Worldwide Aeronautical Research and Development Face Competitive Challenges

Advances in technology and global competitiveness are changing the research and development landscape of the aerospace industry, and are offering potential new safety benefits.

by
U.S. International Trade Commission

The 17 major public and private organizations that conduct most of the world aeronautical research and development (R&D) are located in the United States, Western Europe, Russia and Japan (Table 1, page 2).

The incorporation of new technologies that advance aircraft performance (measured by fuel efficiency, range and speed), reliability and safety, and that increasingly reduce noise and other environmental effects, significantly affects marketability of an aircraft and in turn impacts on the competitiveness of manufacturers of large civil aircraft (LCA).

Nevertheless, before new technologies are implemented, LCA manufacturers must consider whether they are compatible with existing systems, what the development and production costs will be and how they will affect airline direct operating costs (i.e., fuel consumption), retraining and maintenance. The benefits derived from the major areas of aeronautical R&D are shown in Table 2 (page 4).

LCA R&D results can be separated into evolutionary changes (resulting in incremental improvements) and revolutionary changes (resulting in entirely new aircraft paradigms); major LCA manufacturers largely rely on evolutionary changes to serve their customers.[1] Revolutionary technologies, such as the introduction of the turbofan jet engine, which rendered large piston-engine aircraft obsolete, can completely redefine LCA.

LCA producers concentrate their R&D efforts on aircraft design, but R&D also is important for integration, assembly, flight test and aircraft certi-

Table 1
Major International Organizations Conducting Subsonic Aeronautical Research and Development (R&D), 1991

Organizations	Source of funding	Budget/ sales (US$)	Aeronautical R&D budget[1] (US$)	Total employ- ment	Aeronautical R&D focus	Major customers
FRANCE						
Office National d'Etudes et de Recherches Aérospatiales (ONERA)	Public	$237 million	$72 million	2,304	Long-term, up-stream, basic	Public & private sectors
Aérospatiale Group	Public/ private	$8.6 billion	$496 million	1,850[2]	Near-term market-oriented, near-term defense	Airbus, ATR, Defense
GERMANY						
Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR)	Public/ private	$425 million	$112 million	4,500	Long-term, pre-competitive, high-risk	Public & private sectors
Deutsche Aerospace (DASA)	Private	$6.6 billion	$471 million	21,990[3]	Near-term market-oriented, near-term defense	Airbus, Fokker, Defense
JAPAN						
National Aerospace Laboratory (NAL) of the Science and Technology Agency (STA)	Public	$80 million[4]	NA	438	Long-term, pre-competitive, high-risk	Public & private sectors
NETHERLANDS						
Nationaal Lucht- en Ruimtevaartlaboratorium (NLR-National Aerospace Laboratory)	Public/ private	$66 million	$66 million	817	Long-term, up-stream, basic	Public & private sectors
NV Koninklijke Nederlandse Vliegtuigfabriek Fokker	Private	$2.0 billion	$20 million	12,606	Near-term market-oriented, near-term defense	Fokker, Defense
RUSSIA						
Ilyushin Design Bureau	Public	NA	NA	12,000	Long-term up-stream, basic, near-term defense	Public & private sectors
Tupolev Design Bureau	Public	NA	NA	15,000	Long-term up-stream, basic, near-term defense	Public & private sectors
Central Aero-Hydrodynamics Institute (TsAGI)	Public	NA	NA	10,000	Long-term up-stream, basic	Public & private sectors
UNITED KINGDOM						
Defense Research Agency (DRA)	Public	$1.3 billion	$195 million	11,500	Long-term, up-stream, basic	Public & private sectors
British Aerospace (BAe)	Private	$19.7 billion	$255 million	9,100[5]	Near-term market-oriented, near-term defense	Airbus, BAe, Defense

Table 1 (continued)

Organizations	Source of funding	Budget/ sales (US$)	Aeronautical R&D budget[1] (US$)	Total employ- ment	Aeronautical R&D focus	Major customers
UNITED STATES						
National Aeronautics and Space Administration (NASA)	Public	$14 billion	$512 million[6]	15,200[7]	Long-term, pre-competitive, high-risk	Private sector, DOD
Federal Aviation Administration (FAA) of the U.S. Department of Transportation	Public	$7.2 billion	$197.9 million	[8]	Aircraft safety, design and production; quality control	Private sector, DOD, NASA
U.S. Department of Defense (DOD)	Public	$309 billion	$5.8 billion	[8]	Defense	DOD
The Boeing Co.	Private	$29.6 billion	$1.4 billion	87,324[9]	Near-term market-oriented, near-term defense	Boeing, DOD, NASA
McDonnell Douglas Corp.	Private	$18.4 billion	$429 million	109,123	Near-term market-oriented, near-term defense	McDonnell Douglas, DOD, NASA

1 Data for companies are for total corporate, internally funded R&D.
2 Aérospatiale's design office employment. Total corporate employment was 25,894 persons at the end of 1991.
3 Deutsche Aerospace Airbus employment.
4 April 1992-March 31, 1993.
5 BAe Airbus Limited employment.
6 Aeronautical Research and Technology Budget.
7 Office of Aeronautics and Space Technology.
8 Figures for employees involved in aeronautical R&D are not available.
9 Boeing Commercial Airplane Group total employment.
NA = Not available

Source: 1991 Annual Reports of British Aerospace, Aérospatiale, DASA, Boeing, McDonnell Douglas, ONERA, DLR, NLR, DRA; NASA, Budget Estimates, Fiscal Year 1992; *Office of Management and Budget,* Budget of the United States Government, Fiscal Year 1993 *(Washington, DC: GPO, 1992).*

fication. Nevertheless, much of the technological development in propulsion, avionics, control and structures and materials has been achieved by engine manufacturers and other LCA subcontractors. Research currently is being conducted in a variety of prototype technology fields, including ultra-high-bypass engines, very large/ultra-high-capacity aircraft, supersonic and/or hypersonic aircraft, cryogenic fuels and new hybrid fiber-metal laminates such as GLARE (glass fiber aluminum laminates). Other research efforts by LCA manufacturers include advanced-component technology to facilitate commonality in aircraft families and reduce development costs. Research in the advancement of process technology reduces production costs and increases product quality.

R&D funding is critical to the refinement of major technologies and the introduction of new LCA programs. Today, the US$5 billion to US$l0 billion in R&D needed to produce a new family of aircraft places an enormous financial burden on the LCA producer and subjects the firm to potential bankruptcy.

At the same time, success in the LCA market depends on maintaining R&D funding at substantial levels to minimize costs and reduce the time to introduce new LCA models into the market. The majority of the costs are incurred in the develop-

Table 2

Benefits of Aeronautical Research and Development (R&D), by Discipline

	Need area/benefits					
Aeronautical R&D Discipline	Lower user cost greater convenience	Greater capacity	Reduced environmental impact	Greater safety	Improved performance	Aircraft design and development
Aerodynamics	Lower fuel costs	Not applicable	Less noise on takeoff/landing	Not applicable	Greater range and speed (higher lift/drag ratio)	Shortened develop-ment cycle, technology validation
Propulsion	Lower fuel costs reduced maintenance higher reliability	Not applicable	Lower emissions less noise	Not applicable	Greater range and speed (reduced fuel consumption	Shortened engine development cycle, technology validation
Avionics and control	More effective crew increased reliability	Global positioning (ground and air), real-time weather data, optimized air traffic control	Not applicable	Lower demands on crew, fault-tolerant systems	Increased reliability (engine control, actuator control, situational awareness)	Integrated systems, technology validation
Structures and materials	Longer life, lower maintenance	Not applicable	Not applicable	Predictable material fatigue, "smart structures"	Greater range and speed (lower weight)	Shortened development cycle, technology validation

Source: Compiled by the staff the U.S. International Trade Commission from Aeronautics and Space Engineering Board, National Research Council, Aeronautical Technologies for the Twenty-First Century *(Washington, DC: National Academy Press,1992), pp. 33, 99, 111, 151, 189, 223 and 245.*

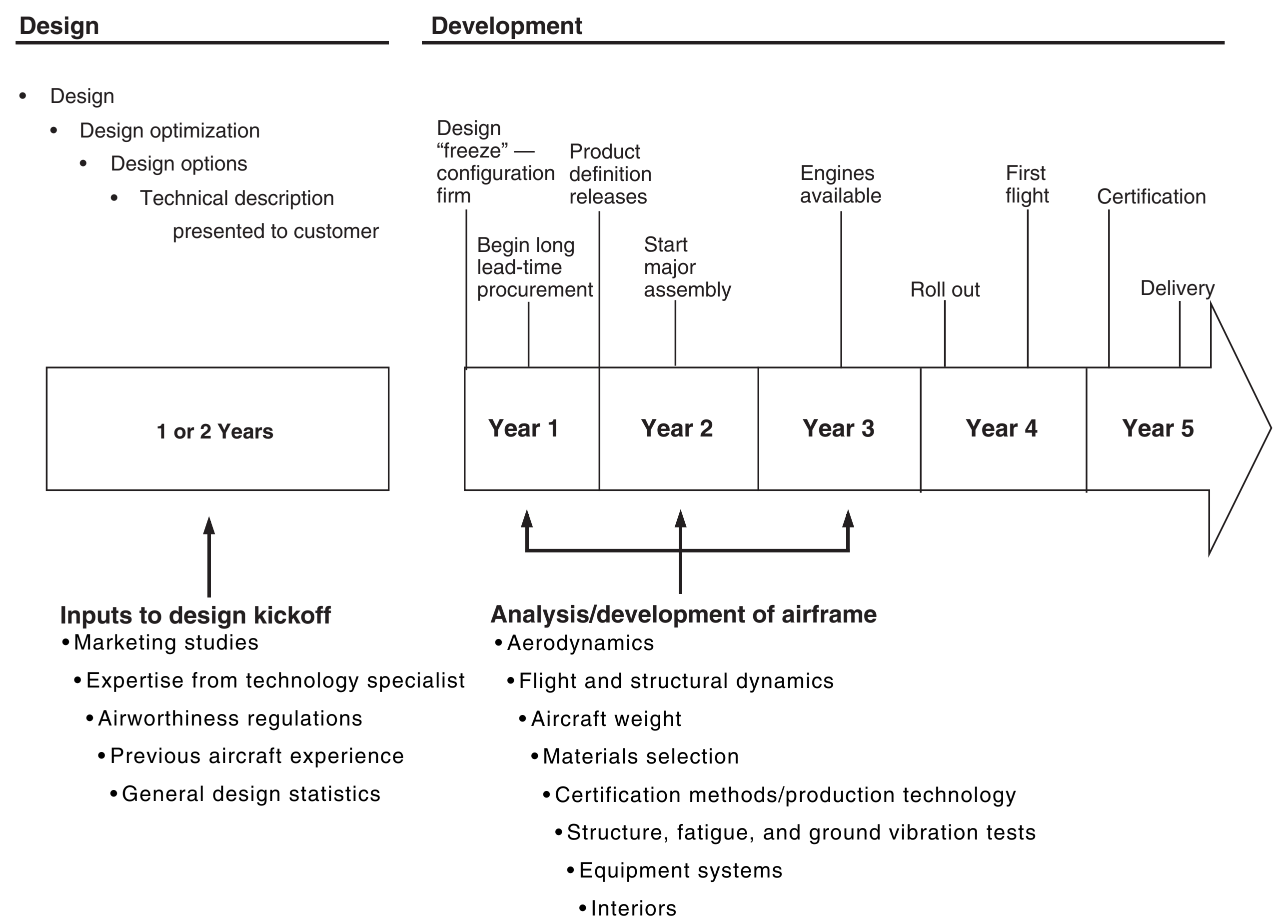
ment of the prototype for the new LCA family, on which new designs and technologies will be proved and refined. Successful technologies are then incorporated into future aircraft. As shown in Figure 1, the development process for a typical LCA can take about five years.

Military programs continue to account for a large portion of global R&D expenditures for aircraft development. Military expenditures are directed to programs with specific military applications, but most precompetitive military research can also have civil applications.[2] Nevertheless, commercial and military programs have diverged and operational requirements and specifications have changed increasingly since the introduction of the first LCA jet.[3]

R&D in the commercial sector now focuses on lowering production costs, improving aircraft reliability, increasing fuel efficiency and reducing engine noise.[4] R&D in the military sector focuses on increasing speed, maneuverability and radar evasion.

Successful design refinements are achieved through the use of computational fluid dynamics (CFD) and wind tunnel tests to validate aerodynamic designs. CFD and wind tunnels play crucial roles in aircraft design and flight testing by reducing development time and allowing LCA producers to investigate a greater number of design options. CFD is used to numerically simulate flow fields around realistic computational models on a supercomputer. The use of increasingly complex algorithms reduces the dependence on empiricism and experiment. Supercomputer simulations using CFD produce much of the data formerly collected through wind tunnel testing although wind tunnel tests are required to verify the results of the simulations at critical junctures in the development

Aircraft Development Process



Source: Compiled by the staff of the U.S. International Trade Commission from U.S. and West European industry and government sources.

Figure 1

process. Because CFD cannot completely model LCA flight characteristics, wind tunnels are still used to perform aerodynamic modeling. Government support for CFD and wind tunnels is regarded as essential to competitiveness in the global LCA industry and to defense. Many of the aerodynamic principles, testing techniques and R&D facilities are common to civil and military aircraft development.

Wind tunnels are enclosed passages in which aircraft flight characteristics can be simulated by directing a controlled stream of air, or other gas, around a scale model of the aircraft and measuring the results with attached instrumentation. Capabilities of a wind tunnel are expressed by its Mach number (speed value), Reynolds number (fluid characteristics of air), flow visualization, data system and data security. Most of the wind tunnels discussed here are subsonic tunnels (able to simulate speeds ranging from Mach 0.l to 0.8), transonic tunnels (able to simulate speeds ranging from Mach 0.8 to l.2), or supersonic tunnels (able to simulate speeds ranging from Mach 1.2 to 5). Aerodynamic forces created in wind tunnels include aircraft lift, drag and side forces.

