his friends down. However differently others might act, one should not take oneself too seriously.

It is understandable then, that during his lifetime Herbert Wagner did very little to build and adorn his own memorial. The phrase "publish or perish" did not mean anything to him. He was impelled only to act, think, reflect, and expand his own horizons!

He seemed the personification and the confirmation of the statement of the anthropologist Arnold Gehlen:

> *"Unfortunately, only the acquisition of knowledge, not its possession is delightful. Something already known cannot again provide the joy of its discovery."*

Once Wagner told an amusing story, indicating the way he viewed the results of his own work:

> *"The patent for the turbo-engine had been submitted by me, as usual without the assistance of a lawyer. After leaving Junkers, I did not care any longer for this matter. However, I am sure that a patent had been granted because in the fifties, I received a letter from France asking for an explanation of a specific part of this patent. I don't know anymore who sent this letter. As was by no means unusual with me, I neither answered this letter, nor did I file it."*

Was Herbert Wagner happy? Was he successful? I suspect that he would have dismissed this question. I think he was conscious of his worth. Of course, he was pleased any time his outstanding performances were acknowledged. It is perfectly conceivable that he simply was not able to resist the temptation of solving the most ticklish problem presented to him: he simply had to give it a try. Yet, as soon as he had found the solution, the problem did not matter to him anymore. In any case I feel that he preferred to let things happen in their own way, rather than going far out of his way to engage in activities for the sake of reputation.

During my entire life, I have never met a personality like Herbert Wagner. He was a hale and hearty man, yet he also had the gift to accept things and events which – from his point of view – he could not change. This included even his fatal illness. When he knew that he would soon die, he phoned his many friends all over the world, in order to take his leave and say farewell.

As for his gifts and talents, they seem to me incomparable, and he used them incomparably. He demanded much more of himself than of those surrounding him. I suppose that everyone who met him had an experience similar to mine: in his presence one felt invariably obliged to give one's very best.

Herbert Wagner viewed others to be as worthy of respect as he himself was. Of course, this meant that he was often disappointed. He knew how to listen to others. He was never above advice or objection from others. He knew how to learn, even from his students.

Although he actually did very little for his posthumous reputation, he would have been grateful to the world, had it granted him at least some acknowledgement for all the extraordinary achievements which he did not only set out to perform, but indeed carried out so successfully.
Herbert Wagner gave generously – of himself.
For his achievements, one had to admire him and highly esteem him. For his honest human nature, one could not but love him.
Together, they constitute his distinction and his dignity.

Biographical Sketch: Rudolf Brée

1907 Year of birth.

till 1923 Attendance of high school for classical education.

1924–28 Mechanical engineering apprenticeship at the firm of Ludwig LOEWE & Co., Berlin.

1928–31 Scholarship holder at the Beuth Mechanical Engineering School (HTL) in Berlin.

1933–35 Designer at firm Ernst Heinkel Flugzeugwerke (Aircraft Company) in Warnemünde.

1935–45 Reichsluftfahrtministerium (German Air Ministry) in Berlin, development of commercial and military seaplanes, guided missiles (from 1939) and aircraft torpedos (from 1943) eventually department head. From 1940 in cooperation with H. A. Wagner.

1945–46 Prisoner of war in the USA, second encounter with H. A. Wagner.

1948–55 Managing Director of Mikro Kopie GmbH in Hamburg, development and management of micro-film devices and methods.

1955–57 Managing Director of Vermittlungsstelle für Vertragsforschung e.V. (Agency for Contract Research) in Bonn.

1957–58 Consultant at the Bundesverband der Deutschen Industrie (Federation of German Industry), section Research for Small Businesses.

1958–61 Bundesministerium für Verteidigung (Federal Ministry of Defense), General offices (budget, personnel, patents, international relations), eventually division head.

1961–72 Kommission der Europäischen Gemeinschaften (Commission of European Communities), Brussels and Luxembourg, dissemination of technical scientific information about peaceful utilization of nuclear technology, development of the first European large data computer memory for scientific data. Eventually General Director.

1972–74 Bundesministerium für Forschung und Technologie (Federal Ministry of Research and Technology) consultant for international exchange of scientific technical information.

From 1953 Member of various national and international associations concerned with technical and scientific information exchange.

PART I

Symposium Papers

Papers of the Symposium of the Deutsche Gesellschaft für Luft- und Raumfahrt DGLR (German Society for Aeronautics and Astronautics) and the American Institute of Aeronautics and Astronautics, held in Munich on May 8, 1984 in memory of Professor Herbert A. Wagner.

Herbert Wagner's Contribution to the Theory of the Growth of Dynamic Lift of Airfoils

by H. Försching, Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR) Göttingen*

1. *Introduction*

Time-dependent changes in incidence of a lifting system relative to a uniform flow (e.g. due to oscillatory motions), or – equivalently – time-dependent changes of the translatory motion of a lifting system with fixed angle of attack in a fluid at rest, give rise to unsteady lift. Unlike steady lift, unsteady lift does not occur instantaneously with a corresponding change of motion of the airfoil. This unsteady behavior of the motion-induced lift is of basic importance in aeroelastic problems, particularly in context of the flutter and the gust problem. In one of the first pioneering works on unsteady fluid dynamics, Herbert Wagner succeeded in contributing fundamentally to this problem with his doctoral thesis [1] "On the Growth of Dynamic Lift on Airfoils", submitted in 1924 to the Technische Universität Berlin-Charlottenburg. In honoring the outstanding scientific merits of Herbert Wagner, his topic, known in unsteady fluid dynamics as "Wagner's problem", will be presented in the following discussion together with the far-reaching technological consequences in the field of aeronautics of his solution, known as the "Wagner function".

2. *Wagner's problem*

In his above-mentioned dissertation, Herbert Wagner investigated the two-dimensional problem of the development of unsteady aerodynamic lift on an airfoil following a sudden change in angle of attack, or following an impulsive start from zero speed to a uniform forward velocity of $V = \text{const.}$ with a fixed angle of attack α in a nonviscous and incompressible fluid. *Fig. 1* shows schematically the corresponding geometric and fluid-dynamic details of this problem. The airfoil at rest with a chord of $2b$ and angle of attack α is impulsively started at time $t = 0$ with a constant velocity of V; $sb = Vt$ is the distance in semichords travelled by the airfoil. This is tantamount to an impulsive step change in angle of attack α, and since the flow must be tangent to the airfoil, the vertical velocity component of the fluid, the so-called downwash, is

* Biographical Sketch see page 47

$$w = V \sin \alpha \approx V\alpha, \quad \text{at } \alpha \to 0. \tag{1}$$

According to Wagner's solution the lift due to the impulsive motion of the airfoil in terms of the Wagner function W(s) on a strip of unit span is

$$L(s) = 2\pi b \rho V w W(s)\,, \tag{2}$$

where ϱ denotes the density of the fluid. The Wagner function W(s) is illustrated in *Fig.* 2. It develops monotonously from 0.5 and approaches, as $s \to \infty$, asymptotically the steady limit value of 1.0. For $W(s \to \infty) = 1$ we obtain the steady lift

$$L(s \to \infty) - \frac{\rho}{2} V^2 (2b) 2\pi\alpha\,, \tag{3}$$

with $dc_L/d\alpha = 2\pi$ as the steady-state lift slope (of the flat plate). It is the particular merit of Herbert Wagner to have first attacked this fundamental problem in unsteady fluid dynamics and to have brought it to an analytical solution.

Fig. 1 Schematic sketch of Wagner's problem

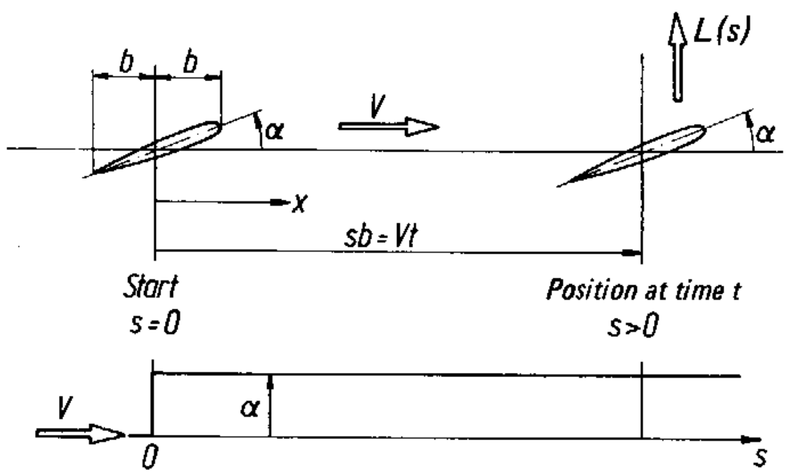
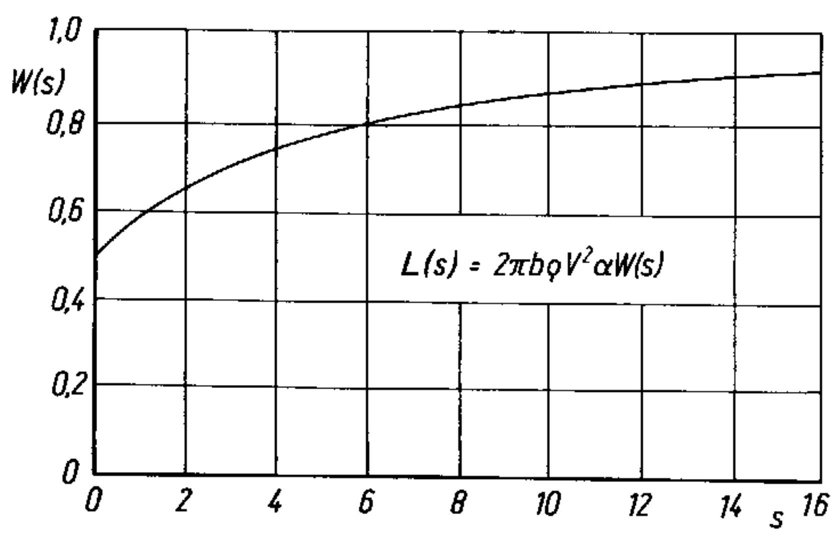


Fig. 2 The Wagner function W(s)



3. *Wagner's method of solution*

In the analytical solution to his problem, Herbert Wagner applied the method of conformal mapping, by which he transformed the airfoil idealized by a flat plate into a circle (circular cylinder), the 2-d flow behavior of which had been known potential-theoretically for many years. In *Fig. 3* the main features of this conformal mapping, as used by Herbert Wagner in his famous work [1], are illustrated. The starting point in his investigations is the physical assumption that the velocity of the fluid at the trailing edge of the airfoil during its motion must be finite, thus giving rise to a shedding of free Helmholtz vortices from the trailing edge and hence to a formation of circulation. To shed light on this basic concept, we first consider the airfoil (plate) and the fluid at rest at infinity. It is assumed that, from the trailing edge point K of the plate, a "sheet of unsteadiness" (as called by Herbert Wagner) is shed in positive x-direction up to the point x_o. The amount of unsteadiness of this vortex sheet (i.e. the amount of rotational velocity) may be denoted by u(x), and points along the x-axis correspond to the points in the transformed system:

$$X = x + \sqrt{x^2 - b^2}\,;\ \ Y = 0\,, \tag{4}$$

i.e. in the transformed system the sheet of unsteadiness is oriented in the X,Y plane and has the intensity U(X). For downwash dw induced by a vortex at X,Y = 0, with circulation dΓ = UdX at K' on the trailing edge,

$$dw = -\frac{d\Gamma}{2\pi b}\,\frac{X+b}{X-b} \tag{5}$$

holds. Then, for downwash w induced by a vortex sheet at K' during the starting motion from X = b to X = X_o, one obtains

$$w = -\frac{1}{2\pi b}\int_{X=b}^{X=X_0} \frac{X+b}{X-b}\,U(X)\,dX\,, \tag{6a}$$

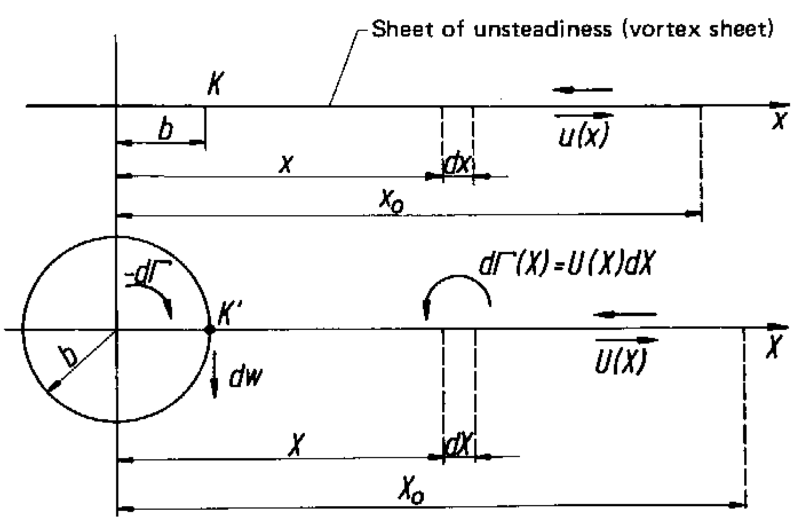


Fig. 3 Wagner's conformal mapping of the wake-induced velocity field

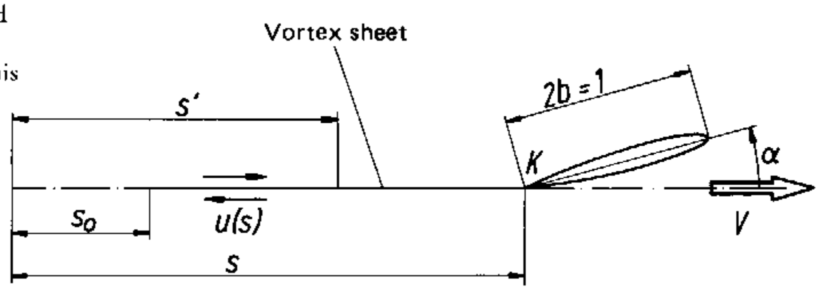
or
$$w = -\frac{1}{2\pi b} \int_{x=b}^{x=x_0} \sqrt{\frac{x+b}{x-b}}\, u(x)\, dx \tag{6b}$$

in the retransformed x,y-system.

Based on this concept of lifting vortices, we now conceive of the fluid at rest at infinity and the plate moving with a speed of V = const. in the direction of the s-axis (or x-axis), see *Fig. 4*. Then, the following three conditions must be satisfied:

1. The total amount of circulation Γ of the bound vortices on the wing and of the free vortices shed at any time t from the trailing edge of the wing must be zero. Thus at any time at which the bound circulation changes, a corresponding free vortex develops. These free vortices flow downstream from a point K off the trailing edge with the velocity V, thus forming the well-known wake behind the wing which Herbert Wagner called the "sheet of unsteadiness."
2. The relative velocity is tangential to the surface of the wing (kinematic flow condition).
3. The normal velocity w (downwash) at the trailing edge K' is zero (Kutta condition).

Fig. 4 Variables and coordinates used by Wagner in deriving his integral equation



Satisfying these conditions and with the assumption that the angle of attack α is very small, we obtain from Eq. (6b) and Eq. (1), according to *Fig. 4*, the relation

$$V \sin \alpha = \frac{1}{\pi} \int_{s_0}^{s} \frac{\sqrt{1+s-s'}}{\sqrt{s-s'}}\, u(s')\, ds' , \tag{7}$$

where for simplicity the chord of the wing 2b has been set equal to 1. This is Herbert Wagner's famous solution to his problem in the form of an integral equation. In solving this equation the unsteadiness u(s') at any control point s' along the s-axis in the x-direction has to be determined such that Eq. (7) is satisfied for all values of s. Then, with u(s') determined from Eq. (7), the total circulation is given by

$$\Gamma(s) = \int_{s_0}^{s} u(s')\, ds' , \tag{8}$$

and hence the resulting unsteady lift per unit span:

$$L(s) = \rho V \Gamma(s) . \tag{9}$$

Thus, the Wagner function W(s) is defined as follows:

$$W(s) = \frac{\Gamma(s)}{2\pi bw} = \frac{L(s)}{2\pi b\rho V^2 \alpha}. \tag{10}$$

At that time (1924), without the aid of electronic computers, the numerical solution of this integral equation surely posed Herbert Wagner great difficulties. For the investigation of the start of the airfoil's motion for $(s - s_0) < 1$ he overcame this problem by means of a convergent series expansion of u(s'). In the s-domain mentioned, he investigated two different motions, namely the impulsive start of an airfoil from zero speed to a constant forward velocity V with fixed angle of attack, and the airfoil with fixed angle of attack at constant acceleration. The W(s)-function for the first case, known as Wagner function, is shown in *Fig. 2* and its practical importance will be discussed below. The W(s)-function of the second case appears quite similar; for $s = 0$ it also starts at a value of 0.5 and approaches unity asymptotically as $s \rightarrow \infty$. For $s > 1$ he presented in his classical paper [1] approximate solutions for both cases and, in an appendix, he treated, in addition, the case of an airfoil performing a pitching motion with time-varying angular velocity.

4. *Fourier integral formulation of Wagner's function*

Whereas Herbert Wagner achieved the solution to his problem in the form of an integral equation which he could only solve numerically in terms of the W(s)-function shown in *Fig. 2*, ten years later his solution could be derived in closed form in terms of a Fourier integral representation. A pre-condition for this was the knowledge of the solution of the harmonically oscillating airfoil (plate) at V = const. This solution was published in 1935 by Th. Theodorsen [2] and – independently – in 1936 by H. G. Küssner [3]. It is noteworthy in this context that both (exact) solutions were found in different ways. Whereas, like Herbert Wagner, Theodorsen applied the method of conformal mapping, Küssner's solution was based on Prandtl's lifting vortex theory [4] and the resulting concept of replacing the lifting surface by a continuous vortex sheet (singularity method), as it had been applied in the early 1920's by W. Birnbaum [5] in his solution of the 2-d problem of a wing performing harmonic heaving oscillations. Birnbaum and Wagner were contemporaries who worked at that time on quite similar unsteady fluid dynamic problems, but presumably had no personal contact. Whereas Birnbaum was able to express the density of vortex shedding by means of the density of bound vortices on the wing (since the change in time of all vortices was known a priori from the prescribed harmonic motion), Wagner was forced to calculate directly the density of free vortices because no information was first available with respect to its change in time. In the paper mentioned above, H. G. Küssner [3] has shown the way in which Wagner's problem can be solved by means of a Fourier integral representation by taking into account the exact solutions of the harmonically oscillating plate, as shown in the following discussion.

The unsteady lift (per unit span) of a flat plate oscillating harmonically in a non-viscous incompressible flow at V = const. (see Refs. [2] and [3]) can be expressed by

$$\overline{L}(t) = 2\pi b \rho V w(t)\, C(\omega^*) , \tag{11}$$

where

$$w(t) = w_0\, e^{i\omega t} \tag{12}$$

is the vertical velocity (harmonic downwash) at the 3/4-chord point. In Eq.(11)

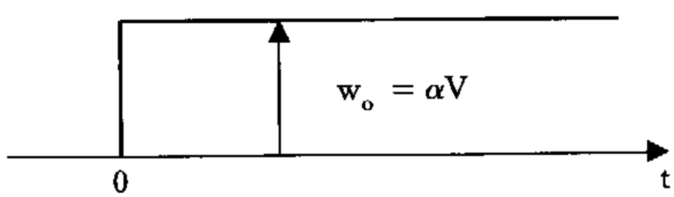
$$C(\omega^*) = \frac{T(\omega^*) + 1}{2} = \frac{H_1^{(2)}(\omega^*)}{H_1^{(2)}(\omega^*) + i\, H_0^{(2)}(\omega^*)} \tag{13}$$

denotes the so-called Theodorsen function and $T(\omega^*)$, its equivalent, is the Küssner wake function. $H_n^{(2)}$ are the Hankel functions of the second kind and of order n which are a function of the reduced frequency

$$\omega^* = \frac{\omega\, b}{V} , \tag{14}$$

where ω is the circular frequency of oscillation. It is of interest that, as pointed out by Küssner [3] and implied also in the work of Theodorsen [2], that the vertical velocity at the 3/4-chord point determines the circulation on the airfoil in oscillatory motions. The resulting lift acts at the forward quarter-chord point.
According to Eq.(13), the wake functions $C(\omega^*)$ and $T(\omega^*)$ are complex (i = imaginary unit), which means that the unsteady lift $\overline{L}(t)$ lags in time with respect to the known and prescribed downwash w(t). Resuming Wagner's problem, the downwash resulting at the 3/4-chord point for a step change in angle of attack is:

$$w_0 = \begin{cases} 0, & \text{for } t < 0 , \\ \alpha V, & \text{for } t \geq 0 . \end{cases}$$



This has the Fourier transform

$$f(\omega) = \frac{\alpha V}{2\pi i \omega} , \tag{15}$$

and hence we obtain the following Fourier integral representation for the unsteady lift resulting from a unit step change in angle of attack:

$$L(t) = \int_{-\infty}^{\infty} f(\omega)\, \overline{L}(t)\, e^{i\omega t}\, d\omega , \tag{16a}$$

or

$$L(s) = \int_{-\infty}^{\infty} f(s)\, \overline{L}(s)\, e^{i\omega^* s}\, d\omega^* , \tag{16b}$$

with the non-dimensional variable in time

$$s = \frac{V\,t}{b}\,. \tag{17}$$

Inserting Eq.(11) into Eq.(16b) we then obtain the unsteady lift (per unit span) due to a sudden change in angle of attack expressed by the Wagner function according to Eq.(2):

$$W(s) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{C(\omega^*)}{i\omega^*}\, e^{i\omega^* s}\, d\omega^* = \frac{1}{4\pi} \int_{-\infty}^{\infty} \frac{T(\omega^*) + 1}{i\omega^*}\, e^{i\omega^* s}\, d\omega^*\,. \tag{18}$$

This is the closed-form representation of Wagner's function derived by H. G. Küssner in Ref. [3]. It is mentioned that the integrand becomes singular for $\omega^* = 0$, and that the integration in Ref. [3] can only be carried out numerically by means of a convergent series expansion.

5. *Practical significance and application of Wagner's function*

The Wagner function is of basic practical importance in context with the problem of calculating the unsteady aerodynamic reactions (lift and moment) on thin airfoils performing arbitrary motions such as rapid maneuvers, and particularly in the treatment of the aeroelastic gust problem. Without entering into analytical details, it is mentioned that, in treating these problems, first the characteristic unsteady aerodynamic functions for the lift and moment resulting from a sudden change in angle of attack (unit step function) must be known. For 2-d incompressible flow these so-called indicial functions contain as a solution the Wagner function. With knowledge of these indicial functions, and by means of superposition and by applying Duhamel's integral and the aerodynamic strip theory, the unsteady airloads due to arbitrary time-dependent motions of a wing with finite span and large aspect ratio can be calculated. Thus, with reference to *Fig. 5* and as discussed in detail in Ref. [6], the unsteady lift on an airfoil executing an arbitrary time-dependent motion is:

$$L(t) = w(0) + \bar{L}(t) + \sum_{\tau = \Delta t}^{\tau = t} \frac{\Delta w}{\Delta \tau}\, \bar{L}(t - \tau)\, \Delta \tau\,, \tag{19a}$$

and hence with $\Delta\tau \to 0$

$$L(t) = w(0) + \bar{L}(t) + \int_0^t \frac{dw(\tau)}{d\tau}\, \bar{L}(t - \tau)\, d\tau\,, \tag{19b}$$

where the indicial function $\bar{L}(t) = W(t)$ is the Wagner function as solution of the unit step downwash

$$w(t) = 1(t) = \begin{cases} 0, \text{ for } t < 0\,, \\ 1, \text{ for } t \geqq 0\,. \end{cases} \tag{20}$$

Since the Wagner function W(s), given by Eq.(18), cannot be expressed in terms of well-known elementary mathematical functions, several convenient approximate formulations have been presented, such as

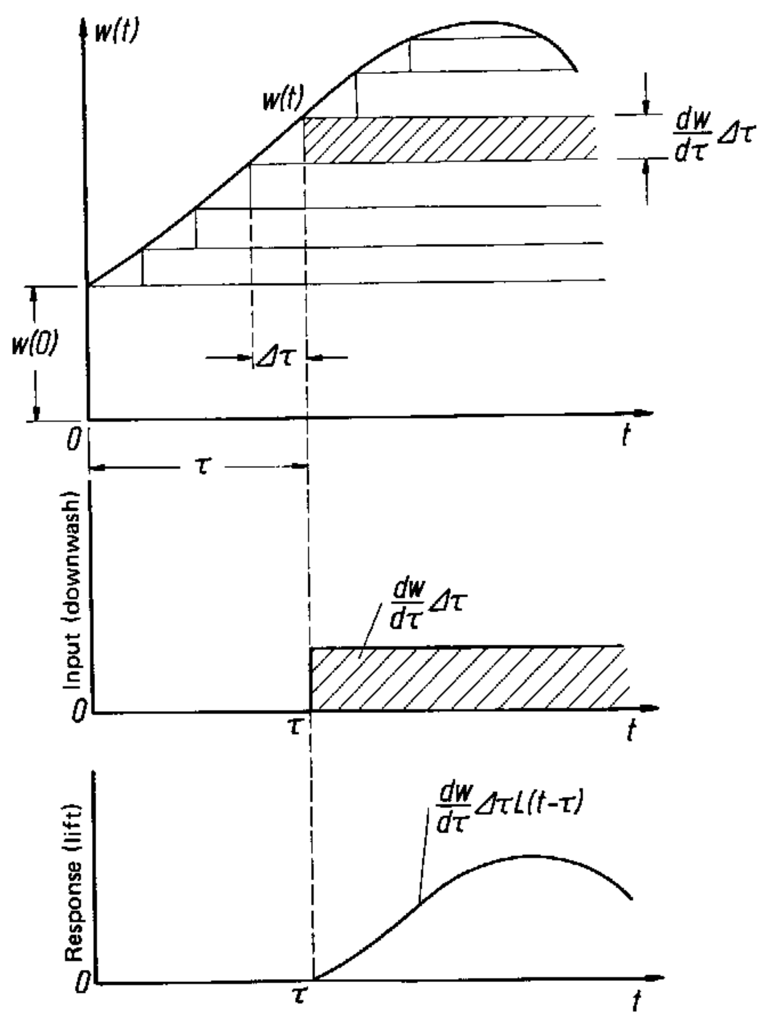
$$W(s) \cong 1 - \frac{2}{4 + s'} \tag{21a}$$

by I. E. Garrick [7] and

$$W(s) = 1 - 0{,}165\ e^{-0{,}0455s} - 0{,}335\ e^{-0{,}3s}\,. \tag{21b}$$

by R. T. Jones [8], to which an elementary Laplace transformation can be applied. On the other hand, in treating the aeroelastic gust problem, Wagner's function must be seen in direct context with the so-called Küssner function K(s). The latter describes the unsteady lift on an airfoil when it penetrates a sharp-edged gust with V = const. The resulting unsteady aerodynamic problem, the so-called Küssner problem, is closely related to Wagner's problem. This situation is illustrated in *Fig. 6*. The gust front strikes at t = o the leading edge of an airfoil at x = -b. Then, the vertical component w_B of the gust field acts like a vertical displacement of the airfoil which induces a downwash

Fig. 5 Superposition of step functions (indicial function) by means of Duhamel's integral



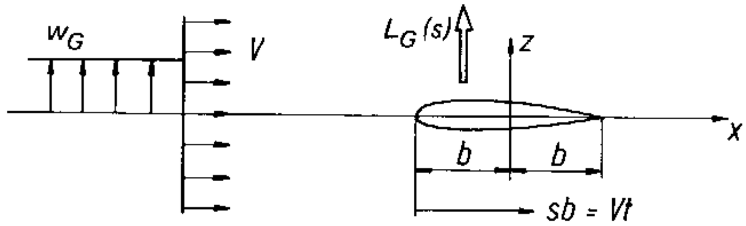
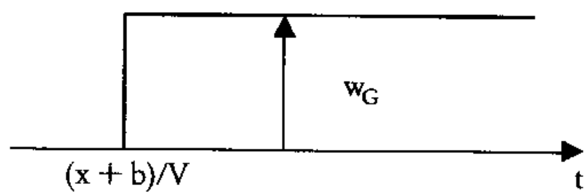


Fig. 6 Airfoil penetrating a sharp-edged gust

$$w = -w_G, \tag{22}$$

with
$$w_G = \begin{cases} 0, & \text{for } t \leqq (x+b)/V \\ w_G, & \text{for } t > (x+b)/V \end{cases}$$



Analogous to Eq.(2) the resulting unsteady lift can be formulated as follows:

$$L_G(s) = 2\pi b \rho V w_G K(s); \; s = \frac{V\,t}{b}. \tag{23}$$

Here

$$K(s) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{\{[T(\omega^*) + 1]\,[I_0(\omega^*) - i\,I_1(\omega^*)] + i\,I_1(\omega^*)\}\; e^{i\omega^*(s-1)}}{2i\omega^*}\, d\omega^* \tag{24}$$

is the so-called Küssner function illustrated in *Fig. 7*. Obviously, this has a direct similarity to Wagner's function illustrated in Fig. 2. The only difference is posed by the unsteady lift, which in Küssner's problem develops from zero, whereas in Wagner's problem half of the total unsteady lift develops quasisteadily and simultaneously. H. G. Küssner derived his K(s)-function in Ref. 3 in the same manner as he did for the Wagner function, i.e. by a Fourier integral superposition of the harmonic solutions obtained for the airfoil penetrating a sinusoidal gust. In Eq. (24) $I_n(\omega^*)$ are Bessel functions of the first kind and of order n as a function of the reduced frequency ω^*.

