Chapter II

ADVANCED HIGH-SPEED AIRCRAFT: THE NEXT 30 YEARS

Air transport technology is entering a new evolutionary phase. Both American and European manufacturers are midway in the development of the next generation of subsonic jetliners, a first step along a path to create more energy-efficient equipment for the air carriers.

Photo credit. Airbus Industrie

Airbus Industrie's A-310

The pattern is being established by the Boeing Company's 757 short-range transport and medium-range 767 and in Europe by the Airbus Industrie's A-310, another new medium-range aircraft, all scheduled for introduction into service during 1981 to 1983. New long-range aircraft, including derivatives of present models, are expected to be introduced later in the decade by a number of manufacturers.

These new models are incorporating what the industry calls "phased improvements" in technology covering materials, manufacturing techniques, aerodynamics, cockpit automation, and propulsion. The goal is a 15- to 20-percent improvement in fuel efficiency over the decade to offset rising energy costs. Further substantial technological advances are expected in the 1990's and beyond the year 2000.

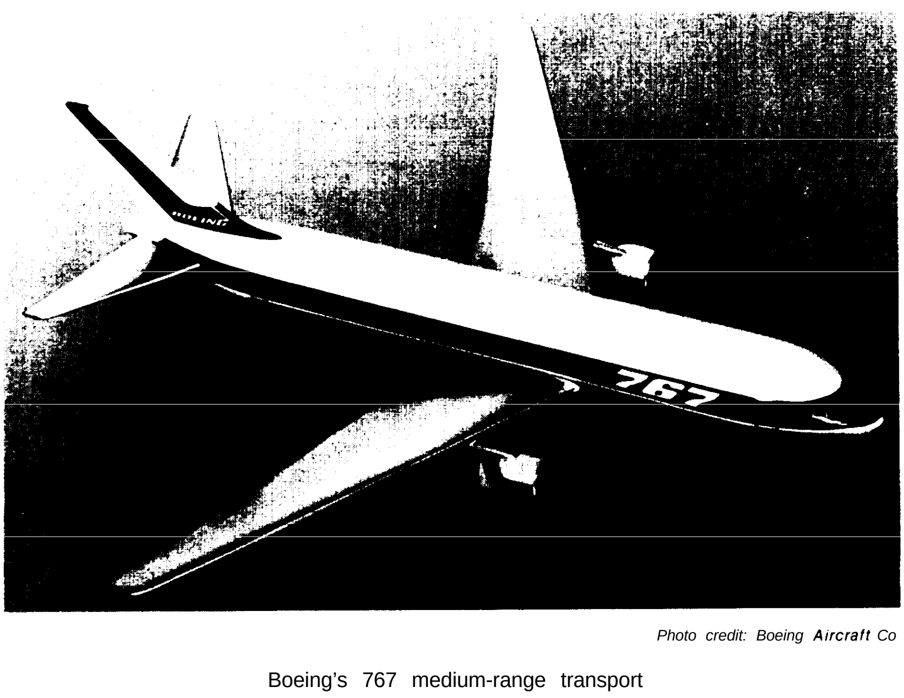

Photo credit: Boeing Aircraft Co

Boeing's 767 medium-range transport

OUTLOOK FOR NEW AIRCRAFT TYPES

Intercontinental versions of these aircraft, designated as advanced subsonic transports (ASUBTs), probably will carry between 200 and 400 passengers, being sized to replace 707s and DC-85, which will be 30 years old by 1990, and to fill market gaps between these early jets and the present generation of widebody aircraft. The range of the ASUBTs will be about the same as the present long-range jets or slightly greater—up to 6,500 nautical miles at cruising speeds of up to 600 mph (Mach 0.85).[1]

[1] J. M. Swihart, *The Boeing New Airplane Family,* paper presented to the American Institute of Aeronautics and Astronautics, 15th annual meeting, Washington, D. C., Feb. 6, 1979.

Under the evolutionary approach, there will be no quantum jump in size or performance, such as occurred with the widebody jets introduced in the early 1970's, to greatly increase productivity (the number of seat-miles generated by an aircraft per unit of time). Instead, the ASUBTs will contain improvements leading toward reduced operating costs. The industry considers it possible over the long run to obtain fuel consumption rates in the ASUBTs that are 20 to 30 percent better per seat-mile than the 2,450 Btu per seat-mile typical of today's widebody jets.

Total operating costs (in constant dollars) could be perhaps 10 to 20 percent below those of

Photo credit: American Airlines

Boeing 707 transport

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the most efficient aircraft now in service, even with increased fuel prices. High-bypass-ratio engines and noise suppression materials used in inlets and ducts will allow quieter operation over a wide range of power settings to increase environmental acceptance.[23]

Beyond 1990, further development of subsonic aircraft is possible and, therefore, so is the continuation of the trend toward more fuel-efficient, economic, and environmentally acceptable aircraft. These aircraft might be derivations of the ASUBTs introduced in the 1980's or might be of an entirely new design. There is also a possibility that very large advanced aircraft (400 to 800 passengers) will be developed to provide service on high-density transcontinental and transoceanic routes.

The demand for very large aircraft, however, is likely to be restricted because they could be productive only on routes with extremely high passenger travel densities. At present, no estimates are available as to when there will be a sufficient number of high-density routes to warrant undertaking the development of such an aircraft.

A further option would be the development of an advanced supersonic transport (AST), a second-generation aircraft with performance capabilities substantially better than those of the British-French Concorde and the Soviet TU-144. An AST operating at more than twice the speed of sound (Mach 2 +) offers the only remaining path to significantly greater aircraft productivity. It could haul twice the number of passengers as a subsonic airliner of equivalent size in the same time period. There are major questions, however, whether it is possible to create an AST that is both economically viable and *environ*mentally acceptable. These questions are analyzed at length later in this study.

