Advanced Subsonic Transports – A Challenge for the 1990's

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Subsonic aircraft will be serving the major share of the future long-haul commercial aircraft market, at least well into the next century. Providing the fleet of advanced long-range subsonic aircraft that will result in an economically viable and environmentally acceptable world air transportation system in the 1990's will be a major challenge. The design requirements for these airplanes, to a large degree, will be established by future economic, social, and political conditions. Satisfying these design requirements will necessitate an extensive and in-depth technology base that is not only relevant to the airplane, but also to the total air transportation system. This will involve creative and effective work in acoustics, aerodynamics, propulsion, structures, advanced composite materials, and avionics, as well as the systems analysis of the total air transportation system, to improve both its efficiency and its productivity.

Introduction—Future Economic, Social, and Political Environments

SINCE 1935, each generation of commercial aircraft has provided improved characteristics such as increased speed, longer range, larger size, higher levels of comfort, better safety, and lower operating costs (Table 1). These gains were the result of an ever-advancing technology. The design requirements for the future long-range subsonic aircraft will be determined more by the future economic, social, and political environments than by technology. Costs, especially those for labor and fuel, have been rising at a rapid rate. By the 1990's the problem of high fuel costs may well be compounded by an actual shortage of petroleum fuels. In the 11-yr period of 1964-1974, airline wages in the United States have increased 231%, while fuel costs have increased 130% (Fig. 1). Until the late 1960's, increases in costs were more than counterbalanced by improved productivity and lower seat-mile costs. Unfortunately this trend has not continued because of public concern about noise, pollution, and congestion, in addition to demands for increased comfort, convenience, and relatively low fares. During the next few years, until the mid-1980's, it will be very difficult to provide new aircraft designs with seat-mile costs substantially lower than those for present aircraft. The reductions in cost are more than offset by the increases caused by inflation.

Introduction of a new aircraft design requires a substantial reduction of direct operating costs, on the order of 20 to 30%. This is because a new aircraft design also is a costly effort for the airlines, involving training, spare parts support, as well as new ground facilities. It is for this reason that many people feel that the present wide-bodied aircraft and their derivatives will have long and profitable lives. When passenger demand increases sufficiently, growth versions of the present aircraft will become especially attractive, since they provide lower operating costs per seat-mile, improved fuel efficiency, and higher productivity than the original design; these improvements are obtained in the derivative aircraft with little or no increase in aircraft complexity, which is very attractive in times of high labor costs. The future economic, social, and political environments also will have a very significant impact upon both the size and character of the long-haul passenger market. This market, in turn, dictates the requirements for long-range subsonic aircraft.

It is not likely that the high passenger growth rates of the 1950's and 1960's will continue. However, substantial average annual growth rates, on the order of about 7%/yr, will continue through the 1990's. This passenger growth rate will result from such diverse factors as increased disposable income, more promotional fares, freer life styles, additional leisure time, zero population growth, changes in communications, and inflation. Airlines compete in the open market with almost every other conceivable form of discretionary spending.

The next aircraft program may not be able to offer a large improvement in those aspects that appeal to the passenger. Much of our work today is concerned with reducing operating costs, and thus appealing to the passenger through his pocketbook. Because of the forecast of the continuing high cost of fuel, and therefore the increasingly high proportion of the direct operating cost that is due to fuel costs, much of the technology today is focused on reducing fuel consumption. (Table 2). It is also evident that equal attention will have to be placed on airline labor costs and productivity.

World Traffic Growth

World traffic growth trends will have a very strong influence upon the characteristics of the next new aircraft program. The passenger air transport market is maturing, as is shown by the world revenue passenger-miles generated for the period 1955-1974 and a forecast of passenger-mile traffic for the years 1975 to 1995 (Fig. 2). Although the forecast volume of world revenue passenger-miles in 1995 is expected to reach a level of more than 40 times the 1955 level, the annual rate of growth is anticipated to decline. Between 1955 and 1974, the average annual traffic growth was 13.4%. However, between 1974 and 1995 the average annual traffic growth rate is expected to fall by 50 to 6.7%/annum. This decline in the traffic growth rate is expected to occur slowly. It will be about 4%/yr in the 1990's. This rate will be comparable to the annual growth rates of other modes of transportation, and for the economy as a whole in the 1990's.