From these explanations it has become clear that the Wagner function W(s) and the Küssner function K(s) are of equal importance in the analytical treatment of the aeroelastic gust problem. Both are the result of the analytical solution of a similar unsteady fluid dynamic problem, where each problem has been solved individually by different methods. It was a noble gesture that both outstanding pioneers in unsteady fluid dynamics were jointly awarded the Ludwig Prandtl Ring in 1980 by the German Society of Aeronautics and Astronautics (DGLR). In this context it is perhaps of interest to mention that Herbert Wagner acted as co-reviewing professor for Küssner's doctoral thesis at the Technische Universität Danzig in 1928.

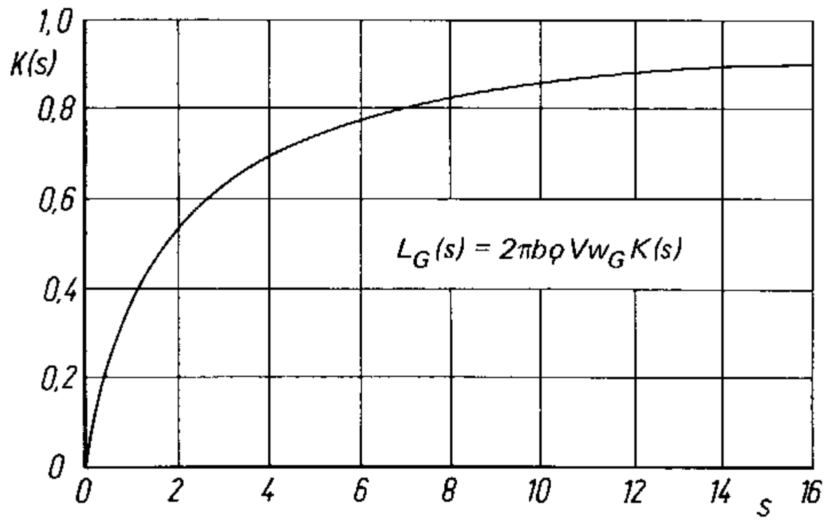
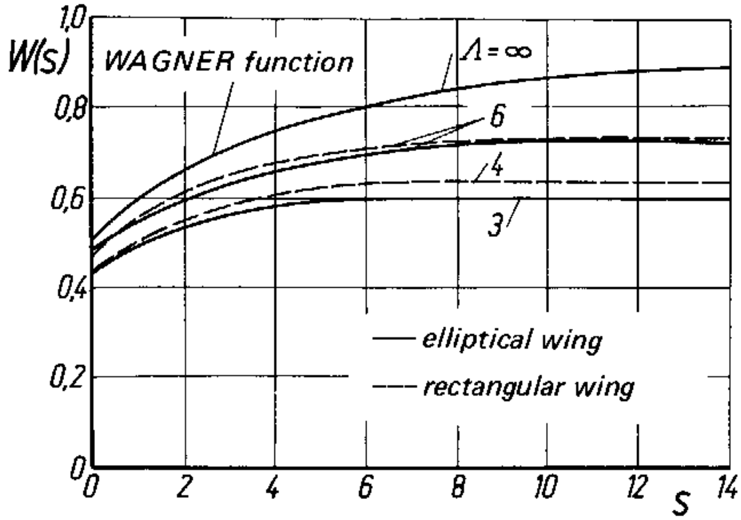


Fig. 7 The Küssner function K(s)

6. *Outlook*

Although Herbert Wagner's investigations on the growth of dynamic lift on an airfoil following a sudden change in angle of attack were confined to 2-d incompressible flow, this pioneering work nevertheless contributed much to the physical understanding of the phenomenon of the development of unsteady lift. It has been shown that Wagner's fundamental findings are of practical importance still today, particularly in context with the solution of the aeroelastic gust problem. Not until the early 1950's were Herbert Wagner's investigations extended to the compressible subsonic flow regime. However, this was only possible in numerical form by applying Küssner's Fourier integral method and taking into account the 2-d solutions of the harmonically oscillating flat plate in subsonic compressible flow elaborated at that time.

The method of conformal mapping, applied by Herbert Wagner in an elegant manner for the solution of his problem, remained confined in aerodynamics to the 2-d incompressible flow regime, beyond which the method leads to insoluable analytical problems. In both steady and unsteady fluid dynamics all further progress has been restricted to the singularity method based on Prandtl's lifting vortex concept. Application of modern electronic computers accomplished the rest. In fact, a complete solution of the threedimensional aeroelastic problem for a lifting system performing arbitrary time-dependent motions and for arbitrary planforms, taking into account elastic deformations (mode shapes) as well, can be reasonably achieved only on the basis of a Fourier integral representation of harmonic solutions. Needless to say, this is numerically only possible by applying modern computers. A typical result for an elliptical and a rectangular wing in threedimensional incompressible flow is illustrated in *Fig. 8*. With his early pioneering work, Herbert Wagner made a fundamental contribution to the problem of the growth of unsteady lift on an airfoil with arbitrary time-dependent motion. With the "Wagner function" he obtained worldwide repute in the field of unsteady fluid dynamics.



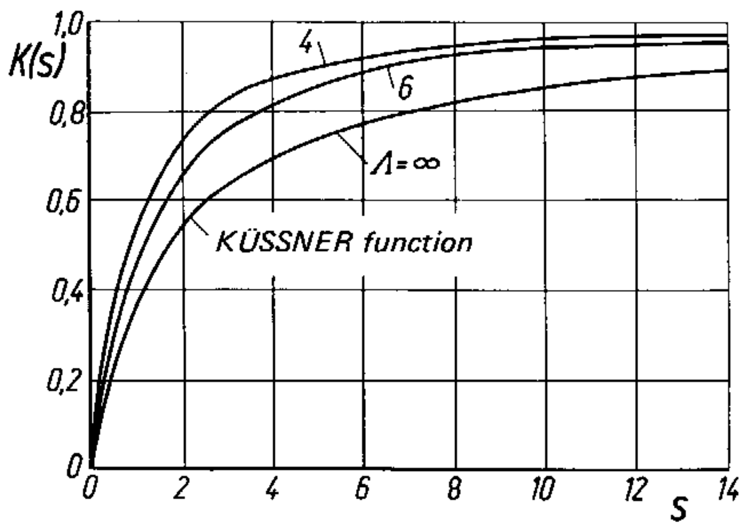


Fig. 8 The W(s) and K(s) functions for an elliptical and rectangular wing with variable aspect ratio Λ in three-dimensional incompressible flow [6]

7. *References*

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Biographical Sketch: Dr. Hans Försching – Professor

Head of the Institute of Aeroelasticity of the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR) (German Air and space Research Establishment), Research Center Göttingen
Born on 15 April 1930 in Rastatt, Germany

Education
1955 Dipl.-Ing., Technical University of Karlsruhe, Germany
1962 Dr.-Ing., Doctor of Engineering, Technical University of Braunschweig, Germany
1975 Professor, Technical University of Braunschweig, Germany

Teaching experience
1968 – present: Lecturer (Professor since 1975) at the Technical University of Braunschweig, Department of Mechanical Engineering
Subject of teaching: Aeroelasticity, structural dynamics, unsteady aerodynamics of oscillating lifting systems and bodies

Practical experience
Industrial experience including about 6 years spent in the aircraft and automobile industry as senior engineer and research specialist in the field of structural vibration, aircraft structural dynamics and aeroelasticity. About 25 years research work in the field of aircraft structural dynamics, aeroelasticity and unsteady aerodynamics at the Institute of Aeroelasticity of the DFVLR in Göttingen, Germany, since 1968 as head of this institute.

Special research activities
- Theory of elasticity
- Vibration behaviour of complex aircraft and spacecraft structures (theoretical studies and development of ground vibration test techniques)
- Flutter stability investigations of aircraft structures
- Wind engineering research work and related theoretical and experimental aeroelastic studies on bluff bodies
- Studies in unsteady aerodynamics of oscillating lifting systems
- Aeroelasticity at separated flow.

Professional activities
- Head of the Research Council of the DFVLR in Germany
- Member of the Structures and Materials Panel of AGARD

Publications

- Grundlagen der Aeroelastik (Foundations of Aeroelasticity), Springer Publ. Co., 1974, 700 pages. This book has been translated into Russian and Chinese.
- "Dynamic Aeroelastic Calculations of Aircraft Based on Ground Vibration Test Data", in: D. Küchemann (Ed.) Progress in Aerospace Sciences, Pergamon Press, 1970.
- "Prediction of the Unsteady Airloads on Oscillating Lifting Systems and Bodies", in: *Progress in Aerospace Sciences*, Vol. 18, Pergamon Press 1978.

Author of more than 50 publications in the field of structural dynamics, mechanical vibrations, unsteady aerodynamics and aeroelasticity in several technical and scientific journals and official research papers.

Summary of Herbert Wagner's Works in Hydrodynamics

by George E. Knausenberger*

Through the good offices of Professors Dr. K. Oswatitsch, Vienna, and K. Wieghardt, Hamburg, it has been possible to solicit a talk from a prominent hydrodynamicist Dr. Theodore Y. Wu, Professor of Engineering Science at the California Institute of Technology who wrote: "early in my study I was deeply impressed by the beauty and simplicity of the ideas, with which at least three of Wagner's pioneering contributions I know were conceived... ."
The three areas are: 1) planing surface theory, 2) the mathematical model of the re-entrant jet cavity, 3) the Wagner effect in unsteady wing theory.
Wu's interest was, as he says, "accented by interesting discussions offered by von Kármán and Prandtl (such as those made at the Stockholm and Cambridge meetings of the International Union for Theoretical and Applied Mechanics IUTAM or its predecessors) on these papers".
Wu has been "stimulated to make humble attempts to pursue, with my students, further generalizations of these beautiful solutions first brought to us by Wagner".
It is a privilege and pleasure to learn from Dr. Theodore Y. Wu on this occasion about Wagner's favorite scientific accomplishment.

* Biographical Sketch see page 112

Pioneering Contributions of Herbert Wagner to Hydrodynamics

by Theodore Y. Wu, California Institute of Technology, Pasadena, California, USA*

Honorable Chairman, my dear Frau Dr. Wagner and all the Wagner family members, ladies and gentlemen, distinguished guests, colleagues of DGLR, fellow members of AIAA, and friends!

First of all, warmest congratulations are due to this museum of world renown on this jubilant occasion of your 1984 Congress as well as the recent Inauguration Ceremony for the opening of the Halle für Luft- und Raumfahrt (Air and Space Exhibit).

Today we are assembled for the special Commemoration in honor of Professor Dr.-Ing. Dr.-Ing. E. h. Herbert Wagner. Personally, I feel especially honored and pleased to be invited by the honorable Dr. Benecke and Dr. Ludwig Bölkow to attend, and further, at the urging of Professor G. E. Knausenberger and Professor Dr. K. Wieghardt, to deliver a tribute to Professor Herbert Wagner with a focus on his contributions to the theme of hydrodynamics. In my attempt to fulfill this privileged task, I would feel gratified if I could succeed in expressing even only a token of the high respect and gratitude held by so many admirers of Professor Wagner, whose voluminous works have endowed them with lasting benefit and inspiration.

Herbert Wagner was gifted in mind, possessing genius and vision in many fields of science and engineering, both theoretical and applied, as today's speakers jointly come to give testimony. As I have just learned, he even had talents to spare for enriching the physics of the special and general theories of relativity. However, it is evident that hydrodynamics was near the top of Professor Wagner's favorite subjects, for this was the field he chose first to cultivate with a keen interest.

In the decade following 1925, his publications included at least three pioneering works in which giant and bold steps were taken to advance the then frontiers of the new subject of unsteady aerodynamics and hydrodynamics. It gives me great pleasure indeed to speak on Wagner's splendid achievements in hydrodynamics; they have enlightened students and scholars and helped them acquire a profound appreciation of this inspiring theme.

Gliding surface

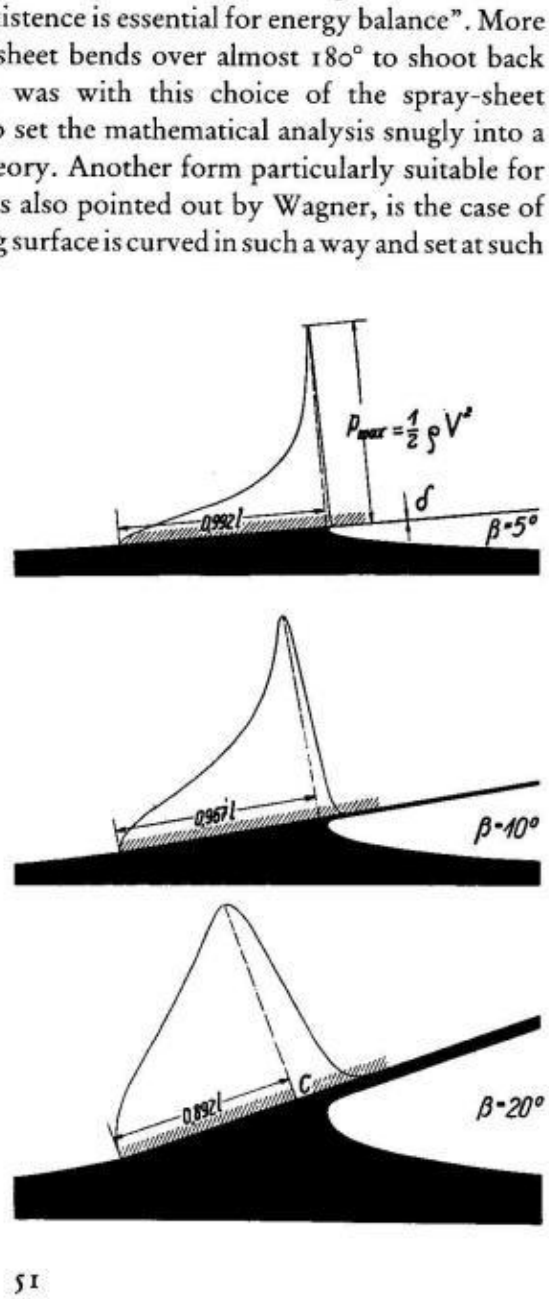
It is well to note that in 1930 Wagner delivered a paper, at the 3rd International Congress for Applied Mechanics held in Stockholm, on the problem of water entry by a two-dimensional body and in 1934 another paper, at the 4th International Congress of the series in Cambridge, reporting on an extended study on "gliding surfaces" (also called planing surfaces in America) and three-dimensional water entry by a slender body. Before this, linear theory had prevailed for predicting the wave drag due to a distribution of surface pressure moving over the surface of water under

* Biographical Sketch see page 61

gravity. The theories in this class are all based on the assumption of infinitesimally small wave amplitude but cannot describe the shape of the perturbed waters surface *a priori*. In other words, for a gliding surface of given shape, it was only the 'inverse problem' that one could solve by applying these theories. No one seemed to know then how to handle the direct physical problem.

Wagner was the first to make a frontal attack on the direct problem of water impact and gliding surfaces but in his theory the gravity effects were neglected, an issue which we shall discuss later. Nevertheless, it is of significance to observe several new features of the solution that resulted from his pioneering study. First, he found that it is generally impossible to keep the water surface elevation small at the leading edge of these pressurized surfaces. Instead, Wagner discovered that it is necessary to have a sheet of water, which he called a "spray", dart forward to return upstream from the leading edge because, he argued, "its existence is essential for energy balance". More precisely, he assumed that the spray sheet bends over almost 180° to shoot back upstream as shown in Figure 1. It was with this choice of the spray-sheet configuration that Wagner was able to set the mathematical analysis snugly into a proper form consistent with linear theory. Another form particularly suitable for linear theory consideration, which was also pointed out by Wagner, is the case of sprayless entry; that is, when the gliding surface is curved in such a way and set at such

Fig. 1 A flat plate gliding with a horizontal velocity V and at various incidence angles over a water surface originally at rest. As first pointed out by Wagner, a spray sheet of water shooting back upstream along the leading portion of the plate determines the operating condition, that the centrifugal acceleration, V^2/R, of the water particles turning around the root of the spray, as measured by the local small radius of curvature, R, is so great that the gravity effects must be comparatively insignificant.



an angle that the leading edge "enters" the water smoothly. With any other spray formation the problem becomes nonlinear and more difficult to solve. In the framework of linear theory, an elegant analogy was discovered by Wagner between the gliding surface and thin airfoil theories, provided the planing velocity is very large. In that case, the analogy states that the flow field of a gliding surface is identical to the lower half of that generated by a thin airfoil of the same geometric shape, held at the same incidence angle. The analogy can be regarded as complete for the case of sprayless entry at high speeds (or rather, very high Froude's numbers), but when a spray is present, the flow around the leading edge of the airfoil must be replaced by the spray formation, which implies a resistance on the gliding plate as the corresponding leading-edge suction acting on the airfoil is removed in order to draw the analogy. In either case, we see that the gliding surface experiences a lift just half of the airfoil lift, as illustrated in Figure 2.

With respect to the assumption of neglecting the gravity effects, Wagner was of course considering the case of very high Froude's numbers; that is, when the fluid acceleration, as measured by the plate velocity squared divided by the plate chord length, is large compared with the gravitational acceleration. For that case, Wagner argued, as if to convince his audience and future readers, that as the fluid particles accelerate around the sharp bend along or near the free surface of such a large curvature and at such a high speed of plate motion, the centrifugal acceleration of the fluid must be so large that, relatively speaking, the gravity effect just cannot be of any significance (see Figure 3).

Wagner's argument about the local acceleration is certainly true, but the work was nevertheless criticized in spite of the eloquence with which the defense was laid out. Some objections were indeed misleading and irrelevant; for example, the question

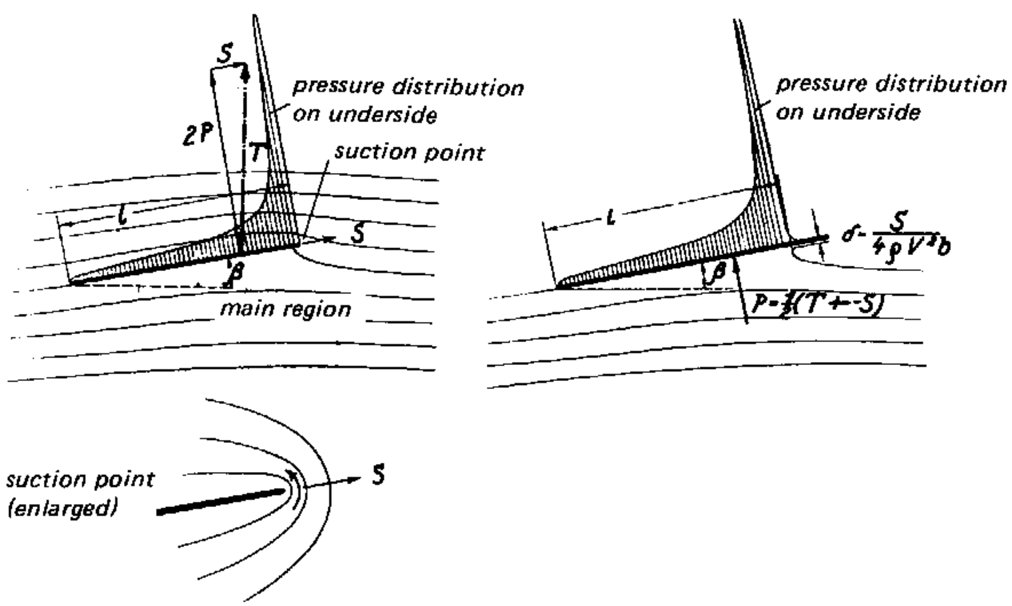


Fig. 2 A simple and elegant analogy was found by Wagner between the suction force, S, acting at the leading edge of a flat plate airfoil and the momentum flux in the returning spray, of thickness δ, along the planing plate. This analogy thus establishes, to the leading order (in which the gravity effects are neglected), the correspondence of the pressure distributions over the airfoil and the planing surface.

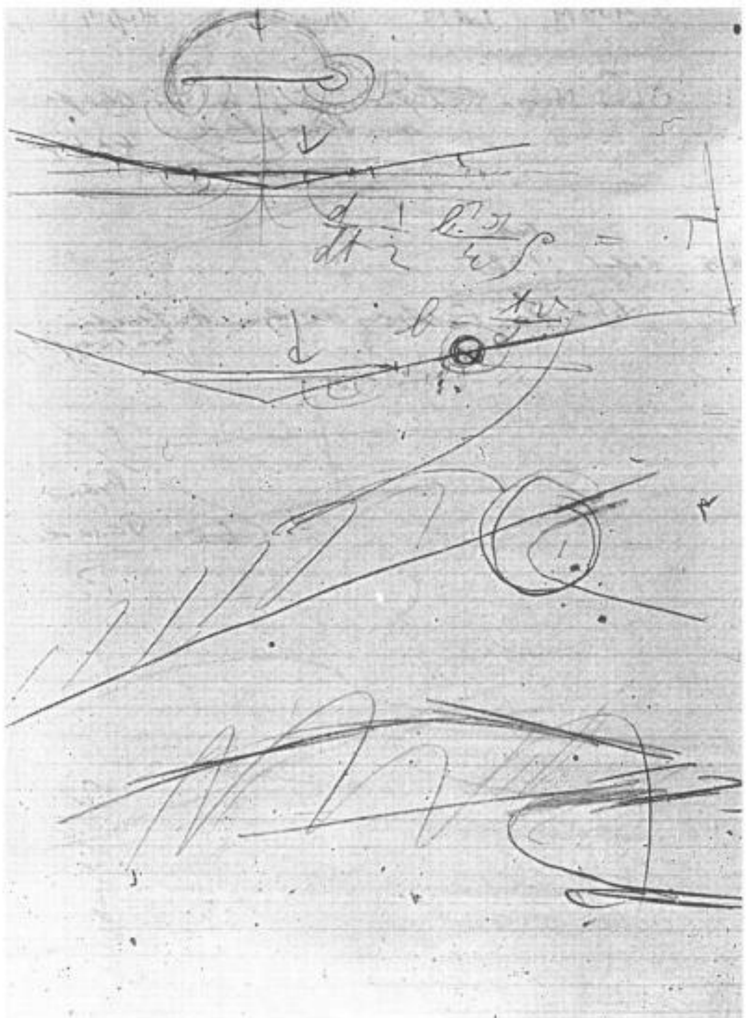


Fig. 3 This original hand drawing by Professor Herbert Wagner, signed and dated on 27 July 1972 in Thousand Oaks, California, and now in the personal archive of Professor Georg Knausenberger, treasures a revisit with friends to the original conception of spray formation in front of a planing surface. The region of central interest about the root of the spray sheet is accentuated with a circle. The top sketch suggests further thoughts concerning the case of sprayless planing previously explored by Wagner himself (1932).

about the unique extension of analytic functions around the leading edge. However, it is still worthwhile to address again the central assumption of neglecting the gravity effects since it stimulated interesting discussions that continued for some time.

Critics argued that while, admittedly, the gravity effects can be neglected near the gliding surface, they cannot be neglected at large distances, especially at infinity, because in complete absence of gravity, the long-range influence of the lift force acting on the plate would cause the flow velocity to diminish with increasing distance so slowly that the water surface in this plane flow must then fall down to negative infinity logarithmically.

The recognition of this nonuniform validity of the approximation is so essential that we should rank it at the same level as Stokes's paradox in the theory of low-Reynolds-number flow and Prandtl's concept that underlies his boundary-layer theory. This argument has in fact stimulated much interest in making new investigations of gliding surface in the presence of a gravity field. Several such linear theories were published subsequently, all of which retained Wagner's leading-edge singularity of the velocity and pressure fields, but which nevertheless still lacked the freedom of prescribing the draft of the gliding plate – by the draft we mean the distance of the plate above or below the original undisturbed water surface.

In summary, this pioneering work of Wagner's has exerted a major thrust to open a new field by uniting freestreamline jet theory and water wave theory into one compound subject. It accomplished this inspiring cross-breeding with a simple and elegant stroke of genius which can be regarded as successful in the following sense. If the spray sheet thickness rather than the draft of the plate is employed as a reference flow parameter, which is assumed to remain small, and if the assumed geometry of an almost 180° return jet direction is maintained, Wagner's theory would still be capable of determining the lift force with an accuracy to leading order for high Froude's numbers. This achievement should be of great value, even though the theory fails to provide information about the draft of the plate. This is affirmatively indicated by comparison with the more complete nonlinear theory which was developed much later by Rispin (1967) and reported by Wu (1967), as illustrated in Figures 4 and 5.

