UNIVERSITY OF KANSAS AEROSPACE ENGINEERING

KUAE 50

1944-1994

PROCEEDINGS OF THE ALUMNI REUNION

Compiled by

David R. Downing

Chairman of
Aerospace Engineering

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University of Kansas
School of Engineering 1994

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Contents

Acknowledgments

Many people made the 50th anniversary celebration possible. However, only a few made the anniversary's *Proceedings* happen. What on the surface seemed like a simple job turned out to be a year-long project that was much more difficult than anyone had ever imagined! Therefore, I would like to acknowledge the efforts of several people from the Division of Continuing Education. First I would like to recognize Production Artist Malcolm Neelley who worked almost a year on the typesetting and layout for the book. Program Assistant Barbara Edwards spent untold hours patiently contacting people all over the world securing copyright permissions. Last, but certainly not least, Production Editor Joan Davies' coordination of the project ensured that all the *t*'s were crossed and *i*'s dotted. I thank them for their tenacity and effort to make the *Proceedings* a book of which to be proud!

Introduction

David R. Downing

Professor and Chairman of Aerospace Engineering
The University of Kansas
Lawrence, Kansas

This volume was prepared as part of the celebration to recognize the contributions of the staff, faculty, students, and alumni of the department of Aerospace Engineering on the occasion of the 50th graduating class. Included you will find a brief history of the department, reproductions of presentations given at the 50th celebration, material and photographs from the 50th Anniversary held in Lawrence on April 15–16, 1994, and a listing of the members of each graduating class from 1944 to 1994.

I hope it will faithfully document this special point in the history of the Aerospace Engineering Department at the University of Kansas and will honor the students, faculty, staff and alumni who have been, and are, the KU Aerospace Engineering Department.

History of the Aerospace Engineering Department (1944–1994)

Ammon S. Andes
Professor Emeritus of Aerospace Engineering
The University of Kansas
Lawrence, Kansas

and

David R. Downing
Professor and Chairman of Aerospace Engineering
The University of Kansas
Lawrence, Kansas

Brief Chronology

1903	Wright Brothers make their first airplane flights.
1918–1919	Courses in aeronautical subjects offered during World War I.
1928	First engineering courses offered in aeronautics.
1929–1931	Wind tunnel constructed.
1931–1932	Tandem-wing airplane model tested in wind tunnel. Full-scale model flown.
1939–1944	Rapid build-up of aircraft industry in Wichita and Kansas City. Extensive instruction given to workers and students.
1941	Degree program authorized.
1946	Large enrollment of veterans.
1952	Department acquires first plane capable of flying.
1957	Chancellor Murphy provides equipment funds. Juniors and seniors given permission to ride in departmental airplane.

1962	Department moves to Learned Hall.
1968	Flight Research Laboratory established.
1968–1969	Master and Doctor of Engineering program approved.
1970–present	Active research operations.
1972	Space Technology Laboratory dedicated (Nichols Hall).

Degrees

1944–1993	B.S.	1,208
1957	Professional	1
1948–1993	M.S. & M.E.	172
1972–1993	Ph.D. & D.E.	68
	Total Degrees Granted	1,449

Chairman or Head

1941–1942	J. J. Jakosky (Acting)
1942–1944	Harry S. Stillwell
1944–1952	W. M. Simpson
1952–1961	Ammon Andes
1961–1967	Kenneth Deemer
1967–1973	David L. Kohlman
1973–1976	Jan Roskam
1976–1988	Vincent Muirhead
1988–present	David R. Downing
1991–1992	Saeed Farokhi (Acting)

The Beginnings

The first documentable activity in aeronautics at the university appears in the January 1911 issue of *Graduate Magazine* which states that three undergraduates constructed a Bleriot-type flying machine. (This is within eight years of the Wright brothers' first flight.) Two of the builders, Paul Elliott and Gilbert Smith, were sophomore engineering students reported to have carried out some successful glider flights before constructing their airplane. The plane weighed 350 pounds, had a thirty-horsepower engine, and a lifting surface of 186 square feet. The builders announced several dates for making their first flight, but wind and weather forced cancellations. No record has been found stating that they actually flew the plane. The two engineering students left the university at the end of the school year, and one might conclude that they may have spent more time on the airplane than on their studies.

In 1914 the next serious activity was undertaken by senior mechanical engineer Lawrence Allison (B.S. in M.E., 1914). He built a plane and wrote a thesis in which he made a stress analysis of the various members. Allison flew solo in 1915 and became a member of the "Early Birds" (those who flew before World War I). During his absence from Lawrence, an assistant in the construction, Karl White (B.S. in M.E., 1921), tried to fly the plane and crashed it. White had never flown a plane. Allison's brother John (B.S. in M.E., 1927), also a pilot, held the opinion that the plane could have been flown if the pilot had known how to fly. Larry, his brother John, and White were all connected with aviation activities in their professional lives.

The first formal aviation courses at the university were taught in the fall of 1917 and in the spring of 1918. In the fall of 1917 a five-credit course was established, presumably corresponding to the first three months of ground school given to aviation students in the army flying schools. Twelve students from the college and two from engineering took the course. The course was divided into three parts: The General Theory of Flight (two credits), taught by Solomon Leftschetz of the Department of Mathematics; Internal Combustion Motors for Aeroplanes (two credits), taught by A. H. Sluss of the Department of Mechanical Engineering; and a Special Course in Mechanics (one credit), taught by T. T. Smith of the Department of Physics. The course was repeated in the spring and an advanced course added. After the spring of 1918 the university offered no courses in aeronautics until the fall of 1928.

In 1927 Perley Walker, who was serving both as dean and chairman of mechanical engineering, died. George Shaad, who was then chairman of

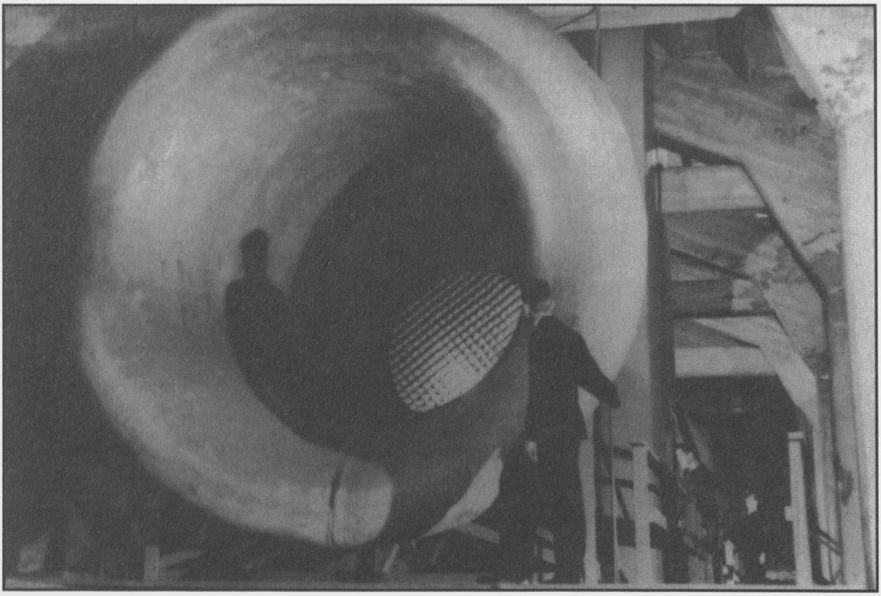


Figure 1. The First KU Wind Tunnel under the Memorial Stadium, 1931–1965. (Courtesy University of Kansas archives)

electrical engineering, became dean. Earl D. Hay, who was serving as both dean and chairman of mechanical engineering at the University of Wyoming, was hired in 1928 as chairman of mechanical engineering at KU. Hay was interested in aeronautical engineering.

Under mechanical engineering the 1928–1929 catalog shows a list of eight courses under the heading "technical options." Two of these involved aeronautics for the first time. Both were three-credit courses taught by Hay. The three or four courses previously described and offered in 1917–1918 in aeronautics were never listed in the catalog but were advertised in the student newspaper. Of the two 1928–1929 courses, one treated aerodynamics and the other aircraft design.

Between 1929 and 1931, $2,000 was provided in the mechanical engineering budget to build a wind tunnel under the stadium. Three master's theses, under Hay's direction, were produced: "Standardization Tests of the Kansas University Wind Tunnel," by George E. O'Mara, 1931; "Wind Tunnel Test of a Tandem Wing Airplane," by Ralph D. Baker, 1931; and "Test of 1/20 Scale Model of Spartan C2-50," by Norfleet L. Carney, Jr., 1932. Unfortunately, none give an account of the building of the tunnel, although descriptions and photographs exist.

The first successful airplane built at KU had tandem-joined wings. (A Wright brothers' plane and some current aircraft have tandem wings.) It is said to have been built by O'Mara, Baker, Ben Brown, Bill Wells and Smith (a welder). O'Mara and Baker were graduate students in mechanical engineering, and Baker did his master's thesis on a wind tunnel test of a model of this craft. Brown was a physics graduate and a World War I pilot. Wells was an active pilot and a developer of airports. He received many awards for his activities in aviation. He also donated the land south of Lawrence known as Wells Overlook. The plane was probably built in the early thirties. A picture of the plane may be seen in a videotape (from a movie, "Early Airplane Oddities") made by the Federal Aviation Administration. The A.E. department has a copy of the tape. The model of this airplane, which weighed 1,600 pounds empty, climbed to 10,000 feet in seventeen minutes, and was powered by a 90-hp Cirrus air-cooled engine in the front, which drove, through a long shaft, a propeller in the rear. This shaft, even with two universal joints, soon failed on the first ground tests due to variation in torque of the four-cylinder engine, which set up torsional vibration. This was overcome by incorporating an automobile brake drum and brake shoe system into the drive. Brown designed and patented it, and Wells built the new drive.

"How well did that joined wing airplane fly?" Wells said, "There was only one problem. When the ailerons on the wing tips were deflected to roll the airplane, it rolled in the wrong direction because extra air force on the ailerons twisted the wing in the opposite direction because the wing was too limber. Extra bracing and deactivating some ailerons corrected this. The airplane was very stable because the rear one of the joined wings would stall last and hence the plane would not tailspin after it stalled like so many of the early airplanes did. The airplane would not complete a loop, but when a loop was attempted the plane would roll over right side up at the top of the loop and fly on level." The first persons to fly that airplane were Louis Cogwell, then Wells, at the KU airport.

Professor Hay was also interested in gliders and the student newspaper describes flights made from the hill to the south of Marvin Hall.

For the first time the 1931–1932 catalog lists four professional options in the mechanical engineering department: aeronautics, design, petroleum, and power. Each of these options consisted of about six courses. The courses required for the aeronautical option are shown in the following table.

Title	**Semester Credit Hours**	**Instructor**
Aeronautics	3	Hay
Airplane Design	3	Hay
Aerodynamics Lab	1.5	Hay, Baker
Aero. Constr. Lab	1.5	Hay, Baker
Aircraft Welding	1	Smith
Thesis	3	Hay and Staff

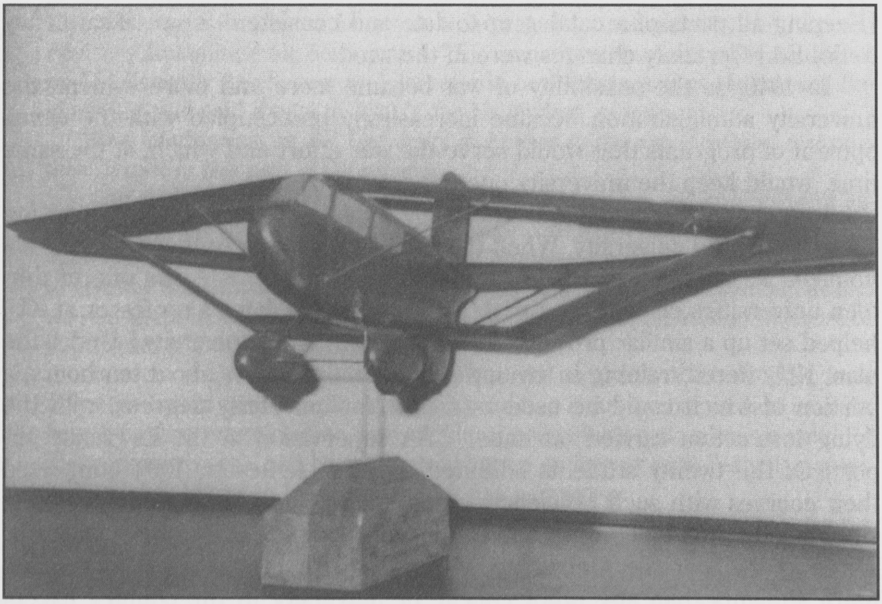


Figure 2. Wind Tunnel Model of the Tandem Wing Airplane. (Courtesy University of Kansas archives)

The various departments applied to the Engineers' Council for Professional Development (E.C.P.D.) for accreditation in 1936. A visiting team inspected the school and its curricula. The next year the council had this to say about the mechanical engineering undergraduate program, which included aeronautical engineering: "The curriculum of mechanical engineering, with the present staff and equipment, should offer at most two options, one in industrial management and the other in power or heat engineering. Electives, to a limited extent, may be available in aeronautics and heating and ventilating. The petroleum option in mechanical engineering should be discontinued."

One could well interpret this as a denial of the adequacy of the aeronautical program. Furthermore, there is nothing in the E.C.P.D. records to show that the aeronautical program at Kansas was accredited before 1949.

No change was made in the courses in the aeronautical option from 1931 to 1939 except to add a three-credit course in civil engineering (Statically Indeterminate Structures) in 1939. Prior to 1940–1941 the catalogs showed all five aero courses under mechanical engineering. The Board of Regents, on January 28, 1941, authorized a major leading to the degree of B.S. in aeronautical engineering. The action of the board was based on developments in the previous two years, especially the war in Europe. In the 1940–1941 catalog these five courses still appear as options in the mechanical engineering program, but there is another section headed Aeronautical Engineering. It shows twenty new courses and Professor Hay, Associate Professor Tait, and two instructors, Henry and Kenneth Razak, teaching them. [Keeping all parts of a catalog up-to-date and consistent is not always easy to do. Ed.] Certainly changes were in the wind.

In 1940, as the possibility of war became more and more evident, the university administration became increasingly preoccupied with the development of programs that would serve the war effort and which, at the same time, would keep the university operating.

Instruction associated with the many aspects of aviation was promising activities for the university. When the Civil Aeronautics Authority (CAA) announced its program of training for college students, KU was one of thirteen universities chosen for a trial. (Ammon Andes, later a professor at KU, helped set up a similar program at Washington State University.) Under the plan, KU offered training in ground school amounting to about ten hours, a portion of which could be used as credits for university degrees, with the flying instruction carried on under CAA supervision at the Lawrence airport. Of the twenty students admitted the first semester, 100% completed their courses with such efficiency and in such a short time that the university ranked second among all universities following the prescribed standards. Three years later the University of Kansas CAA program had graduated more students than any other college or university in the country except the University of California.

The Degree Program Established

These prewar activities, together with the rapid buildup of the aviation industry in Wichita and Kansas City, undoubtedly gave a strong impetus to the idea of setting up a separate program in aeronautical engineering at KU. On January 2, 1941, J. J. Jakosky, dean of the School of Engineering and Architecture, having received many letters promoting the need for aeronautical training at KU, wrote to Chancellor Malott requesting that a department of aeronautical engineering be established. On January 10, 1941, Chancellor Malott, using excerpts from Jakosky's letter, wrote to the Board of Regents requesting that a separate department be established:

> I should like to ask the approval of the Board of Regents for a major in Aeronautical Engineering in our Engineering School, leading to the degree of Bachelor of Science in Aeronautical Engineering.
>
> This proposed course has been prepared after careful study of similar courses given at other institutions.
>
> The graduates in Mechanical Engineering from the University of Kansas who took the option in Aeronautical Engineering have been successful in their work. The following is a list of ten companies employing one or more graduates of our School of Engineering.
>
> Graduate work in Aeronautical Engineering leading to the degree of Master of Science has been given here during the last few years. [All degrees were in mechanical engineering, however. Ed.]
>
> The option in Aeronautical Engineering was accredited in 1936 by the Engineers' Council for Professional Development. [1939. Ed.] In 1931 the University of Kansas was chosen for a research project on autogiros by the National Advisory Committee for Aeronautics. This committee financed work conducted by Mr. Kenneth Razak, now an instructor in our department of Mechanical Engineering, and paid a total of $600.00 for his student assistance.
>
> *The wind tunnel at the University of Kansas is the only precision measurement tunnel in this part of the country.*
>
> Our department of Mechanical Engineering now has an enrollment of approximately one-third that of the total Engineering School. One of the major options of that department is Aeronautical Engineering. We seek an opportunity to give the students a more thorough training in aeronautical fundamentals and to train them in a line of industry which is becoming of increasing importance in this part of the State.
>
> In view of the fact that we have pioneered in this field since 1928, have unexcelled wind tunnel facilities, have worked up a substantial student interest, have a program requiring no new additional costs (until and unless demand for the work increases), and have a large program underway with Federal cooperation, we should like to have approval for this new major.

On January 28, 1941, the Board responded to his request: "It was moved by Mr. Markham and seconded by Mrs. Muir that the University of Kansas be authorized to change the present aeronautical option in Mechanical Engineering to a major leading to the degree of Bachelor of Science in Aeronautical Engineering; it being understood that this major is specifically allocated to and limited to the University. The motion carried unanimously."

The chancellor's statements carried with them some hyperbole, but the statement about the "program requiring no new additional cost," without the qualifying parenthesis, was to be acted on by him and his successors with a determined tenacity for several decades. Despite the unequivocal statement by the regents about where aeronautical engineering would be taught, two universities, KU and Wichita State, now offer degrees in the subject.

Finally, it should be pointed out that Professor Hay, the chairman of mechanical engineering, was of the opinion that aeronautical engineering was a subbranch of mechanical engineering, as his May 22, 1941 letter to Jakosky illustrated:

> It has been found by a number of the larger schools giving work in aeronautics that the great majority of students prefer the option in mechanical engineering, as it gives them a broader field of action, and also because the preparation required for the aeronautical engineering requires a more thorough knowledge of mathematics and structure of material. Quite a number of the larger universities are requiring a bachelor's degree in mechanical engineering before the student is permitted to take the extra year's work leading to the degree of Bachelor of Science in aeronautical engineering. This is the case at such schools as Purdue, Alabama and Georgia Tech.

Hay was behaving in a manner similar to that displayed earlier by Dean Walker, a mechanical engineer, when the idea of a degree program in petroleum engineering was advanced in the mid-twenties. Walker, being both dean and chairman of mechanical engineering, decided it should be in mechanical and so it was. In the case of aeronautical engineering, Jakosky was dean, and his sanguine ideas about the future of aeronautics are, even today, unrealized. So a degree program in aeronautical engineering was established.

The first catalog description of the program follows:

> Aeronautical engineering is primarily the design of aircraft, aircraft components and aircraft accessories; also included under the term is a more complete definition of what might be aircraft testing, aircraft maintenance supervision, aircraft manufacturing methods and, of course, research on aircraft problems. It is obvious that work as widely diversified as the above could hardly be completely mastered by one man; it is therefore likely that a man will specialize in the type or types of work that interests him most. It is impossible for a university to give an undergraduate course covering in detail all of the above fields; experience is the sole teacher in some categories. A university attempts to give a sound course in the fundamentals of aeronautical engineering and to acquaint the student with the problems involved and the approach to their solution; detailed specific knowledge of such things as jig and fixture design, maintenance supervision, specifications, or armament design is only secured through experi-

> ence. This can be appreciated when it is remembered that theoretically only four years is devoted to the undergraduate engineering degree. Fundamentals, application and general procedure of the different types of aeronautical engineering are well covered in the present curriculum of the aeronautical engineering department of the University of Kansas, as a study of the curriculum will indicate.

The courses in the 1942 curriculum are shown on the following page.

At this juncture it was necessary to hire people to teach the courses and operate the department. Dean Jakosky appointed himself acting chairman, and in August 1941 he hired Edward Brush as potential chairman. Whether Brush was satisfactory was never determined, because he resigned in the summer of 1942 after less than a year at KU. Razak, who received his B.S. in mechanical engineering in 1940 and was working on his M.S. in the same area, was retained as an instructor through 1942. He later went to Wichita University where he established a department of aeronautical engineering and became dean of engineering. His brother, Virgil Razak, also received his degree in aero from KU in 1944 and later became head of aeronautical engineering at Wichita.

Brush was heavily engaged in wartime instructional activities, as was his successor, Harry Stillwell. Stillwell, with senior George E. Verhage, designed and tested in the KU wind tunnel the "KU #1 airfoil." In 1943, because of the demand for aeronautics in Kansas, Chairman Stillwell had a design prepared for an aeronautical building and laboratories at KU. Stillwell claimed the department had earned a surplus of more than $90,000 from the Civil Aeronautics Administration War Training programs and that he had pledges or funds from several aircraft manufacturers to be used for a new building and wind tunnel. Stillwell left in late 1944 to head the A.E. department at the University of Illinois. Illinois had the resources and was willing to finance the type of developments Stillwell had envisioned for Kansas. William M. Simpson, who succeeded Stillwell in 1944 as professor and chairman, stated that he was not able to get any of the funds from the university, or, as a consequence, from the aeronautical companies. The aeronautical department was first located in a room in Marvin and moved in 1943 to several offices in the Engineering Experiment Station (known as the "Mud Hut"). The department remained there until 1948 when it moved to a quonset hut north of the Electrical Engineering Laboratories. The department stayed there until 1962 when it moved to the newly constructed Learned Hall.

Brush, Stillwell, and Simpson all had advanced degrees in engineering (Simpson had a Ph.D. in civil engineering with a specialty in structures), and each had several years of experience in the aircraft industry. One may presume that they knew their subject and its application to industrial operations.

Courses in the 1942 Curriculum

COMMON FRESHMAN YEAR

First Semester	Hrs.	Second Semester	Hrs.
Math. 2a, College Algebra	3	Math. 4, Analytical Geometry	5
Math. 3, Plane Trigonometry	2	Engl. 2E, Rhetoric II	2
Engl. 1E, Rhetoric I	3	Chem. 3E, Inorg. Chem. and Qual. Anal.	4
Chem. 2E, Inorganic Chemistry	4	Engr. Dr. 2, Machine Drawing	2
Engr. Dr. 1, Lettering and F. H. Draw	2	Engr. Dr. 3, Descriptive Geometry	3
C. E. 5, Engineering Lectures	1	M. C. 8, Metal Working	1
Gym. or R. O. T. C.	..	Gym. or R. O. T. C.	..
Total	15	Total	17

AERONAUTICAL ENGINEERING

FRESHMAN YEAR

Common freshman year

SOPHOMORE YEAR

First Semester	Hrs.	Second Semester	Hrs.
Math. 5E, Calculus I	4	Math. 7E, Calculus II	4
Physics 7a, Gen. Engr. Physics	5	Physics 7b, Gen. Engr. Physics	5
Econ. 1E, Introductory Economics	3	A. M. 1, Statics	2
M. C. 1, Foundry Practice	1	M. C. 2, 6, Pattern and Machine Tool Work	2
A. E. 1, Aeronautics	2	M. E. 3, Mechanism	3
A. E. 2, Navigation and Meteorology	3	M. E. 154, Heating and Air Conditioning	2
Total	18	Total	18

JUNIOR YEAR

M. E. 151, Thermodynamics	3	M. E. 150, Machine Design	5
A. M. 50, Dynamics	3	A. M. 55, Hydraulics	3
A. M. 51, Strength of Materials	4	M. E. 159, I. C. Engines	3
A. M. 52, Testing of Materials	1	Engl. 56, Technical Report II	½
M. C. 50, Heat Treatment	1	A. E. 101, Aerodynamics II	3
Engl. 59, Advanced Composition	3	A. E. 102, Aerodynamics Lab. I	2
Engl. 6, Technical Report I	½	A. E. 105, Aircraft Materials and Processes	2
A. E. 100, Aerodynamics I	3		
Total	18½	Total	18½

SENIOR YEAR

E. E. 71, Direct Currents	3	A. E. 151, Airplane Design	5
E. E. 91, Electrical Lab	1	M. E. 53, Seminar	½
A. E. 162, Aero Structures	3	A. E. 166, Aero Engine Lab	1½
A. E. 163, Aero Structures Lab	2	C. E. 267, Statically Ind. Structures	3
A. E. 150, Airplane Design I	3	E. E. 72, Alternating Currents	3
C. E. 56, Industrial Administration	3	Nontechnical option	2
Nontechnical option	3	Technical option	2
Total	18	Total	17

Technical Options

A. E. 5, Aero Drafting	1	M. C. 51, Aircraft Welding	1-2
A. E. 155, Propeller Theory and Design	2	A. E. 103, Aero Laboratory	1
A. E. 160, Aircraft Engine Design	2		

Six men (the first) graduated from the program in 1944. Probably Richard V. Ramsey received the first degree in February.

By the beginning of the 1946 fall term, Simpson had hired two staff, Reid B. Lyford in 1945 as an instructor from North American and Andes in September 1946 as an associate professor from Consolidated Vultee. Many of the students enrolled were ex-G.I.'s who had seen service as pilots and aircraft mechanics. Some of them must have been amused by the physical and laboratory facilities of the department. The faculty members were assiduous in obtaining government excess property consisting of surplus aircraft, engines, and parts, including two German aircraft, an ME 162 and a Heinkel jet. The Heinkel jet was a great attraction at Engineering Expo when it was started up with a tremendous roar. When first attempts to start the Heinkel engine proved unsuccessful, a staff member from the German department was called to translate the start-up instructions. He found it very difficult, but between him and the ex-G.I. aircraft mechanic, it was finally started to everyone's delight and stupefaction.

In 1946–1947 Andes and some students undertook to make wind tunnel tests on a tailless airplane. Calculations of the results showed them to be physically impossible. A check of the weights used to measure the lift, drag, and pitching moments of a test specimen showed that the pitching moment weights had been labeled four times their actual value. Andes used this experience, along with other personal experiences, to emphasize to his students the absolute need always to calibrate test equipment before using it.

The Changing Curriculum

Some of the changes in the aero program over the years are shown in the following table and the curricula for 1961, 1968, and 1988.

The number of hours in required aero courses has increased markedly—from 31.5 hours to 53 hours. Since the total credit hours for graduation have remained essentially the same, this increase in aero credits implies, in part, that the program has become more and more specialized. Several ten-

Semester Credit Hours (1944–1988)

Year	**1944**	**1961**	**1968**	**1988**
Credits in the A.E. Dept	31.5	35	34	53
Credits in basic engrg. subjects outside A.E.	39	27	20	17
Credits in other eng. subjects	15	7	5	5
Total Credits required	140	140	134	137

1961 Curriculum

AEROSPACE ENGINEERING

Freshman Year

First Semester	*Hrs.*
Math. 21, Calc. and Anal. Geom. I	5
Eng. 1, Comp. and Lit.	3
Chem. 2a, Principles of Chemistry	4
E. Dr. 6, Geom. of Engr. Draw.	3
E. Dr. 5, Engr. Lectures	0
Hum. and Soc. Sci. Elective	3
	18

Second Semester	*Hrs.*
Math. 22, Calc. and Anal. Geom. II	5
Engl. 2, Comp. and Lit.	3
Chem. 3, Chemistry of Elem.	4
E. Dr. 8, Prin. Engr. Graphics	2
Hum. and Soc. Sci. Elective	3
	17

Sophomore Year

First Semester	*Hrs.*
Math. 23, Calc. and Anal. Geom. III	5
Phys. 5, Gen. Physics I	5
Econ. 7, Economics	3
Speech 1, Fund. of Speech	2
Hum. and Soc. Sci. Elective	3
	18

Second Semester	*Hrs.*
Math. 145, Applied Math. I	3
Phys. 6, Gen. Physics II	5
E. M. 49, Statics and Dynamics	5
M. M. E. 49, Science of Materials	3
E. M. P. 1, Intro. Engr. Mfg. Proc.	1
	17

Junior Year

First Semester	*Hrs.*
E. M. 57, Fluid Mechanics	3
Engr. 43, Basic Engr. Thermo	3
E. M. 61, Strength of Materials	4
E. M. 62, Testing Materials Lab.	1
E. E. 71, Circuit Theory	3
A. E. 120, Basic Aerodynamics	3
	17

Second Semester	*Hrs.*
Engl. 59, Technical Writing	3
A. E. 106, Aircraft Structures I	3
A. E. 113, Instrumentation Lab. I	1
A. E. 130, Adv. Aerodynamics	5
A. E. 160, Dynamics of Flight	5
E. E. 71, Circuit Lab.	1
	18

SENIOR YEAR

First Semester	*Hrs.*
A. E. 68, Aero. Seminar	½
A. E. 116, Aircraft Structures II	3
A. E. 124, Propulsion Systems	5
A. E. 132, Aerospace Design	3
Electives	3
M. E. 40, Mechanisms *	2
Adv. E. M. P. (shop) *	1
	17½

Second Semester	*Hrs.*
A. E. 68, Aero. Seminar	½
A. E. 88, Inspection Trip	0
A. E. 108, Airc. Matls. and Proc.	3
A. E. 152, Airc. Structural Design *	3
Electives	3
Hum. and Soc. Sci. Elective	5
M. E. 143, Machine Design *	3
	17½

Electives are to be chosen in consultation with the faculty advisor.

1968 Curriculum

aerospace engineering

Aerospace Engineering Courses—34 hours

45	Introduction to Aerospace Engineering	3
107	Aerospace Structures I	3
108	Aerospace Structures II	3
110	Aerospace Materials and Processes or Mechanical Engineering 52	3
121	Aerospace Systems Design I	2
122	Aerospace Systems Design II	3
130	Aerospace Instrumentation Laboratory	1
140	Aircraft Aerodynamics	3
145	Advanced Aerodynamics I	4
150	Dynamics of Flight	4
170	Propulsion Systems	4
190	Aerospace Seminar	½
191	Aerospace Seminar	½

Engineering Courses—25 hours

C. E.	51	Statics and Dynamics	5
C. E.	63	Strength of Materials	3
C. E.	75	Fluid Mechanics	3
C. S.	16	Introduction to Computers	2
E. E.	40	Basic Circuits	3
M. E.	6	Engineering Drawing	3
M. E.	28	Basic Engineering Thermodynamics	3
M. E.	49	Science of Materials	3

Science Courses—17 hours

Chem.	11	College Chemistry I	5
Phys.	7	General Physics I	4
Phys.	8	General Physics II	4
Phys.	55	General Physics III	4

Mathematics Courses—18 hours

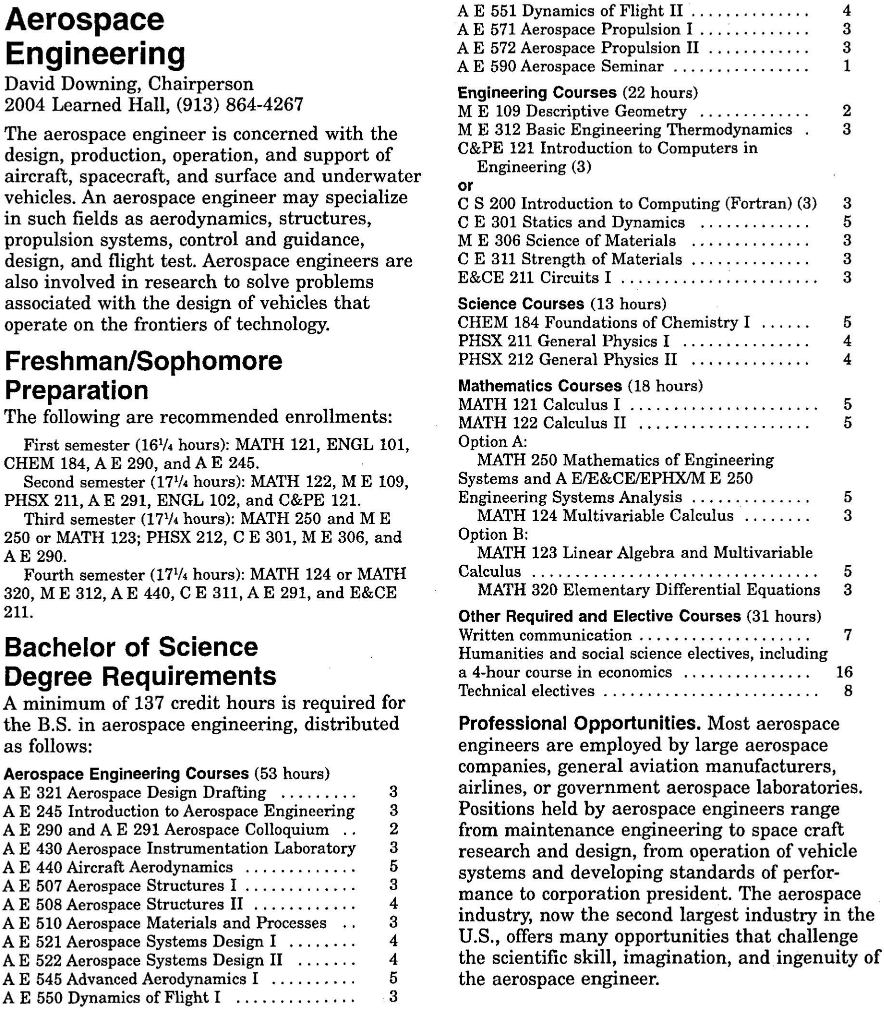
21	Calculus and Analytic Geometry I	5
22	Calculus and Analytic Geometry II	5
23	Calculus and Analytic Geometry III	5
55	Elementary Differential Equations	3

Other Required and Elective Courses—40 hours

Engl.	1	Composition and Literature	3
Engl.	2	Composition and Literature	3
Engl.	59	Technical Writing	3
Econ.	10	Introductory Economics	3
Spch.	1	Fundamentals of Speech	2
Humanities and Social Science Electives			14
Technical Electives			12

Total—134 hours

1988 Curriculum



Aerospace Engineering

David Downing, Chairperson
2004 Learned Hall, (913) 864-4267

The aerospace engineer is concerned with the design, production, operation, and support of aircraft, spacecraft, and surface and underwater vehicles. An aerospace engineer may specialize in such fields as aerodynamics, structures, propulsion systems, control and guidance, design, and flight test. Aerospace engineers are also involved in research to solve problems associated with the design of vehicles that operate on the frontiers of technology.

Freshman/Sophomore Preparation

The following are recommended enrollments:

First semester (16¼ hours): MATH 121, ENGL 101, CHEM 184, A E 290, and A E 245.

Second semester (17¼ hours): MATH 122, M E 109, PHSX 211, A E 291, ENGL 102, and C&PE 121.

Third semester (17¼ hours): MATH 250 and M E 250 or MATH 123; PHSX 212, C E 301, M E 306, and A E 290.

Fourth semester (17¼ hours): MATH 124 or MATH 320, M E 312, A E 440, C E 311, A E 291, and E&CE 211.

Bachelor of Science Degree Requirements

A minimum of 137 credit hours is required for the B.S. in aerospace engineering, distributed as follows:

Aerospace Engineering Courses (53 hours)

A E 321 Aerospace Design Drafting	3
A E 245 Introduction to Aerospace Engineering	3
A E 290 and A E 291 Aerospace Colloquium	2
A E 430 Aerospace Instrumentation Laboratory	3
A E 440 Aircraft Aerodynamics	5
A E 507 Aerospace Structures I	3
A E 508 Aerospace Structures II	4
A E 510 Aerospace Materials and Processes	3
A E 521 Aerospace Systems Design I	4
A E 522 Aerospace Systems Design II	4
A E 545 Advanced Aerodynamics I	5
A E 550 Dynamics of Flight I	3
A E 551 Dynamics of Flight II	4
A E 571 Aerospace Propulsion I	3
A E 572 Aerospace Propulsion II	3
A E 590 Aerospace Seminar	1

Engineering Courses (22 hours)

M E 109 Descriptive Geometry	2
M E 312 Basic Engineering Thermodynamics	3
C&PE 121 Introduction to Computers in Engineering (3) **or** C S 200 Introduction to Computing (Fortran) (3)	3
C E 301 Statics and Dynamics	5
M E 306 Science of Materials	3
C E 311 Strength of Materials	3
E&CE 211 Circuits I	3

Science Courses (13 hours)

CHEM 184 Foundations of Chemistry I	5
PHSX 211 General Physics I	4
PHSX 212 General Physics II	4

Mathematics Courses (18 hours)

MATH 121 Calculus I	5
MATH 122 Calculus II	5
Option A:	
MATH 250 Mathematics of Engineering Systems and A E/E&CE/EPHX/M E 250 Engineering Systems Analysis	5
MATH 124 Multivariable Calculus	3
Option B:	
MATH 123 Linear Algebra and Multivariable Calculus	5
MATH 320 Elementary Differential Equations	3

Other Required and Elective Courses (31 hours)

Written communication	7
Humanities and social science electives, including a 4-hour course in economics	16
Technical electives	8

Professional Opportunities. Most aerospace engineers are employed by large aerospace companies, general aviation manufacturers, airlines, or government aerospace laboratories. Positions held by aerospace engineers range from maintenance engineering to space craft research and design, from operation of vehicle systems and developing standards of performance to corporation president. The aerospace industry, now the second largest industry in the U.S., offers many opportunities that challenge the scientific skill, imagination, and ingenuity of the aerospace engineer.

dencies may be responsible for this development. One could be the increasing complexity of the discipline over the years. Another could be the desire of a particular discipline to teach as many courses as possible. This insures that the subjects are "properly" covered. More courses also require more staff, which increases the departmental student-credit hour production. The increase in aero courses has been balanced by a diminution in other engineering subjects. Similar observations could well be made about other curricula in the school.

Beginning in 1949 the department has been visited regularly by engineering accrediting teams to determine whether the undergraduate program merits accreditation. In every case it has been judged accreditable, but in many cases the teams have found deficiencies in the physical facilities:

> The housing is not good. (1949)
>
> No laboratory or research equipment in structures. (1954)
>
> Power plant laboratory is unsatisfactory. (1954)
>
> Obsolete laboratories and classrooms. (1956)
>
> The department has extremely poor physical facilities dispersed in three areas. (1959)
>
> Lab equipment nonexistent for the structures area. (1977)
>
> The structures and materials laboratories and equipment need administrative attention. (1983)

In the university files there is ample evidence provided by the department and the deans of the school calling the attention of the University administration to these physical deficiencies, but the canker planted with the seed of this degree program in 1941 (little or no cost), continues to limit healthy growth.

The 1983 findings regarding the department were, except for the previous item, complimentary.

Simpson, Lyford, and Andes were the staff when the peak enrollment of ex-G.I.'s came after World War II. The department was quartered in the mud hut with the radio station until 1948. The aero department received several World War II surplus aircraft, engines, and parts, and for years had the wings from Frank Hawks's airplane, which won the early transcontinental U.S. race. The wings were disposed of one summer when Andes was away. Also two museum airplanes (a ME 162 and a Heinkel) were disposed of because of 1951 flood damage and lack of storage space at the airport.

The first A.E. department mechanic was John H. Stanfield (1946), who decided there would be more opportunity for him as an M.D. In 1947 he left aero engineering to study medicine and became a successful surgeon. Then Norman Hoecker came as department mechanic and pilot, but AE had no airplanes to fly.

About 1948 when the aero department was in new quarters in the quonset hut and had a graduating class of twenty-seven, the accrediting committee (then E.C.P.D.) told the department it had to build more laboratories to stay accredited. A corrugated sheet metal hangar was built which also housed AE surplus property. Later a "quickie" test stand was attached for testing an old Franklin piston engine, but it provided only for measurement of torque and r.p.m., and hence power.

The aircraft industry became depressed soon after World War II (1951) when the U.S. Air Force was not allowed to buy many airplanes. Then came the Korean War and drafting of college men. Many A.E. students, to secure a choice of service in the army, navy, or air force, volunteered. These factors lowered A.E. enrollment of sophomores, juniors, and seniors to thirty-four [freshmen engineering students were not put in the departments at that time]. Professor Lyford resigned to go back to North American and graduate Harry Johnson (1946) stayed for a year as an instructor. In January 1952 Chairman Simpson resigned to become head of the research department at the U.S. Navy Civil Engineering Laboratory at Port Hueneme, California, and later became its chief scientist. This left Andes as the only full time staff and he became chairman for ten years. Dick Etherington, (later a member of the A.E. Department Advisory Committee and Senior Director Program Manager for Learjet) was helping in the A.E. laboratory, and graduate student Robert Miller was working part time, expecting to finish his M.S. that year. Andes persuaded Miller to work full time.

A.E. graduate students had previously carried out several research and design projects. John Brizendine (1949), a graduate assistant with A.E. (later president of Douglas Aircraft Company and in 1987 president of Lockheed Aeronautical), had staff-tested a muffler for a U.S. military supply depot. They had designed an elaborate copper muffler to cool engine exhausts to avoid fires set by fork-lift and storage trucks. It failed to work. Then the A.E. staff, with Brizendine, designed and tested a simple air injection exhaust system that worked. Several graduates designed a scale model of a proposed new wind tunnel. It was a closed return air flow type, with an elliptical cross-section at the test section. After much analysis and labor they built a model of the tunnel with the help of Hoecker. By then they decided the shape was impractical, but in 1952 Miller set up a drive system using counter-rotating propeller blades Andes designed. These were two odd-looking sets of six blades each. That summer Miller and Hoecker made the two wooden patterns for casting them and located a foundry. Then they machined and mounted the blades. Subsequent tests proved they produced the desired smooth air flow and uniform velocity from wall to wall of the test section.

The department's first airplane capable of flying was secured by Hoecker in 1952 by trading two of the department's damaged World War II airplanes for a Cessna 120 with a badly damaged landing gear which he rebuilt. Later, with some funds from KU, the Cessna 120, a two-seater, and an old Stinson were traded for a four-place Cessna 172 which the department was allowed for the first time to use for travel. In about 1955 Hoecker and Beech Aircraft Company refurbished a U.S. Air Force surplus twin-engine Beech airplane. At last, Chancellor Murphy and other KU administrators were able to fly to places when they were short on time. This also became possible because after two years of investigation and administrative study, Andes secured a change in Hoecker's classification and salary from "aircraft mechanic" to "aircraft mechanic and pilot." Thus for the first time, a KU chancellor had an airplane he could use.

Dr. E. K. (Ted) Parks came from the University of Toronto in January 1953. Parks was an excellent teacher, designer, and laboratory developer. He designed and helped build the department's first supersonic wind tunnel and did preliminary design for the new large wind tunnel. He also worked well with A.E. graduate students, whom A.E. still had to use part time for labs until Dr. James B. (Jim) Tiedemann came in the spring of 1954. Dr. Parks taught the first graduate class in A.E. at the KU Medical Center, and Andes taught jet propulsion there. Parks also later wrote and published a wind tunnel manual, and developed a hot wire anemometer.

Dr. Tiedemann (1954–1961) was an outstanding teacher, working well with both students and staff. His specialty was structures, but Andes said that, in addition, Tiedemann was the most capable laboratory engineer he had ever known. He could fix lab equipment and make test measuring devices out of old surplus property instruments made for something else. With Tiedemann, the department was back to three professors and a new life.

In the summer of 1953 when Andes worked at the General Electric Aircraft Turbo-Jet plant in Ohio, he followed up one of many requests he had made seeking a turbojet engine for a test lab. He and his General Electric test methods supervisor went to the Air Force Wright Patterson Field test station where they found a turbojet engine that was to be declared surplus. At the end of the summer, when Andes traveled with his family to Washington, D.C., he contacted the U.S. Navy Air Service, which owned the engine, before it knew the engine was being declared surplus. The U.S. Navy sent KU the engine in a sealed container, free of charge, including the freight. When staff members looked over the engine log, they found that a new turbine, the part that often must be replaced first, had just been installed. For a couple of years the department could not use this turbojet until a new test set-up was built as an addition to the quonset hut hangar.

In about 1954 several of the engineering department chairmen began to talk about the need for a new dean who would have a Ph.D. and know more of the technical aspects of engineering. In Andes' opinion, Dean T. DeWitt Carr (retired Captain, U.S. Navy) was the best recruiter and most conscientious worker for the students the school had ever had, as evidenced by the build-up in engineering enrollment. When the chairmen set up their discussion meetings, Andes attended to keep informed. Finally the chairmen invited Chancellor Franklin D. Murphy to hear their ideas. After listening for over an hour, Chancellor Murphy turned to Andes and said, "Andes, you have not said anything. How do you feel?" He answered, "My main problem is no money for laboratory equipment for ten years." The chancellor replied, "Call my secretary and make an appointment with me." Andes did, and from that meeting came funds to build a jet engine test cell and secure most of the instruments needed for testing the J-34 turbojet engine.

In 1954 Robert Hollman (1952), for his M.S. thesis, designed a turbo jet test stand. During the summer of 1955 he and mechanic Hoecker built the test cell and, with other equipment donated by Westinghouse Aircraft Gas Turbine plant in Kansas City (where Andes had worked), mounted the engine. The final need of a thrust indicator was furnished by the ingenuity of Dr. Tiedemann. That summer Donald T. Higdon (1954) won a U.S. National Science Foundation Graduate Scholarship.

In 1953 the department set up meteorological recording equipment. Fred Bates (M.S. in meteorology), who helped establish the severe-weather warning station for the United States in Kansas City, tried to enroll for a M.S. in A.E. and was denied because he had no B.S. degree. He enrolled, secured a B.S. in A.E., then worked one-fifth time and later as a professor for the A.E. department. Bates later studied and received his Ph.D. in meteorology from Washington University at St. Louis and came back to set up the meteorology program at KU. Marjory Heard (Franklin) (1956), was the first woman A.E. graduate and the first female member of Sigma Tau. She was also editor of the *Kansas Engineer.* Joe Engle (1955) became a U.S. Air Force test pilot on the X-15, then astronaut and commander of the third flight of space shuttle Columbia. As "best-qualified astronaut," Engle was the first person allowed to maneuver the Columbia just before landing. He is now a colonel in the Kansas Air National Guard.