'Ibid., pp. 1, **4-5.**
'OTA Working Paper, Lockheed-California Co., Feb. 5, 1979.

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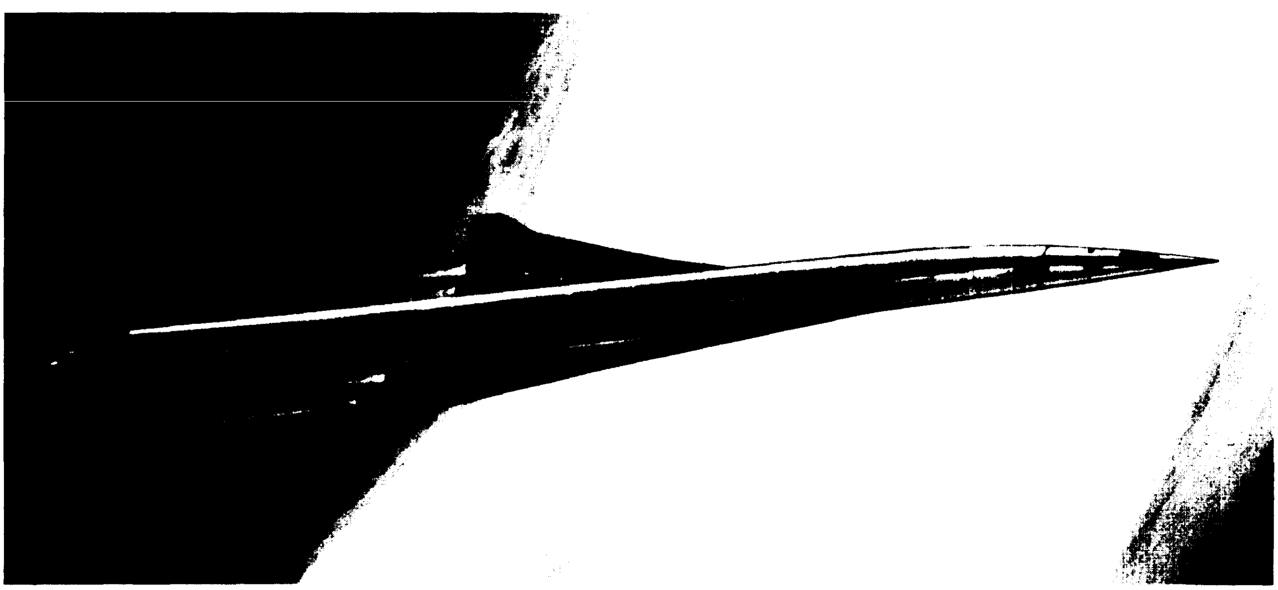
Looking beyond an AST to the prospects of hypersonic cruise aircraft coming into commercial service, the consensus of those involved in this study was that it will not happen before 2010. This judgment is based on the present status of knowledge of the hypersonic regime, the time it would take to obtain a state of technology readiness to design such a craft, plus the time needed to go through a development cycle to produce one. Although research has been conducted on problems associated with hypersonic aircraft, the knowledge base is small compared to the status of knowledge in the supersonic area. The technical problems and requirements of a hypersonic transport, although more extensive and severe, do contain all the requirements of a supersonic aircraft. Therefore, it seems reasonable to assume that supersonic technology readiness must be achieved before hypersonic technology readiness and that any decision to leapfrog the supersonic system for a hypersonic aircraft should come after supersonic technology readiness is achieved.

A similar situation exists for suborbital flight. Although technology advances appropriate to this type of flight could come from the National Aeronautics and Space Administration (NASA) space shuttle program, it is doubtful that this technical base could be translated into a suborbital commercial passenger airplane within the **1980-2010** time frame for this study.

As indicated, the consensus decision to delete the hypersonic and suborbital commercial transports from the current study was made on practical considerations. This decision by no means implies that research should not continue in these areas in order to determine the potential of such aircraft.



Illustration' Courtesy of Lockheed Aircraft Corp.

Artist's concept of Lockheed's hypersonic cruise aircraft

WORLD REQUIREMENTS FOR NEW AIRCRAFT

Perhaps one of the more surprising developments during 1979, in view of economic uncertainties, continuing inflation, and an energy supply picture clouded by unrest in Iran and rising oil prices, was the placement of multibillion dollar orders for the 757, 767, and A-310 by the air carriers. Boeing's sales for the year increased to an unprecedented $12 billion, according to company estimates. Moreover, these orders were booked in the face of an expected U.S. economic recession in 1980 and at a time when the long-range effects of passenger fare deregulation on airline revenues are far from clear.

Underlying the airlines' decision to order hundreds of new planes are projections for continued strong growth in air travel demand. Annual traffic growth has averaged 11 percent since 1977 and hit 15.6 percent in the first half of 1979. While industry analysts expect a recession to hold growth to only 2 percent in 1980, they are forecasting an average annual traffic expansion of 7 percent through 1990.

If air traffic increases by only 6 percent annually on average, passenger-miles over the next 30 years would quadruple. A potential also exists for a doubling of present airline route-miles in this period as more areas of the world, such as the Orient, are opened to commercial traffic.

These projections assume that there will be no major disruptions in the growth of the world economy and that the airlines, along with other transportation sectors, will be able to meet their needs for fuel that is becoming increasingly more expensive. If traffic growth holds up, so will the market for new aircraft. Both the aircraft manufacturers and the airlines agree an increase in passenger-carrying capacity already is indicated for mature travel markets over the next decade, particularly for short- to medium-range routes.