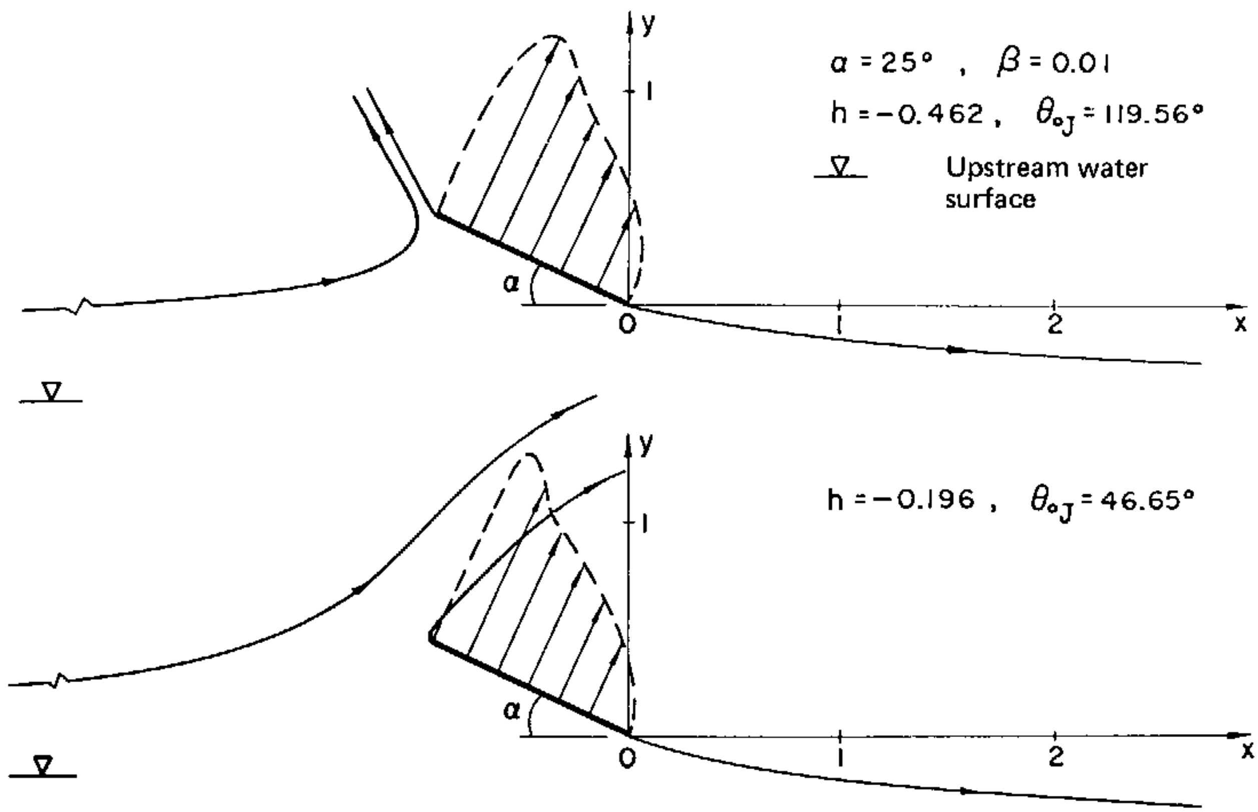


Fig. 4 According to the nonlinear gravity-wave planing surface theory of Rispin (1967), a development stimulated by Wagner's pioneering work, the returning angle, θ_{oJ}, of the spray sheet (in the oth order, i.e. unaffected by the gravity after detachment), depends on the plate incidence angle α, the plate draft h/l (h being the vertical distance of the plate trailing edge below the still water surface far upstream and l, the plate length, being normalized to 1), and the parameter $\beta = gl/V^2$, the inverse of the Froude-number squared. The dashed curves exhibit the pressure distributions over the plate for $\alpha = 25°$ and $\beta = 0.01$.

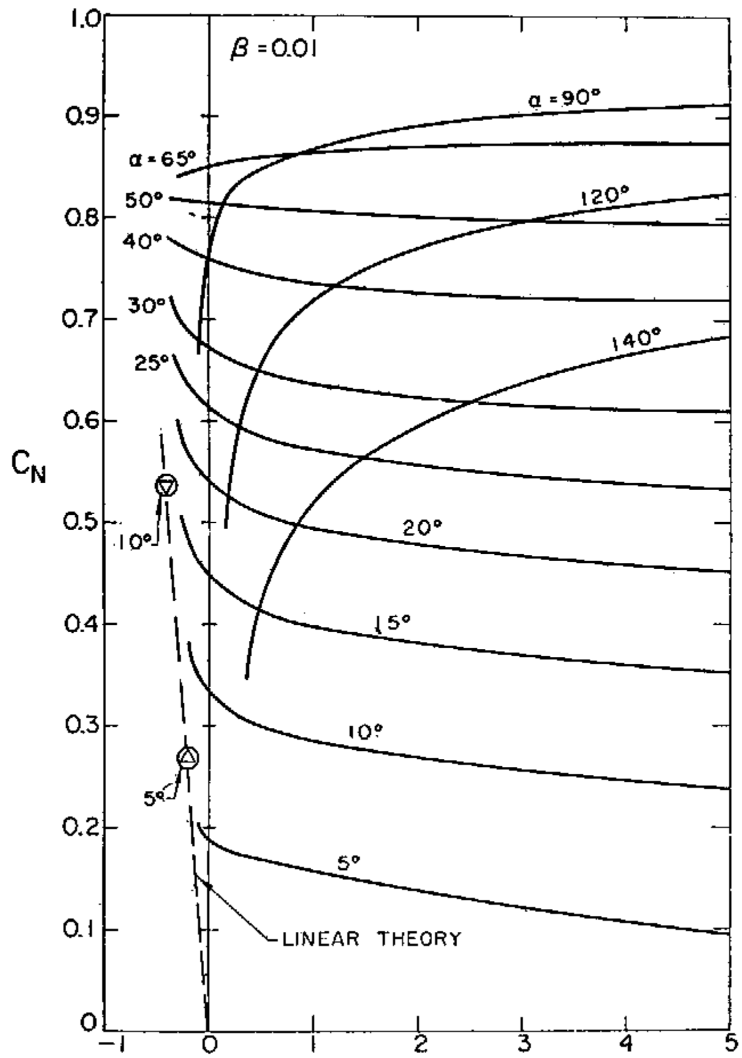


Fig. 5 Compared with the nonlinear theory of Rispin (1967, shown in solid lines), Wagner's theory, marked by a dashed line with ○ for a flat plate planing at incidence angles $\alpha = 5°$ and $10°$, is seen to be valid in the asymptotic limit as the plate draft becomes extreme (beyond which the planing plate would "take off"). In this case $\beta = 0.01$.

Water entry and slender gliding body

The basic idea advanced by Wagner for evaluating the hydrodynamic force acting on a slender gliding body, such as the seaplane floats when used during landing and take-off of a seaplane, is another example at hand to illustrate how ingeniously he made observations of an apparently complex phenomenon with a clear physical concept and in turn put it in a simple mathematical formulation.

The crucial step here is his central idea to reduce the original three-dimensional problem to a two-dimensional one for the cross flow in the sectional plane transverse to the forward motion of the float. This approximation is especially effective and powerful when the gliding body is sufficiently slender. An observer who remains stationary with respect to the undisturbed fluid as the slender float passes by would see a local slice of the body penetrating into the water just like a two-dimensional body of the same cross-sectional shape making impact on a still water surface. Thus by this change of reference frames, Wagner was readily able to convert the space

coordinate in the longitudinal direction into a time coordinate, with the forward velocity of body translation as the conversion coefficient. In addition, the way in which he treated the two-dimensional problem by making use of the virtual masses of the fluid introduced another elegant method that attracted many followers. The entire concept is again simple and elegant, as can be clearly seen from Figure 6 and from the original hand drawings of Professor Wagner shown in Figures 6, 7 and 8.
In retrospect, we may note that although the same idea had been introduced shortly before Wagner (1934) by Max Munk (1924) in the U.S.A. in a NACA Report, Wagner's contribution should be appreciated in the light that it was brought forward in a pioneering spirit by an original thinker, before the concept of slender-body theory became widely known. It is in this light that Wagner opened the door to a new subject involving not only a slender body in unsteady motion, but also a free surface so that the solution requires the introduction of a spray sheet formation and an additional condition on the surface pressure.

Cavity flow: the reentrant-jet model

Wagner's contribution to cavity flow theory is, I believe, in comparison with the above achievements, much less known, though equally significant. In the development of cavity-flow theory, various mathematical models have been proposed to account for the cavity pressure, or wake-underpressure, as a characteristic pressure which can be different from the pressure at infinity so that solutions of practical value can be obtained to form a one-parameter family in terms of the cavitation number, or the wake-underpressure coefficient. Of the commonly used models, the so-called re-entrant jet model can be attributed – according to

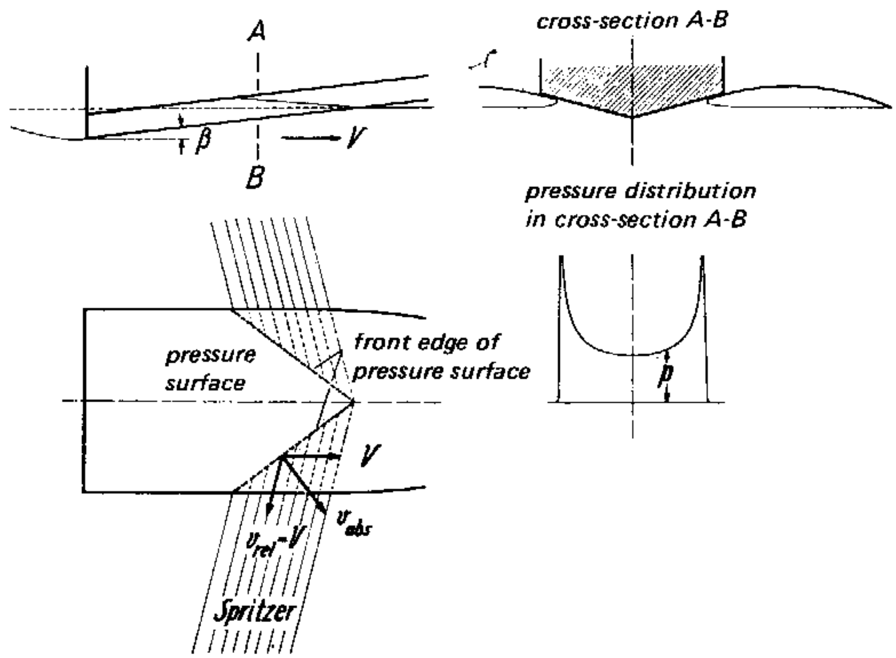


Fig. 6 Planing of a slender rectangular plate over a water surface.

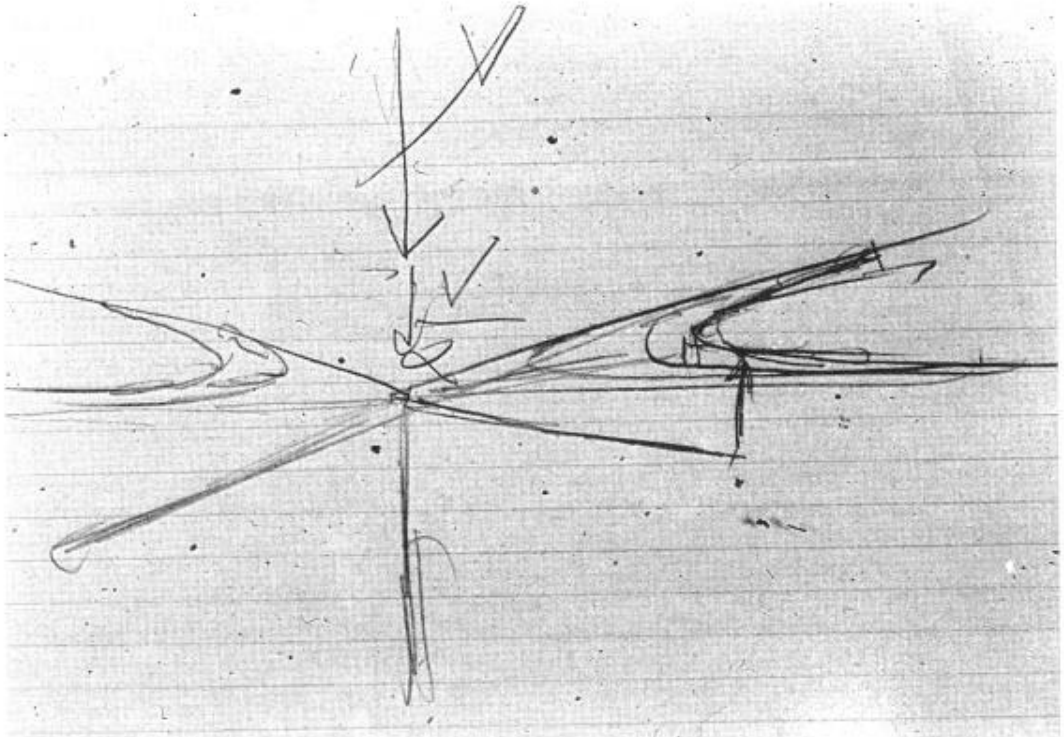


Fig. 7 This original hand drawing by Professor Herbert Wagner vividly depicts the concept of spray formation during the water entry of a wedge, with velocity V, under the condition that the inertial acceleration of the water dominates over that of gravity.

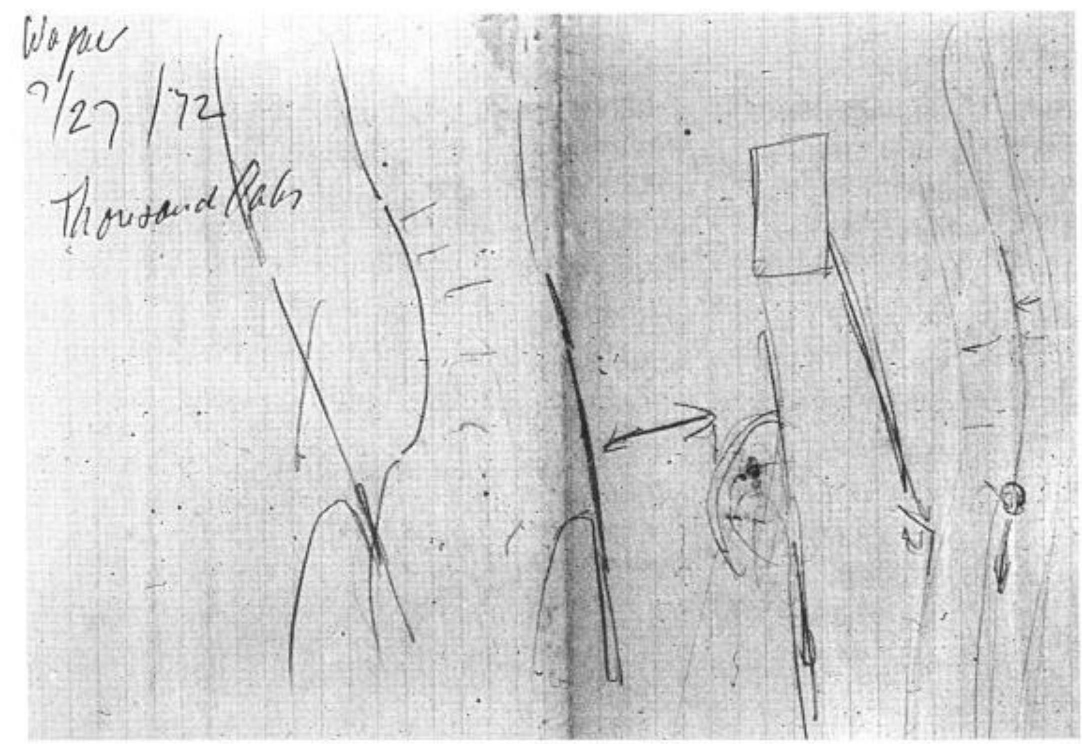


Fig. 8 This original hand drawing by Professor Wagner apparently relates the water entry solution to the impact load on a wedge-shaped slender float during landing. It originated from a lively bottom pressure and wake spray development disenssion.

Professor David Gilbarg (1961) – to Professor Wagner as its first inventor, though no publication was ever made by him on this very subject. The essential features of the theoretical models are illustrated in Figure 9.

In the framework of free streamline theory, Wagner was evidently aware that in order to obtain a finite drag for an obstacle with an attached finite cavity immersed in an irrotational flow of an inviscid, incompressible fluid, it would be necessary to remove from the fluid-body-cavity system either a definite amount of mass, momentum, or fluid energy. Such removals of otherwise conserved flow quantities can be made arbitrary to various degrees; hence they are often viewed as artifices (if not made under the disguise of no viscous effect whatever) and can be implemented either singly or jointly on these quantities. Wagner chose to work with a loss of mass, which implies jointly a loss of fluid momentum and energy. The intriguing idea, therefore, is to have a certain part of the fluid issued from upstream infinity not to return to the downstream infinity, but to reverse in direction to form a jet which proceeds, mathematically speaking, onto a second Riemann sheet. So, like the other cavity models, the Wagner model also has an artifice of its own, but the intent really is to avoid altogether the need of dealing directly with the viscous effects on the drag of a blunt body with a wake formation, a problem which remains formidable even with the facilities of super computers.

Differences in the artifices notwithstanding, some researchers give preference to the Wagner model over the others because the re-entrant jet like enclosure does appear, frequently in experimental observations of this basically unsteady phenomenon, at the posterior end of a near-wake. Such a picture can be found from photographs depicting cavity reattachment configurations, as exemplified in Figure 10.

While these models have served well the purpose of furnishing engineering solutions for industrial design, we are not likely to see the end of their utilities in this respect

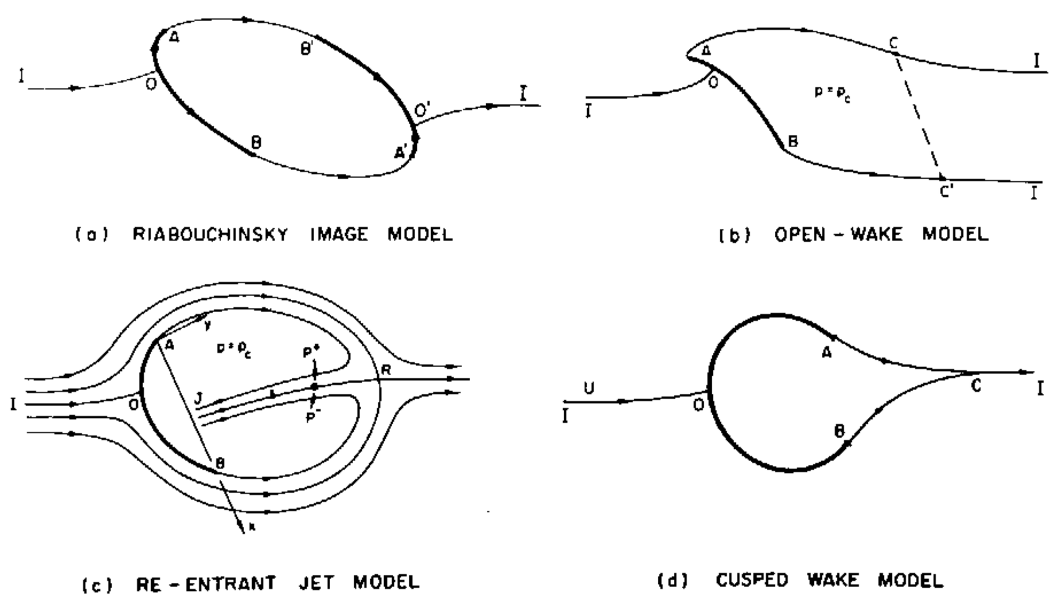


Fig. 9 Of the several theoretical cavity flow models, the re-entrant jet model is a contribution of great significance from Professor Wagner.

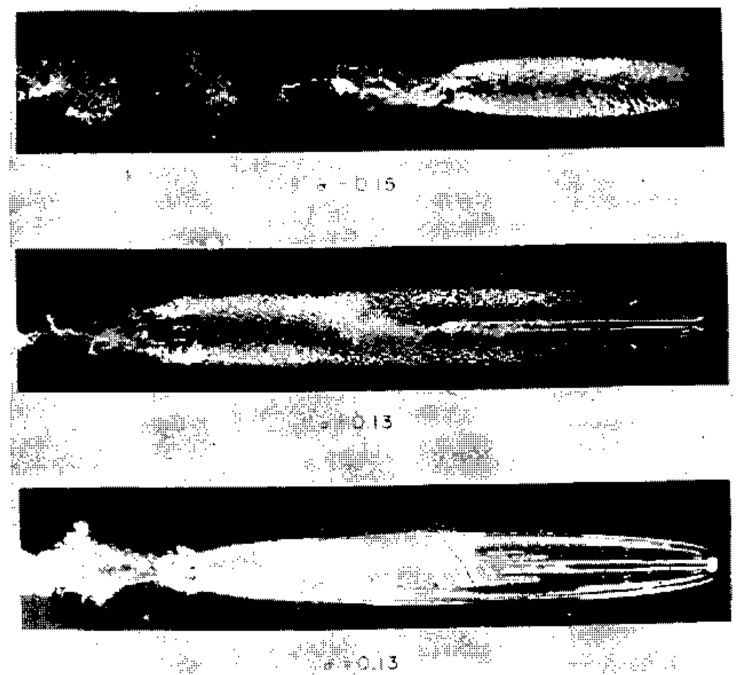


Fig. 10 Several top views of cavity flows past a circular disk at some specified cavitation number σ (taken in the horizontal working section of the high-speed water tunnel, California Institute of Technology). The structure of an re-entrant jet can often be observed near the cavity end when the front portion of the cavity boundary is laminar and transparent.

only. A problem of much greater significance concerns the question what the real wake will eventually be like as the Reynolds number tends to infinity. In this new prospect of such a searching study, it is an entirely open question whether the classical cavity flow theory will have an important role in it.

From the inspiring quality of Wagner's works it is at once selfevident that Herbert Wagner was an enlightened and clear thinker very rarely seen and far ahead of his time. From those who had the opportunity to work with him and those who still make use of his work, we have learned that he possessed an unusual talent to explain his ideas, analyses, and conclusions in such a logical and illuminating manner that all could be easily understood by those interested in the subject – and even by those not fully equipped with the mathematical knowledge. In examining a new problem, Wagner would first explore with a deep insight, discuss with coworkers the basis of his reasoning, and then define explicitly the terms in which he formulated the problem. He knew well when to test out his intuition, when to apply his mathematical tools, and when to expand the data base. Those around him found it most rare indeed to see a researcher pursue the solution to a problem with a concentration as avid as Wagner's. It was also a characteristic of his that as soon as he accomplished a task with results measuring up to his own satisfaction, he would move on to a new problem. Perhaps this is not uncommon for a person gifted with an active mind, incessantly searching far and wide into the world of the unknown.
To a teacher, no award of honor could possibly surpass the recognition from students as the best teacher they ever had. This, fortunately, and naturally, was the case for Wagner. With a clear physical concept and a lucid explanation of a subject, he could make a profound point to a challenging problem so simple to see and so firm to grasp.

And he did it all so conscientiously, for he would often ask his listener, "Do you understand it all?" This happened one time, it is told, to a manager who went to Wagner for consultation. Facing the same question, the manager replied, with a candid smile, "No, but we have you!"

So, the heritage has been handed forward, from generation to generation.

As time marches on, more scholars and students become deeply appreciative of the pioneering steps taken by Wagner in pushing forward the frontiers of the discipline of hydromechanics. It is still being heard from those who read his work that from him they have received nourishment for the soul and enlightment for the mind. Over the years, three former students of mine, while working on their Ph.D. theses related to Wagner's works, all told me this. Most recently, Dr. Jean-Luc Cornet (1984) told me of his being so inspired from reading Wagner's papers that he was inevitably led to the proof for a theorem that relates the circulation around an airfoil, impulsively crossing a vortex wake, to the lift acting on the same airfoil continuously crossing a vortex wake. We indeed owe Wagner a great debt of gratitude for his scientific contributions in his own time and for his inspiring intellectual stimuli he left for posterity.

Let me conclude by extending my sincerest wishes to you all, to your professional institutions and your intellectual and national leaders. To place such a meaningful and visible emphasis like today on paying tribute to a great thinker and teacher is in no small way to set up an outstanding example worthy for all to emulate. By so doing, your country, or any country so cultivated, shall never see the day of being short of resources.

Let me end my talk with a prayer,

May this spirit and heritage of yours be everlasting!

Acknowledgment

Warmest thanks are due from me to Professor George Knausenberger and Professor Karl Wieghardt for their continuous encouragement and moral support. This privileged task of mine could not have been completed without receiving from them their interesting accounts of the work, views, and philosophy of Herbert Wagner, and, in a vivid way, Wagner the man.

I am also indebted to Professor David Gilbarg for his kind assistance in providing me with information from Professor G. Kreisel who once held a personal interview with Professor Wagner regarding the concept of the re-entrant jet-cavity model.

Further, I would like to express our deep appreciation for the continued research support from the US Office of Naval Research and National Science Foundation.

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Ph. D. 1952, California Institute of Technology

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Member, Society of Naval Architects and Marine Engineers
Sigma Xi, Phi Tau Phi, Pi Mu Epsilon
Member, US National Academy of Engineering
Member, Academia Sinica

Areas of Research Interest:
Fluid Mechanics, ranging from low-Reynolds-number problems in biophysics to high-Reynolds-number problems of swimming and flying in nature; cavity and wake flow, ship hydrodynamics, hydrofoil propulsion, fish locomotion, slender-body theory, micro-organism motility, tsunami, forced nonlinear waves.