Although growth rates are expected to decline, there will be a large increase in the number of people traveling by air. A number of factors provide the stimulus, desire, and ability for air travel. These include income, education, employment status, industrial affiliation, and increased leisure. The demand for travel is directly related to real income levels, provided that fares do not increase more rapidly than overall prices. As more and more families move into the middle and

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upper income levels, the demand for air travel will be stimulated, as the use of leisure time for recreational activities tends to place a premium on travel time rather than cost.

Education leads to the increased use of air travel, because educated people usually have both the desire and the means to travel. The employment requirements of educated people generate a considerable amount of air travel. Statistics indicate that professionals and managers take more trips in relation to their group size than other occupations. Employment status has a substantial role in the generation of air travel. The level of industrial development and the development of a large services sector are also important factors in the use of air travel. Industrial development and higher incomes allow individuals to travel for all purposes. One study has concluded that visiting friends and relatives is one of the single most significant purposes for travel.

Aircraft Productivity Trends

There has been a dramatic increase in seat-mile productivity since 1947, (Fig. 3); this is illustrated by the fact that the DC-10-10, introduced about a quarter of a century after the DC-6, is over 10 times as productive as the DC-6.

A comparison of the seat-mile productivity of a number of commercial aircraft types introduced since 1947 and that for a possible future advanced supersonic transport is of interest. Increased seat-mile productivity leads to lower direct seat-mile costs. As has already been pointed out, advances in technology had largely offset airline cost increases in other areas until the late 1960's. Although these advances will continue to be made, they cannot be expected to fully offset the recent large increases in airline wages and fuel costs. Aircraft seat-mile productivity can be raised by increasing block speed, utilization, or seat capacity. The Advanced Supersonic Transport (AST), which may be introduced in 1984 or later, will be more productive than any previous commercial trnsport. It will achieve this distinction by offering much higher block speeds than the large wide-bodied jets. AST's with increased seating capacities could be introduced later, in accordance with future market requirements. It is not possible to increase utilization significantly because of scheduling and curfews; therefore, significant seat-mile productivity increases in the near future will result from stretching the current wide-bodied jet transports, rather than by increasing speed or utilization.

The introduction of jet aircraft resulted in an average annual increase in seat-mile productivity of almost 15% when measured against the seat-mile productivity of the DC-6. This large increase in productivity occurred because the introduction of the jet engine permitted substantial increases in both speed and seating capacity. New commercial jet transports introduced since that time have not increased significantly in speed; rather, only seating capacity has been increased. The average annual rate of seat-mile productivity increase for each succeeding generation of jet transports has accordingly decreased when compared to the DC-6 (Fig. 4). Improving productivity by increasing capacity is not an economically viable solution unless the aircraft's size will satisfy the market characteristics. Technological advances occurring toward the end of the century may well reverse this trend of smaller rates of productivity increase for new aircraft, provided the market conditions warrant larger aircraft.

A Technology Base is Necessary

Efforts must be concentrated in those research areas most likely to provide the technology base necessary for the development of aircraft that will be competitive in the world markets of the 1990's. The advanced subsonic transports that will meet the challenges of the 1990's will reflect the research and development efforts of the late 1970's and 1980's. These efforts must provide the technology base from which airplanes can be developed which are more highly productive, more efficient users of fuel, and have better economic charac-

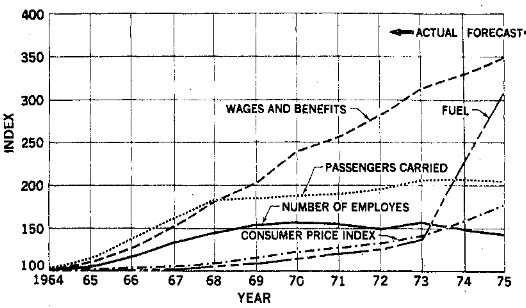

Fig. 1 Cost trends for major domestic airlines.

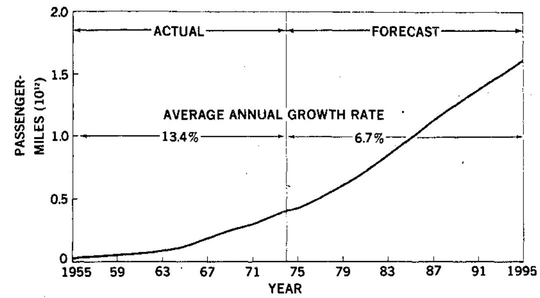

Fig. 2 World revenue passenger-miles, 1955-1995 (excludes USSR and China).