Thus, based on current trends and projections, there is a potential market over the 1980-2010 period for 6,500 to 8,500 short- and medium-range aircraft, both additional and replacement. This part of the market could mean sales totaling $235 billion in 1979 dollars. Over the same 30-year period, the potential market for long-range aircraft (more than 2,700 nautical miles) is estimated at 2,200 to 3,300 units with a sales volume of $150 billion. Should a successful AST be developed, it is believed it could capture about one-third of the dollar volume of this market with sales of about 400 aircraft between 1990 and 2010. But many technical problems and other uncertainties need to be overcome in the near term before it is possible to contemplate whether an AST is indeed feasible in all respects.

To gain an appreciation of the magnitude of the difficulties—and the scope of the issues—it is instructive to review briefly the short history of supersonic flight programs in the United States and abroad and to look at where supersonic technology stands today.

BEGINNINGS OF SUPERSONIC TRANSPORT–THE CONCORDE

In the late 1950's, commercial aircraft designers began turning their attention to passenger transports that could add the element of speed to aircraft productivity. In Great Britain and France, studies were initiated independently about 1956 into the feasibility of supersonic passenger aircraft. In the United States, technical feasibility studies were begun slightly later. However, by 1959, NASA was giving serious consideration to a supersonic transport that would be a civilian derivative of the XB-70 bomber which was later canceled.

For the Europeans, the impetus to develop a supersonic transport came from several sources. In Great Britain, it was seen as a way of recouping the loss in prestige and market advantage suffered by the failure of the Comet jet transport. By the time the Comet's problems had been corrected and the aircraft was ready to re-

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enter service, the U.S. Boeing 707 and DC-8 had built up an unassailable lead. In the words of Sir Cyril Musgrave, permanent secretary of the United Kingdom Aviation Ministry in 1956, "All the major airlines were buying the 707 or the DC-8 and there was no point in developing another subsonic plane. We felt we had to go above the speed of sound, or leave [the market]."[4]

The British aircraft industry had serious doubts about the economic soundness of the supersonic transport proposed at that time. The development costs were estimated to be high, * the market for such an aircraft was uncertain, and the operating cost for a New York-London nonstop flight at Mach 1.2 to 1.8 was projected to be five times greater than the cost of subsonic jets then in service. Designers later increased the speed and capacity of the proposed aircraft, but the industry members of the British Supersonic Transport Aircraft Committee remained skeptical.

While study and debate were going on in Britain, the French Government and aircraft industry were also conducting preliminary studies of a supersonic transport. The French design concept, like the British, was a Mach **2.0, all-aluminum aircraft,** but it had a shorter range and a higher payload intended to serve a European, near Eastern, and African travel market, In France, the impetus for developing such an aircraft came largely from outside the sphere of technology and economics. The French Government was determined to enhance the role of high-technology industries in both the national and the European economy. A supersonic transport was perceived both as a response to "the American Challenge" and as a means to generate the expertise and skills needed to build and sustain a European industry that could compete in high-technology aerospace engineering.

Doubts about development and production costs and about the eventual world market for the aircraft continued to nag the British and the

4P. Gillman, "Supersonic Bust: The Story of the Concorde, " *Atlantic, vol.* **239,** January 1977, p. 73.

● Depending on range, speed, and payload, the estimates at that time varied from $165 million to $265 million. These estimates proved to be wildly optimistic—the British Government's final figures on Concorde development costs were **$3.25** billion, shared by Britain and France.

French. In 1960, both began to cast about for ways to lessen cost and to reduce the technological and capital risks. Negotiations between the two governments began in the summer of 1960 and culminated 2 years later in November 1962 with an agreement for a joint effort to build an aircraft appropriately called Concorde. The design team consisted of the British Aircraft Corp. and Sud-Aviation (later reorganized as Aerospatiale), with Bristol-Siddeley and SNECMA providing the engine.

The aircraft that emerged from the joint design effort had a thin, fixed ogee wing and was powered by a "civilianized" version of the Olympus 22R—a then lo-year-old military engine that had been developed by Bristol-Siddeley for the TSR-2 multimission combat plane (which was canceled in 1965 after $532 million had been spent). The Concorde originally was intended to have a payload of 112 to 126 passengers (later reduced to 90 to 100) and a range of 3,500 to 4,000 nautical miles. The speed of the Concorde was limited to Mach 2.2 because of a decision to employ aluminum instead of titanium, which was more difficult and risky to use but would have allowed speeds up to Mach 3.

The cost of the Concorde development program was estimated in 1965 at $400 million and later revised to $770 million, then to $1.26 billion, $1.75 billion, and ultimately $2.63 billion by 1975. The final cost figures quoted by the British Government in **1977** were $3.25 billion for development and $0.85 billion more for production costs and losses sustained in operating the Concorde, making a total program cost of over $4 billion. Sales estimates made at various times during the course of the program varied widely—from 100 to 500—and the projected purchase price fluctuated accordingly, from $30 million to $56 million.[5,6] But only 16 Concordes were built, 2 for testing and 14 for sale; 9 have been sold at a price of $80 million each to the State-owned airlines of the two countries, British Airways and Air France. The Concorde production line was closed in September 1979 and the remaining seven planes were given to the two airlines.

Construction of the first prototype Concorde began in 1965. The first test flight was in March **1969,** and the first supersonic flight took place 7 months later in October 1969. Commercial passenger service began in January 1976 with flights from Paris to Rio de Janeiro (via Dakar) by Air France and from London to Bahrain by British Airways. Service from Paris and London to

[5] D. Rodd, "The Concorde Compromise: The Politics of Decision-Making," *Bulletin of the Atomic Scientists,* vol. 34, No. 3, March 1978, p. 47.