The private sector in the United States and Western Europe provides most of the global funding for subsonic LCA R&D.

Large capital investments are needed for the purchase and development of aircraft design tools, such as supercomputers, wind tunnels and testbed for flight demonstrations and technology validation by test-bed aircraft. Wind tunnel and computer upgrades are required to support an LCA producer abreast of new technological developments. The R&D areas and the technological infrastructure required to support LCA development are shown in Table 3 (page 7).

The private sector in the United States and Western Europe provides most of the global funding for subsonic LCA R&D. Boeing, McDonnell Douglas, and the major Airbus partners (Aérospatiale, Deutsche Aerospace and British Aerospace) are the major LCA manufacturers and the leading sources of subsonic LCA R&D. Private-sector R&D for civil aeronautical research, as well as private-sector R&D for military research, by the top six countries (United States, Germany, France, United Kingdom, Japan and Italy) increased from US$14.2 billion in 1980 to US$38.9 billion in l990 (Figure 2, page 8). During that 11-year period, the United States accounted for more than 65 percent of total aeronautical R&D expenditures.

The United States, Western Europe, Russia and Japan support their aerospace industries through national research and testing facilities (Table 1, page 2).[5] However, the role of government in the aerospace industry differs in each of these nations. Government-funded research programs generally are long-term ventures that are not product-oriented and not crucial to short-term projects.

LCA R&D in the United States is funded principally by the private sector, but the U.S. aerospace industry is not as R&D-intensive as certain other domestic industries. Traditionally, private-sector aerospace R&D expenditures have amounted to 3 percent to 5 percent of total annual sales.[6] The U.S. aerospace industry ranked eighth among all U.S. industrial sectors in R&D expenditures as a percentage of sales, at 3.8 percent in 1991.[7] In contrast, Western Europe's private sector aerospace R&D expenditures historically have amounted to more than 15 percent of sales, placing aerospace third behind the electrical engineering and electronics and the chemical industries as Europe's leading investor in R&D.[8]

Almost all U.S. private-sector funds for LCA R&D are consumed by new programs or by projects to improve existing products. U.S. private-sector aeronautical R&D tends to be near-term proprietary R&D, which can guarantee a short-term economic return to justify the expenditures. The U.S. private sector tends to under-invest in long-term generic R&D projects that have limited ability to capture a sufficient rate of return in the short term.[9]

During the period 1980-1992, R&D expenditures of Boeing and McDonnell Douglas ranged from a low of US$708 million in 1983 to a high of nearly US$2.4 billion in 1992 (Table 4, page 8).[10] Boeing and McDonnell Douglas principally perform LCA R&D related to the airframe and its manufacture; typically, they do not perform R&D on the major aircraft systems, such as engines, avionics, hy-

Table 3

Large Civil Aircraft: Research Area and Corresponding Infrastructure

Research Area	Major Technology Infrastructure
Aerodynamics	Numerical simulation: computational fluid dynamics (CFD) using supercomputers; wind tunnel models, sensors, high Reynolds numbers; flight demonstrators for technology validation
Flight dynamics[1]	Supercomputer modeling; flight simulators; wind tunnel simulation; computer programs with modules; structures made for ground vibration tests before first flight
Structural dynamics and assumed loads[2]	Computer modeling of loads; computer programs for finite element method (FEM) or finite element analysis (FEA)
Aircraft weights	Scales
Materials selection	Materials laboratory; manufacturing technology; materials performance data; price data
Manufacturing methods and production technology (long-term)	Research: in-house, at research institutes, at universities or through government programs; applications-oriented development work, in-house or contracted
Special test and certification methods	Work with certification bodies
Structural design	3-D computer-aided-design workstations and software
Preparation for certification	FEM computer programs; mechanical tests; documentation
Structure, fatigue and ground vibration tests	Ground facilities with hydraulic actuators and computers to simulate flight and product life-cycle conditions
Avionics and flight controls	Integrated aircraft systems laboratory for the integrated testing of avionics; engine controls; flight controls; electrical, hydraulic and other systems
Equipment systems	Specialist departments in technology areas including error-tolerant computer systems; electronics data transfer (bus) structures; sensors; display technology; optronics; electric drive and actuating systems; diagnosis and testing systems; built-in test

1 Flight dynamics consists of flight mechanics, flight guidance and control, propulsion technology and flight performance.

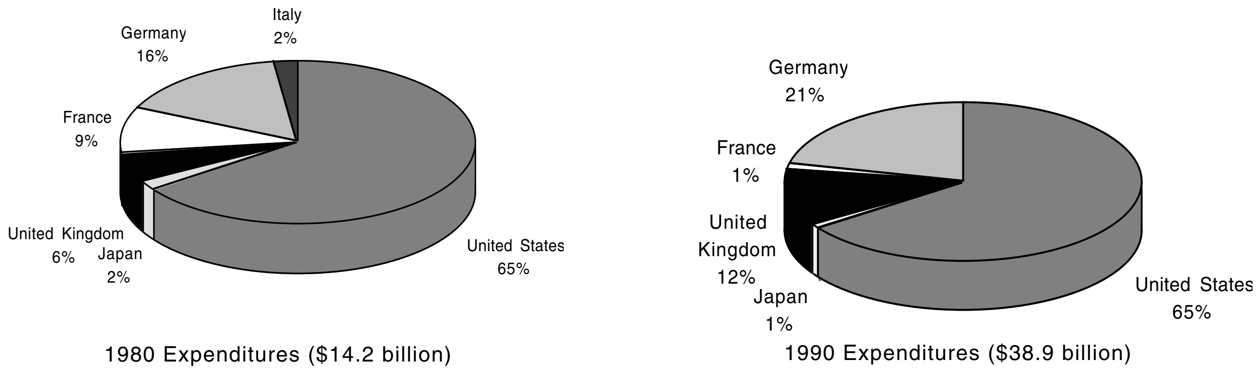
2 Thousands of load cases, including basic operations and systems failures, are generated and compared. This may continue for about 36 months. Fly-by-wire significantly changed the work of the structural dynamics department by moving the process from conservative design to realistic simulation.

Source: Compiled by the staff of the U.S. International Trade Commission.

draulic systems, and landing gear, which is done by subcontractors. Aside from in-house R&D, LCA manufacturers also pursue civil and military contracts (mission-oriented solicitations and concept exploration, demonstration, full-scale development and full production contracts) offered by the U.S. National Aeronautics and Space Administration (NASA) and the U.S. Department of Defense (DOD). These contracts are related primarily to space or defense programs, and the R&D results usually do not spill over directly to LCA R&D. The spillover is more likely to be in the areas of components (e.g., electronics, computers) and production expedience. U.S. LCA manufacturers also fund internal R&D activities, known as independent R&D, which by their dual-use (civil and military) nature allows them to recoup a portion of R&D costs from U.S. government-related contracts.

NASA is the chief source of publicly funded aeronautical R&D in the United States. The principal goal of NASA subsonic research is to maintain the status of the United States as the pre-eminent leader in aerospace technology, and to develop a new

Private Sector Aeronautical Research and Development Expenditures, 1980 vs. 1990 By Country



Source: Organization for Economic Cooperation and Development (OECD), Directorate of Scientific and Technical Intelligence (DSTI) (STAN/Industrial Database), 1992.

Figure 2

Table 4

U.S. Private Sector Research and Development Expenditures (Large Civil Aircraft and Other Civil Aircraft, Military and Space)[1] and R&D Expenditures As a Share of Sales, 1980-1992

			Boeing		McDonnell Douglas[2]	
Year	Total expenditures	R&D as a share of sales	Total R&D expenditures	R&D as a share of sales	Total R&D expenditures	R&D as a share of sales
	Millions (US$)	Percent	Millions (US$)	Percent	Millions (US$)	Percent
1980	967	6	768	8	199	3
1981	1,060	6	844	8	216	3
1982	945	6	691	8	254	3
1983	708	4	429	4	279	4
1984	832	4	506	5	326	4
1985	785	3	409	3	376	3
1986	1,206	4	757	5	449	4
1987	1,391	5	824	5	567	5
1988	1,271	4	751	4	520	4
1989	1,325	4	754	4	571	4
1990	1,392	3	827	3	565	4
1991	1,846	4	1,417	5	429	2
1992	2,355	5	1,846	6	509	3

1 R&D expenses are charged directly to earnings as incurred. Such expenses include independent R&D, bid and proposal efforts, and costs incurred in excess of amounts estimated to be recoverable under cost-sharing contracts.

2 In 1992, McDonnell Douglas lowered its R&D expenses as reported in previous annual reports to account for risk-sharing funds received from vendors and subcontractors participating in the development of LCA. R&D expenses in 1991 were reduced by US$20 million and in 1990 by US$76 million, and also were reduced for other years during 1985-1989.

Source: Compiled by the staff of the U.S. International Trade Commission from annual reports of The Boeing Co. and McDonnell Douglas Corp.

generation of economical subsonic transport aircraft. Other government sources of aeronautical R&D include the DOD and the U.S. Federal Aviation Administration (FAA). As shown in Table 5 (page 10), NASA's total budget has grown from about US$4.9 billion in fiscal year (FY) 1980 to about US$14.7 billion in FY 1994. Nevertheless, the NASA aeronautics budget, which does not differentiate between civil and military projects, declined as a percentage of the total agency budget from 6 percent in FY 1980 to 4 percent in FY 1992, though it is expected to increase to an estimated 5 percent in FY 1993 and 6 percent in FY 1994. Actual expenditures have risen from US$308 million in FY 1980 to US$555.4 million in FY 1992. For FY 1994, expenditures are estimated to grow substantially to US$877 million (with personnel costs growing to US$1.0 billion).

The NASA Office of Aeronautics funds programs under its research and technology base program and its systems technology program (Table 6, page 10). Spending under both programs for civil transports by the Office of Aeronautics' Subsonic Division, also shown in Table 6, was significantly lower during the period 1981-89. The research and technology base program provides design and analysis tools in the following areas: aerodynamics; propulsion and power; materials and structures; controls, guidance and human factors; flight systems; systems analysis; and hypersonic flight (added in FY 1994). The systems technology program supports technology and validation demonstrations that are valuable for the near-term application of technology by the civil industry. The principal areas of the systems technology program are high-performance computing, materials and structures, rotorcraft, high-performance aircraft, advanced propulsion, numerical aerodynamic simulation and advanced subsonic technology. In FY 1992, the advanced subsonic technology (AST) program was initiated under the systems technology program. The AST focuses on the highest payoff technologies that will increase aircraft efficiency and system capacity, and improve aircraft environmental compatibility.

In recent years, most of NASA aeronautics funding has been allocated to its hypersonic programs, supercomputers and advanced composite materials research.

In recent years, most of NASA aeronautics funding has been allocated to its hypersonic programs, supercomputers and advanced composite materials research. Of the total 1992 aeronautical research and technology (R&T) and transatmospheric budgets, approximately 16 percent was allocated to advanced subsonic aircraft (other than short-haul aircraft); 6 percent to short-haul aircraft (also subsonic); and 16 percent to high-speed commercial transports such as the high-speed civil transport (HSCT) (Figure 3, page 11).[11] High performance aircraft, principally jet fighters, accounted for 21 percent of those budgets. The National Aerospace Plane (NASP) accounted for about 5 percent. The remaining 35 percent was accounted for by aerodynamics, high-speed computing, numerical aerodynamic simulation and other critical disciplines.

The DOD and FAA play minor roles in subsonic aeronautical R&D. The FAA is involved in every aspect of LCA design through its principal role of certifying the airworthiness of LCA produced or flown in the United States. Part of its certification process requires that the FAA approve aircraft designs and production quality-control methods. The FAA funds R&D related to its mission, particularly in the area of air traffic control. In FY 1991, the FAA budget for research, engineering and development totaled US$197.9 million, of which US$100.5 million, 51 percent, went to R&D on air traffic control, while FAA R&D expenditures on aircraft safety technology and environmental research, both areas of interest to LCA manufacturers, totaled US$61.0 million and US$2.1 million, respectively. The remainder, US$34.3 million, was for R&D on advanced computers, navigation, aviation weather needs and aviation medicine.[12]

DOD support for the LCA industry also has been limited. LCA manufacturers have performed R&D as part of U.S. government contracts and DOD-funded independent R&D contracts. In the past, technology developed with a portion of DOD funding has been transferred to the LCA industry through plane-to-plane, major component and minor component transfers. In FY 1991, the DOD expended

Table 5

NASA Budget Expenditures, Total and Research and Development (R&D), Fiscal Years 1980-1994

(Millions of U.S. dollars)

Fiscal Year (FY)	Total budget	Total R&D budget	Aero-nautical R&T[1, 2] budget	Transatmos-pheric R&T budget	All other R&D including space-related
1980	4,851.6	4,088.1	308.3	—	3,779.8
1981	5,425.6	4,334.3	271.4	—	4,062.9
1982	6,035.4	4,772.0	264.8	—	4,507.2
1983	6,663.9	1,902.5	280.0	—	1,622.5
1984	7,047.6	2,064.2	315.3	—	1,748.9
1985	7,317.7	2,468.1	342.4	—	2,125.7
1986	7,403.5	2,619.3	337.3	—	2,282.0
1987	7,591.4	3,153.7	374.0	45.0	2,734.7
1988	9,091.6	3 254.9	332.9	52.5	2,869.5
1989	11,051.5	4,237.6	398.2	69.4	3,770.0
1990	12,427.8	5,227.7	442.6	59.0	4,726.1
1991	13,876.6	6,023.6	512.0	95.0	5,416.6
1992	13,959.9	6 827.6	788.2	4.1	6,035.3
1993[3]	14,077.6	7,089.3	865.6	0.0	6,223.7
1994[3]	14,670.0	7,712.3	1,020.7	80.0	6,611.6

1 Research and technology. NASA does not perform technology development, but validates technologies and performs technology demonstrations.

