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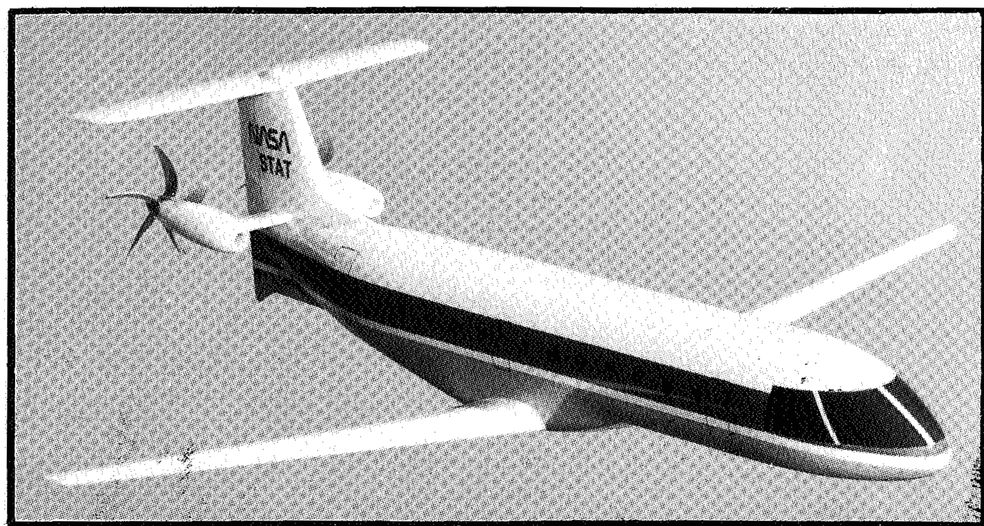
SMALL TRANSPORT AIRCRAFT TECHNOLOGY



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SMALL TRANSPORT AIRCRAFT TECHNOLOGY

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Foreword

During the development of this report on small transport aircraft technology (STAT), some questions were raised concerning the most effective mechanisms for providing the advanced-technology knowledge and expertise needed by the U.S. commuter aircraft manufacturing industry (primarily the general-aviation firms) to allow the development of a significantly improved new generation of commuter aircraft for introduction near the end of this decade. Since U.S. industry is behind in the present round of commuter aircraft development, it must introduce considerable technological improvements and refinements in the next round of new aircraft in order to compete successfully with the aggressive foreign competition.

In view of this situation, several manufacturers have expressed great interest in a variety of technological advances, but have indicated an inability to acquire the needed technology on their own. The consensus of both the government and industry representatives involved in the STAT studies was that this industry must continue to depend in large part on government research and technology transfer in the next few years (as it has in the past) for the evolution of practical advances in most aeronautics technologies. This industry does not have the technical staffs and facilities for research, nor can it afford to assume the financial risks (particularly in the present business climate) of initiating new aircraft developments based on unproven or unfamiliar technology that is significantly advanced beyond present practices and experience. Despite the sometimes apparent plausibility and attractiveness of doing so, the risks are normally much too great for established firms. To complicate matters, most of the foreign firms in competition for new commuter aircraft markets are heavily supported by their national governments, not only in research and technology but also in product development, production, and marketing. In reality, U.S. firms must compete in this market with foreign governments, not merely with foreign firms.

The question of whether the government can or should conduct research specifically directed at improved commuter transports, particularly in the face of needs for overall reductions in federal expenditures, lies outside the scope of the STAT study activities, and is beyond NASA's authority to resolve. Yet this question and others that stem from it are extremely important, not only because they impact NASA budget decisions but also because of their bearing on national and industrial policies relative to the future of the U.S. aircraft industry. Related questions are: How important is it to U.S. interests to have a strong, high-technology-based small-transport industry? Is it possible for that industry to achieve the necessary technological capability to match foreign-government-backed competition without the help of our own government in research? How can the U.S. government best assist our industry in its attempt to compete with the impressive foreign competition in commuter aircraft? Are cooperative efforts possible, or should government take no action at all? While the government debates the issues of small-community air service, many dollars are being spent to subsidize essential air service, finance imports of foreign aircraft, and contend with reduced levels of service between many smaller communities.

The resolution of these issues is clearly outside NASA's purview. However, given adequate resources, there are some key elements that are fully within NASA's charter, responsibility, and areas of expertise. These key elements involve the development of the advanced technology necessary to allow manufacturers to build significantly improved commuter/regional transport aircraft. The identification of the most promising advanced-technology areas and their improvement is the subject of this report.

Contents

Introduction

On May 10, 1978, in the report on the NASA Authorization for Fiscal Year 1979, the U.S. Senate Committee on Commerce, Science, and Transportation stated that it perceived a problem in air service between smaller cities and major hubs; that is, in the commuter-type small-community air transportation. The Committee recognized the fact that one factor inhibiting public acceptance and use of commuter air transportation was the technological lag between commuter aircraft and the equipment used by the major civil air carriers. In an effort to address this problem area, the Committee requested that NASA, in consultation with the Department of Transportation and the Civil Aeronautics Board, prepare a comprehensive report on the subject of technical improvements in commuter aircraft which would likely increase their public acceptance and use, including an assessment of whether NASA's aeronautics research and development program could help commuter aircraft manufacturers solve these technical problems related to passenger acceptance and use.

To deal with these questions, NASA formed a small transport aircraft technology (STAT) team to conduct the necessary studies and analyses. These activities were undertaken in consultation with the Department of Transportation, the Federal Aviation Administration, and the Civil Aeronautics Board. NASA also consulted with many potential U.S. commuter aircraft manufacturers, commuter and local-service airlines (recently designated regional and national airlines, respectively), and other interested organizations. Investigations focused on 19- to 50-passenger aircraft, since indications were that the greatest future markets would exist for larger commuter aircraft, and that these aircraft might derive the most benefit from advanced technologies. A preliminary report on the STAT team findings, published in October 1979 (ref. 1), outlined advanced technologies whose application had the potential to improve commuter transport aircraft of the future. This report also included background information on the commuter and short-haul local-service air carriers, the regulations pertaining to their aircraft and operations, and the overall airline system interfaces.

In November 1980, an Ad Hoc Subcommittee of the NASA Advisory Council (NAC) Aeronautics Advisory Committee was convened to review the study results available at that time. The Subcommittee was made up of representatives from industry, universities, and government. The conclusions and recommendations of the Subcommittee provide a basis for evaluation of the study results and research recommendations presented herein. (The full report of the Subcommittee appears at the back of this publication.)

The present report provides updated information on commuter airline trends and aircraft developments, and presents the results and conclusions of the full set of completed STAT studies. These studies were performed by five airplane manufacturers, five engine manufacturers, and two propeller manufacturers. The report also summarizes those portions of NASA's overall aeronautics research and technology programs which are applicable to commuter aircraft design, and suggests areas of technology that might beneficially be expanded or initiated to aid and encourage U.S. commuter aircraft manufacturers in their evolution of improved aircraft for this market.

This publication represents the culmination of substantial efforts by many people over the past several years. Although many of these contributors are identified in the reference list, particular acknowledgement should be given to Thomas L. Galloway, NASA Ames Research Center; William C. Strack, NASA Lewis Research Center; Robert E. Bower, NASA Langley Research Center; and Harry W. Johnson, NASA Headquarters.

Commuter Airline Growth

The commuter airlines (designated as regional airlines by the Civil Aeronautics Board in 1981) have experienced high growth rates during the last 3 years. It is anticipated that this strong growth will continue as the deregulated U.S. air transportation system is reshaped to contend with substantially higher fuel prices. The transition of the U.S trunk airline fleet from piston to turboprop to jet-powered transport aircraft was conducted primarily when fuel was an inexpensive, seemingly inexhaustible commodity. Jet transport aircraft offered major improvements in speed, comfort, reliability, and productivity relative to the older technology piston and turboprop aircraft they replaced. This transition to jet transport aircraft has also taken place at a more gradual pace in the fleets of U.S. local-service airlines. Currently, over three-fourths of the aircraft operated by the local-service airlines are jet powered and have passenger capacities above 100 passengers.

The average daily fuel usage by fight length for the jet transport aircraft used by the U.S. scheduled carriers (ref. 2) shows the dominance of fuel usage in short-haul operations by the smaller two- and three engine jet transport aircraft (fig. 1). This fuel usage distribution (fig. 2) shows that 24 percent of the fuel used is for flights less than 500 miles in length. Another 23 percent is used for flight operations between 501 and 1000 miles in length. An examination of fuel usage by aircraft type shows that over 54 percent of the total commercial jet transport fuel is used by the two-engine Boeing 737, McDonnell Douglas DC-9, and British Aerospace BAC 111 aircraft and the three-engine Boeing 727 aircraft. For stage lengths of less than 500 miles, these two- and three-engine jet transports account for over 87 percent of the U.S. jet transport fuel usage.

Unfortunately, jet transport aircraft are less energy efficient than propeller-driven aircraft for short flights. On longer flights the speed and altitude capability of the jet engine can be used more effectively (ref. 3 and fig. 3). This reduced efficiency is particularly evident for short-haul flights of less than 500 miles. The reduced fuel efficiency of jet transport aircraft for short-haul service was tolerable at cheap fuel prices. However, from 1973 to 1981 the average price per gallon of jet fuel for the U.S. trunk airlines increased from 13 cents to over 103 cents (fig. 4). These fuel price increases show up very directly in aircraft operating cost and have significantly altered the relative importance of the direct operating cost (DOC) elements. In 1973, fuel accounted for about 25 percent of the direct operating cost for a Boeing 727-200 aircraft. By 1978 this percentage had risen to 40 percent, and in 1979 it was over 50 percent. The influence of fuel price on the average direct operating costs for the U.S. trunk airline fleet (ref. 4) dramatically illustrates its dominance since 1973 over the other operating cost elements (fig. 5).

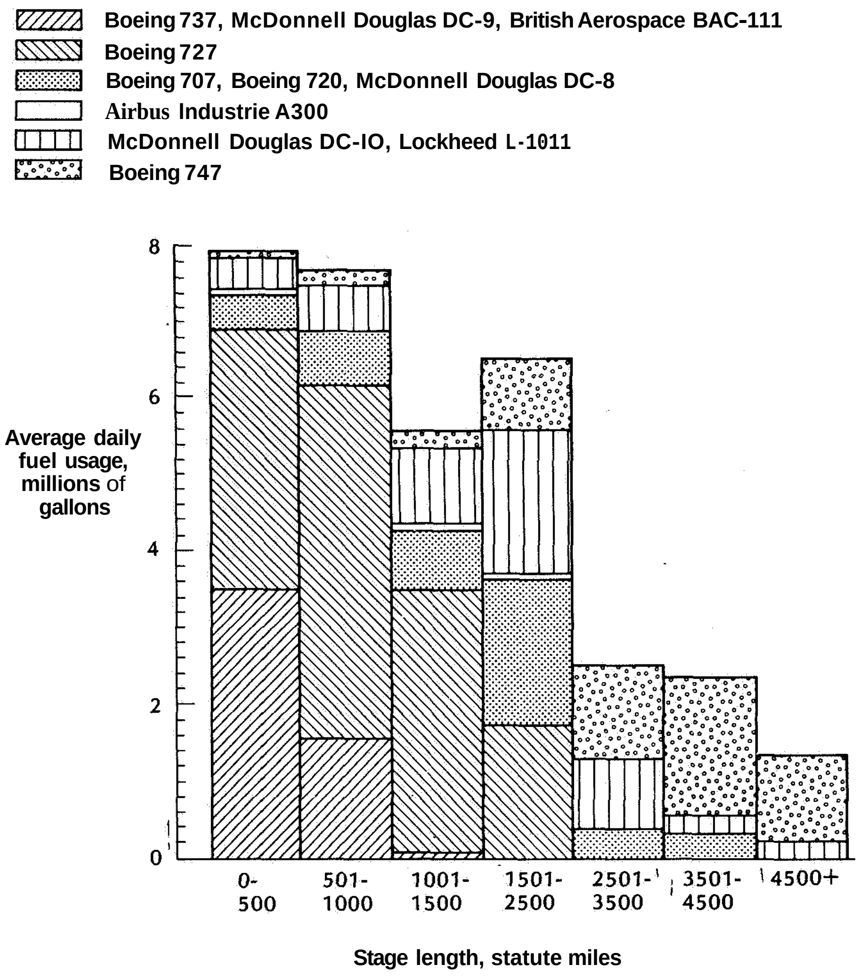


Figure 1.-Average daily jet transport fuel usage for February 1980 for domestic and international operations of U.S. scheduled carriers.

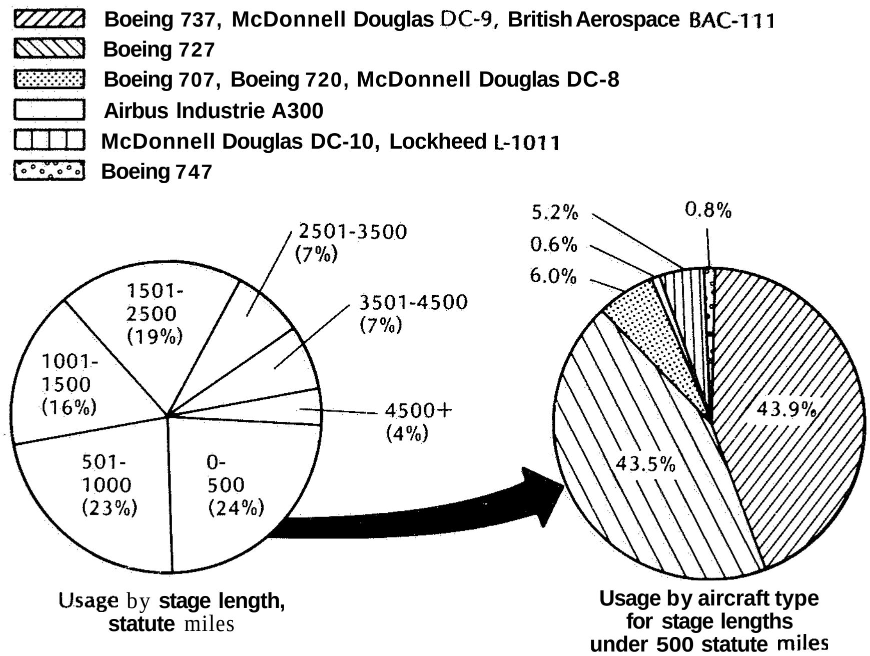


Figure 2.- Average daily jet transport fuel usage distribution for February 1980 for domestic and international operations of U.S. scheduled carriers. Data taken from reference 2; calculations by David E. Winer, FAA.

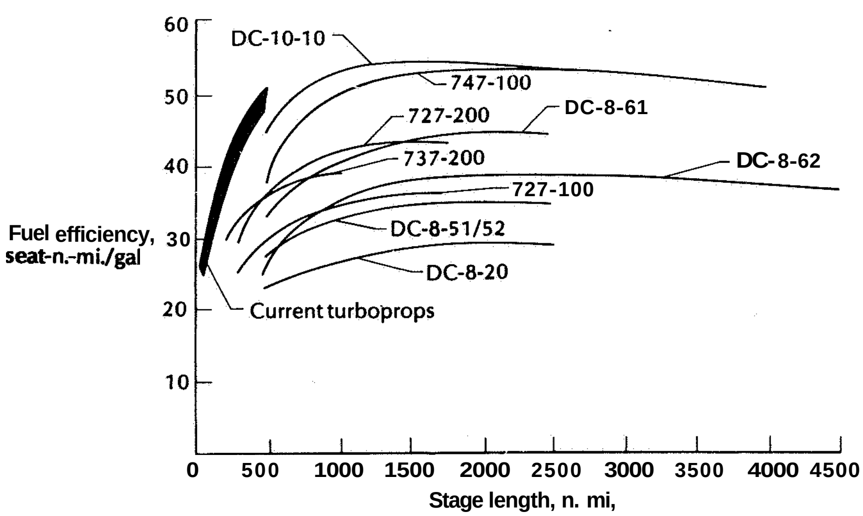


Figure 3.- Aircraft fuel efficiency for aircraft operation at different stage lengths.

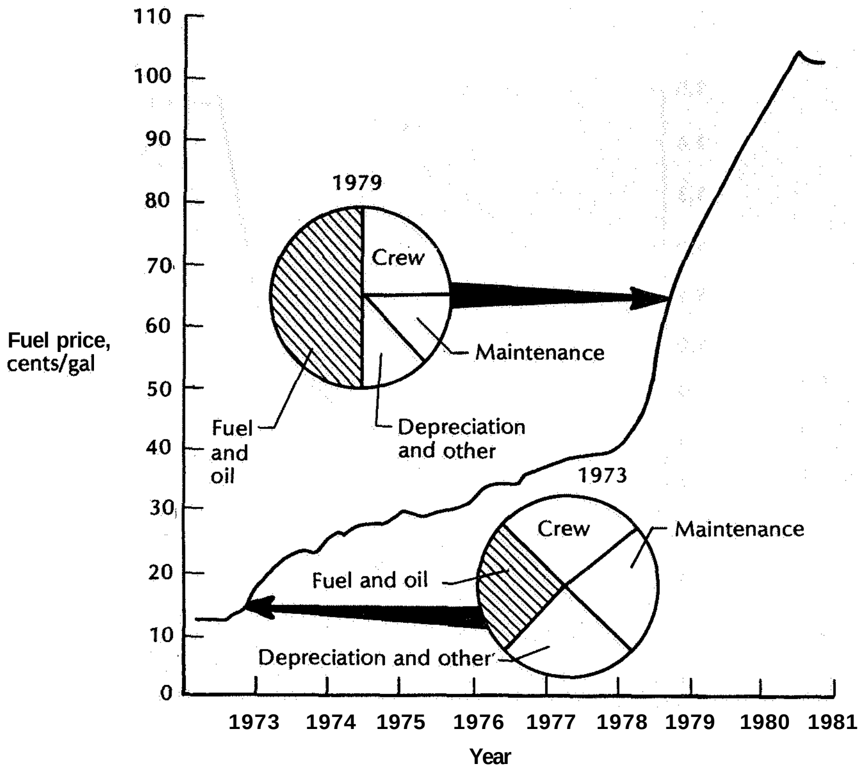


*Figure 4.- Monthly average ofjetfuelprice and associated **DOC**fractions for U.S. trunk airline domestic operations of Boeing 727-200 aircraft.*

Because fuel costs are expected to continue to dominate aircraft operating cost, increasing aircraft fuel efficiency has become the major new transport design objective, and the airlines have also implemented efficiency improvement strategies with existing aircraft Much attention is being applied to operating the existing aircraft as efficiently as possible, and consequently the jet transport aircraft are being moved to longer, higher density routes where they are more efficient and more profitable (fig. 6). The transition has been most noticeable since deregulation, which has allowed more freedom of airline route selection and has thus resulted in major shifts in airline service schedules, routes, and type of equipment being used (ref. 5).

In response to the airline service transition, the U.S. commuter airlines have expanded their operations in order to provide service on the short-haul lower density routes abandoned by the trunk and local-service airlines. The resulting rapid growth in commuter airline service (fig. 7) has made this the fastest growing segment of air transportation. In 1979 commuter airline activity increased by 27 percent in passengers carried and 18 percent in cargo (ref. 6). In 1980 commuter airlines continued to grow by 6 percent in passengers carried, while the trunk

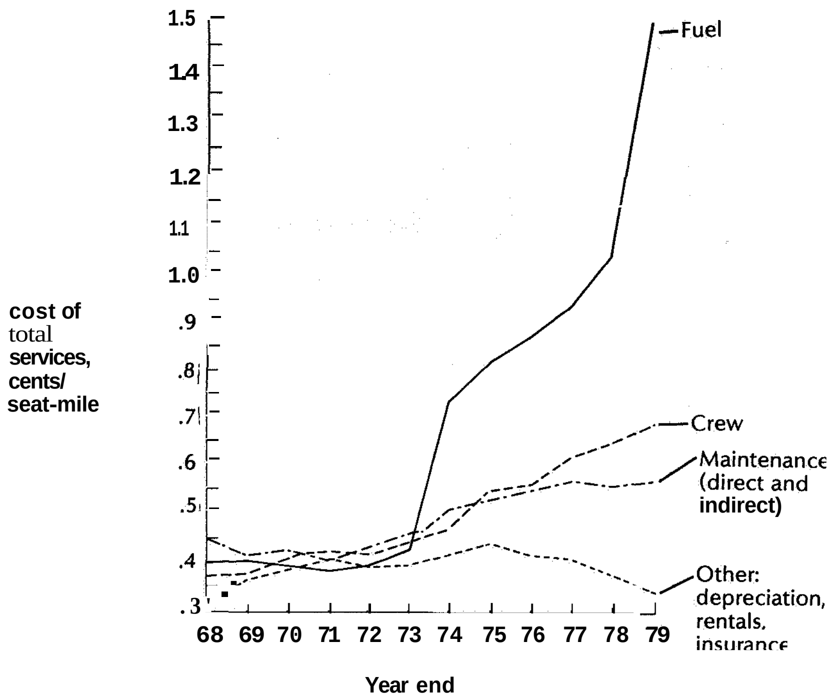


Figure 5.- Influence of fuel prices on direct operating cost elements for U.S. trunk airlines.

airlines decreased by 10 percent. With the combined effects of deregulation, high interest rates, unsettled economic conditions, and air traffic control capacity limitations, 1981 was a very turbulent year for all airline operators.

Commuter airlines have also been affected by the reduced and uncertain major airline schedules, which directly impact the demand for connecting travel. Many commuter airlines have suffered severely under these conditions because they are smaller and do not have the financial resources necessary to survive a prolonged difficult period. Also, the recent expansion of commuter activity attracted some new investors who lacked airline experience, moved into markets that could not support their operations, and ultimately failed, in some cases carrying other previously successful small airlines down with them. However, even with this generally unfavorable operating environment, reported traffic for 62 large regional and small regional/commuter domestic airlines increased by 17 percent in passengers carried and 32 percent in revenue passenger miles during the first 9 months of 1981 (ref. 7). During this same period, the amount of cargo carried by these airlines plus 10 U.S. commuter cargo carriers increased by 23 percent (ref.

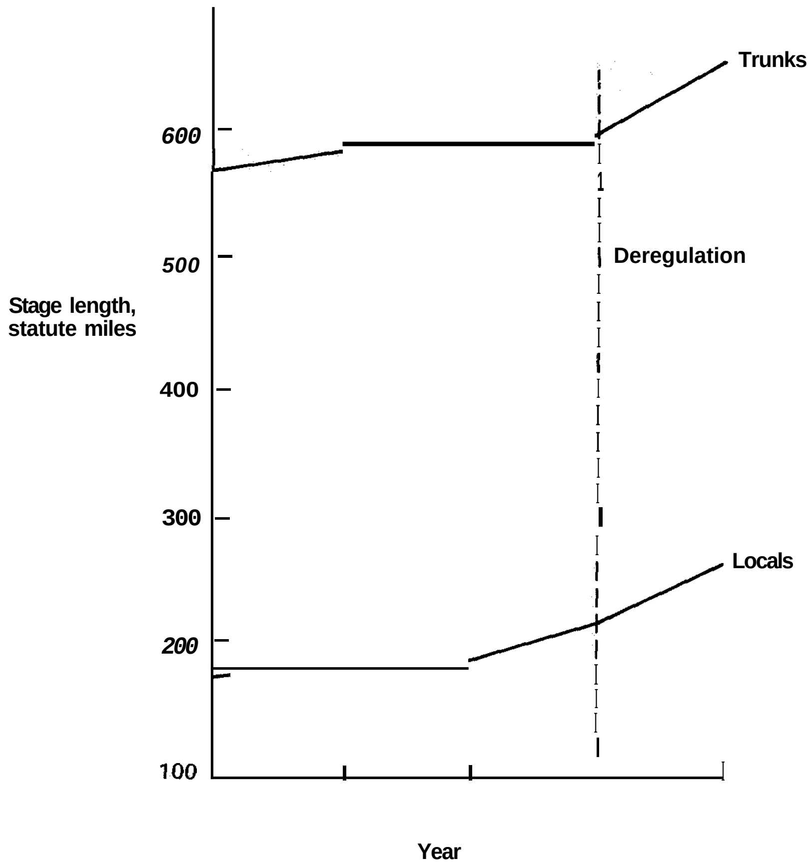


Figure 6.- Average stage length for U.S. trunk and local-service carriers.

7). In 1981 there were 259 commuter airlines operating in the 50 states plus Puerto Rico, the U.S. Virgin Islands, Guam, and American Samoa, These 259 commuter airlines operated a total of 1676 aircraft, of which 1436 aircraft were in passenger service (ref. 8). This represents an increase of 85 aircraft from 1980. In 1981 the average number of seats per passenger aircraft was 16, compared with 14.8 in 1980 (ref. 8).

The transition to commuter airlines using smaller aircraft for short-haul air transportation is evident at most airports. The dramatic expansion in short-haul service with turbopropppowered commuter aircraft represents a remarkable change in the last few years, particularly since these aircraft are so different from the larger jet transports to which the public has become accustomed.

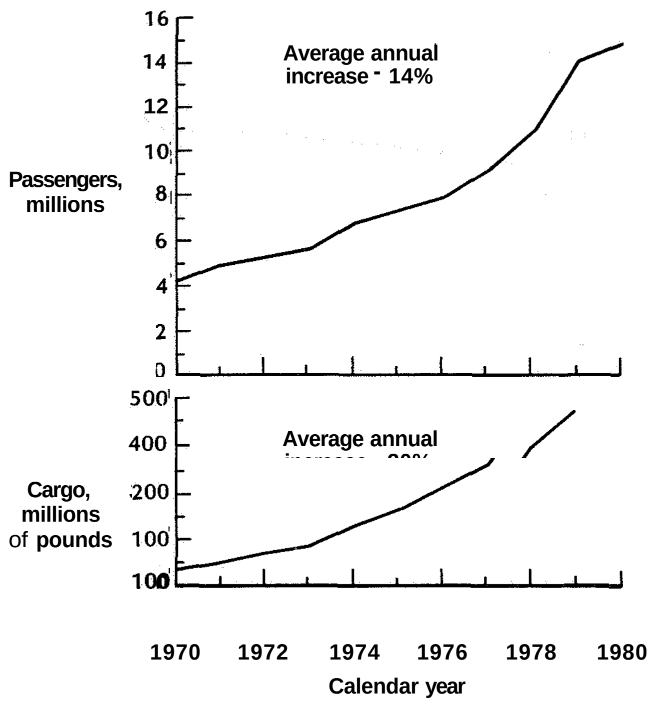


Figure 7.- Commuter airline growth from December 1970 to December 1980. (Note: 1979 values include carriers that were commuters in 1978 and obtained certificates in 1979.)

Current Commuter/Regional Aircraft and New Aircraft Under Development

The evolution of the commuter airline fleet by aircraft type (refs. 6 and 8 to 11) indicates the dominance of multiengine piston and turboprop aircraft (fig. 8). In 1981, in terms of numbers of aircraft, 47 percent of the fleet was made up of multiengine piston aircraft and 37 percent consisted of turboproppowered aircraft Single-engine piston aircraft accounted for a relatively constant 13 percent of the fleet, turbojets accounted for 2 percent, and helicopters made up less than 1 percent. Because the turboprops are usually larger than the multiengine piston aircraft, they accounted for 63 percent of the fleet's available seating capacity in 1981.

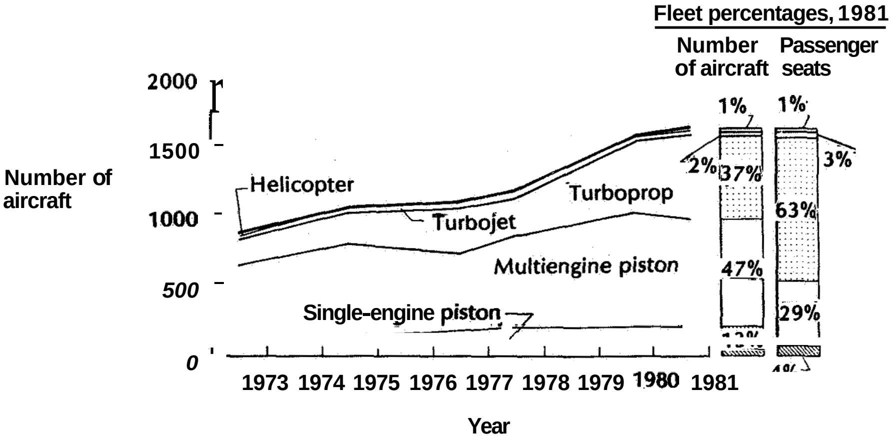


Figure 8.- Commuter airline fleet evolution by aircraft type.

Some examples of current commuter aircraft are shown in figure 9. Although they represent older technology and some sacrifices in passenger comfort, these aircraft use 15 to 20 percent less fuel per seat mile at short stage lengths than the larger jet transports they are replacing. This efficiency improvement, coupled with the smaller aircraft's ability to provide a better match with passenger demand, results in a significant improvement in overall system efficiency. The technology levels of the commuter aircraft being produced currently are representative of conventional riveted skin-stringer aluminum construction, 1960's engine technology, 1930's and 1940's airfoil designs, and conventional wing-body-tail configurations.