[6] Gillman, op. cit., p. 78.

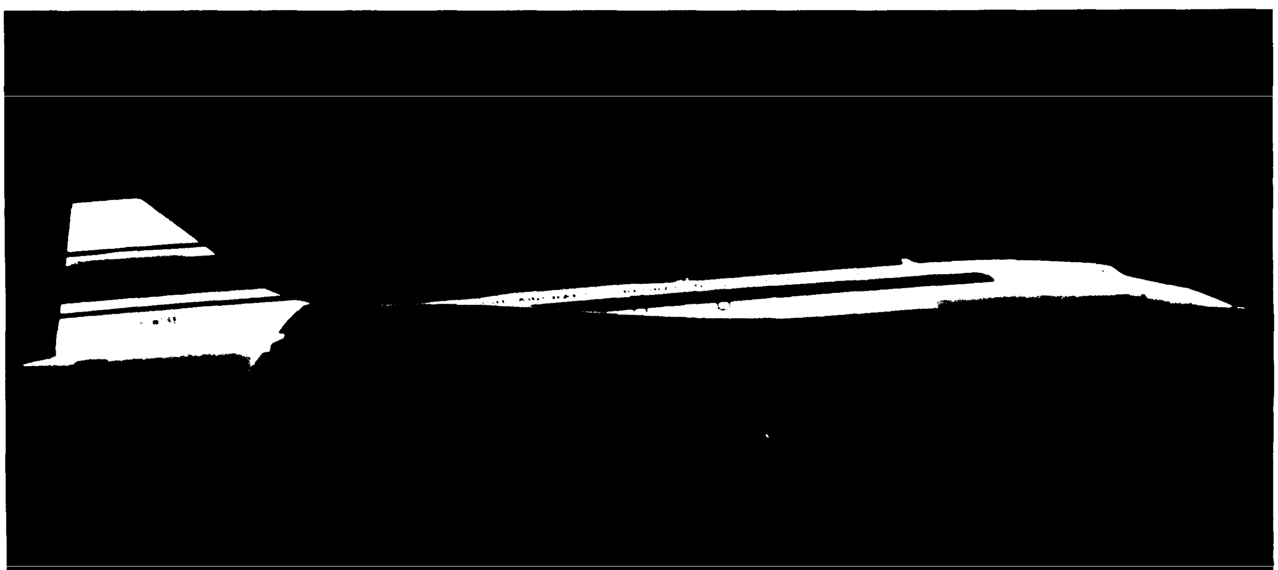

Photo credit: British Aircraft Corp

The Concorde

Washington started on May **24, 1977.**[7] The Concorde now operates on routes from Paris and London to New York, Washington, Caracas (via the Azores), Rio (via Dakar), and Bahrain. The level of service for the two airlines combined was about 110 flights per month for the first year of operation and has risen to about **140** per month since inauguration of flights to New York in December 1977. Load factors for all routes have averaged slightly under **50** percent, but have reached as high as **85** to **90** percent for the North Atlantic routes. g The aircraft presently operates at an average of 70-percent capacity on these routes.

While many feel that the Concorde program proved economically disastrous, several benefits were obtained from it. First, the Concorde showed that an aircraft could be developed and produced which is capable of safe, sustained revenue operations at supersonic speeds. Much has been learned about commercial supersonic aircraft operations which would be extremely beneficial to any future generation of supersonic transports. Secondly, the British and French gained much experience in working together, especially in learning how to manage an advanced technology program with many coordination problems. The Concorde has aided the French in a military regard, specifically in the technology applied to the Mirage series of fighters (Mirage **2000)** which is capable of speeds of Mach 2.5. Last, the project helped preserve and focus the French and British commercial aerospace industry, which has gone on to become a major contender in the world commercial air transport market.

[7]F. Melville, "The Concorde's Disastrous Economics, " *Fortune,* Jan. 30, 1978, p. 67.

[8]P. Sweetman, "Concorde First Passenger Year, " *Flight International*, Feb. 12, 1977, p. 358.

THE AMERICAN SUPERSONIC TRANSPORT (SST) PROGRAM

The official entry of the United States in the supersonic transport competition dates from June 1963 when President John F. Kennedy announced at the commencement exercises of the U.S. Air Force Academy:

> It is my judgment that this Government should immediately commence a new program in partnership with private industry to develop at the earliest practical date the prototype of a commercially successful supersonic transport superior to that being built in **any** other country in the world . . .[9]

Actually, the U.S. interest in an SST began much earlier. The Director of the NASA Office of Advanced Research Programs had testified before the House Committee on Science and Astronautics about the prospects of an SST as early as 1960. [10]

From the outset, the U.S. concept of an SST was shaped by two primary considerations—technological preeminence and economic viability. It was recognized in President Kennedy's speech and specifically stated by NASA and the Federal Aviation Administration (FAA) later that the SST had to be a "better airplane" than the Concorde or the Soviet TU-144 and that "better" meant more advanced technologically and more productive economically. Thus, the initial design concept of the SST called for a 400,0()()-lb titanium airplane capable of flying at Mach 2.7 or faster with a range of at least 4,000 nautical miles and a payload of 125 to 160 passengers. The importance of sonic boom was also recognized, and the FAA request for proposals in August 1963 specified that overpressure could not exceed 2 lb/ft^2 during acceleration and 1.5 lb/ft^2 during supersonic cruise. Further, the SST had to be at least as quiet during approach and takeoff as subsonic jets. [11]

In January 1964, three U.S. aircraft manufacturers submitted design proposals to FAA. The

'John F. Kennedy, commencement address, U.S. Air Force Academy, June 5, 1963, in *Public Papers* of *the President,* speech No. 22., cited in M. E. Ames, *Outcome Uncertain:* Science and *the Political Process* (Washington, D. C.: Communications Press, 1978), p. 50.