2 Data for 1980-91 exclude program management costs (i.e., salaries and support systems costs). Beginning in FY 1992, NASA changed appropriation categories for the civil service work force and center support systems from its aeronautical R&T budget from the agency's Research and Program Management appropriation to a new category, Research Operations Support, a subcategory of Aeronautical R&T. Data for the aeronautical R&T budget include $232.8 million for research operations support in FY 1992, an estimated $148.8 million for FY 1993 and an estimated $143.5 million for FY 1994.

3 Estimated by NASA.

Source: Compiled by the staff of the U.S. International Trade Commission from NASA, Budget Estimates, FY 1982-94*. Data for FY 1980-82 appear in* Budget Estimates for FY 1982-84, *respectively.*

Table 6

NASA Aeronautical Research and Technology (R&T) Budget: Expenditures on the Research and Technology Base Program, Systems Technology Program and on Civil Transport, Fiscal Year (FY) 1980-1992 and Expected Expenditures, FY 1993-1994

(Millions of U.S. dollars)

Fiscal Year (FY)	Research and technology base	Systems technology	Civil transport[1]
1980	120.8	187.5	122.0
1981	133.8	137.6	80.9
1982	172.8	92.0	70.0
1983	198.5	81.5	46.0
1984	228.3	86.9	36.6
1985	223.5	119.1	50.6
1986	228.6	108.7	71.8
1987	271.1	102.9	59.3
1988	257.2	75.8	48.7
1989	309.6	88.6	69.4
1990	321.8	120.8	114.4
1991	336.4	175.6	162.1
1992	343.3	212.1	193.2
1993[2]	436.5	280.3	290.4
1994[2]	448.3	428.9	441.1

1 Data are for subsonic transport R&T, air traffic management systems, and supersonic transports.

2 Estimated by NASA.

Source: Compiled by the staff of the U.S. International Trade Commission from NASA, Budget Estimates, FY 1982-94 *(data for FY 1980-1982 appear in* Budget Estimates *for FY 1982-84, respectively) and information supplied by Subsonic Transport Division, NASA.*

US$5.8 billion for aeronautical R&D under its research, development, test and evaluation budget, of which US$5.4 billion was spent on specific military aircraft, including the NASP. The remainder of the DOD 1991 aeronautical budget was spent on aircraft equipment, aerodynamics, CFD and other generic aeronautical technologies.[13] In FY 1994, the DOD is expected to be the sole funding source for the NASP. Technology spinoffs from the NASP to the LCA industry have been minimal, but recent materials technologies developed in the NASP program may be applied to Boeing's 777.[14] In addition, LCA manufacturers may have benefited from manufacturing R&D funded by the DOD manufacturing technology program (Mantech).[15] In FY 1993, the budget authorization for Mantech was US$374.6 million. Mantech funding is not specifically for aeronautics, and is not included in the figure for the DOD aeronautical R&D cited above.

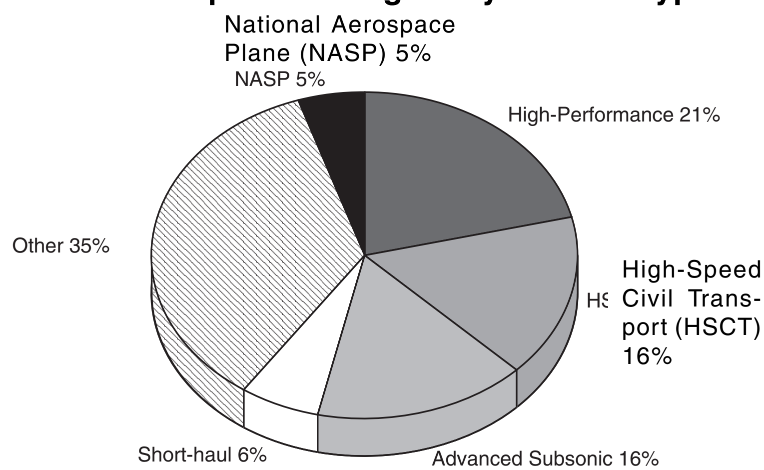
R&D Programs in Western Europe Detailed

Airbus, through its member companies, conducts the bulk of all private-sector R&D for LCA in Western Europe.[16] In 1991, Airbus consortium members spent approximately US$1.6 billion for R&D (civil and military aeronautical, space and other) (Table 7, page 12). In 1992, this figure rose to US$1.9 billion. Airbus consortium R&D during the early 1980s and 1990s has focused principally on developing advanced technologies to include in its LCA families.

At its headquarters in Toulouse, France, Airbus employs about 350 engineers, who organize the design of new aircraft and coordinate and implement the improvement of parts on existing aircraft.[17] These engineers also coordinate engineering efforts among the Airbus partners. Within the Airbus organization, R&D is conducted principally by partners Aérospatiale, Deutsche Aerospace and British Aerospace. To promote specialization and avoid costly duplication of effort, each partner is responsible for conducting R&D only within a particular aircraft subsection area. This degree of decentralization limits the effective management of costs, but it offers the advantage of expanding the consortium's R&D base. The consortium benefits not only from projects undertaken by the member partners but also from R&D performed by the national aerospace laboratories within France, Germany and the United Kingdom. Airbus relies heavily on France's Office National d'Etudes et de Recherches Aérospatiales (ONERA) for product-oriented R&D and Germany Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) for theoretical R&D.[18] Much of the R&D performed by the partners is proprietary and its dissemination is limited to companies within the consortium.

Public sector West European aeronautical R&D laboratories are quasi-governmental nonprofit organizations. Their principal duties are to develop and guide mid- to long-term precompetitive aerospace research; to provide scientific and technical support to their respective governments and industry; to design, build and implement the resources needed to conduct this research; and to circulate the results and promote the use of such results by European Community (EC) aerospace and other industries.[19] In the past, Western Europe's

U.S. National Aeronautics and Space Administration Aeronautical Research & Technology and Transatmospheric Budgets by Aircraft Type



Source: Aeronautics and Space Engineering Board, National Research Council Aeronautical Technologies for the Twenty-First Century *(Washington, DC, U.S.: National Academy Press, 1992).*

Figure 3

Table 7

Private Sector Research and Development (R&D) Expenditures: Major Airbus Partners,[1] 1985-1992

R&D type/year	Airbus Consortium: Total expenditures	Airbus Consortium: R&D as a share of sales	Aérospatiale Group[2]: Total expenditures	Aérospatiale Group[2]: R&D as a share of sales	British Aerospace[3]: Total expenditures	British Aerospace[3]: R&D as a share of sales	Deutsche Aerospace[4]: Total expenditures	Deutsche Aerospace[4]: R&D as a share of sales
	Millions US$	Percent	Millions US$	Percent	Millions US$	Percent	Millions US$	Percent
Company-funded:								
1985	450	6	267	10	71	2	112	6
1986	614	6	373	10	92	2	150	6
1987	675	5	417	10	120	2	139	4
1988	559	3	285	6	135	1	138	4
1989	703	3	397	7	197	1	109	4
1990	1,254	3	514	7	286	2	426	5
1991	1,595	4	849	9	184	1	542	5
1992	1,857	5	1,014	10	267	2	576	5
Third-party-funded R&D:								
1985	(5)	(5)	494	18	(6)	(6)	(6)	(6)
1986	1,871	17	623	17	568	12	679	28
1987	2,351	17	815	20	618	9	919	29
1988	2,951	16	1,074	23	933	9	944	25
1989	2,710	11	1,325	25	643	4	742	24
1990	4,860	13	1,954	25	734	4	2,173	28
1991	4,802	12	1,644	18	688	4	2,471	24
1992	5,398	14	1,938	20	706	4	2,753	25
Total R&D:								
1985	(5)	(5)	760	28	(6)	(6)	(6)	(6)
1986	2,485	23	996	27	660	14	829	34
1987	3,026	22	1,231	30	738	11	1,057	33
1988	3,510	19	1,360	29	1,069	11	1,082	28
1989	3,413	13	1,722	32	840	5	851	28
1990	6,086	16	2,468	32	1,019	5	2,599	33
1991	6,003	16	2,492	27	872	5	3,013	30
1992	7,254	19	2,952	30	973	6	3,330	30

1 R&D data for Construcciones Aeronáuticas, S.A. (CASA) are not available from annual reports.

2 Data for Aérospatiale are for research, development and industrialization (which includes computerization of certain company functions). Civil aircraft sales, excluding helicopters, as a share of total sales rose from 28 percent in 1985 to 42 percent in 1992. Helicopter sales (civil and military) accounted for 22 percent of sales in 1992; space and defense, and tactical missiles for 29 percent; avionics for 3 percent; and miscellaneous products for 4 percent. In 1992, Aérospatiale changed its accounting policy for RDI; 1991 data restated to reflect the new policy.

3 In 1988, British Aerospace (BAe) acquired the motor vehicle producer Rover and a property development subsidiary; R&D performed by these product groups is included in BAe's data for 1988-1991. Civil aircraft as a share of sales declined from 25 percent in 1985 to 14 percent in 1992. In 1992 motor vehicle sales accounted for 35 percent; defense for 39 percent; and space, construction, property development.

4 For 1985-89, data are solely for Messerschmitt-Bolkow-Blohm GmbH (MBB). Data for 1990-91 include Dornier GmbH, Motoren- und- Turbinen-Union Munchen GmbH, MBB and Telefunken Systemtechnick GmbH, which were merged in 1990 to form Deutsche Aerospace AG (DASA). According DASA's annual reports for 1990 and 1991, Deutsche Airbus GmbH was not included in its consolidated financial statements. Deutsche Airbus GmbH spent DM 600 to DM 650 ($371 to $402 million) in 1990 on R&D. In its 1992 annual report, Deutsche Aerospace included Deutsche Airbus in the consolidated annual report and restated its 1991 data to reflect this. During the period 1985-1989, sales of military aircraft generally ranged from 51 percent to 56 percent of total sales of MBB, with the exception of 1988 during which such sales accounted for 42 percent. Civil aircraft sales ranged from 26 percent to 28 percent; however, in 1988, such sales accounted for 37 percent of total sales. Data for DASA in 1992 are not comparable with categories for MBB. In 1992, aircraft civil and military) sales accounted for 44 percent of total DASA sales; defense and civil systems for 21 percent; propulsion (aircraft, land and marine applications) for 21 percent; space systems for 11 percent; and other businesses for 3 percent.

5 Not calculated due to lack of data.

6 Not available from annual reports.

Source: Compiled by the staff of the U.S. International Trade Commission from annual reports of Aérospatiale, British Aerospace, Deutsche Aerospace, MBB and Fokker; Deutsche Airbus GmbH, Deutsche Airbus (1991).

aeronautical research institutions relied heavily on government funding, especially from their respective ministries of defense.

In recent years, West European governments have reduced dramatically their spending in the aeronautical field, especially on LCA activities. Defense procurement has declined, as have indirect military subsidies.[20] Provisions of the General Agreement on Tariffs and Trade (GATT) and the 1992 United States-EC agreement on aircraft subsidies also have limited direct government R&D funding to Airbus consortium members. These developments have forced these research institutions to compete for business in the marketplace and to rely more heavily on third-party contracts for funding. In 1991, the four major West European aeronautical R&D laboratories (DLR, ONERA, Defense Research Agency [DRA] and National Aerospace Laboratory [NLR]) had a collective budget of US$2 billion and aeronautical R&D expenditures of US$445 million (Table 1, page 2).

In addition to national governments, the European Commission of the EC also plays an important role in funding aeronautical R&D in Western Europe through programs such as Basic Research in Industrial Technology for Europe/European Research in Advanced Materials (BRITE/EURAM). Another significant program is the Group for Aeronautical Research Technology (GARTEUR) and its subgroup Collaboration on Aeronautical Research and Technology (CARTE).

EC BRITE/EURAM aeronautics projects aim to promote upstream research[21] and strengthen the R&D base in countries that are not currently strong in aircraft development. Of total BRITE/EURAM funding, 50 percent comes from the EC; the remainder comes from the participants, such as DRA, NLR, ONERA and DLR, or private-sector companies.

The aeronautics programs under BRITE/EURAM resulted from a technology assessment called the European Cooperative Measures for Aeronautical Research and Technology (EUROMART), conducted by a group of nine West European aircraft manufacturers.

In March 1988, the EC Commission initiated a two-year exploratory program valued at 60 million ECU (US$71 million), which was implemented during the period 1989-1991.[22] The program goal was to further EC collaboration in the fields of aerodynamics, acoustics, airborne systems and equipment, and propulsion. In September 1991, the EC Council decided to fund another aeronautics program for the period 1992-1994, which continued the work of the initial program.[23] The proposed level of funding was 53 million ECU over three years (US$65.8 million).

One of the largest EC Commission-sponsored aeronautical R&D programs funded under BRITE/EURAM is the European Laminar Flow Investigation (ELFIN). Introduced in 1989, ELFIN is a joint R&D project on laminar flow involving 24 private and public partners in 11 European countries. ELFIN is led by Deutsche Airbus; other participants include Aérospatiale, Dassault, BAe, CASA, Alenia, Fokker, NLR, DLR, ONERA and the Centro Italiano Ricerche Aerospaziali (CIRA).[24]

GARTEUR, founded in 1973, is a five-country consortium (United Kingdom, France, Germany, Switzerland and the Netherlands) with the goal of strengthening collaboration among EC member states in the field of aeronautical R&D through the pooling of resources, exchange of technical information, identification of gaps in facility needs and avoidance of duplicative efforts. CARTE was founded in 1981 as an industry group within GARTEUR.

Neither GARTEUR nor CARTE receives much funding from the EC Commission. Fears of the leaking of information on technological R&D by the participants have limited many of these projects to precompetitive R&D.[25]

Russian Research Efforts In Transition

The LCA R&D establishment in Russia is more centralized than in the West. However, as Russia privatizes its LCA and supporting aerospace industry, the organizations that perform R&D, their capabilities and their sources of funds are changing.