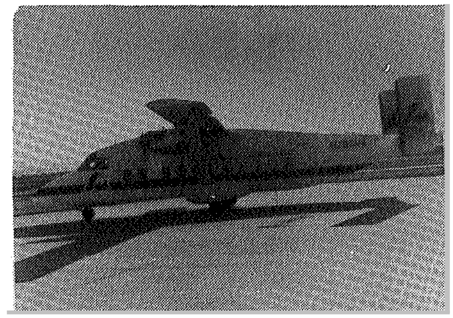
The expanding U.S. commuter market that has resulted from the restructuring of the large jet transport market has caused the introduction of increasing numbers of small commuter transports, primarily foreign built. In 1981, 42 percent of the

de Havilland DHC-6 Twin Otter — First flight 1965
19 passengers

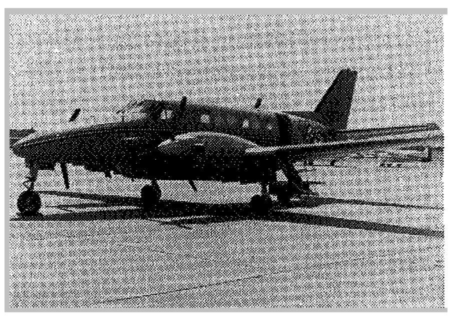
Fairchild Swearingen SA-227AC Metro II — 1969
19 passengers

Figure 9.- Typical current commuter aircraft.

Embraer EMB-110 Bandeirante 1972
18 passengers

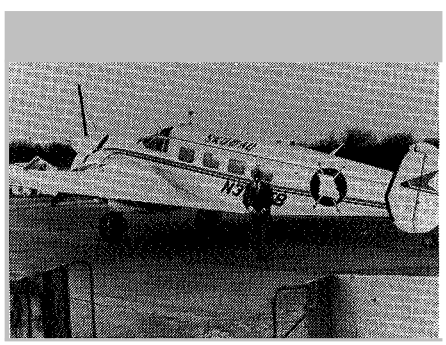


Shorts 330 1974
30 passengers



Beech B99 1966
15 passengers

British Aerospace HS 748 1960
50 passengers



Beech 18 First flight 1937
9 passengers

de Havilland Dash 7 1975
50 passengers

Figure 9.- Concluded.

commuter airline passenger seats were in foreign-built aircraft (fig. 10). The changes in the commuter airline fleet (for aircraft with 15 or more passenger seats) that took place from 1980 to 1981 (table 1) are indicative of the strong shift toward more foreign aircraft. During this period a net fleet increase of 89 aircraft took place; 12 of these aircraft were U.S. built and 77 were from foreign manufacturers. In terms of available passenger seats, the net changes resulted in the addition of 88 seats in U.S.-produced aircraft and 2306 seats in foreign aircraft. This shift will probably continue as the older U.S.-produced aircraft that are no longer in production (e.g., the Convair 440, 580, and 600, Douglas DC-3, and Martin 404) are replaced by new, primarily foreign aircraft. The new-production aircraft fleet additions from 1980 to 1981 (table 2) involved 40 U.S.-produced aircraft with 696 passengers seats and 79 foreign aircraft with 2383 seats.

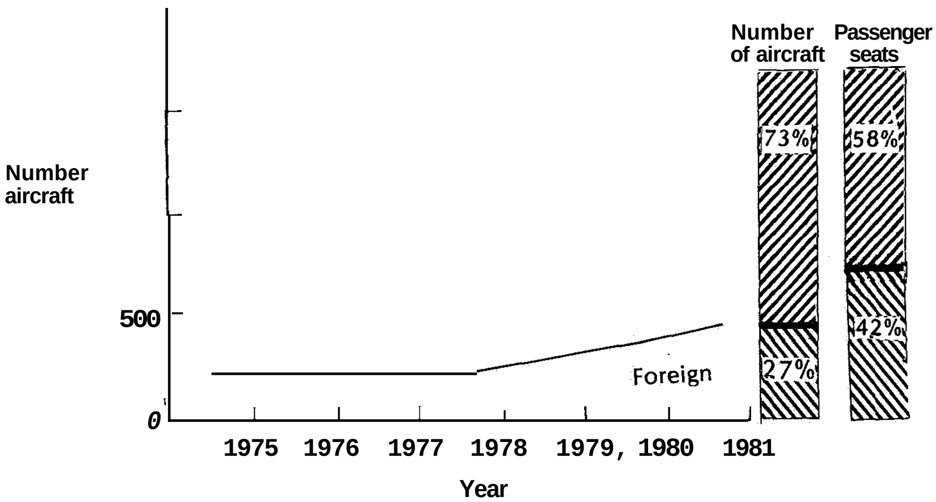


Figure 10.- Commuter airline fleet trends by manufacturer origin.

The current successes of foreign commuter aircraft in the U.S. market are due not necessarily to technological superiority but primarily to the fact that they were available when U.S. products were not. Continued foreign manufacturer commitment in this area is evidenced by the wave of new aircraft developments that should enter the fleet in the early and middle 1980's. Future foreign dominance of the commuter market for aircraft is evidenced by the commitments (announced orders or purchases) for $1.65 billion in commuter aircraft (announced by U.S. commuter/regional airlines) from 1978 through 1985. Based on data supplied by the Regional Airline Association of America in May

TABLE 1.- COMMUTER AIRLINE FLEET CHANGES FROM 1980 TO 1981

[Aircraft with **15** or more passenger seats]

Aircraft	Country of Origin	Typical Passenger Capacity	Operation 1980	Operation 1981	Change No.	Change Passenger Seats
Beech B99	U.S.	15	102	94	− 8	− 120
Handley Page HP 137	UK	18	16	16	0	0
CASA C-212	Spain	28	2	10	+ 8	+ 224
Convair 440,580,600	U.S.	44-50	76	68	− 8	− 376
de Havilland DHC-6	Canada	19	97	109	+12	+ 228
de Havilland Dash 7	Canada	50	15	33	+18	+ 900
Douglas DC-3	U.S.	28	49	51	+ 2	+ 56
Embraer EMB-110	Brazil	18	28	49	+21	+ 378
Fairchild Hiller F-27, FH-227	U.S.	46	13	12	− 1	− 46
Fokker F-27	Netherlands	50	7	6	− 1	− 50
Fokker F-28	Netherlands	85	5	8	+ 3	+ 255
GAF N24A	Australia	16	4	12	+ 8	+ 128
Gulfstream American Gulfstream IC	U.S.	37	0	2	+ 2	+ 74
Martin 404	U.S.	44	20	21	+ 1	+ 44
Mohawk 298	France	25	8	8	0	0
Nord 262	France	27	19	18	− 1	− 27
Shorts 330	UK	30	35	44	+ 9	+ 270
Swearingen SA-226TC Metro II	U.S.	19	103	127	+24	+ 456
Totals:	U.S.		363	375	+12	+ 88
	Foreign		236	313	+77	+2306
Grand total			599	688	+89	+2394

1982, $1.43 billion of this total is for foreign-manufactured aircraft, and **$1.31** billion is for foreign aircraft (including the Saab-Fairchild **340)** for which there are no U.S. equivalents.

Although this report concentrates on the expanding market and technology requirements for commuter aircraft with capacities greater than **19** passengers, smaller aircraft are also an important part of the overall commuter fleet. The U.S. manufacturers continue to provide most of the small commuter-size aircraft (**19** seats or less). Of the small-commuter orders through **1985, 65** percent of the dollar value is for U.S.-manufactured aircraft. In **1981,** over **40** percent of the commuter fleet (**732** aircraft) and **22** percent of the passenger seats (ref. **8)** were provided by aircraft with under **10** passenger seats. Most of these aircraft were

TABLE 2.- NEW AIRCRAFT ADDITIONS TO COMMUTER AIRCRAFT FLEET FROM 1980 TO 1981

[Aircraft with 15 or more passenger seats]

Country of origin	No. of new aircraft added	Aircraft model	Total increase
U.S.	16	Beech C99	40 aircraft
	24	Swearingen Metro II	(696 seats)
Spain	8	CASA C-212	
Canada	12	DHC-6	
	18	'Dash 7	79 aircraft
Brazil	21	EMB-110	(2383 seats
Netherlands	3	F-28	
Australia	8	N24A	
UK	9	Shorts 330	

produced by the Cessna Aircraft Company (47 percent) and the Piper Aircraft Corporation (42 percent).

During 1981, in order to strengthen its position in supplying the smaller commuter aircraft, Piper established a new commuter division to provide special service support and introduced two new nine passenger unpressurized airplanes. The Piper T-1020, which has two Lycoming piston engines, is a derivative of the unpressurized Piper Navajo/Chieftain design. The Piper T-1040, powered by two Pratt & Whitney of Canada PT6A-11 turboprop engines, is a more extensive development which combines the wing, nacelles, and engines of the Piper Cheyenne with the fuselage of the Piper Chieftain.

Listed in table 3 are some of the characteristics of the improved or new aircraft designs under development (as of June 1982) in the 15- to 60-passenger size range, along with their estimated date of first airline delivery and projected price in 1981 dollars (refs. 12-14). At least 13 aircraft manufacturers, including 6 in the U.S., are now developing new aircraft designs or modifications to existing aircraft (9- to 60-passenger capacity) for introduction into service by 1985. Several plan to use all-new or uprated turboprop engines now being developed by three companies: the Garrett Turbine Engine Company, the General Electric Company, and Pratt & Whitney Aircraft of Canada Ltd., United Technologies Corporation. The commuter/regional transports scheduled for introduction in the near term (1981 to 1983) (fig. 11) and in 1984 and 1985 (fig. 12) represent a considerable amount of industry activity.

TABLE 3.- COMMUTER/REGIONAL AIRCRAFT IN DEVELOPMENT

[19 to 60 passengers]

Aircraft	No. of Passengers	Engine type (a)	Cruise speed, knots	Cabin height in.	Maximum cabin pressure differential psi	Estimated first delivery	Price, 1981 $'s, millions
Beech 1900	19	2 PWC PT6A-65B	265	51	4.8	1983	1.6
BAe Jetstream 31	19	2 GA TPE331-10	263	71	5.5	1982	2.2
Shorts 360	36	2 PWC PT6A-65R	211	78	0	1982	3.7
Domier Do 228-200	19	2 GA TPE331-5	200	61	0	1982	1.5
Ahrens AR 404	21-30	4 All 250-B17C	170	73	0	1982	1.8
Embraer EMB-120 Brasilia	30	2 PWC PW115	294	69	1.0	1985	3.2
de Havilland Dash 8	32-36	2 PWC PW120	270	14	5.5	1984	3.9
Saab-Fairchild 340	34	2 GE CT7-5A	260	72	7.0	1984	3.5
Commuter Aircraft CAC-100	50-60	4 PWC PT6A-65R	300	76	6.5	1985	5.5
Aerospatiale-Aeritalia ATR 42	42-46	2 PWC PW100/2	211	75	6.0	1985	5.0
CASA-Nurtanio CN-235	34-38	2 GE CT7-7	250	15	(b)	1985	3.8

[a]PWC: Pratt & Whitney of Canada; G A Garrett Turbine Engine Company; All: Detroit Diesel Allison Division, General Motors Corporation; GE: General Electric Company.
[b]Pressurized; specific value not available.

New or Derivative 15- to 19-Passenger Aircraft

Beech C99

The Beech C99 (fig. 11), the latest derivative of the 15-passenger Beech B99 that first flew in 1966, was put into production in 1981. Changes incorporated in the C99 include some structural modifications, hydraulic rather than electric landing gear, upgraded systems, and Pratt & Whitney of Canada PT6A-36 engines rather than the previous PT6A-27 version.

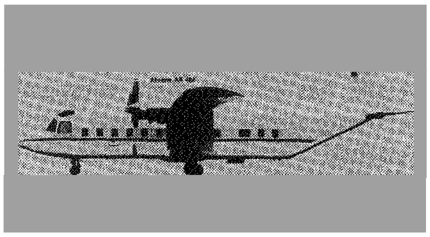
Beech 1900

The Beech 1900 (fig. 11) is a new 19-passenger pressurized aircraft scheduled for introduction in 1983. The largest aircraft yet undertaken by Beech, the 1900 is designed for quick-change passenger-&cargo conversion and will also be offered in a special cargo version. The Beech 1900 will be powered by Pratt & Whitney of Canada PT6A-65B engines with three-blade propellers.

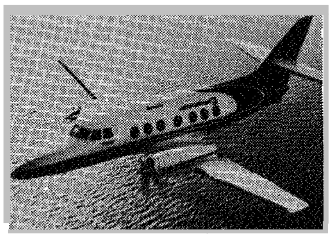
Beech C99 **1981**
15 passengers

Beech 1900 **1983**
19 passengers

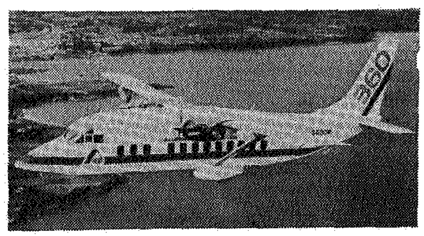
Dornier Do 228 **1982**
15-19 passengers



Ahrens AR *404* **1982**
27-30 passengers



British Aerospace **1982**
Jetstream31
19 passengers



Shorts 360 **1982**
36 passengers

Figure 11.- Current or near-term regional transports (1981 to 1983).

British Aerospace Jetstream 31

The British Aerospace Jetstream 31 19-passenger aircraft (fig. 11) is the latest version of the Handley Page **HP** 137 Jetstream that first flew in 1967. The Jetstream 31 differs from the original **HP** 137 design in ***that*** it uses **Garrett TPE33** 1-10 engines rather than the original Turbomeca Astazou 16C2 engines, new Dowty Rotol four-blade propellers, a new cockpit, and some new systems. Certification of the Jetstream 31 was received in 1982.

Domier Do 228

The Dornier Do 228 (fig. 11) will be offered in both a 15-passengerversion (Do 228-100) and a 19-passenger version (Do 228-200). The only difference between the two versions is the fuselage length. The unpressurized aircraft is powered by two Garrett TPE331-5 turboprop engines driving Hartzell four-blade propellers. The Do 228 features a new-technology wing (TNT) design to provide improved aerodynamic performance.

Fairchild Swearingen Metro 111

The Fairchild Swearingen SA-227AC Metro 111 is the latest version of the highly successful Swearingen SA-226TC Metro II 19-passenger aircraft (fig. 9). Relative to the original Metro II, the Metro III is certificated at increased gross weight, has 10 feet more wingspan, and uses Garrett TPE 331-11U-601G turboprop engines with Dowty Rotol four-blade propellers. Another version, the Fairchild Swearingen SA-227AC Metro IIIA, will be powered by Pratt & Whitney of Canada PT6A-45R engines, and is scheduled for introduction in 1983.

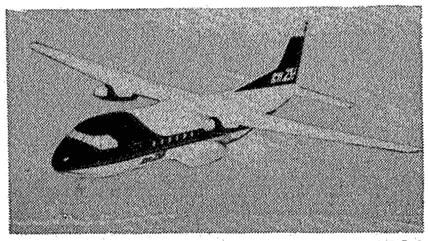
New or Derivative 20- to 50-Passenger Aircraft

Although demand remains strong for smaller aircraft to satisfy the airlines' needs until the next generation is delivered, much industry activity is currently aimed at filling the market gap for new 20- to 40-passenger aircraft for the mid-1980's. This market gap, which is clearly evident from the data of figure 13, was caused in large part by previous regulatory restrictions affecting the operation of aircraft above 12 500 pounds gross weight (corresponding to about 19 passengers). Industry estimates of the potential market for new aircraft of this size from now to the year 2000 range from 1500 to 2000 aircraft. The second-generation 20- to 50-passenger aircraft designs currently under consideration by the commuter airlines are the Ahrens AR 404, the Aerospatiale-Aeritalia ATR 42, the CASA-Nurtanio CN-235, the Commuter Aircraft CAC-100, the de Havilland Dash 8, the Embraer EMB-120, the Saab-Fairchild 340, and the Shorts 360.

Ahrens AR 404

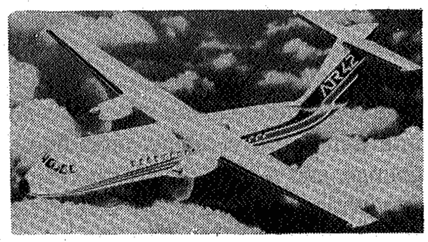
The Ahrens AR 404 (fig. 11) is a conventional high-wing aircraft configuration using four Allison 250-B17C 420-shp turboprop engines and Hartzell three-blade propellers. This unpressurized aircraft is designed for rapid cargo-to-passenger conversion and incorporates a rear cargo-loading ramp. Originally developed in the United States, the aircraft is currently in the final stages of certification in Puerto Rico. At a quoted price of $1.8 to $2 million, the AR 404 is

Embraer EMB-120 1985
30 passengers

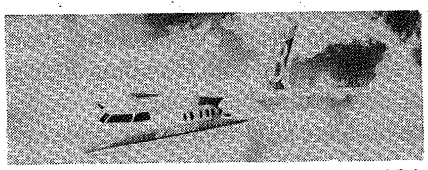


CASA-Nurtanio CN-235 1984
34-38 passengers

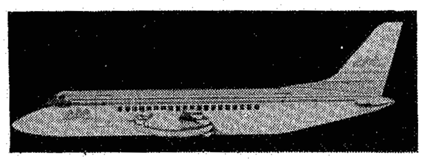
Saab-Fairchild 340 1984
34 passengers



Aerospatiale-Aeritalia ATR 42
42-46 passengers



Dash 8
passenger



Commuter Aircraft CAC-100 1984
-50 passenger

Figure 12.- Regional transports to be introduced in 1984 and 1985.

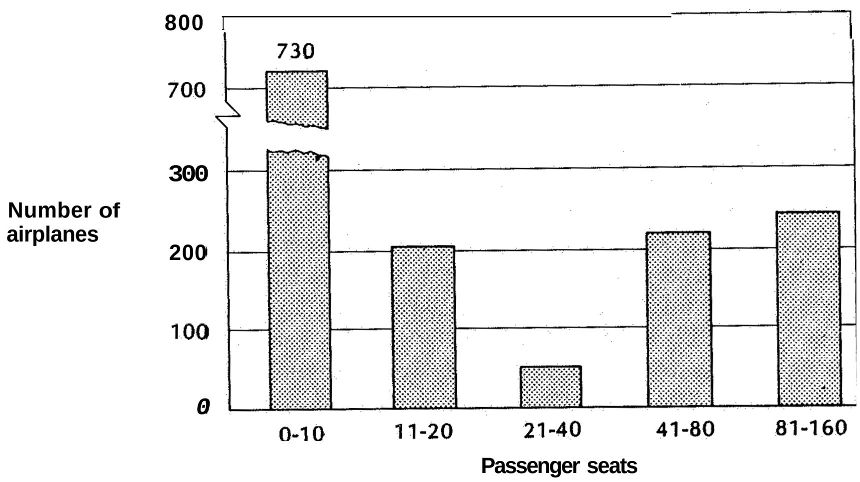


Figure 13.- Number of aircraft in scheduled U.S. service for regional and commuter carriers (1976).

substantially lower in initial cost than any of the other new 30-passenger aircraft, including the Shorts 330, which is currently offered at $3 million. At a cruise speed of 170 knots, the AR 404 is also the slowest of the new 30-passenger aircraft.

Aerospatiale-Aeritalia ATR 42

Aerospatiale of France and Aeritalia of Italy embarked on their first joint commercial venture to develop the ATR 42, a 42- to 46-passenger aircraft (fig. 12). This high-wing aircraft design is an outgrowth of the previously separate design activities being conducted by each company. It is a relatively recent arrival in the new commuter aircraft development arena, and appears to include more than some others in the way of advanced technology. The aircraft will be offered in a number of versions, including the ATR 42F freighter, ATR 42QC quick change, and ATR XX stretched aircraft The ATR 42 uses digital avionics with conventional displays for CAT (Category) I or II landings, and this can be extended to CAT III. The interior cabin noise goal is 80 dBA, which is nearly as quiet as the Airbus Industrie A300's 78 dBA and significantly quieter than the 90 dBA of the Nord 262. The pressurized aircraft has a four-abreast passenger cabin and can accomodate LD-3 cargo containers. The aircraft will use two Pratt & Whitney of Canada PW 100/2 turboprop engines fitted with Hamilton-Standard 14SF four-blade propellers of metal spar composite-shell design.

Concurrent with the development of the baseline aircraft, Aerospatiale has an advanced-technology program to investigate several items for possible incorporation. These include wing tip optimization, composite control surfaces and empennage fins, airfoil/propeller slipstream tailoring, cathode-ray-tube and head-up displays, flight management systems, and an active gust alleviation system driving the aft flap segment and ailerons. The program is also investigating a graphite-epoxy wing box.

CASA-Nurtanio CN-235

The CASA-Nurtanio CN-235 aircraft (fig. 12) is being developed jointly by CASA (Construcciones Aeronauticas, S.A.) of Spain and Nurtanio of Indonesia. These two companies also produced the CASA 212 as a joint venture. The CN-235 is a pressurized high-wing twin-engine aircraft with a seating capacity of up to 38 passengers. The aircraft will use two General Electric CT7-7 turboprop engines driving new Hamilton Standard 14RF propellers. The CT7 version of the military T700 turboshaft engine used in several helicopters features a high compressor pressure ratio for significantly better fuel efficiency than that of current engines.

Commuter Aircraft CAC-100

Commuter Aircraft Corporation is currently preparing manufacturing facilities in Youngstown, Ohio, to produce the new Commuter Aircraft CAC-100 aircraft (fig. 12). The CAC-100 is a 50- to 60-passenger pressurized low-wing aircraft design. The cabin is designed for four-abreast seating and will also accommodate LD-3 cargo containers. The aircraft will be powered by four Pratt & Whitney of Canada PT6A-65R turboprop engines. This aircraft, the design of which was originally initiated in the late 1960's, is currently the only announced 50- to 60-passenger aircraft under development in the United States. The aircraft is currently undergoing extensive redesign to incorporate a new NASA-developed airfoil, a new single-slotted Fowler flap system, and a revised fuselage design.

de Havilland Dash 8

The de Havilland Dash 8 (fig. 12) bears an obvious family resemblance to the de Havilland Dash 7, but the aircraft is a new design. Originally conceived as a shortened twin-engine Dash 7, the Dash 8 is a faster, higher flying aircraft with a fuselage cross section somewhat smaller than that of the Dash 7. However, the thinner, faster wing of the Dash 8 is less obtrusive in the cabin and allows the use of the same seats as the Dash 7, so that comfort standards are not significantly different. The Dash 8 is designed to have the same low internal and external noise characteristics as the Dash 7, and uses two 1800-shp Pratt & Whitney of Canada PW120 engines driving 13-foot four-blade Hamilton Standard 14SF-1 propellers.

Embraer EMB-120

Embraer's 30-seat EMB-120 Brasilia (fig. 12) is a conventional low-wing aircraft seating three passengers abreast in a pressurized cabin that has galley and lavatory facilities. Like most other second-generation commuters, its cruise speed is 40 to 50 knots faster than the current-generation commuter aircraft, and its field length requirement is on the order of 4000 feet. The aircraft structure is primarily of aluminum, although composites are used in the wing leading edge (for bird strike durability), tail surfaces, seat, cabin floor, and fairings. The wing design is conventional, using NACA 230-series airfoils. The Brasilia will be powered by two 1500-shp Pratt & Whitney of Canada PW115 turboprops with Hamilton Standard 14RF-9 propellers. The Brasilia is being marketed very aggressively in the U.S., and has an attractive financing package and an excellent parts and maintenance reputation (based on the record of the Embraer EMB-110 Bandeirante).

Saab-Fairchild 340

The Saab-Fairchild 340 (fig. 12) is a conventional low-wing aircraft seating 34 passengers. This aircraft is being developed and will be produced under a joint Swedish-American program aimed at achieving certification by the first half of 1984. It offers a three-seat-abreast pressurized cabin with a 6-foot aisle height, a lavatory, a coat closet, and under-seat carry-on luggage space. A cargo door is standard and a rigid, movable bulkhead allows the ratio of passenger space to baggage or freight to be adjusted easily. The Saab-Fairchild 340 wing design incorporates a newly developed NASA airfoil section €or lower cruise drag. The aircraft will be powered by General Electric CT7-5A engines. Saab-Scania and Fairchild Industries have selected Dowty Rotol four-blade composite propellers, which use the new ARA-D airfoil sections. Fabrication of the airframe will be shared by both partners. The Fairchild Republic Company will manufacture the wings, empennage, and engine nacelles in the U.S., Saab-Scania will manufacture the fuselage, and the complete aircraft will be assembled and flight tested in Sweden. The Fairchild Swearingen Corporation will market the aircraft in Canada, the U.S., and Mexico, and aircraft for these markets will be fitted out by Swearingen. Marketing for the rest of the world will be handled by Saab-Fairchild HB, a new company jointly owned by the partners.

Shorts 360

The Shorts 360 (fig. 11) is a low-risk derivative of the Shorts 330. The main changes from the 330 are a stretched fuselage, new empennage, and more powerful engines. These fuselage and tail changes permit the addition of two seat rows for an increase in capacity to 36 passengers. The new tail also reduces drag and allows an increase in cruising speed. The new propulsion system uses two Pratt & Whitney of Canada PT6A-65R engines driving new Dowty-Rotol four-blade composite propellers.

Prospects for Advanced-Technology Commuter/Regional Transports

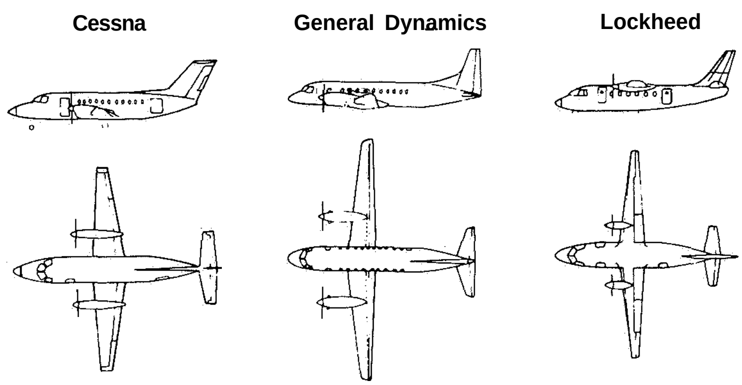
Although the new commuter/regional aircraft designs now being developed represent substantial manufacturer commitments, commuter airlines personnel attending the meeting of the NASA Ad Hoc Advisory Subcommittee on Commuter Air Transport Technology (held November 19-21, 1980) expressed concern that even the currently available technology is not being applied to the maximum extent possible in any of these designs, and advanced technology is almost entirely absent. The U.S. small-transport manufacturers represented at the meeting countered that the level of technology incorporated in their new designs was consistent with the companies' available budgets, staffs, research and development (R&D) bases, and facilities. The capital cost of developing and certificating a small transport aircraft represents a major challenge for any U.S. firm, and in consideration of their own limitations and of the large risks involved in innovation, the smaller firms feel forced to choose conservative technology approaches and program commitments and to avoid technologies yet unproven or with which they are unfamiliar. This situation has resulted in the smaller U.S. manufacturers either incorporating straightforward modifications into existing designs or else joining with a foreign partner for new product development. Whereas the smaller U.S. manufacturers do not seem to be in a position to apply the modern technologies, the larger transport manufacturers, even with their larger budgets, staffs, R&D bases, and facilities, as well as their greater familiarity with advanced technologies, have declined to develop and manufacture small (less than 60-passenger) transport aircraft. For the larger manufacturers, a primary reason is their concern over both the high product costs that would result from their higher operating overheads and the attendant increased risks in a competitive marketplace. In addition, U.S. manufacturers, both large and small, recognize that most foreign firms in the commuter aircraft market are substantially assisted by their governments in all phases of research, development, production, and marketing, with the result that they simply do not face the same risks now inhibiting their U.S. counterparts. For example, in 1982 alone the French government provided approximately $50 million in support for the development of the Aerospatiale-Aeritalia ATR 42 commuter aircraft (ref. 15).

Potential Benefits of Advanced Technology – STAT Studies

To identify and quantify the benefits of advanced small transport aircraft technology, a broad range of advanced-technology application studies (referred to as the STAT studies) was conducted for NASA by several airframe, engine, and propeller manufacturers. The manufacturers under contract included the Beech Aircraft Corporation, the Wallace Division of Cessna Aircraft Company, the Lockheed-California Company, the Convair Division of General Dynamics Corporation, Pilatus Britten-Norman Ltd., the Garrett Turbine Engine Company, the General Electric Company Aircraft Engine Group, the Detroit Diesel Allison Division of General Motors Corporation, the Hamilton Standard Division of United Technologies Corporation, and the McCauley Accessory Division of Cessna Aircraft Company.

Airframe Studies

STAT studies by Cessna (ref. 16), Convair (ref. 17), and Lockheed (ref. 18) investigated new small transport aircraft designs with 19-, 30-, and 50-seat capacity capable of carrying a full payload of passengers and baggage for 600 nautical miles and optimized for minimum direct operating cost (DOC) over a 100-nautical-mile stage length. The fuel price used for the DOC calculations was usually $1.00 per gallon, although some studies also examined the effect of higher fuel prices, which increase the importance of efficiency and, hence, technology. Additional design goals include a 4000-foot field length and passenger comfort levels equivalent to those of the large jet transports; i.e., stand-up headroom along the aisle, space for carry-on baggage, low cabin noise levels, low airport noise levels (8 EPNdB (equivalent perceived noise in decibels) below FAR 36 Stage 3 (ref. 19)), and improved ride quality. Initially, current-technology baseline designs were established for use as a reference against which the benefits of advanced technology could be measured. The general arrangements of the 30-passenger baseline aircraft designed by each manufacturer are shown in figure 14.