[10]U.S. *congress,* Committee on Science and Astronautics, Special Investigating Subcommittee, *Supersonic Air Transport, Hearings*, May 17, 18, 19, 20, and 24, 1960, 86th Cong., 2d sess. (Washington, D. C.: Government Printing Office, 1960), p. 9.

[11]M.E. *Ames, Outcome Uncertain: Science and the Political Process* (Washington, D. C.: Communications Press, 1978).

Lockheed design theoretically was the fastest, flying at Mach 3.0 with 218 passengers. However, the range of the aircraft was limited. The Lockheed "double delta" wing was designed to provide safe and efficient operation at low speeds while offering good aerodynamic characteristics in the supersonic cruise regime. Boeing proposed a Mach **2.7** aircraft with a small payload of 150 passengers. The unique feature of the aircraft was a variable-sweep wing—developed by Boeing in its unsuccessful bid for the TFX military fighter-bomber—which added mechanical complexity to the design and was perceived as a serious technological risk. North American Aviation, Inc., (now Rockwell International) proposed a commercialized version of the B-70 bomber design, which had a fixed delta wing and a forward stabilizing wing called a canard. The design speed was Mach 2.65 and it carried 187 passengers. Three engine manufacturers—Pratt & Whitney, Curtiss-Wright, and General Electric—proposed various turbojet and turbofan designs, none of which were clearly superior to the others in noise characteristics or efficiency. [12]

The competing aircraft designs were evaluated by the Government and a panel of 10 airlines. None met both the range and payload requirements specified by FAA and none promised to fulfill the general objective that the aircraft be profitable in commercial operation. In May 1964, FAA awarded contracts to Boeing and Lockheed for further airframe design studies and to General Electric and Pratt & Whitney for additional work on the engine. Improvements in three fundamental areas were desired: aerodynamic design (a fixed wing or a variable-sweep wing), engine performance (thrust, fuel efficiency, and noise), and operating economics (payload, range, and commercial profitability). Of these, the economic problem was the most intractable.

In December 1966, after 2½ years of additional design studies and reviews by 3 presidential committees, the National Academy of Sciences, 7 congressional committees, 13 Federal Government agencies and departments, and untold analyses by profit and nonprofit consulting organizations, FAA announced that it was awarding contracts to Boeing to build the airframe and to General Electric to produce the engine. This decision was taken despite the findings of two FAA-sponsored studies—one by the RAND Corp. in 1962 and the other by the Stanford Research Institute—which concluded that there was "no direct economic justification for an SST program."[13] The cost of the program by then had reached **$311 million,** plus another $200 million soon to be requested to help finance the construction of two preproduction aircraft. Furthermore, there were major technological problems of range, payload, weight, and engine noise still to be solved.

Why then did the Government (specifically FAA) proceed with the SST program? In part, it was because aircraft designers and Government technical experts presented strong arguments that, given enough money, time, and hard work, the technological problems could be solved. There was some wishful economic thinking, supported by a series of studies commissioned by FAA which raised the market forecast from the original estimates of **25** to **125** aircraft to 500 and eventually to over 800.[14] Not to be overlooked was the personal commitment of those in key positions at FAA from 1960 to 1970—Lt. Gen. Elwood L. Quesada, Najeeb Halaby, Maj. Gen. William F. McKee, Gen. Jewell C. Maxwell, and William M. Magruder. All were publicly avowed proponents of an American SST, and all had had previous involvement with high-technology aerospace programs in military or industrial settings. They never voiced any doubt that the SST could, and should, be built or that it would be technologically and commercially superior to the Concorde and the TU-144.

However, these factors may not have sustained the SST program, if it had not been that the SST had also become a political symbol of the preeminence of U.S. technology. The SST was seen, at that time, as a counterpart to the

[12] 1 bid., p. 59-60.

[13] *Final Report: An Economic Analysis of the Supersonic Transport* (Stanford Research Institute, SRI project No. ISU-4266, August 1963), p. 1.

[14] L. D. Clark, "controversy About Supersonic Transport in the United States, " Miner-m, vol. 12, No. **4, 1974, p. 427.**

Apollo man-on-the-moon program. By failing to keep up with foreign competition the U.S. aircraft industry might lose its leadership in the world market. This argument was advanced in 1962 by FAA Administrator Halaby who listed the consequences of failure to develop an SST as loss of world civil transport leadership, an unfavorable balance-of-payments situation, loss of exports, declining employment in the U.S. aircraft industry, and dependence on foreign sources.[15] Halaby warned that a successful Concorde, with no U.S. equivalent, could "conceivably persuade the President of the United States to fly in a foreign aircraft."[16]

By 1968, after a total of $650 million had been appropriated for the program, the SST was still beset with technological difficulties and political controversy. Boeing announced that the swing-wing design would have to be scrapped on account of its mechanical complexity and the **25** tons it. added to the aircraft weight which affected the range requirements. The redesign to fixed-wing configuration would set back the schedule and raise the development costs of the aircraft. The estimated cost of the overall program, through testing and two preproduction aircraft, had grown to approximately $4.5 billion of which the Government share was about $1.7 billion. The $4.5 billion broke down into: total costs through the prototype of $1.6 billion (of which the Government would supply $1.3 billion); certification cost of $0.8 billion (of which the Government would supply $0.4 billion); and production startup cost of $2.0 billion to $2.5 billion (which the industries would undertake without Government support). The forecasts of sales, return on investment, and operating costs were still not very encouraging.