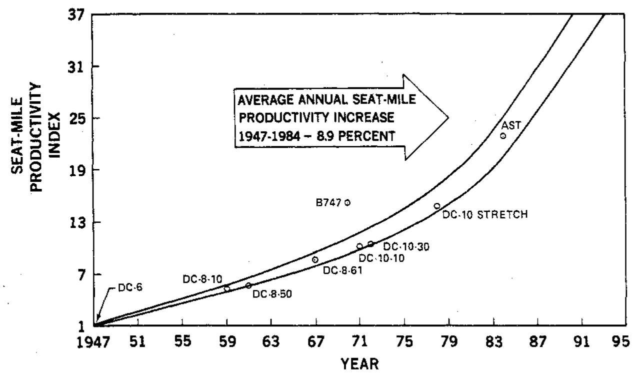

Fig. 3 Aircraft productivity trends.

teristics than the present generation of aircraft. In addition, these airplanes also must be environmentally acceptable in order to be successful.

The fuel savings that are possible by the use of improved commercial operating procedures will have been achieved well before 1980. Therefore, further energy savings only can be obtained in two ways: by advances in design, and by introduction of larger capacity aircraft, whose fuel usage per passenger-mile benefits from the economics of size. The large capacity aircraft are, however, only efficient if the passenger market is sufficient to support operations at viable load factors. The limits of the nation's resources, as well as high fuel prices, will dictate that the advanced technologies be directed toward reducing fuel consumption per seat-mile, as well as increasing aircraft productivity and reducing operating expenses.

Before reviewing the technologies needed to improve aircraft productivity, reduce operating expenses, and increase fuel efficiency, this paper will review briefly the basic factors that determine fuel efficiency. Fuel burned per passenger-mile is indicated by the following relationship

$$\text{fuel/passenger-mile} \propto [1+(\text{OEW}/P)]\ [1+\tfrac{1}{2}(R/C)]/C$$

where OEW = operator's empty weight, P = payload, R = range, C = range constant = $(V/\text{SFC}) \cdot (L/D)$ V = average

Table 1 Evolution of commercial transports[a]

Aircraft	Speed	Range	Size	Comford	Safety	Direct operating cost
DC-1			Basic			
DC-3	✓	✓	✓	✓	✓	✓
DC-4	✓	✓	✓	✓	–	✓
DC-6/L-749	✓	✓	✓	✓	✓	✓
DC-7/L-1249	✓	✓	Slight	–	–	–
DC-8/B707	✓	✓	✓	✓	✓	✓
B727	–	1	✓	–	–	–
DC-9/B737	–	2	–	–	–	–
DC-10/L-1011	–	–	✓	✓	–	✓

[a] ✓Successive improvement. –No change. 1 Optimized for medium range. 2 Optimized for short range.

Table 2 Energy becoming a greater proportion of DOC[a]

DOC item	Fuel price 20¢/gal	35¢/gal	50¢/gal
Fuel	31.5%	44.6%	53.5%
Depreciation	25.5%	20.6%	17.3%
Maintenance	19.0%	15.4%	12.9%
Crew	18.2%	14.7%	12.3%
Insurance	5.8%	4.7%	4.0%
Change in DOC	–	23.6%	47.2%

[a] DC-10-10 at 3000 naut miles.

Table 3 Theoretical fuel saving on long trips with stop at midpoint

Total trip Length (naut miles)	Percent fuel saving with midpoint stop
4,000	4.6
5,000	8.3
6,000	10.7

No additional distance flown to make midpoint stop

Table 4 Potential fuel efficiency increases through technology

Now 8 to 10 percent	Improved operations Wing-tip extensions Leading-edge modifications
Next generation 8 to 20 percent	Supercritical airfoil Optimized wing geometry Longitudinal stability augmentation Composite secondary structures Long-duct composite nacelles
Future 10 to 20 percent	Essentially 100% composite structures Advanced engine cycles Fully active controls Laminar flow Compliant surfaces Nonconventional configurations

speed, SFC = average specific fuel consumption, and L/D = average lift-to-drag ratio.