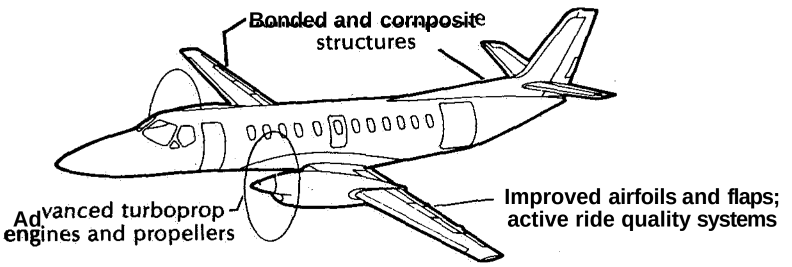
	Cessna	General Dynamics	Lockheed
Gross weight, lb	24 210	29 600	28 606
Power/eng, hp	1930	2343	2403
Propeller diam, ft	10.0	11.5	10.6
Design Mach no.	0.456	0.456	0.600
Design cruise alt, ft	10 000	10 000	28 000
Design range, n. mi.	600	600	600
DOC @ 100 n. mi., cents/seat-n.-mi.	10.48	10.45	9.95

Figure 14.- Configurations and specifications for baseline new small transport aircraft (30 passengers, 4000-ft field length).

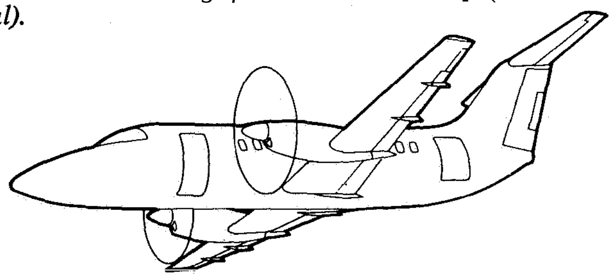
The Cessna 19- and 30-passenger baseline designs use the technology level of the Cessna Citation business jet and are designed to cruise at Mach 0.456 (250 knots indicated airspeed). The 30-passenger fuselage has been designed to give stand-up headroom, the wing geometry has been optimized to minimize direct operating cost (DOC) for fuel at $1.00 per gallon, and the propulsion system is based on Pratt and Whitney of Canada PT6 turboprop technology. The Cessna designs did not address the interior noise design goals. General Dynamics/Convair designed 30- and 50-passenger current-technology baseline aircraft that are similar to Cessna's except for the additional cabin wall acoustic treatment required to achieve the interior cabin noise goal of 85 dB overall sound pressure level, which is typical of current jet transports. The additional acoustic treatment weight was estimated to be 2300 pounds for the Convair 30-passenger baseline design. Lockheed-California chose higher design cruise speeds of Mach 0.6 and 0.7 for their 30- and 50-passenger aircraft, respectively, and they also included the necessary acoustical treatment to meet the interior noise goals.

Cessna

Cessna's 19- and 30-passenger advanced-technology designs are shown in figure 15, along with the improvements in fuel usage and direct operating cost. The utilization of structural bonding, along with the use of composites in selected primary and secondary structural components, had a major impact on improving aircraft weight, cost, and operating economics. The major improvements



(a) 19 passengers, cruise speed = 0.5 Mach. Relative to the current-technology baseline, the advanced-technology design offers a 38-percent fuel savings and a 21-percent DOC savings for a 100-n.-mi. trip (calculated at a fuel price of $1/gal).



(b) 30 passengers, cruise speed = 0.5 Mach. Relative to the current-technology baseline, the advanced-technology design offers a 40-percent fuel savings and a 21-percent DOC savings for a 100-n.-mi. trip (calculated at a fuel price of $1/gal).

Figure 15.-Cessna advanced-technology small transport aircraft design.

resulting from advances in propeller, engine, and aerodynamic technology were in fuel usage, followed by significant savings in direct operating cost. Combining all the advances resulted in advanced-technology aircraft designs that used 38 to 40 percent less fuel on a 100-nautical-mile trip, compared to the current-technology baseline. These improvements resulted in a 21-percent reduction in direct operating cost on the 100-nautical-mile trip. The general arrangement of Cessna's advanced designs is the same as that of their baseline configurations. Notably, the 2-abreast 19-passenger design does not offer the same passenger comfort levels (headroom or storage area) as the 3-abreast 30-passenger design.

Convair

In the Convair study, advanced technologies in aerodynamics, structures, systems, and propulsion were fvst applied individually, and those with the greatest payoff were subsequently incorporated in an advanced-technology design. All the Convair aircraft were designed to cruise at 250 knots indicated airspeed. The advanced 30-passenger aircraft design (fig, 16) incorporates a new high-lift wing design using low-drag airfoils, composite structure, active controls,

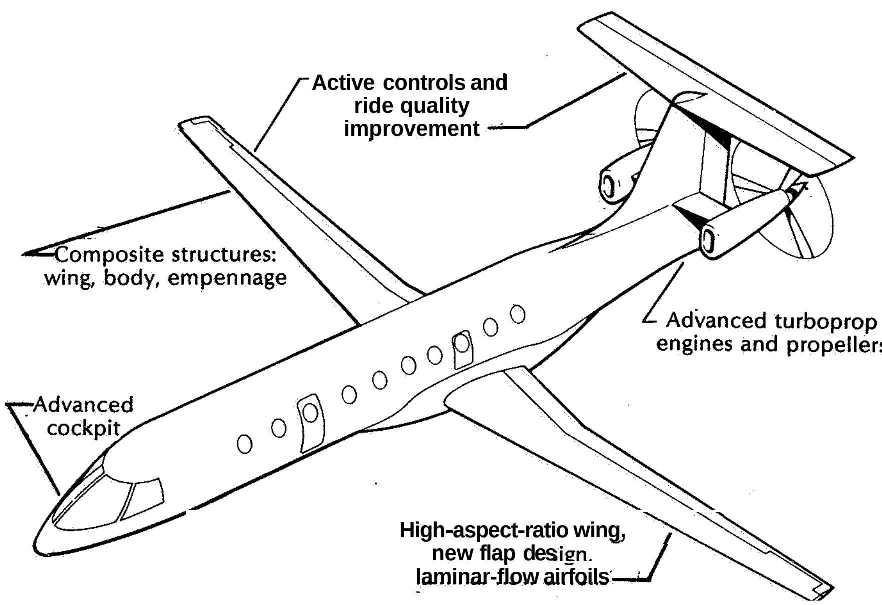


Figure 16.- General Dynamics/Convair advanced-technology small transport aircraft design (30 passengers, cruise speed = 0.5 Mach). Relative to the current-technology baseline, the advanced-technology design offers a 31-percent fuel savings and a 24-percent DOC savings for a 100-n.-mi. trip (calculated at a fuel price of $1/gal).

and improved propeller and engine technology. Compared with their current-technology baseline, the Convair advanced-technology 30-passenger aircraft design is 22 percent lighter in gross weight, has 51 percent less wing area, requires 37 percent less horsepower, and uses 31 percent less fuel on a 100-nautical-mile trip. These improvements result in a 24-percent reduction in direct operating cost for a 100-nautical-mile trip with fuel at $1.00 per gallon. The advanced-technology configuration has the engines mounted on pylons at the back of the fuselage. A major design goal is to provide a cabin interior noise level equal to what the passenger is accustomed to in large jet transports, and this aft location avoids the large fuselage acoustic treatment penalties required for a configuration with wing-mounted engines. The aft fuselage location also reduces engine-out lateral control requirements, provides much of the desired longitudinal static stability, improves the wing efficiency by removing the engine nacelle from the wing, and places the propeller and engine in an improved position to be idled safely, thus avoiding damage from aircraft servicing equipment at the airport terminal.

Lockheed-California

In the Lockheed-California study, a major emphasis was placed on reducing airframe manufacturing costs. Alternative fuselage and wing-structural concepts were investigated using both aluminum and composite materials, and these were compared to the skin-stringer aluminum structure of the baseline design. Lockheed's orthogrid or isogrid composite structural concept utilizes laminated bars built up of alternating layers of syntactic resin and high-strength fibers. Prepreg (resin-impregnated) graphite and syntactic resin tape can be obtained in combined form so that both layers can be wound together on automatic machines. The manufacturing technology gives the structural designer considerable flexibility in choosing a grid size and pattern to meet specific load distribution and fail-safe requirements. Since the resulting stiffened skin is very stable, much of the substructure normally required for stiffness is minimized. This provides a savings in both parts and labor. For a 30-passenger design, this concept resulted in a 25-percent structural cost savings relative to the conventional aluminum skin-stringer design practice. One of the promising advanced-technology designs resulting from this study incorporates an improved high-lift low-drag wing design, composite structures, active controls, and propulsion system improvements (fig. 17). This design also has aft-mounted engines, for the same reasons as the Convair 30-passenger aircraft design. The Lockheed advanced-technology 30-passenger aircraft design uses 26 percent less fuel on a 100-nautical-mile trip and offers a 16-percent reduction in DOC over their current-technology baseline.

Beech

In the STAT study with Beech (ref. 20), the application of advanced technologies to one of their near-term 19-passenger designs was investigated to

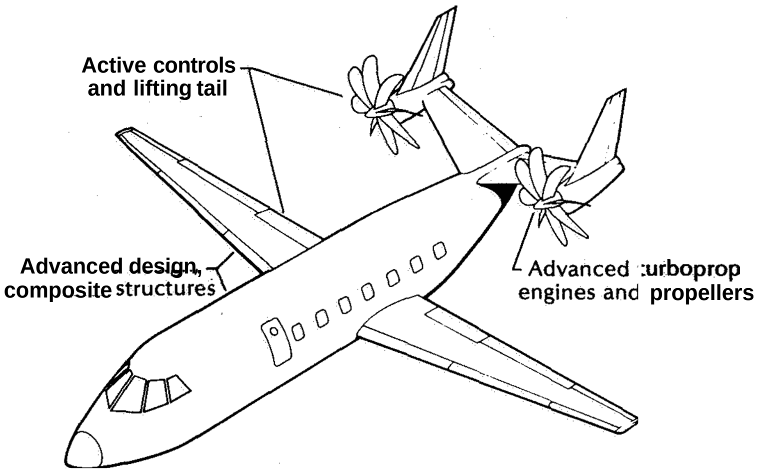


Figure 17.- Lockheed-California advanced-technology small transport aircraft design (30 passengers, cruise speed = 0.6 Mach). Relative to the current-technology baseline, the advanced-technology design offers a 26-percent fuel savings and a 16-percent DOC savings for a 100-n.-mi. trip (calculated at a fuel price of $1/gal).

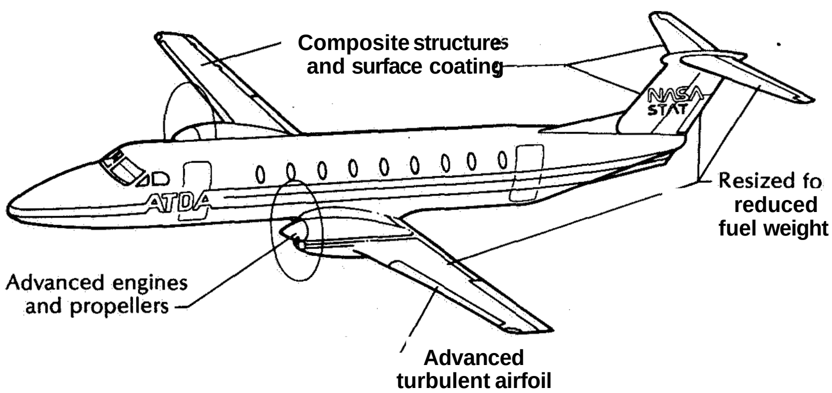


Figure 18.- Beech advanced-technology derivative small transport aircraft design (19 passengers, cruise speed = 0.4 Mach). Relative to the current-technology baseline, the advanced-technology design results in a fuel savings of 34 percent, a DOC savings of 21 percent for a 100-n.-mi. trip (calculated at a fuel price of $1.75/gal), and a 17-percent higher acquisition cost. (It is estimated that the DOC savings would allow payback in less than 1 year.)

determine the technology benefits for derivatives of current designs as compared to completely new designs. The resulting derivative aircraft design shown in figure 18 maintained the same fuselage and mission requirements of the current near-term design, but incorporated advanced technologies in turbine engines, propellers, surface coatings, turbulent-flow airfoils, and composite structure in the wing and empennage. The advanced-technology 19-passenger derivative design uses 34 percent less fuel on a 100-nautical-mile trip and has a 21-percent reduction in DOC for fuel at $1.75 per gallon. Because of the additional development cost required, these potential reductions came at a 17-percent higher acquisition cost for incorporating the technologies in the fully amortized near-term aircraft; however, the operating cost reduction would be large enough to pay back this additional investment within the first year of operation.

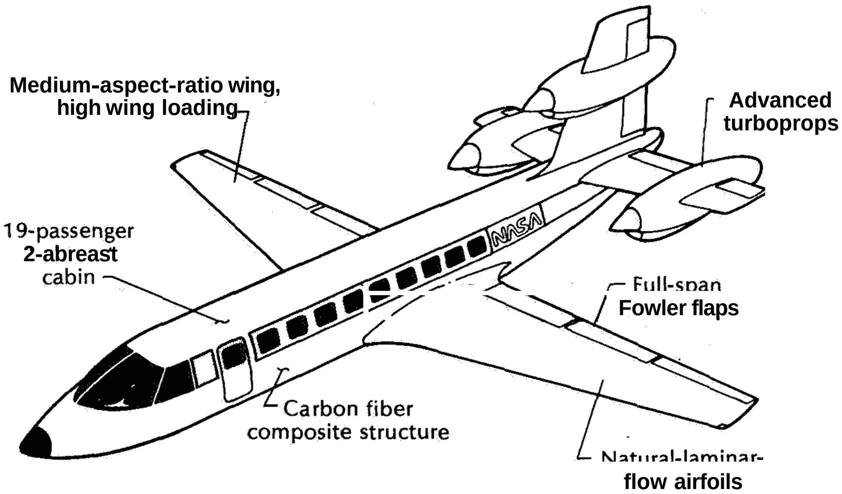


Figure 19.- Pilatus advanced-technology derivative small transport aircraft design. Relative to the current-technology baseline, this design provides a 32-percent higher cruise speed, a 100-percent increase in range at full payload, and a 40-percent DOC savings.

Pilatus Britten-Norman

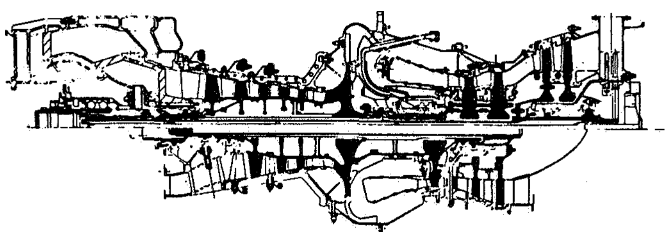
Pilatus Britten-Norman Ltd. has studied the application of advanced technologies to derivatives of a current commuter design. In this case the baseline aircraft was the Pilatus Britten-Norman Trislander, a unique 3-engine 16-passenger design. The study indicated that the Trislander offered a very limited platform for advanced-technology application. Although the design is initially low cost, it has a very narrow fuselage without an aisle, high cabin noise levels, low cruise speed, and limited range capability at full payload. Rather than apply technology to a derivative of this configuration, Pilatus recommended that the advanced technology be applied to develop a new 19-passenger design. This advanced-technology design (fig. 19) would offer improved passenger cabin accommodations, a 32-percent increase in cruise speed, a 100-percent increase in range at full payload, a 16-dBA decrease in external noise level, and a 40-percent decrease in direct operating cost (DOC) per seat mile compared to the Trislander.

Propulsion Studies

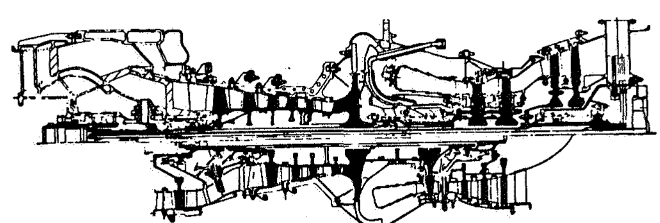
The preceding airframe company results were based in part on substantial propulsion system improvements that were assumed rather than calculated. However, the validity of these assumptions was subsequently verified in a series of STAT engine studies conducted by Allison, General Electric, and Garrett, as well as in STAT propeller studies by McCauley and Hamilton Standard (refs. 21 to 25).

General Electric

The General Electric study identified a dozen candidate advanced 1500- to 2500-shp turboprop technologies that collectively could improve engine efficiency by 14 percent and reduce engine weight by 11 percent relative to the General Electric CT7 (a 1600-shp class engine still under development). This potential is realizable through increased component efficiencies, higher cycle pressures (up to 20:1), and higher temperatures (up to 2400°F). (See fig. 20 and table 4.)



(a) Cross section of engine for 30-passenger Mach-0.45 application.



(b) Cross section of engine for 50-passenger Mach-0.45 application.

Figure 20.- General Electric advanced-technology small transport aircraft engines.

TABLE 4.- SPECIFICATIONS FOR GENERAL ELECTRIC ADVANCED-TECHNOLOGY SMALL TRANSPORT AIRCRAFT ENGINES

[Engines scaled to **1625** shp, **90°F]**

Parameter	CT7-5 baseline engine data	Changes relative to baseline engin	
		Engine for 30-passenger aircraft	Engine for 50-passenger aircraft
Turbine temperature, °F	2290	2300	2400
Pressure ratio	16.9	17	20
Cruise SFC*	0.46	– 9%	–14%
Weight, lb	1070	– 9%	– 11%
cost	Base	– 11%	–12%
Maintenance cost	Base	–21%	–17%

Compressor aerodynamic improvement includes (1) customized high-speed axial-flow airfoils tailored to the specific airflow conditions experienced by each blade row, (2) a centrifugal stage that is split into axial and radial regions in order to increase aerodynamic efficiency in each region, and (3) removal of the diffuser boundary layer through suction. Other turbomachinery technologies include thermal-barrier combustor coatings for increased durability, more effective turbine blade cooling configurations, technologies to reduce turbine running clearances, metal matrix shafting, and the exploitation of digital control technology to reduce compressor tip clearance margins. Gearbox weight reduction and efficiency improvement are also feasible by utilizing split-power gear train concepts. A dual compound idler system was identified which requires advanced gear-mounting technology to insure that the torque is shared equally in the dual load paths. This configuration would eliminate 30 percent of the gears and raise efficiency by one-half percent.

Allison

In the Detroit Diesel Allison study, analyses were carried out for both 2400-shp and 4800-shp class engines, which would be suitable for 50-passenger aircraft designed for cruise at Mach 0.45 and Mach 0.70, respectively, In both cases, the current-technology baseline engine chosen was a scaled version of the 8000-shp-class Allison XT701 turboprop derivative engine. Using DOC as the optimization criterion, Allison maintained the same turbine temperature level as in the Allison T701 (2250°F) but raised the compressor pressure ratio from 12.5:1 to 201 for both advanced-technology engines. This cycle pressure improvement, together with many advanced-technology features (fig. 21), yields an engine efficiency gain of 17 to 19 percent, a 13- to 25-percent weight reduction, a 16-to 19-percent cost reduction, and a maintenance cost reduction of 56 to 62 percent. Factoring these engine improvements into an airplane mission analysis resulted in a 10-to 22-percent fuel savings and a 13-to 16-percent **DOC** savings, assuming a **fuel** price of **$1.50** per gallon and a stage length of 100 nautical miles.

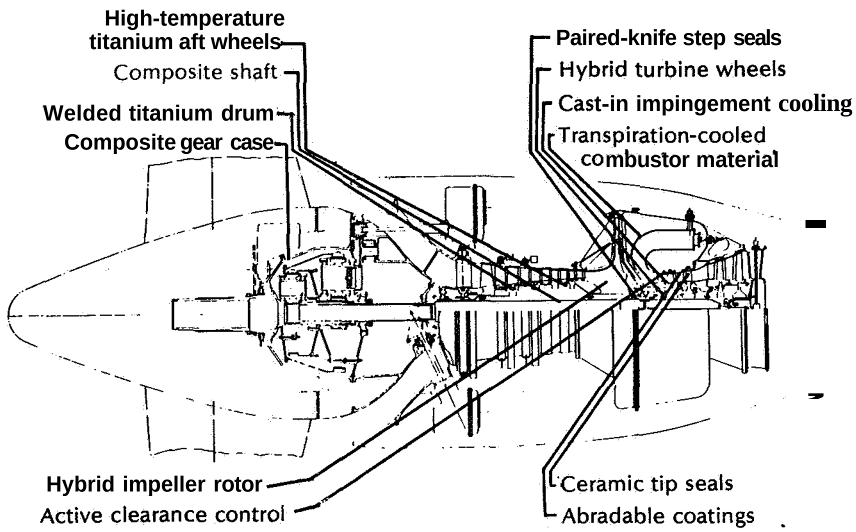


Figure 21.-Allison advanced-technology small transport aircraft engines. The design includes digital controls, modular construction, and condition monitoring. Improvements relative to the current-technology baseline engine include a 17-to 19-percent decrease in SFC, a 13- to 25-percent decrease in weight, a 16- to 19-percent reduction in cost, and a 56- to 42-percent decrease in maintenance cost.

These benefits are predicated on a 21-element advanced-technology program that includes (1) research to alleviate the efficiency and manufacturing problems associated with very small blade sizes in the aft axial compressor section, (2) research to incorporate a low-specific-speed, high hub-to-tip radius ratio centrifugal compressor to match preceding axial stages, (3) enhancement of dual-property turbine wheel materials to achieve appreciably longer fatigue life, (4) cast-in impingement cooling research for small turbine blades, and (5) vortex-controlled diffuser research to achieve low pressure drop in short-length diffusers. Additional areas for improvement include accurate prediction of rotor case response to rotating compressor stall in order to minimize tip clearances, composite shafting to obtain high stiffness in high-speed low-diameter turbomachinery, a full-authority digital electronic turboprop control system, suitable fuel pump and metering technology, and engine condition monitoring technology to enable on-condition maintenance.

Garrett

Garrett examined powerplants for 30- and 50-passenger Mach-0.45 aircraft requiring 1800- to 2500-shp engines. The proposed configuration would be either a twin-centrifugal arrangement with a 16:1 pressure ratio (fig. 22 and table 5) or a 20:1 axicentrifugal arrangement that would increase efficiency by 3 percent but would also raise engine cost by 20 percent. Recommended advanced features include compressor tip treatment to raise efficiency, powdered-titanium centri-

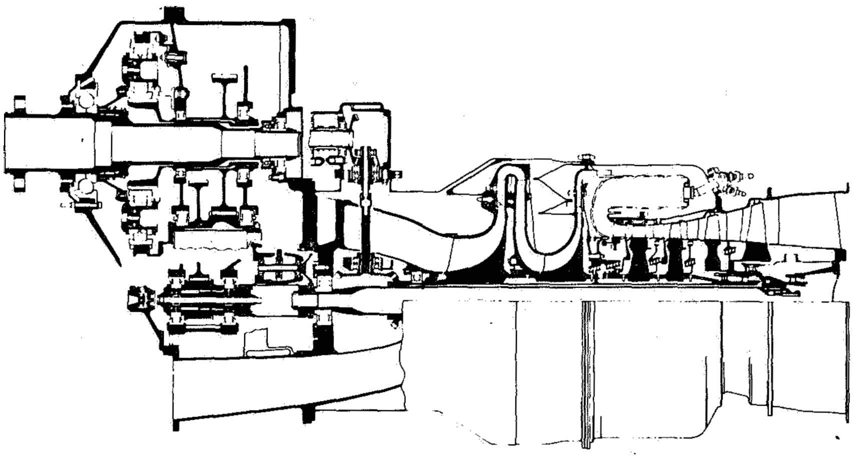


Figure 22.- Garrett advanced-technology small transport aircraft engine (cross section).

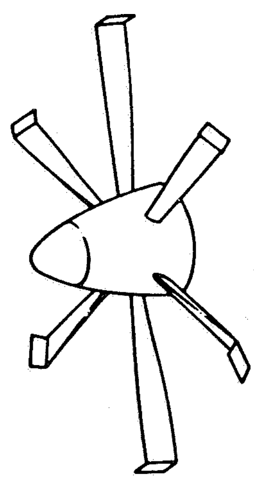
TABLE 5.- SPECIFICATIONS FOR GARRETT ADVANCED-TECHNOLOGY SMALL TRANSPORT AIRCRAFT ENGINES

Parameter	Engine for 30-passenger aircraft	Engine for 50-passenger aircraft
Shaft horsepower (shp)	1842	2384
Cruise SFC	0.415	0.415
Weight (incl. gearbox), lb	623	824
Turbine temperature, °F	2350	2350
Compressor pressure ratio	16	16

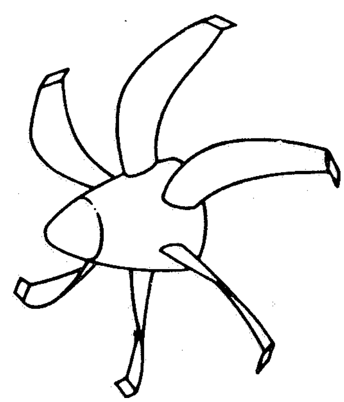
fugal impellers to lower component cost by 25 to 40 percent, turbine tip treatment and active clearance control to increase turbine efficiency, and low-cost airblast fuel nozzles to reduce nozzle cost by 60 percent. These features and general aerodynamic improvements permitting higher pressure ratios offer an engine efficiency improvement of 13 to 14 percent and a 22- to 23-percent weight reduction relative to scaled versions of the recently introduced 1000-shp Garrett TPE331-11 engine.

Hamilton Standard

Hamilton Standard defined advanced propeller technologies and associated benefits for the 30-passenger Mach-0.45 Convair advanced-technology airplane and the 50-passenger Mach-0.7 Lockheed advanced-technology airplane. The analyses concluded that for both applications a six-blade propeller with lightweight composite construction, advanced airfoils, tip proplets similar to winglets, and an advanced precision synchrophaser would be required to increase efficiency and lower cabin noise. (See fig. 23 and table 6.) The Mach-0.45 design employed straight but extremely narrow blades, whereas the Mach-0.7 design used wide, thin blades that were swept 45° at the tip. These propellers would be 5 to 6 percent more efficient than the best of today's propellers. This gain is largely due to the use of advanced materials and construction techniques that permit narrower and thinner blade geometries, as well as to improvements in propeller aerodynamic efficiency through the use of proplets. For low-speed airplanes with tail-mounted powerplants, these improvements result in an 8-percent fuel savings



(a) Propeller for 30-passenger Mach-0.45 application.



(b) Propeller for 50-passenger Mach-0.70 application.

Figure 23.- Hamilton Standard advanced-technology propeller designs.

TABLE 6.- IMPROVEMENTS IN HAMILTON STANDARD ADVANCED-TECHNOLOGY PROPELLERS RELATIVE TO CURRENT-TECHNOLOGY BASELINE

Parameter	30-passenger Mach-0.45 aircraft propeller		50-passenger Mach-0.70 aircraft propeller, wing-mounted
	Wing-mounted	Tail-mounted	
Fuel savings, percent			13
DOC savings, percent	6	3	6
Cabin noise reduction, dB	13	8	13

and a 3-percent DOC savings. For wing-mounted powerplants, these values increase to 13 percent and 6 percent, respectively, due to the elimination of a large acoustic-treatment weight penalty required in the baseline to achieve the cabin noise level of a Boeing 727. For the high-speed airplane, advanced precision synchrophaser technology could also reduce cabin noise by as much as 8 dB by keeping the phase angle between the left and right propellers to within 1".

McCauley

The McCauley study examined propeller technology for a 19-passenger Mach-0.45 aircraft. Using advanced aerodynamics, materials, and structural concepts similar to those employed by Hamilton Standard, the projected efficiency improvement would be 8 to 9 percent relative to typical general-aviation propellers (fig. 24). General-aviation propellers are generally unsophisticated low-cost designs with low performance features, such as non-airfoil-shaped shanks. Discounting about one-half of the 8- to 9-percent efficiency improvement to account for available but underutilized technology still leaves a 4- to 5-percent advanced-technology potential, which corroborates the Hamilton Standard results, with similar fuel and DOC payoffs.

Teledyne Continental and Curtiss-Wright

Additional studies conducted by Teledyne Continental Motors and the Curtiss-Wright Corporation (refs. 26 and 27) have recently defined very advanced rotary and diesel engines as alternative powerplants to conventional turboprops. These intermittent-combustion engines feature multifuel stratified-charge combustion systems, high-pressure-ratio turbochargers (5 to 9), high-speed fuel injection technology, and low-heat-loss cylinders. These advanced-concept high-technology alternatives offer very competitive fuel consumption

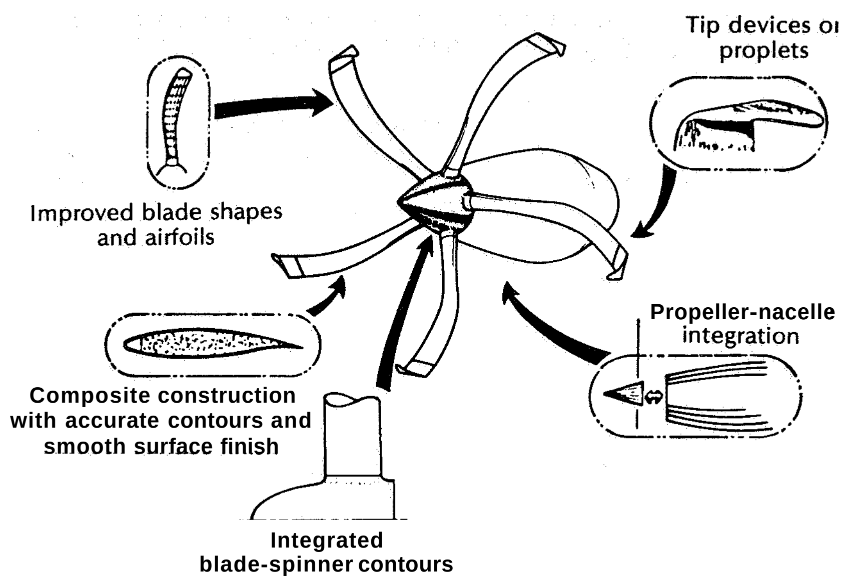


Figure 24.- Cessna-McCauley advanced-technology propeller design features.

and would operate on jet fuel rather than aviation gasoline. However, a total assessment of these engines and of unconventional turboprop cycles (e.g., with regeneration) will require further economic evaluation.