Just as World War II had a significant effect on aeronautical engineering at KU, so did the space race. In October 1957, the Russians launched Sputnik. In 1962 the Department changed its name to the Department of Aerospace. By the mid-sixties, the National Aeronautics and Space Administration (NASA) had discovered that it needed individuals with advanced engineering degrees who were educated in the aspects of project management. Furthermore, NASA was willing to support such educational efforts. The dean of engineering, W. P. Smith, along with a number of faculty, responded to this need and developed the Master of Engineering (1968) and the Doctor of Engineering (1969) programs. These programs, along with the usual M.S. and Ph.D. programs, have been successful in producing many graduates who have entered both government and private service in the areas of aerospace, communications, and remote sensing.

Up and Flying

In 1957, for the first time, permission was granted for junior and senior A.E. students to be given a "demonstration ride" in the A.E. airplane as part of their course in Aircraft Performance, Stability, and Control.

In 1960 Professor Parks moved to the University of Arizona. Professor Bates and Hoecker studied "Severe Thunder Storms" using the department's Beech C45 (with its new propellers, a $1500 donation by Bill Horton, 1950). In 1961 the A.E. department name was changed to "Aerospace Engineering" to match its expanded program. The A.E. department also helped Midwest Research Institute secure a $250,000 federal grant on "How to Best

Promote Aerospace in the Kansas City Area" which brought an aerospace building to KU. Costas (Gus) Choliasmenos (1959), former director of aeronautics for Greece, became part time instructor and, with Dr. Bates, did Boundary Layer Control Tests on Wing Devices. Choliasmenos was attracted to KU by the first newsletter on "Aerospace at KU" by Andes. Professor Tiedemann was granted a sabbatical year to teach in Japan. Commander Vincent U. Muirhead (pilot) Executive Officer of Technical Training Naval Station at Memphis, Tennessee, retired to become assistant professor of A.E. at KU. In addition to U.S. Navy training, he had three years of graduate study at the U.S. Naval Postgraduate School and at California Institute of Technology, along with a degree in Aeronautical Engineering. Professor Andes set up the "Aerospace Engineering Development Fund" in the KU Alumni Association to receive tax-deductible gifts.

Beginning in 1962 two departments were combined for five years as the Department of Mechanics and Aerospace Engineering with Professor Kenneth Deemer as chairman. Muirhead obtained a $25,000 grant from the National Science Foundation and more than matching funds from Kansas University to build a wind tunnel in the new engineering building. In 1964 Professor David Kohlman (1959—M.S. 1960) joined the staff to teach Design, Aerodynamics, and A.E. laboratories, after earning a Ph.D. at MIT and spending summers and one and a half years in the aerospace industry.

In 1966 Professor Choliasmenos (1959) was killed in an automobile accident in Tucson, Arizona, where he had flown to visit former A.E. Professor Parks and his family. Hoecker brought the body back in the airplane Gus had borrowed. Choliasmenos was respected for his able work in aeronautics and missed as a warm enthusiastic friend. He was nominated posthumously for the "Gould Award" established at KU for "the most outstanding undergraduate engineering teacher of the year." Professor Tiedemann accepted the post of chairman of aeronautical and mechanical engineering at the University of Alaska.

Department Growth

The period 1967–1980 was an era of retooling, refocusing and relative stability. The aerospace department was again a separate department. Andes, Muirhead and Kohlman were joined by Jan Roskam, Howard Smith, and Eddie Lan to form the foundation of the department for more than ten years. A research mission was added to the education mission when the department became involved with numerous aircraft design and stability and control projects funded by NASA. Several of these projects involved major flight test programs, e.g. ATLIT, SSSA, and the Red Hawk.

The department began to develop a national reputation for excellence in design education. This was possible since the department faculty, in addition to excellent academic training, came to KU with extensive real world industrial experience.

The period 1980–1994 was one of growth and refocusing. The design education excellence of the department was given an opportunity to be documented when the AIAA established a set of national design competitions. In 1981 the AIAA in cooperation with United Technologies established the Individual Aircraft Design Competition. This was followed by the establishment of the General Dynamics Team Aircraft Design Competition in 1986 and the General Electric Airbreathing Propulsion Competition in 1987. Due to a well coordinated curriculum, an experienced faculty, and a commitment to design education, the KU Aerospace Engineering Department has dominated the aircraft and the propulsion competitions. The table below is a summary of the outstanding performance by the department's students.

The department was expanded to nine faculty positions. In 1981 Dr. David R. Downing joined the department. He had taught system engineering at Boston University and worked in design and flight testing of advanced display and flight control systems at the NASA Langley Research Center. At KU he taught instrumentation and developed advanced aircraft flight control courses. Dr. Kohlman left the university to establish Kohlman Systems Research (KSR) in Lawrence. KSR specializes in flight test hardware and software systems that are used to develop sophisticated flight simulator models. His departure was a loss to the department.

In 1983, John Ogg joined the department from VPI. His expertise was experimental fluid mechanics.

The next year, Saeed Farokhi joined the department from the Gas Turbine Division of Brown, Boveri & Company in Switzerland. He took over

United Technologies Electric Individual Aircraft Design		**General Dynamics Team Aircraft Design**		**General Electric Team Engine Design**	
1981	1st & 2nd	1986	1st	1988	1st
1982	1st,2nd,&3rd	1987	1st&3rd	1989	2nd
1983	1st,2nd,&3rd	1988	1st	1990	1st
1984	1st	1989	1st&2nd	1991	1st&2nd
1985	1st&2nd	1990	2nd,3rd,&4th	1992	1st
1986	1st	1992	2nd	1993	1st
1987	2nd	1993	2nd		
1988	3rd				
1989	1st				
1992	1st				
1993	1st&2nd				

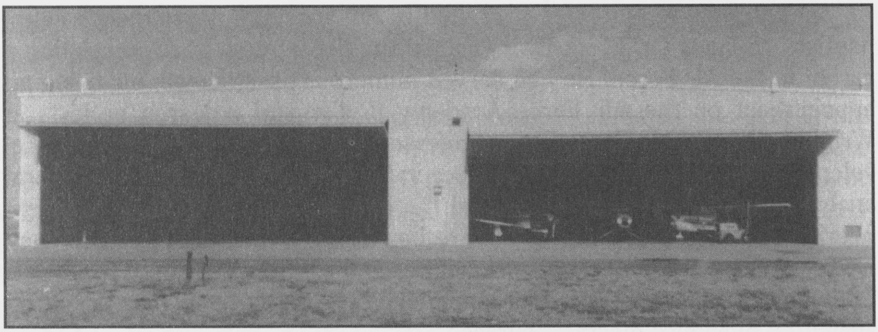


Figure 3. Hangar and Mal Harned Propulsion Laboratory, 1982. (Courtesy University of Kansas archives)

the propulsion sequence as well as developing courses in advanced fluid mechanics and propulsion. William Schweikhard left to join Kohlman at KSR.

1988 was an active year. Dr. Ogg left to teach at Dowling College on Long Island, New York, while James Locke and Dave Ellis joined the faculty. Dr. Locke, who did his thesis at the NASA Langley Research Center, joined the department when he finished his work at Old Dominion University. His arrival doubled the number of structures faculty and allowed Smith to develop and teach more graduate courses. Ellis was a designer at Cessna prior to joining the department, and had extensive flight test experience at Princeton University. He taught propulsion and aircraft performance. Also in 1988, Muirhead who had been chairman for 12 years, stepped down and Professor Downing was appointed to replace him.

In 1989 Muirhead retired and was appointed Emeritus Faculty. He had served the department for 28 years. Professor and Mrs. Muirhead were honored at a retirement party attended by university colleagues, family and former students. In 1990, Ellis left the department to join Commander Aircraft.

In 1991 Roskam completed the publication of a comprehensive eight-volume set of design books. This set, like his previous books in flight dynamics and control, has become the standard textbook used at more than 30 universities worldwide. It has also become a major reference at many industry sites. Roskam's recent research has led to the development of an interactive computer version of the design books.

In 1991, Ray Taghavi left his position as Experimental Research Engineer at NASA Lewis (Branch of Sverdrup Technology Inc.) to join the department. Dr. Taghavi filled the void in experimental fluid mechanics created by Professor Muirhead's retirement. In addition to teaching fluid mechanics and propulsion courses, Professor Taghavi is responsible for the upgrading and expansion of the department's experimental fluid mechanics facilities.

In 1992 two faculty were recruited to enhance the department's astronautics offerings. Dr. Mark Ewing joined the department after completing a career in the Air Force. He had served numerous assignments including an appointment on the Air Force Academy faculty and research projects at Wright-Patterson Air Force Base. Professor Ewing is responsible for the development of the undergraduate spacecraft design and advanced structural analysis courses. Dr. Tae Lim joined the department from Lockheed Engineering and Sciences Company where he worked with NASA Langley engineers on Space Station Freedom structures and control problems. He teaches orbital mechanics and spacecraft attitude control and is developing advanced structural dynamics elective courses.

In recognition of the department's long history of design excellence, Joan Finney, the Kansas Governor, officially proclaimed November 13–19, 1992, as University of Kansas Aerospace Engineering Week.

Short Course Program Goes International

Adding to the department's national and international reputation is the short course program started by Roskam in 1977. This program, offered under the auspices of the Division of Continuing Education, has grown into an internationally recognized education resource for aerospace professionals. Close to 7,000 professionals representing 300 companies—66% United States and 34% international—have attended throughout the years. Approximately 35 classes, both public and in-company, are offered each year. Six of the nine members of the aerospace engineering department faculty teach short courses.

Besides the courses held in Lawrence, public courses have been held in southern California; Williamsburg, Virginia; and Seattle, Washington; as well as in Australia, Italy, Singapore, Norway, the Netherlands, and Switzerland. On-site courses have been held at 35 business and government laboratories throughout the United States, Canada, England, France, Germany, Israel, Mexico, and Sweden.

Alumni and Industry Support

The department has been blessed with the strong support of alumni, friends and corporations. In 1989 an Alumni Steering Committee was formed to advise the department on alumni matters. In 1990 this committee designed and started the first Aerospace Engineering Fund Raising Campaign, independent of school and university drives. Contributions from these campaigns were deposited in the Aerospace Development Fund created by Professor Andes and have been used to create Graduate Teaching Assistantships.

Cessna Aircraft has been a consistent supporter of the department through gifts of aircraft, hardware, technical support, and instrumentation grants. From 1985 to 1998 Cessna will provide more than $225,000 to upgrade our experimental facilities. A major item purchased was a Laser Velocimeter System.

The department's ability to support aerospace students was greatly enhanced in 1990 when the estate of Irene Goldsmith included a gift of $709,000. Mrs. Goldsmith designated these funds to establish an endowment with the proceeds assisting aerospace students. The department has used these funds to create Graduate Teaching Assistantships. Mrs. Goldsmith, a 1924 graduate of the KU math department, had a long and active career in the aerospace industry in California.

In honor of the 50th Aerospace Engineering graduating class, Brizendine (1949) and Walter Garrison (1948) established a $50,000 challenge gift. This gift is to be matched by alumni contributions during the 1994 and 1995 annual fund drives. The combined funds will be used to develop a state-of-the-art design classroom.

Alumni and Faculty Recognition

Alumni Awards

Throughout its history the department has always been blessed with outstanding students who have brought it much honor. In recognition of these outstanding representatives, KU awards have been established at the department, school, and university level.

As part of the 1994 50th Anniversary celebration, the department established a University of Kansas Department of Aerospace Engineering Alumni Honor Roll Award. The purpose of this award is to recognize aerospace department alumni who have made significant contributions to the aerospace profession and to have the recipients serve as role models to our current and future students. Honor Roll members will be added annually with the awards presented at a department's spring awards dinner.

The charter members of the Aerospace Alumni Honor Roll, inducted in 1994, were Brizendine (1949), Engle (1955), Garrison (1948), Bruce Holmes (1973), and Wendell Ridder (1959).

The School of Engineering in 1980 established the Distinguished Engineering Service Award. Three Aerospace Engineering alumni—Brizendine, Engle, and Garrison—have received this award.

In 1941 The University of Kansas Alumni Association established the Distinguished Service Citation Award. This award is the highest award KU presents to alumni and friends. Two Aerospace Engineering alumni—Brizendine and Engle—have received this recognition.

The department faculty, knowing the quality of its graduates, anticipates that in the future there will be other department alumni added to these lists of recipients of department, school, and university awards.

Faculty Awards

Throughout the department's 50 years, it has also been blessed with outstanding faculty. In 1989 the students established the "Outstanding Aerospace Educator Award." This award is given each spring by the graduating class. Winners have been:

1989	Jan Roskam
1990	Saeed Farokhi
1991	Jan Roskam
1992	Eddie Lan
1993	Saeed Farokhi

The department faculty has received numerous teaching, research, and service awards from the school of engineering, the university, and several state and national organizations. These include:

School of Engineering Awards

David R. Downing

Recipient of the Miller Award for Service.

Saeed Farokhi

Recipient of the Gould Award for Distinguished Service to Undergraduate Engineering Education.

Jan Roskam

Recipient of the Gould Award for Distinguished Service to Undergraduate Engineering Education.

University of Kansas Awards

Saeed Farokhi

Recipient of the Burlington Northern Foundation Faculty Achievement Award for Outstanding Classroom Teaching.

Recipient of the Mortar Board Outstanding Educator of the Year Award.

Eddie Lan

Appointed Bellows Distinguished Professor.

Jan Roskam

Appointed Deane Ackers Distinguished Professor.

Recipient of the Higuchi Award.

Recipient of the Ned Fleming Teaching Award.

State and National Awards

Ammon Andes

The Sigma Gamma Tau, the National Honor Society in Aerospace Engineering, names its national honor student award the "Ammon Andes . . . Award".

Eddie Lan

Appointed Consultant Professor by Northwestern Polytechnical University in China.

Jan Roskam

Recipient of AIAA John Leland Atwood Award.

Recipient of AIAA General Aviation Award.

Elected a Fellow of the AIAA.

Recipient of SAE Forrest McFarland Award.

Elected a Fellow of SAE.

Recipient of Kansas Governor's Aviation Award.

Aerospace Professorial Faculty

Name	Appointment Year	Name	Appointment Year
Edward E. Brush	1941	Theodore Bratanow	1967
Harry S. Stillwell	1942	Jan Roskam	1968
Robert W. McCloy	1942	Chuan Tau Lan	1968
William H. Simpson	1944	Howard Smith	1970
Reid B. Lyford	1945	William Schweikhard	1979
Ammon Andes	1946	Paul E. Fortin	1981
Harry W. Johnson	1950	David R. Downing	1981
Edwin K. Parks	1952	John C. Ogg	1982
James B. Tiedemann	1953	Saeed Farokhi	1984
L. G. Kimbrel	1959	James E. Locke	1988
Ferdinand Bates	1960	David R. Ellis	1989
Costas J. Choliasmenos	1960	Ray R. Taghavi	1991
Vincent U. Muirhead	1961	Mark S. Ewing	1992
David L. Kohlman	1964	Tae Lim	1992
Leroy Devan	1965		

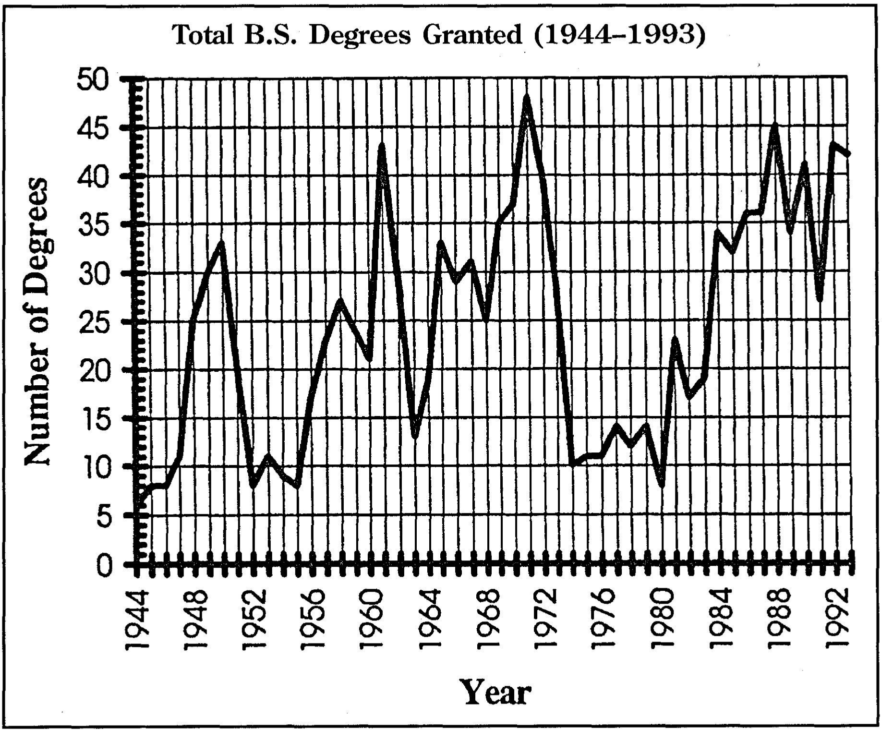


Figure 4. (Chart prepared by Ken Lieber, July 19, 1994)

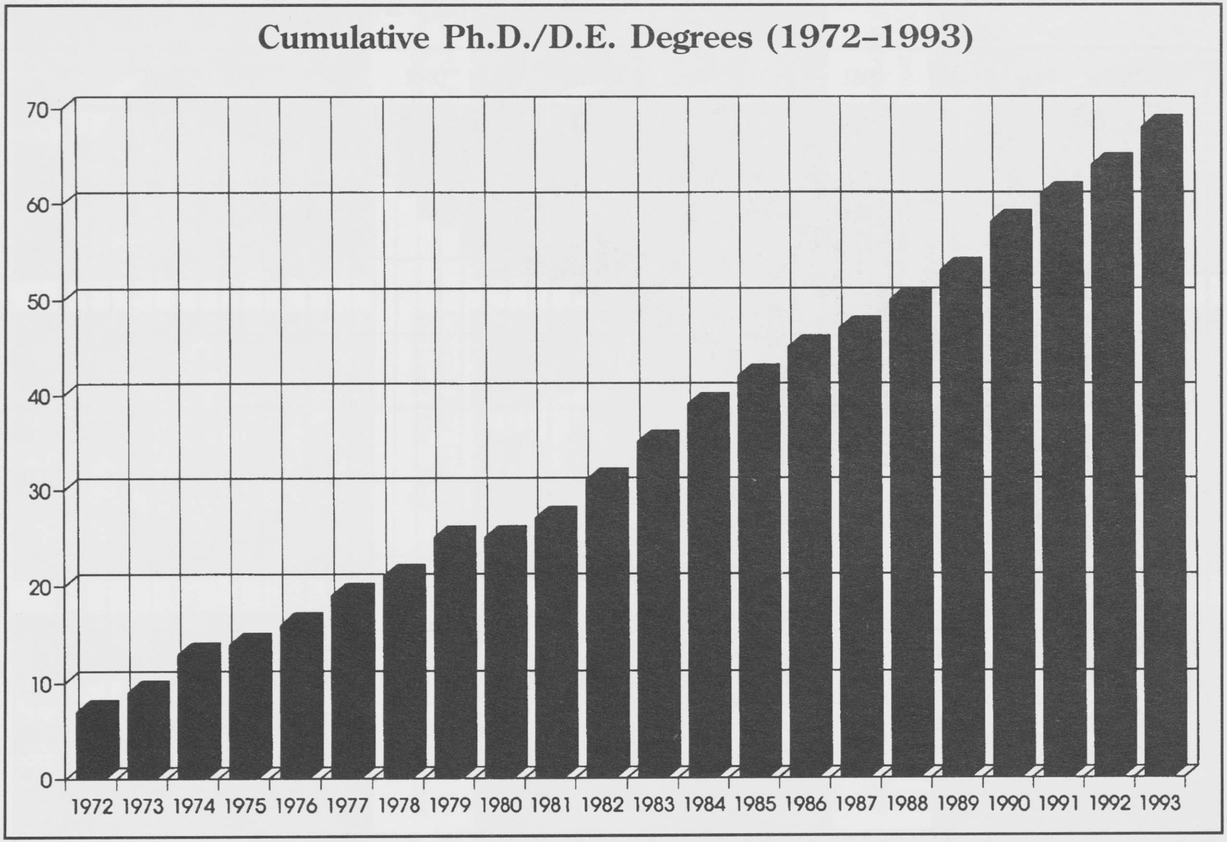


Figure 5. (Chart prepared by Ken Lieber, April 13, 1994)

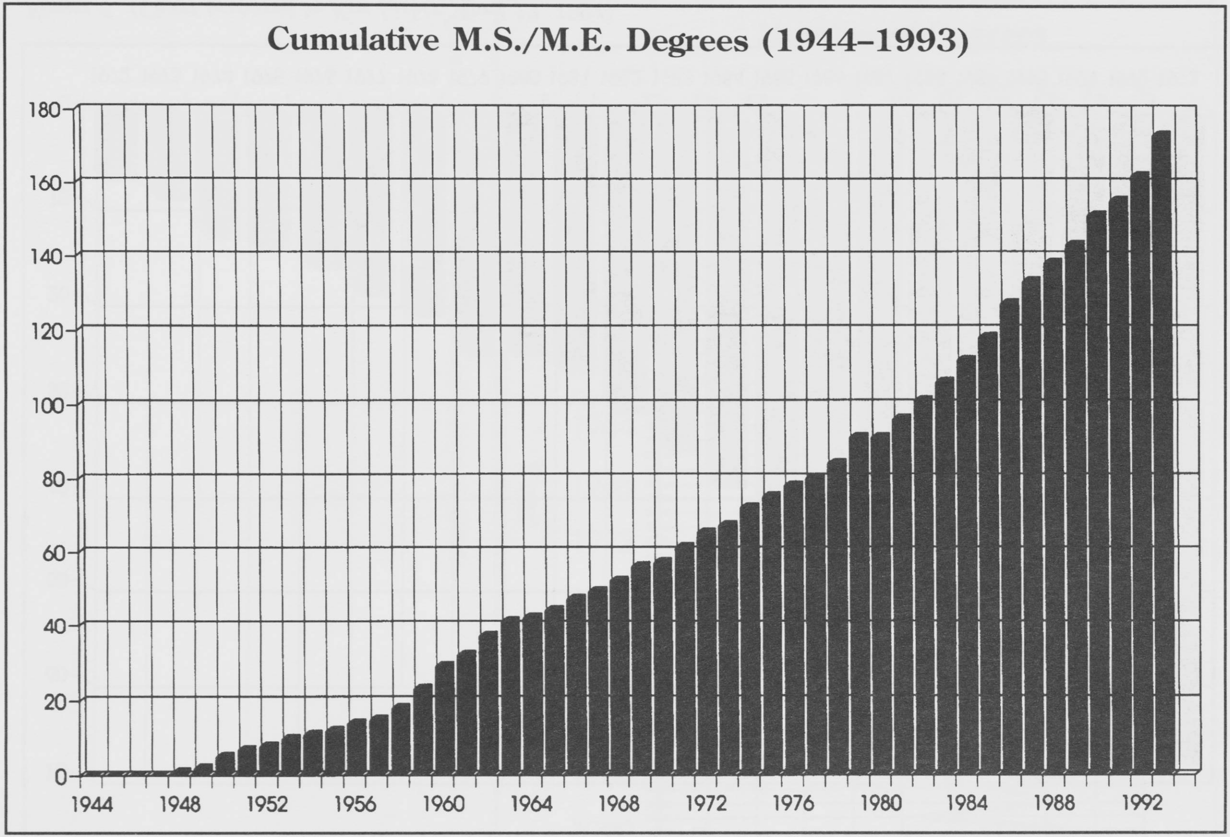
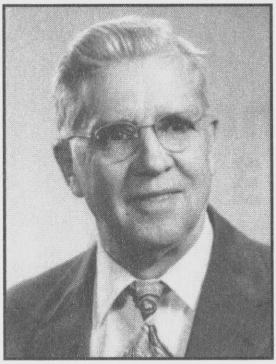
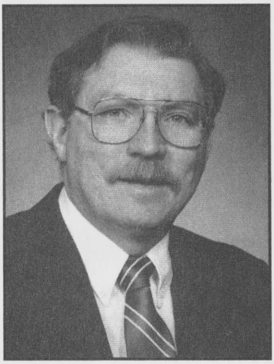


Figure 6. (Chart prepared by Ken Lieber, April 13, 1994)

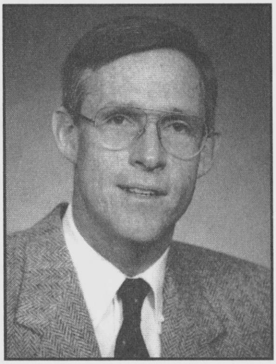
Present and Emeritus Faculty



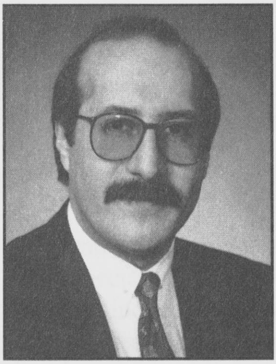
Ammon S. Andes
Emeritus Professor



David R. Downing
Professor & Chairman

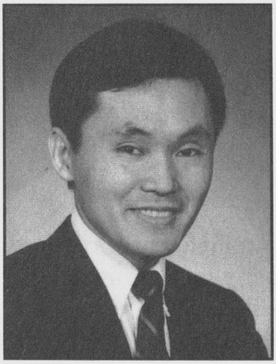


Mark Ewing
Associate Professor



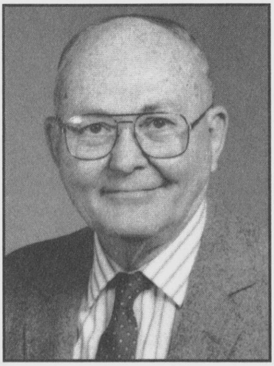
Saeed Farokhi
Professor

Chuan-Tau (Eddie) Lan
Bellows Dist. Prof.

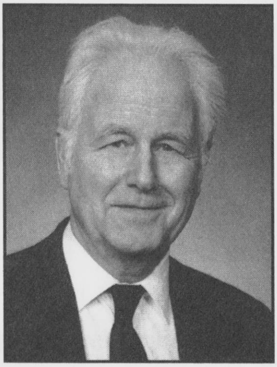


Tae Lim
Assistant Professor

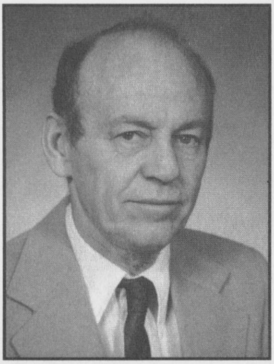
James Locke
Associate Professor



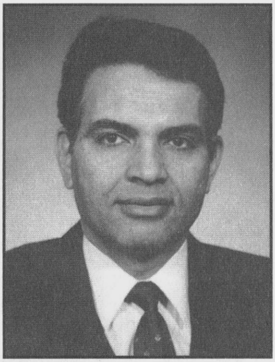
Vincent Muirhead
Emeritus Professor



Jan Roskam
Ackers Dist. Prof.



Howard W. Smith
Professor



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Commercial Transport Evolution and the Role of Technology

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Abstract

One of the most fascinating aspects of aviation is the rapid evolution of commercial transports. In this paper, some of the technological driving factors behind commercial transport evolution are identified and put in a historical perspective. The paper ends with some speculative comments about the future.

Introduction

Commercial air transportation is now 75 years old. In that period of time, significant changes have occurred in the seven factors which are of prime interest to the airline operator, to the airline customer, and to the community:

- block time
- comfort
- environment
- useful weight

This was the Keynote Address given at the 50th anniversary of the Department of Aerospace Engineering of The University of Kansas, April 15, 1994.

- cost
- schedule reliability
- safety

These seven factors are not listed in any implied order of importance. It is of interest to consider the trends of these factors over 75 years of commercial air transportation.

Block Time

For moderate to long stage lengths, block time is closely related to cruise speed. Figure 1 shows how cruise speeds have changed with calendar time. Cruising speeds of subsonic transports have peaked out at true airspeeds well below the speed of sound. Cruising speeds have been fairly constant since the 1970's. An exception is the Concorde (not shown in Figure 1) which cruises at M=2. Although technically a successful airplane, the Concorde is not a commercial success. An efficient, environmentally friendly supersonic transport is still over the horizon.

Useful Weight

Useful weight is defined as the difference between the maximum allowable takeoff weight and the operating weight empty. All else being the same, a larger useful weight results in more economical operation. The ratio of operating weight empty to takeoff weight is a measure of this parameter. Figure 2 shows the trend of the ratio of operating empty weight to takeoff weight with calendar time. It is of interest to note that no significant improvements have been made in this parameter since the 1980's.

Schedule Reliability

Passengers insist on schedule reliability. Airlines insist on dispatch reliability. These factors are strongly related to engine, airframe and system reliability. In the DC-6 and Constellation days dispatch reliability rates of 95% were achieved. In the modern jet era the dispatch reliability of a mature airplane approaches 99.8%. Newly introduced transports tend to have worse dispatch reliability: 98% is considered good in that case. It is difficult to find consistent data on schedule reliability. Reasons for this are: air traffic control, airline politics, government politics and government requirements to publish "honest" schedule data. No graphical data are presented for these reasons.

Comfort

The extent of passenger comfort depends on the quality of the following factors:

- vibration level
- cabin heating
- ride through turbulence
- seat pitch and seat width
- meal service
- noise level
- cabin pressurization
- cabin air pollution due to smoking
- lavatories
- entertainment

Figure 3 shows the improvements made in several of the passenger comfort factors. Improvements in ride quality are easily quantifiable using the sensitivity of vertical acceleration to turbulence as a criterion. Major improvements have been made since the days of the early transports.

Cost

Cost is typically measured in terms of DOC per seat-mile or per hour. Because of past trends in inflation, interference from government regulations and the vagaries of airline fare decision making, no historical fare data are presented. Instead, Figure 4 shows a spectrum of block hour costs for four different jet transports, averaged over the airlines which operate these airplanes. These data apply to domestic operations only. Observe that about 70% of the block hour cost consists of:

- crew
- fuel and oil
- maintenance

Together these costs should be an attractive target for designers to try and reduce!

Safety

Safety can be measured by many different yardsticks. From a passenger viewpoint the most meaningful yardstick is probably the number of fatalities per million departures. Figure 5 shows how this parameter has improved over 32 years of commercial jet transportation. A disturbing trend is shown in Figure 6: the world hull loss is increasing. That does not bode well for the accident and insurance cost component of DOC if left unanswered! Another factor which needs attention is the increase in accidents involving controlled flight into terrain. Figure 6 also shows some recent trends which must be reversed.

Environment

Environmental concerns in aviation fall mainly in two categories: noise and pollution. In the beginning of aviation, environmental considerations played no role in design decision making. With the early jets, noise and pollution became concerns which had to be addressed. FAR36, particulate control and ozone control, are now concerns which affect the introduction of new technology transports. Figure 7 shows improvements which have been made in the areas of noise and pollution.

The Role of Technology

Behind all the trends shown in Figures 1–7 are many enabling technology areas:

- configuration
- manufacturing
- aerodynamics
- propulsion
- structures
- systems

Figures 8–10 illustrate when specific technologies in these areas were phased in and out of the manufacturing of transports.

The remainder of this article will focus on the role of specific technological developments on the evolution of commercial air transports. This is done by classifying the development of airliners into five phases:

Phase I	The Pioneering Years 1919–1930
Phase II	The Settling-in Years with Piston Engines 1932?–1950
Phase III	The Turbine Revolution 1950–1970
Phase IV	The Turbine Evolution and the Decades of Derivatives 1970–2000
Phase V	The Future 2000–?

Phase I The Pioneering Years 1919-1930

Commercial transportation began officially in Europe in 1919 with the KLM (Royal Dutch Airlines) inauguration of Amsterdam to London service using a converted DH 4 WWI biplane, carrying two passengers. Flying in this airplane was slow, expensive, uncomfortable and unnerving. The weather played havoc with schedule reliability. Figure 11 shows a 1921 KLM timetable (in Dutch) for service between Amsterdam, Rotterdam, London, Brussels and Paris.

Aircraft designers and operators rapidly caught on to the fact that comfortable "cabin type" transports would have to be developed. The first examples of such types were the 4-passenger Junkers F-13 (1919) and the 5-passenger Fokker F-2 (1919).

Note that both types already had cantilever wings (not counting the very much inboard mounted front struts on the F-2). Figures 12 and 13 show renditions of these early transports.

During the pioneering years, much attention was given to improving the flight performance of the transport airplane: gradual speed increases were obtained by combinations of reducing drag and increasing power. Figure 1 shows the resulting trend in cruise speeds.

The creation of NACA (National Advisory Committee on Aeronautics) in 1917 with its first research facility at Hampton, Virginia (NACA-Langley) has had a major impact on the rapid development of military and commercial aeronautics, particularly in the USA. Examples of early NACA contributions to aeronautics technology were:

- NACA engine streamline cowling which resulted in major drag reductions
- lowering interference drag between nacelle and wing
- systematic development of airfoils for use in wings and tails
- development of retractable cowl flaps for large radial engines
- development of the tricycle landing gear
- development of slotted flap systems
- systematic research on wing aerodynamics and design, high lift system aerodynamics and design, flying qualities, etc.

Figure 14 shows examples of drag reductions which were pointed out by NACA as achievable by attention to detail design.

The development of the cantilever wing over the biplane wing also resulted in a significant reduction in drag over the strutted-wing or biplane configuration despite the weight penalty associated with such a move. However, the biplane wing configuration did not disappear immediately. Figures 15 and 16 show examples of the Handley Page 42 and the Curtiss Condor transports which soldiered on well into the early forties.

The cantilever wing of the F-2 was actually evolved from the Fokker DVIII fighter of WWI. Fokker used a mixed construction technique in the early airplanes:

- wings were made out of wood
- fuselages and engine mounts used welded steel tube trusses
- fuselage cover was doped fabric

These airplanes were very easy to repair: access to systems and primary structure was simple. The resulting family of transports (F-2 through F14) was widely used in the United States and Europe. KLM even used these airplanes on its routes from Holland to Indonesia (then the Dutch East Indies) and to Curacao and Paramaribo (then the Dutch West Indies). Figure 17 shows the F-7b-3m.

Junkers departed from this fairly standard construction method with an all aluminum tubular spar with corrugated skin structure. The resulting transport, the Junkers 52-3m, was a rugged, practical and low cost transport used in Europe before, during and after WWII. Figure 18 shows the Ju-52. Note that it also was a three engine transport. The rationale behind that configuration was that for flight over mountains the airplane should be able to maintain a reasonable altitude on 2 engines.

The Junkers method of construction, albeit in a much refined form with smooth external skin (called semi-monocoque construction and invented by Jack Northrop) was the predecessor of many commercial aircraft to follow. The Lockheed Vega was the first commercial transport using this type of construction. As Figure 19 shows, the Vega had a very good useful weight fraction.

The riveted, aluminum stressed skin construction of the Vega was also very easy to repair. However, access to systems was made more difficult: access panels had to be reinforced around the panel edge and the temptation was (and is) to keep them small. That limits accessibility.

Phase II The Settling-in Years with Piston Engines 1932–1950

The cost of operating airplanes and the ability of the air carrier to make a profit became a major problem for airplane designers. It became apparent, that to reduce the operating cost per seat mile, larger units would be required. This development led to the DC2/3 via several interim types. The DC3 in particular combined the right number of advanced technologies (for its day) with the right size and, further propelled by the need for military transports during WWII, became a cost effective airliner. The critical technologies which made this airplane into such an astounding success were:

- stressed skin construction
- retractable landing gear
- NACA engine cowls
- variable pitch propellers
- engines mounted on the wing in a minimum drag fashion

It should be noted that the real breakthrough here was not any individual technology, but the synergistic use of a number of technologies at the same time!

Figure 20 shows the classical lines of the DC-3. Many of these airplanes are still flying in 1994. In this airplane, a requirement was sustained flight on one engine at a reasonable altitude.

Development of the pressurized cabin was a significant development which enabled the airplane to cruise at higher, more economical and less turbulent altitudes. The Boeing Stratoliner shown in Figure 21 was the first commercial airplane certified for flight with a pressurized cabin. The airplane was "caught up" in the priorities of WWII and only 12 were built. These all served with distinction.

After the war, the Douglas DC4, 6, and 7 and the Lockheed Constellation, 049 and 1049 became the mainstays of long distance commercial carriers. The Lockheed Constellation is shown in Figure 22. None of these airplanes succeeded in significantly changing the travel habits of people for trips across the Atlantic; most passengers still took the boat. That all was to change during the turbine revolution.

Phase III The Turbine Revolution 1950–1970

The transition from piston-propeller power to turbine power took place after 1950 largely as a result of major improvements made in turbine engine fuel consumption and engine reliability. After the introduction of materials for combustion chambers and turbine blades so that engine life became acceptable, it rapidly dawned on airframe designers that the turbine engine not only allowed flight at higher altitudes and Mach numbers but also made the airplane much more reliable. Piston engines had reached the end of their practical development and become so complicated that reliability was a major issue.

In addition, the adaptation of the wet, swept, high aspect ratio wings with externally podded engines allowed good useful weight fractions to be achieved. The sweep feature was made necessary because of drag rise problems with flight at high Mach numbers.

It is to be noted that these developments were made feasible by the earlier validation of these technologies on military airplanes, notably the Boeing B-47 of Figure 23.

Transatlantic service in eight instead of sixteen hours, in a comfortable environment (Figure 3) with very little interference from the weather, now caused a shift in travel habits. Within a decade after the introduction of the long range jet transport, scheduled passenger ship service across the Atlantic disappeared. In addition, because of the acceptable cost per seat mile, many people who had never contemplated travelling that far from home now found this to be within their means.

Because the jet engine allowed flight at high Mach numbers, compressibility as affected by wing/ airfoil design became an important design problem. The design trade between sweep angle, thickness ratio, aspect ratio and compressible drag received major emphasis after the introduction of the 707 and the DC-8 which represent the "first generation" jet transports. Figures 24 and 25 show renditions of these airplanes.

Phase IV The Turbine Evolution and the Decades of Derivatives 1970–2000

Since the introduction of the first and second generation jet transports (Figure 5) a slow but significant evolution has taken place. This evolution has been characterized by developments in a number of technologies:

Engines

High bypass ratio jet engines, more efficient combustion chambers, longer component life by using advanced materials and turbine blade cooling all contributed to improvements in efficiency. Particularly the latter feature allowed turbine blades to be operated at temperatures above their static melting point! Engine efficiency increases with higher turbine inlet temperatures. Figure 26 shows the evolution in internal engine design that has resulted in the modern very high bypass ratio engine.

Aerodynamics

Development of "aft-loaded" airfoils with high critical Mach numbers allowed designers to trade wing thickness, wing sweep and critical Mach number to suit any given mission requirement. With the introduction of supercritical airfoils it has been possible to increase the aerodynamic quality, ML/D of the transport wing, by 22% in less than two decades. Figure 27 illustrates the type of improvements achieved. Airplanes which benefited from this design capability were: F-100, Airbus A 300, B-767, B-757.

Computational Fluid Dynamics

This development was enabled by the development of high speed digital computers which made it possible to analyze complex flow interactions such as those encountered by integrating:

a) jet engine nacelles with wings in close proximity
b) wings and fuselages for minimum interference drag
c) engine nacelles close to a fuselage
d) winglets and wing tips

Figure 28 shows an example of the Boeing 737-300+ wing nacelle integration solution. To be financially successful a transport must be "stretchable." Figure 28 shows an example case.

Materials and Manufacturing

The introduction of new composite and metallic materials with significantly better properties in the following areas:

- strength-to-weight ratio
- crack propagation
- corrosion sensitivity

made more efficient structural design possible. New manufacturing techniques now allow large components to be manufactured out of materials such as CFC (Carbon Fiber Composites). An example of the materials distribution in a modern jet transport is shown in Figure 29.

Systems

Flight control technology changed from purely mechanical signalling of the flight control surfaces to fly-by-wire via a series of intermediate steps:

1) Completely reversible, mechanical flight control systems
2) Mechanically signalled, hydraulic power assisted flight control systems with complete mechanical backup
3) Mechanically signalled, irreversible, hydraulically powered flight control systems
4) Electrically signalled (fly-by-wire), hydraulically powered, irreversible flight control systems
5) In the cockpit, some companies adopted the so-called side-arm controllers while others retained the old style central control column.
6) Flat panel display systems and the dark panel idea.

   Items 5) and 6) have resulted in a major revision of the cockpit. Figure 30 shows an example of a modern cockpit layout.
7) Engine control systems gradually changed from complete mechanical control to FADEC (Full Authority Digital Engine Control).

   This resulted in much more precise control over the engines as well as improvements in mission fuel consumption.

Concurrent Design and Manufacturing

In the late 80's and early 90's it was recognized by management that the intense compartmentalization in analytical engineering, design engineering, manufacturing and service liaison had led the industry into very inefficient operations. By forcing a new management culture which assures that people really communicate with each other and use each others' expertise to the benefit of all, major improvements in operating efficiencies are being achieved. These new management structures are seen under a variety of labels: concurrent design and manufacturing and total quality management are typical examples.

Rise of Ocean Crossing Twins

Twin engined jet transports are less expensive to operate than three- or four-engined jet transports. With increasing reliability of engines and systems it has gradually become feasible to build long range, twin jet transports for over-water flights. This has resulted in a significant shift in the types of airplanes which are operated over the Atlantic. Figure 31 illustrates this shift. It also shows the experience obtained with the Boeing 767-ER which now has 99.8% probability of arriving at the destination airport rather than at an alternate airport due to engine or system failure. This success story is expected to be repeated with the Boeing 777 and the Airbus A-330.

Phase V The Future 2000–?

For the future, cost considerations will dominate the design decision making for new commercial transports more than ever. Figures 32 and 33 show typical cost-pies for flying and maintenance costs of two medium size transports. Several lessons are to be learned from these data:

- Fuel and oil cost are subject to the vagaries of the international oil trade. Airplane designers can influence the fuel and oil cost to the airlines by designing for higher L/D and lower specific fuel consumption. However, the cost of achieving such improvements must be affordable.

  With hybrid laminar flow significant improvements in ML/D are possible. The trick is to develop the right manufacturing technology to make this development affordable.

  Improved engines will probably come about slower than before: the military which pioneered the road to today's commercial jet engines will be doing less of that as a result of the changing political situation in the world.

- Figures 32 and 33 also show that the cost of owning (or renting) and operating a fleet of transports is significant. Since design and development of an airplane typically cost about 10% of what it costs to manufacture an airplane, the emphasis must be on lowering the cost of manufacturing. One inevitable trend is increased automation and increased exportation of manufacturing activities to lower cost areas.

- It is of interest to contemplate the large share of crew costs in Figure 32. A logical thought for a designer is to consider the possibility of eliminating the cockpit crew altogether. There are several problems with this idea but the reader is reminded of Figure 10: since the 40's the cockpit crew complement has gradually decreased from 5 to 2. The reason for this decrease has been: cost reduction through automation of certain cockpit tasks. It is probably not rational to assume that this development will stop.

- Autonomous automatic approaches and landings will become a standard feature of commercial transport operations.
- Maintenance costs can be lowered by focussing more attention on the "ilities" during the airplane preliminary and detail design phases:
  - maintainability
  - serviceability
  - accessibility
  - repairability

  Automatic servicing of transports while parked at the gate may be a way to reduce the manhours required to "turnaround" airplanes. The cost of the required infrastructure must, of course, be affordable.

When addressing the future, several other questions come to mind:

- will higher speeds materialize?
- what other customer and market potential exists?

The possibility of efficient supersonic flight seems within grasp. Recent studies indicate that trimmed L/D values of 10–11 may be possible at Mach numbers of 1.5 to 3.0, depending on the operating altitude. Environmental issues, centering on the chemical reaction between engine exhaust products and the atmospheric ozone distribution and content, appear to allow for a satisfactory compromise. It therefore appears likely that there will be a supersonic transport beyond 2000.

For speeds beyond Mach 3 it is good to reflect on Figure 34. It is clear that the earth is probably too small to justify commercial speeds which are much above Mach 6.

One way to look at the potential for other markets and customers is to consider Figure 35. The solid dots in this figure represent the seat/range capabilities of existing or planned jet transports. Several "voids" appear to exist. The question for designers to establish is whether or not a customer demand exists or can be generated to fill these voids. There are probably several significant market opportunities left to be exploited.

The future of commercial transport design and manufacturing still holds many challenges.