The Central Aero-Hydrodynamics Institute (TsAGI) is the primary R&D and test facility in the Commonwealth of Independent States (CIS). Under the former Soviet administration, the government funded 100 percent of TsAGI's budget. At the beginning of 1991, just 50 percent of the budget came from the government. By October 1992, approximately 30 percent of the budget came from the CIS; 10 percent was supplied by the military and another 20 percent by the Ministries of Industry and Science.[26] In mid-1992, because of the lack of funding, the institute began borrowing from commercial banks at interest rates of up to 150 percent. By November 1992, 20 percent to 25 percent of TsAGI's budget came from foreign investments.[27] Although much of its revenue comes from contracts with Russian design bureaus, TsAGI has been extending credit to the design bureaus because of their own funding shortfalls. TsAGI has had to reduce energy consumption and payments to subcontractors, decrease capital expenditures for modernization and raise prices approximately threefold. At the same time, it has had to increase wages to workers to meet the rising cost of living.[28]

Japan Concentrates on Component Development

Although Japan has not produced an LCA and most of its R&D efforts are focused on other areas (hypersonic aircraft, space and composites),[29] it has the capability to conduct significant R&D related to LCA. The Japanese government's LCA R&D efforts are largely limited to materials and component development and to the financial support of Japanese companies in subcontracting and joint development programs. The Japanese government also sponsors R&D efforts in hypersonic aircraft design and LCA engines.

LCA R&D is supported financially by Japan's Science and Technology Agency (STA) and the Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI).[30] Other agencies involved in aerospace R&D include the National Space Development Agency (NASDA), the Ministry of Transportation (for the development of air transportation capabilities), the Ministry of Posts and Telecommunications (for communications satellites) and the Technical Research and Development Institute of the Japan Defense Agency.

STA has focused its LCA R&D efforts on its National Aerospace Laboratory (NAL) and on funding for R&D performed by the National Research Institute for Metals (NRIM) and the National Institute for Research in Inorganic Materials (NIRIM). NAL conducts R&D on basic aerodynamics, propulsion systems, control and guidance systems, structural mechanics and space technology. NAL had a 1991 budget of US$80 million. The laboratory aerodynamic research concentrates on designing optimal airframe and lift surface configurations for hypersonic flight and developing ultra-light structures for airframes that can withstand cryogenic to ultra-high temperatures without losing structural integrity.

The competitive position of a country's LCA industry is influenced to a large degree by its access to CFD technology, supercomputers and wind tunnels.

Competitiveness Linked to Technology Access

The competitive position of a country's LCA industry is influenced to a large degree by its access to CFD technology, supercomputers and wind tunnels. The use of wind tunnels is an important indicator of a firm's commitment to undertaking forward-looking technology development. The national research laboratories in the United States, Western Europe, Russia and Japan furnish testing facilities for their private sectors that otherwise would not be available domestically because of the high costs associated with building and maintaining such large-scale facilities. Most national laboratories (with the exception of NASA) make their supercomputer networks, wind tunnels and other R&D infrastructure such as simulators and flight-testing facilities, available to foreign and domestic firms.

NASA was once the world's forerunner in aeronautical R&D using CFD. But NASA no longer has a monopoly in this area because major non-U.S. laboratories now have access to supercomputers and CFD technology. The NASA numerical aerodynamic simulation (NAS) program is responsible for maintaining and utilizing two state-of-the-art supercomputers at the NASA Ames Research Center (Moffett Field, California, U.S.), which are used to solve complex CFD problems.

The NAS system is used to measure flow fields around aerospace vehicles, study the behavior of gases around the vehicles and assess the behavior of vehicles in flight. The NAS system can input parameters such as altitude, air temperature, air density, speed and attitude. This system is more sophisticated than other systems used in global aeronautical R&D; however, the parameters it measures are typical to all such R&D. The results of NAS research routinely are provided free of charge to U.S. universities and firms through seminars and technical papers for incorporation in their design processes. LCA manufacturers in the United States account for 15 to 20 percent of the NAS system's computer time.

Many of Western Europe's major universities, its four major national aeronautical research laboratories and the members of the Airbus consortium have access to supercomputers capable of solving complex CFD equations. The West European aeronautics industry reportedly has had great success in using CFD to improve designs for gas turbine engines, new transport and business jets, and jet trainers.[31] Industry experts consider the United Kingdom to be Western Europe's leader in CFD development and application because of its experience in using CFD to develop advanced weapons systems. Germany, the Netherlands and France also have strong CFD capabilities.

The Russian R&D establishment has developed CFD theory and algorithms, and has produced some work comparable to that done in the United States and Western Europe. This has been accomplished despite earlier limited access to large-capacity, high-speed computers, including supercomputers.[32] U.S. industry officials believe that although Russian industry has basic engineering and computing skills comparable to those in the United States and Western Europe, Russian capabilities lag in some areas, in part because of a lack of large capacity, high-speed computers, including supercomputers. Russian industry officials believe that their geometric models are equal to those used in the West,[33] and that they are ahead of the West in aerodynamic models and calculation programs.[34] West European and U.S. private- and public-sector R&D entities have sought access to Russian CFD capabilities. Boeing has established a small R&D office in Moscow to explore Russian technological capabilities, including CFD.

Japanese industry has made rapid progress in developing CFD capabilities. CFD research is performed principally at NAL, the privately owned Institute for Computational Fluid Dynamics, and national universities, such as the University of Nagoya and the University of Osaka. NAL, the institute and several universities have supercomputers produced by Japanese computer companies.[35] Japanese aerospace companies have access to the supercomputers in the NAL Numerical Simulator System. Japanese CFD development currently lags behind that of the United States, but has the potential to challenge Western capabilities as Japan develops validated databases and sophisticated algorithms.[36] Much of the work in Japan's CFD has been driven by the country's development of hypersonic aircraft, spacecraft and propulsion technology, including engines for LCA.

Wind Tunnels Play Pivotal Role

During the past 40 years there has been a fundamental shift away from small wind tunnels to larger, more sophisticated ones. Today, there are approximately 90 major wind tunnels in the United States and 70 others, principally in Western Europe, Canada, Russia, and Japan. Wind tunnels are owned and operated by major universities, the leading airframe and engine manufacturers and all of the leading national aeronautical laboratories.

Wind tunnel fee structures are similar throughout the world; they are based on wind tunnel "occupancy hour" and charges for pretest setup, posttest reporting, power charges and computer usage. (There is an overcapacity of wind tunnels with modest aerodynamic scaling capabilities, according to industry officials. These tunnels are used principally in conceptual and specific research studies.) The leading world subsonic and transonic wind tunnels are listed in Table 8 (page 16).

The U.S. aeronautical industry has access to a wide range of wind tunnels capable of simulating

Table 8
Principal World Subsonic, Transonic and Trisonic Wind Tunnels

A. Principal Public-sector-financed Wind Tunnels

Country	Organization	Tunnel	Location	Speed range (Mach)	Operational year (upgrade)	Replace-ment cost[1] (millions US$)	Special features[2]
Canada	National Aeronautical Establishment	5 Foot (1.5-Meter)	Ottawa	Transonic 0.1-4.25	1962 (1980)	$24	High R_e/m, pressurized
France	ONERA	F-1	Noe	Subsonic 0.37	1977 (1989)	$59	High R_e/m, productivity
		S-1	Modane	Transonic 0.23-1	1952 (1989)	$151	Size, high R_e/m
Germany	European Transonic Wind Tunnel	ETW	Cologne	Transonic 0.15 - 1.3	Transonic 1994	$312	Very high R_e/m, in the transonic range, cryogenic
	DLR	KKK	Cologne	Subsonic	1988	NA	Cryogenic, High R_e/m,
Netherlands	German-Dutch Wind Tunnel (DNW)	DNW	Noordoost-polder	0.18 - 0.45	1980	$63	Productivity, largest low-speed tunnel in Europe
Russia	TsAGI	T-128	Zhukovsky	Transonic 0.15-1.7	NA	NA	Tests range to supersonic
United Kingdom	DRA	16.4-Foot (5-Meter)	Farnborough	Subsonic 0-0.33	1978	NA	Productivity, pressurized
		24-Foot (7.3-Meter)	Farnborough	Subsonic 0.1-0.15	1934 (1970)	NA	Anechoic (Acoustics)
		13-Foot by 9-Foot (4-Meter by 2.7-Meter)	Bedford	Subsonic 0.01-0.27	1953 (1968)	NA	Size
United States	NASA	UNITARY 11-Foot (3.3-Meter)	NASA-Ames Moffett Field CA	Transonic 0.4-1.4	1956	$146	High R_e/m, size
		40-foot by 80-foot (12.2-Meter by 24.4-Meter) 80-Foot by 120-Foot (24.4-Meter by 36.6-Meter)		Subsonic 0.45 0.15	1944 (1982)	$222	High R_e/m, size
		12-Foot (3.6-Meter)		Subsonic 0.6	1946	$38	High R_e/m, pressurized
		NTF	NASA-Langley Hampton VA	Transonic 0.2-1.2	1982	$136	Cryogenic, pressurized

Table 8 (continued)

B. Private-sector-financed Wind Tunnels

Country	Organization	Tunnel	Location	Speed Range (Mach)	Operational Year (Upgrade)	Replacement Cost[1] ($ million US$)	Special Features[2]
United Kingdom	ARA	TWT 9-Foot by 8-Foot (2.7-Meter by 2.4-Meter)	Bedford	Transonic	1956	NA	Productivity, low-cost
United States	Boeing	4-Foot by 4-Foot (1.2-Meter by 1.2-Meter)	Seattle, WA	Supersonic 1.2-4	1957 (1968)	$20	High R_e/m
		8-Foot by 12-Foot (2.4-Meter by 3.6-Meter)		Transonic 0.1 -1.1	1968 (1981)	$50	Atmospheric, continuous flow
		9-Foot by 9-Foot (2.7-Meter by 2.7-Meter)		Subsonic 0.36[3]	1967-69	NA	Propulsion tests
	Calspan	8 Foot (2.4-Meter)	Buffalo, NY	Transonic 0-1.35	1947 (1956)	NA	Pressurized
	Rockwell	7 Foot (2.1-Meter)	Los Angeles CA	Transonic 0.1 -3.5	1958 (1960,1968, 1971,1983)	$17	High R_e/m, size, propulsion tests, acoustics
	Vought	4-Foot (1.2-Meter)	Dallas, TX	Transonic 0.2-5.0	1958 (1972,1975)	$25	High R_e/m, flutter tests, polysonic
	Lockheed	4-Foot (1.2-Meter)	Burbank, CA	Trisonic 0.2-5.0	1960 (1966, (1975,1981)	$20	High R_e/m, polysonic

1 Replacement cost is the current value of the facility, or the cost to replace the facility with all improvements made, in current dollars. Replacement costs for U.S. private and public wind tunnels are based on their value in 1984.
2 R_e/m is the symbol for Reynolds numbers.
3 Not in use at this time.

NA Not available.

Source: *F.E. Penaranda and M.S. Freda,* Aeronautical Facilities Catalogue, Volume 1: Wind Tunnels *(Washington, DC: NASA, 1985); U.S. General Accounting Office,* Aerospace Technology Technical Data and Information on Foreign Test Facilities*, GAO/NSIAD-90-71FS, June 1990.*

subsonic through hypersonic speeds, on a contract basis. Although LCA producers in the United States maintain their own wind tunnels, they generally rely on wind tunnels operated by NASA and by national laboratories in Western Europe and Canada because these tunnels have high productivity, large size and high Reynolds number capabilities. In 1982, U.S. private sector wind tunnels had an estimated total replacement value of US$1.6 billion.

Boeing has the largest privately owned wind tunnel complex in the world, and uses its tunnels for aerodynamic, noise, propulsion and icing testing. Boeing's principal wind tunnels are used for both its commercial and military products. Boeing also has sold wind tunnel time and services to other manufacturers, including non-U.S. aircraft producers of smaller aircraft, such as Embraer of Brazil.[37] In general, Boeing uses outside wind tunnels to supplement its in-house capabilities. Boeing has performed aerodynamic simulation for the development of high-lift systems and wing design at DRA (low-speed testing) and NASA Ames (transonic testing at the 11-foot [3.3-meter] tunnel). In February 1992, Boeing announced that it would not proceed with a plan to build a new complex of wind tunnels.[38] A factor in this decision was the projected increase in available time at both U.S. and non-U.S. wind tunnels because of defense spending decreases.[39]

McDonnell Douglas owns several wind tunnels but relies more heavily than Boeing on outside test facilities, including non-U.S. wind tunnels. For example, in 1992, McDonnell Douglas began 790 hours of low-speed wind tunnel tests at ONERA on the wing design for its MD-12.[40]

The European transonic wind tunnel and the German-Dutch wind tunnel are Western Europe's leading wind tunnels.

NASA maintains 41 major wind tunnels of various sizes and speed ranges at its Ames (12), Langley (23), and Lewis (6) research centers. As of 1990, the estimated replacement value of NASA wind tunnels was US$1.9 billion.[41] Ames was originally created to be the lead NASA subsonic aircraft research facility; almost every civil and military aircraft built in the United States since the 1950s has been tested in one of the NASA Ames wind tunnels. There is presently a two-year waiting period to use these wind tunnels. The NASA Ames wind tunnels were built under the Unitary Plan Wind Tunnel Act of 1949. The act's objective was to enable the U.S. National Advisory Committee for Aeronautics (the predecessor of NASA) to conduct applied high-speed aeronautical research through the development, construction, operation and maintenance of high-speed wind tunnels at Ames. These tunnels, known as the Unitary Plan Wind Tunnels (UPWT), are now the most heavily scheduled wind tunnels in NASA.

The Unitary Plan Wind Tunnel Act mandated that U.S. industry be given priority in tunnel usage; the needs of the military services were to be secondary. According to NASA officials, one-third of its wind tunnel time is devoted to military projects, one-third is for NASA research and the remaining third is private sector usage. NASA wind tunnel facilities are available to U.S. companies, but are closed to all non-U.S. establishments. The results of research conducted by LCA producers on a fee basis are proprietary; however, under cooperative research programs or NASA-funded contracts, research results are generally made available to the global industry.