STAT Study Conclusions

The overall conclusion of the STAT airframe, engine, and propeller studies is that very significant improvements in energy efficiency, operating cost, and passenger comfort are possible for future small transport aircraft through a combination of technological advances in all of the airplane disciplines. The results of the individual STAT studies, including all the technology advances, are summarized in table 7. (The Pilatus results are not given in this table because their advanced design differed so much from the baseline in terms of passenger capacity, speed, field length, etc.) In these studies, the baseline aircraft designs reflect the individual manufacturer's view of current technology levels, and the benefits shown reflect differences in individual study goals and requirements, as well as some selected emphasis on advanced-technology areas. As such, no direct comparison of all the study results shown in the table should be made. The significant point is that in each case, substantial savings were projected for applying advanced technology to all of these new commuter aircraft designs.

TABLE 7.- SMALL TRANSPORT AIRCRAFT TECHNOLOGY (STAT) STUDY RESULTS

Parameter	Cessna					
Passenger capacity	19	30	30	30	50	19
Design cruise speed, Mach no.	0.5	0.5	0.5	0.6	0.7	0.4
Initial cost savings, percent	5	6	19	15	16	-17
Fuel savings, percent (100-n.-mi. trip)	38	40	31	26	24	34
Direct operating cost savings, percent, (fuel cost, $/gal)	21 ($1.00)	21 ($1.00)	24 ($1.00)	16 ($1.00)	18 ($1.00)	21 ($1.75)

Also, in each case the largest benefits came from the synergism resulting from the simultaneous application of several technologies. Some of these advances would be possible now as a matter of choice, but others were viewed by the study contractor as being beyond the current state of the art. Accordingly, each study listed certain areas in which additional research and technology development would be necessary to achieve the potential improvements.

To a large extent, NASA's current programs directed at both large commercial transport aircraft and general aviation will contribute substantially toward the required technological improvements, assuming that these programs continue as planned For example, all disciplines are dependent upon analytical methodologies to advance their respective technologies, and will benefit from the improved design techniques made possible by ongoing advanced analytical activities (e.g., three-dimensional flow field analysis for wings, propellers, and engine compressors).

The following two major sections of this report describe NASA's ongoing research efforts relevant to future small transports and delineate the areas that would require additional emphasis or augmentation. This emphasis would permit U.S. small-transport manufacturers to capitalize on technology readiness by the mid-1980's and initiate development of the improved aircraft described by the STAT studies.

Applicable Ongoing Research

NASA's ongoing aeronautics research and technology (R&T) program (ref. **28)** encompasses all pertinent technical disciplines — aerodynamics and flight dynamics, materials and structures, propulsion, guidance, controls, and human factors. Many of the research objectives are peculiar to specific types of flight vehicles and unique situations, but much of the work is applicable to a broad spectrum of aircraft, including small transports. Those portions of the program that are relevant to small transports are reviewed herein according to technical discipline.

Propulsion

Propulsion system development is often regarded as the pacing element for new aircraft designs. The explosive **growth** of the commercial airline industry which occurred during the **1960's** was spawned by the introduction of the jet engine **into** the civilian marketplace. Since then, numerous powerplant improvements have led to the modern high-bypass-ratio turbofan engines that consume about 30 percent less **fuel** than the early **1960's** turbojet engines **(fig. 25). NASA**

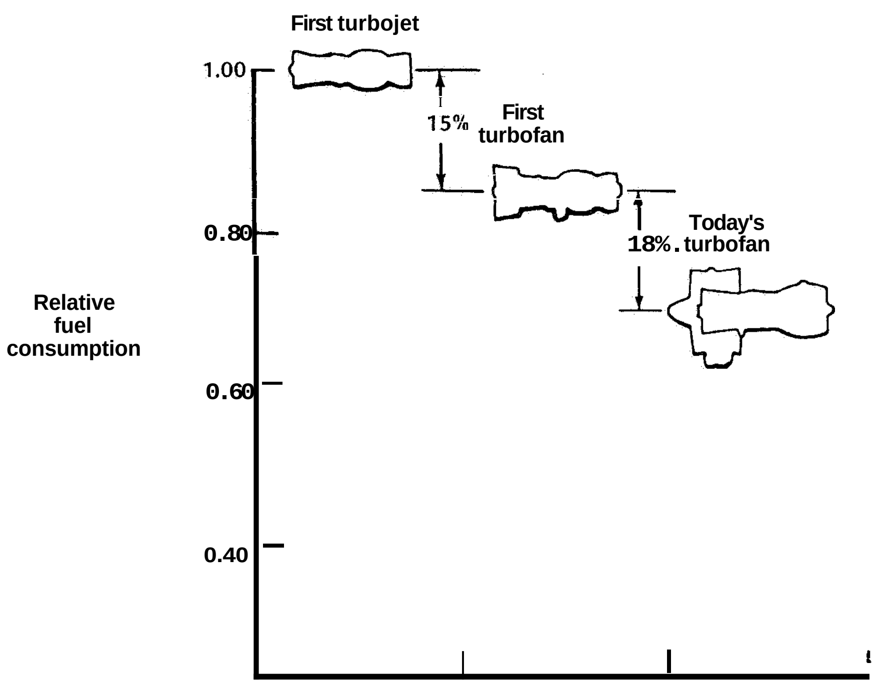


Figure 25.- Progress in aircraft propulsion systems.

contributed to this impressive advance through basic engine component research. During the late 1960's and early 1970's, NASA activities were directed toward the alleviation of engine-generated noise and exhaust pollution. However, the imposition of a foreign oil embargo in 1973 quickly served to refocus NASA's efforts on fuel conservation. Three distinct propulsion programs (fig. 26) were initiated in the mid-1970's' along with three additional airframe programs. These are known collectively as the ACEE (Aircraft Energy Efficiency) program.

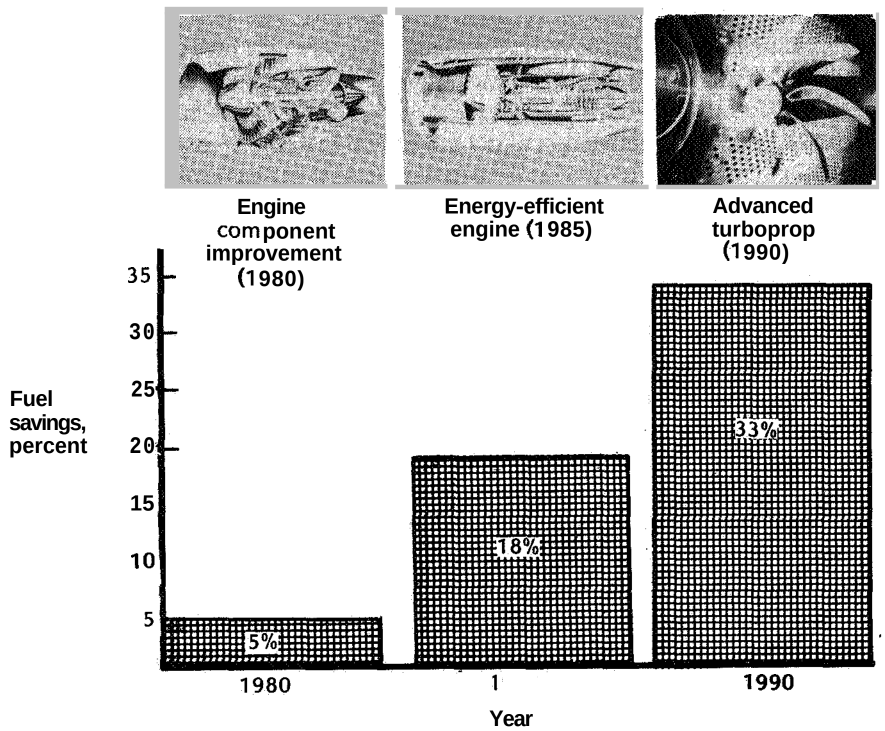


Figure 26.- Projections for energy-efficient propulsion technology.

The near-term ACEE Engine Component Improvement (ECI) program, which has now been completed, was directed both at improving derivative versions of the present generation of engines without making major changes to the design and at reducing fuel consumption by *5* or *6* percent. Example techniques include reduction of the clearances between rotating parts, reduction in the amount of cooling air, and aerodynamic refmement to raise component efficiencies. Many of the 16 individual concepts indentified in the ECI program are already being incorporated into production engines. The ECI program also addressed the task of reducing the performance deterioration that occurs after jet engines are placed in service. At least another 1 percent in fuel savings will be achieved by incorporating both performance retention features that permit closer running clearances and revised maintenance procedures that include compressor parts rejuvenation as well as hot-section overhaul.

NASA's midterm propulsion activity is known as the Energy Efficient Engine (E^3) program. This program is aimed at all-new turbofan engine designs capable of yielding an 18-percent fuel savings relative to Pratt & Whitney JT9D-7A and General Electric CF6-50C technology (fig. 26). The technologies involved include substantially improved components, higher cycle pressure ratios (as high as 40, compared to the more conventional 20 to 30), higher temperature hot-section components, new components such as mixing exhaust nozzles, and advanced control systems that allow the engine to be finely tuned throughout its operational profile. The 5-year E3 program is now at its midpoint and has made satisfactory progress to date. Both of the contractors (the General Electric Co. and the Pratt & Whitney Aircraft Group, United Technologies Corp.) have already incorporated some E3 technology into their latest engines (e.g., the Pratt & Whitney PW2037). Thus, even though the E3 program was conceived to establish the technology base for a late-1980's all-new engine, some near-term benefits are already being realized.

The third ACEE propulsion element is aimed at establishing a technology base for high-speed propellers or propfans. Although the Advanced Turboprop Program (ATP) is still in its early stages, it promises an additional 15- to 20-percent fuel savings over comparable turbofan technology (fig. 26) at the same speeds as the present subsonic jets. The type of propeller required is quite different from that used for conventional turboprop powerplants (fig. 27). The propeller diameter is kept small by the use of many blades, and the blades themselves are ultrathin and highly swept to maintain high efficiency in the tip region, where the local airflow is supersonic. These features must also provide a lower cabin noise level since the noiseabsorbing nacelle acoustic treatment used in turbofan engines is not possible. Recent wind tunnel testing of 2-foot-diameter model propellers has verified that the 80-percent aerodynamic efficiency goal is attainable at Mach 0.8.

Many technology challenges still need to be resolved before the ATP concept is ready for commercial development. The performance and structural integrity of very thin, unconventional-configuration blades constructed of advanced composite materials need to be verified by large-scale testing of approximately 10-foot-diameter propellers.

The potentially adverse interference effects that can result from placing such propellers in close proximity to the flow field of wings, fuselages, or tails must be minimized. Reducing the increase in aerodynamic drag that can result from installing a turboprop on a supercritical wing is the fundamental requirement. At high Mach numbers the wing performance could be seriously degraded by the

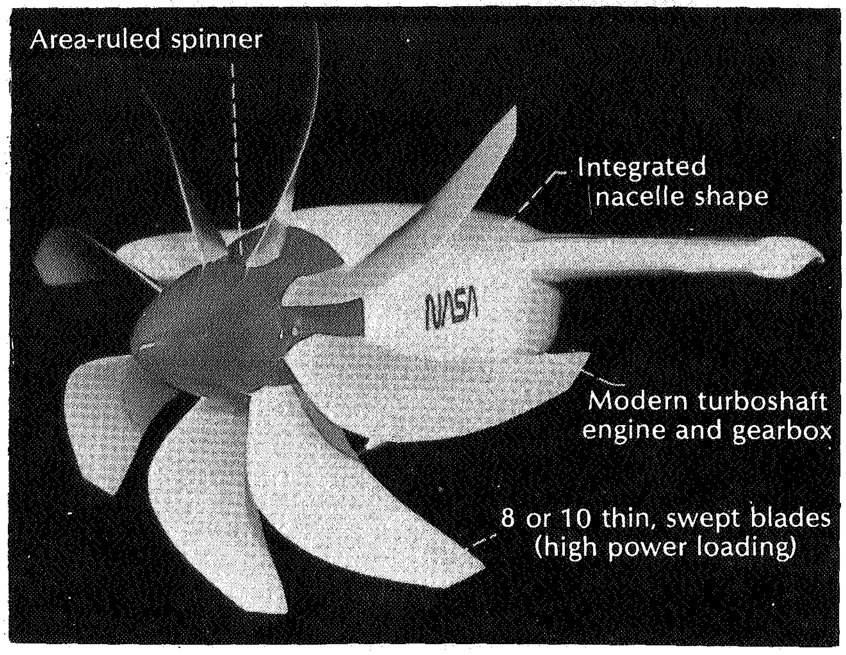
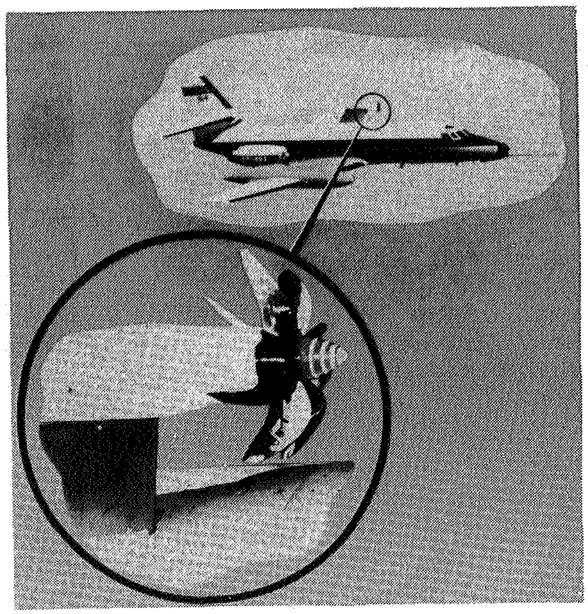


Figure 27.- Advanced turboprop ***propulsion*** *system.*

propeller slipstream and the presence of a large nacelle. In turn, propeller efficiency could be reduced by the induced wing flow. Initial installation tests using a powered 2-foot-diameter propeller model and semispan wing have been conducted in the NASA Ames 14-Foot Transonic Wind Tunnel (fig. 28). These tests are continuing at NASA Ames Research Center, and are being supplemented by additional analytical and wind tunnel testing at NASA Langley Research Center to develop the technology for advanced turboprop installations. This research includes tailoring the wing to minimize any interference drag penalty and examining alternate configurations, such as those with aft fuselage-mounted engines, to overcome installation penalties and also alleviate cabin noise.

Maintaining a low cabin noise level with a minimim acoustiotreatmentweight penalty is another major ATP technology challenge. The problem of interior cabin noise is being investigated experimentally in both wind tunnel and flight tests. Recent tests have been conducted with a 2-foot-diameter model propeller mounted atop a specially modified C-140 Jetstar ,aircraft(fig. 28) which has an array of flush-mounted microphones in the fuselage skin to measure near-field source noise characteristics. Research is also being conducted to develop improved methods for fuselage wall acoustic treatment. As part of this research, the Lockheed-California Company, under contract to NASA, is using a Swearingen Metro II fuselage to examine aircraft structural noise transmission characteristics.



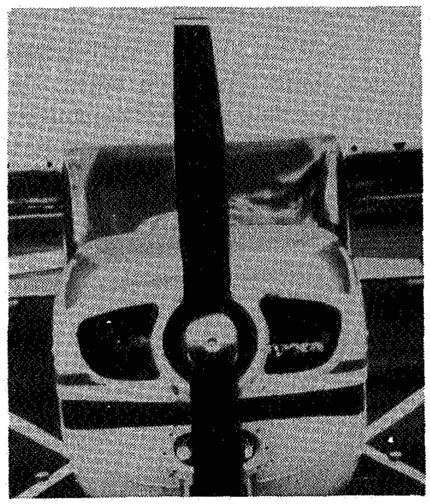
(a) Interior acoustics.

(b) Propulsion-wing integration.

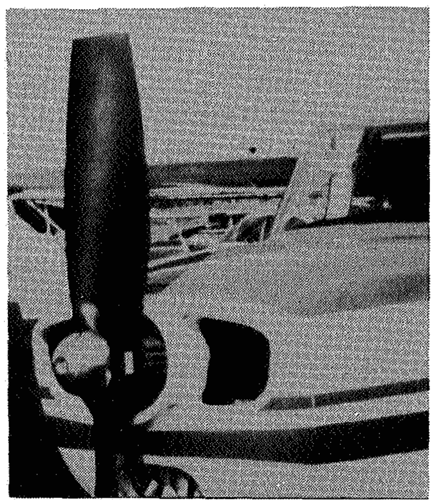
Figure 28.- Turboprop installation tests.

Propeller and acoustic research appropriate to lower speed, lower power installations is also being conducted as part of NASA's general-aviation technology program. Several general-aviation propellers have been tested both in wind tunnels and in flight to measure their performance and noise characteristics.

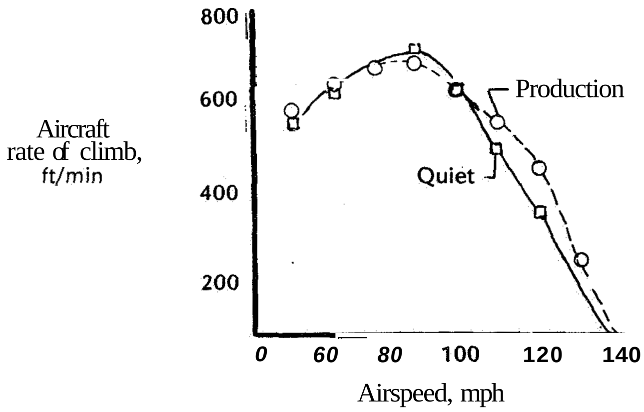
A quiet general-aviation propeller (fig. 29) was designed in a joint effort by NASA, the Environmental Protection Agency, Ohio State University, and the Massachusetts Institute of Technology, Tests with this design demonstrated a flyover noise reduction of 5 dBA with improved climb performance at slower speeds and some performance degradation at cruise speeds. Acoustic research is also being conducted to determine the fbselage noise transmission characteristics



(a) Current-production propeller (77.4-dBA flyover noise).



(b) Quietpropeller: reduced tip speed, improved airfoil, inboard twist and width (72.4-dBA flyover noise).

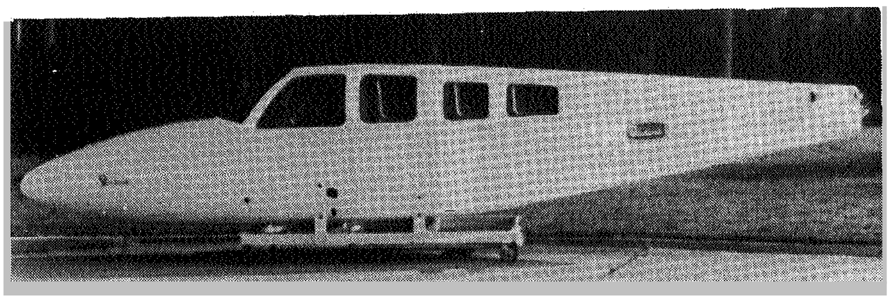


(c) Propeller performance comparison.

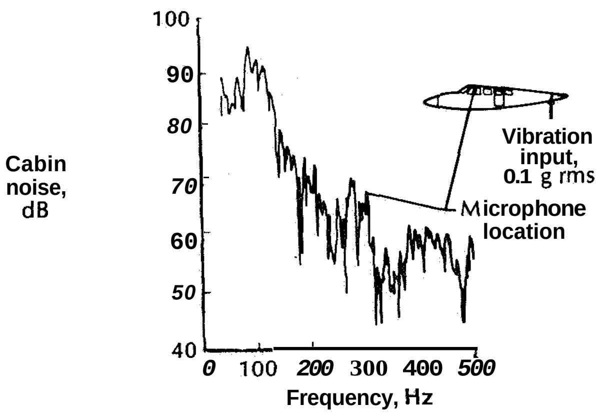
Figure 29.- Propeller noise and performance flight demonstration.

of general-aviation aircraft and to develop improved methods for cabin noise attenuation. Some of these acoustic efforts involve joint programs with manufacturers of general-aviation aircraft, such as the ongoing effort with Beech Aircraft Corporation (fig. 30). Beech supplied an aircraft fuselage and flight data, and NASA is conducting the noise transmission and control research. The data shown in figure 30 indicate that horizontal stabilizer vibration is a potential source of high cabin noise levels. Final results of this joint program will be made available to the entire general-aviation community.

Although NASA research is often summarized in terms of well-focused programs, work is also proceeding in many generic propulsion areas. One example of this is the research aimed at improving our knowledge of combustion and fluid-flow processes in complex turbomachinery. These efforts contribute to a better understanding of component behavior and permit more sophisticated and efficient designs.



(a) Fuselage used for cabin noise research.



(b) Cabin noise caused by horizontal stabilizer vibration.

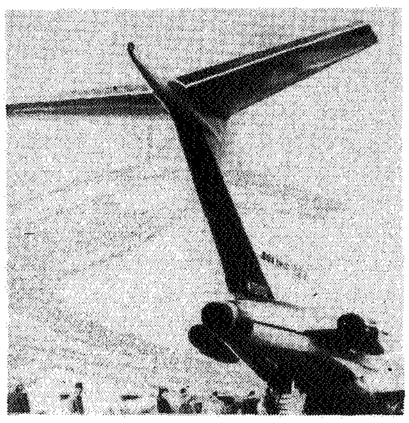
Figure 30.- Cabin noise research program.

Structures

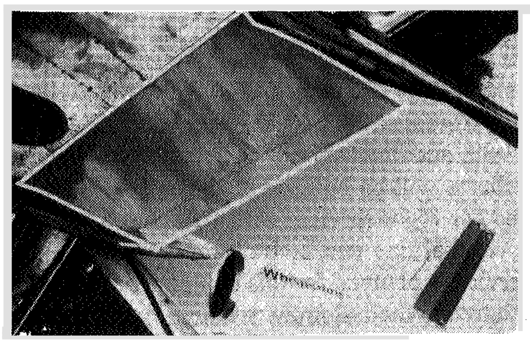
A substantial research effort has been focused on advanced aircraft structures during the last 5 years. The NASA ACEE Composite Primary Aircraft Structures (CPAS) Program was initiated in 1976 to develop the technology and confidence to permit the large commercial transport manufacturers to utilize composites extensively in production aircraft. Specifically, the goals of the program are: (1) to develop manufacturing experience with composites in a production environment, (2) to develop a manufacturing cost data base, (3) to interface with the Federal Aviation Administration (FAA) on certification criteria, and (4) to obtain airline experience with components in flight service.

The first phase of this program, involving the design, fabrication, and testing of secondary components, is now essentially complete (fig. 31). Twenty McDonnell Douglas DC-10 rudders were fabricated and were certified by the FAA in May

(a) DC-10 rudder.



(b) Boeing 727 elevator.



(c) L-1011 aileron.

Figure 31.- Composite secondary structures.

1976, and 12 of these are in flight service. Eleven Boeing 727 elevators have been built and were certified in January 1980, and 10 are in flight service. Finally, 12 Lockheed L-1011 ailerons were built and were certified by the FAA in September 1981, and 8 have been committed to flight service. The weight reduction of these components relative to their aluminum counterparts varied from 23 to 26 percent.

Other program achievements included improved confidence in composite design, manufacturing, maintenance, FAA certification, and airline acceptance. It was also determined that automation in manufacturing is essential to reduce costs. The success of this program was a key factor in Boeing's decision to use approximately 4500 pounds of composites in the secondary structure of the new Boeing 767 (fig. 32). With production of the Boeing 767 and 757 aircraft, the demand for prepreg (resin-impregnated) material in the aeronautics community is expected to increase by a factor of 10, which should dramatically reduce the price of this material.

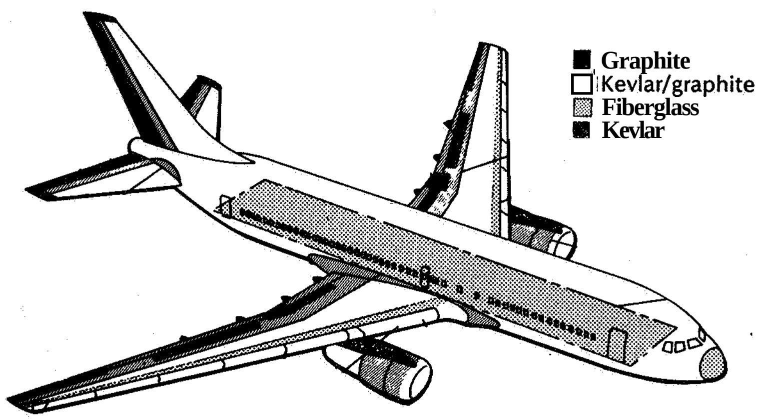
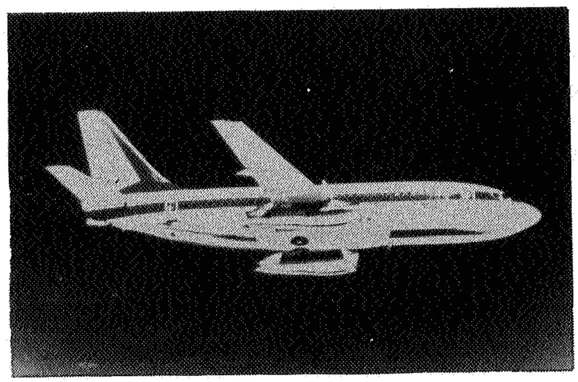


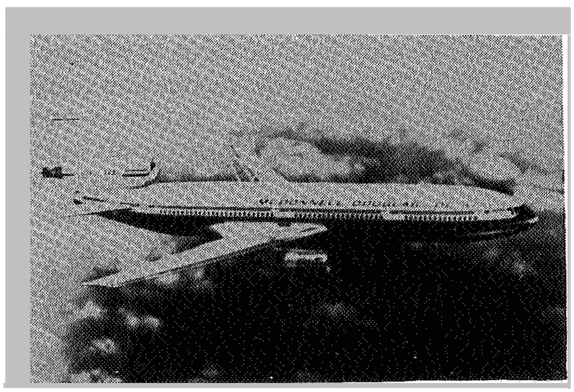
Figure 32.- Composite structure on Boeing 767.

The second phase of the CPAS program, involving medium-sized primary structure (fig. 33), is presently in progress and will be completed in late 1983. Eleven Boeing 737 horizontal stabilizers are being built, FAA certification was received in August 1982, and flight service of ten units may begin in 1983. Three DC-10 vertical stabilizers will be built; two will be ground tested and one will probably be equipped for flight service, with FAA certification anticipated in 1983. Two GlOl 1 vertical fins will be built for extensive ground testing, but currently no flight service is planned for this component. The weight savings for these components relative to their aluminum counterparts ranges from about 22 percent to over 28 percent (fig. 33).

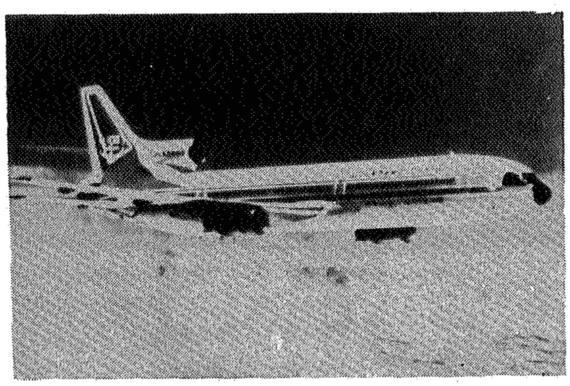
In order to realize the full weight-saving potential of composites, it will be necessary to utilize them in the main wing and fuselage structures. Development of composite wing and fuselage structures would be the third phase of the CPAS



(a) Boeing 737 horizontal stabilizer.



(b) DC-10 vertical stabilizer.



(c) L-1011 vertical fin.

Figure 33.- Composite medium-sized primary structures.

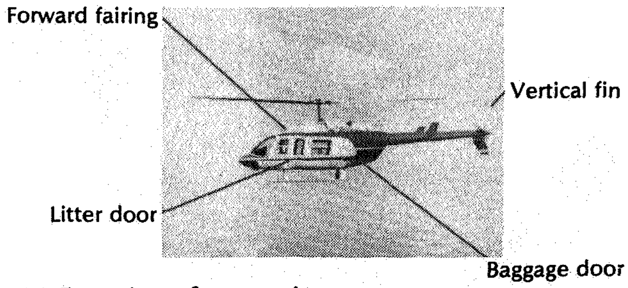
program, with the goal of achieving technology readiness by 1988 and production commitment by 1990. Benefits would include a 25-percent reduction in structural component weight and an 8-percent reduction in direct operating costs. This third phase is estimated to cost about as much as the fvst two phases combined, and to date this phase has not been funded. Efforts have been initiated to develop long-lead-time key technology for the wing structure, with emphasis on durability and damage tolerance, critical-joints technology, and fuel containment.