Editorial Service:
Editor 1982 – *Advances in Applied Mechanics*
Member 1972 – Committee, *Journal of Ship Research*
Member 1978 – Board of Editors, *Journal of Wave Motion*
Member 1980–84 Editorial Committee, *Annual Review of Fluid Mechanics*
Associate Editor 1981–84, *The Physics of Fluids*
Member 1980 – Board of Editors, *Journal of Applied Mathematics & Mechanics*
Member 1980 Editorial Board, *Science and Technology Review*

Reviewer for:
Mathematical Reviews
Journal of Fluid Mechanics
Physics of Fluids
Publications of ASME, ASCE, AIAA, SNAME

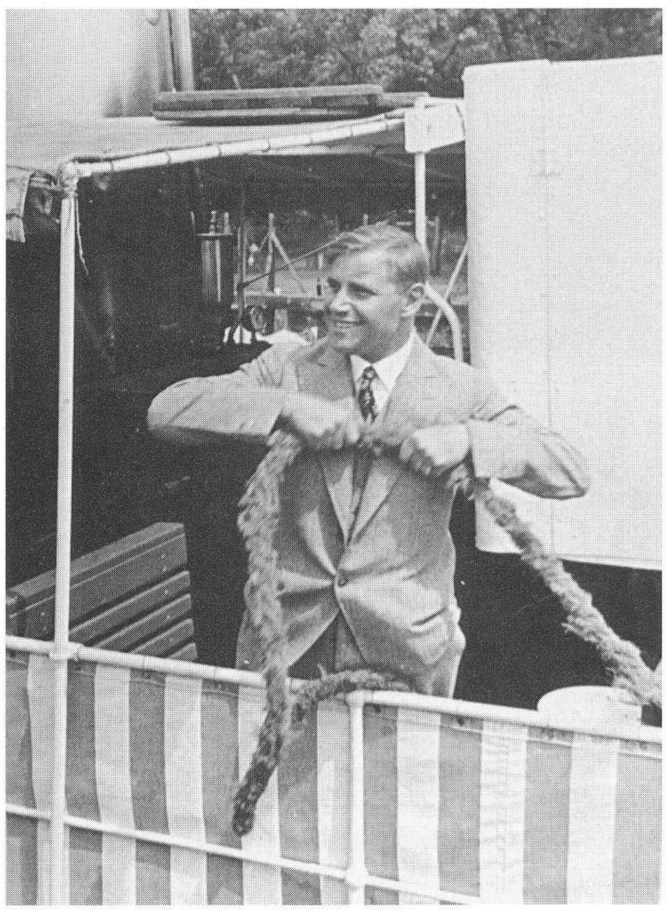
Author of over 100 research papers

Herbert Wagner's Works on the Theory of Structural Strength

by Maria Esslinger, Braunschweig*

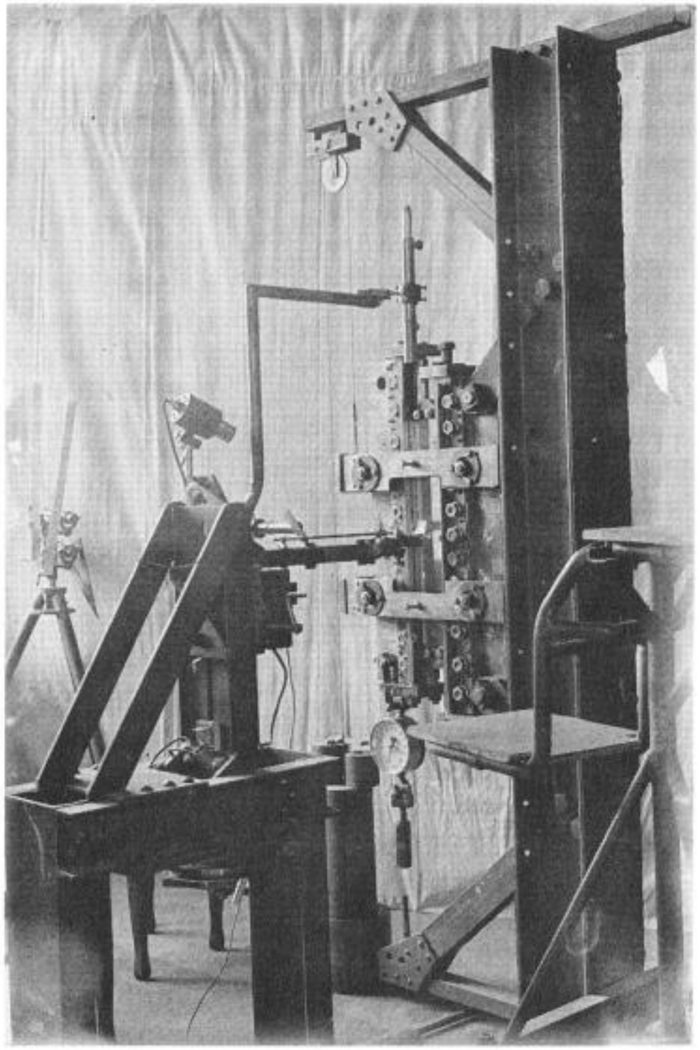
When in 1932 I wanted to begin studying aeronautical engineering, one could do so at two German universities: in Danzig and Berlin. My mother sent me to Danzig. There I did not find a lecturer on aeroplane structures, but I found much enthusiasm concerning an excellent professor, who had left for Berlin not long before. His name was Herbert Wagner. I stayed in Danzig until I had passed my first exams ("graduation", usually four semesters), then I took a Swedish fishing-steamer to Odense and continued my journey to Berlin by bicycle.

In Berlin I found Wagner to be the only professor inviting new students to meet for a consultation on their schedules. Of course I went. In Berlin, the "Elements of Aircraft Structures" belonged to the subjects for the first exams, however, in my first exams at Danzig they were lacking. Therefore I intended to design as my first "big"



Herbert Wagner demonstrates graphically to his students during a boating expedition on the Havel what "pull" [stress] is in a structure (1932). "When there is pull in it, there must be someone there who is pulling!" (Graciously made available by H. Schuck, Taufkirchen)

* Biographical Sketch see page 75



Device for structural testing in the Institut für Flugtechnik, Technische Hochschule Berlin-Charlottenburg (Institute for Flight Technology, Technical University Berlin)

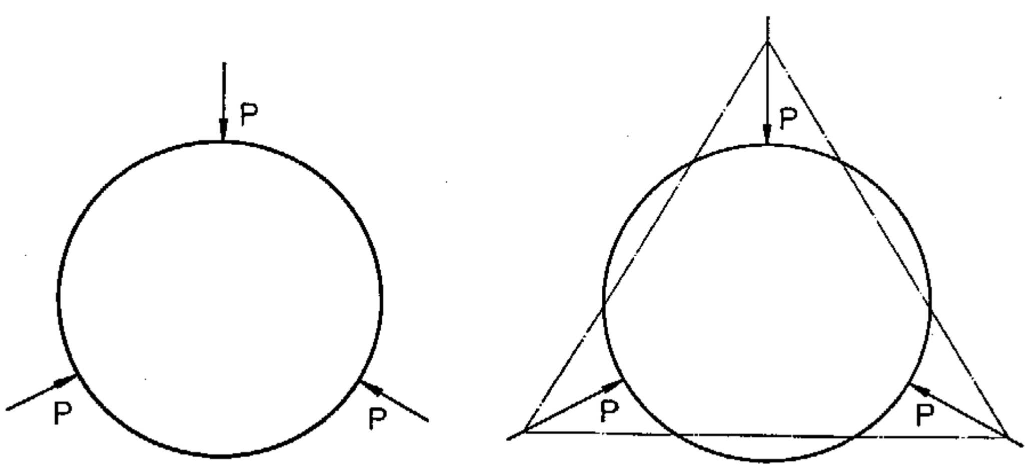
exercise an aircraft engine, and later on, for my diploma thesis, an airplane. Wagner asked, why I did not design an airplane as my exercise. My answer: "Because my understanding of aircraft design is not yet good enough." He accepted with the sceptical remark: "Let's hope you know something about it then!"

I enrolled in all of Wagner's lectures and exercises at the same time; both the "Elements of Aircraft Structures" (which in Berlin belonged to the first exams) and the course on "Strength of Materials", which according to the schedule should have come later. This concentration proved lucky, because Wagner was to lecture only that one year in Berlin.

In his lectures on the elements of aircraft structures he taught us to think; he enjoyed that very much and was very enthusiastic. In his lectures on the strength of materials, he dealt with themes from his publications – with less engagement.
First, I want to talk about his teaching activities, then about his scientific publications in the field of aircraft structures; I will also mention the practical applications of his wise suggestions.

Wagner often advised us: "Do make equilibrium, gentlemen!" The frequent repetition of this advice in those days seemed to us – in spite of the deep reverence for our teacher – an overbred hobby-horse. Now, I know that it was good advice.
An episode from the lecture on elements of aircraft structures is still fresh in my mind. Wagner drew a ring with three radial forces on the blackboard (*Fig. 1a*), called a student to the front, and asked him: "How big are the bending moments in the ring?" He let his victim reflect and meanwhile went on talking to the audience. Only occasionally would he turn to the reflecting student, but always without disturbing him, until finally he shouted with joy: "Hurrah, he's making a line!" The student had found the solution. The radial forces are split into two components each of which joins close to the ring (*Fig. 1b*).
An experienced stress analyst, looking at this figure, might think that the action lines of the force components would lie in such a way that, between the points of load application, the resulting rotation in the ring segment would be zero. This is correct. But as pupils of Wagner, we thought in a more primitive fashion.
Wagner's second hobby-horse was the principle of the minimum of strain energy. Each estimated distribution of forces yields higher strain energy and therefore higher stresses than the real one, as long as the system does not contain an extremely weak link. Here we have a uniformly dimensioned system. The lines of action as drawn adapt themselves so well to the ring that the estimate approaches quite accurately the minimum of strain energy.
Estimating the flow of forces in a structure with the help of the minimum of strain energy, one need not worry about the compatibility of deformations. This comes out right all by itself. But – hobby-horse number one – the equilibrium must be realized in each and every point of the structure.
At the beginning of my first Berlin semester, I contacted the probationers' office. There they required a certificate to prove that I was specially qualified to study aeronautical engineering. Up until then, I had not finished any exercise in Berlin, and

Fig. 1 A problem from the lecture "Elements of Aircraft Structures"



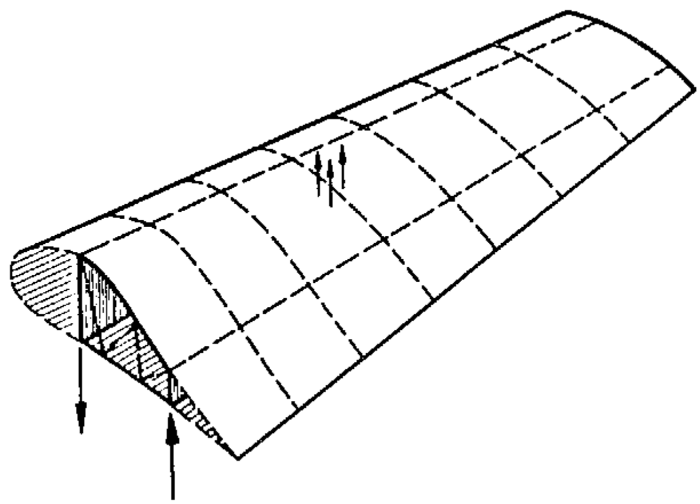
a. Ring with three radial forces

b. Decomposition of radial forces

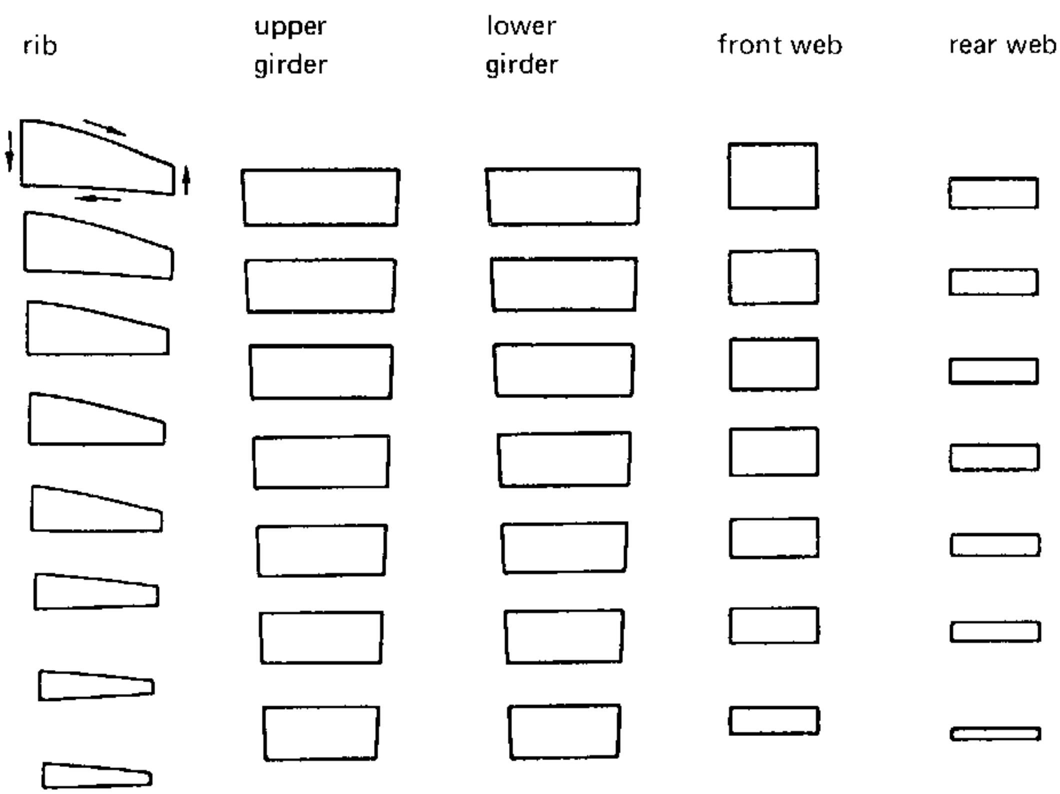
had not yet spoken with any professor except Herbert Wagner, who knew about me only that I did not yet understand anything about aircraft structures. Therefore it was hard to get the necessary certificate.

Finally I did find a way. One could only get an exercise assignment from Wagner if one had proven in a colloquium that one was capable. This colloquium was awe-inspiring; most students failed at their first attempt. One could repeat it as often as

Fig. 2 An exercise assignment



a. Shell wing



b. Decomposition of the wing in panels

one wished. Here I saw a chance to prove that I was specially qualified to study aeronautical engineering.

I went to the "Wagner chair" requesting an appointment. "In fourteen days". There was a large collection of Wagner problems among the students of aeronautics in Berlin. These were put at my disposal with the suggestion "You should practice, practice, practice". For fourteen days I solved Wagner problems from dawn to dusk; I passed the examination and received the certificate.

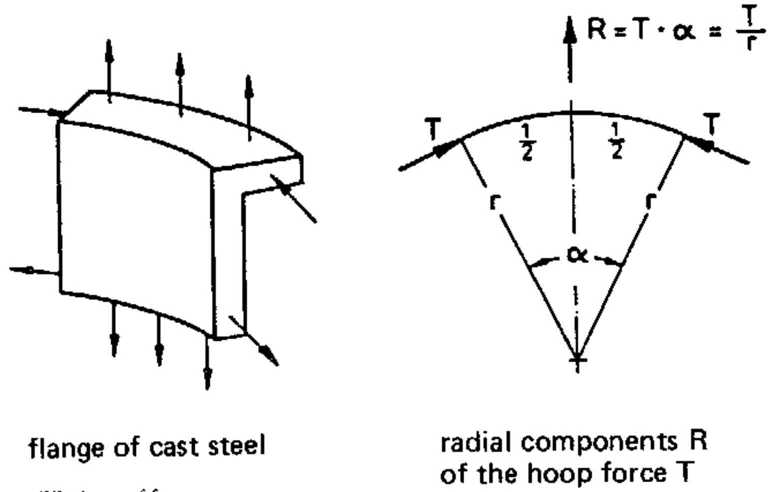
My second exercise with Wagner concerned the shell structure of a wing with several ribs (*Fig. 2a*). "To which degree is the system statically indeterminate?" Wagner questioned. "To the seventh degree". "Correct", said Wagner, "estimate seven forces so as to minimize the strain energy". – And I did that. When I had finished, the wing was decomposed into 36 panels and shear forces were applied to each panel, so that, in my opinion, the strain energy was minimized (*Fig. 2b*). At the next exercise lesson I put my artifax on the table in front of Wagner and explained, "Here are the seven forces I was supposed to estimate." Wagner was astounded, and I then understood that he had not really meant what he said when he asked me to estimate the seven forces. In the end he explained to me the method of the shell wing calculation which he used to present in his lectures. I had not heard that part of the lectures yet. Eight days later I could say, "Now I have calculated the distribution of forces according to your method: the result is the same".

Since then, I have trusted in the minimization of strain energy. This led to a small triumph in my first industrial position. The Dinglerwerke were designing branching pipe lines for the third stage of the Schluchsee power station. Among other things I was to size the flanges. The counterparts of our flanges were the turbine flanges of the Voith Company.

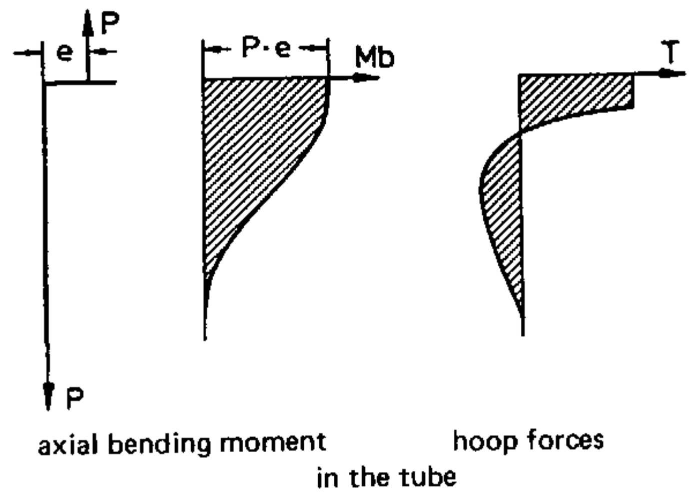
It is known that in a flange the moment due to the eccentricity of the screw force is equilibrated by circumferential forces in the wall of the pipe (*Fig. 3a*). As I could not calculate the flanges exactly, I estimated the distribution of the circumferential forces and calculated the strain energy from the bending of the meridian on the one hand, and from the circumferential forces on the other (*Fig. 3b*). The quicker the bending moment decays, the smaller the bending work and the larger the circumferential forces and their work and vice-versa. Finally I found by trial and error a function for the decay which, in my opinion, minimized the strain energy. But if my calculation was correct, the Voith flanges were too weak. I went to the chief-engineer and asked for help. He reacted sarcastically: "Write to the Voith Company, and tell them their flanges are too weak". I wrote, and as an answer I received an invitation to meet with Dr. Schilhansl. He confirmed that my estimate was correct. Then he showed me how at the Voith Co such structures are calculated according to the transfer matrix method. The turbine flanges were not calculated, but had been sized according to the pantograph principle. They were not changed, in spite of the high calculated stresses, because the designers relied on a reduction of stress peaks by plastification.

The cast steel flanges that I sized by the transfer matrix method after my visit to Voith's were so bulky, that they pleased no one. Therefore I replaced them by welded flanges, consisting of two rings and many ribs (*Fig. 3c*). Sometime later, I changed my place of employment and forgot all about Schluchsee, till the news broke in Germany

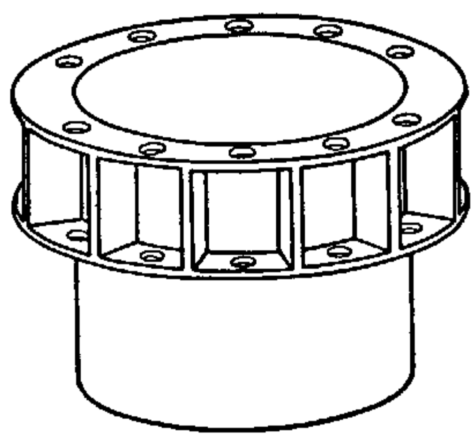
Fig. 3 Flanges



a. Flange of cast steel and equilibrium of forces



b. The internal forces



c. Welded flange

that during a pressure test at the Schluchsee power station a flange of the branching pipe lines had broken and much damage had been done. Naturally I called Dingler immediately to learn all the details. My successor had replaced again the welded flanges with cast steel flanges and one had failed.

Wagner recommended estimating the flow of forces in a structure before each calculation in order to acquire a good sense for force distributions. And he encouraged us with the remark: "If someone tells you 'one simply feels it', do not ever be impressed. Sensitivity is experience, which you too will eventually acquire."

Once a student asked Wagner to exempt him from the third exercise, because of his being an exception, since he had acquired knowledge before. To which Wagner replied: "We are all naturally exceptions, but you still have more to learn."

When Wagner was explaining his theory of the diagonal tension field, I interrupted him with the derogatory remark: "If one neglects that, there's nothing clever in it any longer." I have since forgotten what it was that Wagner had neglected, but his answer was unforgettable: "That is how you recognize the good stress analyst: He knows what he can neglect."

Once we discerned that Wagner had made a mistake in his lecture. After seriously considering the matter, I mentioned it in his seminar in the afternoon: "This morning in your lecture you made a mistake in this point." Wagner's response was without long consideration: "You say I made a mistake! Impossible!" Our united efforts finally succeeded in convincing him. But he was astonished to the very end.

Positive reaction of his students was very important to Wagner; his questioning looks had to be answered by an understanding nod. Indifference during a Wagner lecture was impossible.

Once I could not follow his reasoning. Therefore I interrupted his speech by exclaiming: "I do not understand this!" His response: "It is not at all necessary that you understand everything", destroyed my pleasure in the work. All too quickly I concluded that I would not get a probationar's job, and all would be lost. I therefore shut my copy book, laid down my pencil, crossed my arms, and did not follow Wagner any more with my eyes. This was not play-acting, but a collapse of my resistance. Wagner had not intended this reaction. Now he began to explain in angel's tongues. The students were fascinated. Nobody worried about the regular end of the lecture. Wagner was speaking without stopping. Finally I could no longer resist his eloquence; I now took up my pencil, opened my copy book, and looked again at Wagner. Then, he stopped. We left the room, happy and exhausted. Wagner had succeeded in taming his students, and my inner life was back in equilibrium.

Wagner's publications on the mechanics of aircraft structures can be divided into three groups:

1. Papers from Danzig, printed in the years 1928–29. These reports were evidently written in response to practical concerns. They are characteristic of Wagner's intuitive understanding of the flow of forces.
2. Papers from Berlin, edited in the years 1935–36. These reports were issued by the head of an institute, who had to ccupy his co-workers efficiently, and who presented survey lectures at conferences.
3. The written version of his lecture "Elements of Aircraft Structures" was published

in 1941. The book was soon sold out, but photoprints still exist, and are occasionally circulated among aircraft designers.

I do not know of any later publications, and I assume that my list is complete, since it was compiled from the historical archives of the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR).

Wagner's most famous paper in the field of airplane stress analysis deals with the introduction of the diagonal tension field (*Fig. 4*). It is known that in a beam the bending moment is mainly carried by the girders and the transverse shear mainly by the web. If the girders are supported one against the other by vertical rods, and the web is made thin enough to buckle under shear stress, a diagonal tension field is attained. This basic idea was given convincing foundation in the report by reflections, calculations, and experiments.

First, a significant parameter

$$K_w = \frac{\sqrt{Q}}{h} \qquad (25)$$

is introduced, indicating whether under the given circumstances a diagonal tension field would be economic.

In designing a diagonal tension field we must compute the angle of inclination of the wrinkles; only in the limiting case of rigid girders and rigid vertical rods is it exactly 45°. We must choose a spacing of the vertical rods small enough that the bending moment of the girders, due to vertical components of the tension forces in the web, do not become too large. The vertical rods must be sized. Finally, we may determine the secondary stresses in the web due to wrinkling.

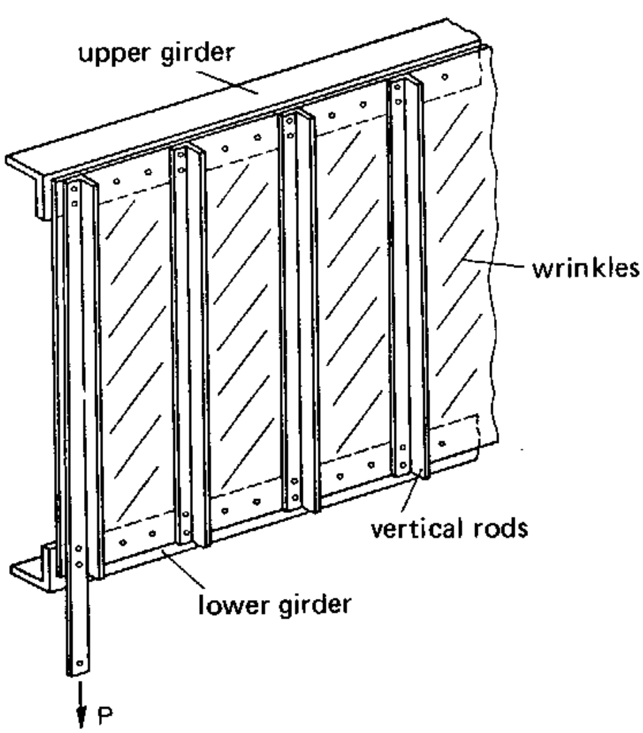
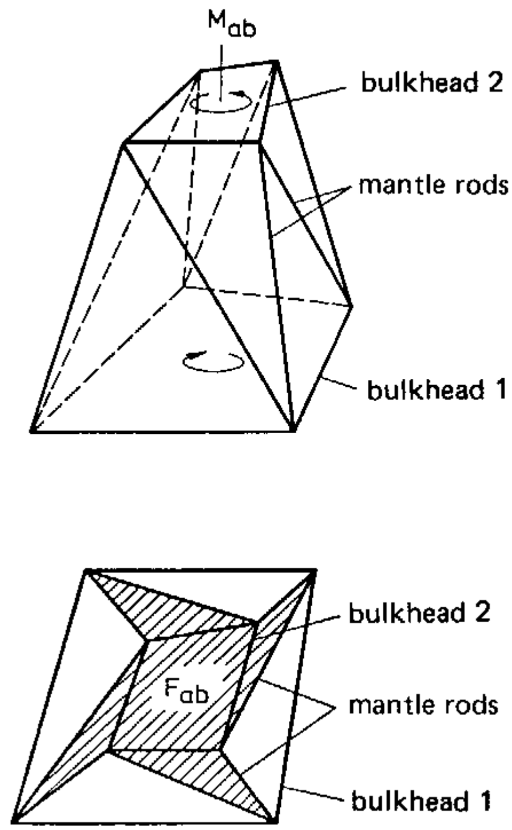


Fig. 4 Diagonal tension field

The brilliant recognition that a shear web may be allowed to buckle has proved itself right. The latest edition of the handbook for structural analysis of the German aircraft industry contains directions for sizing diagonal tension fields for extreme load cases.
One of Wagner's survey lectures was concerned with the analysis of space trusses. Let me give an example that has remained in my memory since my student years: The truss to be analyzed consists of two parallel bulkheads, the corners of which are connected by rods in a statically determined way (*Fig. 5*). These connecting rods are termed mantle rods.

Fig. 5 Space truss



The truss is loaded by a torsional moment M_{ab}, applied in the planes of the bulkheads. One must determine the shaded area F_{ab}, with the factor

$$\mu_{ab} = \frac{M_{ab}}{2\,F_{ab}} \tag{26}$$

and thus obtains the forces in the mantle rods from the simple relation

$$S = \mu_{ab}\, s$$

where s is the length of the respective rod.
The shear center appears for the first time in a Danzig festive report. The "cousine-formula"

$$\tau\, s = \frac{QS}{I}$$

yields the shear flow in a beam as function of the transverse shear force Q, the moment of inertia I and the static moment S, with respect to the axis through the center of gravity.
Applying the "cousine-formula" to the channel section shown in *Fig. 6*, and neglecting the contribution of the webs to the static moment S, yields the shear flow as shown. Their resultant lies outside the section on the left hand. The point at which the resultant intersects the axis of symmetry of the channel is called the shear center. Transverse shear forces leading through this point will subject the beam to pure bending. Transverse shear forces not leading through this point will subject the beam to combined bending and torsion. Wagner demonstrated this phenomenon to us by experiments in his institute.

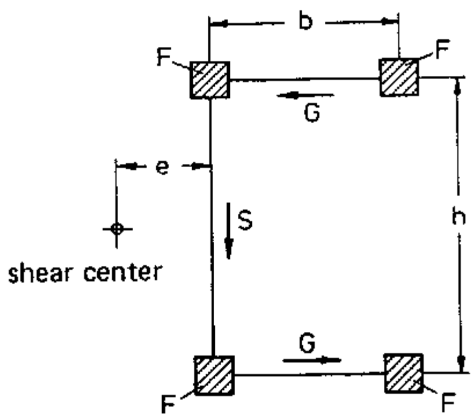


Fig. 6 Shear center

$$G = \frac{Q}{I}\left(F \cdot \frac{h}{2}\right) b$$

$$S = \frac{Q}{I}\left(2F \cdot \frac{h}{2}\right) h$$

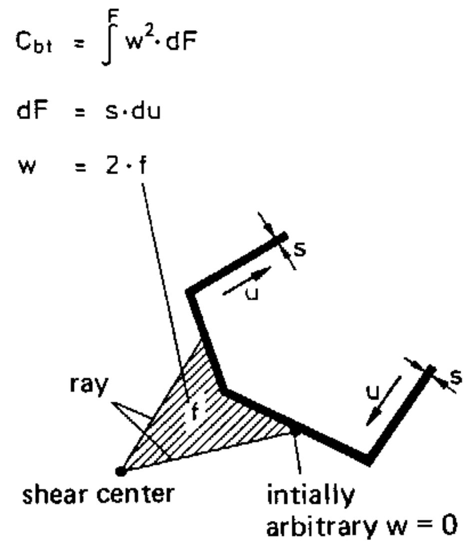
$$e = \frac{G \cdot h}{S} = \frac{b}{2}$$

The Danzig festive report contains a footnote stating that Wagner learned only after finishing his paper that the name "shear center" had been mentioned a short time before by C. Weber in the "Zeitschrift für angewandte Mathematik und Mechanik". But the further development of the shear center concept to the bending-torsion resistance of open sections

$$C_{bt} = \int^{F} w^2 \cdot dF \qquad (27)$$

is doubtlessly Wagner's pioneering achievement (*Fig. 7*). In the formula, F is the cross sectional area of the section and w is twice the shaded area f, i.e. the area between two rays drawn from the shear center to the sceleton line of the section. In pure shear torsion, w is proportional to the warping displacements. Upon determining w, one of the rays must be drawn to the point at which the warping displacement occurs, and the other to the point where the warping displacement is

Fig. 7 Bending-torsion resistance



arbitrarily assumed to be zero (see Fig. 7). The correct position of this zero ray, then, follows from the condition

$$\int^F w \cdot dF = 0 \tag{28}$$

meaning that in the case of prevented warping, the resulting longitudinal force must be zero. C_{bt} has the dimension l^6.