From this relationship it is clear that, if fuel efficiency is to be increased, future technology must be directed toward reducing weight, improving engine specific fuel consumption, and increasing aerodynamic efficiency. For long-range aircraft, it is especially important to stress the advanced technologies that increase fuel efficiency, because flights over 4000 miles are inherently less fuel-efficient than shorter-range flights with the same payload (Table 3). Whereas a midpoint stop on a 4000-naut-mile trip will provide a 4.6% fuel saving, and a midpoint stop on a 6000 naut-mile trip a 10.7% fuel saving, such a practice probably is not realistic for the airlines at presently anticipated fuel prices and availability levels. This practice would increase operating costs and lower productivity.

Advances in technology can contribute significantly to increased fuel efficiency. However, these gains in efficiency will be obtained in an evolutionary manner because of the severe economic penalties of prematurely retiring current aircraft and the time required to fully develop such advanced technologies as primary composite structures and fully active controls (Table 4). The improvements in fuel efficiency can be applied now to derivatives of the present aircraft. The next generation improvements, however, only can be applied to increase the fuel efficiency of new aircraft design, while further improvements may be used for aircraft two or three generations in the future. Achieving the fuel efficiency gains that may be made possible by the next generation of aircraft, as well as future technology advances, will require substantial research and development effort before one can consider incorporating them into commercial aircraft designs. Some of the potential increases in fuel efficiency, such as that which might be provided by laminar flow, may not be feasible from an operational standpoint.

Acoustics

There is a continual need to reduce noise in order to assure that an air transportation system will meet the requirements of the traveling public as well as the needs of those near the airports. Great progress has been made in the development of quiet aircraft with the introduction of high-bypass-ratio engines. Propulsion system noise during approach is already nearing that generated by the airframe. Although further improvements of this magnitude are not expected in the near future, the need for continually improving the noise environment will require that every avenue be explored to develop the technology that will reduce the propulsive and airframe noise of aircraft. Since in most cases the steps that reduce noise tend to increase costs and fuel consumption, an effort must be made to achieve the highest degree of productivity for a given noise exposure. Reaching this important goal will require substantial research and development programs.

Aerodynamics

Support of the design of large long-range subsonic aircraft that will be competitive in the world markets during the 1990's requires more analytical and experimental aerodynamic programs. Advanced airfoil research must continue, with emphasis on its potential for airframe weight reduction rather than increased speed. Supercritical airfoil aerodynamics is one of several emerging technologies that offers the potential of improving productivity and increasing fuel efficiency over that of today's wide-bodied jet transports. This technology can be utilized either to provide an increase in cruise Mach number of a given wing geometry or to increase airfoil thickness for the same cruise Mach number. An increase in cruise Mach number of approximately 0.075 over that of current transports can be achieved with the use of supercritical airfoils with a wing of the same sweep and thickness.

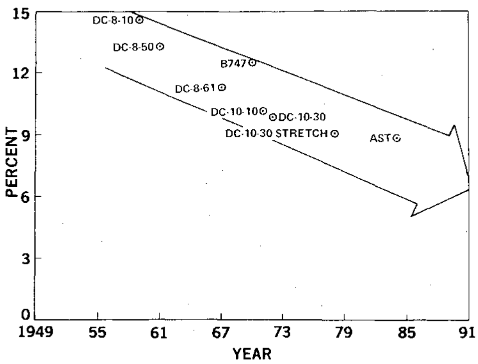

Fig. 4 Rate of change of aircraft productivity based on DC-6--1947.

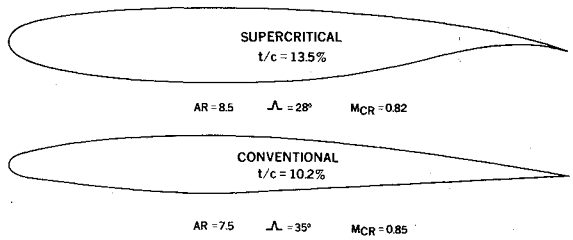

Fig. 5 Advanced airfoil.

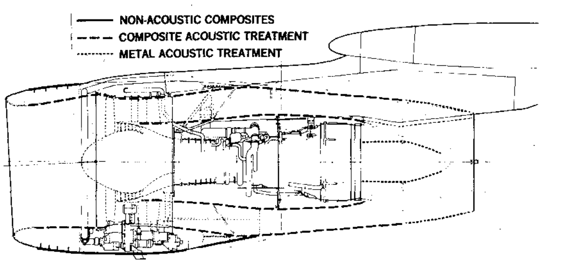

Fig. 6 Quiet nacelle: reduced noise, lower weight, and improved specific fuel consumption.