In addition to the large effort directed at high-performance graphite/epoxy composites, technology development efforts are also under way on other composite materials that are appropriate for commuter transport application. In particular, the helicopter program's materials research is strongly applicable to commuter aircraft.

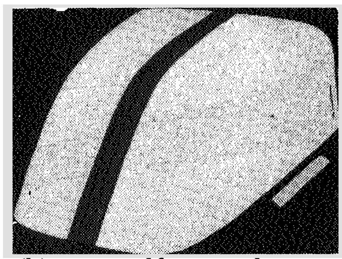
Much of this effort involves the design and fabrication of composite components for flight service evaluation on Bell 206L commercial helicopters (fig. 34). Forty shipsets of four composite components (forward fairiigs, vertical fins, litter doors, and baggage floors) are being installed for up to 10 years of flight service evaluation. The forward fairing is a sandwich structure with a single ply of du Pont Kevlar/epoxy fabric cocured on a foam core. The foam is a polyvinylchloride material (Klegecell, manufactured by American Klegecell Corporation) which is easily preformed to the double-curvature shape using moderate temperature and pressure. The composite forward fairing weighs 38 percent less than the production aluminum fairing. The vertical fin is constructed of graphite/epoxy facesheets bonded to a Hexcel Fibertruss honeycomb core. A layer of fine mesh aluminum wire screen is bonded to the outer surface of each skin to provide protection from lightning. The composite fin weighs 22 percent less than the production aluminum honeycomb sandwich fin. The litter door, constructed of Kevlar/epoxy fabric with local reinforcement at load introduction points (hinges and latch assembly), weighs 35 percent less than the production bonded and riveted aluminum door. The baggage door, which weighs the same as the aluminum component, is constructed of Kevlar/epoxy fabric facesheets and a du Pont Nomex honeycomb core.

The helicopters, with these composite parts installed, will operate in diverse environments in Alaska, Canada, and the U.S. Gulf Coast. Material samples exposed to ground and flight environments will be tested at specified intervals to determine the effects of various helicopter operating environments on material strength. Also, selected components will be removed from service and tested to failure to compare residual strength with original strength. As of December 1982, all 40 shipsets of the composite components had been delivered to various helicopter operators.

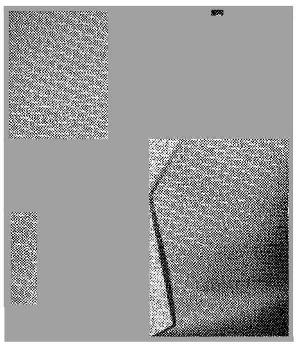
Advanced materials and structures are being used extensively in some of the more recently developed general-aviation (GA) aircraft The emphasis by the U.S. manufacturers has been on the higher performance aircraft such as the Cessna Citation III (fig. 35). However, European manufacturers have focused substantial attention on the use of composites for smaller, lower performance



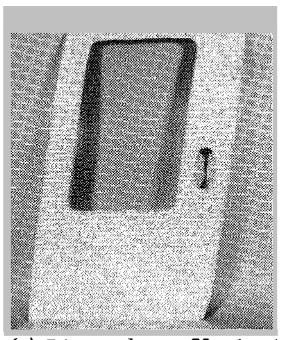
(a) Location of composite components.



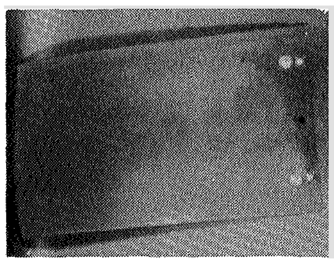
*(b) Forward fairing: du Pont Kevlar/epoxy fabric; stiffened foam sandwich; mass = **2.31** kg; size = 0.90 × **0.74** m.*



*(d) Vertical fin: graphite/epoxy tape; Hexcel Fibertruss core; mass = 5.90 kg; size = 1.98 × **0.50** m.*



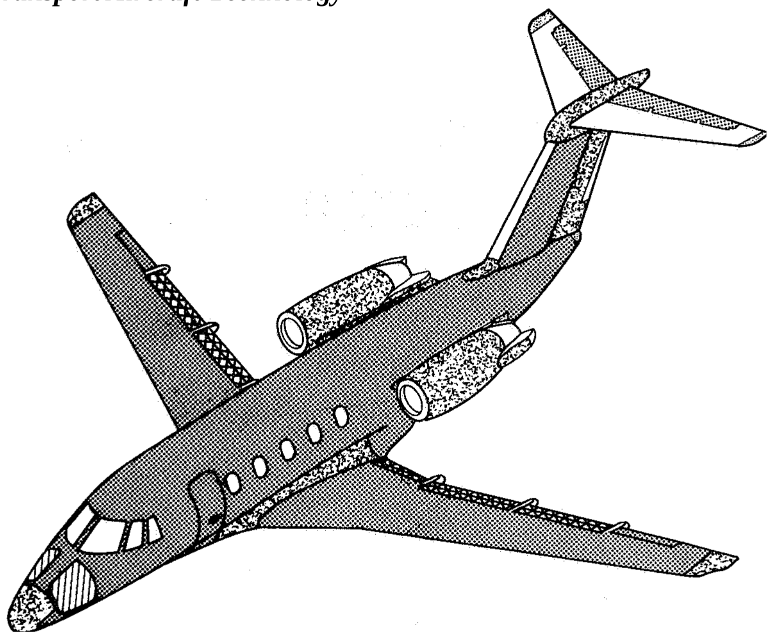
*(c) Litter door: Kevlar/epoxy fabric; two skins — hollow section; mass = **3.72** kg; size = 1.17 × **0.66** m.*



*(e) Baggage door: Kevlar/epoxy fabric; honeycomb sandwich; mass = **1.41** kg; size = **0.97** × **0.58** m.*

*Figure **34**.- Bell 206L helicopter composite components.*

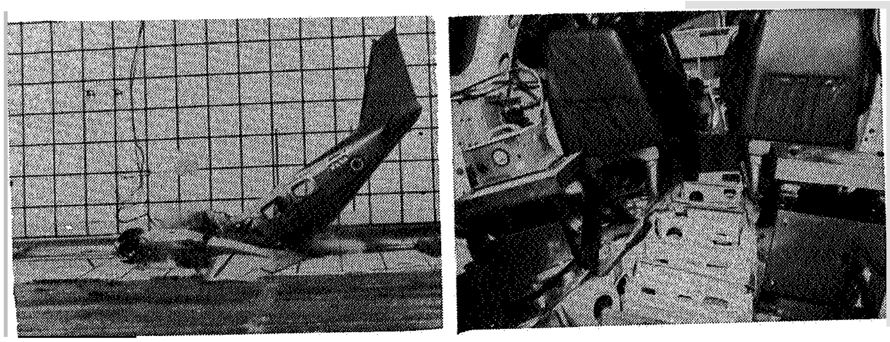
aircraft. Much of the European development has been based on extensive experience with high-performance sailplanes. This experience is now being applied to a new generation of light aircraft, such as the Grob Flugzeugbau G 110 (fig. 36). The G 110 uses a fiberglass/epoxy primary structure with some



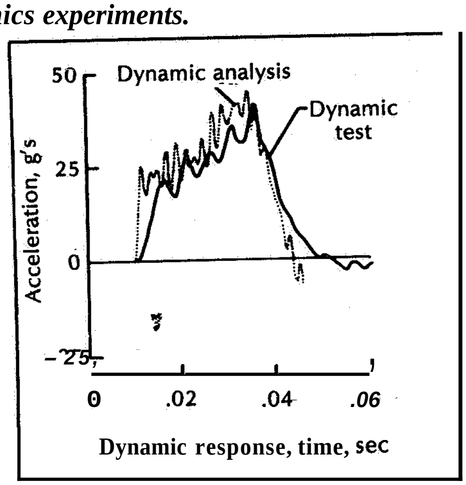
- Kevlar and Kevlar/honeycomb sandwich construction
- Graphite/honeycomb sandwich and graphite/Kevlar hybrid construction
- Adhesive-bonded skins, doublers, and stringers
- Bonded fiberglass construction
- Aluminum skin/honeycomb core construction

Figure 35.- Advanced structure on Citation III.

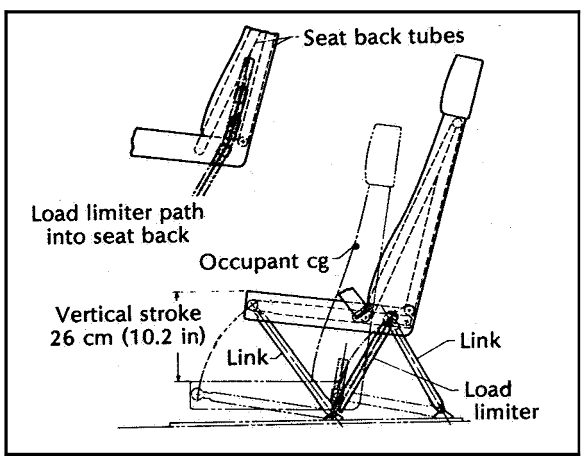
Figure 36.- Grob Flugzeugbau G 110.



(a) Crash dynamics experiments.



(b) Occupant mass acceleration analysis.



(c) Energy-absorbing seat designs.

Figure 37.- Crash dynamics.

graphite/epoxy secondary structure. The use of the composite structure provides smooth, stiff, accurate surface contours that allow the aircraft to take advantage of new airfoils designed for extensive regions of natural laminar flow.

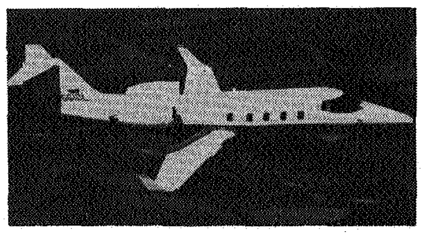
Another area of structures research that is very important to the design of improved small transport aircraft is crash dynamics. Over the past several years considerable research has been conducted on the crash dynamics of general-aviation aircraft ranging in size from small trainers to large twin-engine aircraft. This research (fig. 37), conducted as a part of NASA's general-aviation program, has resulted in a greatly improved understanding of crash dynamics as well as the development of analytical methods to predict structural loading and deformation, improved cabin subfloor energy absorption design concepts, load-limiting seat designs, improved performance of restraint systems design, and improved aircraft subsystems (e.g., emergency locator transmitters and crash recorders). The application of these research results could greatly enhance the chances for occupant survival and injury minimization in the event of a crash.

Aerodynamics

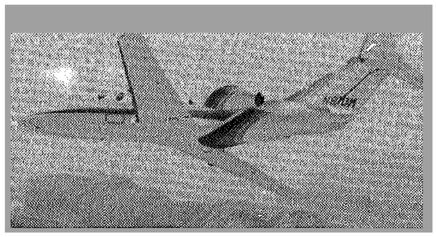
Because of the increased importance of aircraft fuel efficiency, research efforts to reduce aerodynamic drag have been intensified over the past decade. As a result of this research, some very significant progress has been made in the areas of parasite drag and induced-drag reduction. Many of the next-generation high-performance general-aviation aircraft incorporate some of this advanced aerodynamics technology (fig. 38). The application of supercritical high-aspect-ratio wing technology (as used on the Canadair Challenger, the Mitsubishi Diamond I, and the Cessna Citation 111) results in drag reductions of 10 to 15 'percent. Winglets are used to reduce induced drag on the Gates Learjet Longhorn 55 and the Gulfstream American Gulfstream III.

The drag reduction frontier in the far term involves the problem of skin friction, which accounts for about 30 to 50 percent of the cruise drag. While skin friction reduction offers high payoff, past experience has shown that it is also very difficult to achieve. In order to attack these difficulties, NASA has taken a multifaceted approach to this research, including both laminar boundary layer control and turbulence control (fig. 39). Maintenance of a laminar boundary layer on a surface can reduce skin friction by as much as 90 percent. Very smooth surfaces and controlled pressure gradients can delay the transition to turbulent flow and produce significant regions of natural laminar flow (NLF). The Learfan 2100 (fig. 38) is designed to achieve extensive NLF on the wings.

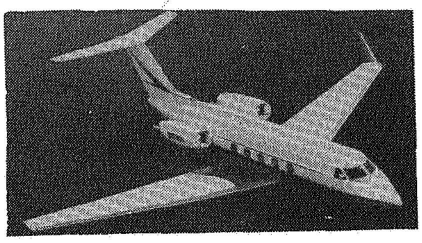
Recent flight tests using sublimating chemicals have confirmed the existence of appreciable regions of NLF on several powered aircraft. Some of these aircraft,



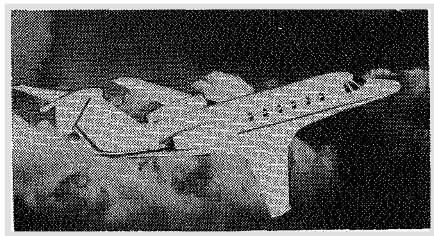
Gates Learjet Longhorn 55
55 passengers



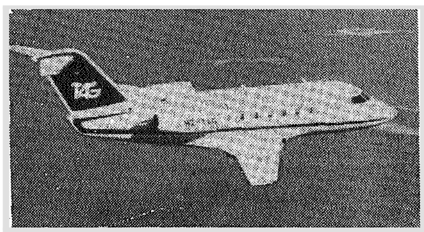
Mitsubishi Diamond I
7 passengers



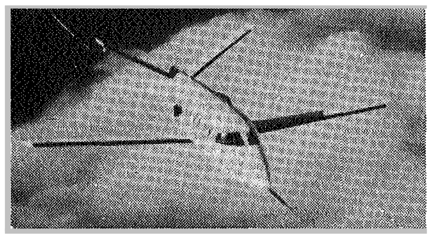
Gulfstream American Gulfstream III
19 passengers



Cessna Citation III
10 passengers



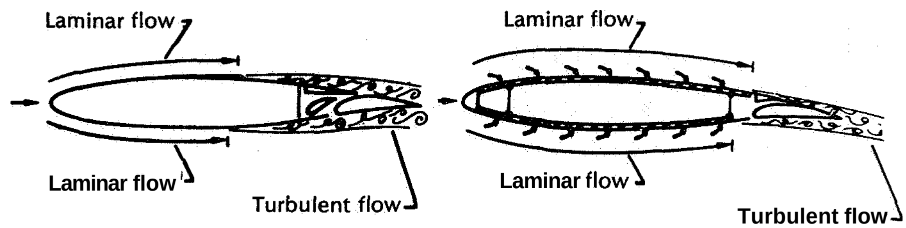
Canadair Challenger
11-13 passengers



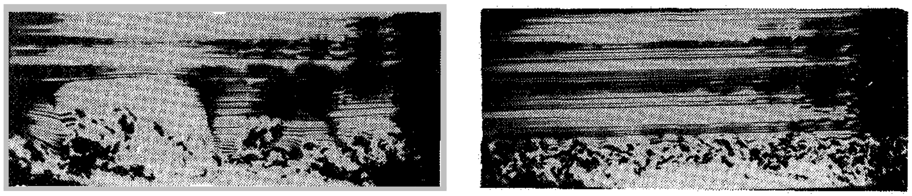
Learfan 2100
7 passengers

Figure 38.- Near-term generaI-aviation aircraft.

such **as** the Bellanca Model **25** Skyrocket (fig. 40), incorporate fust-generation **NLF NACA** 6-series airfoils developed in the **1940's.** Tests to date have indicated that the maximum theoretical extent of laminar flow is being achieved on the lifting surfaces of aircraft using modern smooth-construction methods up to chord Reynolds numbers of **2**1 million. **No** premature transition due to surface imperfections was found on any of the fiberglass airplanes. The **T-34C** aircraft was modified to test an advanced **NLF** airfoil designated **NASA NLF(1)-0215F** (ref. **29).** This airfoil was incorporated in a "glove" (fig. **40)** and tested at chord Reynolds numbers up to **18** million. The flight tests validated the extent of laminar flow as predicted by **both** analysis and wind tunnel tests. An advaneed



(a) Natural laminar flow. *(b) Laminar flow control.*



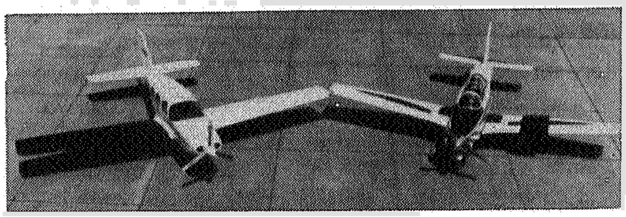
(c) Boundary layer flow without turbulence control (high drag). *(d) Boundary layer flow with turbulence control (low drag).*

Figure 39.- Skin friction reduction.

NLF supercritical airfoil was also flight tested on a modified F-111 aircraft over a range of wing leading-edge sweep angles from 10° to 26° at Mach numbers from 0.8 to 0.85. Results of this experiment demonstrated that a significant amount of laminar flow can be achieved at flight Reynolds numbers (based on wing chord) up to 30 million. The experiment also showed that significant laminar flow could be achieved at off-design cruise conditions of Mach number and leading-edge sweep. These test results encompass the region of interest for small transport aircraft. Although the results of these tests are exciting, much more work needs to be done to determine the maximum extent of NLF that is achievable for different operational requirements, and to develop methods of protecting NLF wings from ice and insect contamination.

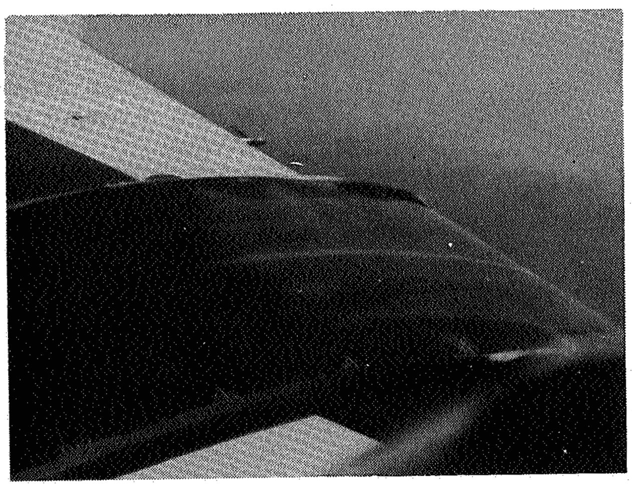
Research is also being conducted to develop airfoil designs with improved maximum lift and climb characteristics. In connection with this research, a handbook (ref. 30) was prepared on upper-surface airfoil contour modifications designed to improve maximum lift coefficients (and therefore stall characteristics) for the many small transport aircraft that use NACA 6-series airfoil sections. Such modifications may be used for possible retrofit on existing aircraft or in the design of new aircraft.

To establish an aerodynamic data base representative of current commuter aircraft technology, unpowered and powered wind tunnel tests of a 15-percent scale model of the Swearingen Metro II transport are being conducted under a cooperative research agreement with the Fairchild Swearingen Corporation. The first series of unpowered tests (ref. 31), which was completed in the NASA Ames



(a) Natural laminarflow test aircraft.

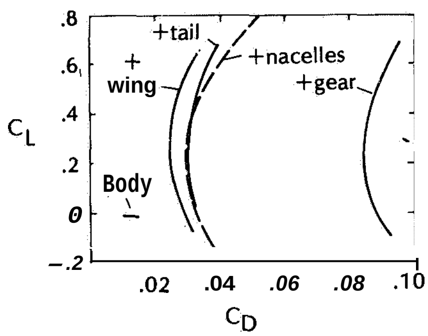
(b) Bellanca Model 25 Skyrocket.



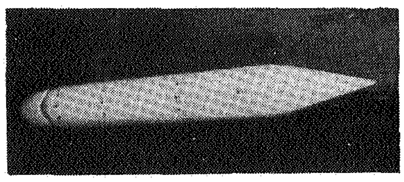
(c) T-34C glove.

Figure 40.- Natural laminarflow measurements.

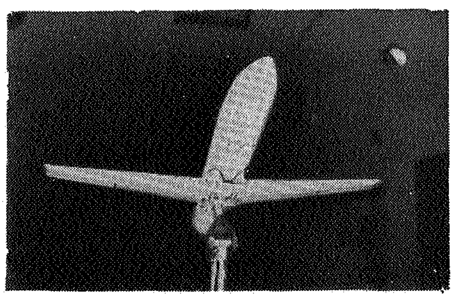
12-Foot Pressure Wind Tunnel in June 1980, tested aircraft component drag buildup, low-, mid-, and high-nacelle locations on the wing, modified wing leading edges, and an alternate flap design. (See fig. 41.) Limited wing flow visualization and pressure distributions (using pressure belts) were obtained with the engine nacelles on and off the wing. In 1983 this model will be tested with powered propellers (using small air turbine motors) and a fully pressure-instrumented wing in order to investigate the effects of the propeller slipstream on the wing aerodynamic characteristics.



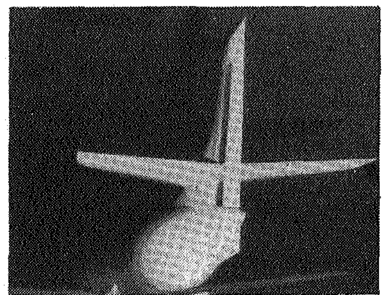
(a) Wind tunnel data. (Data not corrected for model support structure.)



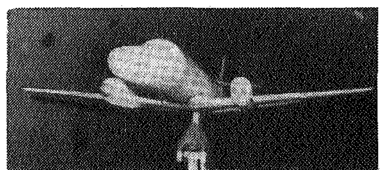
(b) Body.



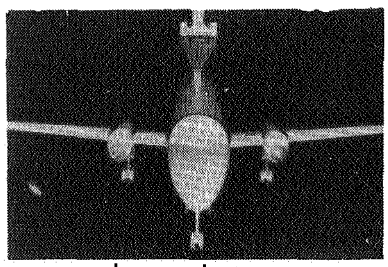
(c) Body + wing.



(d) Body + wing + tail.



(e) Body + wing + tail + nacelles.



(f) Body + wing + tail + nacelles + gear.

***Figure 41.**-Aerodynamic drag buildup characteristics of a typical small transport aircraft.*

Systems

Aircraft systems include the flight control system, the navigation and guidance systems, cockpit displays, and other aircraft subsystems (icing protection, cabin pressurization, air conditioning, landing gear, etc.) These systems are very important to the overall success of the aircraft design, including aircraft performance, passenger comfort, safety, and economics. Quite often these systems interact very strongly with other elements of the aircraft design. For example, one exciting new area of development is the union of modem control technology and aeroelasticity to minimize the weight penalty usually associated with highly flexible structures. Opportunities exist for controlling the maneuver loads on high-aspect-ratio wings, thereby taking advantage of the improved aerodynamic performance of a high-aspect-ratio wing with reduced weight penalty. Gust loads can also be controlled to reduce fatigue damage, improve ride quality, and reduce wing bending moments. Weight penalties for flutter avoidance can be minimized or eliminated with active flutter suppression systems. Successful application of these concepts requires improved methods for unsteady load prediction, integrated design techniques, and improved reliability of components and subsystems.

The application of active controls to the GlOl 1 is illustrated in figure **42.** In this case, a wing load alleviation system employing outboard ailerons was used to allow the L-101 1 wing span to be increased by 9 feet without major structural modifications. Flight tests of the extended span and wing load alleviation system demonstrated a 3-percent fuel savings. These modifications were subsequently

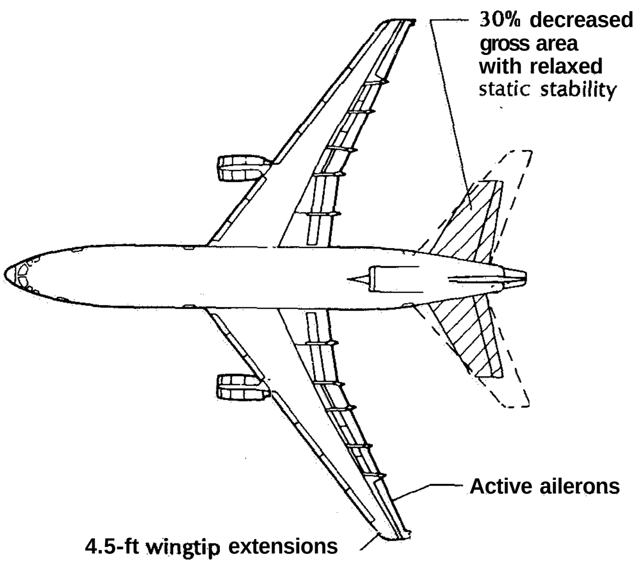


Figure 42.- Application of active controls to the L-1011.

included in the L-1011-500. Lockheed is also investigating the application of relaxed static stability to the L-1011. Based on analytical and wind tunnel studies, a 30-percent reduction in tail area could be achieved with this technique. Projected fuel savings for an L- 1011 having a smaller tail and operating at neutral stability are on the order of 4 percent. Lockheed, under contract to NASA, began flight testing a stability augmentation system in December 1981.

The revolution in digital electronics has dramatically impacted the design and capabilities of emerging avionics systems because of the spectacular reduction in cost, size, and power required by digital electronic components. For a given level of capability, system cost has decreased sharply with the transition from analog to digital hardware (fig. 43). Although digital systems have been used for a number of years in certain onboard applications (e.g., navigation), they are now being considered for safety-critical flight control applications. The new generation of civil transports, such as the Douglas DC-9 Super 80 and the Boeing 757/767 family, is using digital flight control systems. In the far term, reliable micro-processors will increase the utility and decrease the cost of avionics systems even further. These advances will provide new opportunities in the area of aircraft integrated avionics, with application to small transport aircraft as well as to the large transports.

The opportunities in aircraft integrated avionics systems are illustrated in figure 44. Concurrent with the trend in decreasing costs of avionics systems at the component level, impressive technology advances are being made in the use of these components for data sensing, data processing, and data transfer. In the area

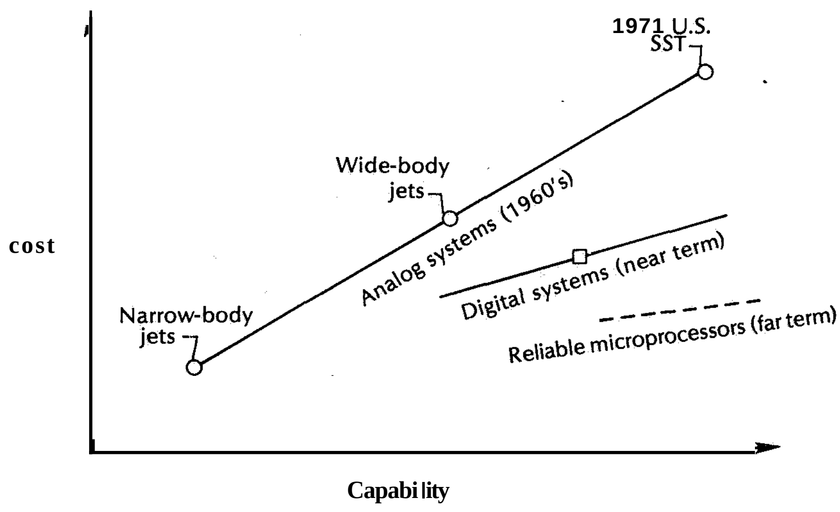


Figure 43.- Trends in avionics systems capability.

of data transfer, for example, high-speed data bus techniques, used in conjunction with microprocessors integrated at the device level, can provide an efficient means for the distribution and sharing of information among numerous subsystems. This can reduce weight and decrease the number of connectors required, and it will also facilitate the retrofit of new avionics systems without the need for extensive rewiring.

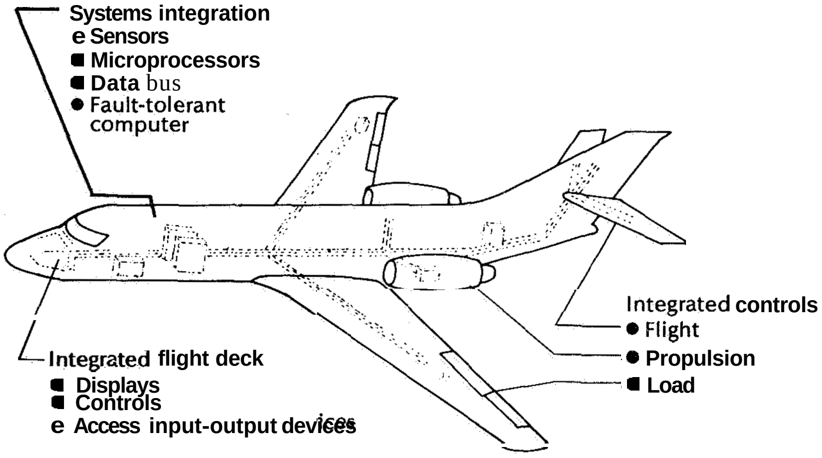


Figure 44.- Opportunities in integrated avionics.

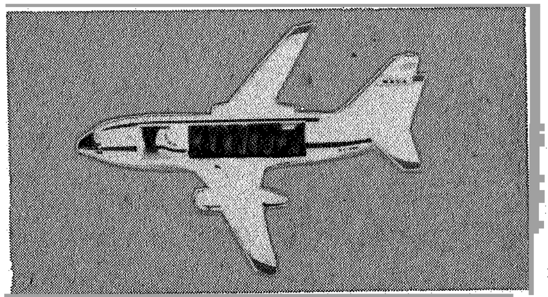
In addition to the improvements in fuel efficiency and reduced operating costs provided by digital fly-by-wire flight control systems, the use of electromechanical actuators in lieu of hydraulic actuators with these systems could offer additional benefits. Electromechanical actuator systems for aircraft have been under development for several years. The relatively recent development of samarium cobalt permanent-magnet brushless DC motors has made the use of these systems much more realistic because of the reduced size, weight, and power requirements of these motors compared to other electric motors. Replacement of the hydraulic actuators with electromechanical actuators could allow the removal of the entire hydraulic system (actuators, servos, pumps, line, and valves).