Test results and productivity at the UPWT, however, are limited by control systems that are nearly 40 years old. The UPWT has been in continual three-shift-per-day operation since 1956, with only minor facility improvements, and is prone to frequent shutdowns and delays because of equipment failure. Downtime at the UPWT has grown to one-quarter of total operating time and is increasing. NASA estimates that comparable non-U.S. wind tunnels are two to three times more productive than the UPWT.[42] Beginning in 1995, the UPWT is scheduled for a two-year shutdown for repair and upgrading.

There are a wide variety of wind tunnels in Western Europe, owned and operated by universities, LCA and engine manufacturers and the various national aeronautical research laboratories. The European transonic wind tunnel and the German-Dutch wind tunnel are Western Europe's leading wind tunnels. Other wind tunnels of importance include the F-l and S-l of ONERA. Wind tunnels owned and operated by Western Europe's public research institutions perform simulation tests on a contractual basis for both non-European and domestic firms. The fee structure for Airbus Industrie is the same as for all non-European companies at these institutions, according to industry officials.

Within the Airbus consortium, only BAe possesses extensive wind tunnel testing facilities and is therefore the consortium's aerodynamics specialist. BAe has designed the wings for all Airbus models. For Airbus-related tests, however, BAe uses wind tunnels operated by Aircraft Research Association (ARA), a privately held firm, and DRA on a repayment basis. BAe in-house wind tunnel capabilities are used primarily for research purposes and are of limited capacity.

ARA was founded 40 years ago when the British aircraft industry decided the country needed a new high-speed wind tunnel. ARA opened its large (9-foot [2.7-meter] by 8-foot [2.4-meter]) transonic wind tunnel in 1956.[43] Since that time, ARA has participated in every major British aircraft and weapons development program.

The German-Dutch wind tunnel (DNW), in the Netherlands, is a bilateral joint venture between DLR and NLR[44] and operates as an independent, nonprofit foundation under Dutch law. The DNW began operating in 1980 and is the largest and most versatile low-speed wind tunnel in Europe. The DNW also is the leading world acoustic wind tunnel and has been used by the U.S. military, Airbus and the global helicopter and automotive industries. West European industry officials state that the DNW is equal, if not superior, to comparable wind tunnels in the United States. The DNW conducts wind tunnel tests on a contractual basis.

The Japanese aeronautical industry has access to a series of publicly and privately owned wind tunnels in Japan, spanning speed ranges from subsonic to hypersonic.

The European transonic wind tunnel (ETW) is located in Germany, adjacent to DLR. The ETW was established in 1988 as a West European equivalent to the NASA National Transonic Facility (NTF) cryogenic wind tunnel in Hampton, Virginia, U.S. The ETW is an independent joint venture among the quasi-national aerospace research agencies in Germany (DLR), France (ONERA), the United Kingdom (DRA) and the Netherlands (NLR), which wanted to equip Western Europe with a large Reynolds number transonic wind tunnel facility. As of November 1992, the ETW was 98 percent complete and expected to be in operation by 1995. The German government paid the largest share of the total construction costs (38 percent of US$337 million) to obtain location rights.[45] The remainder of the construction costs were assumed by France and the United Kingdom (28 percent each) and the Netherlands (6 percent). While government funds will pay for development and an initial operation subsidy, the facility will charge user fees to cover its costs. Germany, France and the United Kingdom will have an equal share in terms of time (31 percent) in the operation of the tunnel; the Netherlands will have access to the remaining 7 percent.[46] The ETW will exceed existing West European capacity in its ability to handle bigger models, larger Mach numbers, and higher Reynolds numbers.

ONERA has a number of wind tunnels; LCA R&D is conducted principally at the F-l wind tunnel at Noe and the S-l wind tunnel at Modane. The F-l has been used for testing Airbus programs and for testing regional aircraft and for developing of Dassault's Rafale jet fighter it ranks as one of the leading world subsonic wind tunnels with high Reynolds numbers. The S-l also has been used for testing Airbus programs, including the A340, and fighter jets. It ranks as one of the leading world transonic tunnels in terms of large size and high Reynolds number test capabilities. McDonnell Douglas has also used ONERA wind tunnels for its M-12 program.

DLR maintains several wind tunnels, the most important of which is its subsonic KKK cryogenic wind tunnel in Köln-Porz, which has high Reynolds number testing capabilities. The KKK wind tunnel uses a gaseous nitrogen medium to simulate the atmosphere.[47]

DRA also has several wind tunnels. Its 16.4-foot (5-meter) tunnel ranks as one of the largest subsonic wind tunnels in the world in terms of size and high Reynolds number test capabilities.[48]

Boeing has used the DRA 5-meter tunnel to conduct low-speed tests for lift, drag and stability on a 3.1-foot (4-meter) model of its 777 aircraft.[49]

TsAGI in Russia claims to have capabilities similar to those of the NASA Ames and Langley research centers.[50] Its 50-plus wind tunnels are divided into five classes: low- and high-speed subsonic wind tunnels and transonic, supersonic and hypersonic wind tunnels. The most popular wind tunnels attracting foreign clients are the T-128 transonic tunnel and the hypersonic tunnel. The T-128 can simulate speeds of Mach 0.15 to 1.7 and can test high Reynolds numbers and low turbulence numbers.[51] This tunnel was crucial in the development of LCA such as the Ilyushin IL-9-300 and the

Tupolev Tu-204. TsAGI's hypersonic tunnel is capable of testing from Mach 10 to Mach 20. TsAGI also has several low-disturbance wind tunnels for performing laminar flow control and hybrid laminar flow control research.

The Japanese aeronautical industry has access to a series of publicly and privately owned wind tunnels in Japan, spanning speed ranges from subsonic to hypersonic.[52] Japanese firms have used these tunnels for research on hypersonic aircraft, space vehicles, and composite materials.

In 1991, less than 1 percent of the total NASA budget was devoted to R&D related to subsonic aircraft. During the last 15 years, NASA funds once dedicated for subsonic aircraft R&D have been diverted to the NASA space program. In 1992, most of the NASA R&D budget was devoted to manned space programs, with more than 30 percent of the total allotted for space station Freedom. NASA expenditures on aeronautical R&T declined from 6 percent to 3 percent of its total budget during the period 1980-91.[53] However, with the introduction of the advanced subsonic technology program, expenditures increased in 1992 and are expected to increase further in the mid-1990s.

NASA officials say supercomputers may give Japanese LCA manufacturers an edge in future aeronautical research.

U.S. industry has long relied on NASA for technology validation (aircraft test beds), the longest and most expensive stage in technology development. However, both NASA and the DOD have reduced dramatically the level of their technology validation. Diverse elements within the U.S. aerospace community have called for NASA to change its policy toward subsonic LCA R&D;[54] increase its involvement in aeronautical R&D by upgrading its facilities (wind tunnels, supercomputer systems, propulsion facilities and test beds); take the lead in the development of a new subsonic aircraft; and support short-haul aircraft, propulsion and avionics research.

In 1991, the four major West European aeronautical R&D laboratories (DLR, ONERA, DRA and NLR) had a collective budget of $2 billion, which represented approximately 14 percent of the NASA total budget. Their aeronautical R&D expenditures totaled US$445 million, or 22 percent of their collective budget, compared with $512 million in aeronautical expenditures for NASA. U.S. private sector expenditures for LCA R&D exceeded those of Western Europe during 1991. Although Airbus partner companies performed more third-party-funded R&D than did Boeing or McDonnell Douglas. Overall, aeronautical R&D spending in the United States exceeds that of Western Europe.

U.S. industry experts have alleged that the Airbus consortium relies on consortium member governments for the bulk of all development funds for Airbus. Publicly financed aeronautical R&D in Western Europe, however, is noted for its fragmentation and emphasis on individual national strategies. According to the EC Commission, the rate of duplication in Western Europe of research infrastructure is about 20 percent to 30 percent. If duplication of operating expenditure is also taken into account, the loss is about 20 percent of total budgets.[55] Although collaboration by West European research organizations has alleviated some of the fragmentation, the lack of a central funding source, as well as the lower level of funding vis-a-vis the United States, inhibits West European R&D efforts.[56]

In the past, wind tunnel capacity dictated leadership in aeronautical R&D. This is not as true with the advent of CFD and advanced supercomputer systems. According to the U.S. General Accounting Office (GAO), the United States currently is the world leader in CFD. However, Western Europe is developing a competitive capability, since CFD is recognized worldwide as a critical technology.[57] The GAO also has indicated that Western Europe currently possesses much of the basic scientific knowledge about CFD. The United Kingdom is considered to have the greatest experience among West European countries in applying CFD to weapons systems; Germany, Italy and France also have strong CFD capabilities. As the number of supercomputers increases in the 1990s, Western Europe's ability to advance in the field of CFD is expected to improve dramatically.[58]

NASA officials say supercomputers may give Japanese LCA manufacturers an edge in future aeronautical research. The Japanese computer industry has invested vast sums of money in the development of supercomputer technology, which is critical for CFD research. Only Russia is lagging behind in access to supercomputers.[59]

NASA officials indicate that although Russia is several generations behind the leaders in supercomputer development, the Russian R&D establishment has developed excellent aeronautical algorithms to compensate for this deficiency, and has excellent wind tunnels and other test facilities.

West European industry experts say the U.S. competitive advantage in aerospace R&D is eroding because many of NASA's aeronautical wind tunnels are old and outdated, thus increasing the dependence of the U.S. industry on West European wind tunnels. NASA experienced funding difficulties during the early 1980s when the Office of Management and Budget (OMB) objected to the use of public money to finance subsonic research with near-term commercial application. OMB considered this to be an improper federal subsidy.[60] OMB and other groups believed that this research would best be done by the private sector, particularly by the LCA manufacturers. However, the NASA aeronautics program was saved by reports from the Office of Science & Technology and the National Research Council that stressed the importance of NASA in sustaining overall industry R&D investments, counterbalancing underinvestment in the private sector and supporting the DOD and the FAA.[61] NASA, during the late 1980s, continued to retreat from projects with near-term commercial application. NASA also shifted more of its aerospace budget away from subsonic to fixed-wing research related to the development of the high speed civil transport.[62]

U.S. and West European industry experts presently consider newer subsonic wind tunnels in the Netherlands, Germany, and France, and the new transonic wind tunnel in Germany, to be superior to U.S. facilities in the quality of test conditions and productivity.

U.S. and West European industry experts presently consider newer subsonic wind tunnels in the Netherlands, Germany, and France, and the new transonic wind tunnel in Germany, to be superior to U.S. facilities in the quality of test conditions and productivity. According to NASA officials, the average age of its wind tunnels is nearly 40 years, some of NASA's composite materials facilities are no longer adequate and some wind tunnels have testing backlogs of up to two years because of low productivity.[63] NASA officials also say that many wind tunnels were designed as research-oriented rather than production-oriented tunnels and are thus of limited use to industry in the development cycle of new aircraft. NASA wind tunnels at present cannot provide the high Reynolds numbers, or flow conditions, required to test some next-generation aircraft, especially new LCA aircraft, nor can they simulate conditions needed to research laminar flow control, high-lift device design and adaptive wing configurations. Current tunnel acoustic measuring conditions that are essential for developing an environmentally compatible aircraft also need improvement. In 1988, responding to industry concerns, Congress authorized US$300 million to revitalize six NASA wind tunnels at Ames, Lewis and Langley.[64]

In anticipation that Ames will close several of its wind tunnels for repair, Boeing has begun wind tunnel tests on its 777 in both the United Kingdom and Russia, while McDonnell Douglas has tested model sections of its MD-12 in France.

Industry experts estimate that once the NASA revitalization plan has been completed, Western Europe will continue to maintain an advantage in wind tunnel capabilities because NASA's current refurbishment plans will cover only the most glaring deficiencies. Industry officials assert that NASA will have to allocate additional funding for further repair, or for the construction of new wind tunnels, in order to equal the productivity and measurement capabilities of West European wind tunnels.

U.S. Expertise Increasingly Challenged

U.S. capability in the field of aeronautical R&D will remain strong for the foreseeable future.

Although U.S. expertise is being challenged increasingly by Airbus and Western Europe's aeronautical research institutions, the overall aerospace funding differential between U.S. and West European R&D public- and private-sector organizations will probably ensure U.S. leadership, particularly in such key areas as CFD proficiency and application.

Nevertheless, U.S. R&D infrastructure does not equal West European capabilities with respect to wind tunnels,[65] which remain essential facilities for the development of aircraft.

Aeronautical R&D spending in the United States exceeds slightly that of Western Europe. NASA's aeronautical R&D budget totaled US$512 million in 1991 compared with US$445 million for the four West European laboratories (ONERA, DLR, DRA and NLR). The U.S. government increased its spending in aeronautical R&D in 1992, and further increases are expected during the mid-1990s. In 1992, NASA's aeronautical R&D expenditures rose to US$555.4 million (not including expenditures for staffing) and are scheduled to increase to US$716.8 million in FY 1993 and to US$877.2 million in FY 1994. NASA officials expect funding at the West European laboratories to remain relatively flat as a result of declines in public funding of LCA R&D.

National governments will continue to play an important role in aeronautical R&D.[66] However, the majority of LCA R&D likely will continue to take place at the company level in the near future because firms can better identify product-oriented R&D. Evolutionary technology will continue to be developed by private-sector firms. Revolutionary developments, however, will continue to require government participation because of the risk and cost involved.[67]

NASA plans to conduct more customer-focused R&D and align its subsonic research to the design philosophies of industry leaders such as Boeing, McDonnell Douglas, Pratt & Whitney and General Electric.[68] NASA officials say industry-government cost-sharing R&D projects are becoming more politically acceptable. NASA will shift its primary emphasis from precompetitive R&D to R&D with a more mid-term focus. In its 1992 through 1995 budgets, NASA has also increased its budget allocations for large scale demonstration projects and for mid-term technology development and validation. ♦

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[Editorial Note: *The preceding article was adapted from* Global Competitiveness of U.S. Advanced-technology Manufacturing Industries: Large Civil Aircraft, *prepared by the U.S. International Trade Commission (USITC), August 1993.]*

Worldwide Civil Aviation Activity, Safety and Security Evaluated

by
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In 1992, an estimated 379,380 aircraft were registered in the 174 contracting states of the International Civil Aviation Organization (ICAO). Of the civil aircraft registered, approximately 5 percent were turbojets, 4 percent turboprops and 91 percent piston-powered. Gliders and balloons were not included.