The increase in productivity of approximately 9%, provided by this increase in Mach number, is achieved at the expense of higher fuel usage and increased direct operating costs.

Advanced transport technology studies show that supercritical airfoils can provide greater gains by increasing airfoil thickness and/or decreasing wing sweep at the same cruise Mach number, rather than by increasing cruise speed. Although increases in wing thickness alone of approximately 40 % can be used to reduce wing weight, it has been determined that the greatest benefit is achieved by a combination of increased thickness, reduced sweep, and increased aspect ratio. Further benefits can be gained by a reduction in cruise speed. This decrease may be small because of scheduling, air traffic control, utilization, and marketing limitations. A comparison of airfoil characteristics, supercritical vs conventional, is of interest (Fig. 5).

Propulsion

The present efforts to reduce engine weight, fuel consumption, engine noise, and engine maintenance costs must continue. However, it seems that no one single development will make such a significant improvement in these areas that a new engine program will be launched; rather, major advances in these important areas will only be made by many small individual steps. Because of the high cost of fuel, it is desirable to reassess the use of turboprops as well as engines using regenerative cycles for commercial transports.

Past propulsion system weight reductions achieved by technology advancements have reduced the weight of the basic engine, but not the weight of the nacelle that encloses the engine. In fact, the weight of the complete nacelle has actually increased because sound absorbing materials are needed to

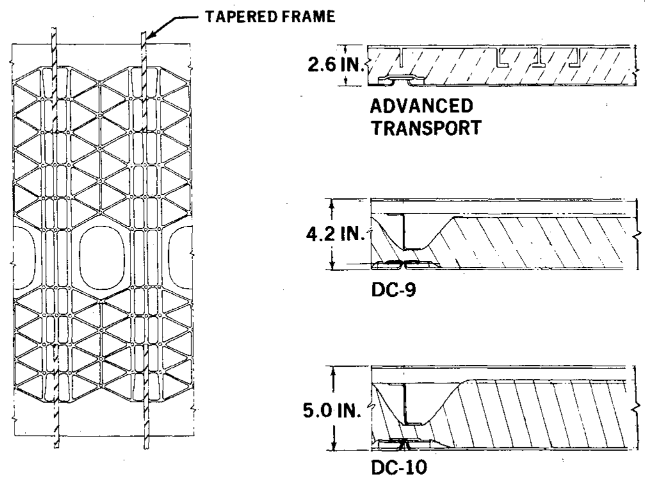

Fig. 7 Integrally machined window belt--comparative wall thickness.

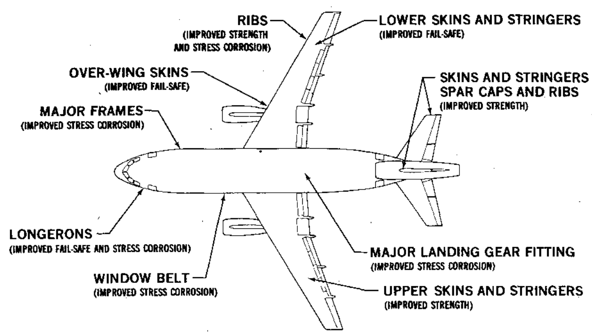

Fig. 8 Advanced metallic applications.

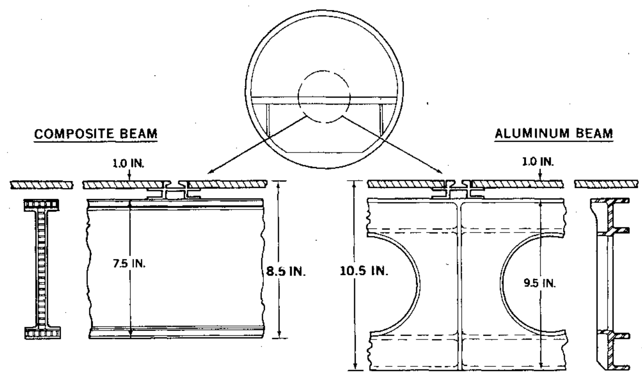

Fig. 9 Composite floor beams.

reduce aircraft propulsion noise. Studies indicate that substantial weight and fuel saving can be achieved by the use of advanced composite nacelles. In addiion, a reduction of both takeoff and approach sound levels is indicated (Fig. 6).