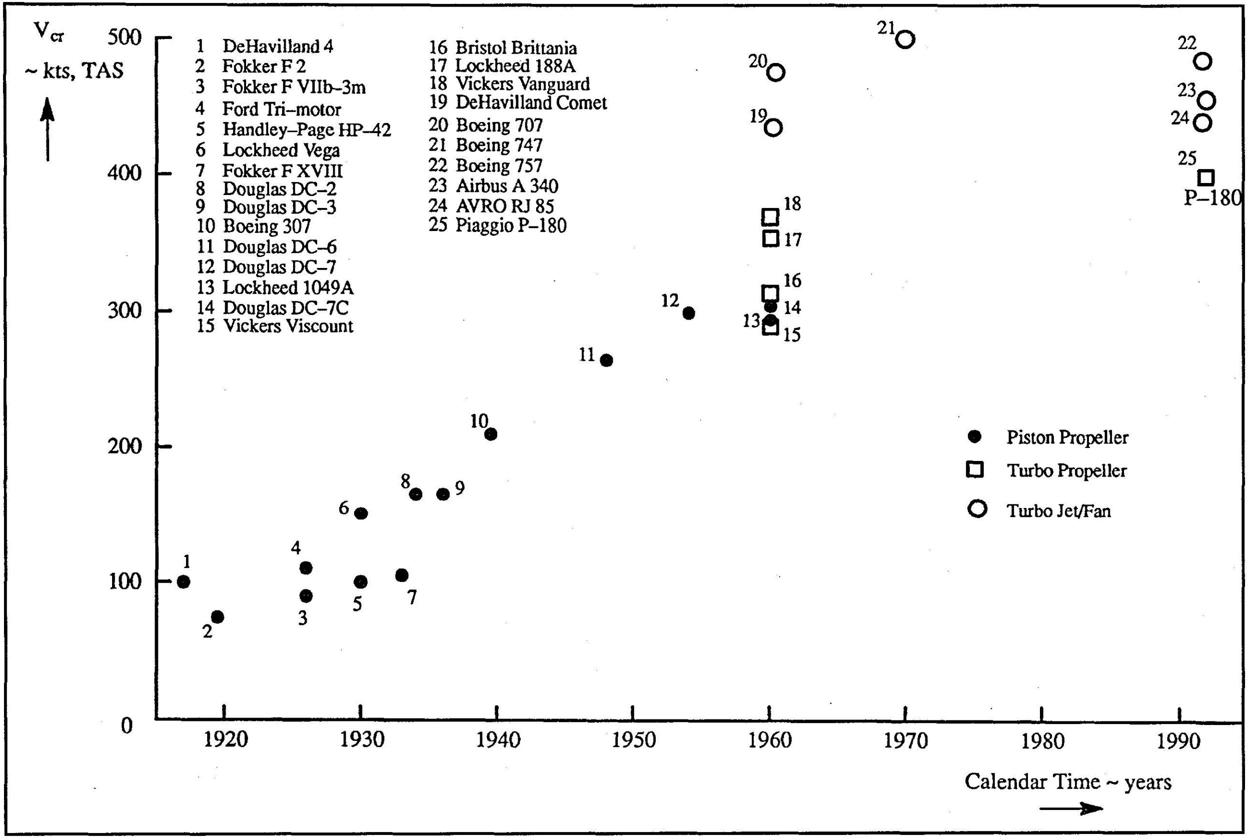


Figure 1. Cruise Speed Trends in Subsonic Commercial Transports. (Jan Roskam)

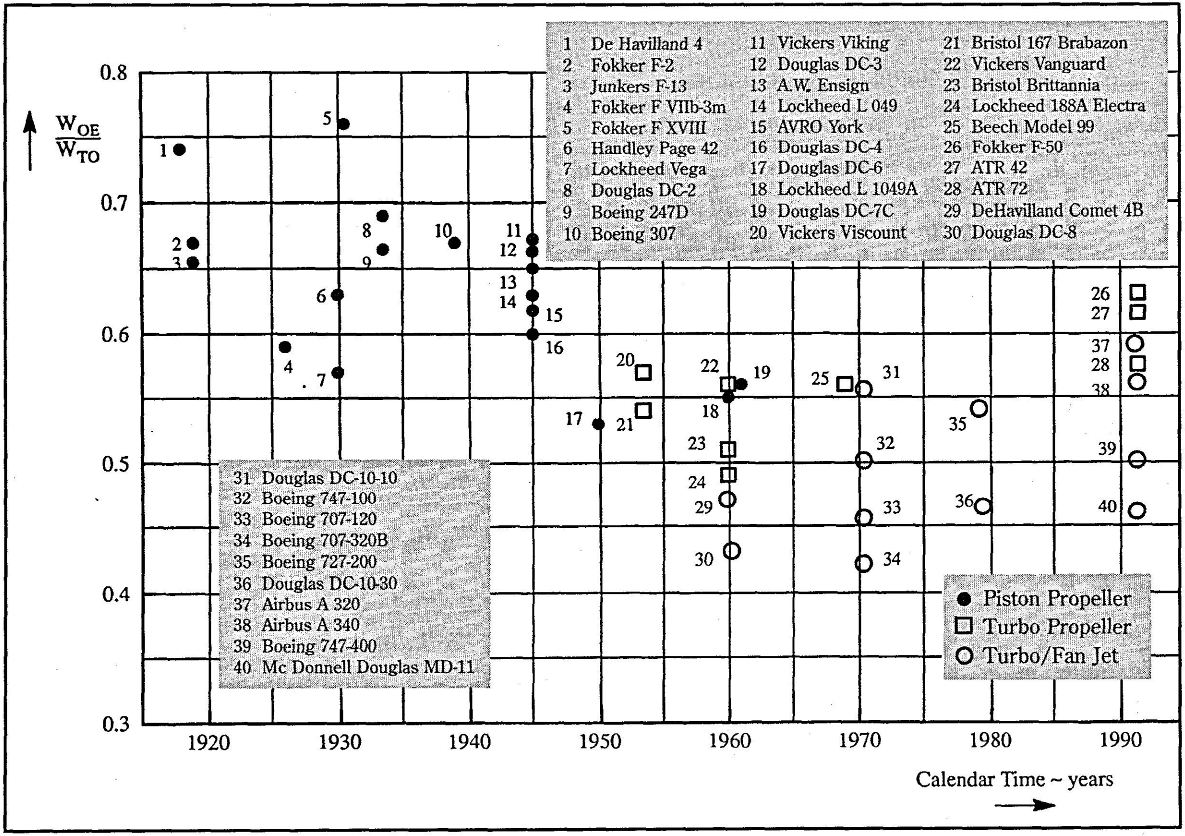
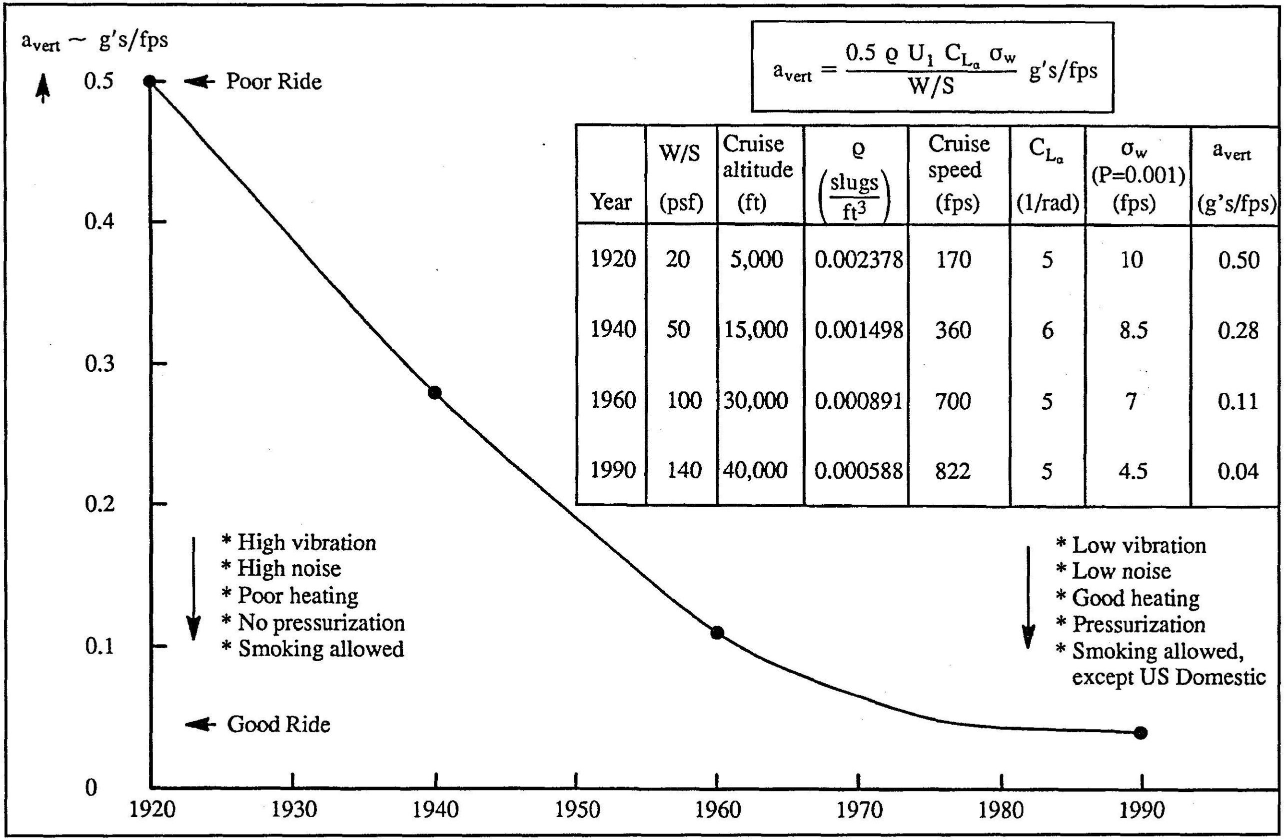


Figure 2. Trends of Empty-Weight-to Takeoff-Weight Ratio for Commercial Transports. (Jan Roskam)



$$a_{vert} = \frac{0.5\ \varrho\ U_1\ C_{L_\alpha}\ \sigma_w}{W/S}\ \text{g's/fps}$$

Year	W/S (psf)	Cruise altitude (ft)	ϱ $\left(\frac{\text{slugs}}{\text{ft}^3}\right)$	Cruise speed (fps)	C_{L_α} (1/rad)	σ_w (P=0.001) (fps)	a_{vert} (g's/fps)
1920	20	5,000	0.002378	170	5	10	0.50
1940	50	15,000	0.001498	360	6	8.5	0.28
1960	100	30,000	0.000891	700	5	7	0.11
1990	140	40,000	0.000588	822	5	4.5	0.04

Figure 3. Evolution of Cruise Comfort (Ride). (Jan Roskam)

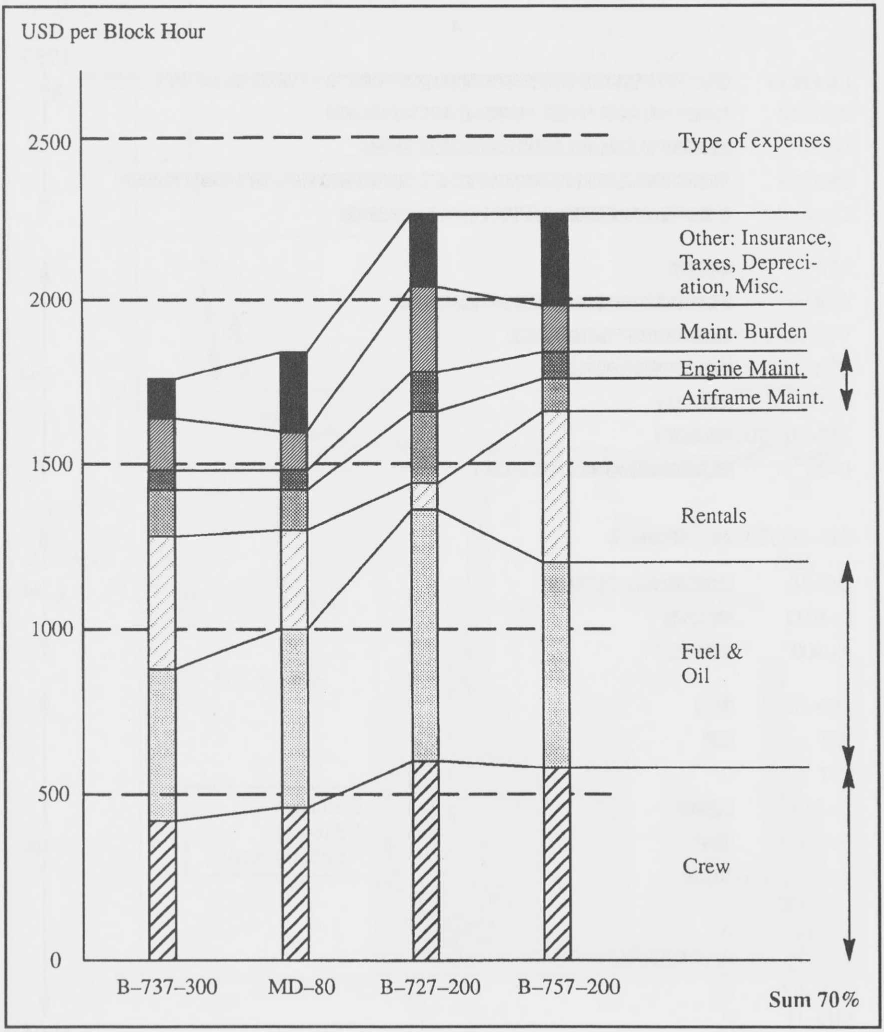


Figure 4. Distribution of Cost per Block Hour for Medium Size Transports. (1992 data from World Aviation Directory, 1993*)*

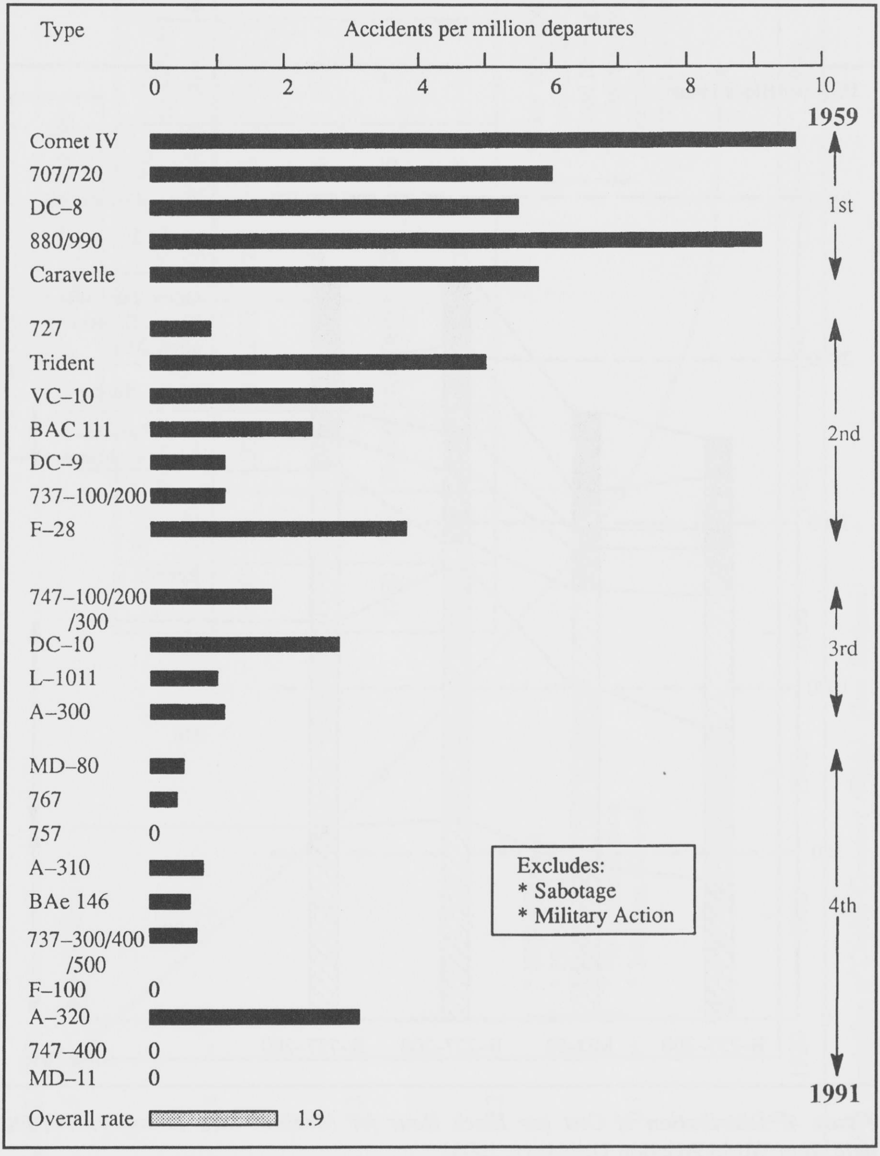


Figure 5. Hull Loss Accident Rate per Million Departures for Four Generations of Jet Transports. (Data from Boeing Airliner, April/June 1993)

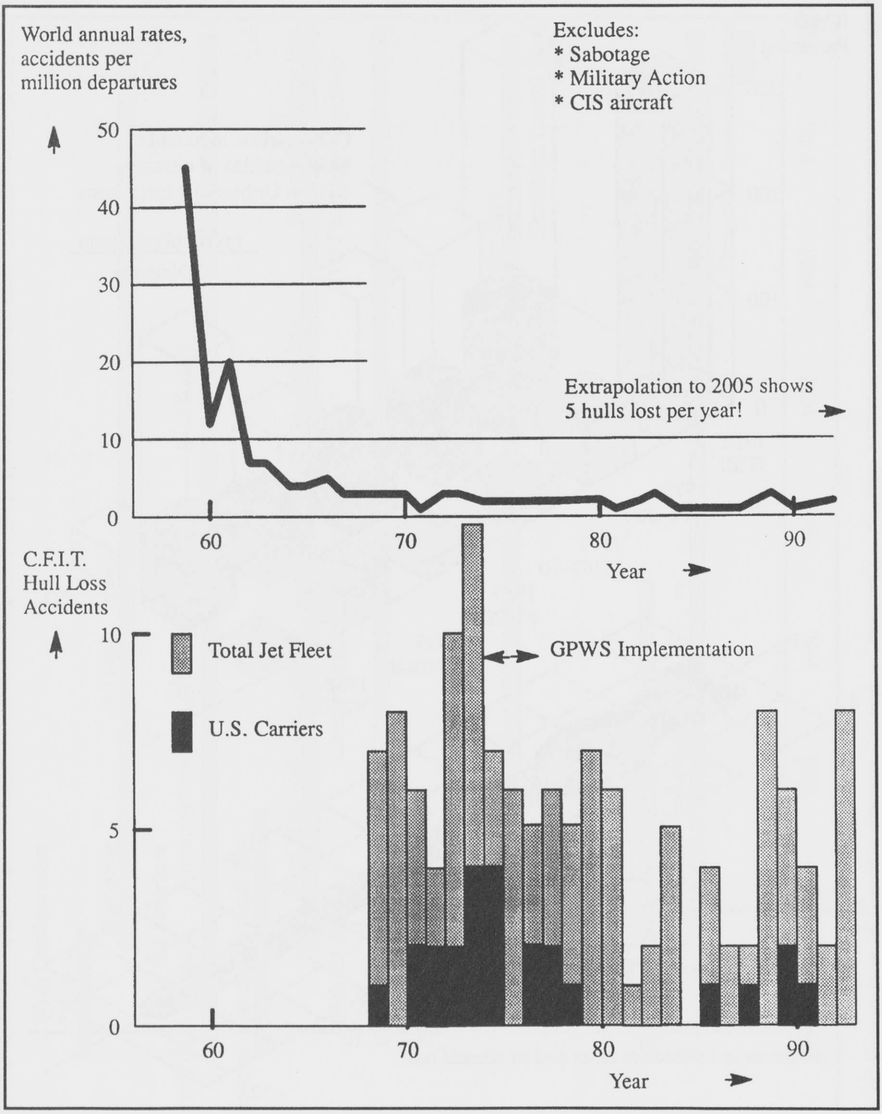


Figure 6. Hull Loss Accidents and Controlled Flight Into Terrain (C.F.I.T.). (Data from Boeing Airliner, April/June 1993)

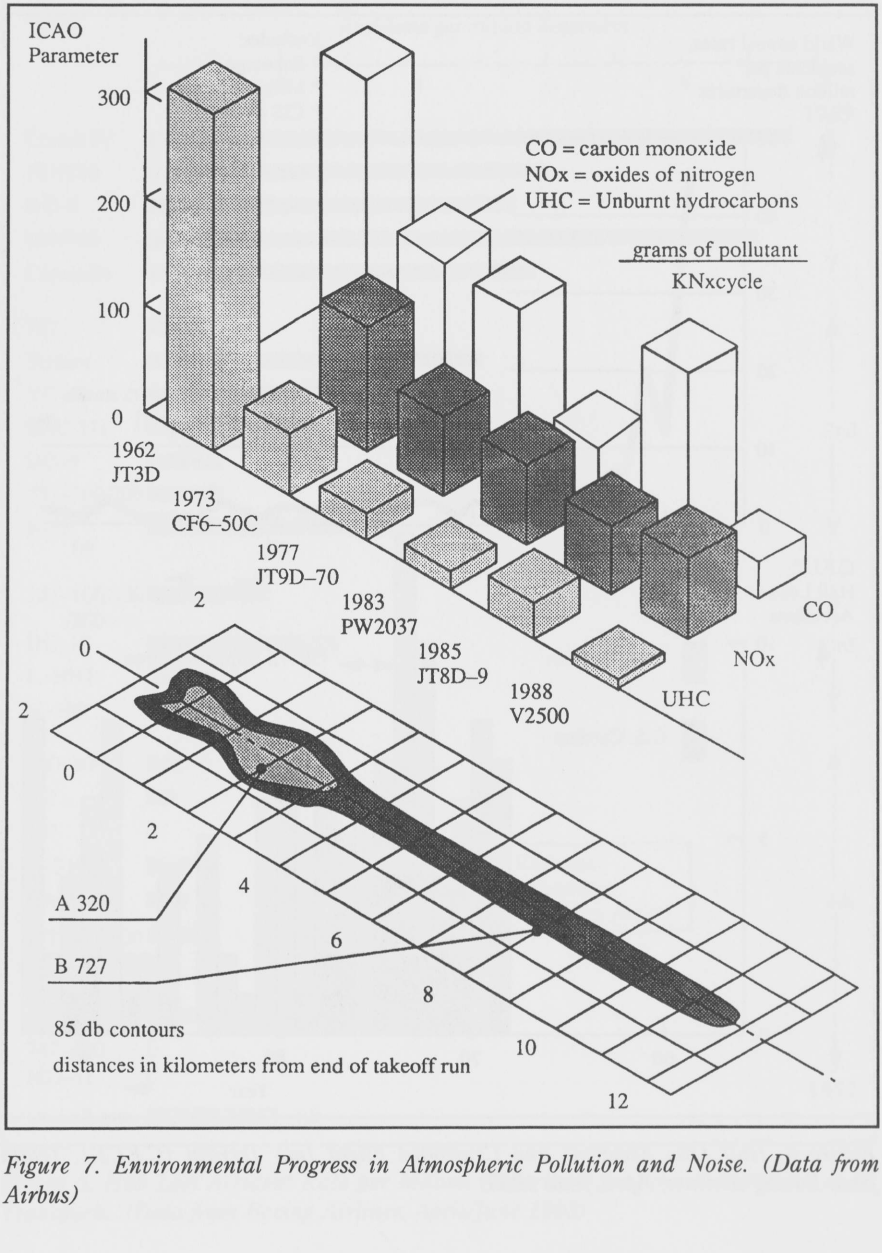


Figure 7. Environmental Progress in Atmospheric Pollution and Noise. (Data from Airbus)

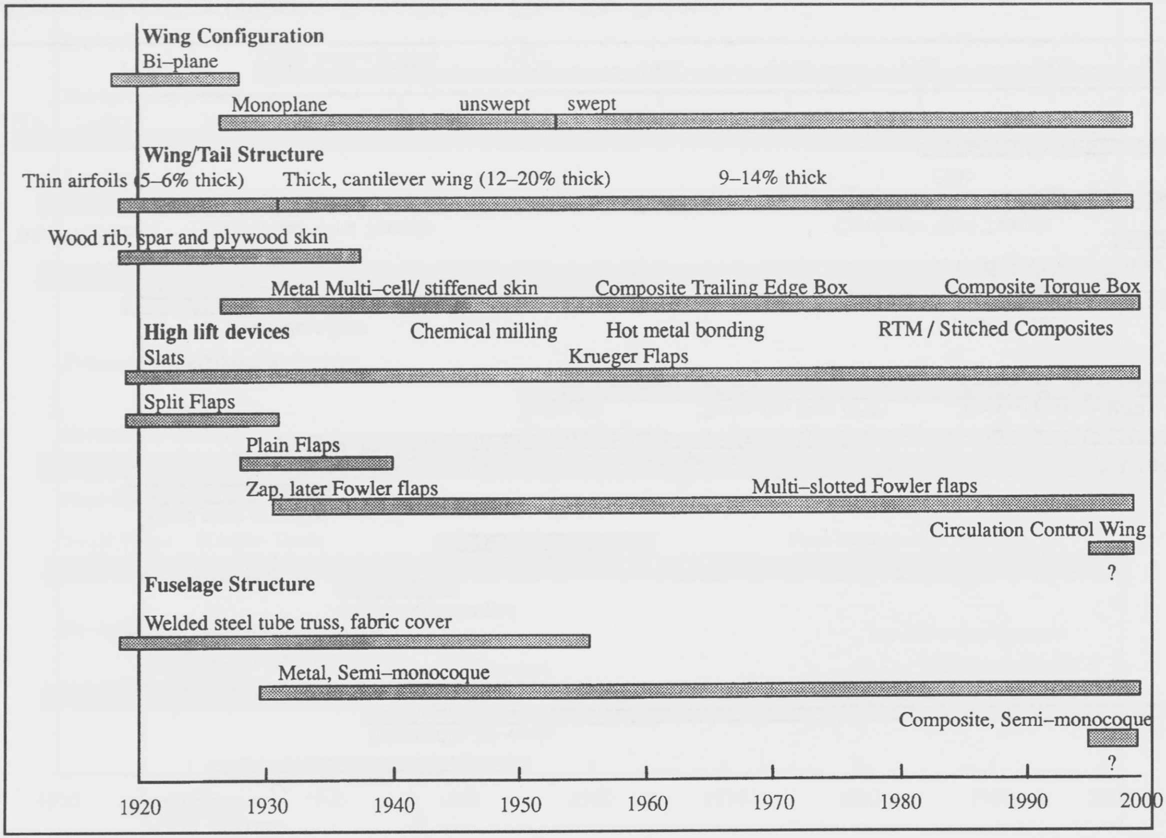


Figure 8. Technology Utilization Versus Calendar Time. (Jan Roskam)

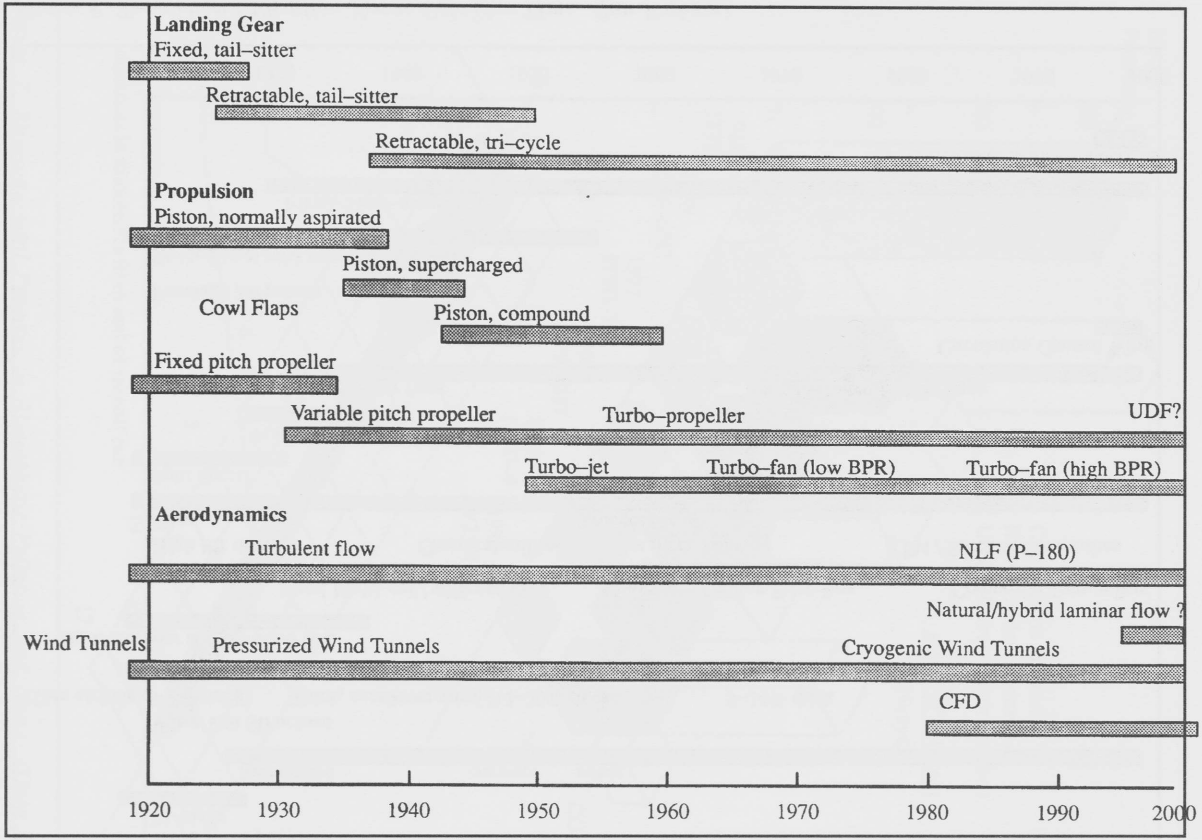


Figure 9. Technology Utilization Versus Calendar Time. (Jan Roskam)

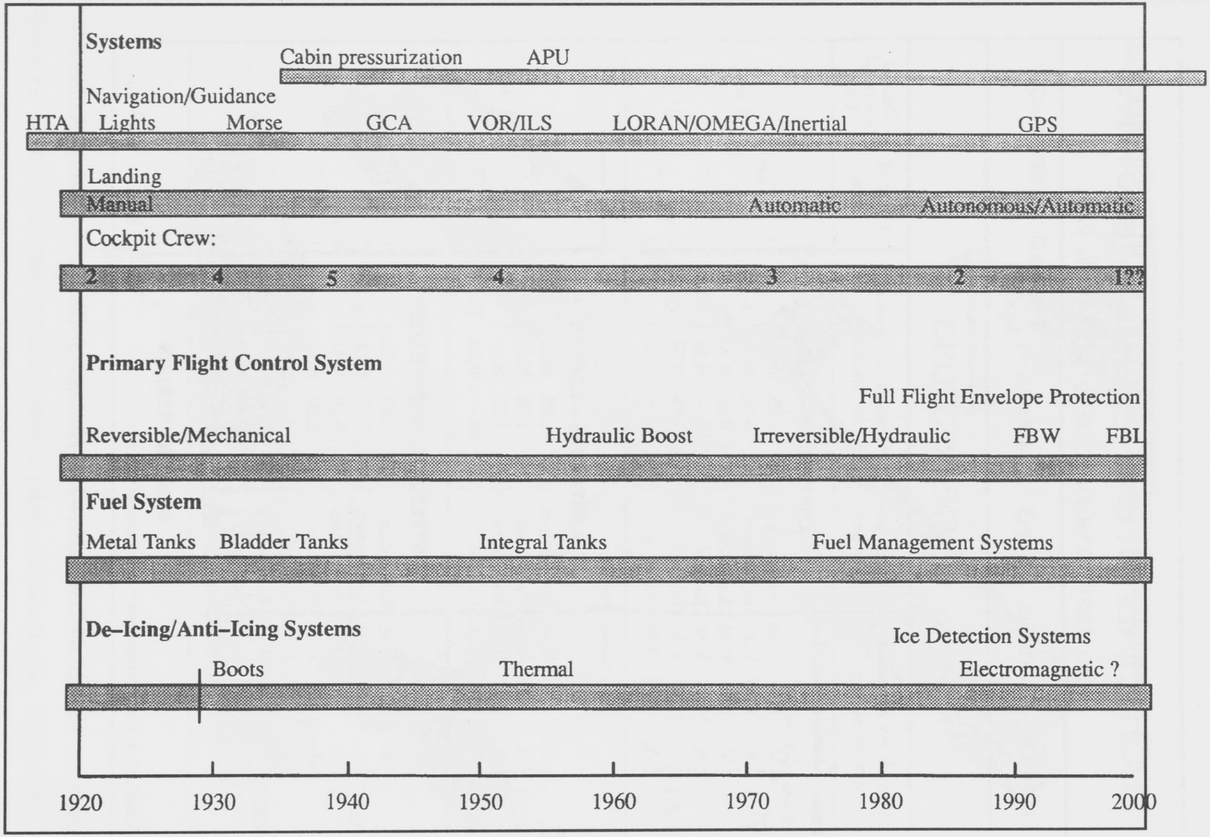
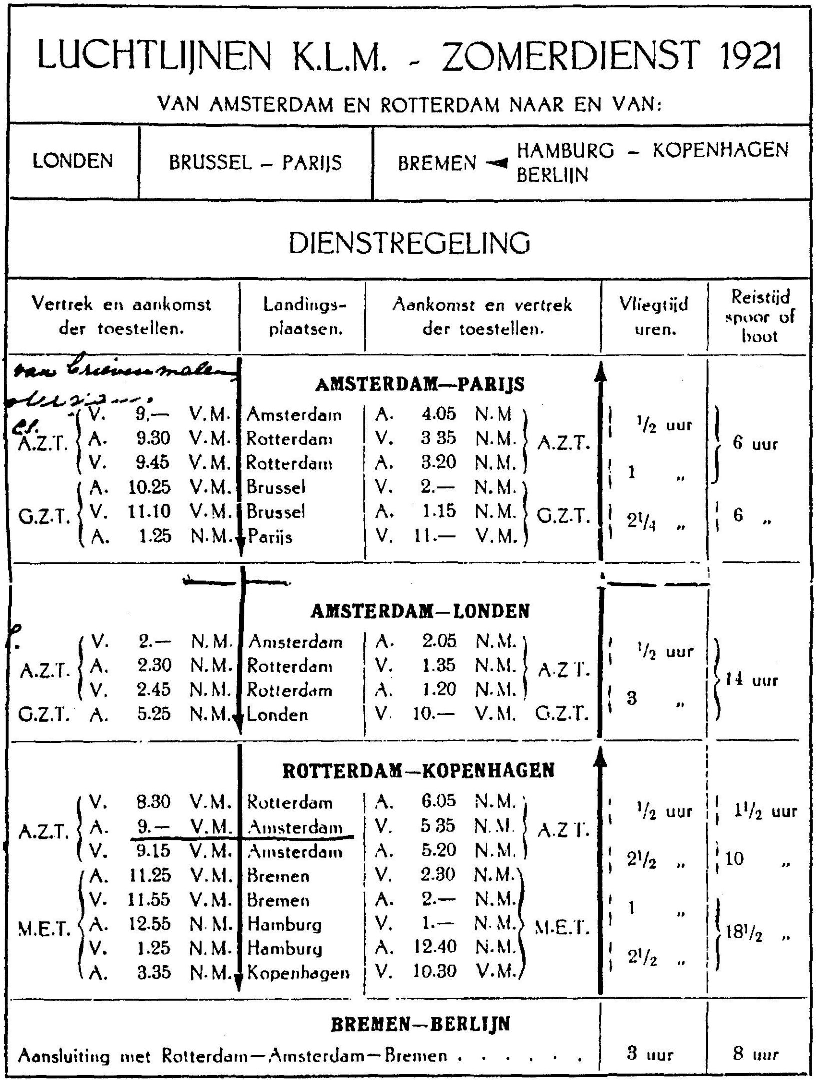


Figure 10. Technology Utilization Versus Calendar Time. (Jan Roskam)



LUCHTLIJNEN K.L.M. - ZOMERDIENST 1921

VAN AMSTERDAM EN ROTTERDAM NAAR EN VAN:

LONDEN	BRUSSEL - PARIJS	BREMEN ◄ HAMBURG - KOPENHAGEN BERLIJN

DIENSTREGELING

Vertrek en aankomst der toestellen.		Landingsplaatsen.	Aankomst en vertrek der toestellen.		Vliegtijd uren.	Reistijd spoor of boot
		AMSTERDAM—PARIJS				
A.Z.T.	V. 9.— V.M.	Amsterdam	A. 4.05 N.M	A.Z.T.	½ uur	6 uur
	A. 9.30 V.M.	Rotterdam	V. 3 35 N.M.			
	V. 9.45 V.M.	Rotterdam	A. 3.20 N.M.		1 „	
G.Z.T.	A. 10.25 V.M.	Brussel	V. 2.— N.M.	G.Z.T.		
	V. 11.10 V.M.	Brussel	A. 1.15 N.M.		2¼ „	6 „
	A. 1.25 N.M.	Parijs	V. 11.— V.M.			
		AMSTERDAM—LONDEN				
A.Z.T.	V. 2.— N.M.	Amsterdam	A. 2.05 N.M.	A.Z.T.	½ uur	14 uur
	A. 2.30 N.M.	Rotterdam	V. 1.35 N.M.			
	V. 2.45 N.M.	Rotterdam	A. 1.20 N.M.		3 „	
G.Z.T.	A. 5.25 N.M.	Londen	V. 10.— V.M.	G.Z.T.		
		ROTTERDAM—KOPENHAGEN				
A.Z.T.	V. 8.30 V.M.	Rotterdam	A. 6.05 N.M.	A.Z.T.	½ uur	1½ uur
	A. 9.— V.M.	Amsterdam	V. 5 35 N.M.			
	V. 9.15 V.M.	Amsterdam	A. 5.20 N.M.		2½ „	10 „
M.E.T.	A. 11.25 V.M.	Bremen	V. 2.30 N.M.	M.E.T.		
	V. 11.55 V.M.	Bremen	A. 2.— N.M.		1 „	18½ „
	A. 12.55 N.M.	Hamburg	V. 1.— N.M.			
	V. 1.25 N.M.	Hamburg	A. 12.40 N.M.		2½ „	
	A. 3.35 N.M.	Kopenhagen	V. 10.30 V.M.			
		BREMEN—BERLIJN				
Aansluiting met Rotterdam—Amsterdam—Bremen					3 uur	8 uur

Figure 11. First KLM Timetable. (Van Holkema & Warendorf, The Netherlands)

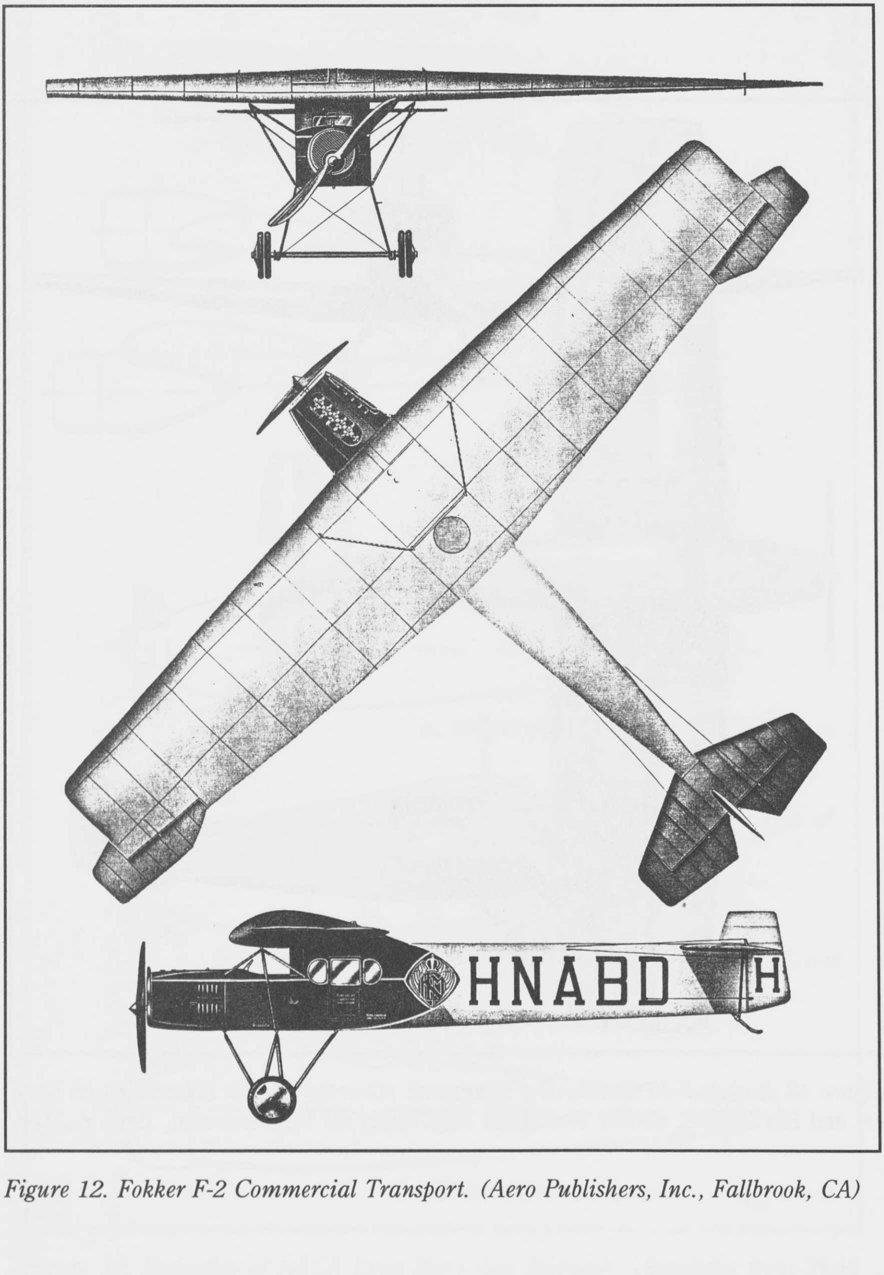


Figure 12. Fokker F-2 Commercial Transport. (Aero Publishers, Inc., Fallbrook, CA)

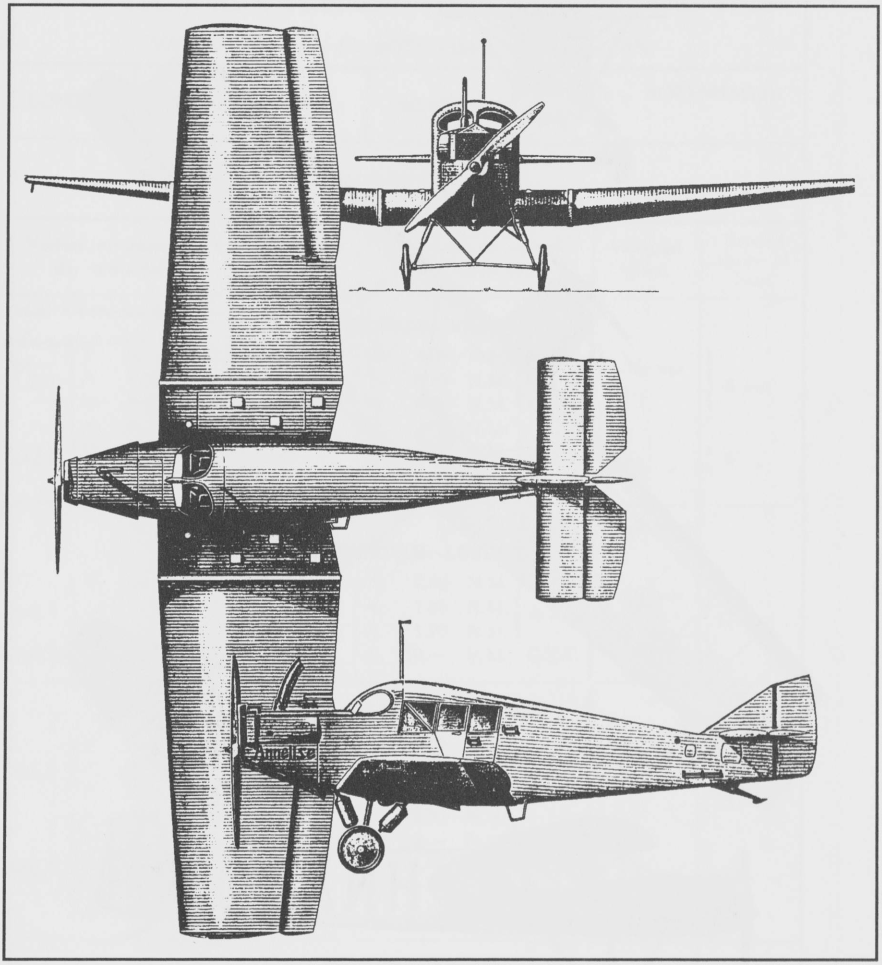


Figure 13. Junkers F-13 Commercial Transport. (Courtesy Günter Schmitt, Hugo Junkers and His Aircraft, *Berlin: Transpress VEB Verlag für Verkehrswesen, 1988, p. 186)*

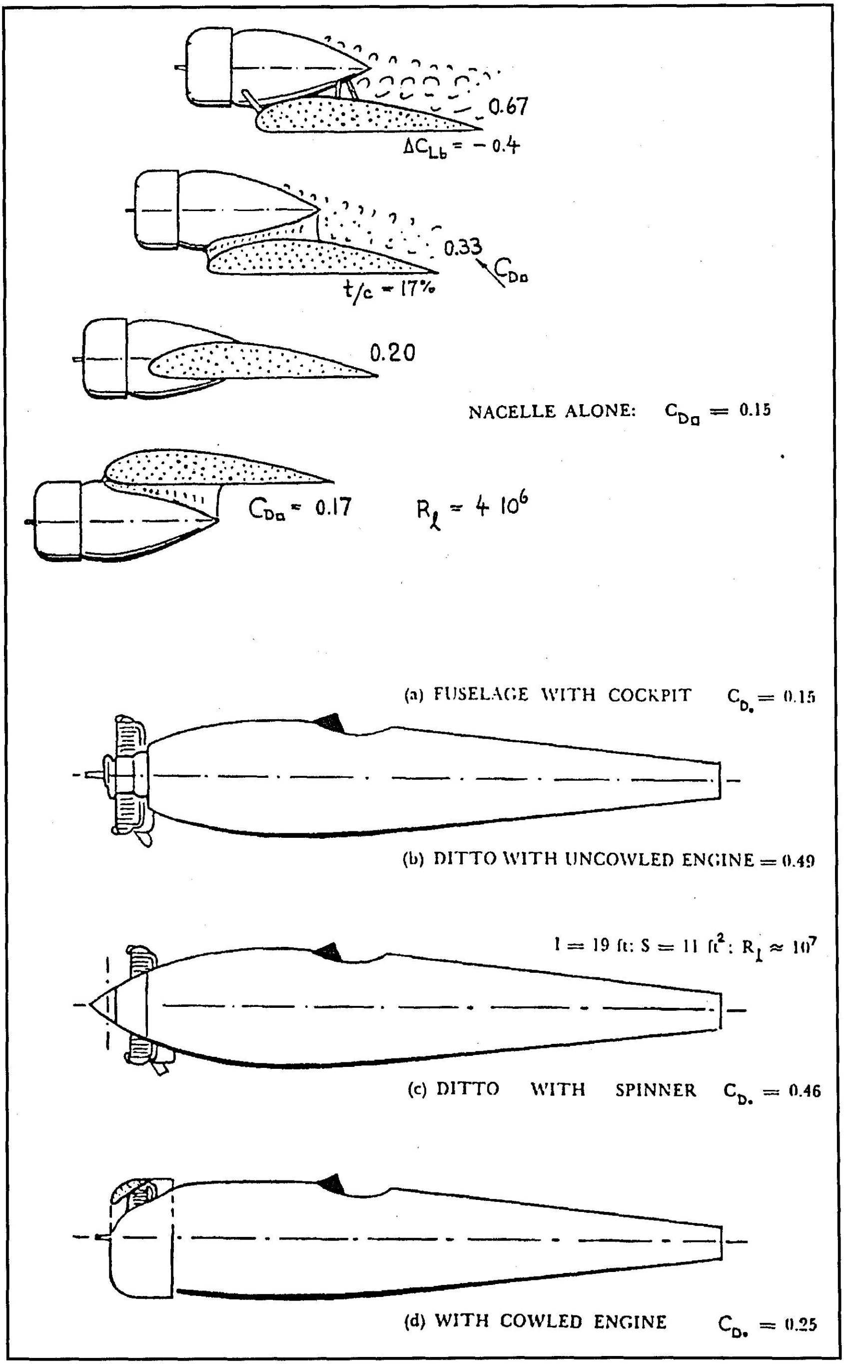


Figure 14. Examples of NACA Drag Reduction Research. (Reprinted from Fluid Dynamic Drag *by Sighard F. Hoerner)*