In terms of aircraft maximum takeoff weight, only about 5 percent of the total registered aircraft were 19,841 pounds (9,000 kilograms) and over; 95 percent were under 19,841 pounds. Table 1 (page 27) shows worldwide registered aircraft by aircraft type and by operator for calendar year 1992. The statistics show that fixed-wing aircraft accounted for 94.7 percent. Rotary-wing aircraft accounted for 5.3 percent.

About 88 percent of registered civil aircraft were used for general aviation flying. The remaining 12 percent used by commercial air transport operators (or about 44,000 aircraft) included 12,000 fixed-wing turbojets, 6,000 turboprops, 20,500 piston-prop aircraft and more than 5,500 rotorcraft. About 1,200 commercial air transport operators engaged in international and domestic scheduled passenger service operated at least one aircraft with a maximum takeoff weight, 19,841 pounds or more.

The worldwide licensed pilot population in 1992, not including student pilots, was estimated to be about 1 million. (Table 2, page 28). About 57 percent were private pilots, 24 percent were commercial pilots and 19 percent were airline transport pilots.

Preliminary information on air transport traffic in 1992 revealed that worldwide airlines in all services recorded a total of 37.7 million aircraft hours flown, and carried an estimated 2.138 million passenger-kilometers and 71.8 million freight tonne-kilometers of freight. Table 3 (page 28) shows worldwide airline traffic by scheduled and nonscheduled operations, in passenger and freight services, for calendar year 1992. In terms of the number of passengers carried, international operations accounted for 54 percent and domestic passengers 46 percent. In freight operations, international operations accounted for 78 percent and domestic operations 22 percent.

Table 1
Worldwide Civil Aircraft by Aircraft Type and Operator Calendar Year 1992

Number of Aircraft on Register at Year-end (Preliminary)

Classification of Aircraft	Commercial Air Transport Operators		Other Operators		Total		
	MTOW 9,000 kg and over	MTOW under 9,000 kg	MTOW 9,000 kg and over	MTOW under 9,000 kg	MTOW 9,000 kg and over	MTOW under 9,000 kg	All Aircraft
FIXED-WING							
Turbo Jet							
4-engine	1,590	—	320	—	1,910	—	1,910
3-engine	2,450	—	330	—	2,780	—	2,780
2-engine	6,710	1,000	1,940	3,530	8,650	4,530	13,180
1-engine	—	30	20	280	20	310	330
Turboprop							
4-engine	270	10	120	20	390	30	420
3-engine	—	—	—	—	—	—	—
2-engine	2,320	3,190	460	6,410	2,780	9,600	12,380
1-engine	—	200	—	820	—	1,020	1,020
Piston-propeller							
4-engine	70	20	300	50	370	70	440
3-engine	—	40	—	30	—	70	70
2-engine	380	7,710	1,110	31,320	1,490	39,030	40,520
1-engine	—	12,100	—	274,000	—	286,100	286,100
TOTAL Fixed-wing	13,790	24,300	4,600	316,460	18,390	340,760	359,150
ROTARY-WING							
Turbine Engine							
2-engine	130	1,000	70	2,320	200	3,320	3,520
1-engine	—	3,490	—	4,640	—	8,130	8,130
Piston Engine							
2-engine	—	10	—	80	—	90	90
1-engine	—	910	10	7,570	10	8,480	8,490
TOTAL Rotary-wing	130	5,410	80	14,610	210	20,020	20,230
TOTAL All Aircraft	13,920	29,710	4 ,680	331,070	18,600	360,780	379,380

Excludes China and the Commonwealth of Independent States
MTOW=Maximum Takeoff Weight

Source: International Civil Aviation Organization, Civil Aviation Statistics of the World 1992.

Table 2

Active Civilian Pilots by Pilot License
Calendar Year 1992

Estimated number of pilot licenses*

Pilot Category	Airplane	Helicopter	Total	Percent
Private Pilots	551,000	14,000	565,000	56.7
Commercial Pilots	208,000	27,000	235,000	23.6
Senior Commercial Pilots	9,000	—	9,000	0.9
Airline Transport Pilots	187,000		187,000	18.8
TOTAL	—	—	996,000	100.0

*Excludes student pilot, free balloon and glider licenses. Excludes China and the Commonwealth of Independent States.

Source: International Civil Aviation Organization, Civil Aviation Statistics of the World 1992.

Table 3

Worldwide Airline Passenger and Freight Traffic by Type of Service and Type of Operation
Calendar Year 1992

Type of Service	International Scheduled Airlines		Domestic Scheduled Airlines		Nonscheduled Operators (International and Domestic)		Total All Operators	
	Passenger-kilometers Performed (millions)							
Scheduled Services								
International	979,440	(50%)	—		—		979,440	(46%)
Domestic	916,670	(46%)	56,440	(88%)	—		973,110	(45%)
Nonscheduled Services								
International	72,500	(4%)	4,690	(7%)	91,360	(92%)	168,550	(8%)
Domestic	6,440	(0%)	3,270	(5%)	8,140	(8%)	17,850	(1%)
		(100%)		(100%)		(100%)		(100%)
TOTAL All Services	1,975,050		64,400		99,500		2,138,950	
		(92%)		(3%)		(5%)		(100%)
	Freight Tonne-kilometers Performed (millions)*							
Scheduled Services								
International	50,060	(76%)	—		—		50,060	(70%)
Domestic	11,750	(18%)	240	(89%)	—		11,990	(17%)
Nonscheduled Services								
International	1,350	(2%)	10	(4%)	5,040	(86%)	6,400	(9%)
Domestic	2,570	(4%)	20	(7%)	800	(14%)	3,390	(5%)
		(100%)		(100%)		(100%)		(100%)
TOTAL All Services	65,730		270		5,840		71,840	
		(91%)		(0%)		(8%)		(100%)

* Includes freight carried on mixed passenger-freight services as well as on all-freight services.

Source: International Civil Aviation Organization, Civil Aviation Statistics of the World 1992.

The Gulf War aggravated a downturn of the world economy that began during the second half of 1990. Worldwide commercial air transport recorded a traffic decline in 1991, the first year ever to record a drop in all operations. In 1992 worldwide passenger traffic showed a recovery over 1991, and reached levels above those in 1990 in all regions except the European region (Table 4).

General aviation is defined by ICAO as civil aviation other than commercial air transport. The number of civil aircraft used for general aviation flying was little changed in 1992, compared to 1991. However, the downward trend of general aviation activity in 1990 continued into 1992. Worldwide general aviation hours flown were estimated to have decreased from 46.4 million hours in 1991 to

Table 4
Worldwide Airline Passenger Traffic
Passenger-kilometers Performed by Region
Calendar Years 1983-1992

ICAO Statistical Region of Carrier Registration	Passenger-kilometers Flown (millions)					
	1983	1988	1989	1990	1991	1992
Europe	388,330	508,250	546,200	590,620	551,930	551,730
Africa	34,360	38,050	40,790	42,210	39,210	44,000
Middle East	38,060	45,620	47,780	46,950	44,930	53,050
Asia and Pacific	190,040	309,230	318,790	343,900	359,340	406,710
North America	478,850	726,540	741,750	783,220	759,840	806,390
Latin America and Caribbean	60,140	77,750	84,530	87,090	87,550	90,670
Total	1,189,780	1,705,440	1,779,840	1,893,990	1,842,800	1,952,550

Source: International Civil Aviation Organization, Civil Aviation Statistics of the World 1992.

Table 5
Civil Aviation Safety — 1991 and 1992
Estimates by Type of Flying

Accidents Involving Aircraft Operated by Commercial Air Transport Operators

Accidents/Fatalities	Accidents with Passenger Fatalities			Other Accidents [b/]	Total	Accidents Involving Aircraft Operated by All Other Operators [d/]	Total All Civil Flying
	Scheduled Services Total	Nonscheduled Services [a/]: Aircraft of 9 Tonnes MTOW and over	Nonscheduled Services [a/]: Aircraft under 9 Tonnes MTOW				
1991 (Revised)							
Total Number of Accidents	—	—	—	—	700	4,200	4,900
Accidents with Fatalities	25	5	120	55	205	755	960
Fatalities, Total	571	285	295	66	1,217	1,563	2,780
Crew	59	14	40	50	163	—	—
Passengers	510	271	250	—	1,031	—	—
Other [c/]	2	—	5	16	23	—	
1992 (Preliminary)							
Total Number of Accidents	—	—	—	—	710	4,250	4,960
Accidents with Fatalities	25	6	130	60	221	760	981
Fatalities, Total	1,090	188	336	152	1,766	1,590	3,356
Crew	100	22	56	67	245	—	—
Passengers	990	166	260	—	1,416	—	—
Other [c/]	—	—	20	85	105	—	—

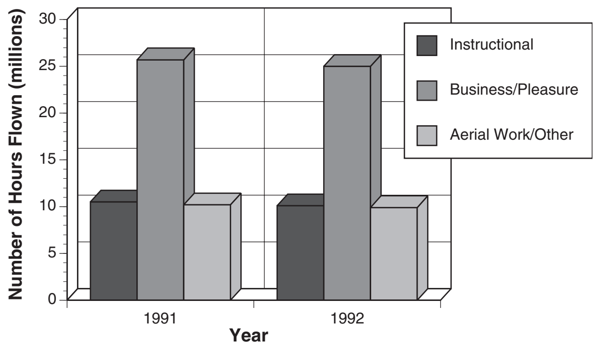
a/ Nonscheduled services of scheduled airlines and non-scheduled air transport operators.
b/ Includes all freight/mail flights and non-transport flights (aerial work, test, training, etc.).
c/ Accident victims not in the aircraft and non-crew members on board all freight and non-transport flights.
d/ Excludes China.

Excludes the Commonwealth of Independent States.

MTOW=Maximum Takeoff Weight

Source: International Civil Aviation Organization, Civil Aviation Statistics of the World 1992.

World General Aviation Hours Flown Estimated by Type of Flying Calendar Years 1991-1992



Source: *International Civil Aviation Organization*, Civil Aviation Statistics of the World 1992.

Figure 1

about 45 million hours in 1992. Of the flight hours in 1992, it was estimated that about 10.1 million hours (or 22.5 percent) were for instructional flying, 25 million hours (or 55.5 percent) were for individual business and personal recreation and 9.9 million hours (or 22 percent) were flown for aerial application, aerial work and other purposes. Most general aviation aircraft are piston-powered propeller aircraft. Figure 1 shows a comparison of general aviation hours flown by type of flying for calendar years 1991 and 1992. There was little percent change in terms of hours flown by type of general aviation flying.

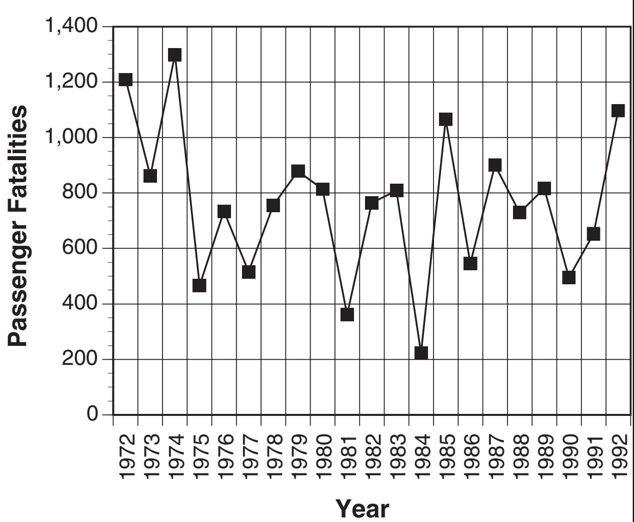
World civil aviation in 1992 recorded about 4,900 accidents (981 of which were fatal) resulting in 3,356 fatalities, compared with 2,780 fatalities in 1991, or an increase of 21 percent. Table 5 (page 29) shows the worldwide civil aviation total accidents, fatal accidents and fatalities for 1991 and 1992.

During 1992, worldwide airlines in scheduled service were involved in 29 fatal accidents that accounted for 1,097 passenger fatalities, compared with 30 fatal accidents and 653 passenger fatalities in 1991. Figure 2 shows the annual distribution of passenger fatalities, which has fluctuated during the past 21 years. No trend can be discerned.

The passenger fatality rate per 100 million passenger-kilometers for 1992 (Figure 3) was higher than rates for the years 1986-1991.

In nonscheduled passenger service, world airlines were involved in 44 fatal accidents in 1992, which

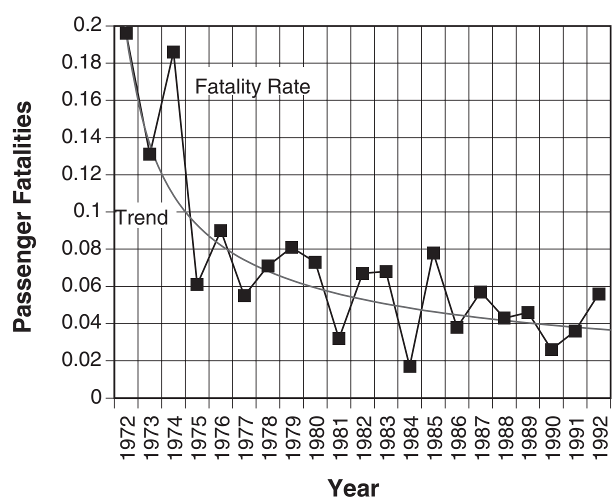
Worldwide Airline Passenger Fatalities All Scheduled Services Calendar Years 1972-1992



Source: *International Civil Aviation Organization*, Civil Aviation Statistics of the World 1992.