With the shear-torsion resistance already known for a long time and the newly defined bending-torsion resistance, the resulting torsional moment amounts to

$$M = GI_t \cdot \varphi' - EC_{bt} \cdot \varphi''' \qquad \text{with} \qquad \varphi' = \frac{\partial \varphi}{\partial s} \tag{29}$$

For pure shear-torsion φ' = constant and $\varphi''' = O$.

With the aid of both torsion resistances I_t and C_{bt}, Wagner calculated the twist-buckling load of open channels. In the case of unrestrained warping at the ends of the rod, the critical longitudinal load for twist-buckling is

$$P_w = \frac{1}{{i_{sp}}^2} \left(GI_t + \frac{\pi^2}{L^2} \cdot E\, C_{bt} \right)$$

where L is the length of the rod, and i_{sp} depends on the shape of the cross section and on the position of the point in the cross section where the longitudinal force P_w is acting. As students, we were easily able to calculate i_{sp}.

These were examples all selected from Wagner's Danzig publications, which he treated in his lectures on strength of materials.

I shall not specially discuss the scientific publications of his Berlin period, but they can be divided into three categories:

1. Experiments on the effective width of buckled plates;
   the state of stress in diagonal tension fields;
   the stability of thin, unreinforced cylindrical shells under shear and axial forces,

2. An outstanding theoretical report about the load diffusion in thin-walled cylindrical shells. This report is signed Wagner/Simon.
3. Survey lectures on strength of shell structures.

Although nearly 50 years have passed since Herbert Wagner taught us to think, his slogan: "Gentlemen, do make equilibrium", still sticks in my mind. It has not lost its relevance in the age of computers. This may be demonstrated by two examples from my own recent work in the last months:
First: At the Hoechst Company, in safety control, the problem of calculating the stress in a cylindrical vessel with a supporting skirt (*Fig. 8*) came up. We had worked out a program for the company, in which the shell was idealised by the meridional line furnished with wall thickness. With this program, the specialist first calculated the stresses and deformations. He then wanted more exact results, especially in the region where the supporting skirt branches off. Moreover, the company had paid good money for a FEM-program that was to be used. Consequently the specialist then calculated the stress on the vessel with the FEM program too. The results calculated with the two programmes differed unacceptably. The specialists sent them to me, asking for my comment. For a former Wagner student, the solution of the problem was not difficult: In the results of the FEM-program, the bending moments in the branching point were not in equilibrium. – The expert did admit this fact.
Second: A brand new Doctor of Engineering mailed his doctoral thesis to me, saying he would be glad if I would take the trouble to recalculate one of his examples. We did so, but I doubt he appreciated the outcome, for the results of our calculations differed from his. The example we had chosen for the comparison was a barrel under periodically distributed pressure load (*Fig. 9a*). It would have been too much trouble to search for the mistake by comparing both programs. It was simpler to use Wagner's magic formula of controlling the equilibrium. We cut out a segment of the shell, as determined by antimetric meridional cuts (*Fig. 9b*). Then, we calculated the

Fig. 8 Supporting skirt

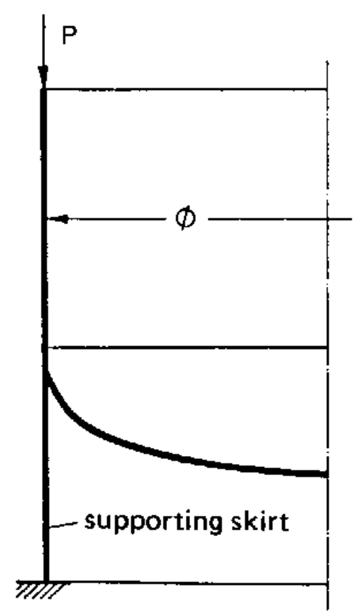
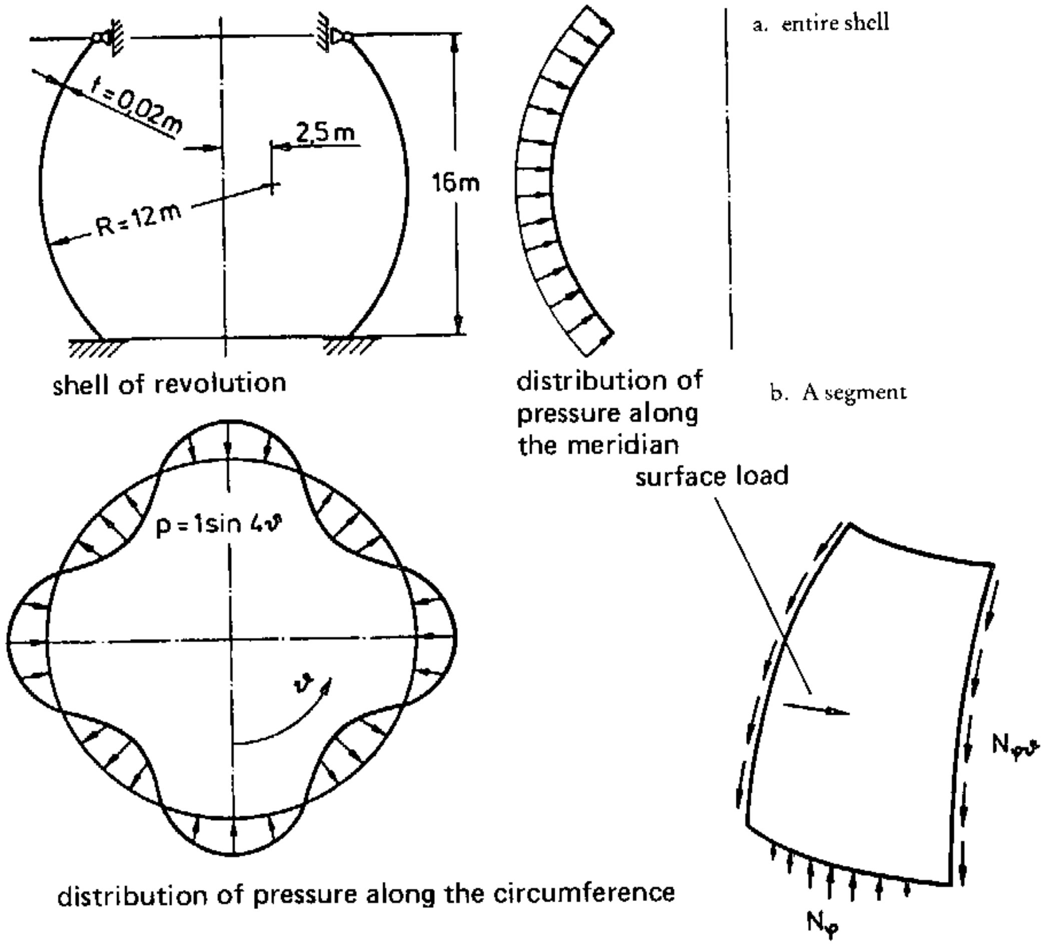


Fig. 9 Barrel shaped shell under periodic external pressure



vertical components of all the forces applied to the surface and the edges for it. They were in equilibrium in the results of our calculation. They were not in those of the new doctor. His reaction has not yet come in.

Many a computer-happy engineer would avoid errors, if he stuck to Wagner's proven advices:

"Before calculating, estimate the distribution of internal forces; after calculating, test the equilibrium."

Biographical Sketch: Maria Esslinger

I was born on March 4, 1913 in Nürnberg. My father Dr. Ludwig Esslinger, a lawyer and officer in the Reserve died in Rumania in 1917. My mother Else, née Hecht, raised my older brother and me alone.

1932 Finished High School (Abitur at Girls Realgymnasium in Nürnberg)

1934 "Diplom" pre-exam in aircraft design and construction at Technical University, Danzig

1936 "Diplom" final exam in aircraft design and construction at Technische Universität Berlin

1947 Dr. Ing. degree, Technische Universität Darmstadt

1953 Inauguration at University, Saarland

1967 Non-tenured professor, later Professor honoris causa at Technische Universität Darmstadt

1937–44 Dingler factory in Zweibrücken: Wind tunnels and pressure pipelines

1945–55 Seibert Firm, first in Aschaffenburg then in Saarbrücken; in between, one semester of study at the École des Ponts et Chaussées in Paris: Bridge- and container construction (Dissertation: "Static calculation of torispherical heads". Inaugural dissertation on "Application of continuum statics to faceted beam calculation")

1955–58 MAN, Gustavsburg: Bridge construction (Research report on orthotropic plates)

1958–62 Gollnow Firm in Düsseldorf: Bridge construction (Design of the Tejo-Bridge in project office)

1962–63 Free scientist: Suspension bridge calculation (Deutsche Forschungsgemeinschaft – DFG-scholarship)

1963–78 Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR), Braunschweig: Stability of thin walled shells

1978 to present: Independent scientist: Stability of thin walled shells (Co-workers financed from research contracts)

Numerous publications in German, French and English.

Scientific member of the DFVLR.

Member of the Braunschweig Scientific Society.

Member of the European Convention for Constructional Steelwork (ECCS), Technical Working Group 8.4, Stability of thin walled shells.

First Work on the Axial Flow Jet Engine

by Rudolf Friedrich, Karlsruhe*

I have the honorable task to describe an important technical initiative which was initiated half a century ago by Herbert Wagner. It is difficult after such a long time to reconstruct the circumstances, considerations, and scientific situation completely; especially since records and documents were lost during the war and the post-war period. Moreover, historical reports are subjectively colored and seen differently by different witnesses, as is human and understandable.
Already at the time of the events and actions, the personal positions, opinions and views of the contributors and participants were different from what they are today. My recollection will be subjective also, despite my best efforts to present actual facts and to respect the achievements of others.
I met Prof. Herbert Wagner for the first time in the fall of 1935 at the Junkers Flugzeugwerk (JFA) in Dessau. Dr. Heinrich Koppenberg, General Manager at Junkers brought Wagner to Dessau, in order to infuse new life and idea into the somewhat stagnant aircraft design. And indeed, Herbert Wagner did come forth with new initiatives.

1. I only remind you of his development of the Experimental-Flugzeug "EF 61", a high altitude aircraft
- the wings of which, having an unusually large aspect ratio, were formed as tube-like containers for fuel.
- the lift of which could be increased by 25 % by means of special extendable high lift devices (Hilfsflügel)
- the high altitude cockpit of which had a special glass dome in front
- which had jet coolers capable of producing a small thermal thrust located directly in front of the motor.

Herbert Wagner closed his lecture at the Deutsche Akademie der Luftfahrtforschung – DAL (German Academy of Aeronautical Research) on October 28, 1937 [1], with the following words: "After very intensive study, I believe that the gas turbine is the right high-altitude engine".
Wagner's ideas were received enthusiastically at first by his colleagues, then with reservation and even resistance – a naturally human reaction to something novel, unusual, and exciting. However, Herbert Wagner succeeded in convincing Dr. Koppenberg of his novel concepts concerning airplane propulsion. Thus on April 1, 1936, in secret and remote from Dessau in the subsidiary at Magdeburg (independent of the Junkers engine construction, perhaps even without the knowledge of its director, Prof. Otto Mader) a group of three young engineers began developing a flight gas turbine under Wagner's guidance and according to his proposals. As we

* Biographical Sketch see page 89

learned later, this coincided, almost to the day, with the beginning of von Ohain's work at Heinkel in Rostock.

2. What was the situation in aeronautics in the middle thirties? In September of 1935, an American, Hughes, established a speed record of 567 km/h. In November of 1937, Dr. Wurster reached with a Messerschmitt Me 109 for the first time the speed of 611 km/h. The maximum speed achieved until then by a seaplane was 709 km/h (demonstrated at the Schneider Pokal Race, 1934, by Agello of Italy). This record-setting seaplane was propelled by Fiat twin-motor AS6, consisting of two sequentially arranged 12-cylinder engines, with a combined HP of 3100, and two co-axial contra-rotating propellers.

In all cases, each propeller was driven by a piston engine and the examples given demonstrate that there was an absolute limit for this kind of propulsion: in April, 1939, the world record was 755 km/h, flown by Wendel with a Me 209. This was only improved in the USA in 1969 by Greenamyer to 777 km/h [2] and finally in 1979 by Hinton to 803 km/h, where it still stands today.

Already in previous years, forward-looking inventors had proposed gas turbines or propellerless jet propulsion for airplanes.

- Hugo Junkers in about 1913 considered using the free piston compressor he had developed as the propellant gas generator of a flight gas turbine. He also thought of replacing the propeller with an "internal jet propulsion" or a "jet propeller" [3], i.e. an axial flow ventilator build into a closed channel and utilizing the waste heat of his propulsion engine.
- M. Guillaume of France proposed in the French patent 534801 in 1921 a turbo-drive with compressor, combustion chamber, and turbine [4].

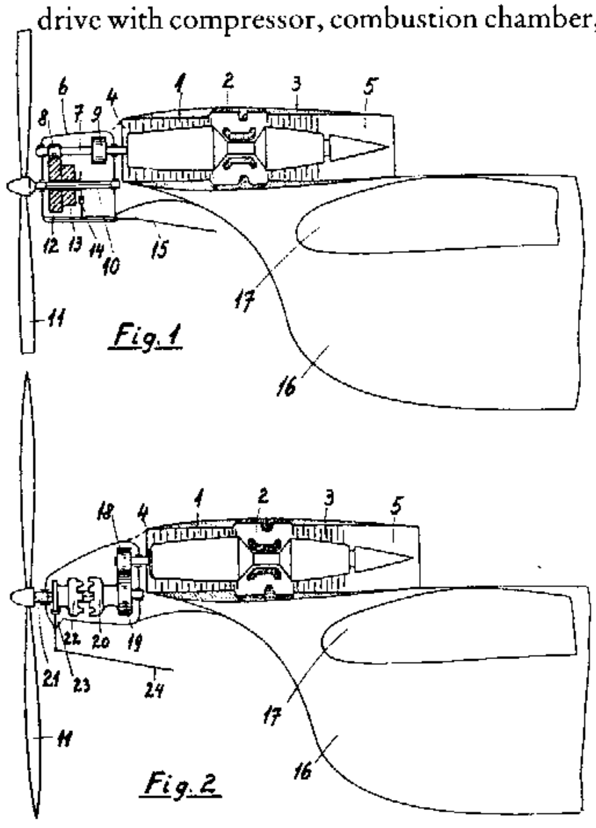


Fig. 1 Herbert Wagner's concept of an axial flow propeller-turbine (1935) according to the British Patent No. 495 469. [8]

– In early 1930, Frank Whittle in England made a proposal for a jet engine in the British patent 347206, and, in 1937, he successfully operated an experimental engine. The first flight with a Whittle-propulsion was performed in May 1941 [5].

3. The demand for higher speeds and altitudes was great, and, after exhaustion of the aerodynamic possibilities, to accomplish this it became a problem of airplane propulsion. Herbert Wagner saw clearly the advantages of the gas turbine and the chance to reach unimagined levels of power output, especially at high altitudes (due to lower air inlet temperature).

Being well versed in aerodynamics and structures, he had in mind the aspects of airframe design – certainly more clearly than Frank Whittle and Hans von Ohain – and at the same time was aiming at a favorable installation of the engine that would have the lowest drag. Thus in 1935 he designed a flight gas turbine using pure axial flow which had a multi-stage axial compressor, a ring combustion chamber in the main flow, and a multi-stage axial turbine at first with combined propeller-thrust and reaction-thrust by means of the waste gas. The mechanical power for the propeller drive was produced by means of a reducing gear from the compressor inlet side (see *Fig. 1*, according to British patent 495469 of 8.2.1937 with German priority of 8.2.1936).

Dr. Hans von Ohain developed and built a jet engine with radial flow, with excellent robustness, adaptability, and simple construction (*Fig. 2*). This made possible, in August of 1939, the first take-off of an airplane, the Heinkel "He 178", propelled solely by a jet engine.

Although Wagner entered virgin territory with the multi-stage axial compressor, he had concrete concepts for its design, which proved to be successful. It was a venture that required optimism grounded in knowledge. Charles Parsons, in 1907, for example, after delivery of 41 axial compressors (*Fig. 3*), had given up their production, for their power was insufficient: the efficiency hardly exceeded 60 %. High efficiency of the turbo engines is decisive for the gas turbine, and the lack of a high performance compressor at that time prevented the realization of the turbine, even a stationary one.

The net power of gas turbines generally is, if I may remind you, the difference of the similarly large powers of turbine and compressor. The compressed air must be heated to 400°–500° C by heat transfer in the combuster in order to raise the power of the turbine sufficiently, to drive the compressor (*Fig. 4*). The cold intake air at high altitudes decreases the power required of the compressor (P_V). Thus, for the power balance, the ratio of the gas inlet temperatures in turbine T_{TI} and compressor T_{VI} is decisive.

The development in Magdeburg, which Prof. Wagner monitored in Dessau from early 1936 until 1938, progressed unhindered, independently, and without organizational burdens. This offered the necessary framework for the creative work of our small department and its leader, the extraordinarily ingenious and congenial Max Adolf Müller (*Fig. 5*), who had previously been engineering supervisor at Herbert Wagner's Aeronautical Institute in Berlin.

4. In our work, the problem of combustion and the multistage axial compressor were of special importance and received special attention. In a turbo-compressor, flow

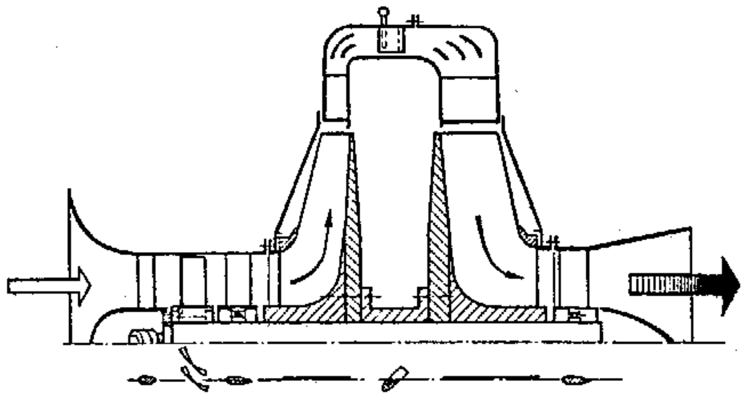
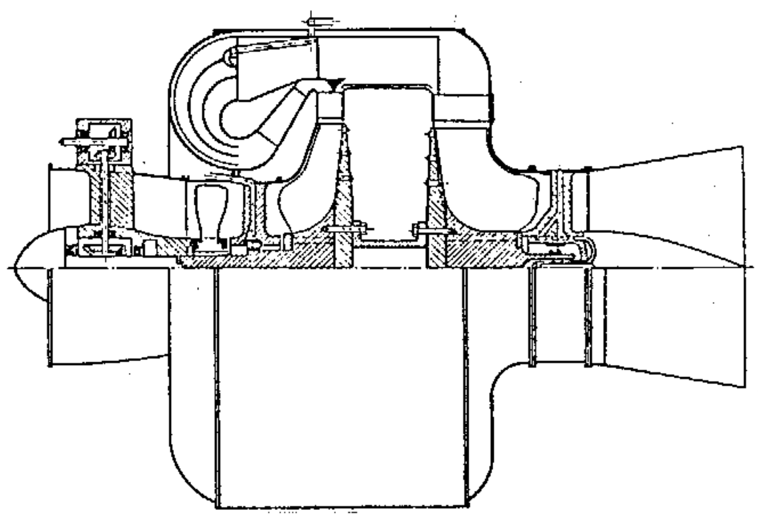


Fig. 2 Heinkel Jet engines (Dr. v. Ohain). [9]

He S 2 (1937)
thrust S = 130 kp (1.27 kN)
Hydrogen combustion
n = 10,000 R/min.
$Da_V = Da_T = 600$ mm



He S 3 (1938/39)
thrust S = 450 kp (4.4 kN)
m = 12 kg/s; $\pi = 2.8$;
Gasoline combustion
Engine-outer diameter
D = 1200 mm
Engine-weight (dry)
G = 360 kg
Front area thrust S/F = 4.34 kN/m²
Spec. consumption b = 220 kg/kN/h

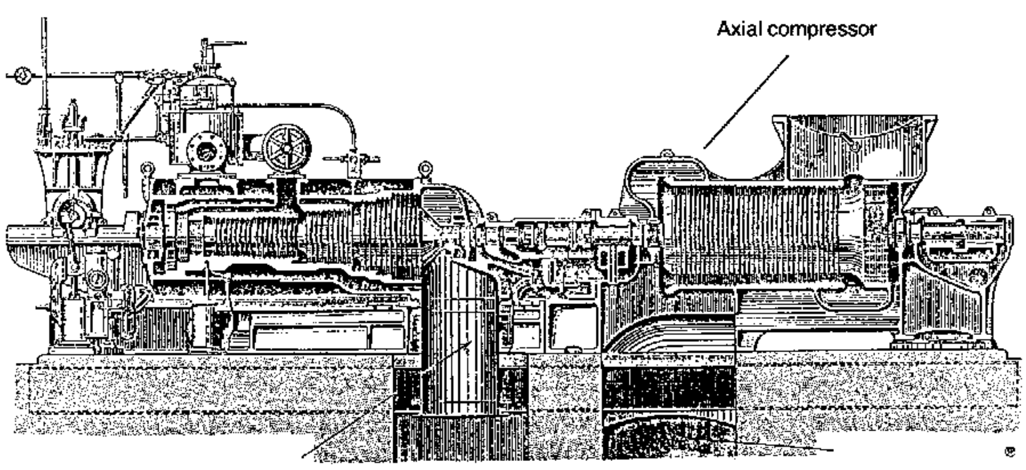


Fig. 3 Parsons Axial compressor (34-stages). [10]
600 m³/min, from 0.7 to 1.26 at ($\pi = 1.8$); 3000 rpm; driven by Parson's steam-turbine (for Samuelson & Co. Ltd. 1903)

net power = turbine power − compressor power

$$P_N = P_T - P_V$$

$$P_N = \dot{m}_T \cdot \bar{c}_{p_T} \cdot T_{T_I} \cdot \eta_T \left[1 - \left(\frac{\sigma}{\pi_V}\right)^{\frac{\kappa-1}{\kappa}}\right] - \dot{m}_V \cdot \frac{\bar{c}_{p_V} \cdot T_{V_I}}{\eta_V} \left[\pi_V^{\frac{\kappa-1}{\kappa}} - 1\right]$$

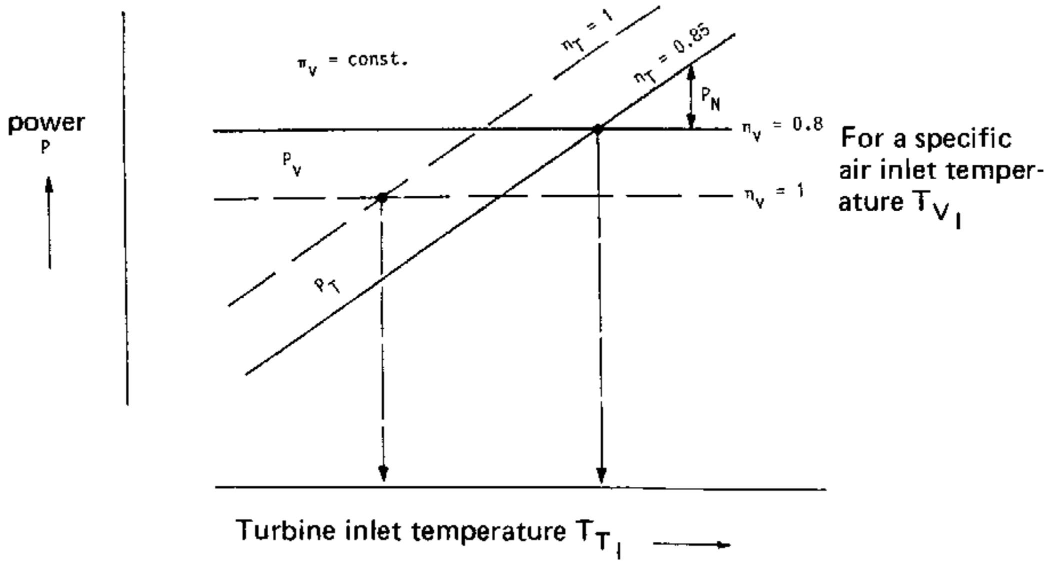


Fig. 4 Influence of turbine inlet temperature and the efficiencies of turbine and compressor on the net power of a jet engine.

velocity energy at every stage is transformed into pressure by forced deceleration of the flow medium. Because of the physics involved, this transformation of velocity into pressure is far more difficult than the transformation of pressure into velocity. A comparison of the flow through a nozzle with the flow through a diffusor makes this obvious. In a compressor the air must be moved "up-hill". The blade profiles of the axial compressor (*Fig. 6*) admit therefore only a moderate load and allow only a small flow deflection so that the flow does not separate from the guide wall. They require the best aerodynamic profiling and highest surface smoothness (roughness of 2–3 μm). A relatively large number of stages is necessary to achieve the desired overall pressure ratio.

In order to decrease the weight and dimensions of the axial compressor as much as possible – and still be compatible with aircraft requirements – it was necessary to achieve the desired pressure ratio with a minimum number of stages. Since the pressure rise in one stage is proportional to the load on the blade profile (the lift coefficient C_L) and increases with the square of the blade tip speed, the task was to find a blade arrangement that allowed the highest blade tip speed (for a given margin below the speed of sound).

The designs that were proposed, or experimentally developed, showed the axial entry of the flow c_I onto the moving rotor blades or onto the fixed stator blades (*Fig. 7*). The two figures on the left show (bottom) the plan of blade profiles, (middle) the related velocity triangles and (above) the stage pressure diagrams.

Fig. 5 Max Adolf Müller (with family), chief of the department jet-engine development at the Junkers subsidiary in Magdeburg (1936–38).