At about the same time, two new issues emerged that were to prove decisive for the SST program. The first of these was mounting concern about potential environmental and health consequences of a fleet of SSTs. Public reaction to sonic boom tests conducted by FAA convinced Boeing that it would be necessary to restrict supersonic flights by the future SST to over water routes, thus eliminating about one-third of the trips on which the original SST market estimates had been based.

The anticipated noise that the SST would generate over populated areas during takeoff and landing touched off intense public protest. The most heated controversy about environmental impacts, however, centered around the possible changes in the upper atmosphere that might be caused by hundreds of SSTs operating worldwide. Evidence was adduced to show that the water vapor and gaseous emissions released by the SST in the stratosphere could deplete the ozone layer and might lead to irreversible climatic change or an increase in the incidence of skin cancer. There was also concern about possible health hazards to passengers and crew from exposure to cosmic radiation in prolonged and repeated high-altitude flights. These concerns, however, were based on preliminary scientific evidence. They have since been shown to be overblown, but at the time they generated widespread fear of potentially catastrophic environmental damage from the SST.

A second issue which became the subject of public debate centered on the social implications of high technology as represented by the SST. The SST was portrayed by some as an elitist aircraft, financed by taxpayer money for the benefit of a privileged few. It became another object of a growing resistance to technology for its own sake, especially when the costs of that technology were high and its potential consequences for the health and well-being of present and future generations might be harmful. This view was summarized in a New *York Times* editorial:

> The attitude . . . was that technology exists to serve mankind and that proposals to move it ahead at great expense must be judged on the basis of cost-benefit analysis of the widest and most comprehensive sort .. .17

The widening of the debate over the SST to include issues of social goals and priorities was to spell the cancellation of the program. Public discussion about the appropriateness of the SST

[15]M. Horwitch, "The American SST Experience—The Transformation of Multifaceted Technological Enterprises, " working papers for AAAS Symposium, February 1972, p. 5.

[16]N. Halaby, memorandum to President John F. Kennedy, 11/15/62 (JFK Library, President's Office Files), cited in M. Horwitch, loc. cit.

[17]Ames, op. cit. p. 73.

as a technological undertaking for the Nation, coupled with the growing societal concerns and cost, brought the matter to a head in House and Senate votes on fiscal year 1972 appropriations. The cost of the program including preproduction development was $1.6 billion. Design problems for the airframe and engine were still to be solved. The commercial success of the airplane was severely questioned. Fears about environmental effects added fuel to the debate. In March 1971, the House, by a vote of 217 to 203, deleted all SST funds from the Department of Transportation appropriation for fiscal year 1972. An amendment to restore SST funds was defeated in the Senate, 51 to 46. On May 1, 1971, the Senate approved $156 million in termination costs. Thus, after 8 years of R&D and an expenditure of approximately $1 billion, the United States withdrew from the supersonic transport competition.

The total cost of the original SST program through prototype and certification would have been shared by the Government and industry on a 73- and 27-percent basis, respectively. As indicated previously, the production startup cost would have been totally supported by industry. At the same time the program was canceled, 9 U.S. trunk carriers, 2 supplemental, 1 leasing company, and 14 non-U. S. flag carriers had invested $59 million of risk money and $22 million for delivery reservations for 122 U.S. SSTs. The manufacturers had invested approximately $322 million. The program was constructed so that the U.S. Government investment would have been returned on delivery of the 300th production aircraft.

The U.S. SST program did generate a number of technical developments that have contributed to advancing aircraft technology. For example, in the area of aerodynamics, relaxed static stability and variable camber flaps on the wing leading edge were developed and evaluated in the U.S. SST program and have since been applied to the F-16/fighter plane. With regard to human factors technology, various elements in the 747 cockpit are direct descendants of development work on the SST. Other examples include digital displays and advanced navigation systems developed for the SST that are now being incorporated in the 767 aircraft design.

In the structures and materials area, the airframe design problems associated with the SST —more complex than those associated with conventional subsonic designs—prompted the development of more sophisticated and accurate computerized structural design and analysis methods. Methods based on these SST developments are currently employed in the design of advanced subsonic aircraft and are being applied to automotive and other vehicle designs. Also, the work on titanium sandwich structures, formerly conducted concurrently in the SST and 747 programs, contributed to the 747 aircraft and is being applied to military aircraft and missiles. In the propulsion area, the original SST program added substantially to the technology of high-temperature turbines and advanced materials which in turn led directly to improvements in the high-bypass-ratio engines used on most current subsonic transports.

In retrospect, the SST program was probably neither as well-founded an undertaking as its supporters claimed nor as ill-considered as its opponents argued. The goal of the program, in building two preproduction aircraft, was to determine whether a technologically advanced and commercially viable supersonic passenger aircraft could be achieved. The program demonstrated that the technology available at that time would have resulted at best in an economically and environmentally marginal airplane. But it is also true that the technology base was greatly enhanced by the effort and that valuable lessons were learned. However, whatever was achieved was lost from sight in the conflict that led up to cancellation. One of the most important lessons learned is that a genuine and important national interest will have to be clearly identified before any future high-technology large-scale commercial undertaking can expect to receive significant Government support in the future.