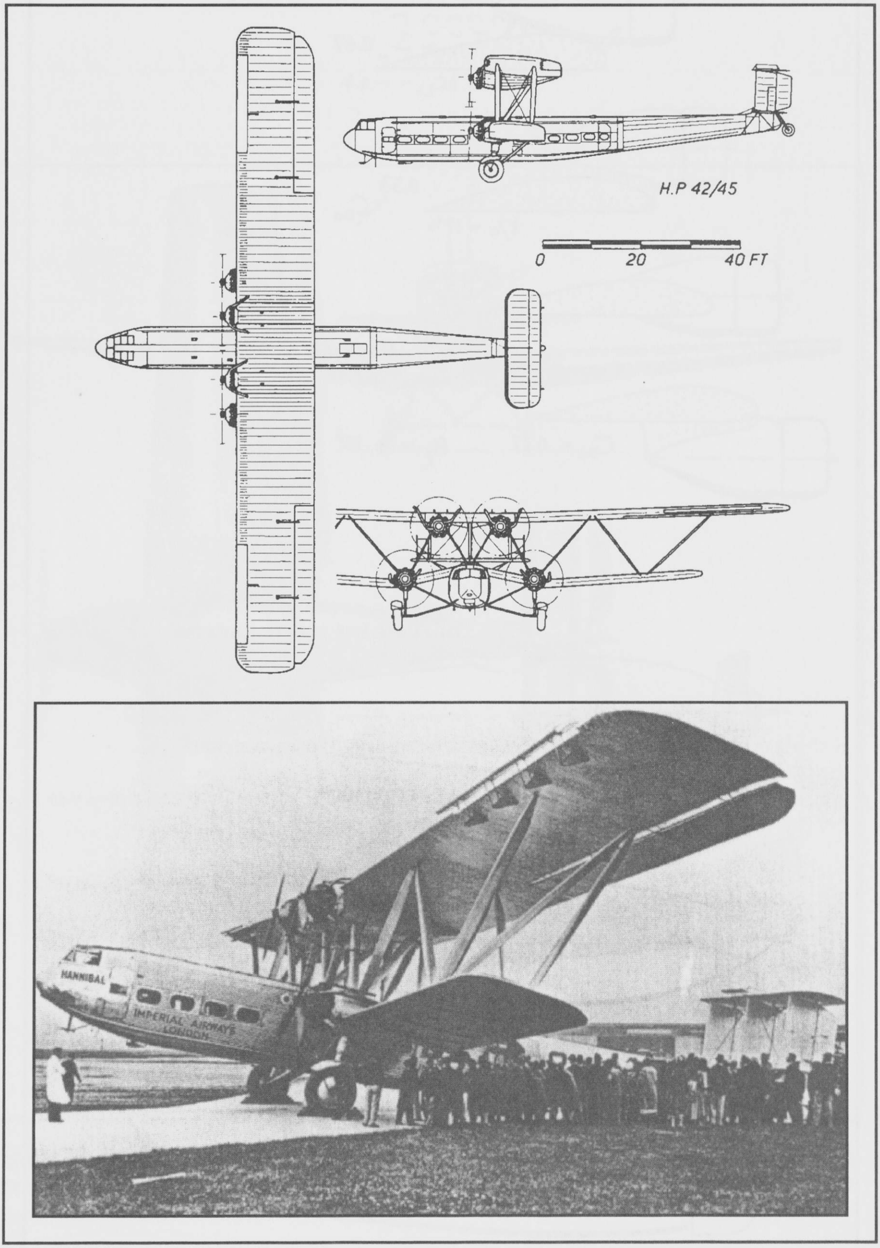


Figure 15. Handley Page Model 42 Commercial Transport. (Courtesy C. H. Barnes, Handley Page Aircraft since 1907, *London: Putnam, 1976, pp. 324 [line drawing] and 315 [photo])*

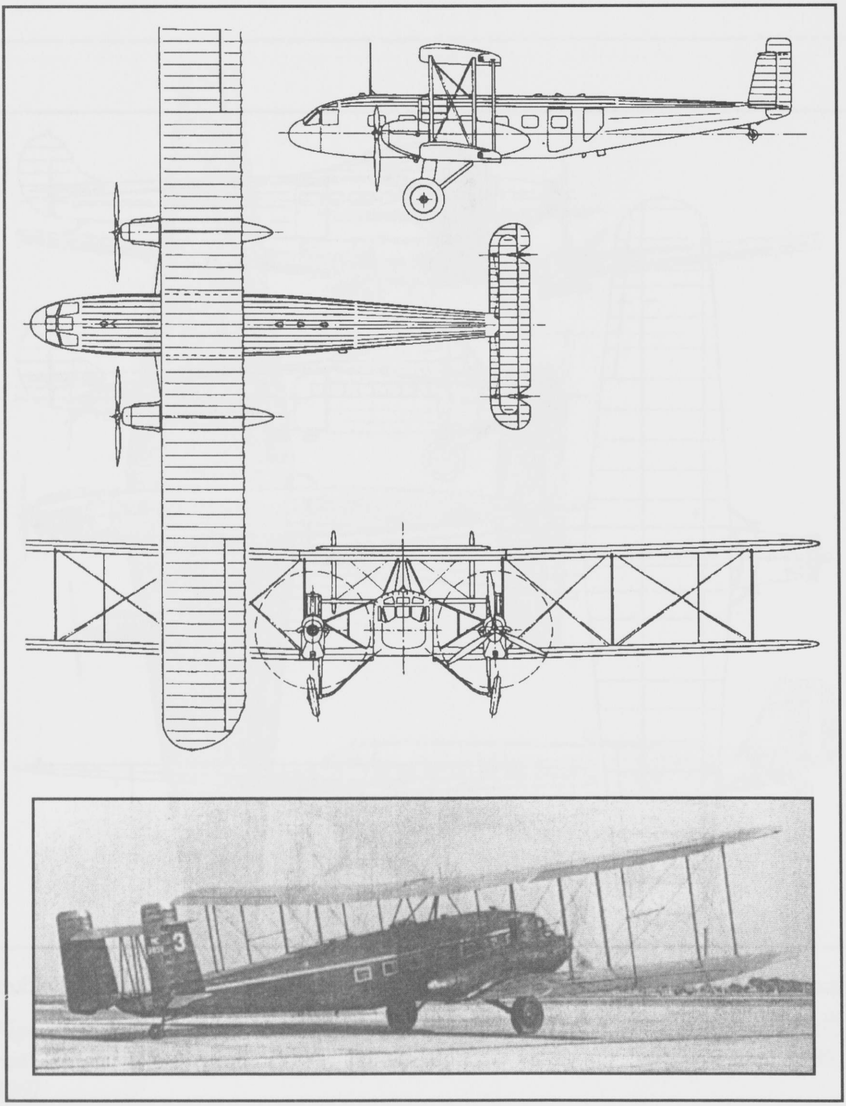


Figure 16. Curtiss Condor Commercial Transport. (Courtesy Naval Institute Press)

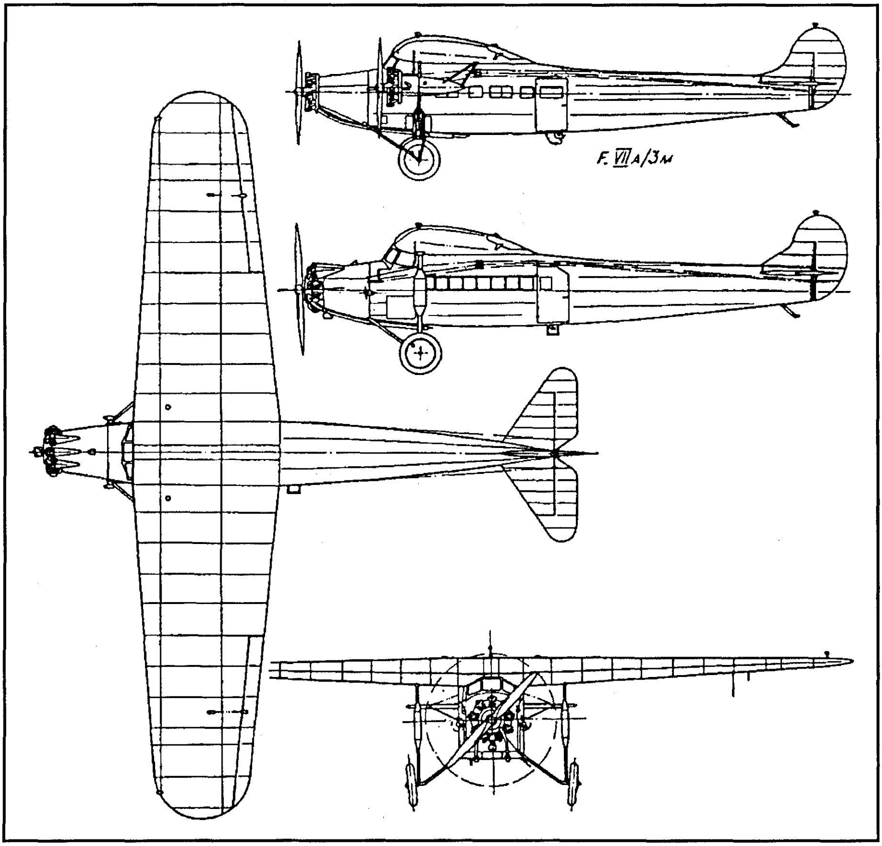


Figure 17. Fokker F-VIIb-3m Commercial Transport. (Courtesy A. R. Weyl, Fokker: The Creative Years, *ed. by J. M. Bruce, London: Putnam, 1987, p. 378)*

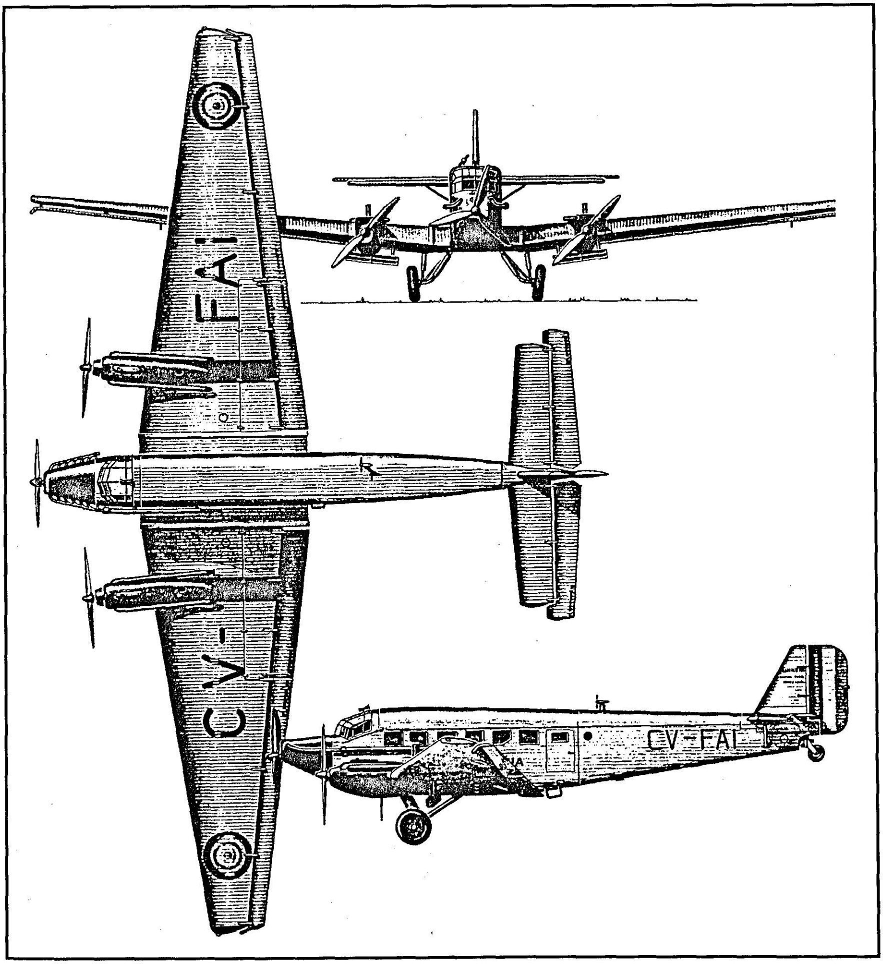


Figure 18. Junkers' Ju 52/3m Commercial Transport. (Courtesy Günter Schmitt, Hugo Junkers and His Aircraft, *Berlin: Transpress VEB Verlag für Verkehrswesen, 1988, p. 199)*

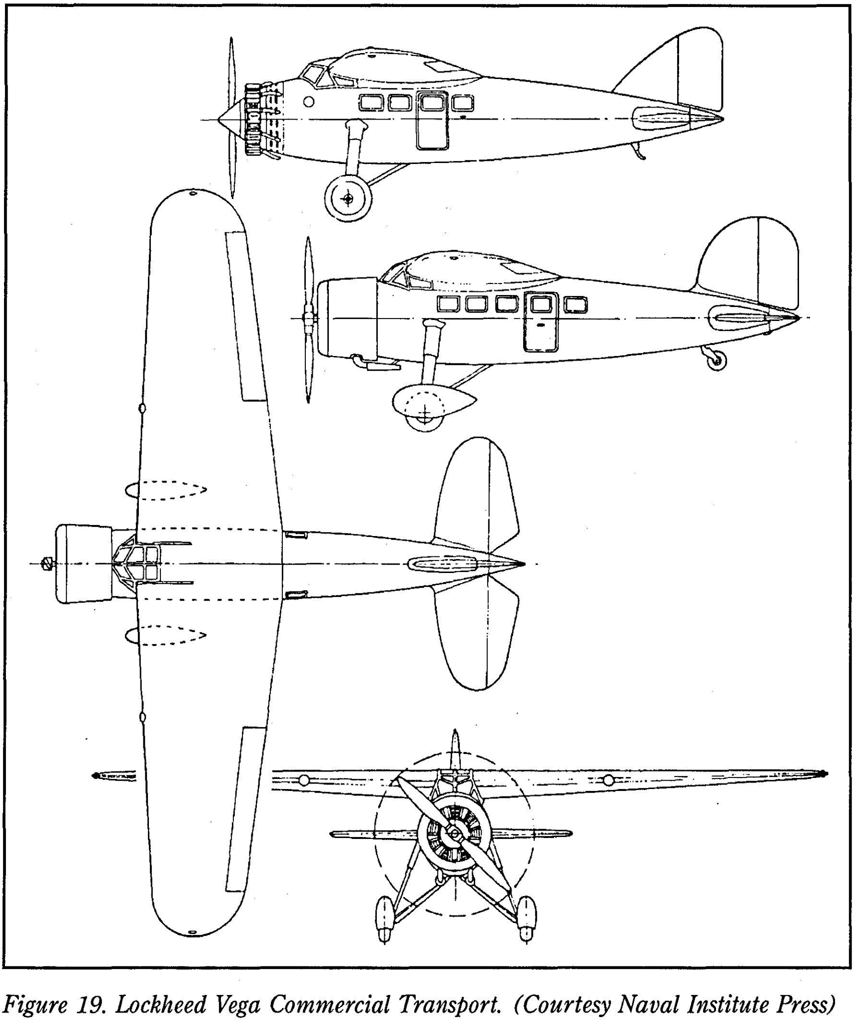


Figure 19. Lockheed Vega Commercial Transport. (Courtesy Naval Institute Press)

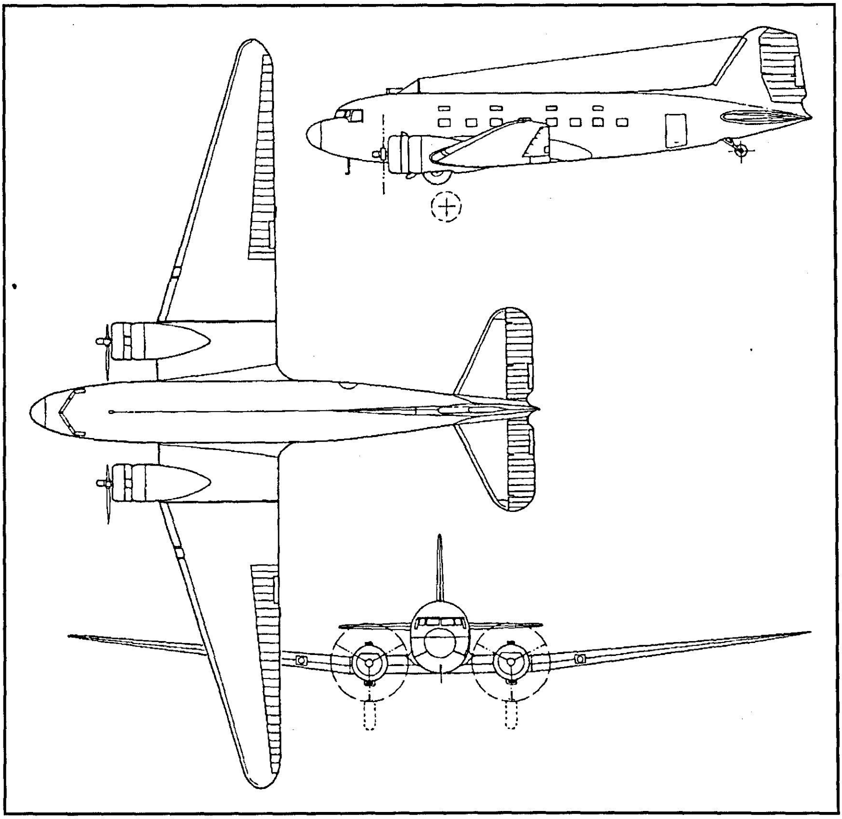


Figure 20. Douglas DC-3 Commercial Transport. (Courtesy Naval Institute Press)

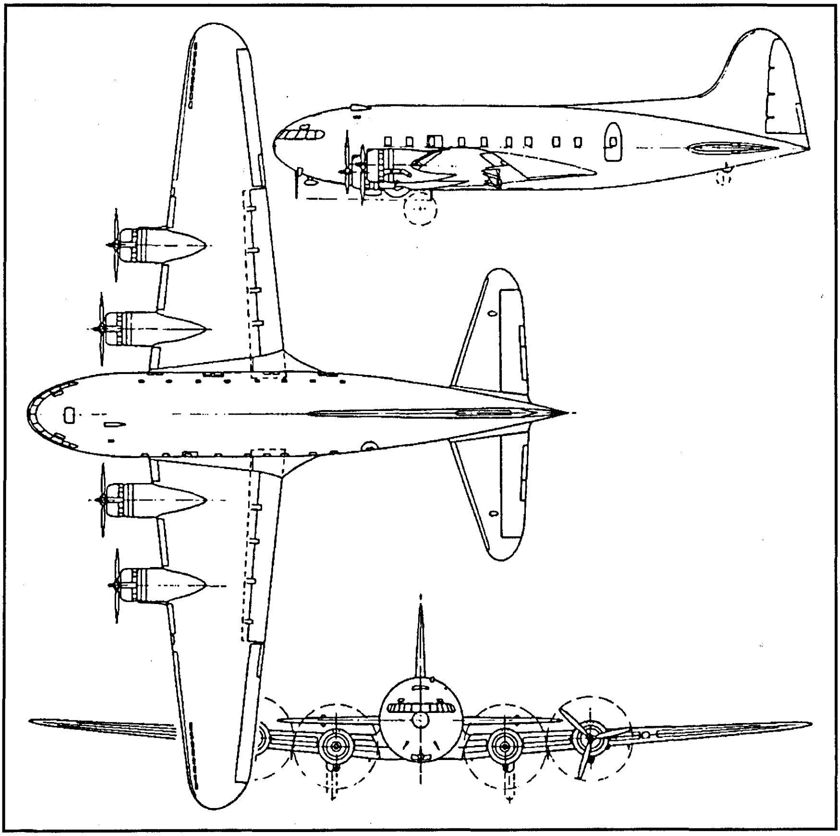


Figure 21. Boeing Stratoliner Commercial Transport. (Courtesy Naval Institute Press)

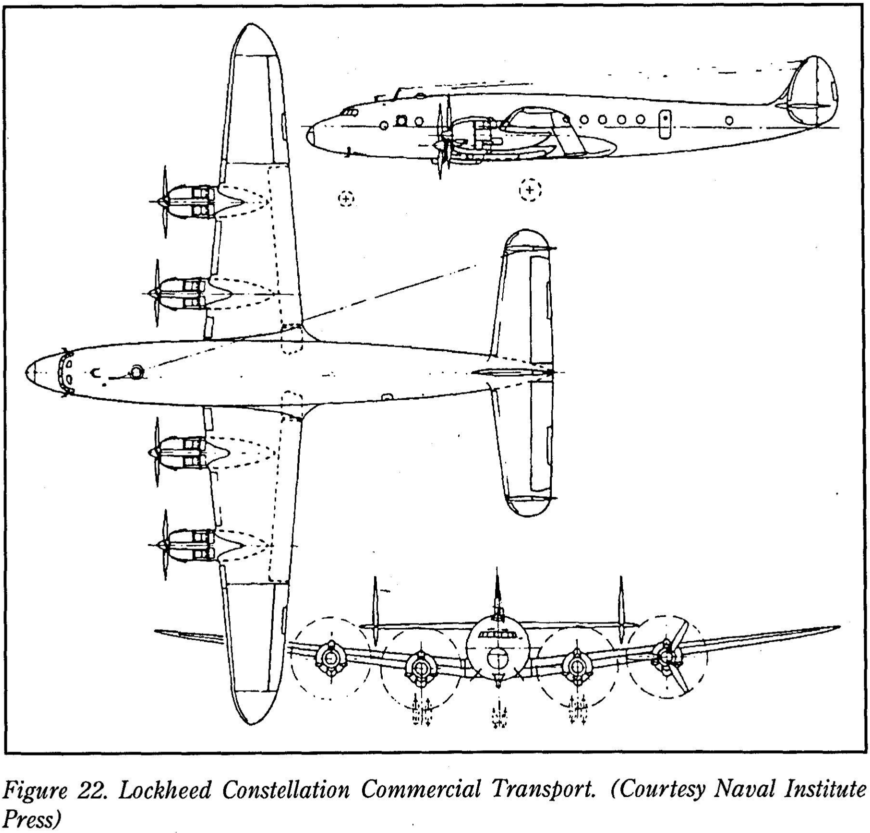


Figure 22. Lockheed Constellation Commercial Transport. (Courtesy Naval Institute Press)

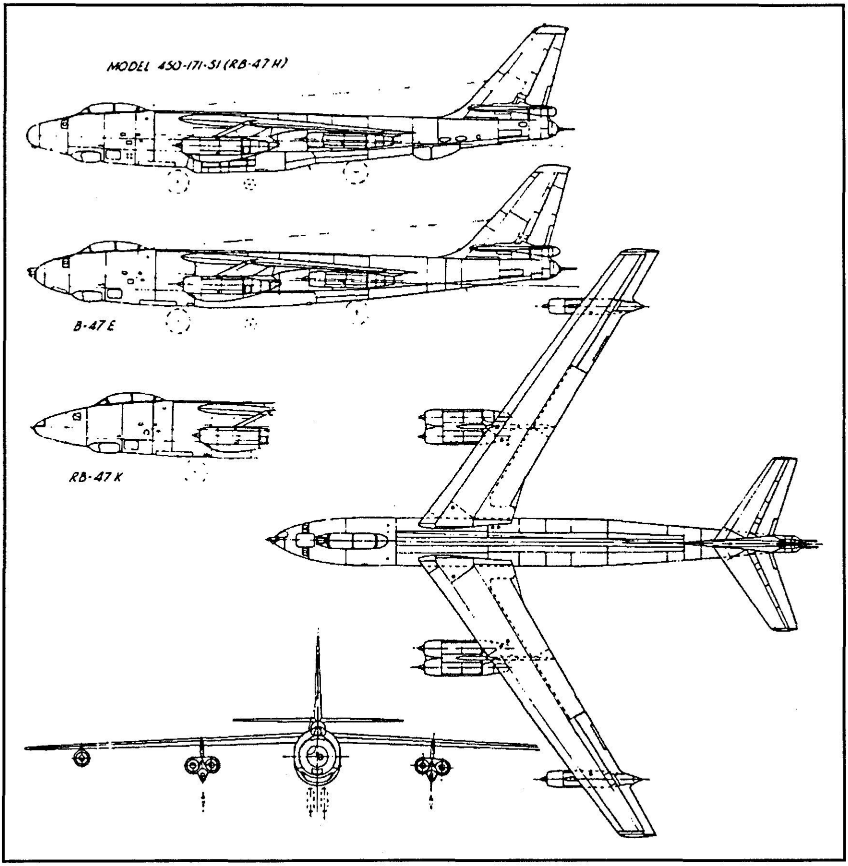
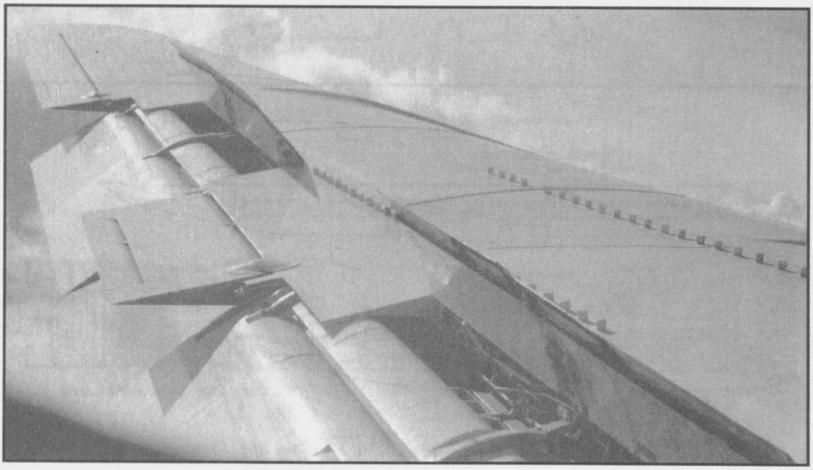


Figure 23. Boeing B-47: Progenitor of Jet Transports. (Courtesy Naval Institute Press)



The double ailerons, flaps, and spoilers of the Model 367-80. The protrusions on the forward wing surface are vortex generators. (Boeing Photo P-15911)

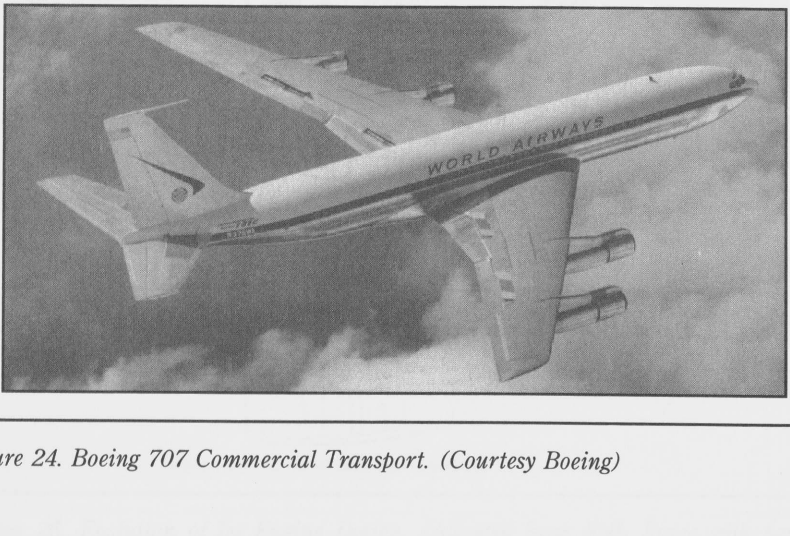


Figure 24. Boeing 707 Commercial Transport. (Courtesy Boeing)

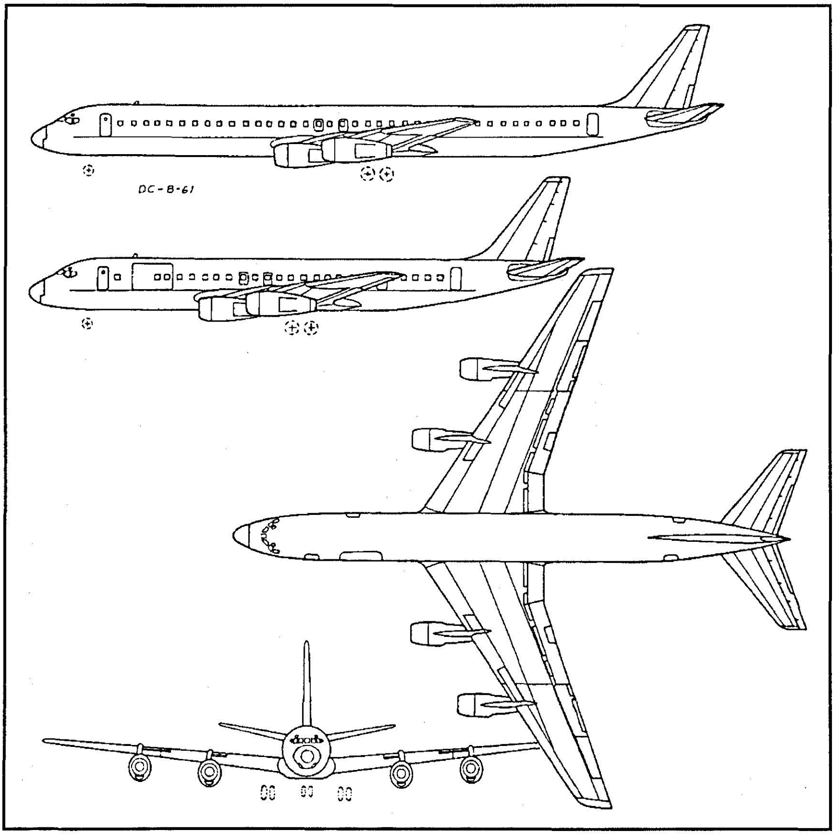


Figure 25. Douglas DC-8 Commercial Transport. (Courtesy Naval Institute Press)

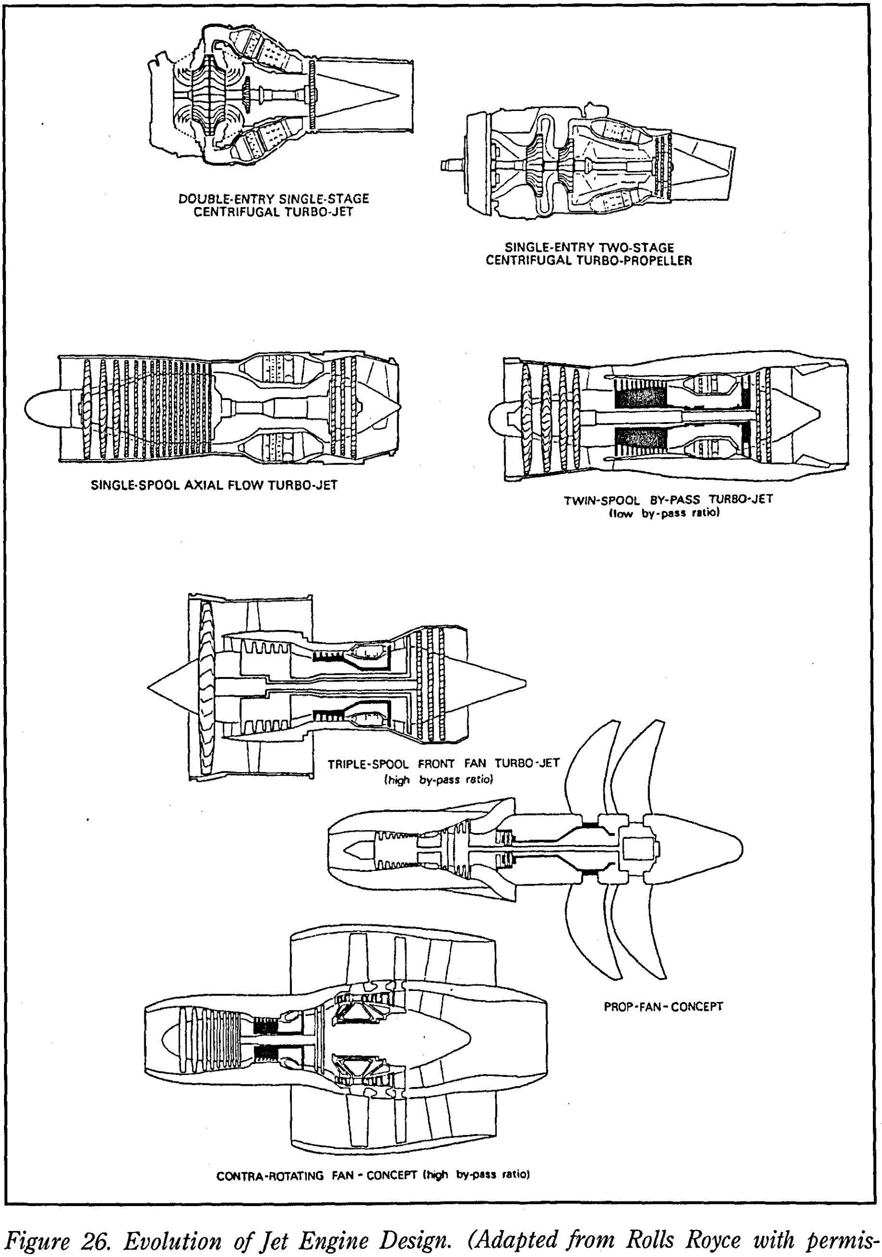


Figure 26. Evolution of Jet Engine Design. (Adapted from Rolls Royce with permission)

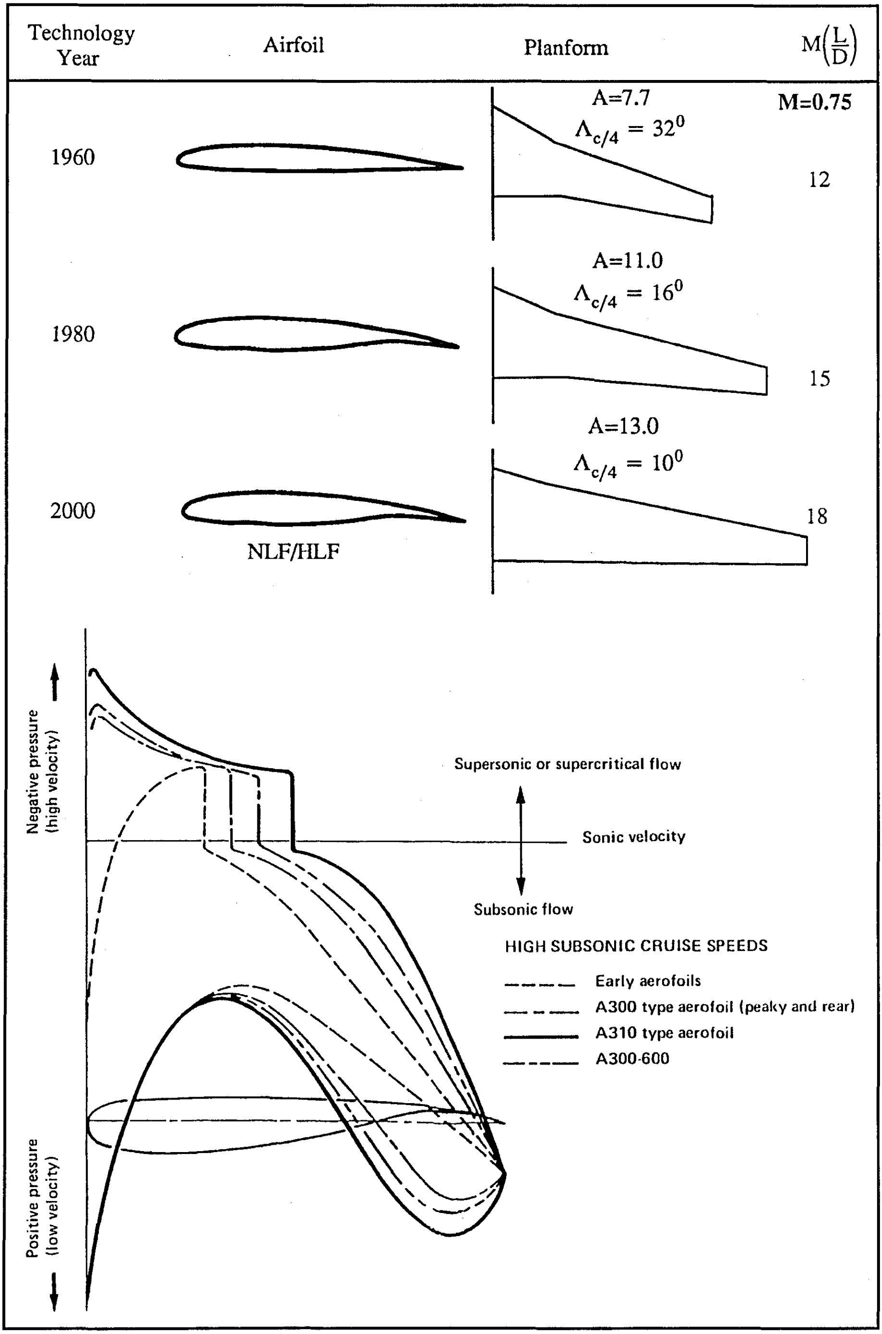
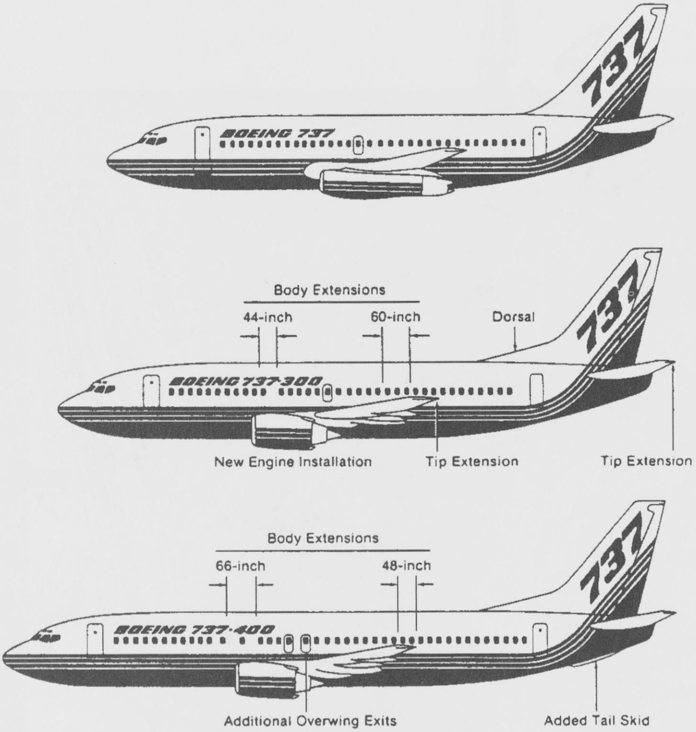


Figure 27. Effect of Wing Aerodynamic Technology on M(L/D) and Pressure Distribution. (Courtesy H. Wittenberg)



Model 737 growth. Top to bottom; 737-200, 737-300 and 737-400. (Boeing drawing)

Figure 28. Integration of Turbofan Engine and Growth of the Boeing 737. (Courtesy Naval Institute Press [line drawing]; courtesy Boeing [photo])

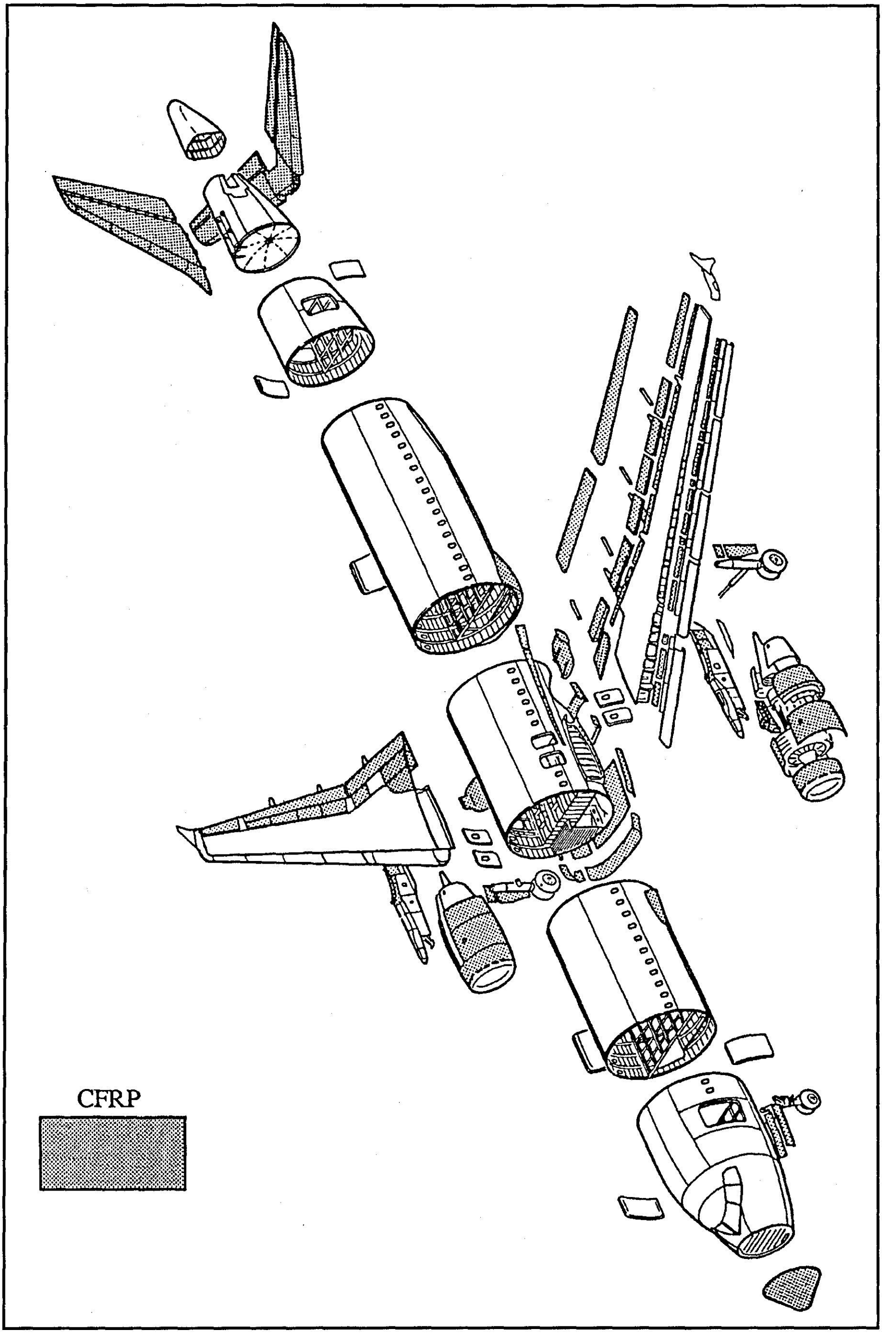


Figure 29. Use of Composite Materials in a Modern Jet Transport. (Courtesy Airbus Industrie 1990)

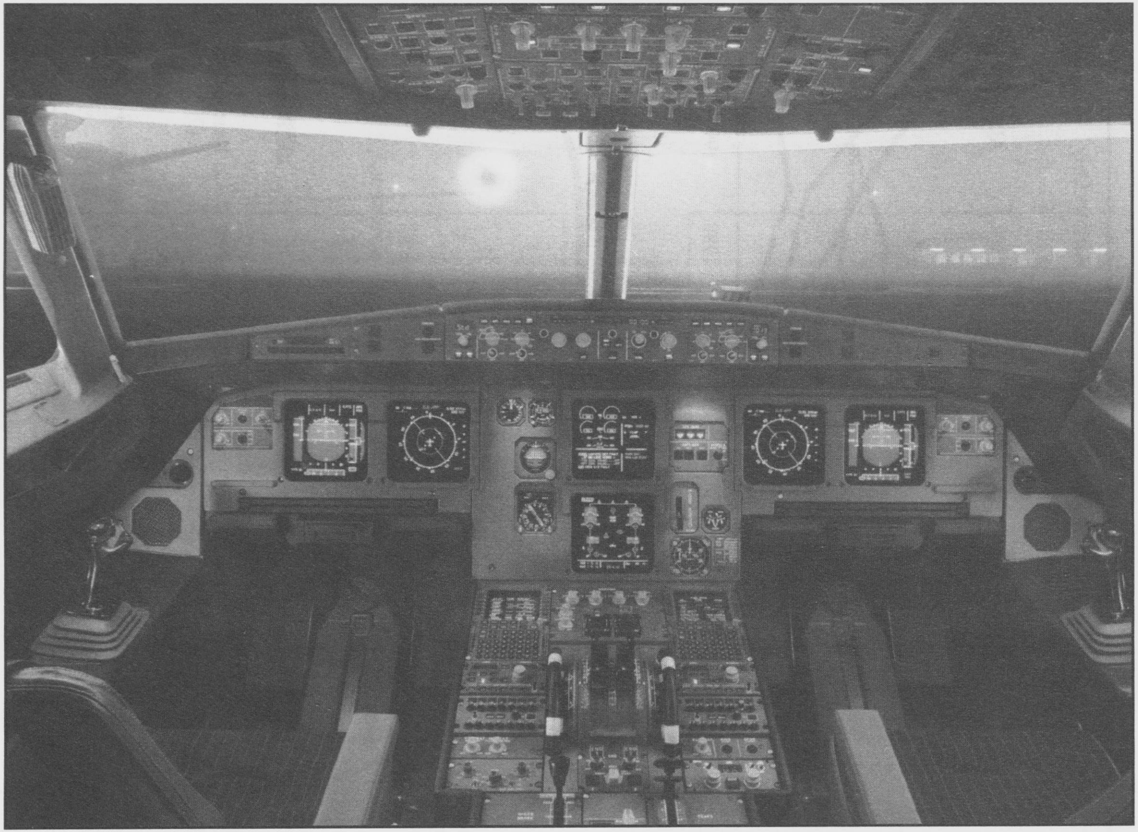
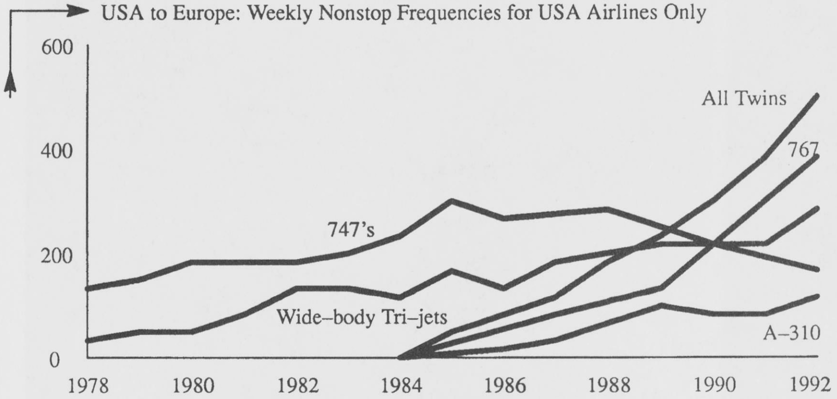
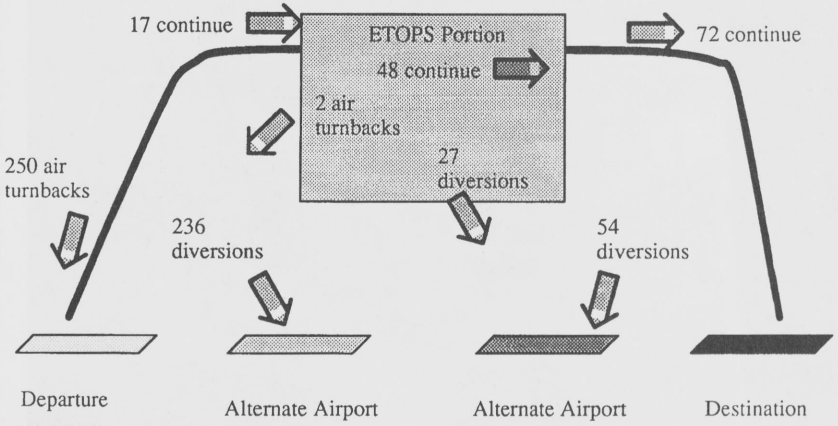


Figure 30. Cockpit of the Airbus A-320. (Courtesy Airbus Industrie 1990)

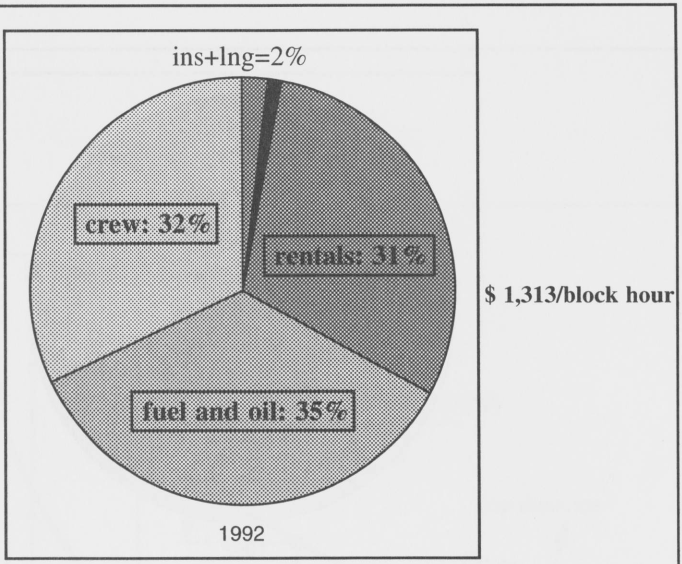


The Rise of the Trans-Atlantic Twins

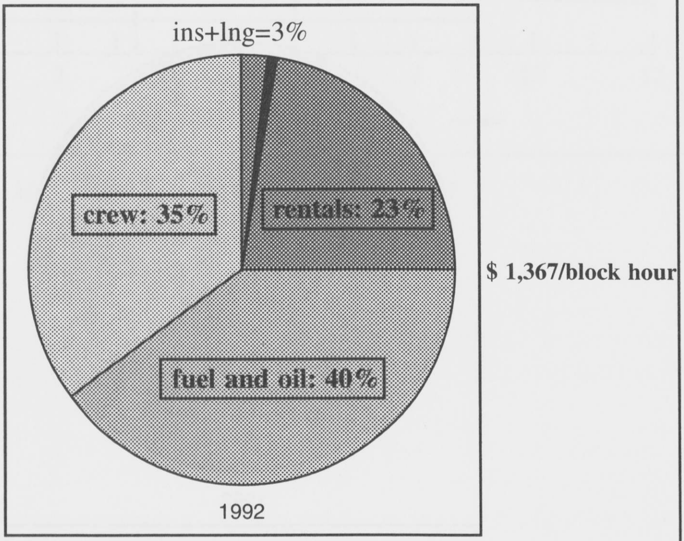


From May, 1985 to December, 1992 the 767 departed for approximately 312,000 ETOPS scheduled flights. The figure shows the record.