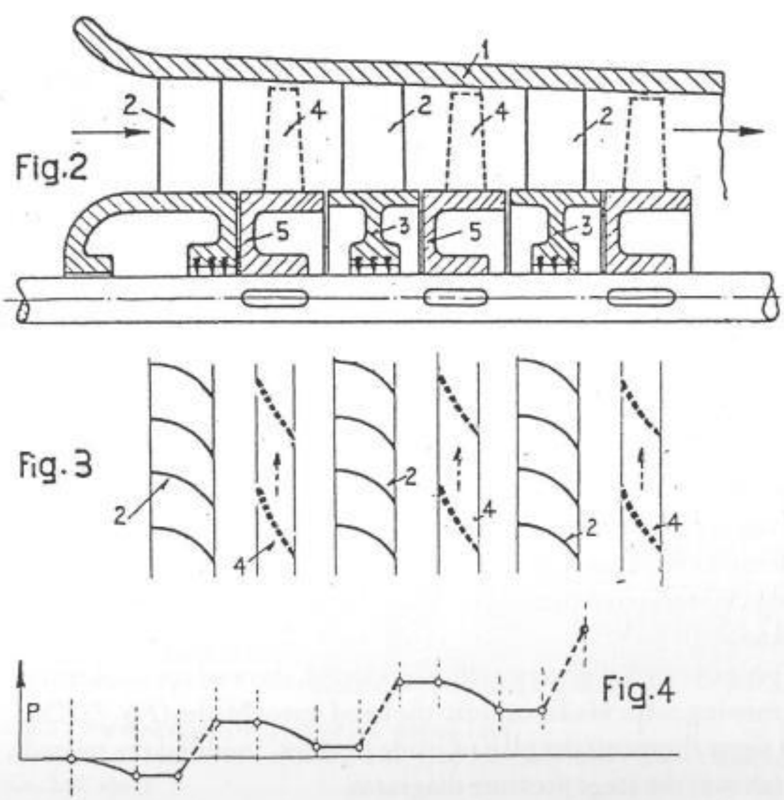


Fig. 6 Longitudinal cross-section, blade profile plan and pressure-diagram of a multi-stage axial compressor (Eduard Gyger, St. Gallen, Switzerland, 1933) from Patent No. 700968, dated Febr. 7 1933.

The various blade combinations can be characterized by the "reaction degree" r, which is the part of the rise in static pressure of the rotor as part of the whole stage, which, in turn, consists of a rotor and a stator.
Herbert Wagner chose an arrangement with r= 1/2 (right side in *Fig. 7*). Thereby the straight axial entry flow onto the blades was dropped and the desired inlet swirl was gained by an additional row of fixed blades to guide the air onto the first row of rotor blades.
In 1936 we were aware of the airfoil theory as it was applied by Curt Keller in 1934 in his dissertation [6] on one-stage axial fans (supervised by Ackeret). Further, it was known that the flow losses rise intolerably when the flow velocity approaches the speed of sound. The speed of sound was at that time the upper limit, to be respected absolutely, as observations on the tips of propellers had clearly shown.
Since, at a reaction degree r= 1/2, the flow velocity and its margin below the speed of sound are equal for the moving and the fixed blades, the possible blade tip speed is at the maximum (*Fig. 8*). Then the pressure rise per-stage reaches a maximum. This results in the smallest and the lightest compressor for a given total pressure rise.
Also helpful were the numerous aerofoil profile investigations and their "polar"-presentation for the relation of lift coefficient C_L, drag coefficient C_D, and angle of

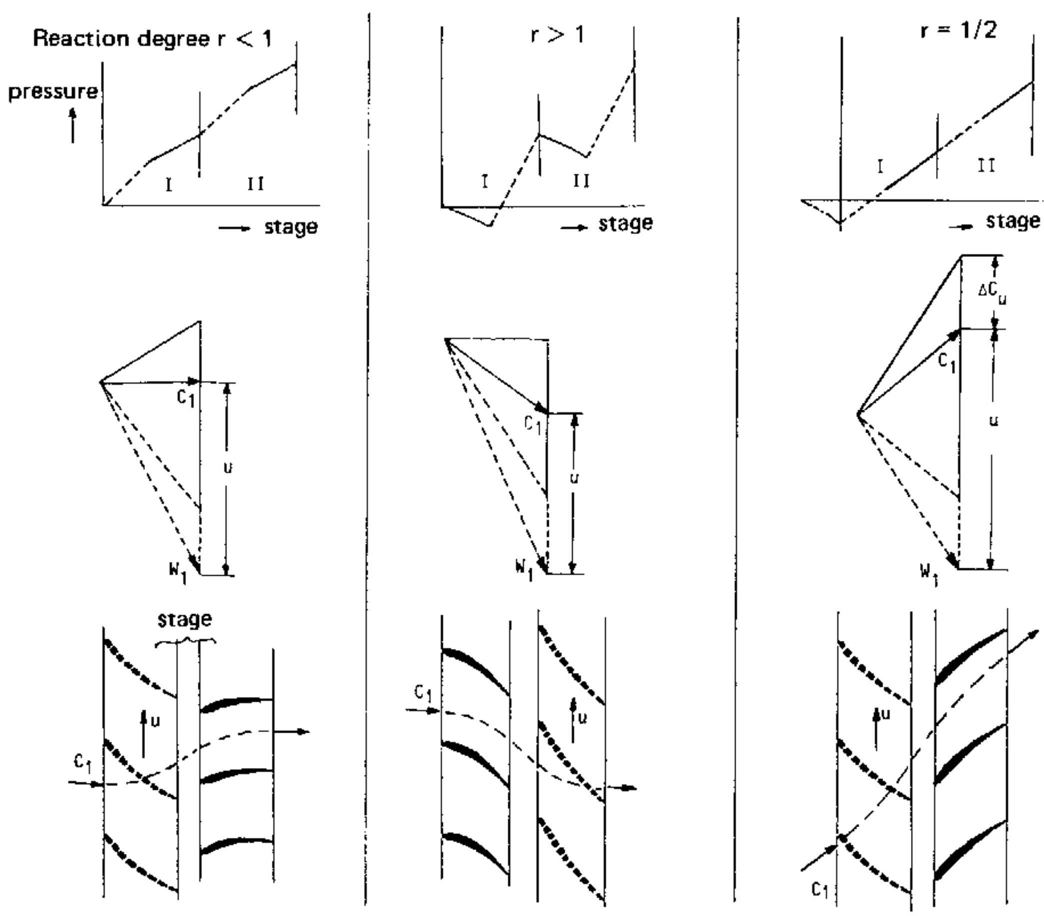


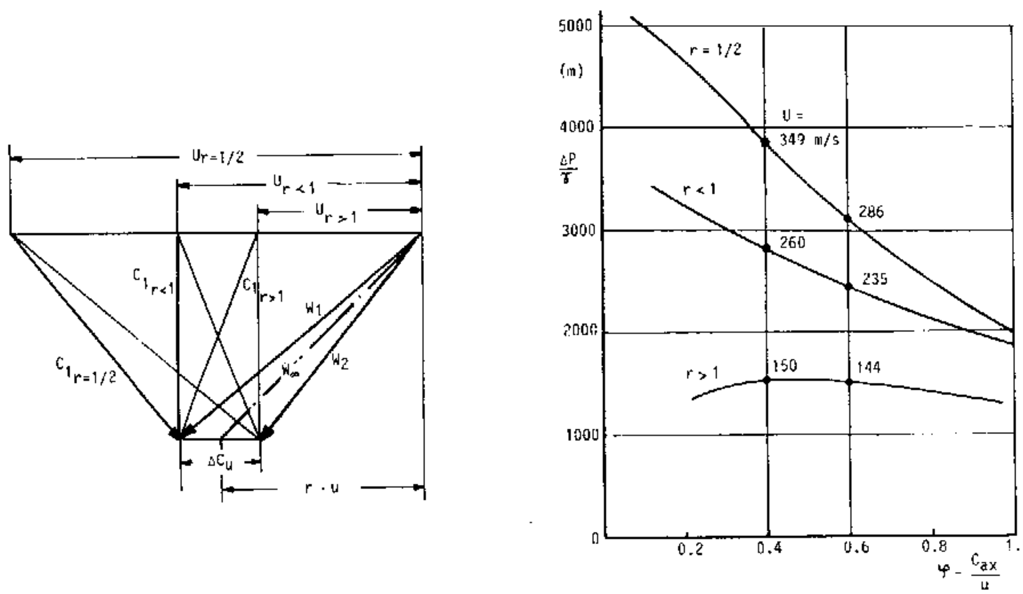
Fig. 7 Pressure diagram, velocity triangles and blade profile plans of compressor stages of different reaction degrees, r.

attack measured and reported by the Aerodynamische Versuchsanstalt – AVA (Aerodynamic Test Institute) in Göttingen [7]. We performed measurements with three selected blade profiles in a one- to three-stage arrangement with adjustable rotor and stator blades in order to correct the Göttinger single profile results in their adaption to a ring profile grid. This meant that the problem of constructing twisted blades with high profile accuracy and uniformity had to be solved. The methods of steam-turbine producers were not applicable. This forced us to rely on ourselves, which we did successfully, using an available *Deckel* copy-milling machine with attached round table and a copying model enlarged about six times for the production of the blade profile (*Fig. 9*). The measurements produced stage characteristics, which served as the basis for the designing of the first (supposedly) 14-stage axial compressor with r=0.55, the test engine RTO.

Herbert Wagner's original concept of driving a propeller in addition to using the propulsive power of the existing turbine jet had been simplified by the end of 1936 to the pure reaction-turbine (RT) jet propulsion, the thrust of which – in contrast to the propeller thrust – increased with increasing flightspeed.

In order to calculate the meridian cross section of the axial compressor, the boundary layer, with the number of stages increasing, was considered as a slowly rising "displacement thickness". The entry swirl produced by the leading stator blading was to correspond to the relation $c_u \cdot R = \text{const.}$

For the combustion chamber an unusually high energy exchange had to be attained in the available space. In numerous combustion tests with gaseous and liquid fuels this



a) Comparison of the velocity diagrams at equal limit velocity of rotor blades w_∞

b) Possible pressure rise per stage
Asumptions:
$C_L = 1{,}0$ $T_0 = 280$ K
$\ell/t = 1{,}0$ $w_\infty = \frac{0{,}88}{1+C_L/\pi} v_{sound} \geq c_\infty$

Fig. 8 Comparison of the blade arrangements for axial compressors of different reaction degrees, r.

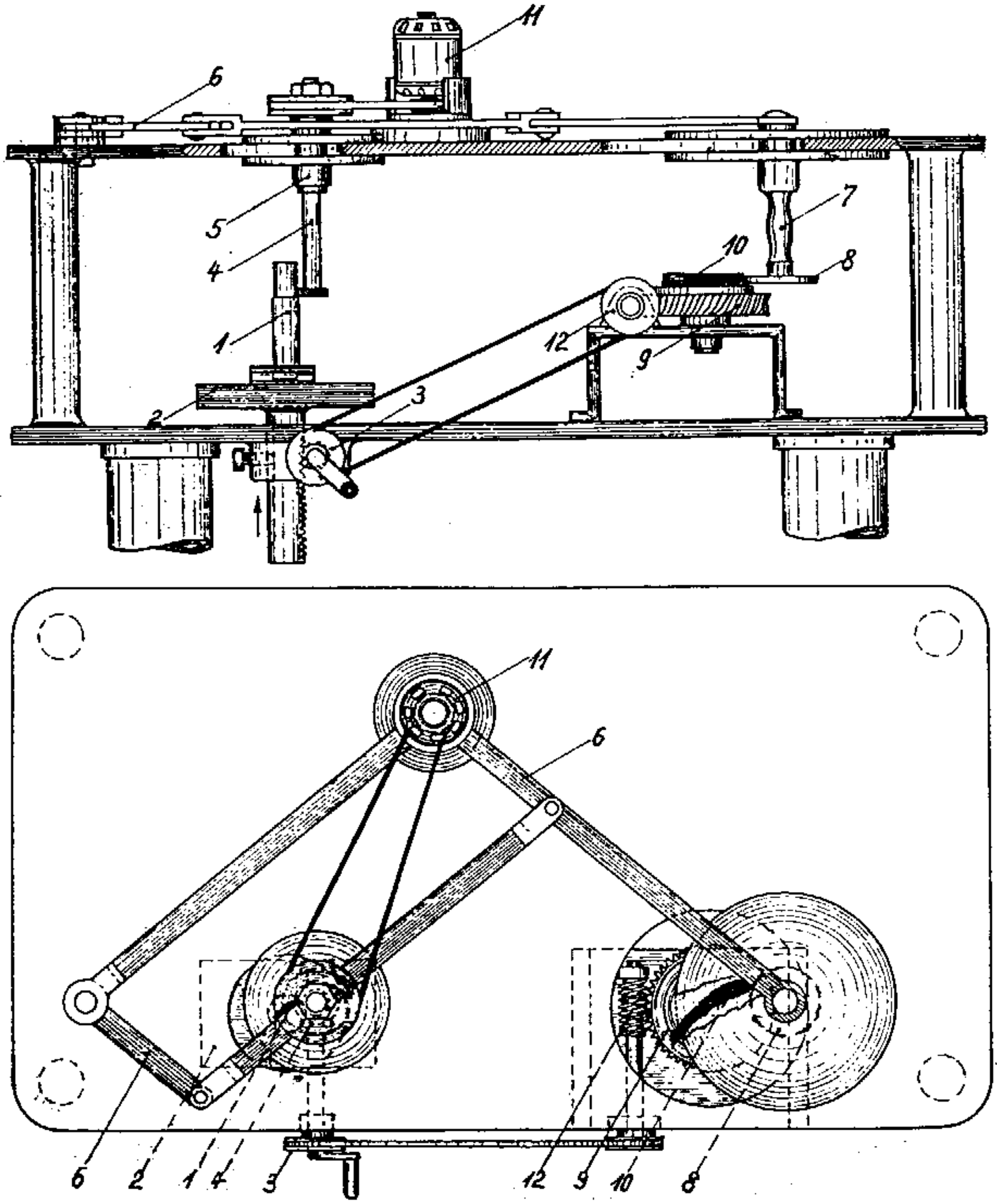


Fig. 9 Assembly for copy milling of twisted compressor blades
Pos. 10: Enlarged copy model of a blade section
8: Scanning disk
4: Milling tool guided by copier
1: Compressor blade in production
3: Feed control in direction of blade axis
(turns simultaneously the copy model in direction of the desired blade twist after each machining step).

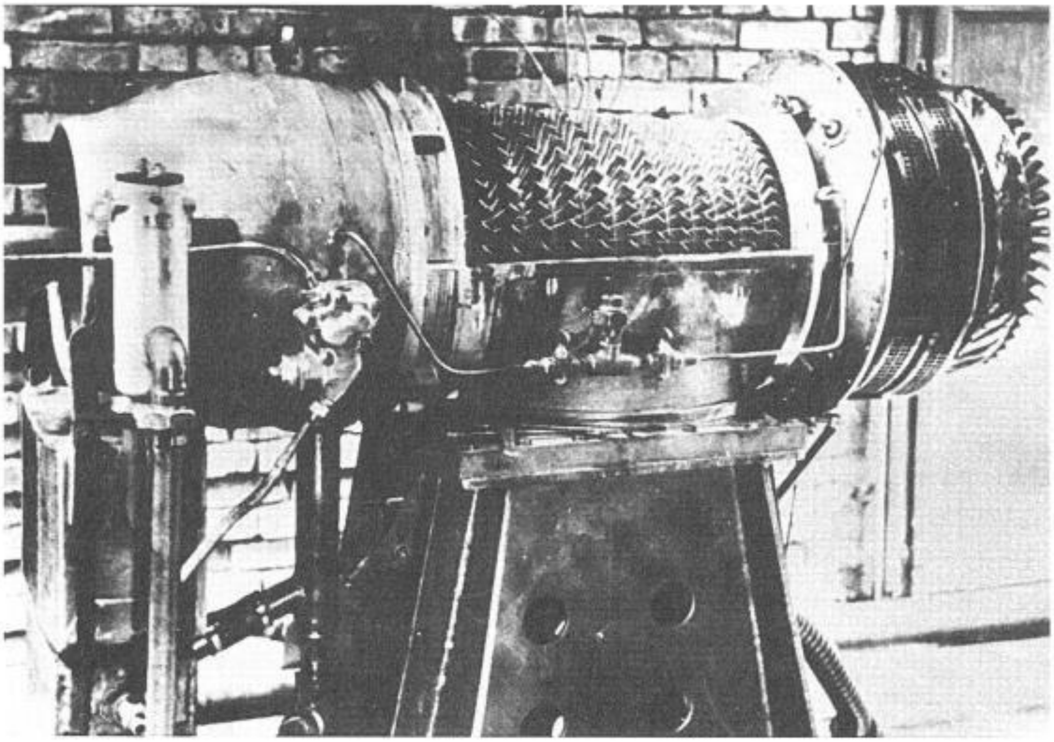


Fig. 10 Test engine RTO in Magdeburg. (Graciously made available by Bruno Lange, Überlingen.)

requirement could not be fulfilled satisfactorily with atmospheric air supply. The construction of a section of 1/10 of the annular combustion chamber enabled combustion tests at higher pressure, which more closely approximated reality.

5. In early 1939 the test engine RTO with its 14-stage axial compressor, annular combustion chamber, and 2-stage axial turbine was mounted on a engine test bed at the Magdeburg factory (*Fig. 10*) and, as a first step, was adjusted for the combustion of propane gas.

The tests, which we anticipated with eagerness and great curiosity, could, however, not be performed. The Reichsluftfahrtministerium – RLM (German Air Ministry), which from then on paid the development costs, demanded that further work proceed with the cognizance of, and within the Junkers Motorenwerke (Jumo) in Dessau, and ordered that our department should be transferred there at once. We could not consent to such a decision at that moment, because we thought we were near the completion of the first stage of development. So we left Junkers, just as Max Adolf Müller had done. Prof. Wagner had already returned to Berlin by the end of 1938.

In August 1939 the approximately 15 men composing our Junkers group accepted an offer by Ernst Heinkel and went via Berlin to Rostock-Marienehe. Here under the leadership of Max Adolf Müller and based upon the previous work in Magdeburg, the axial turbine jet engine was developed now as "He S30" (109.006) (Heinkel S30) with about 750 kp of thrust (*Fig. 11*). Its compressor was designed according to the same concepts, but with separate disks for high blade-tip speeds (u = 313 m/sec) and required only 5 stages (*Fig. 12, 13*) for a compression ratio of 2.8. The average stage-

pressure ratio was 1.23 and this was 43 % higher than of the compressor of Jumo 004, which was 1.16.
Test box experiments and power verification were unfortunately again much delayed by our transfer to the Hirth-Motorenwerke Stuttgart-Zuffenhausen, which had been acquired by Heinkel in the second half of 1941.
A thrust of 820 kp was achieved only in April of 1942, after the 1-stage turbine had been better matched to the mass flow through the compressor. Fuel consumption, outer diameter, and weight of the He S30 were strikingly low; the efficiency of the axial compressor was around 87 % despite the high bladetip velocity.
The turbine jet engine "He S30" was, I am convinced, a successful and auspicious second step of the initiative begun by Herbert Wagner. Unfortunately, because of the pressure for quick decisions and results at that time, and the necessity for concentrating on the development tasks for the powerful He S11, he did not receive proper recognition.
6. Allow me, in conclusion, a few personal and critical remarks. Naturally, historical reflections stimulate, and even require, evaluations.
– Prof. Herbert Wagner had a broad knowledge of basic science and was gifted with a great ability to associate ideas. In an ingenious manner he recognized and used new possibilities, as historical development offered. It was a privilege for us to have had the opportunity to work with him in this field, where there was still so much virgin territory. Without doubt, the credit goes to Herbert Wagner for the fact that in spring of 1936 at Junkers, in Germany, the axial turbine jet engine was promoted with resolution and vigor.
– On the other hand, I still consider the following decisions, although understandable, to have been unfortunate:
- the decision ordering the immediate transfer of the development begun in Magdeburg to the Junkers Motorenwerke in Dessau. As a consequence, the informative tests with the RTO engine were not made, and the three years of preparational work was not utilized by Junkers.
- that Mr. Anselm Franz, to whom the development of the jet engine within the Junkers Motorenwerke in Dessau had been transferred in 1939, placed no trust in the previous work on the axial compressor and relied wholly on the work of the

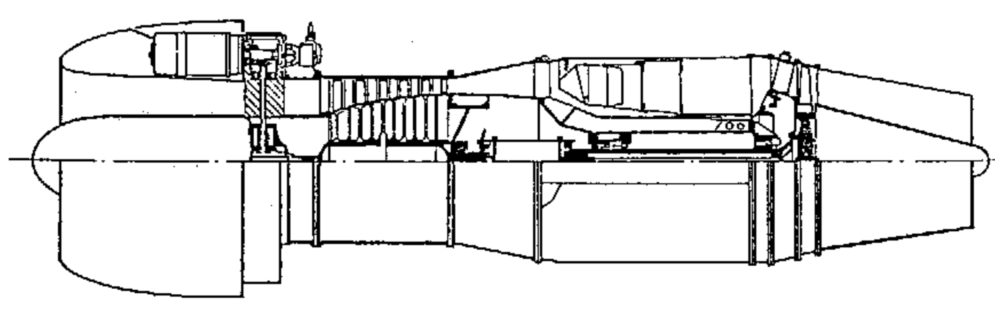


Fig. 11 Heinkel Jet engine "He S30", 1941 (Max Adolf Müller). [9], [11]:
thrust 820 kp (8.04 kN); n = 13,000 rpm; $\pi = 2.9$;
engine-outer diameter D = 580 mm
engine-mass (dry) G = 380 kg
thrust per front area S/F = 30 kN/m^2; spec. consumption b = 121 kg/kN h

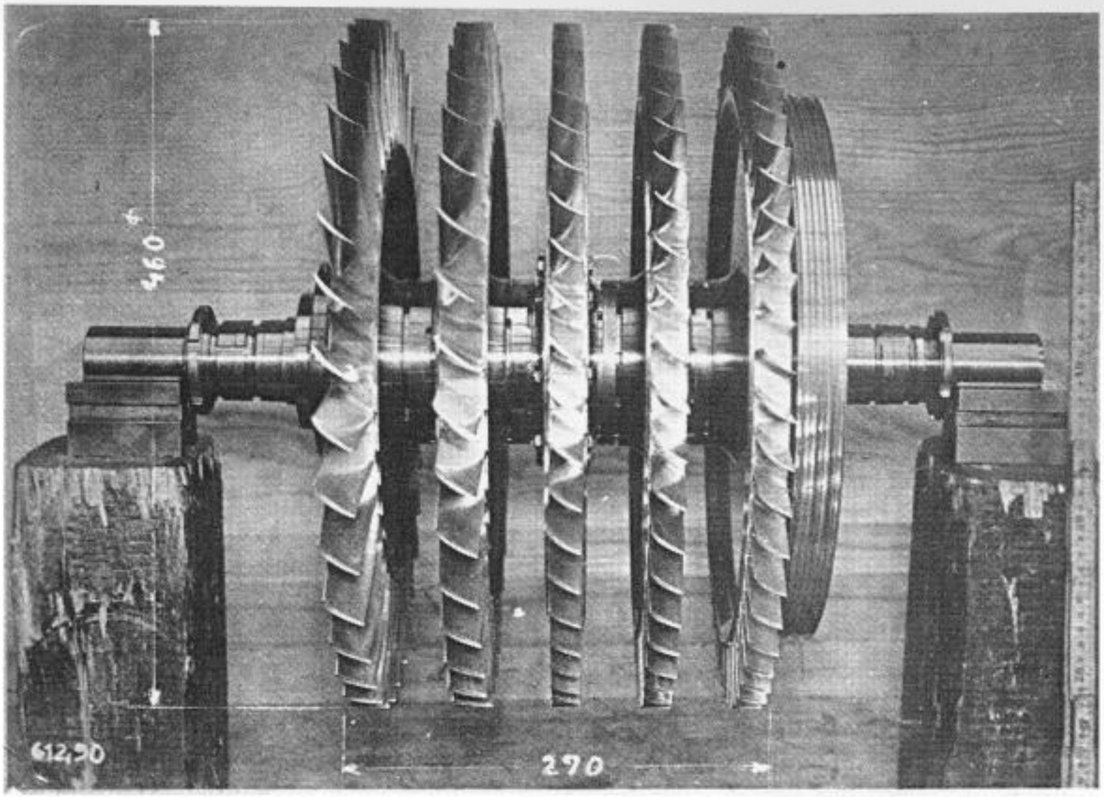


Fig. 12 Axial compressor for jet engine "He S30":
5-stage rotor (r = 0.55).

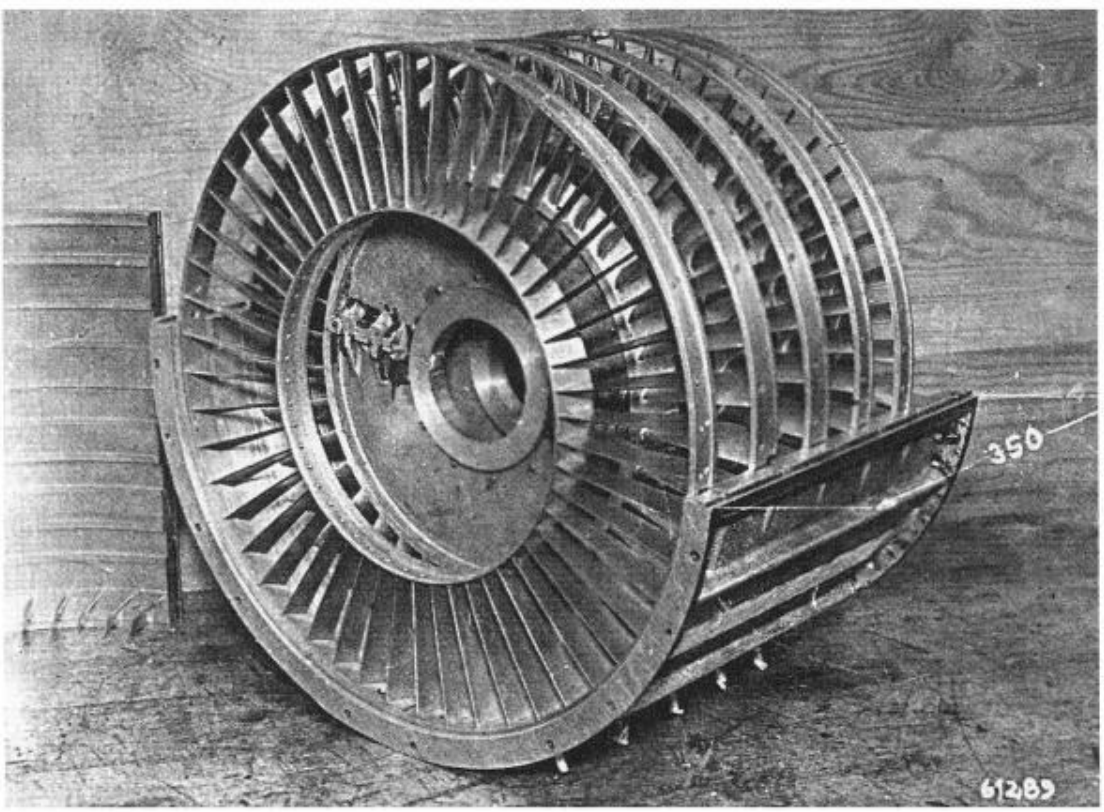


Fig. 13 Axial compressor for jet engine "He S30":
Stator blade rings with guide vanes.

Aerodynamische Versuchsanstalt – AVA (Aerodynamic Test Institute) in Göttingen, which applied r = 1.
– the order by the German Air Ministry (RLM) in 1942 that cancelled the further development of the He S30.