In order to reduce costs, increased emphasis is being placed on reducing the total engine life-cycle maintenance costs. For this effort to be effective it must involve both the engine and airframe manufacturers, as well as the airlines. The airlines can make a very substantial contribution by providing an accurate data base reflecting the cost experience of the present low- and high-bypass-ratio engines. These data will assure that the necessary trade studies involving advanced technology, propulsive efficiency, and costs are carried out realistically, reflecting the requirements of the airlines for increased productivity, greater fuel efficiency, and lower costs.

The engine manufacturer has the fundamental role in reducing engine life-cycle maintenance costs through excellence in design. One attractive approach is reducing the number of parts; another is considering life-cycle maintenance costs during the engine cycle and material selection studies for new advanced engines. A further area in which improvements in both operational efficiency and life-cycle maintenance costs are necessary is in the thrust-reversing system.

The development of electronic engine controls is very attractive, since this advanced system will permit more precise engine control, which, in turn, will result in reduced maintenance costs as well as savings in fuel. Furthermore, electronic engine controls provide system redundancy at low cost and low weight. Future improvements in engine specific fuel consumption will be difficult to obtain, but when achieved, there should be a balance between the fuel saved and the increased engine maintenance costs.

The airframe manufacturer also has an important role in advanced engine development, since engine advances are basic to improving aircraft productivity, increasing fuel efficiency, and reducing costs. A new approach will go a long way toward achieving the improved engine/airframe productivity and efficiency required for future commercial transports.In the past, the engine and airframe technologies were developed in semi-isolation, with a few traditional interfaces. There is the need for closer teamwork in future propulsion system development. The engine should be considered to be an integral part of the aircraft. Goals for the "future cost of ownership" must be established. Engine cycle selection and design concepts must reflect a balance between advanced technology required for reduced fuel consumption and consideration for reduced maintenance costs.

Structures

Advanced structural concepts will make major contributions to the large long-range subsonic transports that will be operational in the 1990's. These concepts will result in airplanes that are not only more economical, but also more efficient users of energy. Advanced structural concepts will make possible a reduction in the complexity of aircraft structural concepts. Present aircraft consist of a myriad of individual parts, much riveting, and a large number of machined components. Studies indicate that the number of structural components can be reduced by about 12%, with a resulting weight reduction of about 8%, and a cost reduction. The use of integrally machined panels can result in a radical reduction in the number of fuselage parts, with a small reduction in fuselage weight. In addition, the fuselage diameter can be reduced by as much as 5.0 in., with the same interior cabin width, by the use of these panels in the window belt area (Fig. 7). An additional advantage of the integrally machined panels is the reduction in overall fuselage diameter with reduced wall thickness. This yields a reduction in fuselage surface area and, therefore, skin-friction drag.

New advanced aluminum alloys also will make significant contributions to future aircraft designs. These alloys are tougher, have improved stress and corrosion resistance, but have equal or improved strength. It is anticipated that these advanced alloys will be used throughout future airplanes (Fig. 8). Although some small weight saving will result, the main impact of these new materials will be to improve the service life of the structure significantly. This will be reflected in reduced inspection and maintenance costs, as well as increased productivity.

Advanced Composite Materials

A new class of recently developed materials called advanced composites opens the possibility of significant reductions in aircraft structural weight. Reduction of structural weight is a direct route to increased fuel efficiency and reduced operating costs. Composite materials have been studied for several years with increasing encouragement. Although composite structures now are more expensive than those of conventional aluminum, they offer the potential of very large structural weight reductions. The major portion of this benefit will come from their use in primary structures. Development of the material and design techniques for their use, leading to the demonstration of adequate reliability for a 50,000-flight-hr life, presents a formidable challenge. However, their weight-reduction potential will make these materials important to the next new commercial aircraft. Aircraft manufacturers now are obtaining service experience by replacing conventional parts on present aircraft with advanced composite test sections in secondary structural areas.

There is a current program to develop, test, and fly composite rudders for the DC-10. The body of this rudder, involving the structural torque box, the spar, and all of the ribs is laid up in one piece of graphite epoxy. The weight of this rudder, as expected, is significantly less than the equivalent aluminum unit. The reduced rudder weight also requires less dynamic balance weight, thus further reducing the weight of the rudder system. This is a particularly effective application from both a weight saving and cost standpoint. A composite rudder may well be adopted for DC-10 production following completion of the test and evaluation program.