The major deterrent to widespread use of integrated avionics is systems reliability. The reliability goal for avionics and control systems is to obtain a system failure probability of less than 10^{-9} in 1 hour, which is 3 orders of magnitude better than the failure rate of today's triplex systems. In order to achieve these levels of reliability, two experimental fault-tolerant computer concepts are being developed at NASA Langley Research Center. Both concepts use redundant computer elements, but each employs a different approach to fault detection and isolation (software voting versus hardware voting).

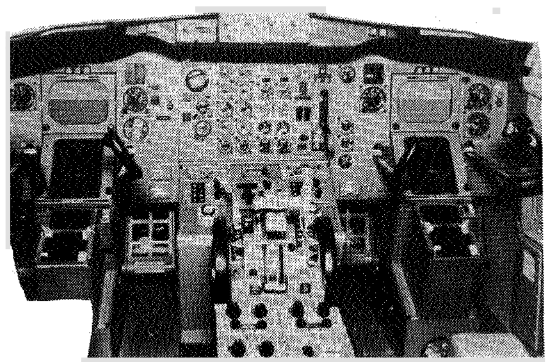
The design of "all-electric" flight systems requires careful integration of the airplane with the crew via advanced flight decks. Over the past several years, numerous flight experiments have been conducted using the NASA Terminal Configured Vehicle (now called the Advanced Transport Operating Systems, or ATOPS), a Boeing 737-100 equipped with a research cockpit in the cabin area (fig. **45).** The airplane has been flown from this experimental flight deck using a fly-by-wire control system, electronic displays, and pilot-selectable automatic navigation, guidance, and control functions in simulated Category III conditions. NASA, the FAA, industry, and airline pilots and engineers have participated in experiments that further characterized efficient descent and approach paths. These efforts were instrumental in establishing a data base that has led to the application of electronic display hardware and flight management keyboards in new transport aircraft, such as the Boeing 767/757.

Future work in this area will address recent advances in both display and control system technology. Advanced crew stations will be a principal focus of this research, to assure that proper integration of the crew with the airplane systems is accomplished. Toward this end, NASA and the Lockheed-Georgia Company are developing an advanced-concepts simulator design that can be used as a starting point for research studies. A number of candidate cockpit layouts were examined, and both conventional and futuristic configurations were considered. A desk-like console design has been chosen and a mockup has been fabricated (fig. **45).** The mockup is being used to investigate the initial placement of pilot controls, electronic displays, multifunction/multimode keyboards, touch panels, and voice recognition devices.

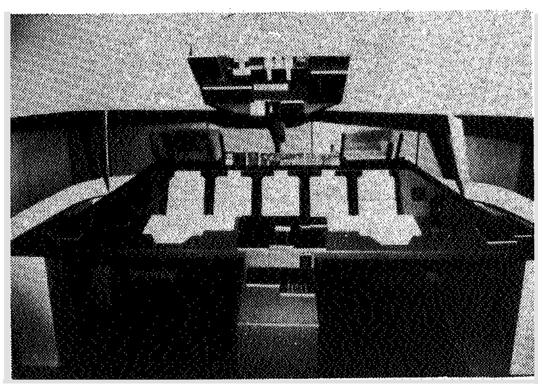
NASA research on display and control technology for GA aircraft also contributes to the development of concepts applicable to small transport aircraft. This research is not aimed at developing flight-weight hardware, which the industry is very well equipped to do, but is focused instead on research to explore the human factor interface between candidate cockpit display formats, avionics system capability, and aircraft performance and handling qualities. The research is conducted in a systematic manner to evaluate candidate concepts using simulators and flight test equipment. Some of the advanced technology resulting from research on single-pilot instrument flight rules (IFR) operations has shown great potential for reducing pilot workload and improving tracking accuracy. Display and control systems developed and flown on the general-aviation flight simulator at NASA Langley and on research aircraft at NASA Wallops Flight Center have demonstrated the advantages of advanced computer-generated display concepts in reducing pilot workload and improving flight track accuracy (fig. **46).** Work in control systems also includes research on advanced autopilot concepts. One such concept, the Automatic Terminal Approach System (ATAS), uses stored instrument approach data and interfaces with the aircraft radios and autopilot controls to fly instrument approach and enroute procedures automatically and safely. Other uses of the ATAS concept include a monitor mode and a direct air traffic control (ATC) mode. In the monitor mode, the pilot



(a) ATOPS research aircraft.

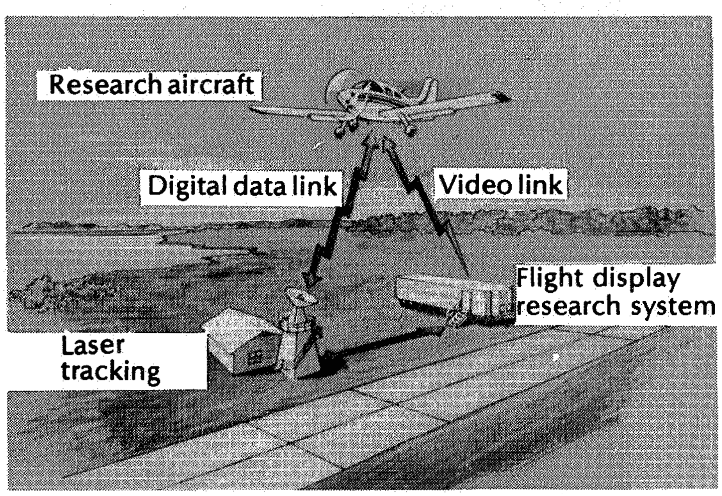


(b) ATOPS research cockpit.



(c) Advanced-concepts simulator.

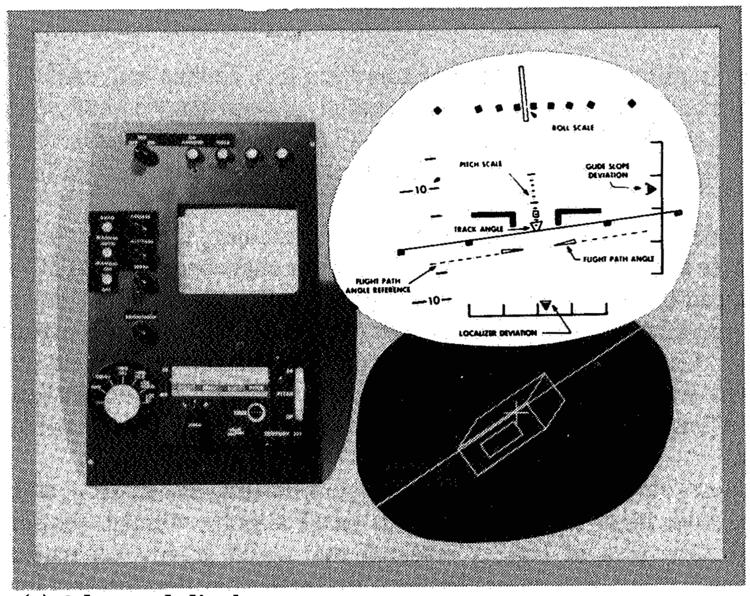
Figure 45.- Progress in flight deck technology.



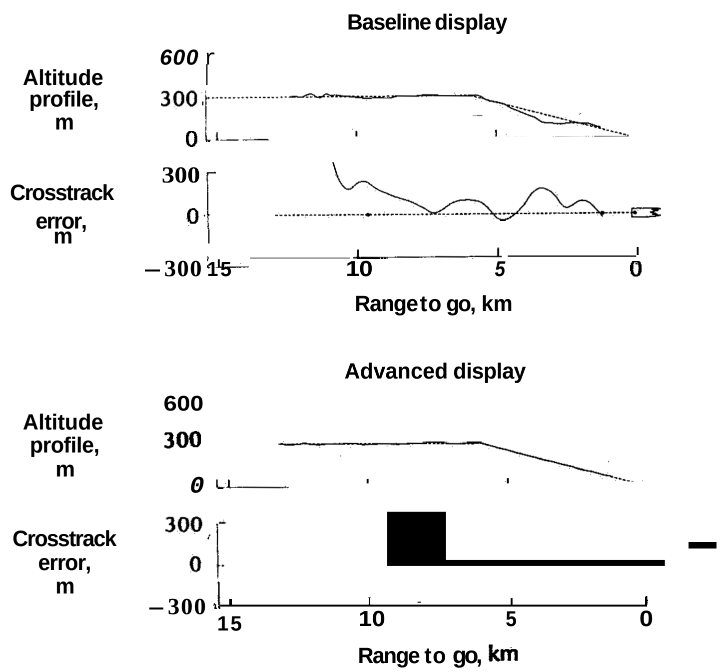
(a) Wallopsjlight testfacility.

(b) Langley general-aviation jlight simulator.

Figure 46.- General-aviation navigation, guidance, and human factors research.



(c) Advanced display concepts.



(d) Pilot ILS (Instrument Landing System) capture and tracking accuracy.

Figure 46.- Concluded.

flies the aircraft and the ATAS monitors the pilot's actions and warns if unsafe deviations occur. Thus the ATAS is essentially serving many of the functions of a copilot. In the ATC interface mode, the ATAS could provide a direct interface between the pilot-aircraft system and the next-generation air traffic control system.

Accomodating increased demand while maintaining the safe, efficient, and dependable flow of air traffic represents a major challenge for the ATC system. Directing air traffic to IFR requirements is already a serious problem, and with aircraft operations expected to double by the mid-1990's, airport congestion will reach an alarming level. With the exception of small, private fields, no new airports have been built in the United States since 1970 because of cost and other factors. Clearly, maximum use must be made of our airspace and existing airports.

Commuter airlines must be able to operate efficiently and safely at all kinds of airports, from large congested hubs to small airports without control tower facilities. One area of NASA research that could greatly enhance aircraft operations at small, non-tower airports is the technology development for a low-cost Automated Pilot Advisory System (APAS). Such an experimental system was tested in 1981 at Manassas Municipal Airport, Manassas, Virginia. The APAS was conceived as a natural extension of the procedural visual flight rules (VFR) system used at non-tower airports. It provides traffic and weather advisories to all aircraft operating in the vicinity of the airport. The experimental system was extremely successful (ref. 32), and if implemented could greatly assist small transport aircraft operations at non-tower airports.

The FAA has an extensive program for developing an improved ATC system. The two-way data link associated with the Discrete Address Beacon System (DABS) (now referred to as Mode S), in conjunction with upgraded computers, will provide the vital missing element for a quantum jump in advanced operating procedures (fig. 47). Mode S, which is scheduled to become operational in the late 1980's, will be capable of uplinking many services to aircraft equipped with electronic displays and other appropriate input-output devices. Eventually these services should augment voice communications with messages providing such information as altitude assignment, weather data, and runway conditions. Mode S may be used to uplink other information, such as holding instructions, approach and departure clearances, and metering and spacing commands. It may also be used to transmit data for Cockpit Display of Traffic Information (CDTI). Ultimately it may relay to cockpit displays the necessary traffic time sequencing data to allow precise space and time (4-D) navigation from takeoff to landing.

The navigational capability provided by the Microwave Landing System (MLS), which is slated for initial implementation in the mid-1980's, will be an important factor in terminal area operations. The MLS will permit the generation of high-precision guidance commands, which will enable aircraft to follow trajectories that have been optimized for energy efficiency, noise reduction, and

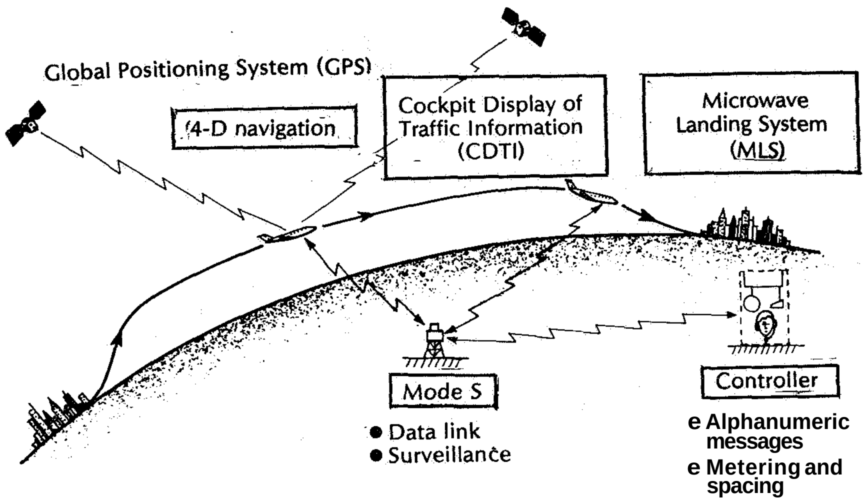


Figure 47.- Air traffic control and flight management.

airport capacity. Another possibility for upgrading the volumetric coverage of accurate navigation information is offered by a satellite-based navigation system (e.g., the Navstar Global Positioning System, or GPS) which will provide position and velocity information over the entire globe and at all altitudes.

As a counterpart to the FAA ground system development effort, NASA is developing advanced airborne system technology that will contribute to safe and efficient operation of aircraft in the future ATC system. These studies, which involve applied human factors, include research in the areas of energy management procedures and displays, CDTI, and data link applications that may increase operating efficiency.

NASA has conducted time-based metering experiments in the Denver area with the NASA Boeing 737 and in the Dallas-Ft. Worth area with the Lockheed L-1011. These tests were conducted in conjunction with the FAA, using a local flow management profile descent concept for arrivals into the terminal area (fig. 48). This concept provides fuel savings by matching aircraft arrival flow to airport acceptance rate. Time control computations allow the pilot to descend at his discretion from cruise altitude to the metering fix and an idle-thrust configuration. NASA developed and flight tested an airborne descent algorithm designed to improve the accuracy of delivering an airplane to a metering fix at a time designated by ATC. The Denver experiments demonstrated that arrival accuracy was improved from current levels (1½ to 2 minutes) using guidance from the radar controllers to within plus or minus 10 seconds with the airborne 4-D flight system (fig. 48). Workload for both pilots and controllers was also much less under test conditions with the airborne algorithm.

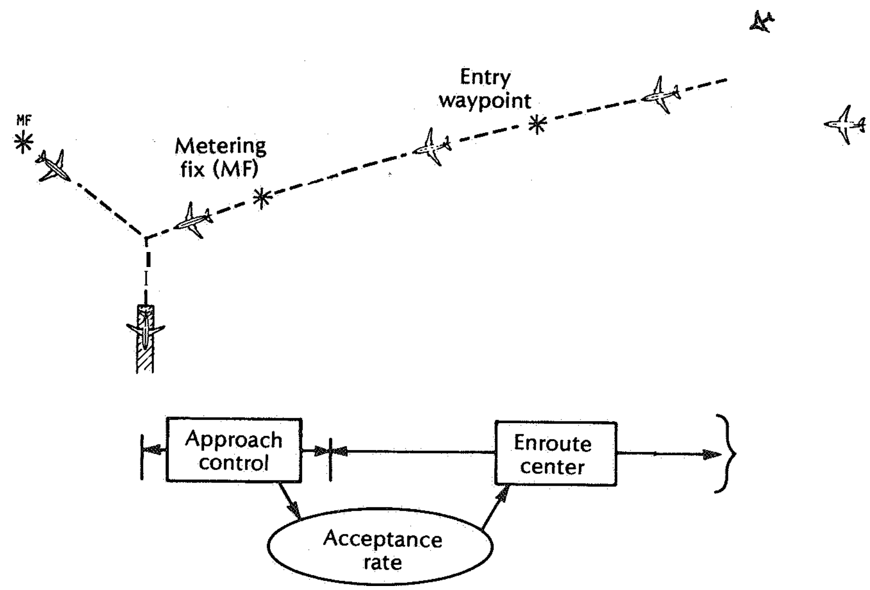


*Figure **48.**- Time-based metering experiment.*

The potential benefits and liabilities associated with displaying traffic information in the cockpit (fig. 49) are being examined in a joint FAA-NASA program utilizing highly integrated simulation and flight facilities. Studies to date have defined information requirements and formats for a workable display, and

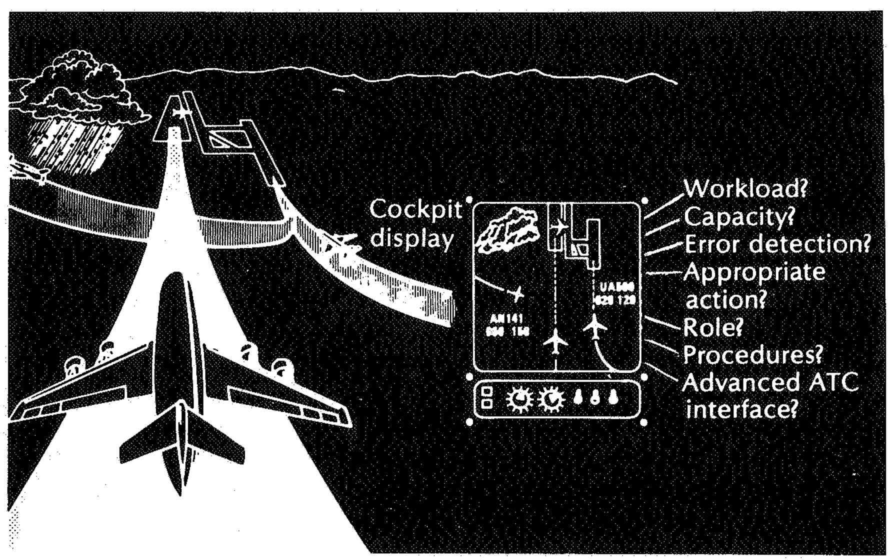


*Figure **49.**- Cockpit Display of Traffic Information (CDTI).*

considerable insight has been provided on pilot ability to use the display for active roles, such as self-spacing on another aircraft. Considerable work remains in the investigation of benefits and liabilities, and both operational and regulatory procedures for using the traffic display have yet to be determined.

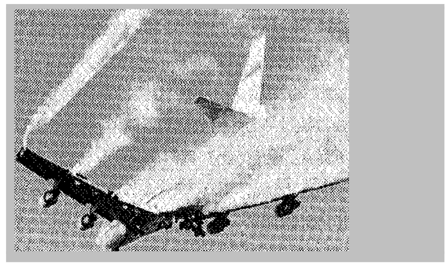
Although advanced avionics, controls, and displays offer great promise for increased efficiency in the terminal area, the current restrictions on separation distance have been set because of the wake vortex hazard. Under IFR conditions this restriction requires a spacing of at least 6 miles for a light aircraft behind a large wide-body transport. Airport congestion, which severely limits the operation of both small transport aircraft and large aircraft, will not be relieved until this restriction is reduced substantially or removed. For several years NASA has conducted research aimed at solving this problem. Work is focused on both wake avoidance and wake attenuation.

Under visual flight rules, flight crews routinely reduce their in-trail separation behind other aircraft. They avoid the wake vortices of the aircraft ahead of them by piloting their aircraft along a slightly altered trajectory. Simulation experiments using CDTI have recently been initiated whereby the lead aircraft is displayed in a forward-looking perspective on a head-up display that can also provide a computer-drawn runway symbol and other guidance information. Consecutive aircraft approaching the same runway could perhaps be assigned different flight paths with a different glide slope angle and different runway intercept. One challenge is to provide a display that will permit the crew to maintain the prescribed separation and monitor the operation of the preceding aircraft for deviation from a nominal descent on its prescribed approach path. Other challenges include resolution of several operational issues; for instance, how to handle the conflict generated when an aircraft on the lower glide path initiates a missed-approach procedure.

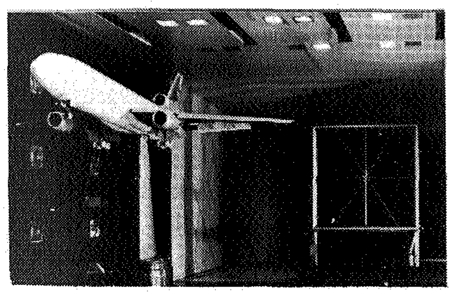
The introduction of heavy jet transport aircraft into airline service in the early 1970's accentuated the problem of wing wake vortices for smaller following aircraft. NASA has conducted extensive research in an effort to develop technology that could alleviate the strength and persistence of these vortices. Early tests in the Langley Vortex Research Facility and in flight indicated that wing-mounted splines were a promising means of vortex attenuation (fig 50). Analysis of flight test data obtained using a C-54 as the wake-vortex-generating aircraft and a Piper PA-28 as the probe aircraft indicated substantial wake vortex attenuation. The minimum distance at which vortex-induced roll of the trailing aircraft was within its roll control power was reduced from 2.5 nautical miles behind an unmodified generating aircraft to less than 0.6 nautical miles behind the same generating aircraft with splines extended (ref. 33). Although the splines did significantly reduce the C-54's rate of climb, the four-engine climb performance remained acceptable and there were no noticeable changes in handling qualities.

Other wake vortex attenuation methods have also been investigated in wind tunnel and flight tests (using smoke to make the vortices visible). (See fig. 50.)

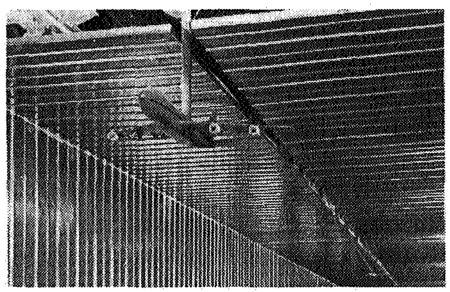
(a) Vortex-reducing splines.



(b) Spoiler and flap positions.



(c) Experiments in Langley 4- by 7-Meter Tunnel.



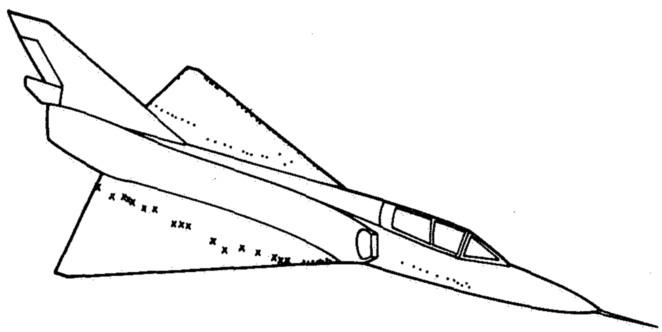
(d) Vortex research facility tests.

Figure 50.- Aircraft wake vortex research.

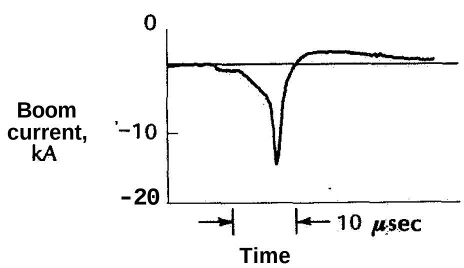
Altering the spanwise loading (for example, retracting outboard flaps) generates systems of vortices that can interact to produce earlier dissipation of the vortex core. The use of spoilers to alter the load distribution as well as to generate turbulence is also effective for some aircraft configurations. Oscillating the spoilers and ailerons in a way that produces a periodic aircraft roll can achieve essentially total wake alleviation. Research is currently continuing on the mechanism of vortex behavior in order to develop operationally acceptable alternatives.

Another deterrent to efficient operation is weather. More information is required on storm hazards and how best to operate aircraft in the vicinity of severe storms. NASA is investigating various methods of providing timely thunderstorm and other weather information to the cockpit. Two other areas of particular concern are lightning and icing conditions.

Some uncertainty exists regarding the way composite structures react to direct lightning strikes. Digital electronic control and avionics systems must also be protected against possible catastrophic effects. Almost all the engineering data available on lightning characteristics have been obtained from cloud-to-ground strokes to instrumented towers. Characteristics of lightning at flight altitudes have not been measured before. NASA is currently obtaining such data by flying a highly instrumented F-106B aircraft into thunderstorms and measuring both the current and the electrical and magnetic flux rates of change for lightning strikes to a time resolution of 10 nanoseconds (fig. 51). As of July 1982, 62 storm flights had been made, with 321 thunderstorm penetrations. Detailed information was obtained for 75 direct strikes and 123 transients (time histories of measured current rise). Several swept strokes have occurred midspan across the wing, and this unexpected phenomenon requires further study. The peak current recorded to date is 15 000 amps. Flight tests are planned to continue through 1982 and 1983. These flight tests support several theoretical modeling activities which are currently under way.



(a) Pattern of unexpected strikes on F-106. Top = ●; bottom = ×.



(b) Transients.

Figure 51.- Lightning hazards research.

Small Transport Aircraft Technology

Over the last few years, the need for advances in ice protection technology has become increasingly evident. Because of fuel cost increases, aircraft designers are seeking better ice protection systems to save weight and fuel. In response to this need, NASA has reestablished an icing research effort at the Lewis Research Center. Studies have recently been completed by both the Douglas Aircraft Company, McDonnell Douglas Corporation (ref. 34) and Rockwell International Corporation (ref. 35) under contract to NASA to determine icing technology and research needs for large transport, light transport, and general-aviation aircraft. The objectives of this research encompass improved icing forecast capability, more accurate ice detection instrumentation, low-cost protection systems, and improved certification methods. This research program includes both short-term goals over the next 5 years and long-term goals extending over 10 years. Developing improved icing protection systems is very important for future small transport aircraft because they spend such large amounts of time in the low-altitude icing environment.

Additional Research Needs

The Ad Hoc Advisory Subcommittee on Commuter Air Transport Technology, which was made up of appropriate representatives from government, universities, airlines, and airframe, engine, and propeller manufacturers, met in November 1980. The Subcommittee members reviewed future commuter aircraft requirements and available STAT study results, and assessed NASA's ongoing aeronautics program for applicability and adequacy for future commuter transport needs. (The Subcommittee's conclusions and recommendations are presented in the report at the back of this publication.)

Briefly, the Subcommittee recommended that NASA undertake an aggressive research program in order to prepare the specialized small transport technologies for commercial development within the next 5 years. The overall goal of this research (fig. 52) would be the establishment of technology readiness to enable significant advances in future commuter aircraft. Results of the STAT studies have indicated the possibility of such improvements as a 20-percent reduction in direct operating cost (DOC), a fuel savings of 35 percent, increased reliability and safety, a level of passenger comfort equivalent to that of the Boeing 727, and reduced maintenance. The Subcommittee recommended numerous specific technology objectives that included improved aerodynamic performance, increased propulsion efficiency, and reduced structural weight (primarily through the application of composite materials). It was also suggested that improvements be sought in systems for flight management, pilot workload reduction, icing protection, and engine condition monitoring and fault detection. Although a wide spectrum of technology objectives and possible programs emphasizing commuter aircraft needs was recommended, in most cases the Subcommittee did not delineate priorities or distinguish between ongoing program elements and possible augmentations.

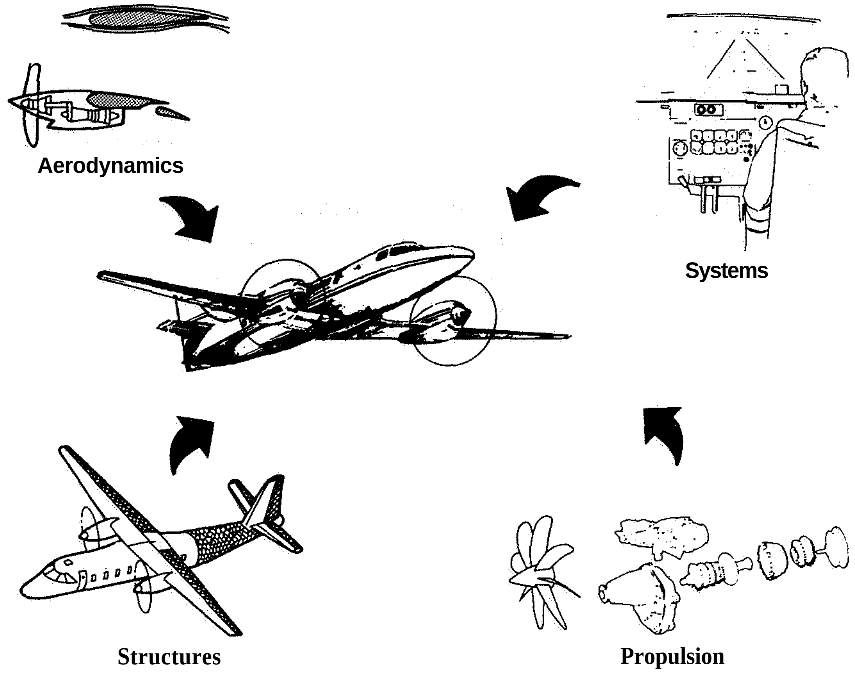


Figure 52.- The overall goal of the small transport aircraft technology (STAT) research is to identify and demonstrate the cost-effective application of advanced technology to allow the development of significantly improved small short-haul transport aircraft.

In evaluating the requirements for specific small transport technology research efforts, NASA can base its program considerations on information from the completed set of STAT studies, the recommendations of its advisory committees, and the results of many discussions with government, industry, and university representatives. From all this information it is concluded that many of NASA's ongoing and planned aeronautics programs directed at transport aircraft and general aviation, as well as many of those directed at fundamental technical disciplines, are largely applicable to or supportive of advanced commuter aircraft requirements. However, certain shifts of emphasis or augmentation in several areas would be needed to exploit fully the possible opportunities for commuter aircraft technology advancement envisioned by the STAT studies. The following topical discussions identify a number of these potential augmentations or shifts of emphasis. The extent to which these various opportunities should or could be implemented has not been determined because of such important considerations as resource limitations, relative importance compared with technology requirements in other application areas, and the prospects of the resulting technology utilization by U.S. industry.