It honors both the Deutsche Gesellschaft für Luft- und Raumfahrt (DGLR) and the American Institute of Aeronautics and Astronautics (AIAA) that they conduct this symposium today commemorating Herbert Wagner and thereby provide the occasion to make better known to the public his initiative and guiding influence on the jet engine now in use worldwide.

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[11] Heinkel Werkzeitschrift 1962, Heft 1, p. 55.

Biographical Sketch: Rudolf Friedrich

Born 1909 in Waldenburg/Silesia. After attending High School for classical studies and half a year of industrial training, studied general mechanical engineering at the Technical Universities of Breslau and Hannover.

Industrial experience: Fall 1933, Junkers Dessau, airframe construction, 1935 in design office of that firm, investigations for the construction of a trans-oceanic airplane. Thereby, closer contact with Professor Herbert Wagner, who came to Dessau from the Technical University Berlin through the initiative of the head of the Junkers Aircraft and Engine Company, Dr. Koppenberg.

Herbert Wagner got the latter to agree to his proposal for the development of a flight gas turbine and asked me to work with him.
On April 1, 1936 a group of three began work at the Magdeburg Junkers plant for the new project. My task: the axial compressor development and manufacturing possibilities for its twisted profile blades.
1939 an offer from Ernst Heinkel, Rostock, for me to participate in the development of the axial jet engine "He S 30".
1941 at the turbine factory of Brückner, Kanis & Co., Dresden, development of the gas turbine for ship propulsion took place. In cooperation with Dr. Vorkauf, construction of a one stage test gas turbine with interior water cooling of the blades.
1945 after Soviet military occupation and destruction of the factory facilities, I was charged with design of gas turbines for locomotives and ships.
1947 removed myself from pending eastward transfer. After one-and-half years in a camp, I was employed by Siemens, Mülheim, to prepare development of stationary gas turbines. When government restrictions were later removed, construction of single axis gas turbines for driving generators up to 27 MW began.
1964 called to the Technical University, Karlsruhe, to take up the new chair for Thermic Flow Engines.

Guided Missiles

by Carl Diederich*/Georg E. Knausenberger

Herbert Wagner, on September 15, 1981, in a letter to the editor of "Scientific American", referring to an article on "Precision-Guided Weapons", characterized his main guided missile development in the following way:

"The German Hs 293 was a winged bomb – 10 feet span, 1100 lbs warhead – rocket propelled after being launched from an aircraft with a 'joy stick' manually guided via a radio command link on the sightline toward a ground target. It was successfully tested in Dec. 1940 and in tactical use since August 25, 1943. I believe these were "firsts" for a device originally designed as a precision-guided weapon i.e., not a manned aircraft later adapted to that purpose. Some destroyers and 440000 tons of merchant ships were sunk. The sufficiently sophisticated radio link was never jammed but the allied bomber aircraft finally destroyed the German airfields.

The German drop-bomb Fritz X was similarly remote-controlled. It sank in September 1943 the Italien battle ship, Roma. This may have caused some caution in the use of such ships."

An original report from 1945/46 will be excerpted for further details in the following:

* Biographical Sketch see page 102

Excerpts from the "Guided Missiles based on the Work of Prof. Herbert Wagner" by *J. J. Henrici*, June 1st, 1946, used by C. Diederich in his talk on May 8, 1984.

Professor Herbert Wagner's Missiles

This paper gives a short review of the firms, organizations, and missiles constructed during the years 1940 to 1945, with a few basic considerations characterizing this work.

Contents

A. List of firms working on these missiles
B. List of Wagner's missiles
C. Characteristic ideas, illustrated by the anti-aircraft rocket "Schmetterling" (Butterfly) and its competitor models

by his collaborators at the Henschel-Flugzeugwerke (Henschel Aircraft Works)
J. J. Henrici,
E. Marcard,
C. Diederich

A. *List of Firms working on these Missiles*

It is useful for judging the following reports to know how this knowledge was gained. The reports are based on work done by Prof. H. Wagner and his collaborators during the years 1940–1945 chiefly at the Henschel Aircraft Works in Berlin, but also to a great extent by the following firms working together with them:

Stassfurther Rundfunk, Stassfurth	Remote control, transmitter, receiver (Strassburg);
Opta Radio, Leipzig	Filter and amplifier unit, control stick;
Apparatebau Heinrich List, Berlin-Teltow	Magnets, elevator control unit;
Allgemeine Elektrizitäts-Gesellschaft (AEG), Berlin	Generator, proximity-fuse;
Siemens u. Halske, Berlin & Balingen	Relays, proximity-fuse;
Askania, Berlin	Potentiometer, control-stick;
Friesecke u. Höpfner, Berlin	Receiver, control-stick;
Telefunken, Berlin	Receiver, transmitter, carrier plane outfit, antennae;
Bayerische Motorenwerke, München	Liquid-fuel rocket;
Walter-Werke, Kiel	Liquid-fuel rocket;
Rheinmetall-Borsig, Berlin	Boosters, fuse, blow-off device;
Schmidding, Bodenbach/Elbe	Boosters;
Horn, Leipzig	DC-gyro.

There were also discussions with research institutes including the Deutsche Versuchsanstalt für Luftfahrt (DVL) in Berlin; Aerodynamische Versuchsanstalt (AVA) in Göttingen; Luftfahrtforschungsanstalt (LFA) in Braunschweig; Deutsche Forschungsanstalt für Segelflug (DFS) in Ainring; Forschungsanstalt der Reichspost, with experts from the Reichsluftfahrtministerium (RLM) and from the test-grounds at Peenemünde-West.

In a few cases, experience gained during the development of other missiles could be exchanged, but this was not done on a large scale.

Professor Wagner had divided the work of his men into groups with headings such as Aerodynamics, Physics, Electrical Apparatus, etc. and had added two special groups for different missile types such as the Henschel "Hs 293", the "Hs 298", and the "8–117".

At Henschel about 1100 men were working under him, 500 for experimental development, 600 for the manufacture and production of test-apparatus. Wagner also had to provide assistants and workmen for the firms working with him. Serial production was done in special plants of Henschel at Berlin-Schöneweide, and at Warnsdorf (approximately 12,000 units of the "Hs 293" and 500 units of the "Hs 234" were produced). Wagner had to gather these men, for he was nearly alone when he started at Henschel; and it was difficult to get skilled men in Germany as late as 1940, which somewhat accounts for the irrelatively large numbers. Only one leading electrical engineer and a few of his former students whom he knew really well were available; most of the men came from the Luftwaffe. Most of them were not well trained for the work they had to do. The first task was to get the men, the second was to adapt their minds to the new business. This had to be repeated every time a new set of men arrived, as happened for example in autumn 1943 when about 500 men arrived for the development of the anti-aircraft rocket "Schmetterling" (Butterfly).

B *List of Wagner's missiles*

At the outset, Wagner was expected to make a missile similar to the later well-known V-1, as we were told by him. But he did not like the idea of expending so much skill on a relatively simple matter; if he had to make so many new devices, he wanted to hit not within an area, but at a point. When this idea was approved, he designed the "Hs 293" as an air-to-sea missile (*Fig. 1*). Several variations of this type were tested, each differing according to the purpose – e.g. against armored ships or against airplanes – and according to technical devices – e.g. remote control by wire or wireless. The special feature of this missile compared with the "Fritz X" (made by Dr. Kramer, Ruhrstahl), was that the "Fritz X" was designed as a guided bomb to be dropped from great heights whereas the "Hs 293" was intended for use even in the presence of low clouds, for instance at a height of 1 km, it was to hit its target at a distance of 17 km. For hitting ships below the water line, a special body was developed that was able – after approach by flight – to run under water for a few hundred meters, guided by its cavitation-bubble (*Fig. 3*). This type was first known as the "Hs 294".

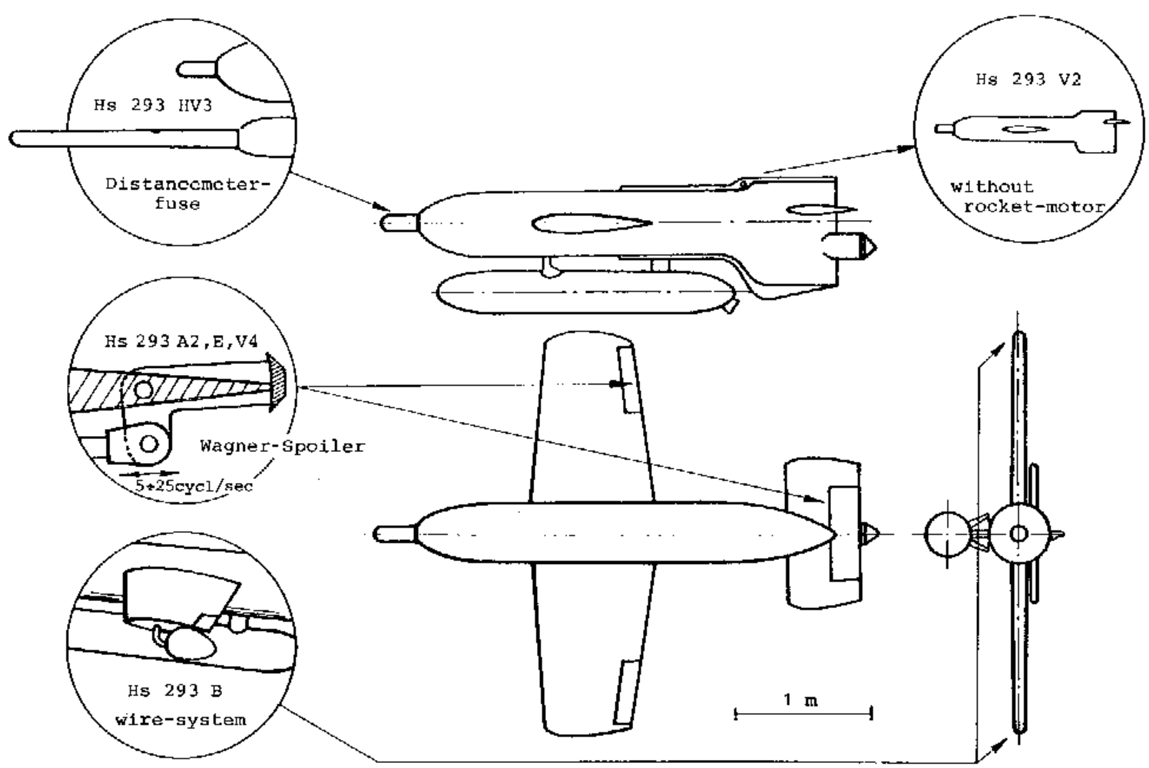


Fig. 1 Hs 293 A1

Fig. 2 Hs 293 D

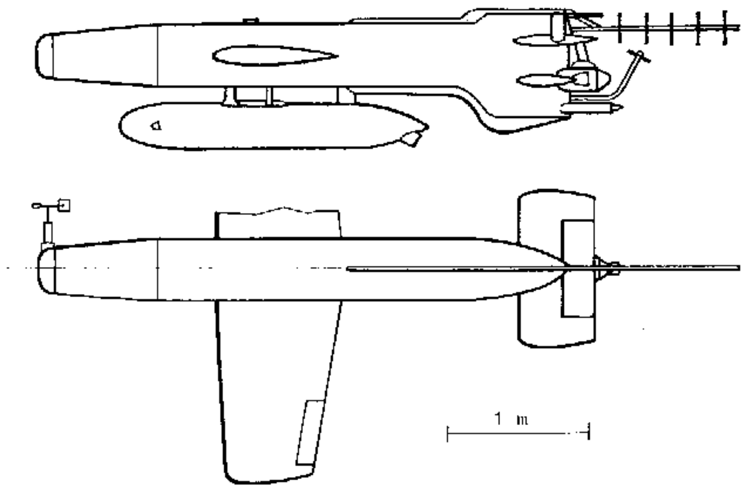


Fig. 3 Sideview Hs 293 C

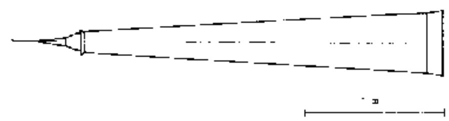


Fig. 4 8–117 A2

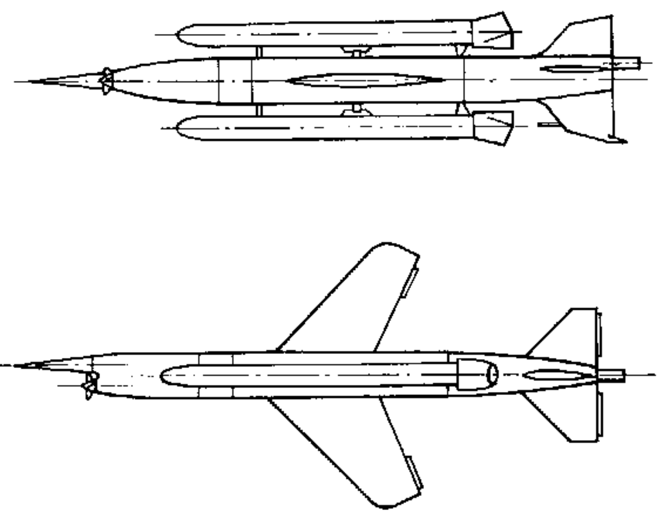
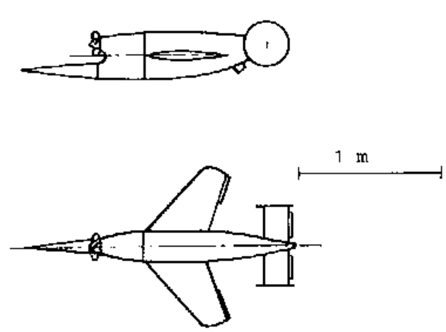


Fig. 5 Hs 298 V2



In 1941, Wagner started the design of an anti-aircraft rocket; but among Wagner's thirty-six proposals, this was the only one cancelled by the Air Ministry (RLM) with the explanation: uninteresting. In autumn 1943, the decision was revised. The new type was called the "8–117", or "Butterfly" (*Fig. 4*).
The smallest of Wagner's prototypes was the "Hs 298" (*Fig. 5*) air-to-air missile, like the "X4" by Dr. Kramer. A modified version of the "8–117" was intended for the same purpose.
The chief features of some individual missiles are outlined below.

"Hs 293"
Glide bomb, for use from planes against point-like targets like ships, was developed after 1940 along several lines. Its main features were shown by the serial type "Hs 293 A1" of which 12,000 were produced. It was designed to hit unarmored ships at a maximum distance of about 20 kilometers. Its weight was 1 ton with an explosive payload of 0,275 tons; its span was about 3 m and its length about 3.5 m (*Fig. 1*). It was controlled according to the line-of-sight by an aimer in the aircraft. The bomb had a liquid-fuel rocket that was fired after release from the carrier, and it reached a velocity of about 225 m/s. Its visibility was guaranteed by a flare in day-time and a reflector at night.

Different stages of the development included the following:

"Hs 293 V2"
First experimental model (1940/41). Glider without rocket motor. Standard control system by means of potentiometers. Lateral control by magnet-driven flaps, elevator flap control by an engine unit. No rudder. Strassburg receiver. Filter and DC-amplifier. Power supply by batteries for 24 and 210 volts. Current: approx. 30 Amp. Number of valves: 27. High frequency range (approx. 6 m band). Control frequencies: 1000, 1500, 8000, 1200 cycl./sec. Control-stick contact frequency: 10 cycl./sec.

"Hs 293 V3"
Improved experimental model (1941). Rocket motor attached. Independent apparatus previously linked by wires were combined in a modular unit (SAG). 24-Volt supply by accumulators, 210-Volt converter. Start of serial production.

"Hs 293 A1"
Improved serial model (1943). Strassburg receiver with relays in output-stage. DC-relays-amplifier. Universal connecting-unit (SAG). Number of valves reduced to 12. Approx. 12,000 of the "Hs 293 V2-A1" were produced.

"Hs 293 B"
In 1941, the type "Hs 293 B" was intended for use with remote control by wire to avoid possible disturbing of wireless control. This development ultimately meant that all models "Hs 293" – "Hs 296" could be controlled by the wire-system too. For this purpose the receiver in the bomb had to be exchanged and in the carrier-plane the transmitter had to be replaced. Also two coils of wire had to be attached to the glider and to the plane as supplementary equipment. This did not influence the range.

"Hs 293 C"

This type was designed for attacking armored ships below the water line. It was a smaller version of Hs 294. The missile was targeted so as to dip into the water about 100 m before the target. The blowing off of wings and rear-section of the body was triggered by contact with the water, so that only the cone-like fore-section would run under water (*Fig. 3*). Stability of course was obtained by corresponding profiles. It was fitted with a way-fuse in addition to an impact fuse. Variations in number of ailerons, shape of control-flaps, and steering-devices were designed. These types were produced in small experimental series.

"Hs 293 D"

This type, designed in 1942, is like the standard type but fitted with television equipment. It is controlled according to the picture of the target transmitter from the bomb. The total length is enlarged by this equipment by about 1 m (*Fig. 2*). The tests of this bomb were carried out by the "Forschungsanstalt der Reichspost" together with "Fernseh AG", Berlin. The results were not fully satisfactory.

"Hs 293 G"

Experimental type. A glider like the "Hs 293" (also in the control system) but fitted for a vertical as well as a horizontal flight path, thus possessing the characteristics of the "Hs 293" and of the "Fritz X" (Dr. Kramer). For this purpose a special gyro was constructed that could be tilted by 90° from vertical to lateral axis. Ten models built in 1942, then work was stopped by the Air Ministry in favor of the "Fritz X".

"Hs 293 H"

Glider "Hs 293 A1" for use as anti-aircraft weapon. Therefore it was specially outfitted for remote control of the fuse with a fifth control-channel. Serial type "Hs 293 A1" could be converted to a "Hs 293 H" by exchanging receivers and by attaching a special relay-box. Small series were built in 1943/44 with corresponding equipment.

"Hs 293 V4"

This was an experimental design in 1943/44, based on the "Hs 293 A". The usual elevator-flaps were exchanged for Wagner-flaps; and the elevator engine replaced by magnets accordingly. It was used for control tests with regard to type "Hs 293 A2". The same control system was used with the "Hs 298" and "8–117" (Butterfly).

"Hs 293 A2"

This was the last serial type (1944). New simplified controlling system. Control-stick contact frequencies, lateral: 16 cycl./sec. elevator: 5 cycl./sec. New 16 cycl./sec. filter and new potentiometer in the lateral control. Wagner-flaps operated by magnets energized directly by receiver-relay. DC-gyro. Forerunner of 298/117 controlling system. Serial production ready to begin but stopped by the Air Ministry (RLM).

"Hs 293 V5"

This experimental model was designed in 1944 like the "Hs 293 A2", but with alterations for use by jet-fighters against bombers flying in tight formation.

"Hs 293 V6"

This type was used for testing the serviceability of the "Hs 293 A2" with fact aircraft (e.g. the "Arado 234"). The necessary increase in velocity of missiles was attained by a second liquid-fuel rocket drive. Both drives were installed at the bottom of the fuselage. They were fired one after the other.

"Hs 294 A"

This type was designed in 1941 for attack on armored ships below the water line. Its gross weight was 2 tons with an explosive payload of 1 ton. Its controls were like those of the "Hs 293 A1", but special fuse devices were provided for blowing off the fuselage's rear section and wings as soon as the body touched the water's surface. The fuselage front section then ran under the water like a torpedo. Small series were produced for experimental purposes during 1941 to 1943. It was Wagner's largest missile.

"Hs 296"

This type is similar to the "Hs 293 G" but had a greater explosive payload (about 1 ton). It is designed to be in a steep attack as well as a glider bomb against armored sea and land targets (Total 2.2 tons).

"Hs 297"

This type was planned in 1941 as an anti-aircraft rocket to be fired at fighter planes from the ground. Being a defensive weapon, it was rejected by the Air Ministry after two months' work. In 1943 it was urgently requested. Work was continued under the designation "8–117".

"8–117"

This type, also called the Schmetterling ("Butterfly"), was started in March 1943. As an anti-aircraft rocket with a gross take-off weight of 460 kg, it was to be launched in the direction of the target by two solid-fuel rocket boosters. Having attained a certain Mach-number, e.g. 0.85, the solid-fuel rocket drives were blown off, and the liquid-fuel rocket, fitted in the fuselage, was fired. It was controlled to fly at a constant Mach-number. It was steered along the line-of-sight by an aimer whose sighting instrument was aimed by an observer. A flare was provided as on all other missiles.
It was fitted with the same simplified system as the "Hs 293 A2", but allowed several additional devices for boosters, Mach-regulator, control-motor for gyro, etc. Experimental series were produced after 1944; serial production of 3000 a month was planned as "Führer-Not-Programm" (Führer's emergency program).

"8–117 C"

The last experimental type with 40 kg of explosives (Autumn 1944). It was provided with a proximity fuse.

"8–117 A2"

This type was to be produced in a large series. The tail plane was improved by tapering and the elevator deflection by pressure-head control. It could be provided with various receivers. Besides the high-frequency proximity-fuses, an acoustic proximity-fuse could be used. Provision was made for radio location with a pilot-transmitter. A homing-device was planned.

"8–117 H"

This modified type was intended for use as an air-to-air missile. Being without boosters, it had a smaller fin. Compared with similar missiles, it had a greater range – about 25 km from the point of release – and a possible ceiling of about 5 km above release point.

"Hs 298"

This type was planned in 1941 as a missile shot from fighters against bombers. It was also stopped for a year and a-half by the Air Ministry; only work on the receiver was continued. In 1943 it was urgently requested, and redesigned on a larger scale. Its gross weight was 125 kg with an explosive payload of 45 kg. Its span was about 1,25 m (*Fig. 4*). It was to be launched from a rail on the carrier by a solid-fuel rocket at a greatest possible distance of 2 kilometers from the target. After acceleration, a second stage of the rocket gave the thrust necessary for approximately constant speed. It was aimed according to the line-of-sight. Its control-system was similar to the "Hs 293 A2", but simplified. Power was supplied by an airscrew-driven generator. Its explosive was fired by a proximity fuse about 7 or 8 meters from the target. Experimental series were produced beginning in 1944; serial production was carried out. It is the smallest of Wagner's missiles and was a competitor of Kramer's "X 4". The "Hs 298 V1" was the first experimental type. The "Hs 298 V2" was to be the serial type with modification of the body shape and tail unit. A tailless type, the "Hs 298 F", was planned.

C *Characteristic ideas*

Illustrated by the anti-aircraft rocket Butterfly and its competitor models.
It is interesting to look for features differentiating Wagner's missiles from the work of others. This may be done with the "Butterfly", as we are best acquainted with its problems.
There were four anti-aircraft rockets ordered by the German Air Ministry:

Firm	Type	Take-off Weight tons	Weight of Explosive tons	Velocity m/s max	Ceiling km
Elektromechanische Werkstätten, Peenemünde	Wasserfall W1 – W3	3,5	.15–.40	700	16
Rheinmetall-Borsig, Berlin	Rheintochter R1 – R3	1,7	.15	500	12
Messerschmitt-Holzbau	Enzian	1,7	.10–.40	300	11
Henschel-Flugzeug-Werke, Berlin	Schmetterling (Butterfly) S1	.46	.04	225–255	10

With the first type an attempt was made to fulfill every possible demand on a long-range anti-aircraft rocket. It was to be fired against the fastest and highest flying planes, without regard to the weather. It was based on the experiences gained from the "V2".
With the second type, the attempt was to fill the gap between the effective range of normal anti-aircraft cannons and the "Wasserfall", also without regard to the weather.
This third type was started after the fourth in order to obtain faster results than were promised with the "Butterfly".
With the fourth type, an endeavor was made to get results quickly with the least trouble and expenditure, but without wasting time for a later development. The first series was to be used in clear weather (day or night) only, whereas the following series, provided with a homing device, could be used without taking the weather into account.
Detailed reasons for this series of missiles are discussed in the following:
The first decisive difference was the method of aiming. A radar beam was the suggested means of aiming. We had made extensive tests on its accuracy at the Flak-Artillerie-Schule (Anti-Aircraft Artillery School) at Berlin-Tegel, where such equipments had been tested. Its accuracy was measured on a Dornier "Do 17" flying back and forth at a distance of about ten kilometers. The measurement was made by a film camera mounted on a mirror that was steered alternately by one of the best crews available and by an average crew. The average error between radar beam and target was about 15 to 20 meters with the best crew, whereas with the average crew, errors of about 60 to 70 meters occurred. The total error between missile and target was even greater. One had to add the errors between target and guide-line, between missile and guide-line, and between the two guide-lines. With a good crew, this meant a total error between target and missile of about 40 to 50 meters at the distance of 10 kilometers. The corresponding explosive payload exceeded 1 ton, and the take-off weight of the missile was about 10 tons.
Furthermore, the total amount of radar equipment necessary in the first type for the required number of anti-aircraft batteries nearly exceeded the capacity of German industry. Also the weight of the necessary apparatus aboard the missiles appeared intolerable. And last but not least, we found no means to counter the attempt by the attacking planes to render such electric aiming equipment ineffective.
Thus, we chose optical aiming, which could be useful under limited conditions, because the electric aiming was thought to need too much time to develop.
A year later, the anti-aircraft batteries decided to use optical aiming.
The second decisive difference was weight, which, according to Wagner, ought to be small enough that one could dispense with ground equipment made of concrete. Even carrying of the missile by hand should be possible.
The weight of the missile at take-off varies among the four types, the ratio of the lightest to the heaviest being 1 : 7.5. Moreover, the weight is an approximate measure of the total amount of work and capital involved in production and service and depends most of all on the load to be carried to a certain height. Considering various factors, an optimum load of explosive of about 40 kg was chosen. See *Fig. 6*.

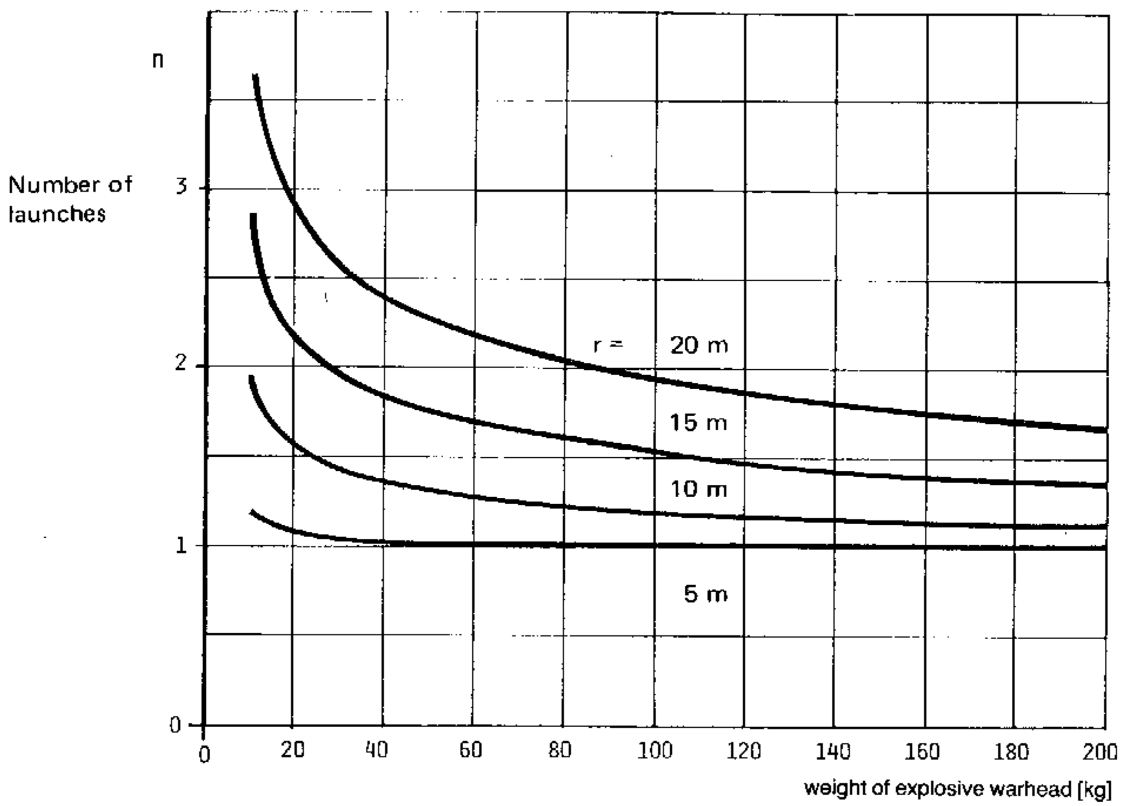


Fig. 6 Number n of required missile launches against a B 17 bomber, related to the weight of the missile's explosive warhead, Wexpl, at four distances r between missile and target.