Currently, landing gear doors, ailerons, spoiler, elevators, and floor beams are being considered as other prime candidates for advanced composite materials. Composite floor beams will not only save weight, but also will reduce the fuselage cross section and, hence, airplane drag (Fig. 9). The use of composites in a few years may become cost competitive with aluminum because of improved manufacturing methods, lower material costs, and the need for fewer parts and fewer manufacturing assembly tools. Advanced design studies indicate that the operating costs of the next generation of commercial transports can be reduced by as much as 15%, depending upon fuel costs, with the use of advanced composite materials.

Longitudinal Stability Augmentation

The advent of control-configured aircraft has led to the study of the economic advances that may be achieved by the use of stability augmentation. If the stability margin is reduced to neutral longitudinal stability, and this neutral stability then is augmented to provide the normal commercial aircraft stability requirements, there will be substantial benefits in terms both of reduced aircraft weight and drag. Compared to an airplane with conventional stability, an airplane with neutral stability has its wing moved forward and the size of its horizontal tail reduced (Fig. 10). Trim drag is reduced by operating the aircraft with the center of gravity further aft, and a reduction in skin-friction drag is obtained because of the smaller area of the horizontal tail. The combined effect of reduced tail weight and reduced drag yields a reduction in direct operating cost of approximately 5%. Even larger improvements are possible for designs with negative unaugmented stability. However, in the near future it is deemed advisable to maintain at least neutral stability. This is to assure that the aircraft will be easily manageable in case the augmentation system fails. This advance in control technology should be considered with the advances in aerodynamics and structural materials as a potential means of obtaining better aircraft economics and increased fuel efficiency.

Avionics

Avionics for the aircraft of the 1990's will assume a role of more fundamental importance than has been the case for present aircraft. This will be brought about by the evolutionary advent of control-configured aircraft and the use of highly automated cockpits. The first step in the introduction of commercial transports incorporating control-configured technology will be aircraft with reduced static stability. The active control system will supply full-time stabilization to augment the basic aerodynamic stability. The primary means for the pilot to provide the inputs to the airplane's control surfaces will be by a multiple redundant electronic flight control system with a mechanical backup system.

The configuration of the computational elements in all of the avionics systems, but especially those for the flight

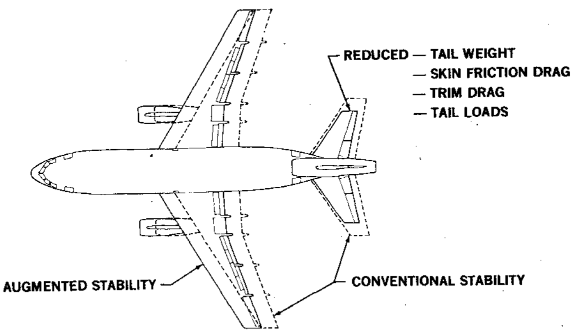

Fig. 10 Longitudinal stability augmentation benefits.

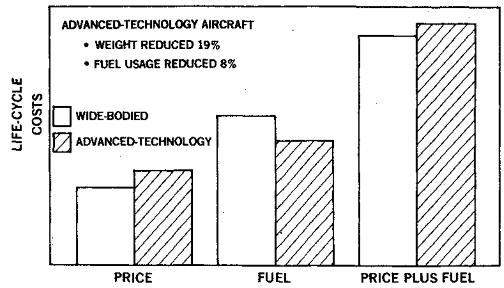

Fig. 11 Wide-bodied vs advanced-technology aircraft—total life-cycle costs—small market—fuel at 35¢/gal.

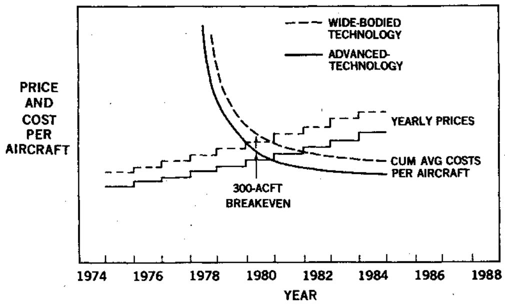

Fig. 12 Wide-bodied vs advanced-technology aircraft pricing and cost—500-aircraft market.