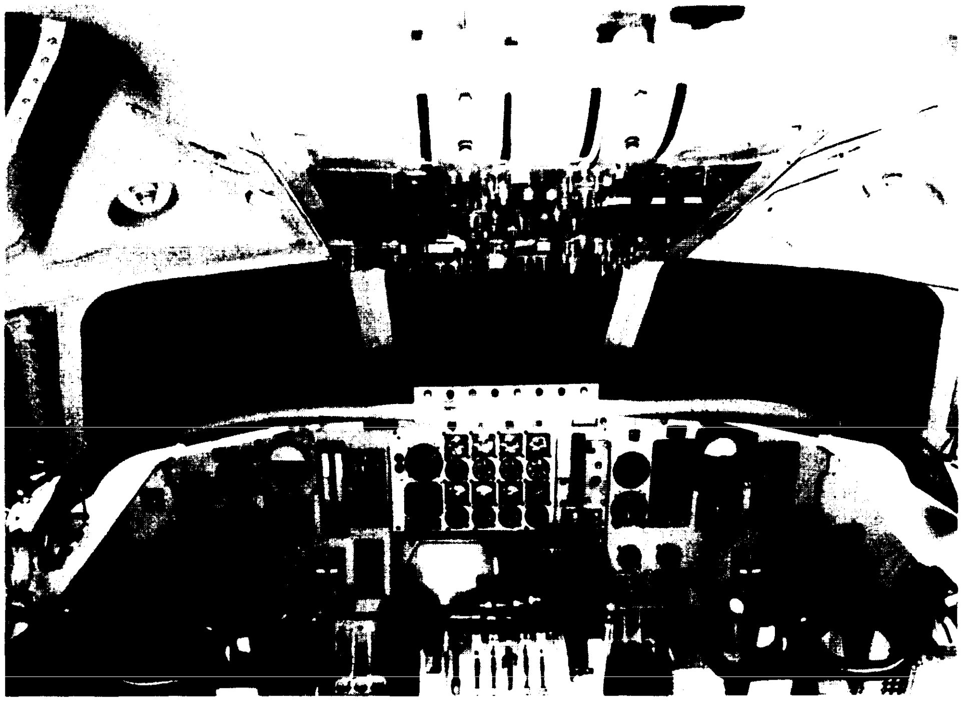

Photo credit National Aeronaut/es and Space Administration

Cockpit of Boeing's 747 aircraft

Photo credit Boeing Aircraft Corp.

Cockpit of Boeing's 767 aircraft now under development

CURRENT STATUS OF SUPERSONIC TECHNOLOGY

Generic research on supersonic cruise aircraft has been continuing at a low funding level since cancellation of the SST program in 1971. Initially, between 1971 and 1973, FAA had responsibility for this research and allotted it a total budget of $15 million, The program was transferred to NASA in 1972 and named the supersonic cruise aircraft research program. In 1979, the name was shortened to the Supersonic Cruise Research (SCR) program. The total appropriation for the NASA program in the fiscal years 1973 through 1979 was $72.9 million, or an average of about **$10** million a year (table 2).

Table 2.—NASA Supersonic Cruise Research Program R&D Expenditures (in millions of dollars; FY 1973.79)

Propulsion	$29.5
Structures and materials	16.7
System integration studies	15.8
Aerodynamics	5.1
Control systems	4.2
Emissions	1.6
Total	$72.9

SOURCE. F. E McLean, Working Paper for OTA, Mar 15, 1979.

Research has concentrated on propulsion, structures, materials, and aircraft and airframe systems technology that might be applied to any AST. At this point in time there are no specific aircraft designs. The results so far indicate that rather impressive improvements over the 20-year-old technology of the Concorde now appear possible. For example, new wing configurations have been tested in wind tunnel tests and have indicated lift-to-drag ratios above 9, which would allow approximately 20-percent more efficient operation than the ratio of the Concorde's wing in supersonic cruise. In the structural area, NASA officials say the most exciting development has been the application of finite-element modeling and advanced computational methods to the design of large aircraft components, allowing for a reduction in design time from 3 months to 1 week. This not only permits rapid analysis of various models but offers promise of lower development costs.

NASA's studies performed with the assistance of aircraft manufacturers show that superplastic forming and concurrent diffusion bonding of titanium may be able to reduce the weight of aircraft structures by 10 to 30 percent and, at the same time, achieve cost savings of more than 50 percent. Various forms of high-temperature polyimide composite structures have been investigated and they show even greater weight-cutting potential.

Variable= Cycle Engine

As seen in table 2, a major portion of the SCR program has been devoted to propulsion technology. These investigations have produced concepts for a variable-cycle engine able to vary the airflow at different power settings. The engine may be able to operate at near optimum fuel efficiency while cruising at either supersonic (turbojet) or subsonic (turbofan) speeds. Because the engine's internal configuration allows the exit nozzle to move and alter the exhaust velocity, it also has potential for reducing sideline noise at takeoff and landing. In addition, an indicated greater combustor efficiency may be able to reduce nitrogen oxide emissions by more than 50 percent, thereby cutting the amount of atmospheric pollution.

Presently within the aerospace industry there is considerable optimism about the engine. Many experts feel that, should the engine prove out in a development and test program, it would bring a second-generation supersonic transport much closer than is generally realized.[18] The engine's promise is twofold:

1. There is a possibility the engine may be able to meet the Federal Aviation Regulation part 36, stage 2 noise rule which was established in 1969.
2. If able to operate optimally at both subsonic and supersonic speeds, the engine would enhance the prospects for integrating an AST into regular airline route

[18] C. Driver, "Advanced Supersonic Technology and Its Implications for the Future, " paper presented to the Atlantic Aeronautical Conference, Williamsburg, Va., Mar. 26-28, 1979.

structures, as opposed to the limited routes flown by the Concorde. For example, it would become possible to originate AST service to London or Tokyo in Chicago, Denver, or Dallas. The over land legs would be flown subsonically and then the AST would switch to supersonic cruise **overseas.** In theory, this extra utility would greatly improve the sales potential for the aircraft. But it still would have higher total operating costs than an advanced subsonic aircraft.