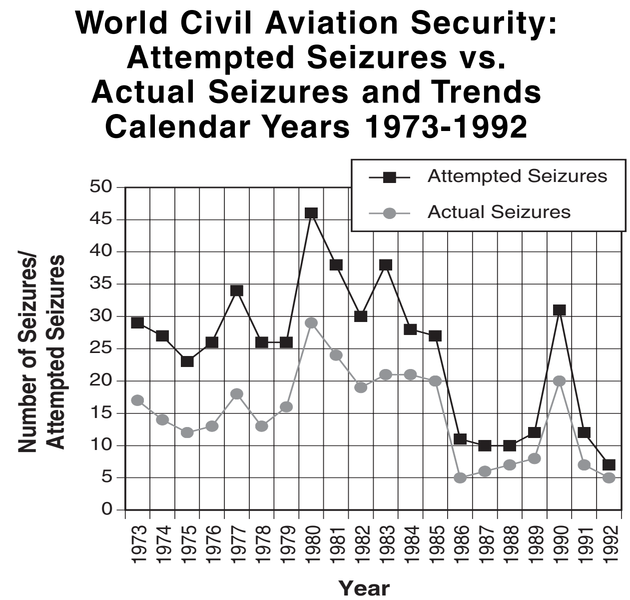
Figure 2

Worldwide Airline Passenger Fatality Rate per 100 Million Passenger-kilometers Annual Rate and Trend Calendar Years 1973-1992



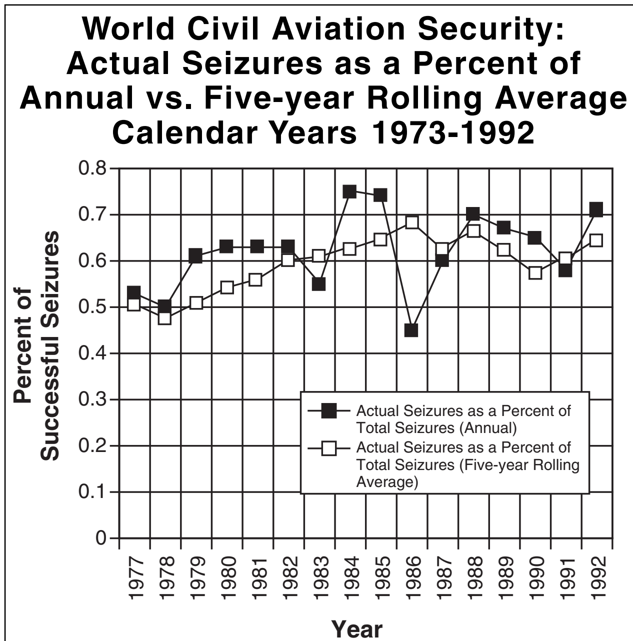
Source: *International Civil Aviation Organization*, Civil Aviation Statistics of the World 1992.

Figure 3



Source: International Civil Aviation Organization, Civil Aviation Statistics of the World 1992.

Figure 4



Source: International Civil Aviation Organization, Civil Aviation Statistics of the World 1992.

Figure 5

accounted for 366 passenger fatalities compared with 26 fatal accidents with 385 passenger fatalities in 1991.

It was estimated that worldwide general aviation was involved in 820 fatal accidents accounting for 1,650 fatalities in 1992, compared with 810 fatal accidents with 1,629 fatalities in 1991. The fatal accident rate per 100,000 aircraft hours flown was 1.82 in 1992 compared with 1.76 in 1991.

Worldwide civil aviation security is measured, among other things, by the number of unlawful seizures and the number of people killed due to the unlawful interference of civil aviation operations. The number of unlawful seizures in 1992 diminished significantly compared with 1991. There were nine unlawful acts in 1992. One was an act of sabotage to ground facility and one was an inflight attack by a ground-to-air missile. The remaining seven incidents were attempted seizures, five of which were successful. Figure 4 shows the annual total attempted seizures and actual seizures between 1972 and 1992. Attempted seizures and actual seizures have declined since 1982. However, an analysis of actual seizures as a percent of total attempted seizures (which was based on annual frequency of seizures and a five-year rolling average as shown in Figure 5) showed that the ratio of actual seizures vs. total attempted seizures has changed significantly. In the 1970s, the success rate of an attempted seizure was about 50 percent. The rate increased to more than 60 percent in the 1980s, and has remained at this level ever since. ♦

Editorial Note: *Because of a production error, three figures, which were published in "Aviation Statistics" in the November* Flight Safety Digest, *contained inaccurate information. Corrected figures are printed on pages 37, 38 and 39 of this issue of the* Flight Safety Digest.

Interior Padding Reduces Risk Of Neck Injury

by
Editorial Staff

New Reference Materials

U.S. Federal Aviation Administration. Advisory Circular 150/5300-15, *Use of Value Engineering for Engineering and Design of Airport Grant Projects*. September 1993. 7 p.

This advisory circular (AC) provides guidance for the use of value engineering (VE) in airport projects funded under the Federal Aviation Administration's (FAA) airport grant program. This AC should be used by sponsors of airport development projects considering the application of value engineering to projects involving grant funds. VE was developed during World War II by industry to continue production in the face of shortages of critical war materiel by substituting materials or systems that are available to accomplish the task. VE is an important management tool for optimizing expenditures for transportation facilities.

Reports

Armenia-Cope, R.; Marcus, J.H.; Gowdy, R.V.; DeWeese, R.L. *An Assessment of the Potential for Neck Injury Due to Padding of Aircraft Interior Walls for Head Impact Protection*. Report No. DOT/FAA/AM-93/14. A special report prepared at the request of U.S. Federal Aviation Administration, Office of Aviation Medicine. August 1993. 11 p.; ill. Includes bibliographical references. Available through the National Technical Information Service*.

<u>Keywords</u>
1. Aircraft Cabins — Safety Measures.
2. Neck — Wounds and Injuries.
3. Head — Wounds and Injuries.
4. Whiplash Injuries.

Summary: This report describes a test program to assess the risk of neck injury that may occur during an aircraft accident if interior wall padding is used to achieve the heightened impact protection requirements adopted by the FAA in 1988. The use of padding has been shown to be effective in reducing the potential for head impact injury. However, a common concern in designing padding to reduce the threat of a head injury is that it may create new load paths that carry a potential for neck injury.

Literature is reviewed on impact-induced neck injury as well as neck injury criteria developed and reported by others. A discussion of injury mechanisms and injury criteria is provided.

The tested pad, in comparison with the unpadded case, substantially decreased the neck extension moment, implying a reduction in neck injury risk, according to the report. A table summarizing test results and references are also included. [Modified Abstract]

Books

Reinhart, Richard O. *FAA Medical Certification: Guidelines for Pilots*. Ames, Iowa, U.S.: Iowa State University Press, 1993. 196 p.: ill. Includes index.

Keywords
1. Air Pilots — Medical Examinations
2. Air Pilots — Health and Hygiene
3. Aerospace Medicine — United States
4. Aviation — Standards
5. Certification
6. Health Promotion — United States

Summary: The book covers a wide range of medical issues related to pilots and the aviation industry. Reinhart, a physician and senior aviation medical examiner for the U.S. Federal Aviation Administration (FAA), discusses health maintenance and exercise programs for pilots and also outlines the FAA's certification process.

In addition, the book examines specific health problems related to flying and explains disqualifying medical conditions. The book's appendix includes Part 67 U.S. Federal Aviation Regulations (FAR) on medical issues and a list of conditions for which a medical certificate will be denied or deferred.

The book is intended primarily for professional pilots because they must meet the strictest medical standards. The objective of the book is to provide pilots with the medical and administrative tools to protect their health and medical certificates.

* U.S. Department of Commerce
National Technical Information Service (NTIS)
Springfield, VA 22161 U.S.
Telephone: (703) 487-4780

Updated Reference Materials (Advisory Circulars, U.S. FAA)

AC Number	Month/Year	Subject
150/5340-1G	09/27/93	*Standards for Airport Markings* (cancels AC 150/5340-1F dated Oct. 22, 1987).
150/5000-3Q	09/29/93	*Address List for Regional Airports Divisions and Airports District/Field Offices.* (cancels AC 150/5000-3P dated May 13, 1992).
35.37-1	09/07/93	*Composite Propeller Blade Fatigue Substantiation* (change 1 replaces pages 5 and 6 dated May 11, 1993).

Accident/Incident Briefs

Traffic Call Sets Up Airmiss

by
Editorial Staff

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

Air Carrier

Traffic Call Sets Up Airmiss

Boeing 737-200. No damage. No injuries.

The Boeing 737 was cleared for a visual approach not below 3,000 feet (915 meters) until established on final. At the same time, a Piper PA-38 Tomahawk on traffic patrol requested clearance through the area.

Instead of clearing the Tomahawk behind the Boeing 737, the air traffic controller advised the pilot of the light plane that he was cleared to proceed with traffic in sight and to maintain his own visual separation.

Tower radar was inoperative and the controller asked the Boeing 737 crew if they had the traffic in sight. The Boeing 737 crew looked right but saw nothing. When they looked again, they saw the Piper was manuevering to avoid the airliner. The Boeing 737 captain estimated the Piper was about 492 feet (150 meters) ahead and between 100 feet and 150 feet (30.5 meters and 46 meters) below. There was no time to attempt evasive action.

The Tomahawk pilot told investigators he saw the Boeing 737's landing light, but estimated that he had enough time to cross in front of the airliner. When the aircraft loomed suddenly larger, he realized he had misjudged the distance and took evasive action.

Assumptions Cause Clearance Bust

Boeing 767. No damage. No injuries.

The flight was identified by radar after takeoff and instructed to cancel its standard instrument departure (SID) at 3,000 feet (915 meters) and "turn left to GUPON."

The crew read back the left-turn requirement. The flight then turned right at 3,000 feet (915 meters) and came into conflict with several arriving and departing aircraft.

The climb had to be stopped and the aircraft was radar vectored to maintain separation from the other aircraft. The flight crew said that they thought they were cleared direct to GUPON and turned right because that was the normal direction of the SID and the most direct route to GUPON.

Routine Cabin Door Closure Turns Dangerous

Boeing 737-400. No damage. One serious injury.

Passengers had boarded the aircraft and final preparations were under way for departure. Both rear cabin doors were open, and a flight attendant went first to the right door to close it. The attendant fell to the ground and was seriously injured.

There were no witnesses to the accident, but a post-accident inspection of the door area revealed no obstructions that would have caused the attendant to trip and no fluids on the floor that could have caused the attendant to slip.

Tree Stump Snags Commuter

De Havilland DHC-2. Aircraft destroyed. Five fatalities.

The aircraft flew at low altitude past a remote village and then attempted a 180-degree turn. Before the turn was completed, the aircraft struck a large tree stump on a low rise.

The aircraft crashed into a rock shoreline about 45 feet (14 meters) beyond the stump and burned. All five occupants were killed. Weather at the time of the crash was reported as visual meteorological conditions.

Course Deviation Ends in Field

Fokker F-28. Aircraft destroyed. Five serious injuries.

The aircraft with 29 passengers on board was on a charter flight in daylight conditions when it strayed off course. The deviation led to fuel exhaustion, and an emergency landing was conducted in a grassy field.

During the landing roll, the aircraft collided with trees. The left wing was sheared off and the landing gear collapsed. Four crew members and one passenger were seriously injured.

Tainted Fuel Curtails Business Flight

Grumman Gulfstream G-1. Substantial damage. No injuries.

While in cruise flight in daylight conditions, the right engine failed and the propeller feathered automatically.

During descent for a precautionary landing, power was restored but the engine stopped again moments later. At 6,000 feet (1,830 meters) the left engine failed. The pilot executed an emergency wheels-up landing in a nearby field.

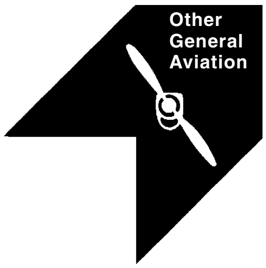
An investigation determined that fuel tanks and filters contained dirt and other contaminants and that fuel supplies had not been checked adequately.

Wrong Direction, Too Little Runway, Spell Disaster

Cessna 414. Aircraft destroyed. Three fatalities.

The aircraft was cleared for a night takeoff on runway 28 with runway visual range (RVR) estimated at 1,066 feet (325 meters).

The aircraft took off from runway 10 with 1,969 feet (600 meters) of remaining runway from the intersection. The aircraft became airborne but collided with trees and a power-line about 2,297 feet (700 meters) from the end of the runway. The aircraft was destroyed by a post-impact fire and the occupants were killed. Airport authorities suggested a review of the airport's taxi guidance system.



Marginal Weather, Inadequate Training Ignored

Beech 76. Aircraft destroyed. Three fatalities.

The pilot decided to attempt the evening pleasure flight despite marginal weather reported along the route of flight.

After acknowledging instructions from approach control to climb to 6,000 feet (1,830 meters) and report when ready for descent, radio contact was lost. The twin-engine aircraft collided with near vertical terrain at about 1,700 feet (519 meters) mean sea level (MSL). The aircraft was destroyed by a post-impact fire, and the pilot and two passengers were killed.

An investigation determined that the pilot had fewer than 200 hours total flying time and was not instrument rated. The accident occurred after the pilot was diverted by approach control to avoid weather. Investigators said pilot disorientation and vertigo may also have played a role in the crash.

Emergency Turn Leads to Fatal Stall

Piper PA-31. Aircraft destroyed. One fatality.

Shortly after a daylight takeoff, the pilot reported unspecified problems and attempted to return to the airport.

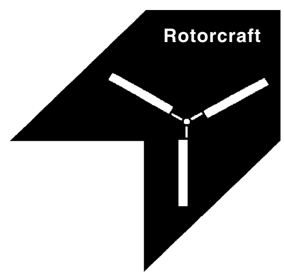
During a steep climb over a high tension wire, the twin-engine aircraft stalled and crashed into a house. No aircraft system abnormalities were found. The pilot was killed.