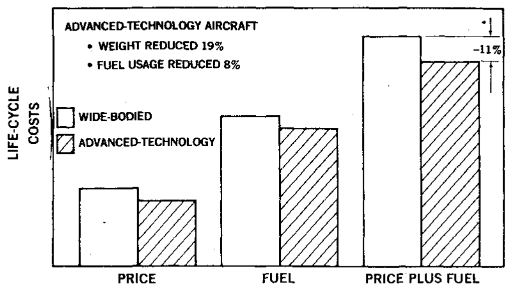

Fig. 13 Wide-bodied vs advanced-technology aircraft—total life-cycle costs—500-aircraft market--fuel at 35¢/gal.

guidance system, will be determined by the rapidly developing digital computer technology. These advances will impact both the hardware and the software. The avionics system will be based upon a network of microprocessors communicating by means of common buses. The advantage of such a system is the lessening of the probability of a major software failure that might defeat the built-in redundancy of the system. Under a system operation such as data acquisition, digital filtering and formatting become parallel operations, with the mainstream functions. This arrangement increases the available speed of the overall computer cycle, as well as making the development of the software more manageable. In addition, there will be increased use of multiplex techniques in new aircraft design to reduce aircraft wiring substantially, with the resulting reduction in airplane weight as well as improvement in system reliability. Not only will multiplexing be used, as in the present generation of wide-bodied aircraft, for the passenger service and entertainment systems, but also for data transfer within the flight guidance, electrical power control, and the environmental control systems.

Advanced Subsonic Transport

In the current economic environment, the question arises as to the feasibility of launching an all-new aircraft program incorporating advanced technology. The energy crisis, recent antiinflationary monetary and fiscal policies, and the current downswing of the business cycle have combined to produce a serious recession, which has postponed temporarily the demand for commercial transport aircraft. The long-term health of the air transportation industry is guaranteed, however, since world revenue passenger-miles are expected to increase almost four times between 1975 and 1995.

The present wide-bodied jets and their derivatives will not be superseded for many years, because their characteristics match the long-term market requirements. Most of the airlines already have committed themselves to these aircraft; therefore, the remaining uncommitted market is small. The premature retirement of the present generation of wide-bodied jets would result in a reduction of the book value of these aircraft, thereby impairing the ability of the airlines to raise the necessary capital to finance new programs.

The significant technology advances that have occurred since the current generation of transport aircraft was designed in 1968 are available for application to new transport aircraft. However, this technology does not represent a threat to current wide-bodied aircraft because of the relatively small size of the remaining uncommitted market. As shown by computer cost models, the necessity of pricing the new advanced aircraft at a relatively low break-even quantity more than offsets the cost reductions provided by advanced technology (Fig. 11). The fuel saving does not counterbalance the higher price of the advanced aircraft when these two major components of life-cycle costs are examined. Future growth in travel demand on the routes now served by wide-bodies aircraft therefore can be expected to be served by wide-bodies aircraft therefore can be expected to be served in the next decade by existing designs and their even more efficient derivatives. However, for routes now served by older-technology narrow-bodies aircraft, and for potential new routes, as well as for new operations resulting from the energy crisis, there could be a substantial demand appearing for efficient aircraft having payload-range combinations different enough from current wide-bodied aircraft to justify a new aircraft program. The cumulative average cost for such an airplane has been computed by use of cost models (Fig. 12). A new advanced technology airplane, having a large market and a break even point of 300 aircraft has shown a significant life-cycle cost reduction of almost 11% (Fig. 13). These costs were based on an advanced technology aircraft weight reduction of 19% and a fuel usage advantage of 8%. The actual gains might be greater.

Not only are the present narrow-bodied aircraft relatively inefficient users of fuel, they also are noisier than present wide-bodied jets with high bypass engines. The economic advantages to be gained by substituting advanced technology aircraft for narrow-bodied aircraft therefore, will be even greater than the amount calculated by the cost models. In summary, the present wide-bodied jets and their derivatives will have a very long and profitable life. When the general economic environment turns upward, a promising future lies ahead for achieving improved air transportation economics and increased aircraft fuel efficiency through the judicious application of advanced technology. "We should all be concerned about the future because we will have to spend the rest of our lives there." Charles Kettering.