Figure 31. The Rise of the Long Range Twin: ETOPS. (Data from Boeing Airliner, July–September 1993)

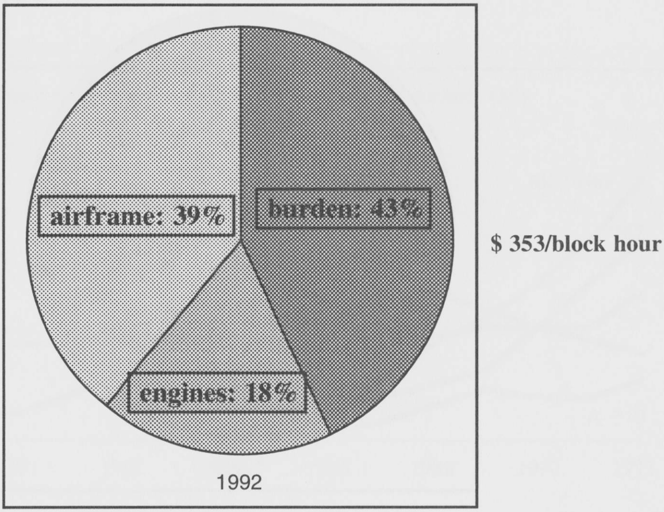


Flying Cost Distribution: B 737-300

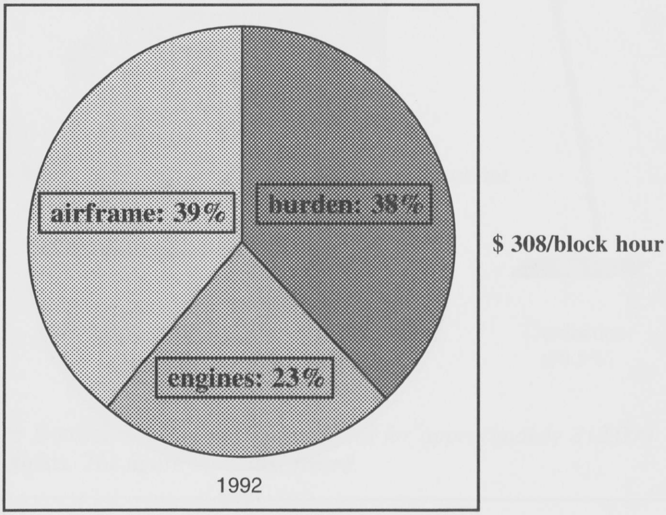


Flying Cost Distribution: MD-80

Figure 32. Flying Cost Distributions for Medium Size Transports. (Data from World Aviation Directory, 1993)



Maintenance Cost Distribution: B 737-300



Maintenance Cost Distribution: MD-80

Figure 33. Maintenance Cost Distributions for Medium Size Transports. (Data from World Aviation Directory, 1993)

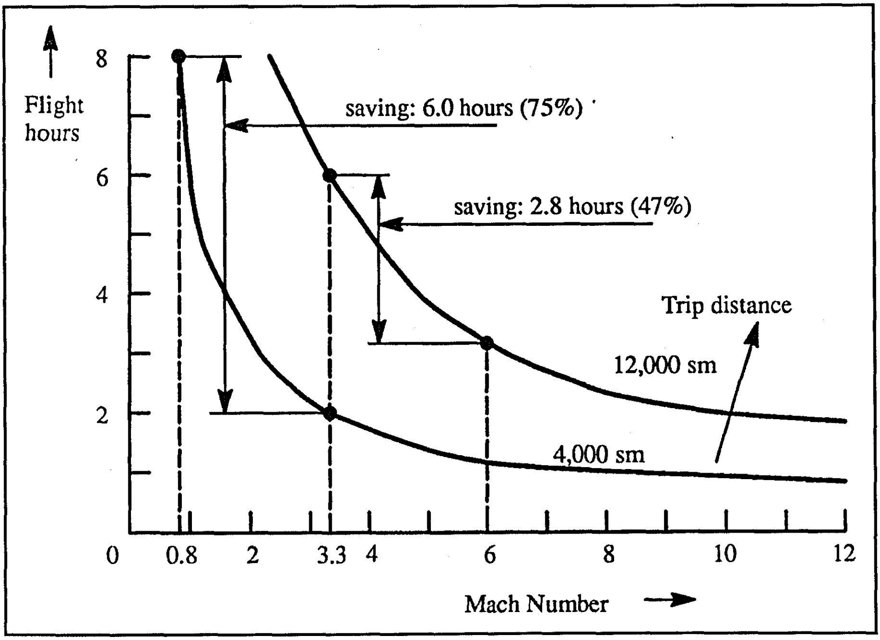


Figure 34. Effect of Mach Number on Trip Time. (Jan Roskam)

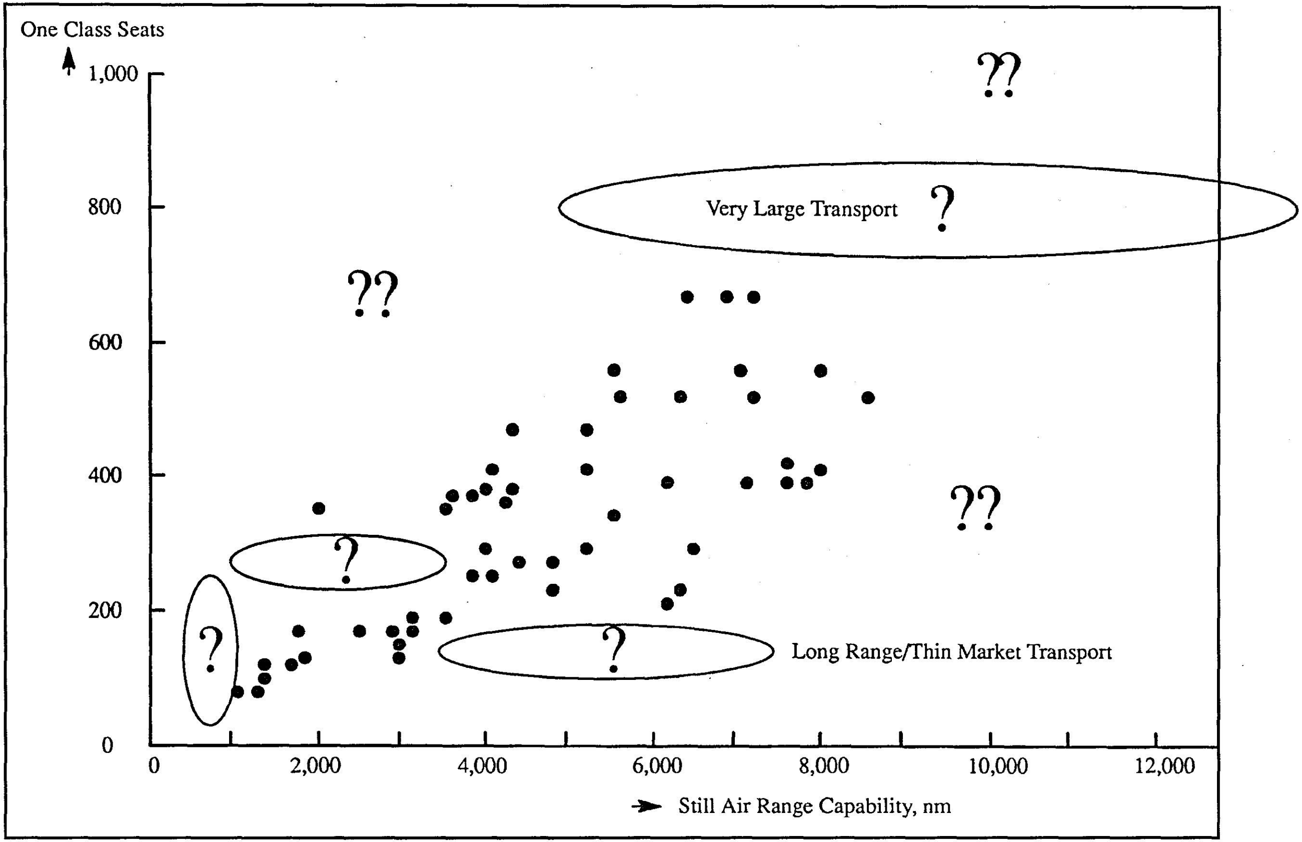


Figure 35. Seat Range Capabilities: Available or Planned. (Jan Roskam)

Prospects for Lighter-Than-Air Aircraft

James Thiele
President
American Blimp Corporation
Hillsboro, Oregon

Introduction

A balloon first carried man aloft. An airship first powered man across the sky. Both events were fundamentally important to the development of flight. Today the science of flight has progressed well beyond lighter-than-air. Still, even in the world of stealth fighters and space shuttles, lighter-than-air flight brings certain unique benefits. Although not highly visible, lighter-than-air flight is making a comeback.

With increasing pressure for efficiency and cost effectiveness, it is now being realized that many missions currently flown with conventional aircraft are best performed with lighter-than-air (LTA) aircraft. It will continue to take time to build the political support necessary to rebuild the infrastructure of LTA. However, this is currently underway with new programs in both the commercial and military markets.

LTA Basics

LTA vehicles are unique in that their primary lift is generated by lifting gas buoyancy. There is no continuous expenditure of energy required to maintain this lift. They are of course large in volume in order to contain this lifting gas and thus have relatively high drag. In the spectrum of speed and endurance, they are low speed, long endurance aircraft.

Air density is critical for LTA buoyancy because it is the difference in the mass of the lifting gas, generally helium, and air that results in the buoyant force. The higher the density altitude the less the difference is for a given balloon size. Most airships are flown at altitudes less than 5000 feet and most tethered balloons are flown at altitudes less than 15,000 feet. Buoyancy increases in the winter and decreases in the summer. The following discussion of LTA performance assumes these altitude limitations in normal summer temperatures.

Lift to drag ratios for a typical airship configuration vary with size and speed. A small airship at high speed is the worst. A 4000 pound gross lift airship at 60 mph has a basic L/D of approximately 5. As the airship size and gross lift increase, and/or as the speed decreases, overall vehicle L/D increases. A 150,000 pound gross lift airship at 40 mph has a basic L/D of 40. This is approximately the size of vehicle currently under study by ARPA for military purposes. The largest airships built to date had a more than 500,000 pound gross lift and at 30 mph had an L/D approaching 100.

Empty weight fractions must be addressed to make a meaningful comparison of efficiency with the airplane or helicopter. Unfortunately that data has not been compiled for modern airships but an empty weight of 2/3 gross buoyancy is not uncommon with current airships. This is well within the range of many other aircraft types. The unusually large L/D ratios possible with LTA are real and the results compare favorably with other aircraft types.

Endurance

Obviously with airspeeds of 30 to 60 mph, vehicle range is drastically affected by winds. Nevertheless, when considering a low speed mission such as border patrol or search and rescue, the airship can easily outperform low speed airplanes or helicopters. An endurance of 24 to 48 hours is straightforward, and an endurance of several hundred hours is possible with some preparation. In 1957 a Navy ZPG-2 airship departed Massachusetts and completed a transatlantic circuit east to Europe, then to Africa and back across to North America for a 264 hour (11 day), 8216 mile un-refueled flight. This record stood as the longest un-refueled flight until the Voyager airplane. With a purpose built airship operating in the extreme case, an endurance of more than 1000 hours might be possible.

Heavy Lift

A significant drawback exists for the airship as a result of this continuous, no energy lift. The lift cannot be regulated other than to let gas go and decrease the buoyancy. Some second order changes are available by heating or compressing the gas but the energy and weight costs for these strategies render them practically useless. As a result, the basic airship is not well suited for heavy lift although it can in fact lift heavy payloads. It cannot however off load this payload without taking on an equal amount of ballast. Only in special cases is this ballasting routine feasible.

A popular approach to solving heavy lift problems is the hybrid airship configuration. In this case the buoyancy of the airship is combined with a wing or rotor to vary the total lift. Another way of looking at this approach is to consider a helicopter or airplane with a balloon attached to offset the vehicle weight. In theory, these approaches might yield good results, but in practice they have generally been burdened with the combined limitations of both LTA and heavier-than-air vehicles with few realized performance benefits.

Two important variations of LTA that represent two extremes are free flying balloons and tethered balloons. Free balloons effectively have no drag and therefore have infinite L/D which can yield impressive results. High altitude scientific balloons have stayed aloft more than two years and made 50 orbits of the earth. At the other extreme, tethered balloons have drag but effectively have a built-in resistance force. A tethered balloon can also off load payload weight without ballasting since the excess buoyancy can be carried in the tether.

Large Payloads

One trait that is common to all LTA vehicles is payload volume capacity. Some payloads, namely radar dishes, are large but lightweight. The balloon itself provides a natural fairing for an internally mounted radar dish that can be much larger than that carried by an airplane or helicopter. At the same time, the LTA vehicle can far exceed the endurance capacity of the competition. Both tethered balloons and airships have proven to be extremely effective radar platforms. They also have the added benefit of being benign low vibration, stable platforms.

Mooring

Experience has shown that the safest place for an airship or tethered balloon is in flight. Parking the airship on the ground presents many challenges. Generally a mooring mast is used to restrain the airship while allowing it to rotate into the wind. The dynamics of these mooring systems in turbulent winds is quite complicated and the mooring loads typically exceed any in flight loads.

Ground handling, which is the period between flight and mooring, during which the airship is moved along the ground, is when most accidents occur. Frequently this is because it is during bad weather that the airship is being retrieved and placed onto the mast. Another common ground handling accident is going into or out of a hangar. Frequently the hangar and the hangar doors themselves create large scale turbulence that affects the airship at a time when precise control is necessary. Many experienced LTA experts feel that ground handling is the single most important area for improvement in LTA.

Snow also presents problems while moored. During flight, snow blows off the balloon and, for as yet unexplained reasons, ice does not accumulate either. While the airship is moored snow can pile up on the back of the balloon and on the fins, actually crushing the balloon into the ground. Snow can represent a significant limitation for LTA.

Figure 1. Thermal Airship, Thunder and Cold Balloons AS-100. (Courtesy The Association of Airship and Balloon Constructors)

Sport Balloons

The most common free balloon today is the manned hot-air balloon. The hot-air-balloon does consume fuel for heat and thus lift. As such, it is endurance limited but overall is inexpensive ($15,000) and well suited for recreational use. Hot air or thermal airships have been flown too. They also are endurance limited but fairly inexpensive ($75,000). The principal dilemma with a thermal airship is that the faster the airship flies the more it cools and the more fuel it consumes for heating. The typical thermal airship is limited to only a few hours endurance. An advantage of the thermal airship is the ability to vary the buoyancy with the heating. One successful application of the thermal airship is carrying an observation raft into the jungle canopy, dropping it off onto the trees and returning a few days later to retrieve the raft and the observing scientists, all the while leaving the forest canopy undisturbed.

High Altitude Scientific Balloons

High altitude scientific balloons have been used for decades to carry scientific instruments into the stratosphere. They are unmanned and controlled by telemetry. Modern plastics have improved the performance and reliability of high altitude balloons. There are many types flown for many purposes. Payloads of 8,000 pounds carried to 100,000 feet for a 100 hour flight are not uncommon. This is above 99.9% of the atmosphere and is virtually as good as space for many scientific purposes. Because the payloads do not need to be hardened for rocket launch, they are cheaper and the development time is much less. A scientist is lucky to get more than two payloads into space during his career but can get numerous balloons into the stratosphere. There is even now a plan to carry balloons to Mars for atmospheric observations.

Aerodynamically Shaped Tethered Balloons

Modern high performance tethered balloon systems that employ aerodynamically shaped hulls with inflated tail fins are called Aerostats. This aerodynamic shape gives better performance in high winds and improves payload stability. They too are unmanned. A typical large system is 230 feet in length and carries a 5000 pound radar to 15,000 feet in winds up to 60 knots. It flies on a single 1 inch diameter tether line that incorporates Kevlar for strength and also includes copper wires for power up the tether and fiber optics for communication both up and down the tether. Normally this type of system is flown for approximately two weeks at a time and then returned to the ground for maintenance and inspection. With two balloons per site it is possible to maintain nearly continuous all weather observations.

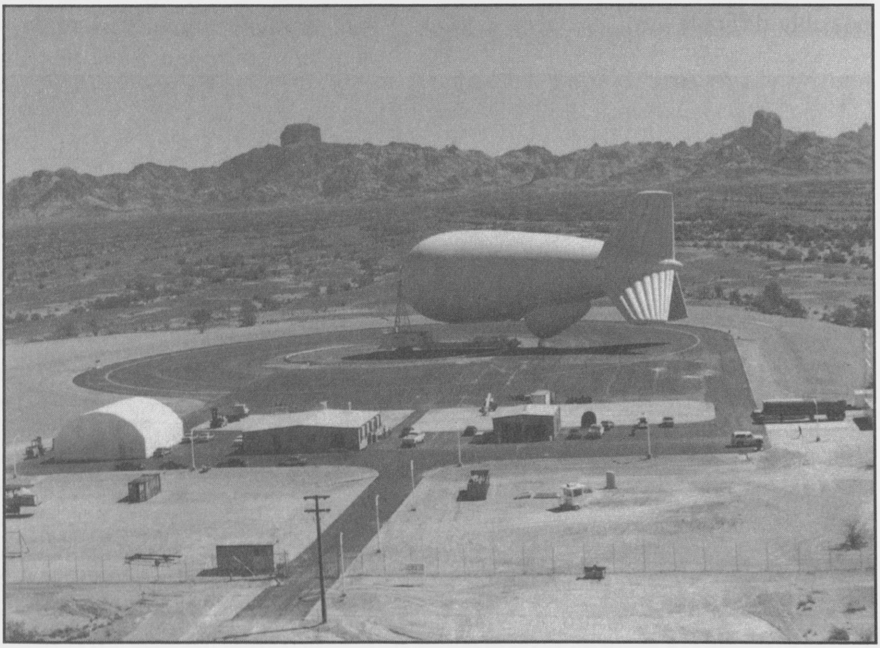


Figure 2. Large Aerostat Tethered Radar—TCOM 71M. (Courtesy TCOM, L.P.)

Currently 16 tethered balloon sites of this type across the southern United States, the Bahamas and Puerto Rico form the Southern Border Barrier of the Low Altitude Surveillance System operated by U.S. Customs and U.S. Coast Guard for drug interdiction. A similar system in Kuwait gave the first warning to the Kuwaiti Air Force of the Iraqi invasion, and that warning provided sufficient notice to permit the Kuwaiti royal family to escape the country. These systems have also been used as relay stations for TV and telephone communications.

Smaller tethered balloon systems, approximately 100 feet in length, have been used for payloads of 1000 pounds to altitudes of approximately 3000 feet. They are generally transportable systems for either land or sea basing. They have been used both to carry radar and to carry very low frequency (VLF) radio antenna. Rapid deployment of these systems has been demonstrated successfully.

Heavy Lift Tethered Balloons

Heavy lift tethered balloons have been used successfully for aerial logging. The balloons are conventional round balloons that stand approximately 175 feet tall. They typically lift more than 25,000 pounds and fly on a 1.25 inch steel cable connecting two huge winches. Normally the flight distance is one mile but may be extended up to three miles. The system works particularly well in steep terrain where other methods of logging become impossibly difficult.

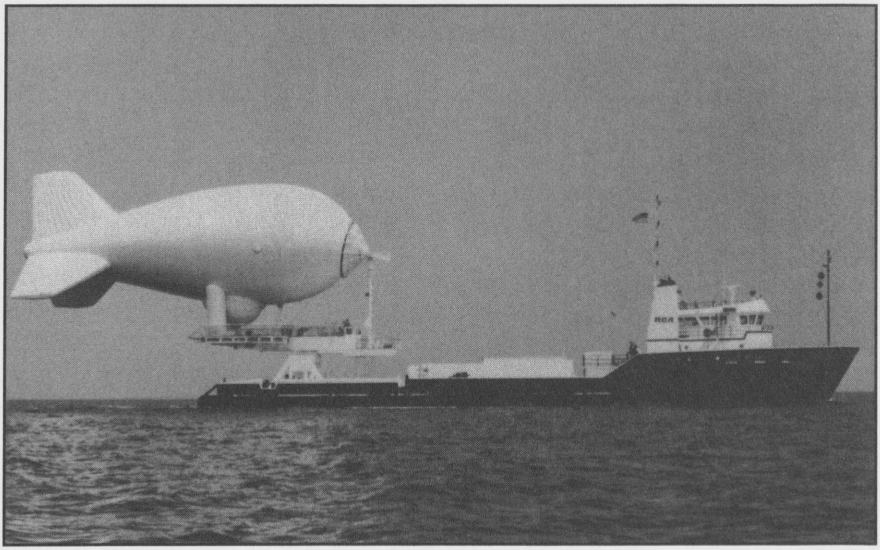


Figure 3. Sea Based Small Aerostat Tethered Radar—RCA 45K. (Courtesy ILC Dover, Inc.)

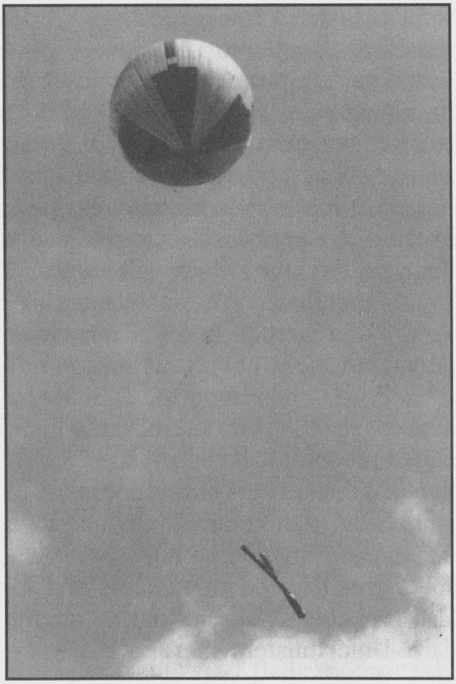


Figure 4. Heavy Lift Logging Balloon—Skyhook 620K. (Courtesy Skyhook Enterprises Ltd.)

The logging balloon is finding particular favor in western Canada. Much of the harvestable land is in valleys 2000 feet deep. The bottom 1000 feet has already been logged by conventional methods. The upper 1000 feet must be logged with aerial methods. Helicopters are one alternative but bring the wood out so fast that the local transportation system for the wood is overloaded. Outside help must then be brought in. The result is that 10 years of local harvest is removed in one season, with most of the money going to outside labor, fuel for the helicopters and parts for the helicopters. This does not help the local economy. The balloon on the other hand brings the logs out at a normal pace and the local transportation system is enough. Balloon logging is labor intensive and it is easy to train conventional timber workers how to balloon log. Thus, most of the money is spent on labor and circulated through the local economy. Additionally, balloon logging is an environmentally clean method of harvesting timber. For these reasons balloon logging is finding widespread support.

Heavy lift balloons have also been demonstrated for ship to shore loading. The idea is to establish a method for handling large parcels from container ships in unimproved ports. Successful demonstrations were flown using existing logging balloons and partially filled containers. A dedicated system for ship to shore will require larger balloons and so far has not been further explored.

Airships

Airships, or dirigibles, are powered, steerable balloons. The word dirigible is French and means "directable". There are three main types of airships: rigid, semi-rigid and non-rigid. Rigid airships depend solely on a structure for their stiffness and non-rigid airships, or blimps, are solely pressure rigidized fabric. Semi-rigids are hybrids of the two that usually have a keel structure attached to a balloon.

Today's airships are all non-rigid or blimps. This is primarily due to their small size and the quality of current fabrics. An airship must be very large (more than 250,000 pound gross lift) for a rigid structure to become as efficient as a pressure rigidized structure. Even then the pressure rigidized structure has certain advantages, namely it can be designed to lower loads because the occasional extreme load will merely bend or wrinkle it versus the rigid structure which will break.

As mentioned previously, mooring loads are generally the highest loads seen by an airship. In flight maneuver loads are relatively low, 1/2 g over gravity. In flight gust loads are more significant, at 1 to 2 g's over gravity. FAA Type Certification regulations exist which specify gust levels and maneuver conditions for establishing limit loads. Unfortunately, there is no simplified motion model established for airships. Added mass factors, the effective additional mass of the entrained air moving with the airship, cannot be ignored as with common airplane flight dynamics models. Neither can the equations of motion be linearized. As a result, only an elaborate non-linear, six degree of freedom model is available for airships. Aeroelastic effects are also probably significant but no attempt has been made to include them to date. Unfortunately, there is also very little wind tunnel data and virtually no in flight motion data to establish coefficients or verify the overall results. This is an area ripe for further study but clearly full of challenging problems.

Minimizing the operating pressure of a pressure rigidized hull reduces fabric stress and thus weight. The minimum required pressure is directly a result of that necessary to prevent hull buckling during maximum bending. The maximum bending occurs during gust penetration. A significant design factor is damage tolerance at that high stress level. If the balloon is cut, the stress previously carried by the cut fibers pass around the cut. This increases the stress at the leading edges of the cut. For a given fabric and a given stress level, there is a critical slit length where the cut will self propagate. Obviously it is desirable to have a fabric with high tear strength to give a large critical slit length. Currently, this is done more as art than science. An accurate math model for prediction of critical slit length of airship hulls has not been established. This is another area ripe for further study but clearly full of challenging engineering problems.

The airship uses a ballonet, or air balloon, within the helium chamber to compensate for expansion and contraction of the helium. Air is pumped in and out as necessary to maintain a constant balloon pressure. The maximum service ceiling is that point at which the ballonet is empty and there is no more margin for expansion. This is known as pressure height. This becomes one of the fundamental design parameters for an airship.

Fin loads are another troublesome area for designers. Given their size relative to the body the fins do not act as wings but rather significantly influence the overall flow field around the body. There is strong evidence that the actual fin loads are less than that predicted by the current dynamics models even though the overall vehicle motion appears correct. This is likely due to the fins altering the flow field around the body and causing much of the total force generated to be applied directly to the body and not carried through the fin. There is also limited wind tunnel data in support of this notion.

Airship Operations

Currently airships are used commercially for advertising and sightseeing. Goodyear has the old standby GZ-20 airship from 1930's heritage as well as one new turbine powered GZ-22. A German manufacturer WDL has manufactured copies of the GZ-20. The now bankrupt Airship Industries of England produced the vectored thrust Skyship 500 and 600, such as the FUJI airship. American Blimp Corporation produces the Lightship A-60, most notable for its internal illumination. All of these airships are twin engine, cruciform empennage blimps that are quite similar. This is because experience has shown it to be the best all around configuration.

These airships typically travel around the country for their sponsor taking VIP's for pleasure rides and carrying TV cameras over sporting events.

Figure 5. Semi-Rigid Airship—1930's Parseval-Natz PN29. (Courtesy The Association of Airship and Balloon Constructors)

Figure 6. Modern Blimp—American Blimp Lightship A-60+. (Courtesy American Blimp Corporation)

The airships sell for $1.5–$10 million and are available for charter at $1000 to $5000 per hour. The commercialization of airships for advertising will continue to grow but will saturate relatively quickly.

There are some manufacturers gambling on the government and military uses of airships. Most notable is Westinghouse Airships, which acquired the military business of Airship Industries with hopes of creating a platform for its radar products. In the end, this is probably the market segment with most growth potential but the highest front end costs.

The Future for LTA

One of the most common dreams for airships is to recreate the luxury of the Graf Zeppelin as an airborne cruise liner. Unfortunately, this will probably remain as just a dream. Even the Zeppelin Company operated at a loss, not withstanding German government subsidies. Numerous modern studies have reestablished the cost of this kind of development as beyond any profit potential.

Another favorite airship dream is for long distance cargo hauling. Again this is unlikely because the niche between a cargo ship and a cargo airplane is small and they both have a well established infrastructure. There is probably a small future for cargo hauling to remote, unimproved sites. This will most likely be done with airships first developed and created for another purpose.

Advertising airships will likely be improved with video screens on their sides, as in the movie Blade Runner. Ground handling may become more automated and the airships more refined. The only significant growth in this market will be in foreign countries that do not currently have airships. The market will likely top out with some form of government regulation of aerial advertising.

Government applications for airships and tethered balloons include border patrol, police, search and rescue and military surveillance. Military surveillance by airship is becoming a higher priority as both the Strategic Defense Initiative and the Air Defense Initiative have shown satellites and airplanes unable to provide defense against small, low flying cruise missiles. Some believe that the airship is the only vehicle capable of carrying large aperture radar operating in the proper frequency bands to see these new threats. If this proves to be the case, it is very likely that airships will once again fly for the military.

Automatic Controls in the History of Unmanned Aeronautical Systems

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Introduction and Scope

Unmanned aeronautical systems are atmospheric flying vehicles that do not carry a pilot as "mission equipment." The popular term is UAV, for Unmanned Aerial Vehicle. Also in common usage is RPV (Remotely Piloted Vehicle). These terms are often used as synonyms, but UAV is a more general category. A completely autonomous vehicle is a UAV, but is not an RPV.

The first topic in this paper is a lengthy but less-familiar history of unmanned vehicles through the end of World War II. The presentation uses an array of graphics and cites selected system details. The reader is expected to notice the missing element in those vehicles. It is not airframe or propulsion technology, but rather a simple and effective means to steer them.

Accordingly, the typical approach to UAV airframe stabilization and control is discussed, continuing into a list of common UAV navigation systems and methods. Aspects of the intercept problem are also mentioned briefly.

Modern UAVs are not really new ideas, just more sophisticated machines due to advances in electronics and sensor technologies. Several of these technologies in current UAVs are listed and discussed, primarily within the context of the author's career experiences. A few of the more recent weapons and related UAV applications are presented.

The paper concludes with a short summary.

A History of Early Unmanned Systems

The earliest successful unmanned flying machine was the work of Professor A. M. Low at the Royal Flying Corps in the early years of World War I.[1] It is true that Dr. Elmer Sperry had a working autopilot as early as 1912, but his airplane required a human pilot.[2] Professor Low intended to build a flying bomb that could be guided remotely, but his intentions were disguised by calling his machine "AT" (Aerial Target).

Low's configurations were monoplanes with rectangular landing gear (Figure 1). The landing gear was probably intended for a single takeoff, because propulsion was a 35 hp engine rated for a two hour life. Low intended to make the machines so stable that an automatic stabilization system wouldn't be required. His focus was development of radio controls. Low's oversight would not be recognized until after World War II, although some of his attitudes were probably driven by the technical limitations of his era.

Several of Professor Low's machines failed at takeoff, a problem that can be tricky even with the more polished methods and apparatuses used to launch unmanned vehicles today. Takeoff was risky even in early manned aircraft. World War I fighters had no nose gear or tail wheel steering to battle crosswinds and yawing from the propeller.

Unmanned vehicle tactical success was reported in 1919 when Dr. Sperry sank a captured German battleship with a pilotless aircraft.[1] Details of the event are somewhat murky. Figure 2 shows a configuration believed to be similar to the aircraft used to sink the battleship. Notice the clever use of railed landing gear wheels to assist the takeoff directionally, avoiding Low's trouble.

The Germans were also active with development and testing of a few unmanned vehicles during the Great War. Figure 3 shows a glide bomb configuration released from airships. It was flown using electrical signals on fine copper wires unwound from a spool. The fuselage and wings split apart to launch a torpedo just above the water. Flight control was direct application of rudder and elevator (no gyros). The rudder was a tri-state control device that was recentered after a command. The elevator must have been similar to a stepper motor because it remained in its last commanded position when released.[3]

Work was also being done during the early years of manned flight to create stability augmentation systems and autopilots for manned aircraft.

Just as full-scale aircraft have been droned for use as targets, early autopilot and stability augmentation systems for manned aircraft established a technical basis for the first unmanned automatic flight controls. Whether manual or augmented, the idea is to make the operator workload easy enough to complete the mission safely. It isn't supposed to matter whether a pilot is sitting in the cockpit or a chair at some remote control site. The unmanned system, however, becomes more complex when *the entire mission* is managed by an onboard, electronic intelligence.

Despite limitations in early automatic flight control systems, it is remarkable that a lot of the conceptual thinking didn't change as analysis methods and hardware systems were improved. A good listing of the early manned autopilot systems with some of their features is given in McRuer, Ashkenas, and Graham's classic text.[4] Further improvements in precision and reliability following World War I were sought as aircraft became more capable in range and endurance.

Not much was done, however, in automatic controls for unmanned vehicles until another war provided a stimulus.

An interesting footnote between the wars was Russian activity to develop surface-to-surface missiles. It has been reported that their configurations looked like a conventional monoplane, were roughly ten feet in length and span, and carried a liquid rocket propulsion system. Weight was close to 500 lbs, and range was 30 miles. The more advanced versions had some sort of autopilot for control, but no guidance.[3]

To make the distinction between control and guidance, this author prefers to use stabilization and control as equivalent terms. Control implies an ability to direct the states of the vehicle (such as airspeed, attitude, and orientation to the flight path) from one set of values to another. Guidance is the movement of a *controlled* airframe to one or more desired points dictated by the mission requirements. This perspective will be revisited later.

The British spent some time between the wars converting some of Professor Low's early designs into target drones (Figure 4). Later vehicles were the first ship-launched cruise missiles called Larynx (Figure 5). Automatic control of these vehicles was a combination of onboard augmentation and external radio control. Flight control was strictly a combination of rudder and elevators for course control and altitude keeping. Engine performance was 220 hp. Ordnance payload was a 250 lb bomb in the more developed systems.

German unmanned vehicle activity before World War II had its focus on a number of developments. The first German vehicles to be developed and fielded were air-launched glide torpedoes. It is likely that the Germans were distracted by the huge disparity between their military and maritime navies and those of the British. Curiously, they chose to ignore developing a lot of air-to-surface UAV capability in favor of the submarine, or U-Boat. The *Friedensengel* L10 glide torpedo (Figure 6), properly integrated to their huge multiengine *Amerika* bomber, would surely have done more damage to the Atlantic convoys than the U-boats.

Although there were key advances in electronics through the war—radio, radar, infrared sensing and even television—automatic controls remained crude. Some people had already concluded that autopilots weren't needed for small aircraft with limited range and endurance. If that were true, then why should an expendable, unmanned vehicle with an even shorter time of flight require an autopilot?

Unmanned Vehicles in World War II

With notable exceptions such as remote sensing and reconnaissance, unmanned tactical and strategic weapons were developed by both sides for largely the same purposes used today. The Germans, however, were far more involved (and advanced) in developing unmanned vehicles. Most people are aware of the Fieseler Fl 103, or the V-1 "Buzz Bomb" shown in Figure 7.

This first practical cruise missile merged a novel pulsejet engine, magnetic compass controlled rudder, barometric altitude controlled elevators, and an air-log propeller to time the flight. Cruising altitude was only 2500 feet MSL. These weapons could be shot down easily thanks to early detection by radar. On the other hand, they were slow enough (350 KIAS) that pilots would fly alongside and tumble their heading compass gyroscope by flipping them over with a wingtip!

A most unusual German design was the Blohm und Voss Model 246 glide bomb (*Hagelkorn*, or Hailstorm). It was carried by aircraft as small as a Focke-Wulf 190, but its primary mission should have been a standoff glide bomb against heavily defended surface targets or shipping. Figure 8 shows why: because the extremely high aspect ratio wing (25.5:1) created a glide ratio of 25:1!

A novel approach to bending stiffness in this wing was to build it from steel cores and airfoils from die-cast *concrete*. Wing loading was an amazing 102 psf. Several different guidance schemes were tried using radio, infrared, and even a form of beam-riding similar to the ILS localizers used today. Passive radar homing was also attempted.

The most successful German air-to-surface missile was the FX 1400, dubbed "Fritz X" by the allies (Figure 9). This design had propulsion and was controlled with spoilers in the tail. It sank a number of allied capital ships in the Mediterranean until fighter cover was coordinated to drive off the bombers that carried the "Fritz." The airframe had roll stabilization with a vertical gyro blended into the controls. It was optically guided by remote radio control into the target.

Believing the British capable of jamming its radio command systems, Germany solved the secure command link problem with the Henschel Hs 293 (Figure 10). It was guided over wires reeled off bobbins in the wing. It was flight tested at ranges as long as 19 miles! Other versions were developed using traditional radio and even a television link. The television and radio versions, however, were limited in range by the electronic state of the art to just a few miles. A remote operator flew the non-video versions using flares on the wingtips as visual cues until intercept. Several ships were also sunk by this weapon.

The Germans were also very active in surface-to-air weapons, or SAMs. Two of their designs called *Wasserfall* and *Rheintochter* (Waterfall and Rheindaughter) never achieved the notoriety of the V-1, but were unusually advanced for their time. *Wasserfall* was a true Mach 3 SAM based on the infamous V-2 design of Wernher von Braun. It had *graphite* control vanes in the exhaust plume to steer the thrust vector (in addition to conventional aerodynamic control surfaces at its tail). It used dual pencil beam radar illumination of target and missile to provide the remote operator with a pair of sightlines to guide the device into intercept.

Rheintochter was a powerful SAM launched from a converted 88mm gun mount (Figure 11). Particularly impressive was its propulsion: a 165,000 lb booster thrust for 0.6 seconds, and ten seconds of sustainer thrust at 8,800 lbs. Given a launch weight near 3500 lbs, the booster creates a 50g launch acceleration—an ambitious and demanding environment for controls. The sustainer thrust ports can be seen between the set of six mid-body swept wings. Guidance was optical tracking of wingtip flares (like the Hs 293), with a human operator using a joystick to manipulate the all-moving nose fins by radio command.

Rheintochter was developed in two versions for the *Wehrmacht* (Army) and the *Luftwaffe* (Air Force). Performance stressed priorities of the two services, but both were intended to be a high subsonic, high altitude anti-bomber weapon near 0.9 Mach.

Two German SAM designs considered successful by the German High Command were the Henschel Hs 117 *Schmetterling* and the Messerschmitt *Enzian*, or the Butterfly and the ironically named Gentle Violet (Figures 12 and 13). The small Me 163 manned rocket plane used in desperation to ram allied bombers at the end of the war is very similar in appearance to the *Enzian*.

Schmetterling was ground and air-launched, but was useful only within visual range. When fired, the pair of upper and lower boosters accelerated the 1000 lb launch weight to more than 550 KIAS in four seconds, and then separated. An 800 lb sustainer was regulated with onboard control to slow the missile down to maintain cruise airspeed near 450 KIAS. The vehicle was guided by a remote operator over a radio link, but had to be detonated manually—a key deficiency in its performance.

The *Enzian* suffered the same fate as modern RPV programs such as the Lockheed Aquila. Conceived as a simple device, military planners kept modifying the mission requirements until the entire project was stopped in early 1945. Keeping the multiple thrust devices properly managed was a major deficiency not related to its political problems, as was the search for a suitable guidance system.

Except for the supersonic *Wasserfall*, the German SAMs were all flown in the high subsonic regime near 0.9 Mach, and had altitude capabilities consistent with the allied bomber threat above 20,000 feet. Range for most of these missiles was approximately 15 nautical miles.

Major successes in German missile weaponry, however, were a pair of air-to-air systems called Henschel Hs 298 and another of Dr. Max Kramer's "X" weapons—the X-4 (Figure 14). Unlike the "dumb" *Vergeltungswaffe*, or Vengeance weapons (V-1 and V-2), these two systems prosecuted a military objective rather than civilian population centers. The X-4 had small wing tabs that were intentionally bent to roll the missile slowly.