Hand-prop Gets Out of Hand

Piper PA-28. Substantial damage. No injuries.

The pilot was hand-starting the PA-28. When the engine flooded, he selected the "ignition off" position, advanced the throttle and rotated the propeller by hand several times to clear the engine.

The pilot then selected the "on" switch, but did not retard the throttle. When he next rotated the propeller by hand, the engine started and the aircraft quickly jumped the chocks, proceeding across the runway into an adjacent field. The nose wheel assembly broke after striking several holes, and the propeller and engine mount also suffered damage.



Two Helicopters Destroyed In Collision

Two Bell 206Ls. Both aircraft destroyed. Two serious injuries and 10 minor injuries.

A Bell 206L helicopter was hover taxiing to a parking pad when it collided with another Bell 206 as it prepared to depart. The pilot of the hovering 206 was not injured, but two passengers were seriously injured and four others sustained minor injuries.

The second 206 was running on the pad when it was struck. The pilot was not injured, but six passengers suffered minor injuries. Weather at the time of the accident was reported as visual meteorological conditions with 5,000 feet (1,525 meters) scattered, 50 miles (80 kilometers) visibility and winds at seven knots. Both helicopters were being operated under Part 135 of the U.S. Federal Aviation Regulations (FAR).

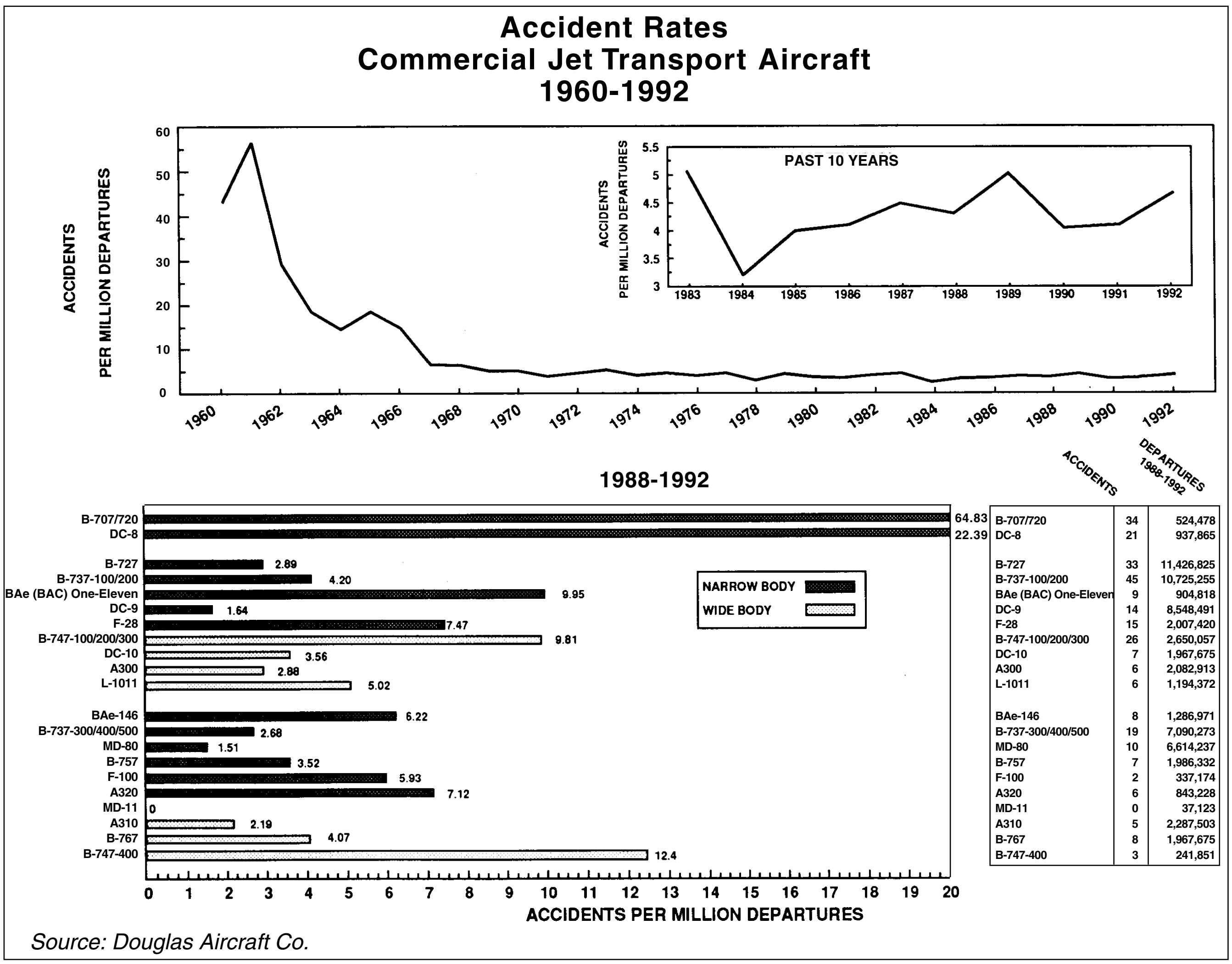
Gust Rolls Helicopter During Ground Operation

Bell 206B. Substantial damage. No injuries.

The aircraft was being used in a sling-load operation. After setting down two fuel drums in a remote area, the pilot landed next to the load and exited the aircraft to recover the drum sling; the helicopter remained under power.

As the pilot re-entered the helicopter, a wind gust caused the aircraft to rock back, and the tail rotor struck the ground. The helicopter rolled onto its side and suffered substantial damage. The pilot was not injured. ♦

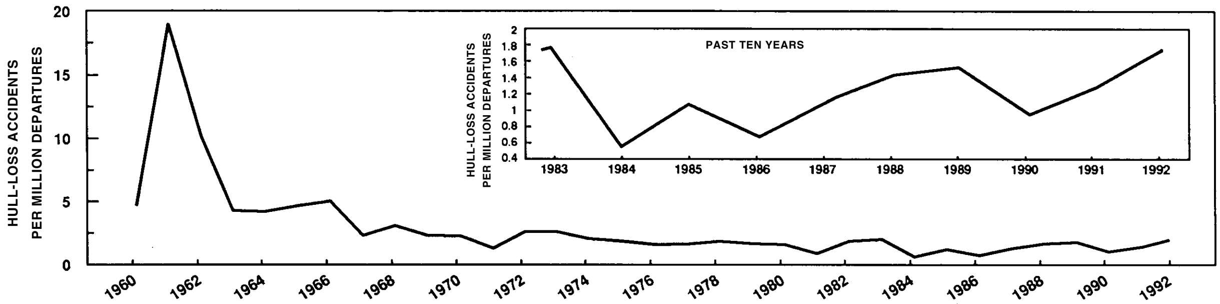
Editorial Note: *The following three figures should be substituted for those on pages 19, 21 and 22 in the November* Flight Safety Digest.



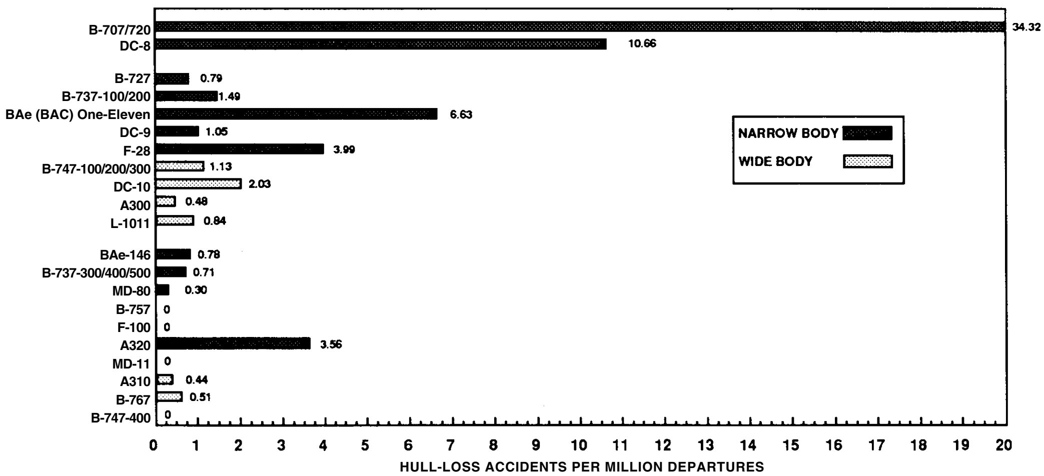
	ACCIDENTS	DEPARTURES 1988-1992
B-707/720	34	524,478
DC-8	21	937,865
B-727	33	11,426,825
B-737-100/200	45	10,725,255
BAe (BAC) One-Eleven	9	904,818
DC-9	14	8,548,491
F-28	15	2,007,420
B-747-100/200/300	26	2,650,057
DC-10	7	1,967,675
A300	6	2,082,913
L-1011	6	1,194,372
BAe-146	8	1,286,971
B-737-300/400/500	19	7,090,273
MD-80	10	6,614,237
B-757	7	1,986,332
F-100	2	337,174
A320	6	843,228
MD-11	0	37,123
A310	5	2,287,503
B-767	8	1,967,675
B-747-400	3	241,851

Figure 3

Hull-loss Accident Rates — Commercial Jet Transport Aircraft 1960-1992



1988-1992

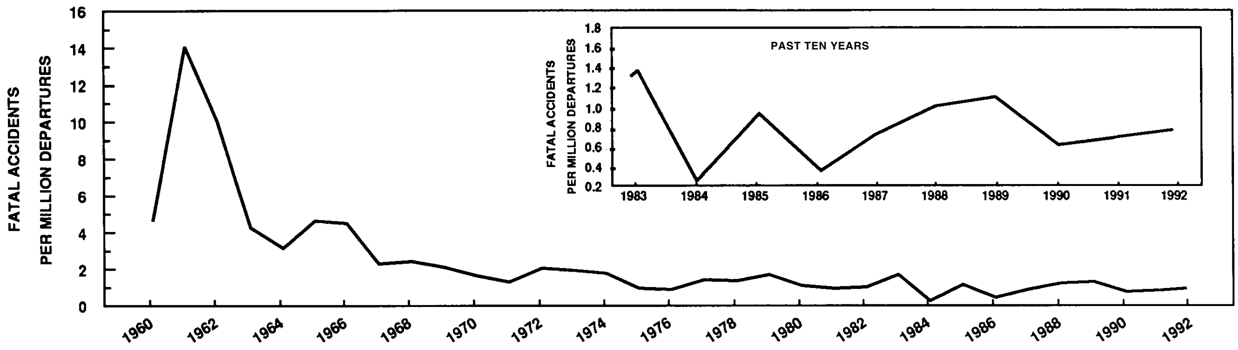


	HULL LOSSES	DEPARTURES 1988-1992
B-707/720	18	524,478
DC-8	10	937,865
B-727	9	11,426,825
B-737-100/200	16	10,725,255
BAe (BAC) One-Eleven	6	904,818
DC-9	9	8,548,491
F-28	8	2,007,420
B-747-100/200/300	3	2,650,057
DC-10	4	1,967,675
A300	1	2,082,913
L-1011	1	1,194,372
BAe-146	1	1,286,971
B-737-300/400/500	5	7,090,273
MD-80	2	6,614,237
B-757	0	1,986,332
F-100	0	337,174
A320	3	843,228
MD-11	0	37,123
A310	1	2,287,503
B-767	1	1,967,675
B-747-400	0	241,851

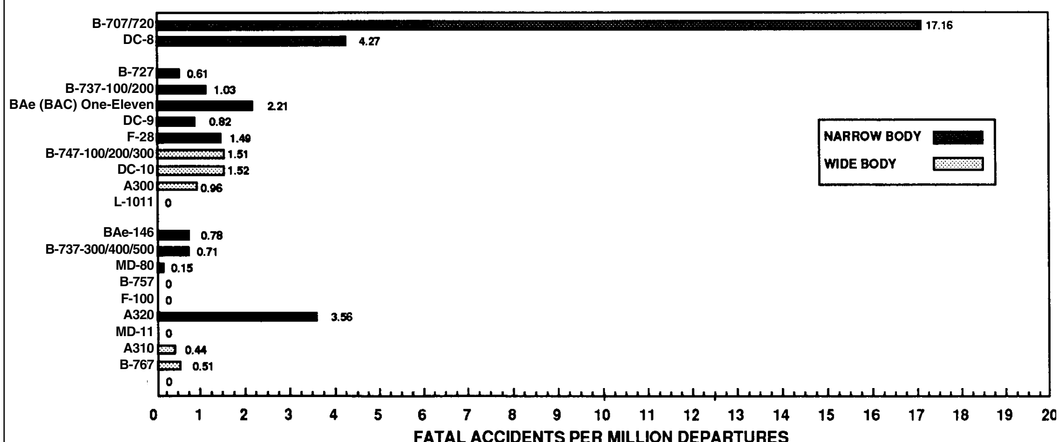
Source: Douglas Aircraft Co.

Figure 6

Fatal Accident Rates — Commercial Jet Transport Aircraft 1960-1992



1988-1992



	FATAL ACCIDENTS	DEPARTURES 1988-1992
B-707/720	9	524,478
DC-8	4	937,865
B-727	7	11,426,825
B-737-100/200	11	10,725,255
BAe (BAC) One-Eleven	2	904,818
DC-9	7	8,548,491
F-28	3	2,007,420
B-747-100/200/300	4	2,650,057
DC-10	3	1,967,675
A300	2	2,082,913
L-1011	0	1,194,372
BAe-146	1	1,286,971
B-737-300/400/500	5	7,090,273
MD-80	1	6,614,237
B-757	0	1,986,332
F-100	0	337,174
A320	3	843,228
MD-11	0	37,123
A310	1	2,287,503
B-767	1	1,967,675
B-747-400	0	241,851

Source: Douglas Aircraft Co.

Figure 8