Propulsion

Since propulsion system improvement (fig. 53) is an important ingredient in developing a more fuel-efficient and economic future small transport aircraft, specific emphasis is needed on appropriate engine and propeller technology. Although research on large engines and high-speed propfans for larger transports is related to advanced commuter needs, it is not entirely applicable. On the other hand, the smaller propulsion system technologies in the general-aviation program do not extend far enough into the size and power ranges needed by future commuter transports. The necessary research would draw upon and extend the technology developed in the ACEE and general-aviation programs, notably in propeller design, acoustics, turbomachinery analysis, digital engine controls, materials, and performance retention technology.

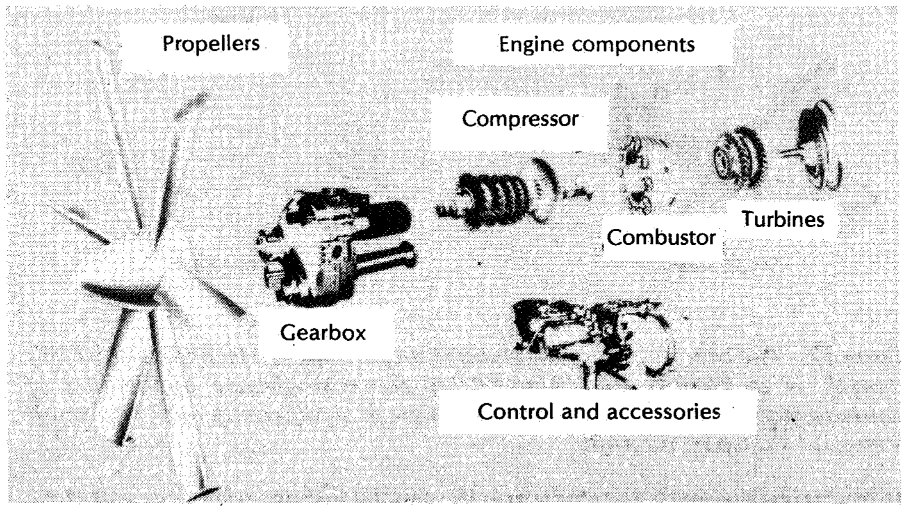
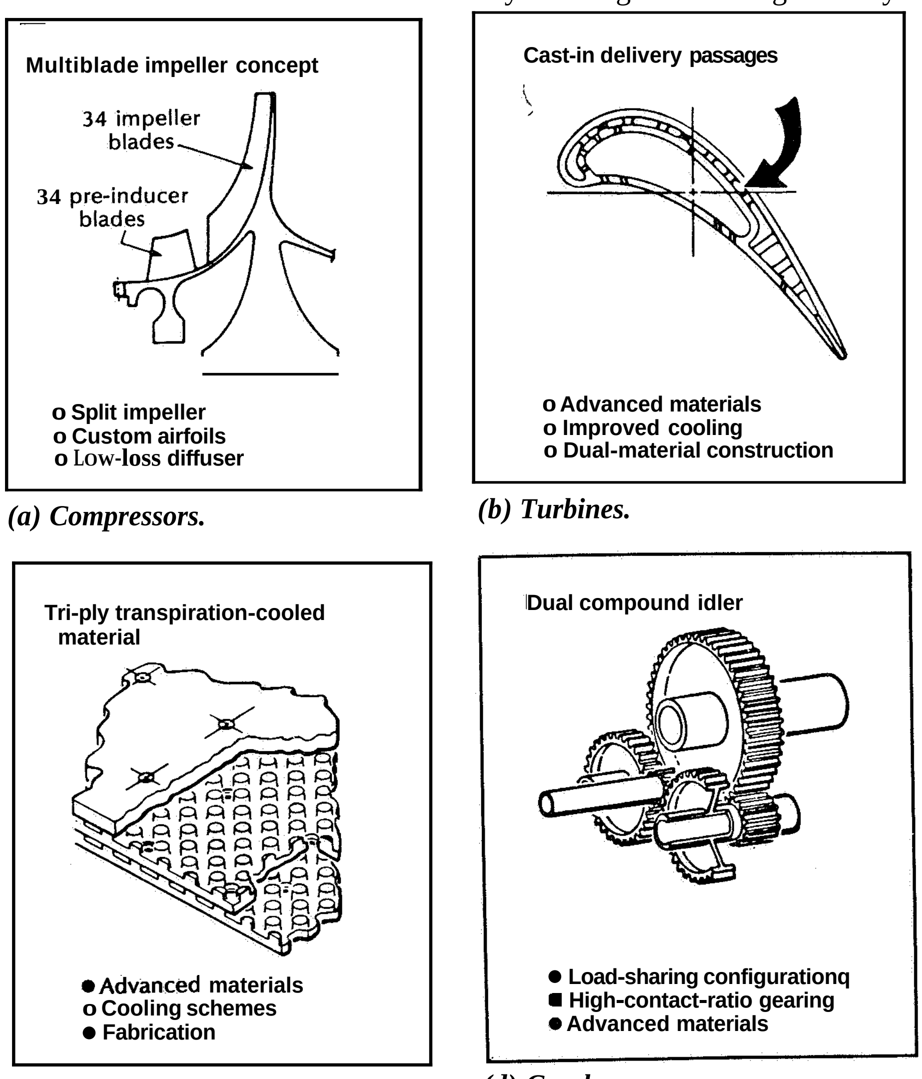


Figure 53.- Improvements in propellers and engine components resulting from small transport aircraft propulsion research. Potential benefits include: (1) a 20- to 30-percent reduction in fuel use, (2) a 10- to 20-percent decrease in DOC, (3) a 15- to 25-percent weight savings, (4) a maintenance cost reduction of 25 to 55 percent, (5) a noise decrease of 10 dB, and (6) improved reliability.

Engines

The additional small-transport propulsion research could complement the ongoing program for larger engines by addressing problems unique to smaller (1000- to 5000-shp) turboprop powerplants designed for severe-duty-cycle commuter transport applications. The turbomachinery in this size class is significantly constrained by small-component manufacturing and design complexity limitations that restrict cycle pressure ratios to no more than 20:1, instead of nearly twice that for large engines. These same limitations lead to axi-centrifugal or dual-centrifugal compressor configurations, very small airfoils, especially challenging problems in sealing and turbine-cooling design, unique combustor designs, supercritical shafting, and other engine design requirements that must achieve technological solutions which are different from those for large engines.

Some potential small transport engine technology advances identified in the **STAT** engine studies discussed previously are illustrated in figure **54.** Centrifugal compressor impellers that are split into two distinct regions would theoretically increase compression efficiency by about **1** percent by allowing the blading to be better tailored to local flow conditions and by retarding loss-inducing boundary



(a) Compressors. *(b) Turbines.* *(c) Combustors.* *(d) Gearboxes.*

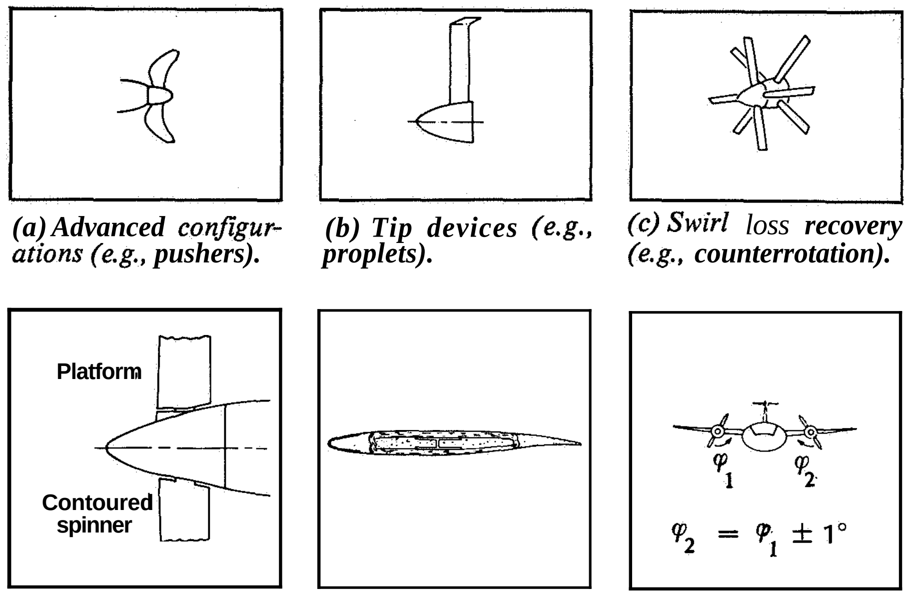
Figure 54.- Small transport aircraft engine technology.

layer growth. Similar gains could be expected from the use of customized axial airfoils and advanced diffuser concepts. Small turbines could be made more efficient by incorporating improved materials with greater strength at high temperatures, and by using advanced fabrication techniques to implement better cooling schemes. Also, since the best turbine blade materials are relatively poor choices for turbine discs, advanced fabrication concepts such as bonding a cast integral blade ring to a machined disc of a different material could be investigated. Similar technologies that are appropriate in each of the other engine components include better materials and cooling concepts for combustors, load-sharing gearbox configurations and high-contact-ratio gears, metal composite shafts, digital electronic control of propeller and engine as a system, improved foreign-object protection systems, and diagnostic monitoring systems that determine both engine health and the life of individual components in order to facilitate low-cost maintenance strategies and improve reliability. Some of these concepts are being pursued in the ongoing program.

Propellers

Propeller research in the U.S. was reactivated only 5 years ago after decades of neglect, and there is much to be done. A number of advanced propeller concepts are very promising for advanced turboprop commuter transports (fig. 55), but they cannot yet be implemented because sufficient experimental evaluation has not been conducted and advanced analytical techniques for accurate prediction of performance and structural behavior are not available. These concepts include advanced composite blades and airfoils, tip devices such as proplets, swirl loss recovery through counterrotating propellers, and better integration of the blade-spinner interface. Since pusher propeller configurations are also under consideration for some advanced aircraft designs, the unique problems associated with this arrangement (i.e., ingestion of airfoil wake and/or engine exhaust) should also be addressed. Additionally, theoretical calculations indicate that a substantial cabin noise reduction (up to 8 dB) is possible in some airplane configurations if the left and right propellers can be precision synchrophased to within 1°.

Several needs and opportunities for propulsion system improvement were identified and recommended to NASA as possible augmentations to the ongoing program. In addition to suggesting research and technology efforts to improve engine components and propellers, the Subcommittee also recommended that the component research ultimately be brought together and focused in an experimental engine program phase to establish the state of technology readiness required for subsequent commercial development of new engines. It was noted that some of the component research could benefit existing engine types in the



(a) Advanced configurations (e.g., pushers). *(b) Tip devices (e.g., proplets).* *(c) Swirl loss recovery (e.g., counterrotation).*

(d) Blade-spinner integration. *(e) Advanced airfoils and composites.* *(f) Noise reduction (e.g., precision synchrophaser).*

Figure 55.- Advances in small transport aircraftpropeller technology.

relatively near term rather than exclusively serving the future development of new engines.

Structures

The STAT studies (including ref. 36) have indicated that the application of advanced materials and manufacturing techniques, particularly with composites, could contribute significantly to improving future small transport aircraft via weight reduction, smoother aerodynamic surfaces, reduced manufacturing cost, and improved crash safety **(fig. *56*)**. This is an area in which ongoing research and the technology developed for larger transport application are almost directly applicable to future small transport aircraft.

An outstanding example of the application of composite materials is the Learfan **2100** currently under development **(fig. 57).** The aircraft structure is almost entirely of composites; the wing, fbselage, tail, control surfaces, and flaps are all graphite/epoxy. The interior elements of the aircraft, including the seats,

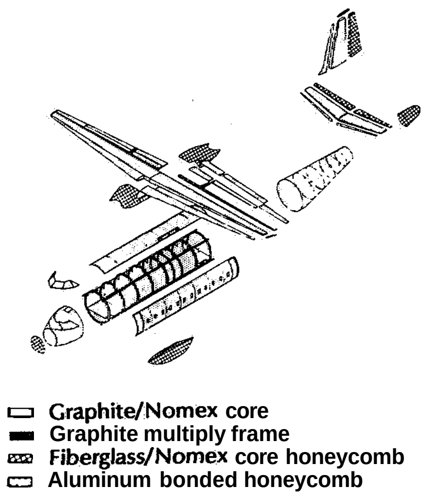


Figure 56.- Small transport aircraft materials and structures technology. Potential benefits include: (1) fuel savings of 4 to 17 percent, (2) DOC savings of 5 to 15 percent, (3) initial cost reductions of 4 to 16 percent, (4) weight reductions of 10 to 20 percent, (5) reduced maintenance, and (6) improved crash safety.

Figure 57.- All-composite structure in Learfan 2100.

headliner, and interior surfaces of the bulkheads, are also composites. The only metal components other than the engine are the landing gear, propeller hub, and many small structural fittings. Even the propeller blades are made of Kevlar/epoxy.

During September and October 1981, NASA personnel visited the major U. S. general-aviation aircraft manufacturers to discuss their current capabilities and technology needs in the field of composite structures. These visits indicated that the existing in-house composite capabilities of these companies vary from strong to almost nonexistent. Unlike the larger aerospace companies, the general-aviation aircraft companies do not have in-house staffs conducting research and development in materials and structures. In addition, the companies have not had the benefit of NASA and Department of Defense (DOD) technology development contracts for composites.

Nevertheless, several other general-aviation aircraft companies in addition to the Lear Avia Corporation have already demonstrated an ability and willingness to use existing composites technology to varying degrees in their product lines. Cessna uses graphite/epoxy and Kevlar/epoxy to make weight-and stiffness-critical structures for the Citation III. (See fig. 35.) The Gates Learjet Corporation is considering the use of existing graphite/epoxy technology in order to reduce the wing weight of the Longhorn 55.

With very few exceptions, the GA aircraft companies plan to use existing composite materials for future structural components. Therefore, their present collective need is for more and better data on existing composite materials (e.g., design allowables, environmental effects, and moisture degradation). A few companies expressed the desire for extensive support from NASA to establish a company capability to use existing technology. However, the companies all agreed that they have a long-term need for the development of new low-cost materials and processes.

The GA aircraft companies do not appear to require extensive assistance from NASA to develop the capability to apply existing graphite/epoxy and Kevlar/epoxy composites technology, except possibly in the area of primary structure. Lear Avia is the only U.S. GA aircraft manufacturer with experience in composite primary structure. Although existing composite materials and processes are in limited use by some of the other GA aircraft companies, manufacturers feel that this technology is not sufficiently cost effective for extensive application at this time, particularly for the lower priced aircraft. (This U.S. position is not reflected in Europe, where composite aircraft technology has been progressing rapidly over the last 20 years and is now being applied to produce substantially improved small general-aviation aircraft that are also very cost competitive with U.S. products.)

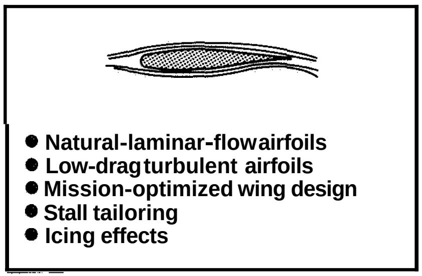
As recommended by the Ad Hoc Advisory Subcommittee on Commuter Air Transport Technology, the application of composite materials to future small transport aircraft could be accelerated through government involvement with the general-aviation industry in the design and testing of some primary structure components. The Subcommittee recommended a focused effort on the wing structure, somewhat similar to that currently being funded by the French government for Aerospatiale's development, testing, and certification of a composite wing box for the Dassault-Breguet Falcon business jet aircraft. However, without additional funding, NASA would have to limit its research to low-cost materials and processes for future applications. NASA recently initiated a study to identify materials, processes, and structures with potential for future applications, and to provide a focus for subsequent research and development. Depending on the results of this study and on the ongoing in-house materials research being conducted, it may be desirable to substantially increase the structures and materials efforts 2 to 3 years hence in order to develop the required data base for promising new materials.

Aerodynamics

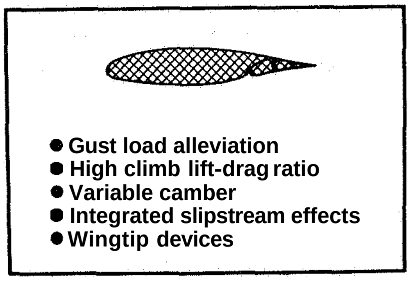
Advanced aerodynamics technology provides the basis for developing future small transport aircraft designs with increased performance, improved efficiency, and better handling qualities. Although much of the ongoing NASA research in aerodynamics, as previously outlined, is pertinent to future small transports, several areas exist in which specific needs may not be adequately covered. These areas, which are indicated in figure 58, were discussed by the Ad Hoc Subcommittee on Commuter Air Transport Technology.

The Subcommittee concluded that there is a present need for aerodynamic design information with particular applicability to low- and moderate-speed small transport aircraft. More information is needed, specifically in the areas of (1) low-drag and high-performance airfoils, including natural laminar flow, (2) three-dimensional wing design, including high-lift devices and the effects of tip configurations, movable surfaces, leaks, gaps, and protuberances such as flap tracks, and (3) overall aerodynamic design integration, including unconventional configurations and propulsion effects. The Subcommittee suggested that some of the needed information and data may have been developed decades ago but is not known today by those presently concerned with small transports. It recommended a thorough reexamination of available data, both to highlight what is available and to identify gaps that should be researched. This would be part of the needed effort to develop a data base of three-dimensional aerodynamic design data. It also emphasized that the design sensitivities to the numerous parameters noted previously should be determined

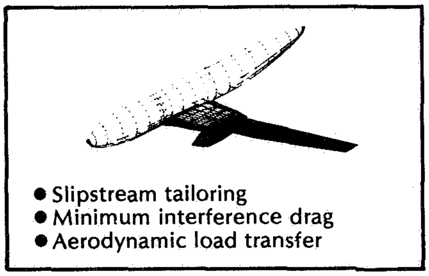
The Subcommittee recognized the potential for substantial drag reduction using natural laminar flow (NLF) airfoils, but was skeptical of the manufacturing and operational practicality. As discussed in the preceding section, recent flight measurements have provided increased confidence in the practicality of obtaining and maintaining NLF. Based on these results, increased effort may be appropriate to accelerate the implementation of NLF airfoils on future small transport



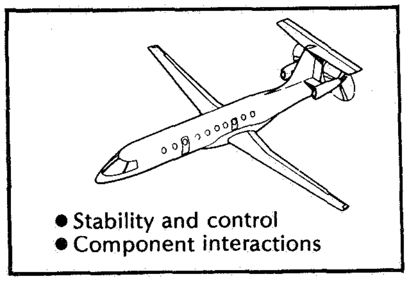
(a) Airfoil and wing design.



(b) Control and high-lift devices.



(c) Engine-airframe integration.



(d) Advanced configurations (canard, three-surface, and tandem wing).

Figure 58.- Areas of small transport aircraft aerodynamics technology in which further research is needed. Potential benefits include: (1) fuel savings of 10 to 20 percent, (2) DOC savings of 6 to 10 percent, (3) improved performance, and (4) enhanced handling qualities.

aircraft. This research must address the surface waviness and roughness criteria, insect and icing protection systems, and three-dimensional wing design, including high-lift devices, controls, and engine integration (such as propeller slipstream and wing/nacelle junction) effects.

Also needed are empirical and theoretical data to aid in assessing the effects of special-configuration elements such as empennage arrangement (T tail, cruciform, and low tail), wing position, and unconventional configurations (flying wings, forward-swept wings, canards, tandem wings, etc.). The question of configuration type and design speed as functions of the gradually increasing stage length also needs to be studied. An additional possibility might be the wider utilization of flaps for climb and cruise as well as for landing and takeoff conditions.

The principal asset of commuter airlines is their ability to provide on-time arrivals and departures with schedules that emphasize frequency of service. More effective high-lift devices will enhance that ability by reducing the maintenance (both scheduled and unscheduled) associated with takeoffs and landings. Lower stalling speeds will reduce takeoff and landing loads and brake and tire wear.

Better maneuvering capability associated with improved handling qualities, high-lift devices, and direct-lift-device glide path control will reduce the time spent by commuter aircraft in the terminal area, and will also allow such aircraft to use stub runways at hub airports.

Additional effort may also be appropriate in the area of basic stability and control. Improved capability is needed to predict the stability and control behavior (including power and control system effects) of conventional and, in particular, of advanced configurations (e.g., canards and pushers). Aerodynamic interference between propeller slipstreams and leading-edge devices should also be explored.

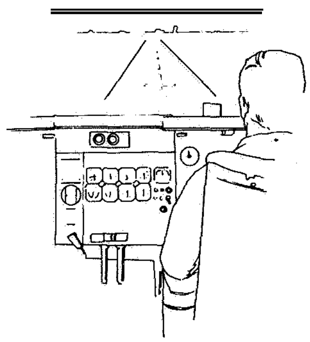
The important factors producing good ride qualities should be determined and then related to the aircraft aerodynamic parameters (such as lift-curve slope, wing loading, and lift distribution control systems), so that ride quality can be considered as part of the basic aircraft design.

Research on aerodynamic considerations that affect the safety of flight should be emphasized. Ground effect during flare is a particularly important area for commuter-class aircraft because of their reduced wing loadings. In other areas, the Subcommittee recommended that NASA should make its extensive and excellent facilities more available to industry, It is especially important that three areas of research and development be more closely integrated and related —these are wind tunnel experience and data, computational aerodynamics, and flight simulation. They should be carefully coordinated to yield more synergistic results.

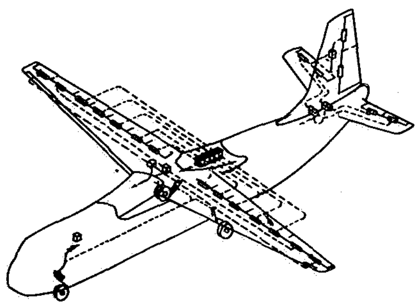
It appears that although many of NASA's ongoing programs in aerodynamics are relevant to commuter transports, there are several opportunities and needs that are not adequately supported. In addition to the previously noted specific research augmentations in several areas of aerodynamics, it has been recommended that many of the technology elements involved be focused eventually in a low-drag wing design demonstration project embodying the advanced aerodynamics, active load alleviation, and relaxed stability features believed to be most important in an advanced high-performance commuter transport. Such a wing would also incorporate advanced composite materials technology, thereby achieving the aerodynamics and structural objectives simultaneously. This research would provide knowledge and confidence to those who may wish to develop future improved small transports.

Systems

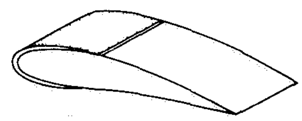
Many of the systems requirements for commuter transports of the future may not differ markedly from those for large transport aircraft and the more sophisticated general-aviation aircraft (fig. 59). Advanced systems research and development have been in progress for a number of years. The Subcommittee recommended (1) additional attention to commuter applications and research



(a) Avionics.



(b) Flight controls.



(c) Icing protection.

Figure 59.- Small transport aircraft systems technology. Potential benefits include: (1) fuel savings of 10 to 15 percent, (2) DOC savings of 6 to 10 percent, (3) improved ride quality, (4) reduced pilot workload, and (5) increased schedule dependability.

efforts in flight management and performance management systems and related cockpit displays, (2) improved icing protection systems, and (3) new systems for health monitoring and fault detection to improve dispatch reliability and safety.

More extensive research into flight management and performance management systems, including advanced displays, is now being conducted for larger transport aircraft and the more sophisticated general-aviation aircraft, and should encompass most, if not all, of the requirements of advanced commuters. A major issue to be addressed is the question of the interface, interaction, and introduction of these airborne systems within the ATC system.

Improved icing protection would reduce systems weight, increase actual protection, and achieve compatibility with new low-drag (NLF) airfoils and wing designs, including composite material construction requirements. Research in this area, which is now under way with emphasis on general-aviation application, should be adequate for commuters as well, and would be augmented only if later experience indicates that this is necessary.

Health monitoring and fault detection, which are very important to large transport aircraft, are clearly also of great interest to commuters, for whom dispatch reliability and on-time connection service are of paramount importance. Here too it seems likely that ongoing research and development activities in other areas may be adequate for commuter applications as well.

Ride quality improvement is an area of particular importance to commuters which is probably not being dealt with adequately in other programs. As the STAT studies indicated, active–controls technology for gust load alleviation could be used to significantly improve the ride quality and reduce both pilot workload and wing structural fatigue for future small transport aircraft. This is a particularly important area for small transport aircraft since they routinely fly at low altitudes and with lower wing loadings than large transport aircraft. As a result, the ride is not as smooth, and passenger comfort and anxiety are adversely affected. Augmentation of ongoing flight controls research programs with this specific objective in mind might well be very beneficial.

Conclusions

The investigation of small transport aircraft technology has highlighted several important factors relative to the future public acceptance and use of commuter aircraft. Regional/commuter air transport service, which utilizes a variety of propeller-driven aircraft, many of foreign origin, is continuing to grow. Although these smaller aircraft provide a better match between capacity and demand than the present jet transports, they do not compare favorably with jet transports in terms of passenger comfort (ride quality, noise level, cabin space, and convenience) or productivity (seat-miles per hour). Present small-turboprop performance and comfort characteristics reflect the use of modest technology levels, primarily in the interest of lower production cost. Cost-effective improvements in each area would be quite desirable.

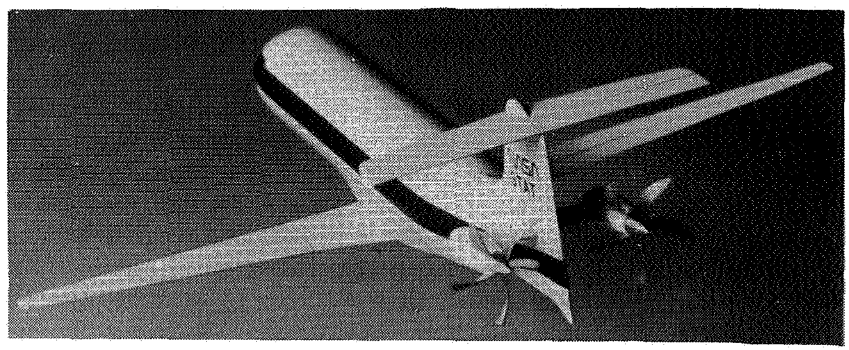
New or derivative commuter transports are now under development by at least 13 manufacturers worldwide (including 6 in the U.S.) for introduction into service in the early and mid-1980's. Most of the new commuter aircraft will be in the 20- to 40-passenger class, which is larger than their predecessors, but they will employ virtually the same technology levels with only modest improvements in performance or passenger comfort. The basic reasons for this are largely economic, including pressure for early product introduction and low price, and, in the case of most general-aviation aircraft manufacturers, unwillingness (and sometimes inability) to attempt the development and introduction of higher technologies with their attendant risks. Domestic large transport aircraft manufacturers, with their greater technological resources and expertise, have thus far chosen not to compete in the commuter market.

Notwithstanding the current new aircraft development situation, interest in higher technology utilization has been expressed by both manufacturers and customers. However, it must be recognized that such technology utilization will not take place until manufacturers are convinced that such a step is feasible with acceptable risk to them, or until this action is necessitated by market demand and/or competition. It is anticipated that competitive aircraft developed by government-subsidized foreign manufacturers will provide the prime motivation for incorporating higher technologies in order to achieve greater passenger acceptance and economy of operation in future U.S.-built commuter aircraft.

The areas of technological improvement for small transports are similar to those for large aircraft, but some unique design and technology requirements result from-the smaller size, lower weight, lower wing loading, shorter stage lengths, and lower altitude operation of commuters. In aerodynamics, climb performance is as important as cruise performance. In propulsion, overall propulsion system efficiency, different duty cycles, and smaller engine component sizes result in different goals and constraints. In structures, smaller sizes, lower loading intensities, and minimum gage limitations mean different trade-offs in airframe design and in the utilization of materials, particularly for composites. In systems, those which can enhance ride quality and safety in the low-altitude operating environment while increasing dispatch reliability take on increased importance.

The small transport aircraft technology (STAT) studies, which addressed the 19- to 50-passenger-aircraft size range, explored all areas in which advanced technology application could provide improved passenger acceptance, increased safety, decreased operating costs, and enhanced profitability. Although some improvements in future commuter aircraft can be achieved merely by utilizing available technology, the STAT studies showed convincingly that very substantial improvements could result if certain potential advances in technology (primarily in aerodynamics, propulsion, structures, and systems) can be achieved in the next few years. The synergistic combinations of these potential advances could reduce fuel use by up to 40 percent, direct operating costs by up to 24 percent, and aircraft acquisition cost by as much as 18 percent. In addition, marked improvements in passenger comfort and convenience could be achieved. Figure 60 illustrates a potential advanced configuration embodying the technology advances identified in the studies.

NASA's ongoing aeronautics research program efforts can contribute substantially toward the required technological improvements for the next-generation commuter transports, provided these programs are supported at previous funding levels. Previously planned research efforts on advanced airfoils and aircraft configurations, improved large turboprops, advanced composite materials, active



(a) Potential advanced configuration.

Aerodynamics
- **Wing design**
- **Engine-airframe integration**

Propulsion
- **Propellers**
- **Engine components**

Structures
- **Composites**

Systems
- **Flight controls**
- **Icing protection**

Economics
- **DOC savings: 16 to 24 percent**
- **Fuel savings: 26 to 40 percent**
- **Initial cost savings: 5 to 18 percent**
- **Productivity improvements (cruise speeds $\geq$ 0.5 Mach)**

Passenger acceptance
- **Ride quality improvement**
- **Noise reduction**

(c) Technology benefits.