A pair of control wires spun off from bobbins at the wingtips, and the launching pilot flew the missile into the enemy aircraft from behind with a joystick. There must have been some form of roll attitude sensing or equivalent scheme to sort out the radio commands to the tail surfaces as the X-4 rolled. The influence of downwash and wake behind a lifting surface was also appreciated by the designer, because the cruciform wings and tail were not in line with each other. There was even an anti-tank version (X-7) that tried to use a variety of guidance schemes such as manual visual aiming, infrared homing, and even a television vidicon sensor. None of these X-7 *Rotkappchen* (Little Red Riding Hood) had matured technically by war's end.

There is a very interesting episode on a few of these "secret weapons" on the popular television program "Wings." Some of the flight test video gives an appreciation for tactical problems associated with remote missile guidance.

Although the Germans were active in developing unmanned guided weapons, America was not unaware of their military significance during World War II. But as in Germany, unmanned guided weapons had detractors among allied military planners in America.

Two very early unmanned American weapon types were called "BG" and "GB" (Bomb Glider and Glide Bomb). Both types were frequently called "Glombs," an obvious compression of two words into one. Bomb Gliders were simple gliders fitted with radio controls and as much ordnance as could be loaded into the airframe. The tactic was to tow the glider to a release point, and fly it into the target remotely.

The VB series (Vertical Bomb) was a similar concept to the modern "smart bomb," but initially without an onboard guidance seeker. The first configuration was steerable in AZimuth ONly (dubbed AZON). Later versions had dual axis capability. Tactical use was viewed with suspicion by operational units, because they required loiter over the target to guide the VB into the target. Some of these weapons were fitted later with image contrast devices (the same principle used in the GBU-15 Walleye of today), an IR seeker (forerunner of AIM-9 Sidewinder, but without propulsion), and so forth.

The most successful American air-to-surface system was called BAT (Figure 15). It got its name from similarity to the guidance system used by bats to navigate by listening to reflections. Originally conceived as a television guided anti-ship torpedo called Dragon, the U-Boat threat turned development toward a steerable depth charge claimed to use semi-active radar homing. This configuration was aptly called Pelican.

Tactical success of this weapon, however, was as a radar guided weapon used to sink Japanese shipping, drop bridges in Southeast Asia, and destroy other hard radar targets held by the Japanese. The author has seen this weapon on display, and thinks the twin circular tails may have had something to do with interferometry to sense target azimuth. The famous aerospace pioneer Hugh Dryden was awarded the Presidential Certificate of Merit for his work in helping conceive and develop BAT.

The most futuristic of the American weapons, however, was the Jet Bomb (JB) series. These weapons were developed as surface-to-surface vehicles, although several were air-launched during development. The earliest system was the sinister looking JB-1 (Figure 16), an obvious Jack Northrop creation. The American JB-2 was a reverse engineering of the German V-1 mentioned earlier. Other Jet Bomb designs included an unmanned turbojet bomber (JB-7), and even a spin-stabilized supersonic rocket (JB-6).

The Japanese also tried to develop two major lines of unmanned weapons: the *Funryu*, or Raging Dragon series, and the I-GO-1 models A, B, and C. The initial Raging Dragon weapon had an air-launched, anti-ship mission, as did the I-GO-1 models. All of these air-to-surface types had radio guidance. The I-GO-1-C was planned to home on shock waves from a ship's anti-aircraft guns!

Advanced Models 2 and 4 of the *Funyru* had small autopilots, radar guidance, and a dual beam intercept scheme that resembled the German *Wasserfall* guidance system.

Despite their prowess in codes and Electronic Countermeasures (ECM), a strange aspect of UAVs during World War II was complete lack of British interest. A pilotless wooden airframe using a 1000 lb bomb for payload had no ability to generate enthusiasm, despite its attractiveness when manned bomber losses were heavy. The configuration resembled a scale model of the famous Lancaster multi-engine bomber, but with only a single propeller in its nose.

In all of these UAV systems, the weakness was *guidance* in flying the machine precisely to the intended target. That capability remains elusive, despite impressive results seen during the recent Gulf War. To examine this a bit further, attention is turned toward the automatic controls that fly the UAV.

Unmanned Vehicle Stabilization Approaches and Methods

All airframe stabilization problems begin with a complete list of simplifying assumptions to make an analysis practical. Usual notions of inertial reference frames, rigid body, symmetry of mass properties, constant mass, and so forth may be applicable for General Aviation autopilots, but a hypersonic vehicle that loses over half its mass in a few seconds is clearly a different problem. Figure 17 represents a general model of a feedback control system. It is used to describe an unmanned vehicle, although any simplifying assumptions about the UAV dynamics will be overlooked in the interest of brevity.

The implication of the diagram is that a set of differential equations can be written to describe the motion of the airframe. The motion is influenced by tabulating all the forces and moments acting on the body, and keeping track of the body's motion with respect to a coordinate system that is fixed.

Because vehicle control devices influence the motion, "results" of the equations are measured with sensors such as gyroscopes, accelerometers, pressure sensors, etc., and are combined for return to manipulate the control surfaces. Returning a key variable to a control which influences that variable is called *feedback.*

The usefulness of feedback was understood before World War II. Publications by Nyquist,[5] Bode,[6] and several others showed how a "loose" system could be made accurate and stable using feedback. Feedback could now be applied to *automatically* stabilize an airframe that was inherently unstable! Making an unmanned vehicle safe enough to carry a human was not required, so wider configuration latitude was possible in the UAV.

To appreciate what is meant by "stable" and "unstable" airframe behavior, consider the simple weathervane: it is stable (returns to streamline) when the tail is downwind of its hinge. It is unstable when its tail is upwind, but will "become" stable if the wind keeps blowing. This is an oversimplified way to illustrate why the tail of most airframes is in the rear. A more complete and thorough discussion of aerodynamic stability is found in Chapters 5 and 6 of Roskam.[2]

Proper application of feedback with automatic controls has a desired characteristic that masks airframe dynamics. Suppressing airframe dynamics is desirable, because key airframe stability parameters can vary by an order of magnitude over a vehicle's flight envelope. With feedback, the UAV appears as an object that follows the sequence of commands shown on the far left of Figure 17. The vehicle is *stabilized* using feedback, and is *controlled* by the set of commands.

Mathematical descriptions that transform sensed airframe states and external commands into control device movement are called *Control Laws.* Control Laws are derived from a combination of stability analysis and prior definition of the mission flight requirements for the vehicle. For example, it may be required to steer the vehicle by banking and pitching it. A logical arrangement would be to stabilize the airframe in bank and pitch angles, so steering commands injected at the left side of Figure 17 require the airframe to bank and pitch in response to the commands.

Because bank and pitch can be sensed by a vertical gyroscope, this might be how a simple stabilization system is implemented. Numerous control objectives have been tried in practical systems. A good survey of different flight control systems, with some of their technical considerations and control objectives, is given in Blakelock.[7]

Even with a well-stabilized airframe, technical problems plagued unmanned vehicle guidance through the 1950's and 1960's. John Truxal's classic handbook for control system engineers[8] was published in the late 1950's. It listed an impressive array of hardware and analytical methods to solve control problems in general, but much of it was directed at aerospace applications.

The postwar UAV difficulty was in reliability of electronic circuits and devices, together with the infancy of seeker technology. Vacuum tubes and even the early transistors suffered from poor mechanical stability. Critical characteristics were heavily dependent on temperature and seemed to be in constant need of maintenance and repair. As reliability was improved, unmanned vehicles eventually stopped crashing so regularly—but the more difficult guidance problem remained. Technology advancements in seekers and navigational aids were needed.

Common UAV Navigation and Guidance Schemes

The UAV steering problem is divisible into two categories: navigation and intercept. Purists may argue they are not distinct, but the intent is to segregate steering according to the type of unmanned vehicle mission. The navigation problem is really a cruise management problem. Intercept requires a much faster responding system, one that could be required to defeat a maneuvering target.

The dual purpose machine required to loiter and attack, such as a small battlefield harassment drone, must have the agility to avoid destruction and still defeat the threat.

The pure navigation problem, however, is the simplest of all UAV system requirements. With improving availability of the Global Positioning System (GPS), economical receivers are easily integrated into digital autopilots to fly a UAV anywhere in the world. Accuracy can vary with number of satellites available, relative orientation of satellites to the UAV, and some other factors involving availability of the special military codes and some rather subtle sources of error outside the scope of this discussion.

An inexpensive GPS receiver will navigate a UAV to places where just about any military objective can be placed inside the field-of-view of an imaging sensor. The simplicity of GPS signals (latitude, longitude, altitude, and time) make computer memory requirements much more compact than the earlier cruise missiles that used Terrain Correlation (TERCON). The TERCON system is actually a topographical map of the flight route stored in computer memory. Navigation progress is checked by a narrow beam radar altimeter that is also used for altitude control of the UAV.

TERCON is the technical basis for cruise missile attack of land targets. Advanced cruise missiles have GPS as well as TERCON for even better navigation accuracy.

Moving backward in history from GPS and TERCON to earlier navaids used in the UAV, guidance schemes using Very-Low-Frequency (VLF) OMEGA, Long Range Radio Navigation (LORAN), Tactical Air Navigation (TACAN), and Automatic Direction Finding (ADF) have been put in unmanned vehicles for strategic and tactical applications. Systems using any external navigation aid (even GPS) usually carry some form of inertial guidance or dead reckoning scheme to continue the mission when navigation system(s) are jammed or otherwise not available.

Many nations are trying to develop UAV systems, primarily for reconnaissance. Most of these vehicles are little more than large Radio Control (R/C) aircraft. Small ground stations fly them visually, or by remote operator reference to onboard imaging sensors or plotting board maps. Some UAV's are more capable, such as the Boeing Condor. The Condor is a huge vehicle with a high aspect wing whose 230 foot span exceeds its commercial Model 747! A pair of 175 hp engines with 16 foot diameter props have reportedly kept Condor aloft for days at altitudes above 60,000 feet.

An excellent review of the history and current UAV programs in the world is given by Gerkin.[1] Just about every shape and size of UAV is listed, including the strange Canadair CL-227 Sentinel Hovercraft (Figure 18) and the very similar British Sprite.

The method of navigation, however, in all of these systems is fairly obvious. Systems that only sense a relative bearing like ADF conduct some form of lateral homing guidance. The method is usually a bank to turn strategy based on "pointing the nose" into the homing antenna. Unfortunately, the flight path will be a spiral in the presence of crosswind. Range to the station can also alter sensitivity of the guidance, and it can go unstable without compensation.

Missile guidance systems solve this problem with Proportional Navigation. They also compensate for range by counting down "time-to-go" from launch, which adjusts the angular guidance error sensitivity as the target is approached.

Other older navaids that generate signals of UAV relative location such as TACAN can be used to perform two-axis navigation. That is, the UAV can now know range to the waypoint in addition to its relative bearing. The waypoint can also be offset from the TACAN antenna. Simple mathematical polar to cartesian coordinate transforms are used in waypoint navigation algorithms, but digital range and bearing data make resolution granular at extreme ranges.[9]

The most challenging mission for a UAV, however, is the intercept problem. All the World War II systems discussed above would have been highly successful with an accurate seeker and reliable ordnance fuze. Manually correcting the flight of a missile is just not going to work in real time, when lethal miss distance is on the order of a hundred feet, the target range is a few miles and the closing velocity exceeds a thousand feet per second.

The earliest types of missile intercept methods were also some form of pursuit or command to line-of-sight algorithms. Simple pursuit is just trying to fly the missile into the target by chasing it (or closing on it in an incoming engagement). Deviated pursuit is like the lead a shooter uses to down game on the wing, except that the lead angle needs to be carefully chosen.

Command-to-line-of-sight guidance draws the missile into a tracking sensor's field of view after launch, and then guides the missile up the tracker line-of-sight into the target. This scheme is similar (but not identical) to the dual radar beam in the German *Wasserfall.*

The real basis for modern missile intercept guidance, however, is Proportional Navigation (Figure 19). Aiming a missile to intercept the target (given their present velocities) creates a triangle. If the target maneuvers, the missile must adjust.

There is no need to examine this problem in three dimensions, because it can be characterized with a single angle called the Line-of-Sight-Angle (LOSA). The two-dimensional picture shown in Figure 19 creates scaler control geometry.

The argument is as follows: two bodies are guaranteed to collide if there is a *constant* relative bearing and a *decreasing* range between them. An increasing range says the two objects are separating (no intercept). A constant relative bearing, however, is the same as *nulling* the rate of change in the LOSA. By measuring the LOSA versus time with a seeker onboard the missile, the missile can be continuously guided by computer to intercept.

In continuous time, this method also will defeat a target taking evasive action.

There is a wide gulf, however, between proportional navigation principles and a practical implementation of the scheme. Items as subtle as radar wave bending when passing through the missile radome have been studied since the first air-to-air AIM-7 Sparrow and Hawk SAM's were tested in the early 1950's. Complete treatment of the deeper aspects of the missile intercept problem can be found in Zarchan[10] and Garnell.[11] Zarchan's work is highly mathematical. Garnell is more illustrative.

Modern Aspects of the UAV Technologies

It is unfortunate that a lot of the impetus to develop UAV's was driven by the needs of war. It is true that today's "smart" weapons are little more than technological extensions of seeker and guidance methods available during World War II. An exception is the LASER, whose acronym (Light Amplification by Stimulated Emission of Radiation) is so familiar that it needs no definition. All the rest of the seeker technologies—radar, infrared, and television—are only improved devices in missiles today.

Even the crude but effective wire-trailing command links are common in anti-tank weapons. There is a short range weapon that even uses the modern fiber-optic cable (Fiber Optic Guided Munition, or FOG-M). The larger bandwidth over an optical link allows a huge amount of information to pass between remote operator and his missile, including high resolution video in the seeker's field of view.

It was common knowledge during the Vietnam era that smaller aircraft could outmaneuver the SAM if the enemy missile could be detected. This was due in part to the original mission of the first Russian SAM's (shoot down high altitude nuclear bombers with limited maneuvering). The SAM threat was countered by adding Radio Receivers (tuned to the SAM RF guidance frequencies to warn the pilot) carrying RF Signal Jammers, and dropping metallic strips called CHAFF. The logical counter by the enemy was to make a more agile SAM, which would be countered by better jamming or other tactics, and so forth.

Details of the fascinating history of Electronic Countermeasures (ECM) as long ago as World War II are only beginning to surface from classification. There was a lot of interest in being able to disrupt communications and deceive remotely guided weapons. That interest continues today, and there are a number of heavily classified projects that deal with cryptology and ECM. These systems can be part of the UAV's defenses. The seemingly redundant field of ECCM, or Electronic Counter-Countermeasures, has even been developed to counter ECM!

The first Laser-Guided Bombs dropped during the latter stages of Vietnam were adaptations of a gas guidance head attached to the nose of general purpose 1000 and 2000 lb bombs. The seekers were guided into a hard target by homing on scattered Laser light from a second participant who was the illuminator. The method was dramatically effective by American armor during the recent Gulf War using anti-tank munitions.

Electro-optic technologies have also made unbelievable progress since World War II. Low Light Level Television (LLLTV) is truly able to see in the dark. Infrared technology, most easily associated with the AIM-9 Sidewinder, has exploited advances in low-temperature cryogenics and refinements in materials and processes from the semiconductor industry. May[12] gives a nice overview of the complexities in accurately resolving a target using electro-optics and infrared imaging. The problem is far from trivial.

Reconnaissance UAV's can also carry sophisticated imaging systems. In addition to the LLLTV, scanning infrared devices can be used to image and locate military targets. Modern, high speed digital data links can return the intelligence to an airborne command aircraft. It is almost certain some of this was done in the recent Gulf War. There are also some very capable imaging radar systems called SLAR (SideLooking Airborne Radar). SLAR and imaging infrared systems can have peaceful applications in UAV's for Remote Sensing of weather, land use, mapping, and surveying.

A key aspect of the UAV is its ability to perform a mission considered too dangerous for a human pilot. The U-2 downing with the capture of Francis Gary Powers had severe political consequences as well. These considerations were not wasted on military planners. At least eighteen derivatives of the popular Ryan BQM-34 *Firebee* target drone (Figure 20) were used in Vietnam to gather ELectronic INTelligence (ELINT) and other reconnaissance data. Other "black" programs similar in scope remain classified. The government acknowledges 3,435 BQM-34 reconnaissance sorties during the Vietnam War.[1]

The modern target drone is actually a predecessor to the reconnaissance UAV. The Ryan *Firebee* was conceived in the late 1940's, when it became apparent that droning obsolete aircraft would not provide the performance of anticipated threats. Subscale target drones provide reasonable radar, infrared, and visual signatures representing manned aircraft and missile threats. These low-cost systems are used to simulate everything from a sea-skimming missile to a hypersonic reentry vehicle. Subsonic, sustained lateral maneuvering at more than six g's has been demonstrated by these remarkable systems.

Disguised target drone versions have also been used in classified projects to carry special payloads, represent advanced aircraft and missiles, and so forth.

As opposed to all the tactical and strategic weaponry, a benign use of the UAV was the NASA High-Maneuverable Aircraft Technology, or Hi-MAT project. In addition to speeding up development of advanced airframes, its specific purpose was to provide an inexpensive way to test an advanced airframe without risking a pilot. The project was conceived in the 1970's, with Rockwell selected as prime contractor.

Two airframes were built using modular construction. This would facilitate modifications anticipated later during flight test. The configuration was a highly swept canard with considerable dihedral, a pair of outward canted vertical fins, and an aft wing with winglets (Figure 21). The propulsion inlet nacelle resembles the F-16 fighter.

The Hi-MAT was flown remotely by a pilot sitting in a simulated cockpit. Video was furnished from the UAV using a television camera mounted in a position close to eye level in the UAV "cockpit." The intent was to give the pilot motion cues as if he were looking through the canopy, but apparently without the motion cues of actual flight.[13]

Summary

Automatic controls technology for the UAV was mostly absent or ignored until after World War II. Despite severe technical handicaps, early unguided weapons had success in combat. Postwar development continued in airframe and propulsion, but the significant UAV improvements were in electronics and onboard computers to navigate and aim the UAV. The intercept problem can be solved under controlled conditions, but remains elusive despite today's technology.

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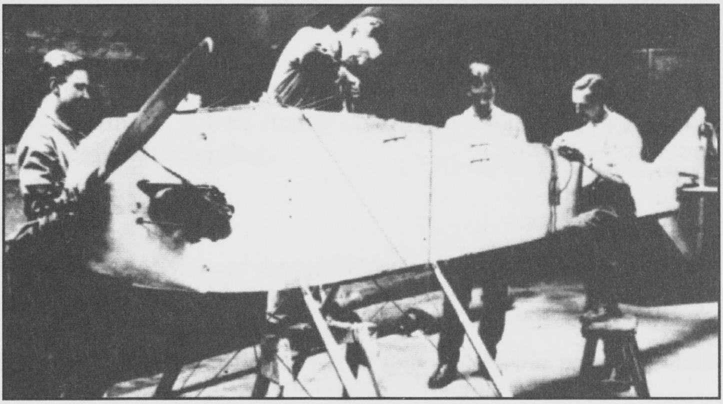

Figure 1. Archibald M. Low Monoplane. (Courtesy London Imperial War Museum)

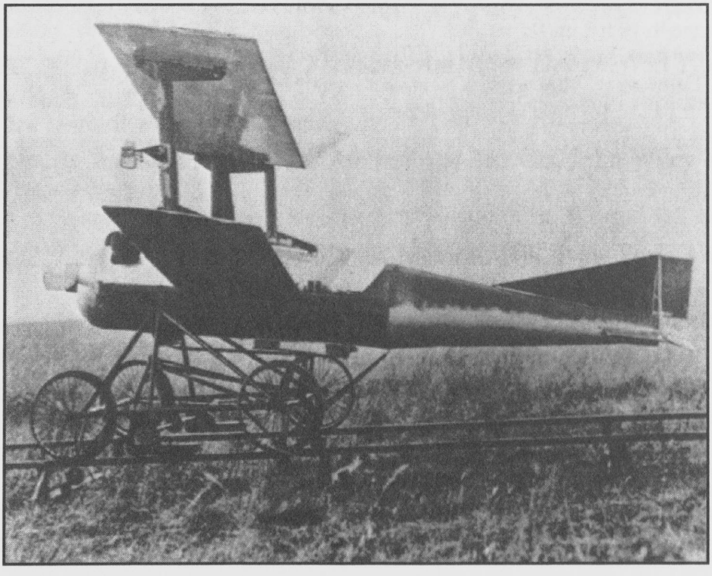

Figure 2. Kettering Bug. (Courtesy National Air and Space Museum, Smithsonian Institution [SI Neg. No. A 42129 E])

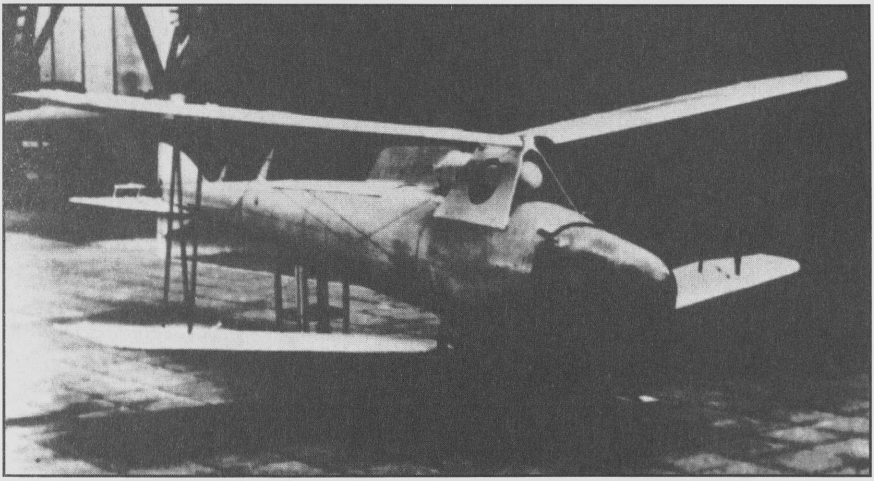

Figure 3. Siemens-Schukert Torpedogleiter 300KG (Glider Bomb). (Courtesy National Air and Space Museum, Smithsonian Institution [SI Neg. No. 79-12403])

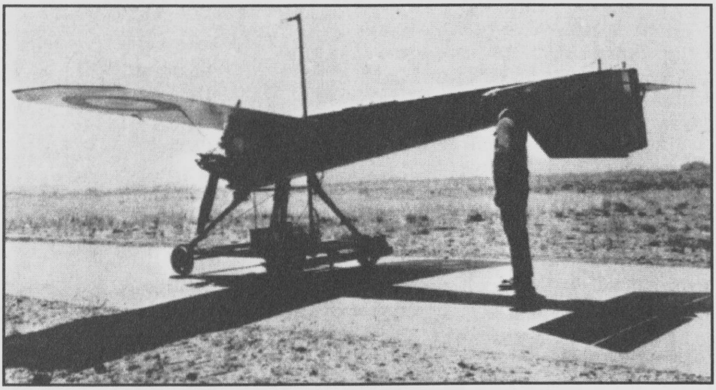

Figure 4. Archibald M. Low Aerial Target. (Courtesy London Imperial War Museum)

Figure 5. Larynx Surface to Surface Missile. (Courtesy Ministry of Defence, London)

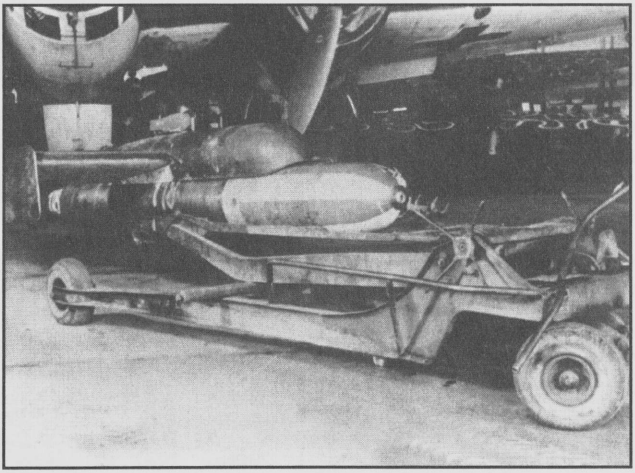

Figure 6. Friedensengel L10 Glide Torpedo. (Pilot Press, Plattsburg, NY)

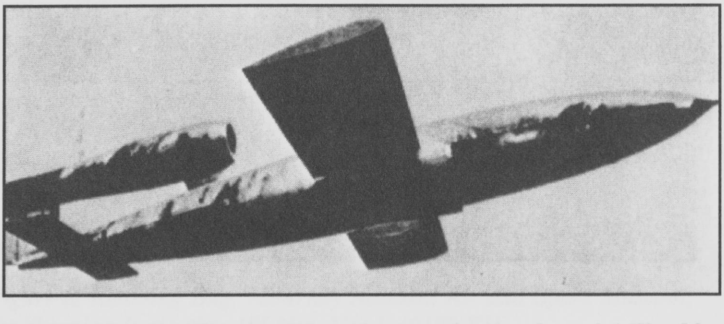

Figure 7. Fieseler F1 103 (V-1). (Courtesy London Imperial War Museum)

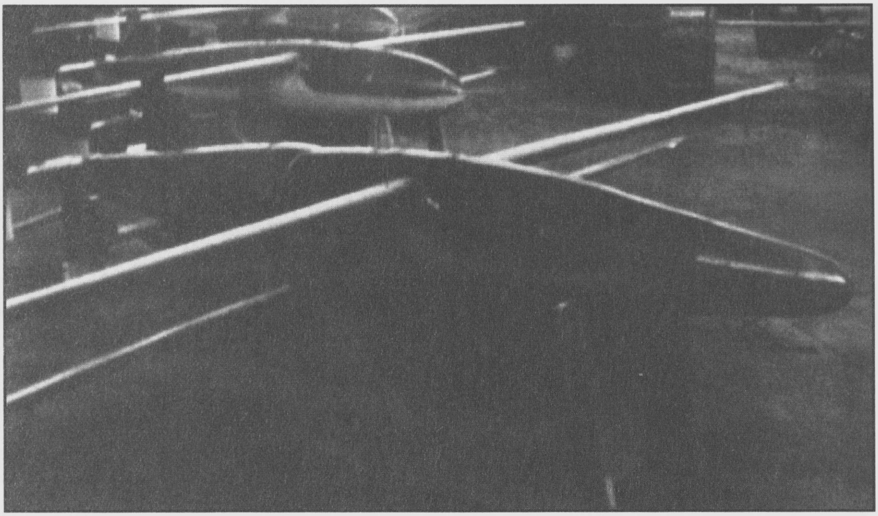

Figure 8. Blohm und Voss 246 Glide Bomb. (Pilot Press, Plattsburg, NY)

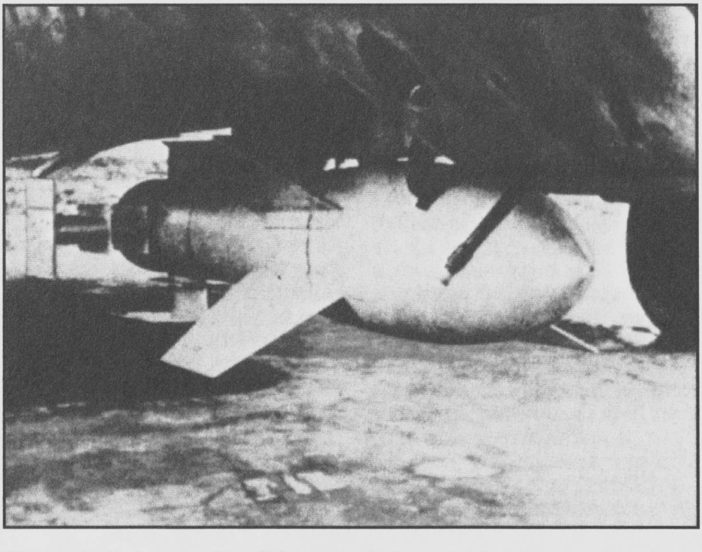

Figure 9. Ruhrstahl X-1/PC 1400 "Fritz X." (Courtesy National Air and Space Museum, Smithsonian Institution [SI Neg. No. 78-14135])

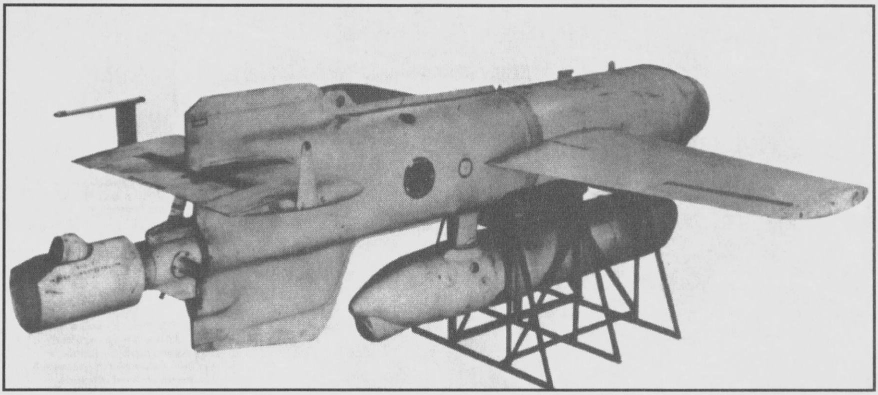

Figure 10. Henschel Hs 293. (Courtesy National Air and Space Museum, Smithsonian Institution [SI Neg. No. 88-8212])

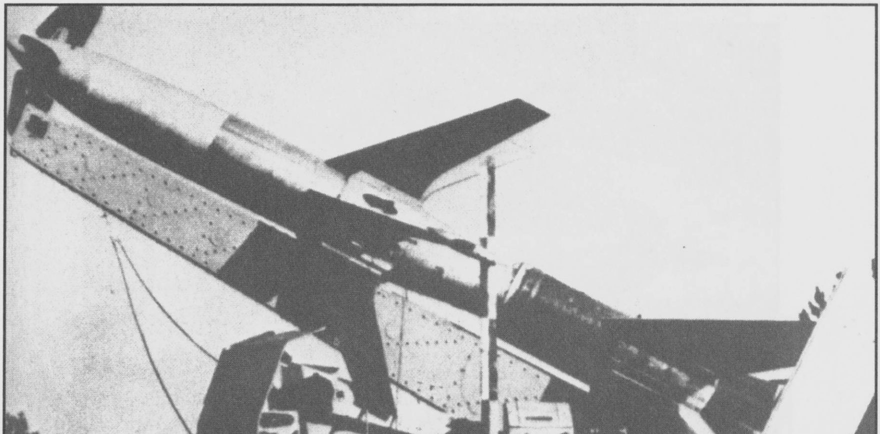

Figure 11. Rheinmetall-Borsig Rheintochter (Rhine Maiden). (Courtesy National Air and Space Museum, Smithsonian Institution [SI Neg. No. 75-16091])

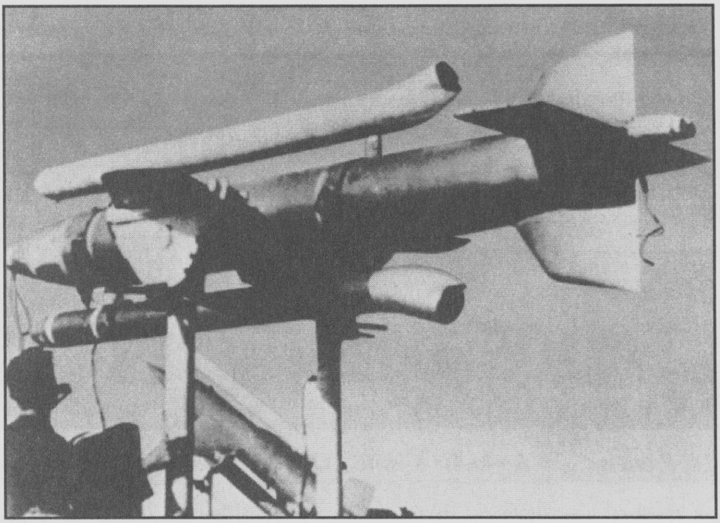

Figure 12. Henschel Hs 117 Schmetterling (Butterfly). (Courtesy U.S. Air Force)

Figure 13. Messerschmitt Enzian. (Courtesy National Air and Space Museum, Smithsonian Institution [SI Neg. No. 78-14133])

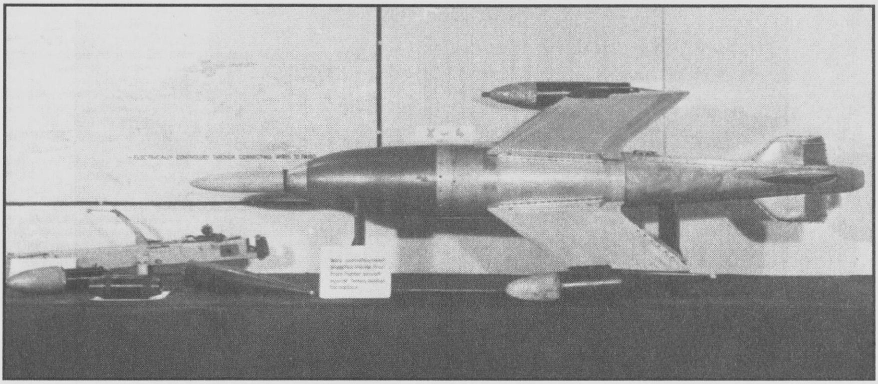

Figure 14. Ruhrstahl X-4 Air-to-Air Missile. (Courtesy Ministry of Defence, London)

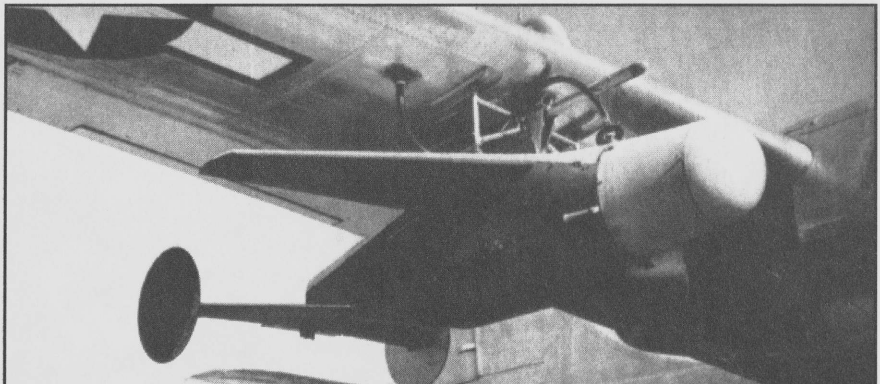

Figure 15. BAT ASM-N-2/Swod Mk 9. (Courtesy National Air and Space Museum, Smithsonian Institution [SI Neg. No. 78-14146])

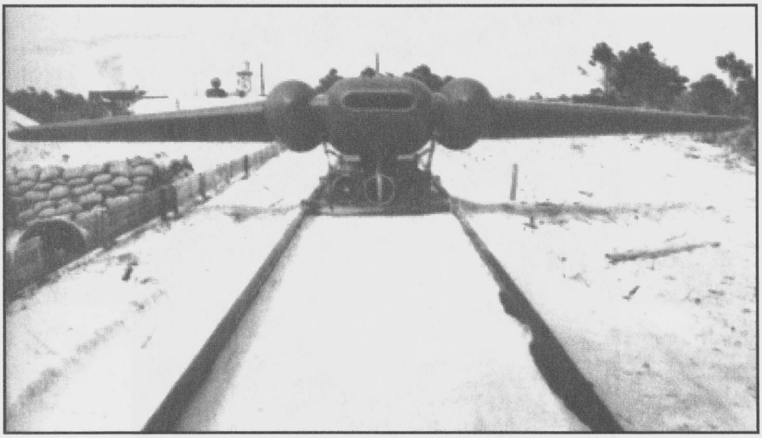

Figure 16. Northrop JB-1. (U.S. Air Force Photo Collection [USAF Neg. No. 169985 AC], courtesy National Air and Space Museum, Smithsonian Institution)

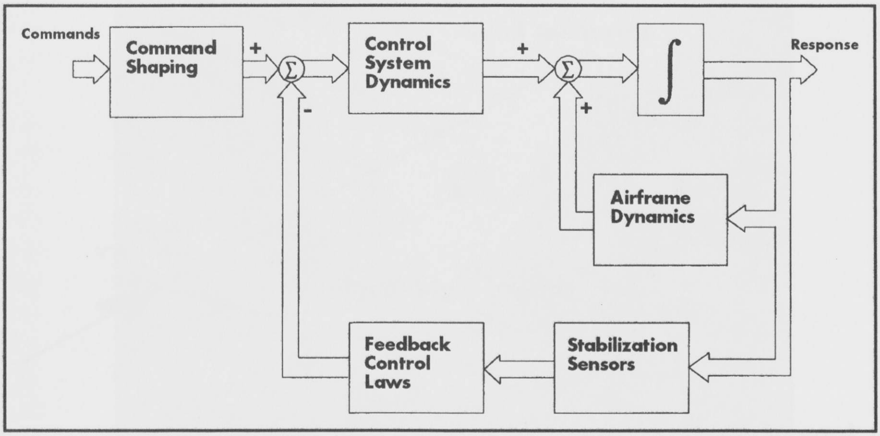

Figure 17. Stabilization Feedback System. (Leland Johnson)

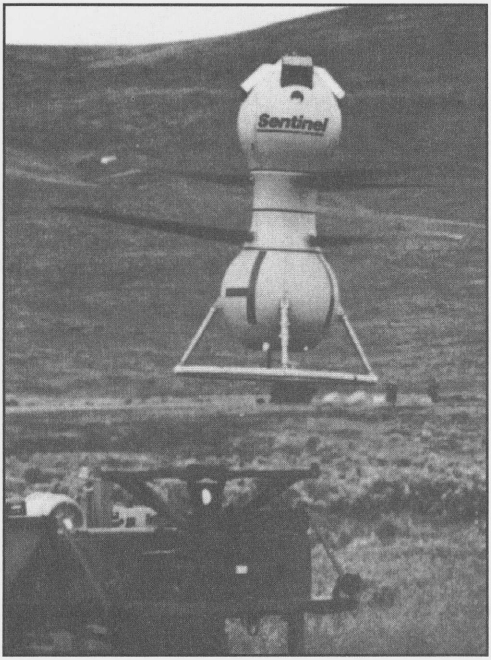

Figure 18. Canadair CL-277 Hovercraft UAV. (Courtesy Jane's Information Group)

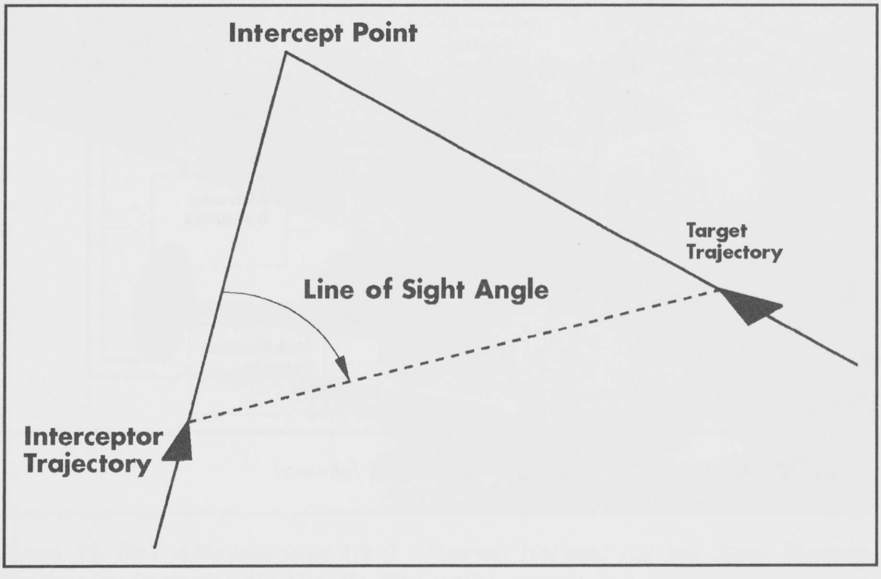

Figure 19. Proportional Navigation Geometry (Constant Bearing Trajectory). (Leland Johnson)

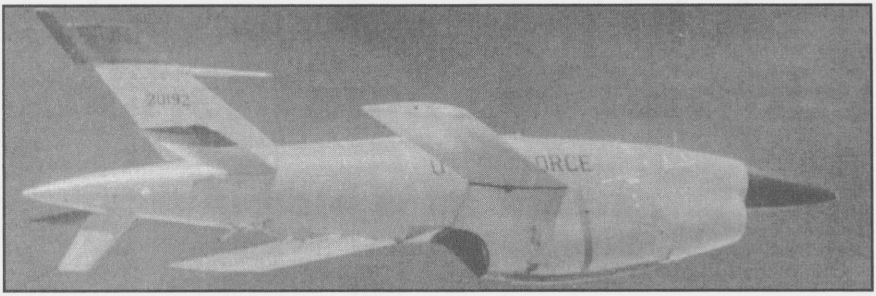

Figure 20. Ryan BQM-34A Firebee. (Courtesy Jane's Information Group)

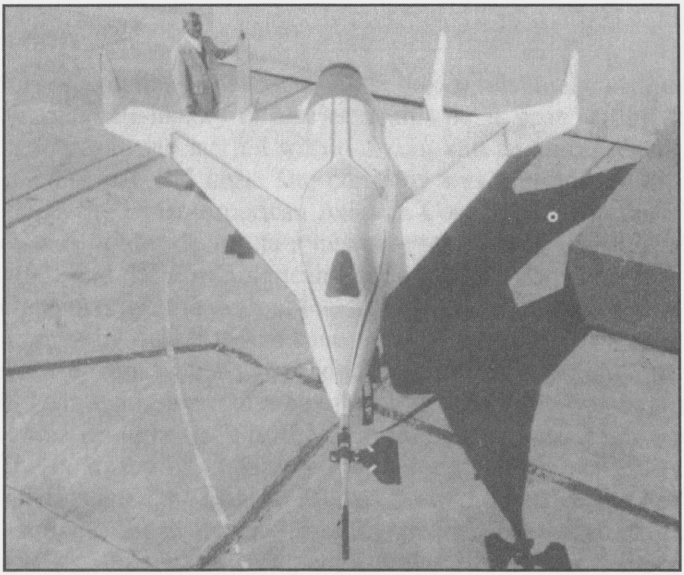

Figure 21. Hi-MAT Research UAV. (Courtesy Jane's Information Group)

The Development of the Learjet Family of Aircraft

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Introduction

The purpose of this paper is to trace the development of the Learjet family of aircraft. The history of Learjet, at this point, spans a time frame of some 30 to 35 years and started with a dream and an entrepreneurial goal of a single individual, Bill Lear. The company was first started in Switzerland in 1959 as the Swiss American Aviation Corporation and the idea was to adapt a Swiss fighter design to a business jet. The design effort became serious in 1961 and the first Americans hired by Bill Lear were sent to Switzerland to help oversee the design. Incidentally, these people were sent over with only a one-way ticket! It was soon decided that the European philosophy of aircraft design would not produce a production product in the lifetime of Bill Lear, exclusive of the fact that Bill's timetable was next year, so the project was brought back to the USA in 1962 and a factory started in Wichita. The company has had some very rough times, starting with the certification efforts for the original Model 23 which included the FAA crashing and destroying the prototype, through several cycles of market slumps, and a fuel crisis. Finally, the company has had three new owners during this time period.

Learjet Family of Aircraft

In order to design an airplane or any mechanical device for that matter, there needs to be a set of design goals and objectives. As product lines evolve and mature, these goals and objectives can become rather involved and complex. Each of the Learjet products has had a definitive set of goals and although these goals were not always right, or always firm, there was a set of goals for each of the aircraft in our product line.

Model 23

The Learjet family started out with a single model, the Model 23. This aircraft has a rather simple set of design goals. These goals probably were never written down but if so they would have looked like this:

Jet powered aircraft
To transport CEOs
At less cost than the JetStar
And faster than the Gulfstream I

The airplane configurations were relatively open. There were more indications of what not to do than what to do. In this time frame, Beech aircraft was marketing a 4-place jet built by the French, the MS-760, and Cessna had been working on a business jet version of its T-37. These aircraft both had inadequate range and a poor cabin arrangement. Beech sold two of these aircraft and Cessna wisely elected not to pursue its proposed aircraft. Bill Lear chose to use a more robust power plant for the Learjet design, the GE CJ 610, a commercial version of a very successful military engine. A Swiss fighter, the P-16, was chosen as the basis for deriving the final or almost final aerodynamic configuration. Initially, and through the development of the Model 23, Model 24 and Model 25, no wind tunnel data was available other than that of the P-16. The certification basis for the Model 23 CAR Part 3, was selected to minimize the certification requirements and to speed the certification process. The prototype first flew October 7, 1963, and was certified on July 31, 1964. I believe 104 of these models were built and 102 delivered.

Model 24

The second in the Learjet line was the Model 24, which also had rather simple design objectives. The purpose was to counter the marketing efforts of competitive aircraft manufacturers, who claimed that the certification basis for the Model 23 was not safe and that only aircraft certificated to CAR 4b (the standard for transport category aircraft) were safe. This was not true, as the FAA had imposed special conditions on the Model 23 that equaled or exceeded CAR 4b in the areas of performance. The only areas not covered included the requirement for fire extinguishers for the engines and bird proofing for the windshield. Of course, by this time, the aircraft had been in the field and there was also an immediate requirement for more payload. To be certificated under CAR Part 3, the takeoff gross weight was restricted to 12,500 pounds. This was a severe restriction if any options were added to the aircraft and it was known from the beginning of the program that a 13,000 pound takeoff weight was highly desirable. The following were then the design requirements for the Model 24:

Model 23 performance
Transport Category Certification
More gross weight

The Model 24 was certificated to the Transport Category Requirements and was, in fact, the first aircraft certificated to the recodified Transport Category with the new label of FAR Part 25. Gross weight was increased to 13,000 pounds (which later grew even further to 13,500 pounds), the windshield was certified bird proof and fire extinguishers were installed. At first the Model 24 was almost indistinguishable from the Model 23 as the only external difference was the bird splitter added to the windshield center post. Early versions of the Model 24 were restricted to 41,000 feet operation. One of the first improvements to the Model 24 was certification to a higher altitude limit of 45,000 feet. This required some minor changes to the pitch control system and also required some operational restrictions. Above 41,000 feet a crew member was required to wear an oxygen mask and the passengers were required to drop their masks and wear them around the neck for quick donning (of course, all passengers complied). Again, Learjet was the first to achieve this altitude certification and we like to call this area above 41,000 feet "Learjet Country."