Technology Validation Program

In August 1979, in response to the House Science and Technology Committee, NASA outlined possible plans for technology validation, which were identified as focused initiatives, in a number of aeronautical fields.[19] The completion of generic research in technology validation would be a necessary step in the future development and production of an AST. In supersonic cruise research the plan concentrated on propulsion, airframe, and aircraft systems technology. The propulsion part of the program would be broadened to include research on a variable-flow system and an advanced core engine system that would be integrated with the variable-cycle experimental engine. The aim would be to produce design options for an array of supersonic aircraft applications, plus potential military applications. The airframe technology program would concentrate on nacelle/airframe integration and suppression design methods, and design and high-temperature structures problems, including the selection, fabrication, and testing of titanium and composite materials. The aircraft systems technology effort would identify those portions of the engine and airframe programs requiring inflight investigation and validation. Accomplishment of these objectives would be expected to take up to 8 years and would bring the SCR program through technology validation leading toward "technology readiness," regarded as a decision point on whether the aerospace industry would consider further development of an AST feasible. There is presently some question whether the aerospace industry on its own would be willing at these decision points to initiate activities leading to full-scale production.

The proposed program would cost $662 million (1981 dollars) over an 8-year period, as opposed to an alternate program offered by NASA in 1978,[20] which was priced at $561 million (1979 dollars) over a similar 8-year period. In addition, NASA also prepared a $1.9 billion plan (1977 dollars) in 1977 which would have sustained full competition in the U.S. industry and would lead directly to "technology readiness."[21] These three plans have raised a question for Congress as to what is the proper level of Federal support for supersonic research, because any one would mean a substantial increase over the approximately $10 million a year that has been invested in SCR since 1971.

[19]"Potential Future Initiative Directions in NASA Aeronautics Programs," Office of Aeronautics and Space Technology, National Aeronautics and Space Administration, August 1979.

[20]"A Technology Validation Program Leading to Potential Technology Readiness Options for an Advanced Supersonic Transport," Office of Aeronautics and Space Technology, National Aeronautics and Space Administration, September 1978.

[21]"Program Options for Achieving Advanced Supersonic Transport Technology Readiness," Office of Aeronautics and Space Technology, National Aeronautics and Space Administration, September 1977.

PROSPECTIVE ISSUES

The issues surrounding the development of an AST, including the technical difficulties, have been given a considerable amount of study by the aircraft industry both here and abroad. The collective judgment on both sides of the Atlantic appears to be that more intensive generic research is needed to determine whether an AST is technically feasible in view of the environmental objections and economically viable from an energy standpoint.

One question concerns the degree of technical sophistication an AST should achieve. Essentially there are two choices, which are the subject of the analysis in chapters IV and V: 1) a 200-passenger, Mach-2 aluminum aircraft with a design superior to that of the Concorde which could be introduced around 1990 and 2) an advanced titanium aircraft capable of carrying 200 to 400 passengers at speeds of Mach-2.4 or higher at ranges of up to 5,500 nautical miles.

In the United States, the aviation community appears to be persuaded that the more advanced version has the best chance of meeting the demands of the marketplace. There is guarded optimism that, in terms of development costs, operating expense, and market potential, such an AST could be made a commercial success. The technological problems of aerodynamic and engine design, structural materials, and aircraft range and payload are regarded as not insurmountable. It is believed that such effects as noise, emissions, and fuel use can be held within acceptable limits through adequate R&D efforts.

Beyond these concerns there are issues of public policy involving value judgments and allocations of costs and benefits among individuals and segments of society. Energy consumption, environmental effects, costs of the program to the public, and societal benefits have to be addressed in the debate over whether or not the United States should continue to support supersonic research and at what level of funding.

The issues are not new. They were raised in connection with the Concorde and the SST. Back then, proponents emphasized such advantages as contributions to national defense, balance of trade, and the health of the aerospace industry. The arguments against the Concorde and the SST centered on the high cost to taxpayers, noise in the vicinity of airports, sonic boom, air pollution, potential harm to people, and climatic effects because of changes in the upper atmosphere. It can be expected that these issues will arise again in connection with the AST, although perhaps not in the same form or with the same emphasis.

There is also a more comprehensive set of issues to be addressed—issues that concern possible choices between supersonic and subsonic aircraft. Regardless of whether an AST is developed, the world market for advanced subsonic aircraft over the next 30 years is expected to be large, perhaps up to 12,000 aircraft to replace older subsonic aircraft in the fleet and to accommodate the growth in travel demand. [22] Historically, the United States has been the principal supplier of passenger aircraft for the world market (as of 1978, over 80 percent of the passenger aircraft in the free world were of U.S. manufacture), but there is concern about the ability of the U.S. industry to sustain this market supremacy in the face of growing competition from foreign government-industry consortia, such as that producing the A-300 and A-310. This raises a question as to the long-term importance of supersonic technology to a competitive and viable domestic aircraft industry and a favorable balance of trade. An allied issue is the magnitude of U.S. Government support to the aircraft industry in the interest of optimizing the prospects for long-term growth and to maintaining a major U.S. share of the world aircraft market.

[22] OTA Working paper, Working Group A—Advanced High-Speed Aircraft, Boeing Commercial Airplane Co., January 1979.

Photo credits: U.S. Department of Transportation, Federal Aviation Administration

These U.S. manufactured aircraft are serving worldwide fleets