The approach to the target depends not only on the methods of aiming, but also of the control system. The Wagner-flaps were developed in order to get a quick responding missile. The shortest delay of response to a command was obtained by using these flaps oscillating with a frequency between 5 and 25 cycl./sec. A fair amount of weight was saved at the same time.

The third decisive difference was simplicity. It was discerned from the outset that many complex problems were involved in this new task. We decided therefore to make the development in several steps so as not to lose time. The first type, to be used with optical aiming, was meant to clarify certain questions while producing a simple but already useful missile and while giving us time to find better solutions. The probability of failure increases with the increasing number of new devices. The steering equipment of the "Butterfly" was well known to us from its use in other missiles.

A later series of the "Butterfly" was meant to be fitted with a small transmitter giving its position, and a homing device. Thus one could get the same range as the largest competitor project with about one fourth of its weight at Mach < 1 or about one third at Mach > 1.

The soundness of Wagner's reflections was proved by the fact that we not only got the highest serial production orders but also kept them when, on account of the difficulties in the German production, other orders were cancelled.

When other means fail, the guided missile can shoot down the aggressor's plane or missile with its terrible payload far away from one's own borders and thereby avoid the worst damage. In peace time the experiences and training gained from development may produce a rocket useful for commercial purposes.
It would be useful if any information about other existing material and problems connected with Wagner's missiles were directed to the Deutsches Museum, (Department "Luftfahrt") which is in contact with the development team left behind by Professor H. Wagner, and which retains the H. A. Wagner Archives. Henrici was responsible for the development of the "Butterfly" and was Wagner's closest collaborator during this time. Marcard and then Diederich were responsible for the development and installation of the greatest part of all electric equipment on Wagner's missiles.

Biographical Sketch: Carl Diederich

Born December 29th, 1915 in Ebergötzen near Göttingen.
Studied electrical engineering in Göttingen and Berlin.
1943–45 Development engineer at the Henschel Aircraft Plant in the department of Herbert A. Wagner:
Development of instrumentation for unmanned aircraft.
1945/46 Aerodynamische Versuchsanstalt (AVA) Göttingen
Reports and evaluations concerning Wagner missile development.
1947 Labor für Angewandte Physik, Posthalde near Freiburg, development and lab-testing of nuclear physics measurement instruments.
1948–57 Military Institute for Research and Development in Argentina. Chief of laboratory for remote control. Reproduction and test of a guided missile similar to the Henschel "Hs 293 A2/D".
1957 at firm Bölkow KG, Control systems development and construction.
1959 Entwicklungsring-Süd (EWR) (Merger of the firms Bölkow, Heinkel, Messerschmitt). Department-head for Flight Control and Simulation. Development of the supersonic VTOL aircraft VJ101.
1965 EWR, Chief of main department for Flight Instrumentation, System Analysis, Development and Simulation and, at the same time program manager for Guided Missiles and Transmitter Systems.
1969–80 Messerschmitt-Bölkow-Blohm, head of Development of Instrumentation and Avionics – main project "Tornado".

Herbert A. Wagner's Activities in the USA

Joint effort by former associates of H. A. Wagner*

*Abstract by G. E. Knausenberger***

In May 1945, recognizing the importance of Wagner's missile design, the Institute of Aeronautical Sciences, under US Navy sponsorship, instigated the transfer of Wagner to the United States.
At the Special Devices Center, Sands Point, Long Island, he documented and extended his system analysis and design concepts, serving under the US Navy Bureau of Aeronautics as consultant.
Later, at the Naval Air Missile Test Center, Point Mugu, he guided the development of various new radar and optical tracking and guidance systems for missiles and aircraft.
He pioneered optical guidance, and later established his own industrial company to provide guidance equipment, simulators and system engineering. During and after a period of teaching at the Technical University, Aachen, he acted as consultant and project engineer to American industrial firms. In this capacity he applied his broad and tested expertise to the solution of many American defense problems as well as general scientific and technological problems.
Because of security classification of, or industrial proprietary restrictions on Wagner's reports, it is only recently that light could be shed on his work and his influence in the USA.
An appeal is made for further contributions in order to extend the present Wagner archives, and to evaluate and publish items which might be of lasting historical and educational interest.

* see Addendum page 110
** Biographical Sketch see page 112

Report:

presented by Nick Mastrocola*
May 8, 1984 – Deutsches Museum, Munich, Germany

To report Herbert Wagner's activities in the United States is to face a dilemma.
His broad interests and contributions found expression primarily in briefings, memos and reports to Government agencies and private industry. These documents are no longer available or are subject to security and proprietary restrictions.
Fortunately, a number of former associates have volunteered reports on his activities, as they saw and experienced them.
I will summarize these, and I wish to express gratitude to those who contributed, particularly Professor Knausenberger who led the effort to solicit, collect, and report information supplied by associates and to provide information to the H. A. Wagner archives, which I am sure will be the subject of intense study.
Fortunately we have Wagner's succinct resume (written in 1975), which I will use as an outline and elaborate with the additional information available.
Wagner starts his account of his work in the United States:
"I was the first German scientist brought to this country after the war. I was employed by the Institute of Aeronautical Sciences. I investigated theoretical guidance problems and the stability of servo-mechanics for the United States Navy."
The Navy was interested in Wagner because his glider bombs could be used in the Pacific war. The scientist and two assistants, whose combined knowledge, experience, and skills were probably unmatched anywhere, arrived in the United States to work with various agencies concerned with national defense.
Dr. Wagner and his associates were the vanguard of a postwar movement of German and Austrian scientists and engineers to the United States, where they worked with military, industrial, and university groups.
Herbert Wagner arrived in the United States on May 18, 1945 at an Army Base near Frederick, Maryland. He was then transferred to the U.S. Naval Special Devices Center, Port Washington, N.Y., where he was of great value in shaping postwar guided missile programmes. He impressed all with his extensive knowledge of mathematics and physics and their application to all areas of weapon development.
Handicapped by security restrictions, Wagner used the first two years with the Navy to further develop his guidance and stability theory, which is – as he said – superior to all others, because of the use of electrical circuits in optimizing the guidance loop, and the special treatment of saturations occurring in the guidance system.
A major concern of Wagner at this time as well as later was shaping control and guidance capability using electronic circuitry, which gave electrical control a greater role in the design of guidance systems. The treatment of saturations in the guidance loop was one of Wagner's own ingenious inventions.

* Biographical Sketch see page 111

The concept may be visualized if we consider a missile guided along the center of a street, with the street defined as the linear range of the guidance loop. If the missile, due to a large disturbance or a large initial guidance error, is outside the street (that is in the saturation area) the street is moved so as to contain the missile within the linear range of control, and the street is programmed back to the originally intended flight path by a time function compatible with guidance stability. This basic principal was used in many of Wagner's later guidance system designs.

After serving with the Navy on the East Coast for two years, Wagner was sent to the Naval Air Missile Test Center at Point Mugu in California to assist in range instrumentation and the redesign of missiles.

Concerning his time at Point Mugu, Wagner writes: "1947 to 1950 employed by U.S. Navy at the Missile Test Center, Point Mugu; developed various successful guidance systems for missiles and automatic bombing systems".

In one of his first projects at Point Mugu, Wagner used two ground radars with radio command to guide a ground-to-air missile (the Lark) to hit a drone aircraft. To our knowledge, this was the first hit achieved by a missile on an air target.

Shortly after, realizing the Lark missile had too much time delay, he developed a spoiler on the wing which decreased the response time by 80 %. This control device was employed on both the Fairchild and Convair Lark missiles. The Convair version became the first homing missile to destroy a drone aircraft.

He then developed an electronic control system in conjunction with spoilers to control the Lark. These were used with the X-band active homing guidance system in Raytheon's version of the Lark. Success with this system led to the Sparrow III missile, using semi-active CW homing system, developed and manufactured by the Raytheon Company.

Wagner then led development of an all-weather close-air support system, proven in the Korean war by the Marines and militarized by the General Electric Company. The system used ground radar tracking and radio control of low-flying attack aircraft. This permitted ground troops close to the front lines to obtain pinpoint bombing of designated targets in all weather conditions. The system was refined and today is a most valuable tool in tactical warfare arsenals.

Another project at Point Mugu was his development of a radio-command guidance system for ship-to-shore missiles. The scheme was proven using a V-1 missile, and later used on the Regulus ship-launch missile.

In summary, Herbert Wagner was associated with numerous projects at Point Mugu. He made significant contributions to Navy missile and aircraft technology, and to weapons systems subsequently developed by all the Armed Services.

After Point Mugu, Wagner states: "1950 to 1952, independent consultant to Raytheon Manufacturing Company on problems of missile guidance and to Collins Radio Company on automatic carrier landing system".

Wagner continued his studies on guidance and control systems with feedback loops and non-linearities.

Raytheon had been working on an air-to-air missile guidance system for several years. The first successful flight test occurred about two weeks after Wagner started work with them. Wagner was then asked to design an air-to-air missile to carry the guidance system.

Wagner worked on all aspects of his design: aerodynamics, controls, guidance and, to some extent, seeker electronics, which were successfully developed and flight-tested. In 1951 the Navy awarded a contract to Raytheon to develop the Sparrow air-to-air missile. Wagner's efforts were then directed toward making the existing beam-rider version of Sparrow work successfully.

After Point Mugu and while at Raytheon, Wagner had been thinking of founding his own company. In 1952 he formed the H. A. Wagner company. The purpose of the company was to contribute to the improvement of United States missile capability by further development of the technology Wagner had initially developed in Germany.

Wagner reports on his company: "1952 to 1957, Chairman of the Board, President and Chief Engineer of the H. A. Wagner company in Van Nuys, California. This was a research and development company for electro-mechanical-optical systems. The largest task was the semi-automatic guidance system for the DART Anti-Tank missile. The company had grown to 250 employees by the time it was sold to Curtiss-Wright in 1957".

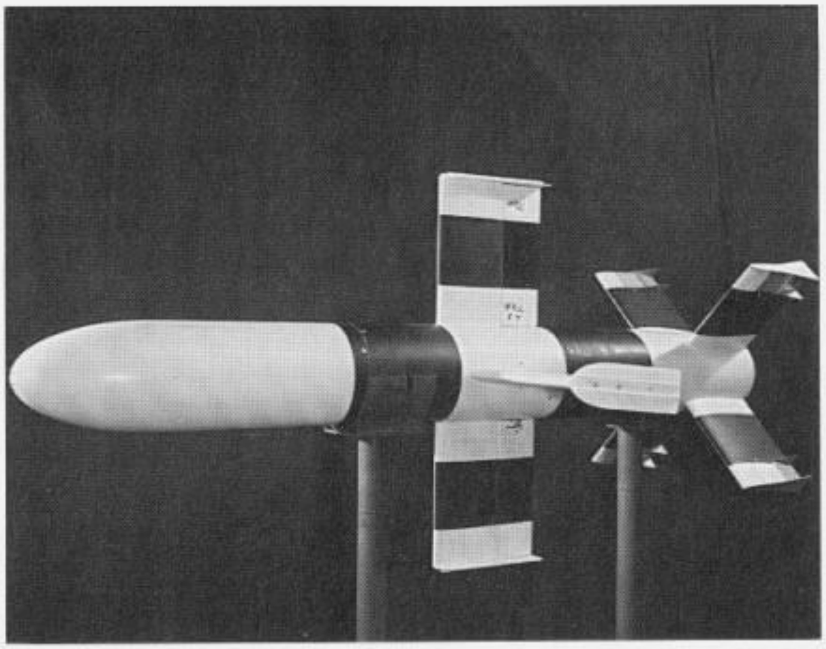
The company's first project led to a successful flight test of a new visual/optical command guidance missile system. The system uses an optical sight based on the sextant principle. A monochromatic flare on the missile with appropriate filters in the target and missile views, permits the operator to superimpose the uncluttered image of the missile on the target by means of a movable mirror. The deflection of the mirror is a measure of the missile's deviation from the line-of-sight to the target. The Wagner sight reduces the operator's task to a simple instinctive motion, reducing the human tracking time lag, thus it permits a stable guidance loop and results in extreme hitting accurary. This new system produced significantly better accuracy than the visual guidance system used for the Henschel missile.

The company also performed a preliminary design study for the BULLPUP air-to-ground missile system utilizing Wagner's visual/optical command guidance missile system and sight. Design specifications were developed for the missile, guidance system, and aircraft installation. Flight tests using experimental equipment in a single-seat jet fighter demonstrated the pilot's ability to perform the guidance task, while simultaneously flying his aircraft in diving attacks against small ground targets.

These projects included development of new electronic circuitry for the guidance loop which had not been used before. Wagner mastered the design of circuitry and the use of electronic components, which up to that time had been completely foreign to him. This progress in development of the Wagner guidance system led to the selection of the H. A. Wagner Company as subcontractor to Aerophysics Development Corporation, the prime contractor for the development of the Army DART antitank weaponssystem (*Fig. 1*). The H. A. Wagner Company was selected to develop a visual/optical guidance system including a precision optical sight, a guidance computer, a tracking flare and related filters and an operator trainer (*Fig. 2*). The company was also responsible for specifying the stability and control characteristics of the missile.

The DART system was successfully tested using manual control (*Fig. 3*). Meanwhile development of automatic control using infrared was well underway. Premature production and changes of requirements, however, contributed to cancellation of the

Fig. 1 DART



DART. (Follow-up project to the DART was the "Shillelagh" anti-tank missile, which attained production status in the Aeroneutronic Division of the Ford Motor Co.)

The H. A. Wagner Company completed other projects not related to missiles, which used the capability of Wagner and the excellent staff he had recruited. For example, a Recording Angular Data Optical Tracking Theodolite for longrange tracking of missiles, which achieved a tracking accuracy of approximately 10 arcseconds and provided real-time digital readouts, was designed and successfully demonstrated.

They also completed a feasibility study for a simulator for training platoon leaders, which permitted trainees to participate in a combat situation that proceeded as a result of their decisions and the actions of a realistic antagonist.

The H. A. Wagner Company was also a financial and managing success; equity of the company doubled each year. The company started with Wagner alone and grew rapidly to over 200 employees. The attraction of working with Wagner was so great that employees voluntarily recruited others to join the company, only after employment reached about 200 did the company begin its own recruitment effort.

The cancellation of the DART program and its effect on the company and employees plus the external factors that affected the company and were beyond his control e.g., the last-minute change in the level of funding for the DART missile system, influenced his decision to accept a professorship at the Technical University, Aachen. He reports: "1957 to 1965 full professor of technical mechanics, i.e. applied mechanical engineering at the Technical University at Aachen, Germany. I am a professor emeritus of this school".

When the Technical University of Berlin bestowed an honorary doctor's degree on him, he said: "After I came to my new homeland, the USA, I did two things new to me – I designed and built electronic devices for remote control and founded my own development company, which began as a one-man shop. Although the

Fig. 2 Wagner instructs a high ranking customer on the use of a joy stick for manual guidance of the DART.

Fig. 3 DART hit the target.

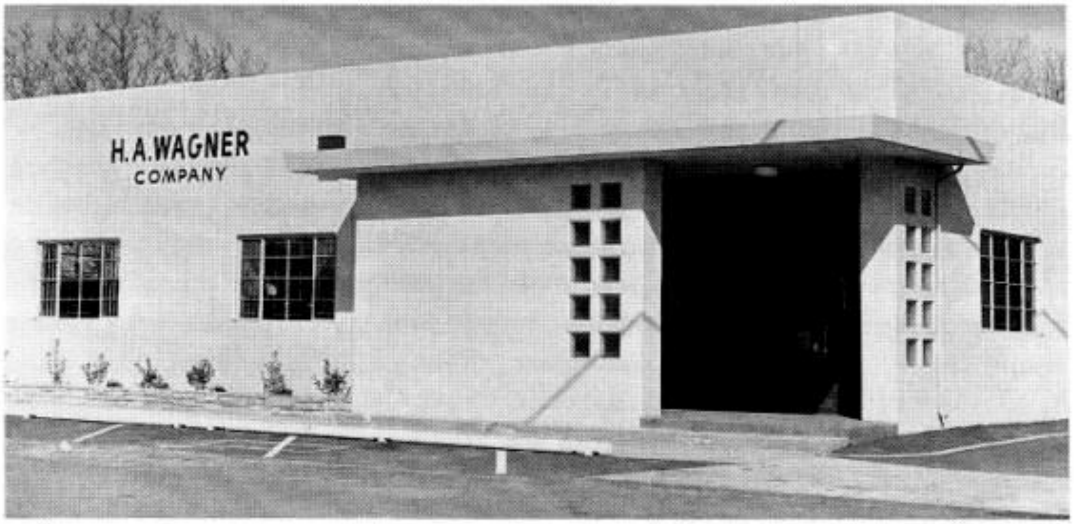


Fig. 4 Entrance to the H. A. Wagner Company in Van Nuys, California.

administrative work required less than ten percent of my time, I enjoyed discovering that a company must work according to an exponential function with a positive exponent and that this exponent is a small difference of large numbers and therefore is easily influenced. I would not like to have missed that experience and I am grateful to my co-workers, who shared that successful adventure with me".

Wagner's résumé continues: "1959 to 1962 in addition to the professorship, I was employed by Astrionics Division, Fairchild Engine and Airplane Corporation, working in Germany, and 40 % of the time in the USA. The main tasks were analysis of the guidance and control system for a deep penetration, automatic reconnaissance drone, and layout and analysis of an automatic tethered helicopter".

Wagner worked at Fairchild on various technical proposals. One problem was to elevate a one-mile long antenna for propagation of VLF radio signals. Wagner's design used a helicopter-vehicle tethered by the antenna and electrically powered through coincident wires.

Wagner's résumé continues: "1962 to 1965 in a similar arrangement. I was employed by the Raytheon Company, Missile Systems Division in Bedford, Massachusetts, for studies of radar applications to missiles and satellite-borne photographic surveillance of the moon".

As consultant to Raytheon, Wagner worked on synthetic aperture radar rate-aided hand-tracking of a vehicular target to assist precision line-of-sight command guidance, using man-in-the-loop computer modeling, he originated higher-order prediction of re-entry body position using Kalman filter type solutions (independent of Kalman) for Raytheon's anti-ballistic missile proposal. He supplied graphs and numerical solutions to multi-state prediction. Finally, typical of his insight, he contributed to synthetic array radar guidance by adding a coriolis term to the guidance law, which allows for a rotating coordinate system.

Wagner continues in his résumé: "1965 to mid-1968, consultant to tactical missiles Aeronutronics Division of Philco-Ford, Newport Beach, California".

Wagner prepared conceptual designs for use by infantry, that led to today's modern anti-tank and air defense guided missiles.
From 1968 to mid-1970 he acted as "Freelance engineering consultant".
He designed a 30-character per second printer for use with computer terminals for Gulton Industries. He also designed and developed an automatic track analyzer system for the Bay Area Rapid Transit District in San Francisco, which measures irregularities of the track for maintenance purposes. He used lasers mounted on the under-carriage of a rail car which determined the track profile with the aid of an on-board computer. This profile was then compared to the original profile on a station computer.
As consultant for Loss Prevention Systems, Irvine, California, Wagner worked on understanding the factors influencing the formation of high-expansion foam occurring when a solution passes through a screen.
This work resulted in significantly more effective fire extinguishing systems and is covered by several U.S. and German patents.
As consultant for Aerojet General, he performed analysis and loop design for an automatic submarine pilot and investigated vibration problems and structural integrity of large automatic sorting systems. Wagner consulted on many industrial design problems faced in the subsidiary product companies of Aerojet; for instance, design of a heat exchanger for nuclear power stations, design problems at large oil storage installations, and transport of molten salt.
What a treasure of ideas we would have in this wide range of activities, if only Wagner had published or, if more of this documents were available!
There is no question but that he left his stamp on many projects of outstanding importance. Success resulted from his ability to offer simple solutions, which led to costs lower than those of his competitors. Wagner is recognized by his contemporaries, superiors, colleagues, and associates as a rare genius in both theory and engineering practice.
The related aspects of scientific and technical management are of interest. But above all, Wagner set an example of how one can – and must – by thorough study, gain insight into the physical elements of a problem, detect the underlying essential phenomena, define them clearly, and then create simple, practical solutions.
I close, first with thanks to the generous contributors to this story, second with an appeal for continued work to retrieve further Wagner's productive efforts; and third with the hope that Wagner's work will be studied by the younger generation.

Addendum by G. E. Knausenberger

The presented report evolved parallel to the Wagner Archives and reflects some of its contents. The report on Wagners' US activities had been started in late 1982 and grew through the cooperation with the late Adm. Fahrney, Col. Grayson Merrill, R. Lahde, N. Mastrocola et al., to name only a few. Composing the report from various inputs has been a long tedious effort of making contacts, integration, of declassification, joint editing ....

It seems proper that this joint effort should be continued and extended.

There are many who have aided the present cooperative work and acknowledgements are due to many:

to Mrs. Dr. Brigitte Wagner for generously making available estate files;
to the initiators and organizers of the Munich conference;
to those who searched their memories and contributed their recollections, opinions and anecdotes;
and last, but not least, to Nick Mastrocola for his untiring help in finding contacts and finally for summarising the information and presenting it in a paper.

A listing of their memos may be shared here (with apologies for possible incompleteness):

Delmar S. Fahrney, Rear Admiral, USN (Ret.)
Grayson Merrill, Captain, USN (Ret.)
LeRoy E. Day, Director, Headquarters NASA
Thomas J. McEnaney, Jr., Assistant to Chairman Tom Phillips, Raytheon Company
Mike W. Fossier, Vice President, Raytheon Company
Hans A. Maurer, Dr., Group Vice President, Hughes Aircraft Company
Nick Mastrocola, former Program Manager, H. A. Wagner Company
Ralph Goodwin, former Executive Vice President, H. A. Wagner Company
Reinhard Lahde, former Assistant to Professor Wagner, TU Berlin, H. A. Wagner Company
Robert B. Katkov, Dr., Vice President, Aerojet General Corporation
Ted F. Kotonias, former Department Head, H. A. Wagner Company
Henry D. Zuerndorfer, Executive, Raytheon Company
Arthur Nitikman, Manager, Ford Aerospace & Communications Corporation
Gabriel M. Giannini, Dr., President, Giannini Petro-Marine
Howard Stults, President, Loss Prevention (L.P.) Systems, Inc.
Harry Linden, Vice President, Engineered Magnetics Division, Gulton Ind.
I. J. Spiro, former Department Head, H. A. Wagner Company
E. O. Throndsen, former Department Head, H. A. Wagner Company
Ralph A. Lamm, formerly Staff Member at Point Mugu
G. E. Hunt, Director, Plans and Management, NAMTC
Steve Harris, Deutsches Museum, Forschungsinstitut

Biographical Sketch: Nick Mastrocola

Born in New York City, Nick Mastrocola graduated from the University of Alabama with a Bachelor's Degree in aeronautical engineering. He completed graduate studies in aerodynamics, mathematics and systems engineering at the University of Virginia and the University of California at Los Angeles.
During World War II, he performed research and development of military aircraft and early work on missiles at the Langley Field Laboratories of the National Advisory Committee for Aeronautics.

After the war he continued work in research, development and flight test evaluation of air-to-air missiles with the U.S. Navy at Point Mugu, California. It was at this time he worked with Herbert Wagner and his associates who had been transferred to Point Mugu to assist in the U.S. Navy missile program.

Shortly after Herbert formed his company in 1953, he asked Nick to join the H. A. Wagner Company. Nick worked directly with Wagner on the BULLPUP air-to-ground missile system and was Program Manager on the tank-launched DART anti-tank guidance system. Developments on these projects included many innovations. Of special note are the Wagner optical sight using the sextant principle, the special treatment of circuitry in guidance loops to overcome instabilities inherent in saturated non-linear systems, and monochromatic tracking flare and related filters.

After Wagner's return to Germany and the merger of the H. A. Wagner Company with Aerophysics, Nick joined the Aeronutronic Division of the Ford Motor Company as a Systems Engineer and Program Manager for the SHILLELAGH Anti-Tank Missile System from initial design through production.

In 1965, Nick recruited Wagner as a consultant for Aeronutronics.

The resumption of the professional relationship at Aeronutronics produced conceptual designs of infantry anti-tank and air-defense missile systems, and later with L. P. Systems and Gulton Industries the design and development of a high-speed printer for computers.

Nick is now a government official in Orange County, California as Project Manager for the Santa Ana River Mainstern Project.

The Wagner and Mastrocola families continued their close friendship during the later part of Wagner's life.

Biographical Sketch: Georg E. Knausenberger, Dr.-Ing., D.I.C., Professor

Born 1909 in Rothenburg, Germany

Studied at Technical Universities, München and Dresden, and Imperical College, London, 1928–1936 engineering sciences, especially electronics.

Professional Experience:

1936–1939: Industry, control and communications technology; development engineer, scientific and management assistant.

1939–1940: Drafted to German Airforce military service.

1940–1945: Air Ministry, development management.

1946–1959: Pennsylvania State University Faculty, engineering research and graduate teaching.

In addition and in between: Industrial Consultant, Division Chief at HRB-Singer Company

Associate Technical Director at H. A. Wagner Company

1959–1968: Participation in NATO Technical Assistant Program:

USAF Assistant for Cooperative Research.

Research Director at Deutsche Versuchsanstalt für Luftfahrt (DVL) Oberpfaffenhofen.

Consultant on Data Exchange Agreements.

1968–1979: US Air force: Science and Technology Advisor (AFOSR);
Director of Research and Development Interaction (Hq. OAR);
Assistant for Science and Technology Planning and Liaison (Hq. AFSC);
Programmanager (AFOSR).

1979 Retirement from civil service; consultant.

Various patents, citations and awards.

Relations to H. A. Wagner:

1943: Contact with Wagner concerning his development and testing of the Hs 294 missile (water-entry and fusing problem)

1946: Joint stay at Sands Point, Long Island with the US Navy Special Center. From then on, as occasions arose, various mutual visits (during 1947 to 1981) encouraged by common interests (hydrodynamics, flight sciences, guidance and control, electronics) and similar periods of residence in USA and Germany (during 1959–1968).

1955: Wagner asked me to join his staff, offering a position as Associate Technical Director and Head of Plans and Proposal Group.

1957: After Wagner sold his company, I organized the transfer of Company assets and remaining personnel to Aerophysics Corporation.

1980/81: Jointly with Dr. Bollay, sponsorship of application to AIAA for honoring H. A. Wagner.

1980: Last personal meeting.

for Part 2 see
Herbert WAGNER-2.pdf
July 2014