Model 25

The next Model Learjet was the Model 25. As might be expected, the next request from the marketing area was to stretch the aircraft and provide more seats. As a first step, a Model 24 cabin was plugged with a two-foot extension and larger tip tanks installed. This aircraft turned out to be totally unacceptable and the next attempt was initiated with a forward and rear fuselage stretch. This added a comfortable two additional seats and the aft fuselage extension provided space for an added 400 pounds of fuel capacity. Gross weight was increased to 15,000 pounds and GE provided an uprated version of the CJ 610 engine. Structurally, the strength margins in the simplified loads criteria of CAR 3 allowed the Model 25 to write off most of the loads for the higher gross weight by using a rational analysis to derive the aerodynamic loads. Except for the tailcone area, the structure had already been tested to loads in excess of those derived for the Model 25. The aerodynamics of the Model 23 were strained somewhat by the added weight and the aircraft was limited to 41,000 feet until some fuel had been consumed. The maximum certified altitude was still 45,000 feet.

First New Owner

Between certification of the Model 24 and the Model 25, Learjet was sold to the Gates Rubber Company. After certification of the Model 23, Bill Lear, who was undoubtedly an innovative genius but was not necessarily a good business manager, decided to enter the DC-3 replacement market and started designing an aircraft called the Model 40. He also purchased Brantley Helicopter. The combination of these programs put a severe financial strain on the company and Bill was forced to sell. In somewhat of a whirlwind deal, Learjet was sold to Charles Gates and the Gates Rubber Company. Mr. Gates was an airplane and helicopter buff so Learjet appeared to be an ideal acquisition. Immediately after the sale of the company, there was some effort to change the looks of the aircraft. The Model 24 picture windows were replaced with the airline style windows of the Model 25. These windows were put in the Model 25 for weight savings. Both the Model 24 and 25 had the tail bullet fairing removed. Many model type changes were made over the production lives of these aircraft. Late in their production lives both aircraft were fitted with -8 versions of the CJ 610 to allow the aircraft altitude certification limit to be raised to 51,000 feet. The only other aerodynamic modification to the 24 and 25 was to droop the tip tanks. The first Model 23 had drooped tanks but Bill Lear didn't like the looks of the drooped tanks on the ground and had them realigned parallel to the wing chord plane. Later, with the Rubber Company ownership, the 2–3% drag reduction became more important and, at a time when the tip tank tools needed to be replaced, the tip tanks were again drooped.

Model 35

Shortly after the Gates Rubber Company bought Learjet, the engine manufacturers began to assess the business jet market and judged it worthy of monetary investment. Both Air Research, a division of the Garrett Corporation, and Pratt and Whitney of Canada began researching the market for a turbofan engine for use in these new aircraft. Up until this point in time, the business jet was powered by old technology turbojet engines that were extremely noisy and fuel inefficient. The new generation of fan engines that was being proposed were some 30–40% more fuel efficient and much quieter. Learjet worked with both P&W and Air Research to size a turbofan to match the Learjet Model 25. Air Research finally agreed to size its engine to match our requirements while P&W chose to develop its engine at a lower thrust level. After selecting the Air Research engine, Learjet contracted with Air Research to provide a flying test bed for its engine. This test bed was a strange looking bird with the small GE turbojet engine on one side and the larger Air Research turbofan on the other. It was very evident what a fuel hog the Model 25 really was with the direct comparison of the two engines on a single airframe.

Initially the task of integrating a turbofan into the Model 25 seemed relatively simple. The design goals were set very simply, i.e.:

Same performance as Model 25
Same cabin as Model 25
Same gross weight as Model 25

The desired results were to be a quiet, fuel efficient Model 25. As it turned out, if the turbofan was sized to give the high altitude performance of the Model 25, it was extremely heavy and the aircraft would exceed the Model 25 takeoff gross weight. Even worse though, the aircraft would not balance. If the engine were sized for takeoff performance, the engine size was smaller, the aircraft would balance, but the high altitude cruise was significantly degraded in both speed and altitude. Because the fan engine was more fuel efficient, there was hope that fuel could be off loaded so that a usable aircraft could be obtained at the Model 25 takeoff weight. Many months were spent in engine/airframe/optimization studies trying to match up a thrust/weight/airframe combination. A thrust level was finally selected and an agreement reached on engine layout.

It soon became evident that a fan powered aircraft with the Model 25 fuel volume would be very attractive. To this point, fuel had been off-loaded to maintain the takeoff gross weight of the Model 25. The fuel efficiency of the fan engine allowed the Model 25 range to be obtained with a sufficiently smaller fuel load to offset the added weight of the fan engine. Since the fuel volume was already available, the attractiveness of the added range became overwhelming and the design goal to hold gross weight was lifted and a requirement for 3000 nautical miles range was added. The flood gates were now open to other design changes as well. As the engine design progressed, the engine got heavier, particularly after the bird won the first round when fired into the engine. The four pound bird did not survive, but neither did the 700 pound engine. As the aircraft got heavier, the takeoff performance deteriorated and the cruise altitude slumped. It was obvious that more wing was required and two-foot tip extensions were added. With the heavier engine, it became apparent that either the forward fuselage would have to be stretched or the nose wheel moved to the tail. The fuselage stretch won and the Model 35 has proven to be a real winner as a business jet.

During the development of the Model 35, it was decided that the continued use of the Model 23 airfoil section was causing a penalty in the stall speed of the aircraft and consequently in the takeoff and landing distances for the aircraft. An additional improvement to the Model 35 aerodynamics included a re-contouring of the leading edge. The airfoil used on the Model 23 was a NASA developed laminar flow airfoil specifically designed for low drag. This airfoil had the desired low drag characteristics of today's highly touted "Natural Laminar Flow" airfoils but it had lousy stall characteristics. The leading edge of the airfoil was re-contoured to improve stall speeds and characteristics. The re-contoured nose used a very old technology but tamed the stall characteristics of the Model 23 airfoil very nicely, resulting in a reduction of stall speeds of about 10 knots with very little increased drag. These airfoil modifications were also applied to the Model 24 and 25 resulting in upgrades to these aircraft as model changes.

During the development of the Model 35, the industry as a whole went through a very serious recession. Had it not been for the support of the Gates Rubber Company and the persistence of the Air Research organization, the Model 35 would never have been completed. At times, even the Rubber Company support seemed shaky. There also was a severe fuel crisis and the Model 35 emerged as an extremely fuel efficient and very quiet aircraft. These two characteristics alone would have made it a success. In addition, the Model 35 has very good field performance as well as good climb and high speed cruise capability. Finally, the aircraft was capable of carrying a big load—you could fill the seats, fill the tanks and go. The combination of characteristics made the aircraft a real workhorse, and consequently the Model 35 designed in the early 70's is still in production today, with almost 800 units sold. The more noisy and fuel eating Model 24 and Model 25 went out of production in the late 70's, with about 350 units each of production.

Shortly after the Model 35 went into serious production, the FAA Aero Medical Branch started to talk about restricting aircraft operating altitude to 40,000 feet. It was known that if the pressurization failed above 40,000 feet, even when breathing pure oxygen, the human being could not survive as the blood boils and the human dies. Below 40,000 feet life can be sustained with oxygen alone. It seemed logical, at least to the FAA, that flight should be restricted to the lower altitudes. This, of course, directly affected Learjet as it totally removed us from "Learjet Country." Our president at that time, Harry Combs, was furious. Harry announced that we intended to certificate our aircraft to 50,000 feet and started to attack the FAA policy. Although acknowledging the loss of pressurization as a problem, it was noted as no worse a problem than:

> If you stick your head under water for five minutes, the same thing happens.
>
> If a wing falls off of your airplane, the same thing happens.

The solution to these problems is not to quit swimming or flying, but to design to criteria that do not allow the failure to occur. Many months were spent with the FAA to establish criteria that would preclude systems or structure failures that would cause catastrophic depressurizations. The Model 24 and 25 were then certified to these requirements and their operating envelope extended to 51,000 feet. Although the initial effort was to certify to 50,000 feet, it was soon realized that the assigned flight levels were at odd altitudes. A 50,000 foot limit would restrict the aircraft to 49,000 feet. Consequently, certification was raised to 51,000 feet. This now extended "Learjet Country" to include 51,000 feet. Although the aircraft were certified to 51,000 feet, the actual aerodynamics of the aircraft did not allow much time to be spent at these altitudes, but the point was made with the FAA.

The next two models developed and marketed by Gates Learjet were the result of three distinctly different factors:

1. The newly won ability to certify to flight levels above 45,000 feet and the desire to develop an aircraft that could truly take advantage of the added altitude.
2. Marketing desire for a large cabin aircraft. The Model 35 had an endurance of over six hours but the small cabin restricted the desire to stay in the cabin for that long a time. A larger walk around cabin was desired to fully utilize the capability of the business jet.
3. Probably the most pressing factor was the announcement by Cessna of the Citation III development which was to be an aircraft that had a stand up cabin with the exact performance characteristics of the Lear Model 35.

Two programs were launched almost simultaneously. This was allowed because in many ways they were complimentary. The first program was to extend the Model 25 into the high altitude operating regime with a configuration that allowed true benefits for operating at the high cruise altitude. We had been following the development by NASA of the winglet and had at the same time been looking at increasing the wing span and area of the Model 25 to allow it to operate efficiently above 45,000 feet. The winglet, when combined with the increased span wing, appeared to be a good combination. We found that the Model 25 with the new wing, when operated at altitudes above 45,000 feet, was almost as fuel efficient as the fan powered Model 35. In addition, the wing could be used on a stand-up cabin version of the Model 35.

The determination of the cabin size for the stand-up aircraft became a major design effort. The first attempts at sizing the aircraft were based on a formula that said the cabin height from the aisle floor to the headliner was to be HBC + 1, i.e. Learjet president Harry B. Combs' height plus 1 inch. This resulted in a fuselage diameter of about 84 inches. To obtain the cruise performance to match the Learjet image required a power plant larger than was readily available. The aerodynamicists preferred the formula to be DJG + 0, Donald J. Grommesh, the vice-president of engineering. As those of you who know Don realize, this would have resulted in only a slight increase in fuselage diameter. Harry magnanimously agreed that the formula could be altered and that a Model 35 with 15 inches more headroom was adequate. Development of the Model 55 was approved with an initial configuration that was a Model 35 split down the centerline and the top raised 15 inches. The fuselage was then re-faired and the cabin stretched to provide Model 35 seating and an aft lavatory. The performance on the Model 35 wing was marginal and the non-round fuselage was going to be a structural nightmare. The program was finally modified to have a round fuselage and the wing from the high altitude Model 25. Since the programs were complimentary, they were both launched about that same time with the Model 25 version being certificated as a Model 28/29 and the stand-up Model 35 being the Model 55. One final objective was added to the Model 55 development—beat Cessna to the market by one year.

Model 28/29

The Model 28/29 achieved the design goals and set some records in time to climb to high altitude. Unfortunately, the range of the aircraft was about the same as the Model 25 and the CJ 610 engine was still very noisy. With the range of the Model 35 in direct competition to the Model 28/29 and the noise issue, the aircraft was not a best seller. Only about 13 were delivered. Much of the high altitude and wing development done on the Model 55 was used on the 28/29, so the effort was beneficial even though the aircraft model was not popular.

Model 55

After much study, the design goals for the Model 55 resolved into:

Performance of the Model 23
Payload of the Model 25 and 35
Economy of the Model 35
Operational altitude of 41,000'–51,000'
Stand-up headroom

The Model 55 was a good example of an aircraft that met all of its design goals but still did not enjoy the success that was expected. Even before the aircraft was certificated, it became apparent that the design goals had missed the mark. Simplistically, the design goals were simply to have Model 35 performance with a stand-up cabin. The customers for the Model 55 did not seem to understand what this really meant. Typically, the Model 35 was being sold with a very modest amount of options running between 250 to 400 pounds. The first 15 Model 55s were spec'ed with over 1200 pounds of options. The cabin was larger and the instrument panel was bigger so they got filled up. The customer for the Model 55 came from larger companies that, in general, operated larger aircraft and were used to more amenities than offered to customers for the other Learjet models. The 55 was improved with gross weight increases to accommodate the large amount of options and the instrument panel updated to include a full glass cockpit. But with the weight increases, the aircraft performance was not as good as the Model 35, and the expected upgrade from Model 35 to Model 55 by existing Learjet owners never occurred. About this same time another depression in the economy hit and the sales of all models took a drastic downturn.

Second New Owner

During the mid 80's, with the economic downturn, funds were not available to further develop the products. At the same time, Mr. Gates was approaching retirement and the Gates Rubber Company decided to sell the Learjet Division. After several unprofitable years, the company was sold to Integrated Resources, a highly successful real estate investment company. The Model 31 and Model 55C were developed during the late 80's while under the guidance of Integrated Resources. Unfortunately, the real estate tax laws were changed and Integrated Resources became bankrupt. Although Learjet was profitable during this time frame, Integrated Resources was forced to put it up for sale.

Model 55C

The Model 55C was a development of the Model 55 with the primary goal of eliminating the stick pusher system and improving the stall speeds and balanced field lengths. This model change was to be based on the addition of what we call Delta fins that eliminated the deep stall from a "T" tail aircraft and allowed removal of the pusher system. Stall handling characteristics still must be met and even the modified airfoil still exhibited poor stall characteristics. After literally thousands of stalls, a combination of fences and stall strips were found to provide very good stall characteristics. An additional benefit from the Delta fins was the improved directional characteristics. The dual yaw damper was also eliminated. Some other minor aerodynamic changes were made and the aircraft exhibited not only improved performance but superb handling characteristics. There was a total of 147 of the Model 55 built before production was stopped to be replaced by the Model 60.

Model 31

The Model 31 was developed during the early part of the Integrated Resources term of ownership. In fact, the program was initiated before the buy out although not approved by the previous owner. The Model 31 was simply a Model 35 with the Model 55 wing installed. Or, it was a Model 28/29 with the Model 35 fuselage installed. Either way, it made a spectacular performing airplane with the short field length and high altitude performance of the Model 28/29, even better fuel flow than the Model 35, 30% more range than a Model 28/29 and the bigger cabin of the Model 35. The aircraft also featured the Model 55C Delta fins that allowed elimination of the stick pusher, dual yaw damper and the Mach trim. The Model 31 also had excellent handling characteristics and was highly praised for its simplicity and performance.

Third New Owner

In mid-1991, the company was sold to Bombardier, a Canadian company specializing in various forms of transportation. At the time of the purchase of Learjet, it also owned Canadair and had recently acquired Shorts in Northern Ireland. This purchase has been very good for Learjet as Bombardier is a large, diversified company that has identified a need for business jet production and is committed to the long term for these products. In addition to the stability and financial support available through Bombardier, the complimentary nature of the Canadair products and Learjet products has proven to be beneficial. Bombardier immediately started Learjet into development of two additional aircraft. These programs have already evolved into one new certified aircraft, the Model 60, and a longer range development program for a Model 35 replacement that is to be our Model 45.

Model 60

The first program that has been completed since the acquisition by Bombardier is the Model 60. Shortly after the purchase the president of Bombardier, Laurent Beaudoin, commented that the only thing wrong with the Model 55 was that the cabin needed to be stretched 36 inches so a standard cabin could be installed with a full aft lavatory. A quick look showed that the 36 inches could be obtained by stretching the cabin 28 inches and moving the door forward 8 inches. The cg was well forward but thought to be manageable. This seemed to be a simple program. However, with further looks it became obvious that if a change were made, the latest BFL regulations would be invoked and the takeoff field lengths would go up significantly. With the weight increase, range would go down slightly and the price would go up. This was thought to be unacceptable. Many iterations later the real Model 60 emerged. It had in addition to the simple 28 inch fuselage stretch, increased fuel capacity, a tailcone stretch of 15 inches, a new engine from a different engine vendor, modified avionics and many system modifications. The aircraft is, however, a very fine aircraft. The Model 60 at the payload range of the Model 35 does, in fact, meet the performance objectives of the original Model 55 even with the added amenities. In addition, it has an even better cabin and a range that is truly transcontinental.

Model 45

The Model 45, which is well along in the design stage as well as in the prototype fabrication stage, is an all new aircraft. This aircraft will replace the 30 series aircraft and is expected to create a sales base as large as the initial 30 series. The aircraft is designed to have the same performance as the Model 35 but with a comfortable eight place cabin of slightly larger diameter, better takeoff characteristics and lower cruise fuel flows. At this point, I can only verify that the design is on target and the first flights are scheduled late this year.

Future Learjet Products

It is difficult to predict what the next product will be for Learjet. The industry at this point is still struggling with low sales. The best direction to move to increase sales remains cloudy. Learjet has moved out of the entry level type aircraft that was the basis of its start in life. There could be no better description for the Model 23 than an entry level jet as it was indeed the first jet aircraft owned by each of the initial buyers of the Model 23. It also was an entry level jet from the manufacture's side as it was not only an entry level jet for Learjet Inc., it was also the entry aircraft for the very new aircraft manufacturer. As a part of Bombardier, we build the lower part of a full line of business jets. As the Canadair aircraft products grow in size and capacity as they inevitably will, the gap between the Canadair aircraft and the current Learjet Model 60 will grow and we will undoubtedly try to fill this gap. Currently we are working with NASA on the development of a higher speed wing that could be applicable to a stretched version of the Model 60. The main purpose of the study is to enhance Learjet's capability to use the latest computational techniques and to help verify further refinements in NASA computational codes. No Learjet product is at this time identified with this study, but the future is good for Learjet and new products undoubtedly will come.

Regional Transport Development: A European Perspective

Ton D. Peschier
General Manager, Design
Fokker Aircraft
The Netherlands

Introduction

General

The aerospace industry is in trouble because the air forces are at peace and the airlines are at war.

Overcapacity and operating losses have resulted in airline bankruptcies and order cancellations (or at best a significant decrease in order volume), and the situation is not likely to improve within the next few years.

When economic improvements become tangible, airlines will start ordering aircraft again, if only to replace ageing, fuel guzzling and noisy types.

The regional market is basically healthy. Not just replacement of existing types is expected, but also a significant expansion both in highly developed areas as well as less developed parts of the world.

However, regional aircraft will have to adapt to a number of new developments. As traffic volume expands, environmental requirements (noise and air pollution) will become increasingly stringent.

Logistics of air traffic will become more complicated and will require demanding changes in ATC (Air Traffic Control) procedures, and ground and airborne equipment. Safety will need increased emphasis to ensure that accident levels remain low. But most important is that cost of air travel will have to decrease significantly to obtain healthy balance sheets again in a very competitive environment.

Fokker

Fokker is specialized in the short-to-medium range market. A series of aircraft tailored to serve specific demands is offered.

The Fokker 50 and Fokker 100 have been in production since 1986 and 1987. The Fokker 70 and Fokker 60 are in full-scale-development and will start operations late this year and in 1996. The Fokker 130 is in an early development stage and will receive a full-scale-development go-ahead as soon as the market is ripe for it.

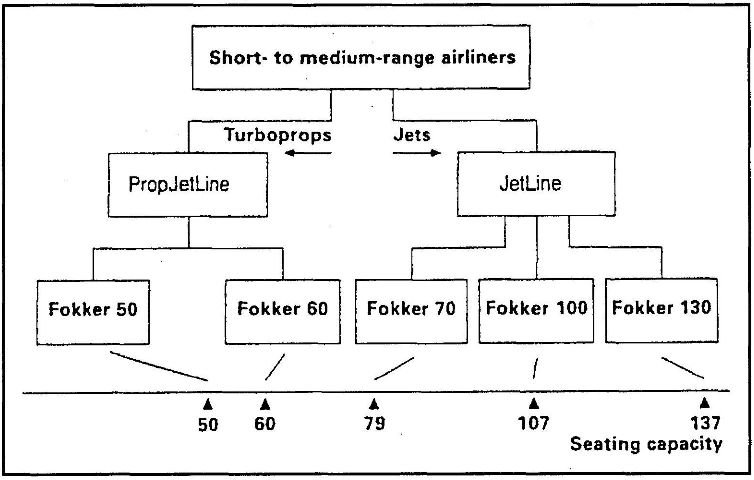


Figure 1. Fokker Regional Aircraft. (Courtesy Fokker)

Research and technology are hard to afford for a non-subsidized company without a vast military backbone. However, Fokker and Daimler Benz (its mother-company) consider technological development unavoidable in order to be able to continuously adapt aircraft in production to changing market requirements, and to prepare for the eventual introduction of successors.

At this time we believe there is no justification for the introduction of an all new aircraft to succeed the Jetline and Propjetline series. Both can be adapted cost-effectively to foreseeable changes. A sufficient breakthrough in technology has not yet been achieved to justify the high development costs of an all new aircraft.

Regional Transport: The Past

Since the Second World War the value of civil aircraft sales has grown at a rate substantially higher than that of the world economy. High rate of growth also characterizes airline traffic since the 1960's. This stems largely from a series of important technological innovations (the progressive introduction of jet propulsion, improved aerodynamic and structural efficiency, resulting in a higher speed, longer range, and so on) which have in turn brought about more comfortable conditions for passengers, greater safety, and reduced travel costs.

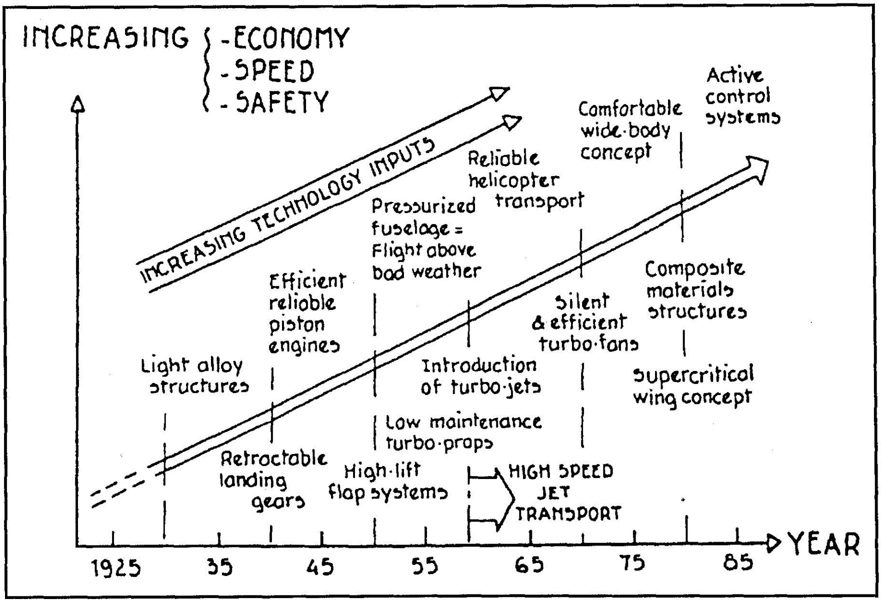


Figure 2. Technological Milestones in Civil Aircraft Development. (Courtesy Fokker)

The development emphasis has changed during the period after the Second World War.

Up to and during the 1960's, performance (speed and range) was important, while during the last decades safety and environmental issues have become more important.

As an example, exterior noise can be mentioned: the first environmental parameter to be introduced into aircraft certification by the ICAO in 1968. Since then, limits have been tightened. The progress in noise control is illustrated in Figure 3.

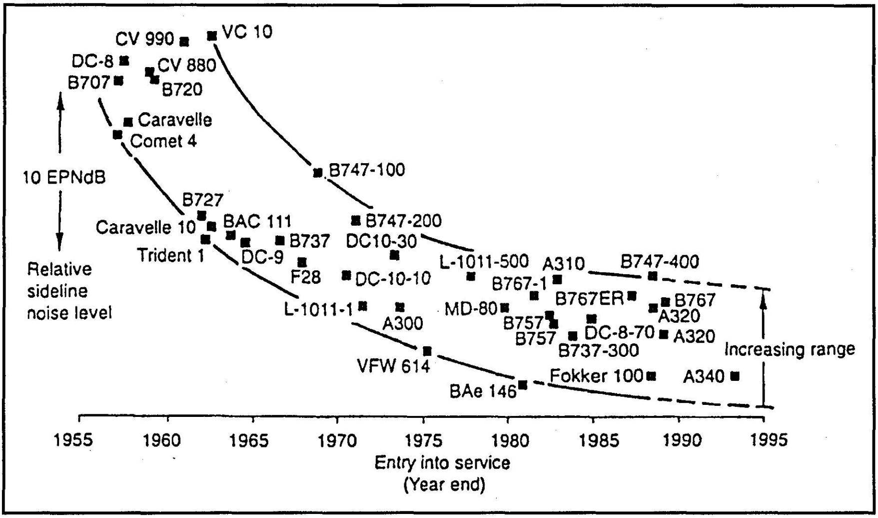


Figure 3. Progress in Aircraft Noise Control. (Courtesy Fokker)

Regional Transport Today

The Marketplace: A Description

The regional market is, per Fokker definition, synonymous with the short-to medium range market. This market is characterized by a multitude of transport alternatives. Strong competition, increasing mobility and tightening passenger demands impose a distinct relationship between distance and service requirements, resulting in a mainstream market of airline operations in its own right.

In the regional market, airlines and ground transportation services are fighting a keen battle for market share.

For passengers, convenient departure and arrival times and minimum door-to-door travel times are the prime factors when deciding how they will get to their destinations. They select air transport over ground transport only if time savings become apparent. Once the selection of air transport is made, the choice of airline is imminent.

Passenger surveys indicate that, in descending order of importance, flights are chosen on the bases of schedule, airline image, and fare.

This pattern, together with the time-saving desire, make high-frequency services crucial to the success of any airline serving the regional market.

The core of the short and medium distance market can be defined as the bracket between 50% and 75% of average seating capacity currently in use. The high-frequency segment of this market concentrates on scheduled air travel times of between 40 and 80 minutes. These correspond to dis-

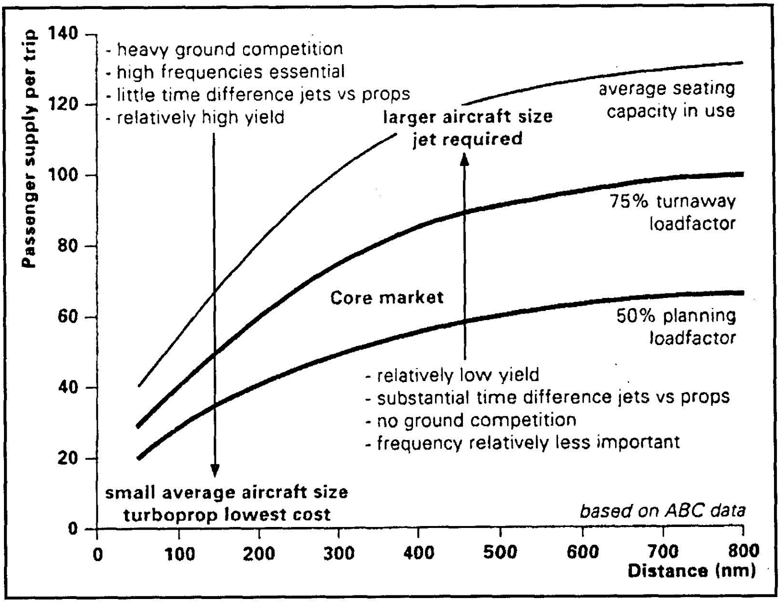


Figure 4. Core Market Regional Transport. (Courtesy Fokker)

tances of 75–225 nm for turboprops and 100–350 nm for jets. Statistics show frequent services peaking at 60 minutes scheduled timing for both turboprops and jets, or 150 nm for turboprops and 225 nm for jets.

Such high-frequency demand calls for relatively low capacity aircraft with a satisfactory load factor, rather than larger aircraft. Above 225 nm, turboprop frequencies get lower and the market becomes dominated with jets. But while longer distances have virtually no competition from surface transport, the need to maintain frequencies as a competitive tool is only slightly reduced.

Carriers, operating in the regional marketplace, range from major international airlines to small operators with limited resources, of which some operate under severe conditions. With the rapid major development of hub-and-spoke networks and intensified competition, major carriers are turning to regional affiliations to provide traffic feed, expand market share and develop new markets.

The regional marketplace is the arena where regionals and majors, and where jets and turboprops, meet and compete.

The Marketplace: Size

The orders, from 1980 until now, for airliners worldwide are shown below (N.B.: excl. USSR built):

Category	Total	%	Aver/yr.
200 + seaters	2114	20	151
125–200 seaters	4413	43	315
75–125 seaters	1272	12	91
40–75 seaters	1057	10	75
30–40 seaters	1508	15	107
	10364	100	740

Regional aircraft, per our definition, thus comprise 37% of the marketplace.

Regional Transport Tomorrow

Market Developments

The regional marketplace will be characterized by an ever increasing competition between airlines, through hubs and through city-pairs. Regional operations will increasingly be carried out by specialized airlines, while intercontinental operators will heavily depend on them as feeder systems. Minimizing cost of regional operations is essential. Specialized operators with a low cost structure will prosper, and affiliationships and cooperation with them will be looked for by intercontinental airlines.

Competition by other means of transportation cannot be disregarded. Fokker does not expect any serious competition from high speed trains in the foreseeable future. However, the combination of trains, faxes and teleconferences will surely affect the development of regional traffic. A reduction in growth of 1–2% per year is not unlikely.

Since the emphasis on economy will be strong, the attitude towards equipment will be one where sophistication is only allowed if it lowers the cost, or if it improves flight operations. Air traffic control in Europe and USA will have to improve in order to ease operations, reduce flight departure delays, and obtain a better fleet efficiency. Enhanced air traffic management must eventually lead to a higher daily utilization, which is essential for lowering cost. The ultimate effect of these factors is a 10–15% lower annual demand in aircraft units.

Taking into account these developments Fokker predicts a future annual demand (1994–2010) as follows:

• turboprops (30–40 seats)	140 units
• turboprops (> 40 seats)	120 units
• jet aircraft (< 130 seats)	140 units

(Note: civil applications only, excl. former USSR)

Both turboprops and jets will have a role in regional operations.

Turboprops have fundamental cost advantages on the routes they are applied today. When higher cruise speeds can be offered while maintaining the cost advantages, an increase in catchment range from hubs will be possible.

Technological Issues

Economy

The emphasis on economy will be strong. An operating cost-reduction of 15% has been defined by the market as a minimum.

At the same time there is an enormous pressure on aircraft price levels. The inability of airlines to afford high prices and the consequential price competition between aircraft manufacturers, necessitates aircraft cost reductions in the order of 25% to 30%.

To our feeling such a price level will not be a temporary, but a lasting requirement.

A 15% DOE (Direct Operating Expenses) reduction, in combination with a 25%–30% aircraft price reduction, poses a gigantic challenge and only appears possible by a combination of measures.

Some technological developments seem promising:

- significant aerodynamic improvements without increased complexity in systems or deterioration of handling characteristics;
- certain structural concepts and materials that offer weight reduction and production cost reduction without sacrificing durability.

Fokker feels that CFRP (Carbon Fibre Reinforced Plastic) will be cost-effective in certain areas, such as lifting surfaces, but metal (including metal bonding) remains important. Fibre-reinforced metal laminates will to a limited extent (e.g. in parts of the fuselage) be affordable.

But an important contribution in cost-savings must come from a design-to-cost approach. Future regional aircraft will not be all-composite.

In the area of systems and avionics the situation is less clear.

There are many developments leading to improved performance at a higher cost (that may be profitable in large, long-range aircraft) that do not pay off in regional aircraft.

It is clear that strict cost-oriented development processes are unavoidable. A statement valid not only for the aircraft manufacturer but equally as well for equipment suppliers. Cost budgeting (design-to-cost), concurrent-engineering, standardization of parts and components (variety reduction) are not just modern notions, but indeed radical changes in the design process. Generally it may be concluded that technology-for-technology's sake can *not* be a starting point.

It will be clear that, in addition to a reduction in aircraft cost and operating expenses, an increase in aircraft utilization will contribute to healthy balance sheets. Tomorrow's battle will be won not only in the air, but also on the ground. It will be necessary to push utilization from today's 2500 flights/yr to 3000 or 3500 flights/yr (10 flights per day). Relevant factors to consider in aircraft design will thus be: reliability, optimization for short turnaround times (quick loading/unloading with and without ground equipment) and operation under restricted conditions (nighttime noise limits).

It should furthermore be emphasized that DOC, as a criterion, is not sufficient. Life-cycle-cost, taking into account spares commonality between different aircraft, crew X-qualification, dispatch reliability, maintenance requirements, etc., (as well as fuel, crew cost, etc.) is a far better yardstick. This complicates the design process considerably, since a new aircraft cannot be considered in isolation: an aircraft is part of a fleet, consisting of several types. Family concepts, as well as commonality between families, can result in significant savings, for both operators and manufacturers.

Operational Reliability

Regional aircraft make eight flights (or more) per day with a 20 minute turnaround time. A five minute delay has a greater impact than on a B747 (with a turnaround time of 1 1/2 hrs.) As a consequence, current designs already have to exhibit:

- reliable systems
- redundant systems (cost and weight).

Fokker experience is that larger, efficient operators specify to this end, for example, triple IRS (Inertial Reference System) into a dual AFCAS-system (Automatic Flight Control and Augmentation System), or even specify a three channel AFCAS just for this purpose.

In the future, emphasis on reliability will further increase in order to improve economics. Moreover, there is an increasing tendency to operate aircraft not just eight flights a day (or better) but also up to seven days a week away from homebase. Deferred maintenance capabilities, a very flexible MEL (Minimum Equipment List) and simple trouble shooting are therefore essential.

Though dispatch reliability and maintenance cost have always been design considerations, an even more focused and more elaborate design process is needed. This will lead to design solutions such as:

- Central Fault Display Units with standard procedures for each system, readouts in simplified English, capability to include company MEL, etc.
- Segregation of flight critical and non-flight critical functions.

Without logistic changes, the number of delays will further increase. Both expansions in the air transport system as well as means to improve its efficiency are necessary.

The aviation world is heading towards 4-D Navigation; the essence being a requirement for strategic flight planning and negotiation, and for aircraft that stick to their contracted flight plans. This in turn leads to requirements with respect to position determination (accuracy and reliability), data exchange, as well as the ability to abide by the flight plan under changing meteorological conditions. A gradual introduction of GNSS (Global Navigation Satellite System) (1st enroute, 2nd Terminal Maneuvering Area), PRNAV (Precision Area Navigation), datalink, ADS (Automatic Dependent Surveillance) is to be expected.

Safety

Total air traffic is expected to double over the next 15 years.

In order to keep track of twice as many aircraft, air traffic control will become more advanced and more complex.

A further complication is that pilots' experience will become less. In five–eight years' time, there will be fewer pilots with military experience. At the same time the feeling emerges that absolute accident rate should not deteriorate. To achieve such improvements, proposals are heard to impose improved safety regulations by requiring more reliable systems, e.g. a failure rate of 10^{-10} instead of 10^{-9}. It is the Fokker opinion however that improvements must be found in the man-machine interface.

> Pilot error is to blame for airline safety standstill in the 1980's. Aircrew error is a primary factor in more than 66% of serious accidents.
>
> *Flight International*, 17–23 Jan. 1990

While sources usually quote a pilot's error in these cases, Fokker believes this to be incorrect. The definition of the "human error" concept should be broadened to encompass factors such as:

- design error
- manufacturing error
- training error
- airline operational error

- ATC error
- aircrew error

The man-machine interface should get prime attention during the design phase of an aircraft. The underlying philosophy is that a higher level of technology should lead to an improved situational awareness for the pilot. "Keep the pilot in the loop" is a Fokker design requirement.

Though safety must improve, the solution does not lie in ever expanding regulations. Harmonization of global requirements is a must, but not by adding up every local regulation. New requirements are sometimes a must, but only if really justified and after an acceptable solution has become available. It should be realized that development costs of new aircraft have increased significantly over the last decades, which was at least partially caused by expanding regulations. See example below:

1. Development cost DC-9 ('63–'65)	US$200 mln.
2. Hourly earnings US industry	'64=100, '94=500
3. 1994 Devel. cost at '64 standards	5 x $200 mln = $1000 mln.
4. 1994 Devel. cost at '94 standards	$2200 mln.
5. Incremental costs from higher technology/certification standards	$1200 mln.

Mr. Bernard Ziegler (Airbus) recently expressed his concern about this subject, noting that the A340 had to comply with 323 more requirements than the A300B2. He put it as follows: "... how to put on board the ever increasing list of airworthiness requirements and still make the passenger fly at the cost he can afford."

Environmental

Because constructing an airport in the middle of nowhere does not make sense, carriers probably will have to comply with stricter noise and emissions regulations. Even without airport expansion, a doubling in air traffic will necessitate more stringent environmental legislation. The incorporation of environmental-friendly technology will no longer be a nice-to-have, but a "must."

Several investigations have confirmed that road traffic is by far the largest source of pollution, even in the vicinity of major airports.

However, non-aviation sectors of the transportation industry are in the process of achieving further reductions in emissions. It is important, therefore, that the aircraft industry continues to remain active in reducing its share of emissions. Environmental concern is being increasingly focused on global rather than local or regional atmospheric problems. Major worries are the impact on the ozone layer and the so-called "greenhouse effect."

Without explaining the chemistry of pollution or the role of short-haul operations therein, the emission characteristics of an aero-engine are influenced by such factors as thrust level and combustor temperatures and pressures. In recent years, significant reductions have already been achieved, as shown below:

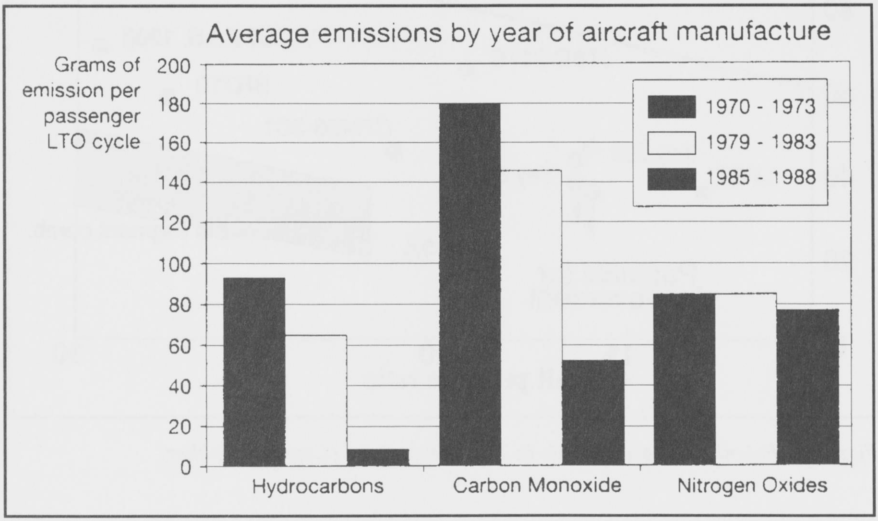


Figure 5. Improvements in Engine Emissions. (Courtesy Fokker)

Intense research is continuing to further reduce NOx-levels by improving the combustion process. In the future, introduction of (complicated and expensive) double-segment combustion chambers may be expected in large, high BPR (Bypass Ratio) engines, since these engines, as a result of higher temperatures and pressures in cruise, exhibit relatively high NOx emissions.

This environmental development leading to more complex and expensive engines leads to a problem when trying to fulfil the other important requirement, namely to reduce cost. We doubt if this is the way to go for regional aircraft.

There is increasing pressure from ICAO member states for more stringent noise certification standards. It has always been the Fokker policy to offer regional aircraft with low exterior noise levels: the Fokker 100 today exhibits a cumulative level of 16 EPNdB below Stage III limits. However, this is necessary when flying eight–ten flights per day into noise-sensitive airports and during curfew hours.

Lowering certification levels in itself doesn't pose a threat. However, expansion of demanding local noise rules does. The significance of noise levels as low as the ones of the Fokker 100 is obvious when it is realized that if 1 dB higher, the payload out of John Wayne airport, Orange County, would be 15 passengers lower on every flight.

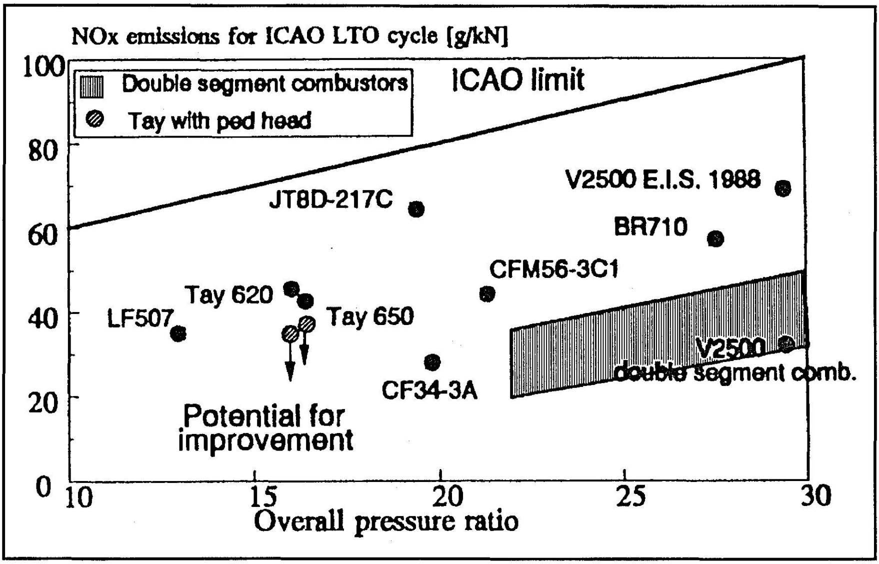


Figure 6. Potential Improvements in NOx Emissions. (Courtesy Fokker)

Conclusion

Regional transport has been through a significant development period since the Second World War. Aircraft have improved considerably in terms of performance, comfort, safety, economy and environmental acceptability. As a consequence, a vast flow of short-to-medium-range air traffic has emerged. It has become a market in its own right.

However, further changes are required in the future. In terms of comfort (interior noise) and performance (cruise, t/o, landing) no dramatic improvements are required. The challenge for the future in regional transport will be to further improve safety and environmental compatibility in order to satisfy a conscious public in an expanding air-traffic environment. But foremost, operational economy will have to improve.

Operational economy is not only affected by fuel consumption and aircraft price, but also utilization, reliability, maintenance cost and commonality between crews and parts of different aircraft versions. The economical improvement needed will only be obtained by optimizing aircraft in all these respects.

At this time, technological developments have not progressed to a stage that development of all new regional aircraft is justified. The high development cost of a new type is an important factor. As a consequence, we foresee that during the coming five–ten years emphasis will be on improving aircraft currently in production.

Acknowledgment

My thanks to my colleagues for their advice on the contents, particularly Jerry Pronk, chief market strategist, and Rudi den Hertog, chief engineer Jetline.

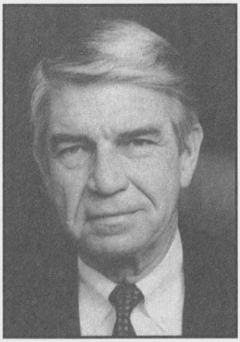
50th Anniversary Reunion

This section contains information and photographs of alumni and faculty taken at the Reunion held on April 15–16, 1994.

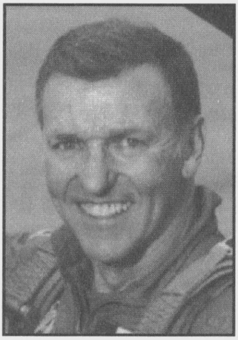
Aerospace Engineering Honor Roll

In conjunction with the 50th Reunion, the Aerospace Engineering Department has established an Alumni Honor Roll Award. The objective of this award is to recognize department alumni for their outstanding engineering achievement, leadership, and service to the Aerospace Engineering profession and society.

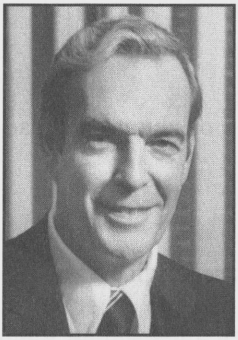
During the Reunion Banquet, five individuals were inducted as the charter members of the Honor Roll. The careers of the members of the charter class span the aerospace engineering profession and provide excellent role models for future students. Elected into the Honor Roll were:



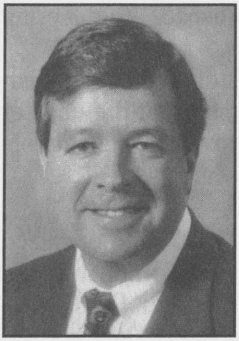
John Brizendine (BS '49 and MS '50), recognized for his outstanding career in the aircraft industry. Mr. Brizendine managed both the DC-9 and DC-10 programs and served as President of both Douglas Aircraft Company and Lockheed Corporation's Aeronautical Systems Group.



Joe Engle (BS '56), recognized for his outstanding career as an experimental test pilot in the U.S. Air Force and NASA. His career included being a test pilot on the X-15 project and the Space Shuttle Columbia.



Walter Garrison (BS '48 and MS '50), recognized for his leadership in pioneering the development of the engineering services industry. He is the President and CEO of the CDI Corporation.



Bruce J. Holmes (BS '72, MS '73, and DE '76), recognized for his outstanding career at NASA as a researcher and technical manager on a broad range of aerodynamic and aircraft technology programs.

Wendell C. Ridder (BS '59), recognized for his outstanding career in the U.S. Navy working on major system development and procurement programs. He served as the Navy's representative on the 5000 Task Force, responsible for the streamlining of the DoD acquisition system.

Department Foundation Award

During the Reunion luncheon, Ammon Andes, past Department Chairman and current Professor Emeritus, was presented with the Department's Foundation Award in recognition of his outstanding dedication and many contributions to the department and its students.

Current and Past Department Chairmen

Front Row: David Downing, Ammon Andes

Back Row: David Kohlman, Jan Roskam, Vincent (Vince) Muirhead

Current Department Faculty

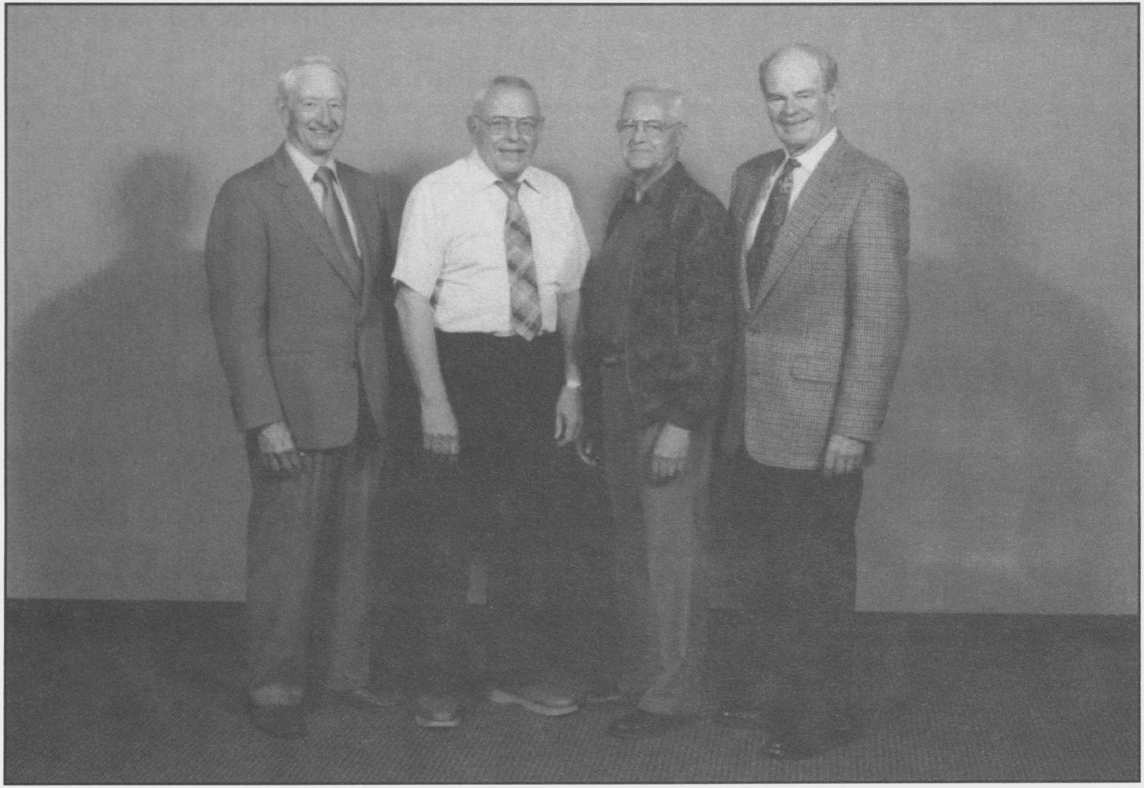
Front Row: Howard Smith, Tae Lim, David Downing, James Locke

Back Row: Mark Ewing, Ray Taghavi, Saeed Farokhi, Jan Roskam, Chuan-Tau (Eddie) Lan

Current and Past Department Faculty

Front Row: David Kohlman, Howard Smith, Mark Ewing, Ammon Andes, David Downing

Back Row: Ray Taghavi, Bill Schweikhard, Saeed Farokhi, Jan Roskam, Vincent (Vince) Muirhead, Chuan-Tau (Eddie) Lan, Tae Lim



Class of 1944

Left to right: Ralph W. May, Jr., Carl W. (Bunch) Davis, Max (Reed) Whetstone, Joseph L. Gray

50's Grads

Front Row: Dick Stutz, Vern Ballenger, James R. Sorem, John Burnett

Back Row: Richard (Dick) Etherington, William Horton, Gretchen Zimmerman Gerig, Jack Le Claire, Bob Huston, Jack Abercrombie, Joe Engle

60's Grads

Front Row: James Lewis, Linda Drake, Leonard Nelson

Back Row: Wendell (Wendy) Ridder, James (Jack) Franklin, Gerald (Jerry) Jenks, Larry Sukut, Robert (Bob) Anderson

70's Grads

Front Row: Bruce Holmes, Stanley (Stan) Sneegas, Marvin (Marv) Nuss

Back Row: Sudhir Mehrotra, Ton D. Peschier, Victor Gillings, Charlie Guthrie, Ralph E. Hite III, Douglas (Doug) Andrews

80's Grads

Front Row: David Levy, Vicki Johnson, Keith Braman

Back Row: Karl Schletzbaum, Tom King, Fridrik Jonsson, Douglas (Doug) Shane, James (Jim) Thiele

90's Grads

Front Row: Steve Hagerott, Hiromi Kawanishi, Carrie Leung, Ricki Drake, Cathy Grant, Susan Denning, James Coudeyras

Back Row: Tom Miller, Sohail Mohammed, Wade Collins, Brian Ullmann, Carl Tosh, Jeff Tidyman, Jeff Cerjan, Ken Lieber, Troy Downen, Richard Hazlewood, Mike Myers, Nevin Swearengin, Mick Unger

The University of Kansas Aerospace Engineering Alumni

1944–1994

Listed below are the University of Kansas Aerospace Engineering Department graduating classes from 1944 through 1994. Degrees earned included the Bachelor of Science in Aeronautical Engineering, the Bachelor of Science in Aerospace Engineering, the Master of Science in Aeronautical Engineering, the Master of Science in Aerospace Engineering, the Master of Engineering in Aerospace Engineering, the Doctor of Engineering in Aerospace Engineering, and the Doctor of Philosophy in Aerospace Engineering.

Name	Degree	Name	Degree
1944			
Carl W. Davis, Jr.	BS	Richard V. Ramsey	BS
Alfred L. Egbert	BS	Virgil L. Razak	BS
Joseph L. Gray	BS	George E. Verhage	BS
Ralph W. May, Jr.	BS	Max R. Whetstone	BS

1945

Name	Degree	Name	Degree
Eugene K. Arnold II	BS	Don R. Learned	BS
William H. Frohoff, Jr.	BS	Nelson A. May	BS
Capt. Edelbert E. Irish	BS		

1946

Charles L. Aylward, Jr.	BS	Rex E. Paulsen	BS
Jack Corber	BS	Donald L. Reid	BS
Dean Corder	BS	Victor C. Ten Eyck	BS
Marshall P. Fryar	BS	Frank H. Wenzel	BS
Roy V. McVey, Jr.	BS	Robert H. White	BS

1947

Donald R. Barrington	BS	James C. Harrison	BS
John J. Bergin	BS	Edsel W. Johnson	BS
Robert V. Coleman	BS	Robert W. McJones	BS
Calvin V. Dresser	BS	Robert H. Ramsay	BS
Charles W. Dreyer	BS	Harry T. Stucker	BS
P. Whitson Godfrey, Jr.	BS	Richard C. Wilson	BS
Paul W. Hare, Jr.	BS		

1948

William F. Armstrong, Jr.	BS	Lynn L. Leigh	BS
Alvin G. Brubaker	BS	Joseph R. Lombrano	BS
Billy G. Corber	BS	Jose J. Portuguez	BS
Forrest E. Cowell	BS	Charles J. Schuler	BS
Walter R. Garrison	BS	Warren R. Seever	BS
John W. Hawley	BS	Harry T. Stucker	MS
Harry W. Johnson	BS	Stanley H. Wade	BS
Robert Keith Lamping	BS	Clyde Wilkerson, Jr.	BS

Name	**Degree**	**Name**	**Degree**
1949			
Levi A. Barnes	BS	Raymond G. Keearns, Jr.	BS
John C. Brizendine, Jr.	BS	Don A. Kuebler, Jr.	BS
Albert B. Callahan, Jr.	BS	John B. Loser	BS
William R. Chaney	BS	John E. McCarty	BS
Alan V. Dougherty	BS	William F. McInturf	BS
William E. Duggins	BS	Milo F. Mracek	BS
George E. Fitch, Jr.	BS	Henry J. Paustian	BS
Dean L. Foster	BS	James C. Shive	BS
Robert A. Frazer, Jr.	BS	Lawrence D. Smith	BS
Norman G. Fritz	BS	Charles W. Spieth	BS
Lawrence L. Gore	BS	Dutton A. Stahl	BS
Marion M. Harter	BS	Ralph W. Ward, Jr.	BS
Roy G. Haskins	BS	William H. Wetz	BS
George Huvendick	BS	Ralph O. Winter	BS
1950			
Lawrence S. Abbott	BS	Byron D. Miller	BS
Vern W. Ballenger	BS	Milton E. Rice	BS
John C. Brizendine, Jr.	MS	Virgil A. Sandborn	BS
John H. Burnett	BS	Edward L. Schmidt	BS
Richard C. Cochran	BS	Ronald K. Smith	BS
Robert W. Cowne	BS	William E. Smith	BS
Earl L. Gadbery	BS	Richard G. Stutz	BS
Walter R. Garrison	MS	Eugene Sylvester	BS
John D. Glenn	BS	Ernest R. Wilde	BS
Charles C. Hicks, Jr.	BS	Clyde Wilkerson, Jr.	MS
Isaac H. Hoover	BS	Richard A. Zlotky	BS
William P. Horton	BS		
1951			
Calvin E. Blair	BS	Raymond E. Rose	BS
James L. Bullard	BS	David R. Shoffner	BS
Wayne I. Burnett	BS	Robert C. Slosson	BS
John P. Fredricks	BS	Giles K. Smith	BS
William C. Hand, Jr.	BS	Richard G. Stutz	MS
Harry W. Johnson	MS	Richard C. Sutton	BS
Brenton L. Lilley	BS	Donald J. Trent	BS
William G. Reschke, Jr.	BS	Robert R. Vetter	BS

Name	Degree	Name	Degree
1952			
Richard E. Etherington	BS	Robert E. Miller	BS
Robert R. Holman	BS	David R. Shoffner	MS
Edward C. Linthicum	BS	Clyde V. Sultzer	BS
1953			
James E. Griswold	BS	Edwin L. Richardson	BS
Gerald R. Hollenbeck	BS	Robert F. Smith	BS
Robert E. Miller	MS	John R. Transue	BS
1954			
Marvin A. Carter	BS	Orvid R. Spoering	BS
Ray E. Griswold	BS	Kenneth G. Wernicke	BS
Fred L. Laqua	BS		
1955			
A. B. Allerton, Jr.	BS	William W. Mains, Jr.	BS
Joe H. Engle	BS	Charles W. Modesitt	BS
Harald Friebe	BS	James R. Sorem, Sr.	BS
Donald M. Gates	BS	Kenneth G. Wernicke	MS
Donald T. Higdon	BS		
1956			
Jack M. Abercrombie	BS	Robert R. Holman	MS
Richard B. Anderson	BS	John C. Kidwell	BS
Robert R. Blackburn	BS	Donald H. Landauer	BS
Gary D. Cool	BS	Alan D. Levin	BS
Don B. Cunningham	BS	Nathan W. McGrew IV	BS
W. Dean DeWitt	BS	James E. Moore	BS
Thomas E. Edmonds	BS	Alfred L. Polski	BS
Marjorie Heard Franklin	BS	Richard J. Reich	BS
William E. Hegarty	BS	Joseph G. Rezin	BS
Donald T. Higdon	MS		

1957

Name	Degree	Name	Degree
William J. Dixon, Jr.	BS	Jack B. Le Claire	BS
Richard L. Dulaney	BS	Richard L. Lee	BS
John O. Eylar	BS	Alan D. Levin	MS
Jerome G. Fish	BS	M. Frank Mastin, Jr.	BS
Gretchen Zimmerman Gerig	BS	Robert W. McJones	BS
Gary Griffith	BS	William Paul McWilliams, Jr.	BS
Ronald D. Herman	BS	Jack R. Shelton	BS
Nancy S. Higdon	BS	David G. Smith, Jr.	BS
Jim Hull	BS	Dale K. Strider	BS
Robert J. Huston	BS	Jack D. Wiseley	BS
Carl R. Kulp	BS		

1958

Name	Degree	Name	Degree
Fred J. Brandon	BS	George D. Meserve, Jr.	BS
True E. Cousins	BS	George B. Michos	BS
Kenneth D. Dewey	BS	Donald A. Moor	BS
Dean F. Grimm	BS	C. Robert Nysmith	BS
Ronald D. Herman	MS	Abe J. Shibe	BS
Robert W. McMichael	BS	James J. Toevs	BS
Donald A. Meis	BS		

1959

Name	Degree	Name	Degree
James L. Baker	BS	Herbert W. Linn	BS
Charles B. Banks, Jr.	BS	Edward L. Martin	BS
Thomas D. Clark	BS	Frank W. Marxen	BS
James R. Cornelius	BS	Don M. Mattocks	BS
Jon R. Gnagy	BS	Jay M. Maxwell	BS
Philip Gotlieb	BS	Joanne M. McPheeters	BS
Barrad M. Gurwell	BS	C. Robert Nysmith	MS
Donald G. Hoelscher	BS	Robert C. Phillips	BS
James W. Kelly	BS	Wendell C. Ridder	BS
Merle W. King	BS	Jerry L. Simmons	BS
Paul L. Klevatt	MS	Richard C. Sutton	MS
David L. Kohlman	BS	Donald E. Wall	BS
Vernon H. Lindhorst	BS	William E. West	BS

1960

Name	Degree	Name	Degree
Peter W. Abbott	BS	Dean T. McCall	BS
Gerald W. Barr	BS	G. Craig McKinnis	BS
Bruce A. Bishop	BS	Robert W. McMichael	MS
T.L. Creel	BS	Donald A. Meis	MS
Gerard W. DeLong	BS	George M. Miller	BS
John E. Foust	BS	Robert D. Ohmart	BS
Joseph R. Gast	BS	Guy L. Quinn, Jr.	BS
Kenneth W. Gates	BS	Joe B. Samuel	BS
Larry L. Jones	BS	Jack R. Shelton	MS
David L. Kohlman	MS	John L. Shideler	BS
Robert L. La Fayette	BS	John F. Shields	BS
William Law	BS	Jerry L. Simmons	MS
William F. Lawrence	BS	Albert H. Werner, Jr.	BS

1961

Name	Degree	Name	Degree
Dale B. Atkinson	BS	William F. Lawrence	MS
Capt. Harold W. Bergmann	BS	Melvin L. Loether	BS
William C. Bowen	BS	Ernest J. Lovelady, Jr.	BS
Richard K. Carnahan	BS	G. Craig McKinnis	MS
William C. Fisher, Jr.	BS	H. Ronald Miller	BS
Alan W. Fleming	BS	Leonard M. Nelson	BS
James A. Franklin	BS	Edgar R. Popham II	BS
Robert D. Fromm	BS	John L. Porter	BS
Scott E. Gilles	BS	William F. Teague	BS
Dayton H. Hunter	BS	Albert L. Thomas, Jr.	BS
Robert J. Huston	MS	Jack W. Vetter	BS
Robert Eric Johnson	BS	George A. York, Jr.	BS
Herbert J. Larson	MS		

1962

Name	Degree	Name	Degree
Peter W. Abbott	MS	Robert E. Langley	BS
Roger L. Benefiel	BS	Michael D. Mack	BS
Russel A. Chambers	BS	John M. Manning	BS
John V. Deffley	MS	Don L. McMillen	BS
John C. Durrett	BS	H. Ronald Miller	MS
G. William Elstun	BS	George A. Oak	BS
Robert W. Finkemeier	BS	Paul Ramirez	BS
Ralph M. Francis	BS	David G. Schnitker	BS
James A. Franklin	MS	John L. Shideler	MS
Gerald L. Gillihan	BS	John A. Trotter, Jr.	BS
Willis D. Harrison	BS	Jack W. Vetter	MS
Lowell W. Hope	BS	Don H. Wagner	BS
William B. Jennings, Jr.	BS	Dallas C. Wicke	BS

1963

Name	Degree	Name	Degree
G. Eugene Barron	BS	Richard L. Peil	BS
Frank J. Breen III	BS	Harold L. Rogler	BS
Wheelock H. Cameron, Jr.	BS	Gerry O. Sibley	MS
James L. Dike	BS	Larry E. Smith	BS
James R. Lewis	BS	Curtis J. Winters	BS
Lorrence A. Mahaffy, Jr.	BS		

1964

Name	Degree	Name	Degree
Henry M. Dodd, Jr.	BS	Gary R. Muller	BS
Thomas J. Dunwoody	BS	Kenneth E. Sahre	BS
Francis W. Gerlach	BS	James O. Sampson	BS
Delton M. Gilliland	BS	Leroy M. Shaw	BS
Willard W. Gregg	BS	Robert J. Waner	BS
Charles P. Koch	BS	Robert L. Wethington	BS
John S. Mauch	BS	Barry E. Wilson	BS

1965

Name	Degree	Name	Degree
Robert M. Anderson	BS	Michael D. Mack	MS
S. J. Baker	BS	Delton A. Masenthin	BS
Morris R. Betry	BS	Robert P. Maynard	BS
Lawrence H. Brown	BS	Dennis M. McCain	BS
Robert C. Brown	BS	Gary L. McClure	BS
Patrick D. Clark	BS	Roy S. Moritsugu	BS
Scott M. Downing	BS	Ronald D. Mumaw	BS
Linda Dotson Drake	BS	Harlan D. Ralph	BS
Lewis A. Felton	BS	Roger L. Ratzlaff	BS
Joseph R. Gast	MS	L. James Roh	BS
Keith E. Gilliland	BS	J. David Summers	BS
Theodore R. Goldstein	BS	Charles F. Twiss	BS
Richard C. Haddock	BS	Robert A. Woodling	BS
John P. Kirkpatrick	BS	R. Deane Woods	BS

1966

Name	Degree	Name	Degree
Robert T. Alfrey	BS	Richard A. Monroe, Jr.	MS
Robert M. Anderson	MS	Ralph E. Najim	BS
G. Eugene Barron	MS	John D. Nesbitt	BS
Peter E. Bartman	BS	Raymond L. Nieder	BS
Robert E. Bryan	BS	Terry L. Oldham	BS
Ronald E. Charlson	BS	Richard W. Richardson	BS
Donald M. Cress	BS	Arnold E. Schumacher, Jr.	BS
John M. Ellis	BS	Leroy M. Shaw	MS
Esam M.S. El-Shafey	BS	Michael G. Shinn	BS
Daniel L. Green	BS	Stephen R. Strayer	BS
Terry M. Green	BS	Larry L. Sukut	BS
William L. Hendricks	BS	Terry N. Tykeson	BS
J. Nelson Ingram	BS	Allen L. Vick	BS

1967

Name	Degree	Name	Degree
Thomas N. Aiken	BS	Paul A. Mitchell	BS
Eugene L. Bollin	BS	Michael R. Peloquin	BS
Stephen K. Bowes	BS	William M. Raker	BS
Dennis G. Cannon	BS	Roy M. Rawlings	BS
Fred E. Chana	BS	Larry W. Rinne	BS
Clement Y.B. Ching	BS	David A. Sagerser	BS
Richard W. Holmes	BS	Elwood W. Shields	BS
Lairy A. Johnson	BS	Douglas W. Steen	BS
Lawrence W. Lay	BS	Terry G. Tarr	BS
William M. Leins	BS	Conrad D. Wagenknecht	BS
Kenneth C. Leone	BS	Edward Wolcott	BS
William H. Lightstone	BS		

1968

Willard R. Bolton, Jr.	BS	Gerald E. Jenks	BS
Carl H. Brainerd	BS	Charles E. Knox	BS
Jeffrey D. Brandt	BS	John R. Louden	BS
Stephen J. Brasher	BS	James T. Mack	BS
Dennis G. Cannon	MS	Paul W. Mayer	BS
Charles E. Cassil, Jr.	BS	Alan R. Mulally	BS
Linda Dotson Drake	MS	Douglas M. New	BS
David M. Evans	BS	Richard W. Richardson	MS
Terry N. Faddis	BS	Edward J. Robertson	BS
Richard L. Frazier	BS	Charles W. Sapp	BS
Robert B. Garrett	BS	Gary E. Temanson	BS
Gerald E. Gaylord	MS	Conrad D. Wagenknecht	MS
Martin Lynn Grogan	BS	Gary K. Waggoner	BS
Ronald A. Gustafson	BS	John A. Zimmerman	BS
Douglas D. Hoople	BS		

1969

Name	Degree	Name	Degree
Gary L. Adkins	BS	Lawrence T. Madden	BS
Gerald N. Baker	BS	Jesse E. Manahan	BS
Edward L. Bohannon	BS	Joseph R. Martinez	BS
Philip H. Bozarth	BS	Robert E. McIntyre	BS
Margaret C. Brake	BS	Ronald K. Moore	BS
William F. Bryant III	BS	Alan R. Mulally	MS
Nicholas Calapodas	BS	Kapil K. Nanda	MS
John D. Carlile	BS	Daniel T. Oliver	BS
Robert C. Colwell	BS	Dennis D. Phillips	BS
Kenneth E. Davidson	BS	Royace H. Prather	BS
Fred R. Emmons, Jr.	BS	Charles W. Sapp	MS
Rudolph E. Florez	BS	Donald R. Seyb	BS
Benjamin F. Gorrell, Jr.	BS	Larry D. Shannon	BS
Gary L. Graber	BS	Charles A. Shoup	BS
Richard T. Hornsby	BS	Victor Welner	BS
Glen D. Jenkins	BS	Chester H. White II	BS
Darryl L. Lamberd	BS		

1970

Rex D. Agler	BS	Paul T. Hetherington	BS
	MS	Robert W. Hickson	BS
Bruce W. Baker	BS	Dwight P. Holm	BS
Richard D. Barrows	BS	Richard F. Juarez	BS
Richard S. Beamgard	BS	James D. Keen	BS
Robert A. Bibb	BS	Daniel W. Keene	BS
John R. Burke	BS	Daniel J. Kolega	BS
John D. Casko	BS	Douglas J. Marshall	BS
Robert L. Chase	BS	Thomas W. McLaughlin	BS
Robert C. Colwell	MS	David M. Reynolds	BS
Hubert C. Connolly	BS	Robert B. Russell	BS
David G. Deeken	BS	Steven H. Salvay	BS
Kenneth W. Dietz	BS	Michael M. Sayler	BS
Terry Funk	BS	Robert J. Slavik	BS
Mark E. Gleason	BS	Thomas K. Washburn	BS
Ronald J. Glidewell	BS	James D. Young	BS

1971

Name	**Degree**	**Name**	**Degree**
Donald Paul Amiotte	BS	Eldon D. Jackson	BS
Gregg I. Anderson	BS	Carl R. Kulp, Jr.	BS
Forrest J. Aull, Jr.	BS	Gerald H. May	BS
Paul E. Berger	BS	Ronald A. McGee	BS
Joseph T. Botinelly	BS	Sudhir C. Mehrotra	MS
Steven R. Brown	BS	Michael G. Miller	BS
George F. Bryan	BS	Ernest R. Perkins	BS
Darrel R. Caldwell	BS	Randall C. Phillips	BS
Keith H. F. Chui	BS	Stephen J. Reynolds	BS
David H. Clark	BS	Loy D. Rickman, Jr.	BS
James M. Evans	BS	Andrew Russell	BS
Terry D. Exstrum	BS	Douglas W. Steen	MS
Glenn R. Gibson	BS	Jamshid Taleghani	BS
Milton L. Gleason	BS	Donald E. Walker, Jr.	BS
Karl J. Grimes	BS	Allen C. Walter	BS
David L. Grose	BS	Robert M. Wasko, Jr.	BS
Richard D. Harre	BS	James R. Weaver	BS
Douglas R. Henson	BS	Walter P. West	BS
Donald L. Horine, Jr.	BS	Timothy M. Whyte	BS
David W. Howard	BS	Ronald E. Wilmore	BS
Boyd J. Inman	BS	James W. Youngblood, Jr.	BS

1972

Franklin C. Berrier	BS	Lawrence R. Martin	BS
Carl H. Brainerd	MS	Dennis W. Miller, Jr.	BS
Michael S. Burtle	BS	James L. Morfeld	BS
Dennis L. Cherry	BS	Alan A. Mueller	BS
Daniel F. Farrier	BS	George B. Oliver	BS
H. Glen Fickel, Jr.	BS	Stephen E. Pieschl	BS
Alan Frazier	BS	Henry F. Reepen	BS
Wayne E. Frazier	BS	Robert G. Shields	BS
Robert B. Garrett	MS	Stanley A. Sneegas	BS
Mark E. Gleason	MS	Gary L. Stuart	BS
James W. Harris	BS	Mark S. Swade	BS
Richard L. Horvath	BS	Tyler W. Trickey	BS
Robert W. Iler	BS	James F. Unruh	PHD
Surinder K. Kaul	MS	Tony Villari	BS
Richard M. J. Kovich	BS	Andrew D. Wales	BS
Allen L. Linsenmayer	BS	Kenneth Neil Williams	BS
William J. Loesch	BS		

1973

Name	Degree	Name	Degree
Kurt D. Bausch	BS	William J. Keith	BS
Charles T. Beno	BS	John Patrick McKenna	BS
Keith H. F. Chui	MS	Marvin R. Nuss	BS
Dean E. Cooper	BS	Larry J. Nutsch	BS
Glenn R. Gibson	MS	Matthew F. Orr, Jr.	BS
Brian F. Goldiez	BS	Marvin J. Pratt	BS
James D. Grounds	BS	Michael T. Probasco	BS
William B. Herpin, Jr.	BS	Douglas E. Rodgers	BS
Michael L. Hinson	BS	Trevor C. Sorensen	BS
Bruce J. Holmes	BS	Ronald J. Wiens	BS

1974

Name	Degree	Name	Degree
Jeffrey J. Baker	BS	Stephen J. Reynolds	MS
Roy J. Beckemeyer	PHD	George F. Rowland, Jr.	BS
Andrew C. Cruce	PHD	William M. Schulthess	BS
Michael L. Hinson	MS	S. Kelly Weller	BS
Bruce J. Holmes	MS	John R. Wittmeyer	BS
Michael T. Probasco	MS		

1975

Name	Degree	Name	Degree
Seetharam H. Chintamani	PHD	Annamma Varghese John	MS
Charles S. Douglas III	BS	Randall G. Oliver	BS
Steven D. Ginter	BS	Michael Overbey	BS
David L. Grose	MS	Harald B. Pettersen	BS
Bruce A. Hames	BS	Mark S. Rice	BS
George C. Hill	BS	Hendirk L. J. Schunselaar	MS
Paul E. Jamison	BS	Gregory J. VanSickel	BS
Henry W. Jarrett	BS		

1976

Name	Degree	Name	Degree
Douglas W. Andrews	BS	Trevor C. Sorensen	MS
Nicholas Calapodas	MS	Robert C. Stolle	BS
Donald W. Durenberger	BS	Michael J. Tierney	BS
Gregory L. Fillman	BS	Thomas M. Tuohey	BS
Terry D. Henderson	BS	Robert D. Wyatt	BS
Paul R. Martz	BS		

Name	Degree	Name	Degree
1977			
Edward L. Baker	BS	Sudhir C. Mehrotra	PHD
Thomas J. Carr	BS	Sharad N. Naik	PHD
Franklin L. Foiles	BS	Chris R. Paraghamian	BS
Douglas A. Griswold	BS	Charles F. Vaughan	BS
Charles A. Hughes	BS	Weldon C. Wainright	BS
Gary S. James	BS	Darrell O. Wigton	BS
Terry L. Janssen	PHD	Donald O. Young	BS
1978			
Charles L. Guthrie	BS	Kenneth D. McCoy	BS
Jim Hammer	BS	Paul T. Meredith	BS
Kevin E. Hawley	BS	Jeffrey C. Miller	BS
David K. Henry	BS	Mark S. Rice	MS
Jerry L. Jordan	BS	Robert W. Rodgers	BS
James C. Kaiser	BS	Steven J. Rosenfeld	BS
Donald D. Markow	BS	Peter VanDam	MS
William R. Martindale	PHD		
1979			
Gary A. Braun	BS	Ralph E. Hite III	BS
Sam Bruner	BS	Charles A. Hughes	MS
James P. Canon	BS	Rebecca L. Kobelt	BS
Scott B. Chellgren	BS	Carl R. Kulp, Jr.	MS
Marlin B. Dailey, Jr.	BS	Charles E. Purvis	BS
Leon R. Dechant	BS	James D. Ritter	BS
Frederick P. Dibble	BS	Gary D. Skinner	BS
David S. Dunn	BS	Bob VanKeppel	MS
Gregory L. Fillman	MS	Ting Wang	MS
Michael R. Griswold	BS		
1980			
David C. Chappell	BS	Mustafa Guroglu	MS
Robert Clarke	BS	Mark J. Harrell	BS
Victor L. Gillings	BS	Fridrik Jonsson	BS
Steven R. Griffith	BS	Thomas M. McAtee	BS
Michael R. Griswold	MS		

Name	**Degree**	**Name**	**Degree**
1981			
David O. Bauer	BS	John A. Pilla	BS
Ricky D. Bess	BS	Stewart J. Platz	BS
Steven Todd Brack	BS	Gilbert J. Potter	BS
Keith B. Braman	BS	Lawrence A. Rosselot	BS
Ronald Lee Culp	BS	Karl Martin Schletzbaum	BS
Dirk J. Deam	BS	William A. Scott	BS
Russell Charles Engel	BS	Michael J. See	BS
Ray Hower	BS	James R. Thiele	BS
Ronald R. Hrabak	BS	Morgan Williams	BS
James P. Hunt	BS	Michael J. Witt	BS
Duayne D. Peterson	BS		
1982			
Alan E. Albright	BS	Rogerio Largman	BS
Jay M. Brandon	BS	Mark League	BS
Yen-Sen Chen	MS	Pai-Hung Lee	MS
Keith Miles Clancy	BS	David W. Levy	BS
Yoram David	MS	Curtis D. Maris	BS
Paul D. Finn	BS	R. Navaneethan	MS
Ferdinand M.W.A. Grosveld	DE	Michael R. Owings	BS
David P. Hughes	BS	Ivan Sheall	BS
Michael S. Johnson	BS	Werachone Nam Singnoi	BS
Van L. Kerns	BS	Scott Stevenson	BS
Russell D. Killingsworth	BS	Barry G. Streeter	BS
Stephen W. Koontz	BS	Kenneth Verderame	BS
Hiroyuki Kumagai	MS		
1983			
Gary A. Anderson	BS	Susan Harris Johnston	BS
Carlos L. Blacklock, Jr.	BS	Mark J. Keary	BS
Jere R. Calef	BS	Paul M. Mullin	BS
Der-Chang Chao	MS	Perry N. Rea	BS
Ghayth Gergi Coussa	BS	Jesse W. Saetz	BS
Ray Kim Davis	BS	Bill C. Schinstock	BS
Stephen Ray Dennon	BS	Kurt F. Schmidt	BS
Paul Vendley Donlan	BS	Sheryl Renee Scott	BS
Jose A. Herrera-Vaillard	MS	Douglas B. Shane	BS
James P. Hunt	MS	Mawshyong Jack Shiau	MS
Paul D. Jackson	BS		

1984

Name	Degree
Paul Wilson Barrow	BS
Paul H. Bastin	BS
Carlos L. Blacklock, Jr.	MS
Jay M. Brandon	MS
Kolin Kent Campbell	BS
Scott Evan Claflin	BS
Dennis L. Cole	BS
Lonnie R. Dillon	BS
Daniel M. Dobbins	BS
Richard T. Geiger	BS
Michael G. Graham	BS
Donald Joseph Jamison	BS
Max Urban Kismarton	BS
Greg C. Krekeler, Jr.	BS
Troy S. Lake	BS
David P. Marshall	BS
Michael Richard Myers	BS
James D. Paduano	BS
Thomas S. Pettigrew	BS
Victus F. Rose	BS
Michael Allen Schmidt	BS
Daryl J. Schueler	BS
Mark Edward Stevens	BS
Ing-Chung John Su	MS
Charles R. Svoboda, Jr.	BS
Douglas J. Vaught	BS
Tina Marie Vesper	BS
Sally A. Viken	BS
Pat G. Vitztum	BS
David B. Weaver	BS
Kenneth L. Williams	BS
John A. Woltkamp	BS

1985

Name	Degree
David L. Beuerlein	BS
Gary A. Braun	MS
Stephen Ray Dennon	MS
David Dwyer	BS
John W. Egner	BS
John D. Elvin	BS
Robert J. Eugster	BS
David Joe File	BS
Wayne Owen Fink	BS
Robert Kelly Freeman	BS
Richard W. Heim	BS
John Jacob Hernandez	BS
Kris R. Howard	BS
David W. Levy	MS
Michael William Lovett	BS
Brett A. Loyd	BS
Patrick A. Magness	BS
Brian K. Manke	BS
Thomas M. McAtee	MS
Timothy E. Menke	BS
James E. Mitchell	BS
Donald J. Nelson	BS
Michael Nelson	BS
Todd M. Post	BS
Timothy L. Riffel	BS
Kyle D. Sperry	BS
Stephen George Spratt	BS
Robert S. Weaver	BS
Daniel J. Wegman	BS
Lue Xiong	BS
John B. Young II	BS

Name	**Degree**	**Name**	**Degree**
1986			
Phillip A. Bahorich	BS	Leroy J. Mergy	BS
Kris B. Bauer	BS	Larry Page	BS
Kirk Anthony Blacklock	BS	Michael R. Peebles	BS
Peter J. Broll	BS	Jerry John Radke	BS
Gerald R. Callejo	BS	James J. Redmond	BS
Eric L. Carson	BS	Steven F. Redpath	BS
Ninan Chacko	BS	Christopher Mark Reinhart	BS
Thomas R. Creighton	BS	William M. Reyer	BS
Troy A. Cummins	BS	Daniel L. Roche	BS
Donald J. Davis	MS	Timothy Brock Schauf	BS
Kenneth S. Dawson	BS	Robert Earl Schooler	BS
Jeffrey B. Drake	BS	John C. Shepard	BS
David P. Entz	BS	Mark Edward Stevens	MS
James B. Greenwood	BS	David Dayton Swartz	BS
John T. Houston	BS	Eric Torgerson	BS
Ching-Chyuan Hsing	MS	Michael E. Turnipseed	BS
Cherie L. Johnson	BS	Kenneth L. Williams	MS
Michael G. Lewis	BS	Kurt E. Zimmerman	BS
John C. Martin	BS		
1987			
Roger D. Albers	BS	Howard Libbert	BS
Adel Rashed Al Thawadi	BS	Dan Martin	MS
Thomas E. Aniello	BS	Todd G. McCready	BS
Michael S. Brandt	BS	Louise K. Morgan	BS
Myron Lee Bultman	BS	Mark H. Norris	BS
Ninan Chacko	MS	Charles R. Oxendine	BS
Nikhil K. Dash	BS	James D. Paduano	MS
Doug Decker	BS	John F. Remen	BS
Edward A. DiGirolamo	BS	Rex J. Reum	BS
Kent Donaldson	BS	Terry K. Robinson	BS
Andrew Fred Dracon	BS	Mark S. Russell	BS
George Michael Dragush	BS	Ronald K. Sadler	BS
Michael Wayne Egner	BS	Kenneth D. Sebek	BS
Shawn A. Engelland	BS	Phillip Norman Smith	BS
John B. Hanson	BS	Bryan Lynn Stauffer	BS
Louis J. Hendrich	BS	John E.C. Stewart	BS
Douglas Dean Hensley	BS	Nicolas Suarez	BS
Michael D. Ison	BS	Reiner Suikat	MS
Paul W. James	BS	David B. Weaver	MS
Joseph C. Katuzienski	BS	Matthew A. Webber	BS

1988

Name	Degree	Name	Degree
Paul Andrew Barnard	BS	Kenneth P. Meissbach	BS
Ronald Martin Barrett	BS	Louise K. Morgan	MS
Craig A. Befort	BS	John Patrick Pavelcik	BS
Charles D. Buffkin	BS	Kendra L. Pierce	BS
Chris Ferdinand Burmeister	BS	Gerry D. Pollock	BS
Timothy Allen Burns	BS	Carmen Manuela Roser	MS
Deborah J. Bushey	BS	Ross Adam Schaller	BS
I-Kuang Chou	MS	Timothy Paul Schmidt	BS
Michael P. Clune	BS	Daniel L. Sherwood	BS
Scott Alan Danenhauer	BS	Wen Lin Sheu	MS
David Eggold	BS	Kevin E. Siebert	BS
David F. Fanning	BS	Kevin Lovett Smith	MS
Tyson H. Flugstad	BS	Jan Beemer Stark	BS
Steven Tod Gilchrist	BS	Robert M. Sutherlin	BS
David S. Henn	BS	Gerald A. Swift	BS
Kevin Lindsey Jackson	BS	Edward Lynn Terrell	BS
Paul Stewart Lane	BS	Jeffrey J. Tuschhoff	BS
Dion P. Lies	BS	David P. Warner	BS
Dennis John Linse	MS	Mark L. West	BS
Patrick T. McKenzie	BS	Michael J. Wolf	BS

1989

Name	Degree	Name	Degree
James C. Allen	BS	Michael David James	BS
Rudolf H. Bartel	BS	Vicki S. Johnson	PHD
Paul F. Borchers	BS	Brian Lochlan Kerns	BS
David Joseph Burdick	BS	John Michael Kiesov	BS
Paul Chase	BS	Robert W. Lane III	BS
Wesley P. Cochran	BS	Lurae D. La Rose	BS
Heather Lea Cooper	BS	Scott Martin Lazaroff	BS
Brian William Cox	BS	Donald K. Leap	BS
Son Francois Creasman	MS	John Francis Love	BS
Paul D. Darrah	BS	Clay Selden Mauk	BS
Darren Clay Davenport	BS	Douglas A. May	BS
Stephen Andrew Denison	BS	Nikos D. Mills	BS
David Dwight Dibble	BS	Kenneth E. Polnicky	BS
Ty Russell Drake	BS	Brian K. Richardet	BS
Shawn A. Engelland	MS	George W. Ryan III	BS
Dawn Sandza Galloway	BS	Ralph A. Sandfry	BS
Fuying Ge	MS	Steven C. Schmidt	BS
Kenneth Forrest Glenn, Jr.	BS	Rueiwen L. Sharng	MS
George D. Gribbins, Jr.	BS	Peter A. Stonefield	BS
Christopher J. Hardin	BS	Phillip B. Stump	BS
Dean Michael Heald	BS	Edmund H. Unterreiner III	BS
Robin L. Hicks	BS	Nicholas Peter Waterson	MS
Mark Holt	BS	Bryan S. Wescoat	BS
Mark H. Hoyle	BS	Linda A. Witt	BS

1990

Name	Degree	Name	Degree
Stephen A. Ashmore	BS	Alan P. Lampe	MS
Emilie Guyot Atkins	MS	Todd C. Lawson	BS
Larry L. Bellmard	BS	Mark League	MS
Spencer Lewis Brackman	BS	Randall K. Liefer	DE
Thomas B. Crabtree	BS	Peter Nelson	BS
Andrew M. Demarea	BS	Cesar Augusto Ocampo	BS
Kent Donaldson	MS	Eric J. Peterson	BS
Stanley Linn Dunaway	BS	Daniel Martin Pfeiff	BS
David W. Ferguson	BS	Mahyar Rahbarrad	BS
Gregory L. Fleniken	BS	Jeffrey Jon Renz	BS
Paul W. Gloyer	BS	Tweed W. Ross III	BS
Charles O. Gomer, Jr.	BS	Diosdado G. Salaveria	BS
Tedmond W. Goodspeed	BS	Jagjit Singh	BS
Eric S. Hamby	BS	Bryan Lynn Stauffer	MS
Dean F. Henderson	BS	Jeffrey Paul Thomas	BS
Lisa Ann Ikerd	BS	Jeffrey J. Tuschhoff	ME
Tavis Jerome Jacobs	BS	Martin J. Vasquez	BS
Eric H. Kivett	BS	William E. Witwicki	BS

1991

Name	Degree	Name	Degree
Amy E. Allen	BS	Alan S. Krause	BS
James A. Anderson	BS	Jerry Kao Kung	BS
Kenneth M. Axmann	BS	Justin Honshune Lan	BS
Bradley E. Bartels	BS	Kenneth Andrew Lieber	BS
Sidney D. Bauguess	BS	Steven W. McArthur	BS
James A. Bernasky	BS	Matthew Wayne Mehl	BS
Paul F. Borchers	MS	Greggory David Miller	BS
Brian Michael Bruckner	BS	Depak B. Patel	BS
Quan Thanh Bui	BS	Bret A. Phillips	BS
David F. Burgstahler	BS	Stephen A. Rech	BS
Kai C. Chang	BS	Doug John Sagehorn	BS
Suei Chin	PHD	Thomas Neal Schaeffer	BS
Philip Everett Chronister	BS	Steven F. Shumate	BS
David W. Crook	BS	Paul A. Soulis	BS
Dwayne Lee Desylvia	BS	Douglas John Squire	BS
David Eggold	MS	Dierk Leon Taylor	BS
Donald R. Frew	BS	Michael Dean Thacker	BS
James H. Frickey, Jr.	BS	Jing-Biau Tseng	PHD
Norair Sarkis Ghazarian, Jr.	BS	David D. Walsh	BS
Brian L. Gilchrist	BS	Jeffrey S. Weiss	BS
Daniel Eugene Huffman	BS	Edward Allan Wenninger	BS
Sean C. Jackson	BS	Kyle Kristopher Wetzel	BS

1992

Name	Degree
Mark Henry Clatterbuck	BS
Brian William Cox	MS
Albert M. Dirkzwager	MS
Gregg A. DonCarlos	BS
Antje Ellrott	BS
Derek Donovan Goad	BS
William D. Gooch	BS
Brian S. Gray	BS
Christopher J. Hardin	MS
Jonathan L. Headrick	BS
Tom Magne Herskedal	BS
Robert Arthur Hixson	BS
Arthur S. Hofmeister	BS
Marty J. Houdeshell	BS
Joseph A. Huwaldt	BS
Douglas Ray Isaacson	BS
Daniel K. Kauzlarich	BS
Stephen K. Kirby	BS
Darren Francis Knipp	MS
Kristopher M. Koenig	BS
Daniel W. Krug	BS
Todd C. Lawson	MS
Chyuan-Hsyan Paul Liaw	PHD
Steven Andrew Maley	BS
Julia Eileen Mathias	BS
Judy Wohletz May	BS
Robert H. Miller	BS
Nikos D. Mills	MS
Matthew John Nelson	BS
William Howell Newton III	BS
Khang Yong Oei	BS
Patel Kalpesh Patel	BS
John W. Roper	BS
George W. Ryan III	MS
Kevin R. Schmitz	BS
Thomas Scott Sherwood	BS
Farzad B. Sistani	BS
Todd Michael Stout	BS
Jeffrey Paul Thomas	MS
John Lawrence Valasek	MS
John M. Verbestel	BS
Jeffrey Scott Wilcox	BS
Stacey L. Winger	BS
Chengzhi C. Wu	PHD
Steven Douglas Young	BS
Khaled Mohsen Zbeeb	BS
Zouheir Mohsen Zbeeb	BS
William C. Zimmerman	BS

1993

Name	Degree	Name	Degree
Latheef Najeeb Ahmed	MS	Clay Selden Mauk	MS
Ronald Martin Barrett	PHD	Albert Julian Mercado	BS
Christopher D. Brandt	BS	Gary D. Miller	BS
David M. Denning	BS	James Eugene Miller	BS
Jeremy L. deNoyelles	BS	Sean Padraig Morgan	BS
Troy D. Downen	BS	Rasvir Singh Mustan	BS
Jean M. Fernand	PHD	Thanh Nguyen	BS
Jason Edward Frank	BS	Marcos Vinicius R. Nogueira	BS
Charles O. Gomer, Jr.	MS	Ahmad Noory	BS
Catherine Michelle Grant	BS	Charles Edward Novak	BS
Kurt Douglas Haack	BS	Craig Scott Peltzie	BS
Thomas Charles Harrison	BS	Bret A. Phillips	MS
Geir Hatling	BS	Clinton R. Povich	BS
Richard Neil Hazlewood	BS	Kevin S. Schlatter	BS
Alan Ikenberry	BS	Tanya M. Smith	BS
Brent D. Johnson	BS	Nevin Ronald Swearengin	BS
Valerie A. Jones	BS	Michael Dean Thacker	MS
Jason M. Jundt	BS	Scott Barrett Thompson	BS
Paul John Kalowski, Jr.	BS	Robert Craig Waner	BS
Hiromi Kawanishi	BS	Eric Christopher Wilson	BS
Larry Lynn Kratochvil	BS	Steven Michael Yates	BS
Armen Haig Kurdian	BS	Yeang Yeow Yuen	BS
Scott P. Lickteig	BS		

1994

Name	Degree	Name	Degree
Travis Jason Berkley	BS	David E. McConnell	BS
Stephen A. Delurgio II	BS	Eric S. McLeroy	BS
Jeffrey Robert Engel	BS	Thomas N. Mouch	PHD
Fuying Ge	PHD	Lewis Raymond Nash	BS
Norair Sarkis Ghazarian, Jr.	MS	Joachim Pollak	MS
Joaquin Gonzalez Guerrero, Jr.	BS	Donald Dale Ringer	BS
Joseph A. Huwaldt	MS	Howard J. Sacks	BS
John Koshy	BS	David Dean Scott	BS
Alan S. Krause	MS	Wen Lin Sheu	PHD
Tacheng Lee	PHD	Todd Michael Wentz	BS
Jan Kirke Lonborg	BS		