Figure 60.- Commuter aircraft study results.

control systems, and improved flight management systems and displays have provided examples of technologies applicable to these aircraft. In addition, some technologies being developed for military aviation use outside NASA's program will also apply. A prime example is engine technology, in which a few new and uprated military turboprop or turboshaft engines are now being developed in power ranges of interest for commuter applications.

Despite the general applicability of ongoing aeronautics research, a number of particular advances appropriate to small transport aircraft either are not being addressed or are inadequately emphasized for that application. In aerodynamics, additional research is required in the areas of advanced wing design (including low-drag airfoils and improved high-lift systems) tailored for commuter aircraft requirements, interactions of configuration components (e.g., wing, body, and tail/canard) for both conventional and unconventional designs, and propulsion systems integration (including slipstream effects for propeller-driven aircraft). Additional structures research should emphasize composite materials and processes that are more applicable to lower cost production than the present systems, even at some sacrifice in the strength-to-weight ratio gains achieved by current graphite/epoxy systems. Expansion of propulsion systems research should address small turbine engine component technology and propeller technology appropriate to commuter aircraft needs. Increased aircraft systems research can contribute to reduced structural loads and improved ride quality by enabling the development of suitable active gust load alleviation systems incorporating the latest state-of-the-art advances in electronics, sensors, and controls.

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Report of the AAC Ad Hoc Advisory Subcommittee on Commuter Air Transport Technology

The Ad Hoc Advisory Subcommittee on Commuter Air Transport Technology of the NAC Aeronautics Advisory Committee met at the NASA/Ames Research Center, Moffett Field, California, on November 19, 20, and 21, 1980. The committee consisted of Dr. Joseph J. Cornish, Mr. Harvey O. Nay, Mr. John W. Olcott, Dr. Jan Roskam, Prof. Richard S. Shevell (Chairman), and Dr. Montgomerie Steele. The executive secretary was Mr. Harry W. Johnson. In addition, there were 14 invited guests representing commuter airline operators; aircraft, engine, and propeller manufacturers, and government agencies. The invited guests, listed in Appendix A, participated actively in the discussions by the subcommittee and in the generation of the ideas and requirements given in the subcommittee report.

The Charter statement of purpose for the Subcommittee was: (1) to review future commuter aircraft requirements, (2) to review NASA's commuter technology studies and related research, (3) to assess NASA's ongoing and planned programs in aeronautics for applicability and adequacy for future commuter aircraft needs, and (4) to report findings and recommendations.

The Subcommittee heard views on commuter aircraft requirements from the commuter airline operators, and views on current and future design objectives from the aircraft industry representatives. They also heard summaries by NASA personnel of ongoing and planned research and technology activities which have potential application to future commuter aircraft design. These included Ames Research Center investigations of commuter aircraft configurations, the results of the contracted STAT (Small Transport Aircraft Technology) airframe systems, engine, and propeller technology studies, portions of the ACEE (Aircraft Energy Efficiency) and large transport technology programs, and the general aviation programs. The reported activities included propulsion, structures and materials, aerodynamics, control systems, and man/machine interactions. NASA personnel also presented a large slate of possible future research and technology options in each technical discipline (included as Appendices to this report) which the several STAT airframe systems and propulsion studies had suggested are appropriate to permit the design of technologically advanced commuter aircraft in the future. These program options and approaches were not presented as firm NASA recommendations since those had not been formulated; instead, they were provided to help focus discussion and assist the generation of Subcommittee conclusions and recommendations.

Following all presentations, the Subcommittee and invited guests were divided into four groups to deal with specific technical areas in greater depth: aerodynamics, structures, propulsion, and systems. The detailed conclusions and recommendations of each group, after discussion and refinement in a plenary session, were accepted by the Subcommittee as a portion of this report.

General Considerations

1. The operators agreed that the most important factors for commuter airline future survival and health are (1) greater fuel efficiency and reduced D.O.C., (2) increased schedule reliability, and (3) increased passenger acceptance, in that general order of importance. New technological features which would improve these qualities would be welcome, but any which add complexity are of concern because of the potential adverse impact on maintenance costs and dispatch reliability. The operators emphasized that initial equipment cost is less important than reduced D.O.C. Even significant increases relative to present equipment costs could be acceptable if accompanied by high-payoff benefits in the aforementioned qualities.

2. A strong recurrent concern expressed by the airline operators was that U.S. manufacturers have failed to utilize presently available advanced technologies in developing modifications of older commuter aircraft designs and in planning new aircraft designs. They are doubtful that many new technologies such as those discussed at this meeting will actually be applied in future generations of commuter aircraft, unless U.S. manufacturers are given some inducement to use them. The manufacturers confirm that the primary deterrents to incorporating advanced technology are financial. Large investment requirements, uncertain markets, and resulting overall risks associated with new, advanced technology aircraft are factors. Present conditions and timing thus encourage them to modify old designs instead of embarking on new high risk developments. Furthermore, most of the likely builders of commuter aircraft, i.e., the general aviation companies, are presently working to capacity on their current private and corporate aircraft projects, and are not strongly motivated to engage in additional programs at this time, particularly high risk ones.

3. There was general agreement that the successes of foreign aircraft in the commuter field today are not due to technical superiority but to availability and to predatory pricing and financing practices. In almost every case this situation reflects foreign government involvement and support. It was agreed that the development and availability of superior future U.S. commuter aircraft based on advanced technologies would be a necessary

factor in countering the present trends, but might be insufficient by itself. Recommendations for dealing with the whole situation are not in the province of this Subcommittee; nevertheless, it was believed important to draw attention to these issues.

General Conclusions

The specific subcommittee recommendations are given in this report under the headings of propulsion, structures, aerodynamics, and systems. In addition, the subcommittee reached the following general conclusions:

1. The subcommittee endorses a strong NASA effort relevant to commuter aircraft The program should include not only technical research, but also the coherent presentation of new and previously available data in a form usable by the commuter aircraft industry.

2. The subcommittee is concerned about the relative decrease in NASA's in-house technical capability and research as compared to the outside funded work It is recommended that NASA make every effort to reinforce their technical capability by acquiring additional highly qualified technicai personnel. This does not necessarily mean more total dollars but implies a gradual redistribution of funds. Meanwhile, NASA should direct its funding in a manner that results in the greatest return in terms of research accomplishment

3. The subcommittee endorses the use of NASA commuter industry workshops as a means of disseminating technical information.

Specific Recommendations

Propulsion

Large projected DOC improvements for commuter aircraft can result from improvements in propulsion. Consequently, NASA should address technology gains in fuel conservation and improved propeller efficiency applicable to engines which meet the unique requirements of the commuter operating environment Studies involving airframe, propulsion, and commuter operator companies have resulted in identifying a need for advanced aircraft in the 19, 30, and 50 passenger categories to enter service in the later 1980s. To prepare for these advanced technology aircraft, the necessary technology base in propulsion must be established now. This should take two basic directions conducted in parallel:

1. improvement programs readily adapted to existing U.S. engines in the commuter market with a view to short term gains in fuel conservation, reliability, and maintenance, and

2. Advanced engine programs tailored to the size and specific needs of the commuter market along with the technology for advanced propeller performance.

The component, gas generator, and engine demonstration program as outlined in Appendix B is strongly supported by the ad hoc group. However, the aggressiveness of the program, in terms of schedules and funding, needs further evaluation. It is recommended that additional effort be undertaken with a view to expediting the whole process.

Multi-component advanced technologies must be evaluated in an engine to quantify the real gains and eventually demonstrate achievable engine performance. The program would provide the information necessary for further evaluation of the risk of embarking on a full-scale engine development program leading to certification. Such engine programs are a mandatory requirement for effective support of the commuter industry.

The propeller programs involving both aerodynamic and structural improvements, including noise, are strongly endorsed. The ad hoc group recommends expanding the scope to address installation interfaces associated with engine and airframe interferences for all propeller-engine configurations under consideration.

Improvements in engine and propulsion systems pace the advances that can accrue to commuter airlines through technology. Because engine development requires a long lead time, the proposed effort in propulsion should be pursued vigorously.

In the area of interior noise, an accelerated program with the goal of obtaining noise levels equal to those in 1980 turbofan airplanes is supported.

Structures

We believe that a significant long-range opportunity exists in the application of composites in primary structure. However, considerable additional knowledge is required to permit industry to incorporate composites in the primary structure of new design commuter aircraft with adequate confidence. A full-scale flight demonstration similar to the candidate STAT structures research program, Appendix *C,* is recommended as the backbone and focal point of an integrated commuter aircraft composites program. This program should provide design data, information on practical operational and environmental effects, and affordable manufacturing and quality control techniques. The effort should also develop the technical data base to assist in defining certification criteria. Priority should be placed on the wing because of the potential multiplicative effect of clean aerodynamic surfaces. Although it would be desirable to include the fuselage if available funding permits, it should not be allowed to dilute the emphasis on the wing. We believe the schedule shown in Appendix *C* should be compressed by at least a year.

We do not see a role for NASA to research advanced aluminum alloys or bonded honeycomb. Sufficient experience and basic data exist in these areas.

We recommend that NASA rejuvenate the highly successful operational loads measurement program. This should include special emphasis on a representative variety of commuter operations. The recording and analysis equipment should be updated to the current state of the art to alleviate the data analysis manpower problem.

Aerodynamics

In studying the candidate aerodynamic research programs, Appendix D, emphasis was given to several factors deemed important to efficient and productive operation by the commuter operators and manufacturers. These are, in approximate order of importance:

- Fuel efficiency and reduced D.O.C. (The commuter operators were unanimous in stating that initial flyaway costs of aircraft were not as critical to them as improved operating costs in justifying and financing new aircraft purchases.)
- Schedule reliability
- Passenger acceptance

Therefore, those aerodynamic parameters which can improve these required capabilities should be considered as highest priority. These include low drag aerodynamics at Reynolds numbers between 6×10^6 and 10×10^6, effective high lift systems, ride qualities and handling qualities. In those areas listed above, the following specifics are important.

Fuel efficiency. A requirement exists not only for low drag airfoil section characteristics but also for three-dimensional wings including intersections at fuselage and nacelles, installation of ailerons and flaps, and access doors. Flap brackets suitable for multi-slotted flaps need optimization as regards configuration and distribution. Surface conditions requiring low maintenance but still giving low skin friction are desirable. Low drag yet thick sections for low weight and good fuel capacity are desirable. Studies yielding low drag wing tips are desirable. Not only winglets but such types as Hoerner and Dornier tips should be compared. Such wing tips should be studied for effects on C_{Lmax} and stall quality, as well as drag.

Effects of leaks, gaps, and intersections should be catalogued so their influence or drag can be minimized, More accurate estimation methods are needed to determine the effects of interference.

Natural laminar flow airfoils offer large potential drag reductions with only a modest probability of achievement in practical operating environments. The airfoils themselves are no more likely to succeed in providing laminar flow than the 6-series airfoils developed by NACA almost

40 years ago. The 6-series never provided laminar flow on practical aircraft except on low Reynolds number sailplanes. The new element, however, is new construction materials and methods which can provide smoother, less wavy surfaces and greater rigidity. These new means of construction include bonded aluminum honeycomb and advanced composite materials such as graphite or aramid (Kevlar) fiber in an epoxy matrix. The crucial question is whether ordinary dust and insects will prevent the regular attainment of laminar flow even with the improved surface conditions.

NASA has proposed testing a Bellanca Skyrocket airplane built with a molded wing of very smooth contour. The committee urges NASA to proceed immediately with this test to establish the extent of laminar flow on a polished wing well outboard of the slipstream, on a polished wing in the slipstream, and in both areas on a wing exposed to the weather for a reasonable period of time. This test would establish the seriousness of the ordinary dust and dirt problem, a question that should be resolved before large expenditures are undertaken on the natural laminar flow airfoil program. A positive result from this would be excellent cause to proceed with the larger elements of the proposed program dealing with developing the natural laminar flow airfoils and the methods of construction to make them feasible. On the other hand, the failure to achieve natural laminar flow under field conditions at the low Reynolds numbers of the Bellanca might cause a reconsideration of the emphasis in the program.

Reduced *D.O.C.* Those items mentioned in the fuel efficiency section are obviously important here. Also needed are empirical and theoretical data to aid the assessment of special configuration effects such as empennage type (T-tail, cruciform, low tail), low wing/high wing, or highly unusual configurations (flying wings, forward swept wings, canards, tandem wings, etc.). The question of design speed as a function of the gradually increasing stage length is important An additional possibility might be the wider utilization of flaps for climb and cruise, in addition to landing and takeoff conditions.

Schedule reliability. The principal asset of commuter airlines is their ability to provide on-time arrivals and departures with schedules that emphasize frequency of service. High lift devices will enhance that ability by reducing the maintenance (both scheduled and unscheduled) associated with takeoffs and landings, Lower stalling speeds will reduce takeoff and landing loads and brake and tire wear. Better maneuvering capability associated with improved handling qualities, high lift devices, and direct lift device glide path control will reduce the time commuter aircraft spend in the terminal area as well as allowing such aircraft to use stub runways at hub airports.

Considerable effort will be required in the area of basic stability and control, Specifically, the following areas are recommended for renewed emphasis. Improve capability to predict stability and control behavior of conventional and, in particular, of advanced configurations (canards, pushers), including power and control system effects. Aerodynamic interference between propeller slipstreams and leading edge devices should be explored.

Passenger acceptance. Factors which allow higher speeds should be emphasized; low drag and effective airframe/propulsion integration should be studied and characterized to allow ready application.

Good ride qualities should be more specifically defined. These characteristics should then be related to aerodynamic parameters such as lift curve slope, wing loadings, and lift distribution control systems, and these, in turn, should be made available in readily applied form.

Aerodynamics affecting safety of flight are, obviously, to be emphasized.

Near-term emphasis. NASA should strive to make the data from the above areas more readily and quickly available in more applicable form. DIALOG data library retrieval or something similar should be employed.

Available data should be examined and analyzed and gaps in these data should be defined. Much of the 6×10^6 Reynolds number data is two-dimensional and was passed over in the rush to transonics. These gaps should be identified and programs established to generate a data bank of three-dimensional data, including broad applications of various flap, aileron, and wing taper ratio influences. The data should be analyzed to define the sensitivities of these influences. Extensive indepth studies should be begun in those areas deemed most sensitive.

Specific critical areas. Three-dimensional wing design is particularly important Aerodynamic parameters affecting handling and ride qualities should be rated in order of priority. Ground effects during flare is an area important to commuter class aircraft.

In other areas, NASA should make more available its extensive and excellent facilities to industry. Moreover, it is especially important that three areas of research and development be more closely integrated and related; these are wind tunnel experience and data, computational aerodynamics, and flight simulation. These should be carefully coordinated to yield more synergistic results.

Systems

It is recommended that NASA increase efforts in the following areas:

1. Flight management and performance management with associated displays. Reduction of pilot workload is seen as an important objective.
2. Icing protection system and generation of data helpful to FAA establishment of icing certification criteria
3. Health monitoring and fault finding systems (including wear and component condition monitoring) are seen as important systems in

near-future STAT vehicles. The emphasis here should be on preventive maintenance capability.

Because of the increased importance of flight simulation, the committee foresees a need for low cost, simpler parameter identification systems suitable for use by the commuter aircraft manufacturers and others.

We recommend that a suitable number of commuter transports be equipped with advanced flight data recorders to obtain a data base on parameters which might impact system health such as temperature, acceleration, etc.

A significant problem in the commuter industry is the area of air conditioning and pressurization systems. The committee recommends a "component improvement" program similar to the NASA ECI program.

To improve existing fuel consumption, it will be necessary to extend and accelerate existing programs in the area of automated propeller, fuel, and engine blade tip clearance control systems.

In terms of budget, the committee agrees with the magnitude of overall technical options described in Appendix E. For earlier availability of research results, it is felt that the program should be shortened by one calendar year.

To allow industry to reduce systems weight, NASA is encouraged to do research in the area of fly-by-wire control systems (electric and fiber-optic).

Appendix A

NASA Aeronautics Advisory Committee

Meeting of
Ad Hoc Subcommittee on
Commuter Air Transport Technology
at the NASA Ames Research Center
Moffett Field, CA
November 19-21,1980

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Appendix B

Candidate NASA STAT Propulsion Research

Engines	Gearboxes	Propellers
Highly loaded axial stages	Compound idler system	Multi-blades, proplets
Advanced centrifugal impellers/diffusers	High-contact-ratio gears	Advanced composite blade - low activity factor
Long life combustors	High purity steels	Precision synchrophaser
Advanced-horsepower turbines (cooling, mfg. techn.)		Advanced airfoils
High-pressure turbine active clearance control		
High-work low-pressure turbine		
Digital control for propeller-engine integration and surge margin		
High-modulus shaft		
Diagnostic monitor for maintenance, health, derate		

STAT Engine Research

Barriers preventing utilization of advanced technology now

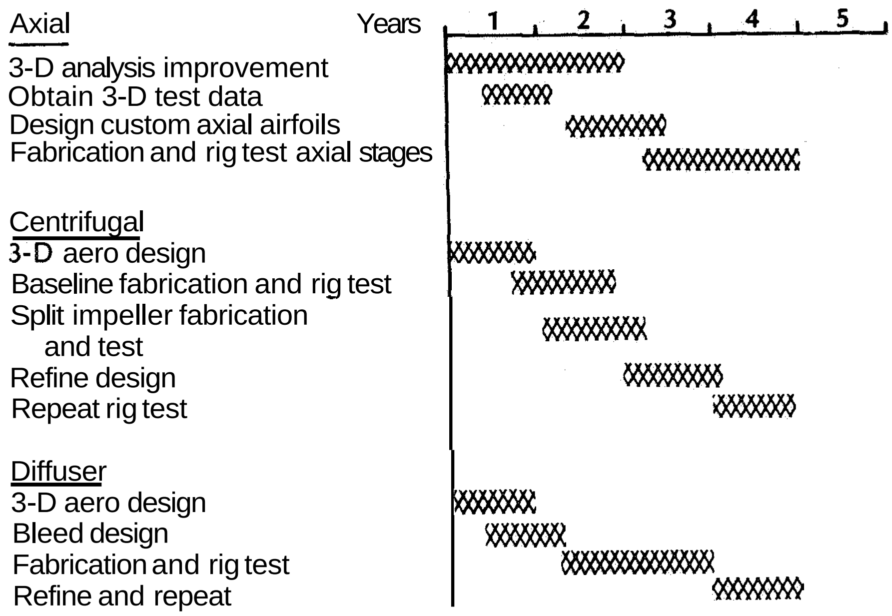
Engine:
- Design methodology - complex 3-D flow fields
- Materials - high temperature limitations
- Small size effects - large engine technology doesn't scale

Gearbox:
- Limited experimental evaluation - balanced load sharing
  - high contact ratio gears
  - high purity steels

Propeller:
- Propeller research re-activated - 3 to 4 years ago
- Advanced analysis methods - not available, but work begun
- Limited experimental evaluation - advanced concepts
- Advanced composite blade and aeroelastic technology - not available

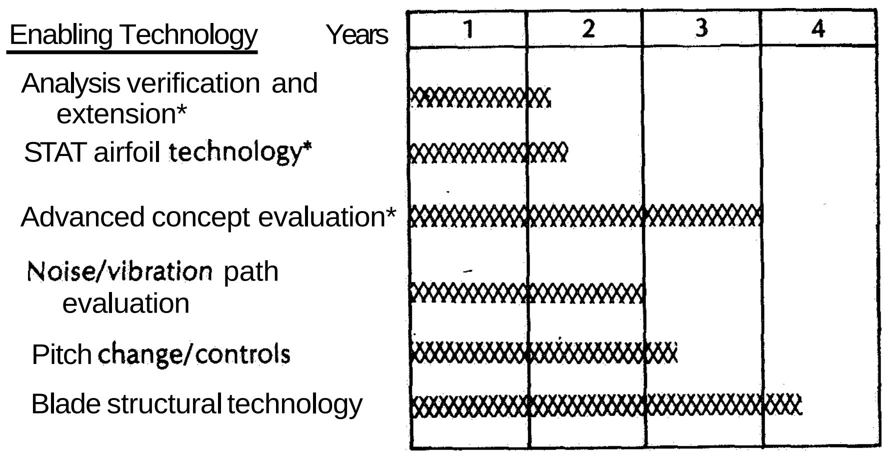
Example STAT Compressor Program ($6M)

Objective: Design and demonstrate 10 lb/s compressors with 3 percent better efficiency at 15 to 20 pressure ratio



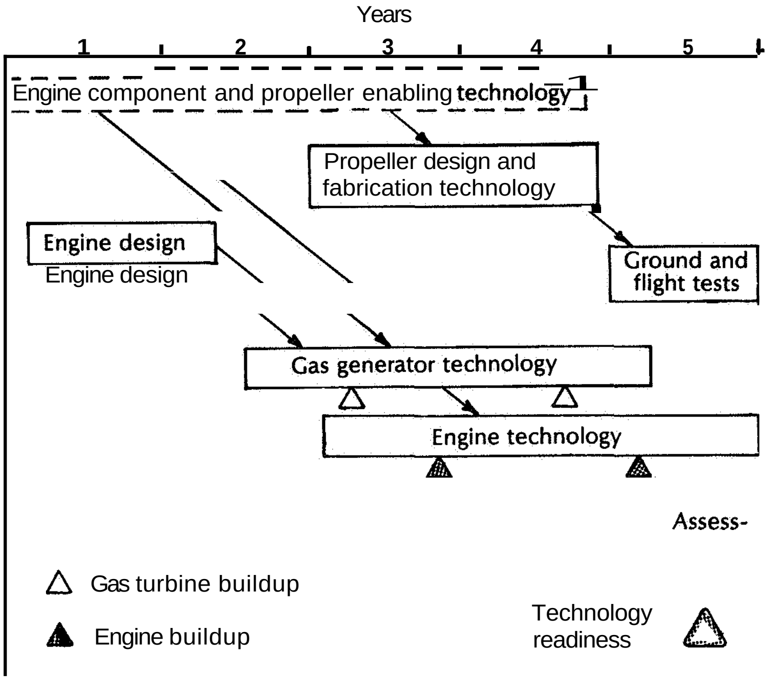
STAT Propeller Program

Objective: Develop technology that offers a 5-percent improvement in commuter propeller efficiency with reduced system weight



*Extension from proposed general-aviation propeller program

Possible STAT Research Engine Program



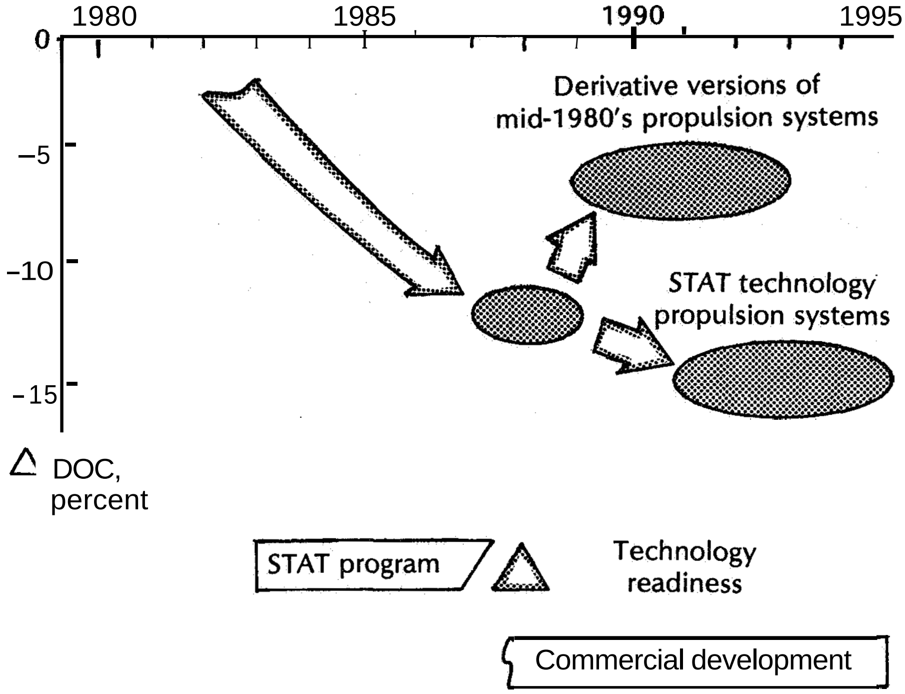
STAT Propulsion Program Options

Small:		
Base R&T supporting technology	3 years	$ 6 M
Medium:		
Advanced component technologies	4 years	$12 M
Propeller enabling technology	4 years	$ 6 M
		$18 M
Plus base R&T support		$24 M

Large:	New engine	Existing engine
Research engine (1)	$40 to $60 M	$25 to $30 M
• 5 years		
• 6 equivalent engines		
• 200 hours testing		
• Above elements		
Full-scale propeller technology verification	$10 M	$10 M
	$50 to $70 M	$35 to $40 M

Introduction of STAT Technology

Propulsion



STAT Propulsion Issues

1. Cabin noise
   Path identification (air or structure)
   Reduction strategy
   - Propeller source noise reduction
   - Fuselage acoustic treatment
   - Rear-mounted engine airplane configuration
   - Combination

   Impact of goals on DOC and strategy

2. What engine size and airplane cruise speed for propulsion research?
   30 passenger Mach 0.5 -- 1600 shp
   50 passenger Mach 0.5 -- 2500 shp
   50 passenger Mach 0.7 -- *5000* shp

3. Scope of effort (base ***R&T*** -- ?)

Appendix C

Candidate NASA STAT Structures Research

Materials:	Structures:
Advanced aluminum alloys Bonded aluminum honeycomb Minimum gage composites	Bonded aluminum honeycomb primary structure Composite primary structure - isogrid, orthogrid, other concepts

STAT Structures Research

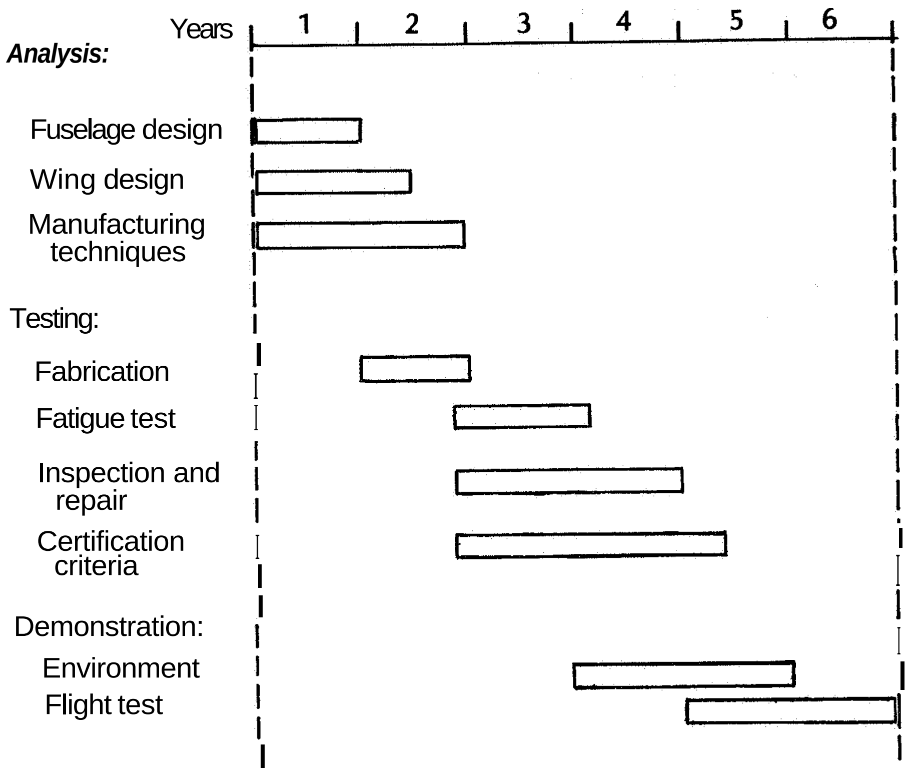
Barriers preventing utilization of advanced technology now

Materials:
- Specifications
- Quality control
- Design criteria
- Certification criteria

Structures:
- Design criteria
- Failure modes
- Environmental degradation
- Automated manufacturing techniques
- Inspection and repair methods
- Certification criteria

Example STAT Structures Program

Objective: Design and demonstrate the application of advanced composites in commuter transport primary structure



STAT Structures Program Options

Small:		
Base R&T studies and component fabrication and test	3 years	$ 6M
Medium:		
Large component fabrication and ground test	4 years	$10 M
Plus base R&T support		$16 M
Large:		
Flight test and evaluation		$20 to $30 M

STAT Structures Issues

1. Focus on advanced aluminum alloys, bonded aluminum honeycomb, or composites

2. Required component size

3. Manufacturing techniques

4. Testing requirements
   - Fatigue
   - Environmental effects
   - Flight validation
   - Certification criteria

Appendix D

Candidate NASA STAT Aerodynamics Research

Airfoils	High-lift devices	Configurations
Climb optimized NLF and low-drag turbulent airfoils	Climb optimized Slipstream effects Leading edge devices; insect shield Wingtip devices Variable camber (mission-adaptive wing)	Slipstream effects Aft-mount props • 2 engines • 3 engines Stability and control considerations Aerodynamic loads Interference drag (wing/body/nacelles)

STAT Aerodynamics Program

Barriers preventing utilization of advanced technology now

Airfoils:

Effect on total aircraft performance
- Airfoil/structures and environmental degradation
- Wing/body integration
- 3-D wing design
- Integration of nacelles and slipstream
- High-lift device trades

High-lift devices:

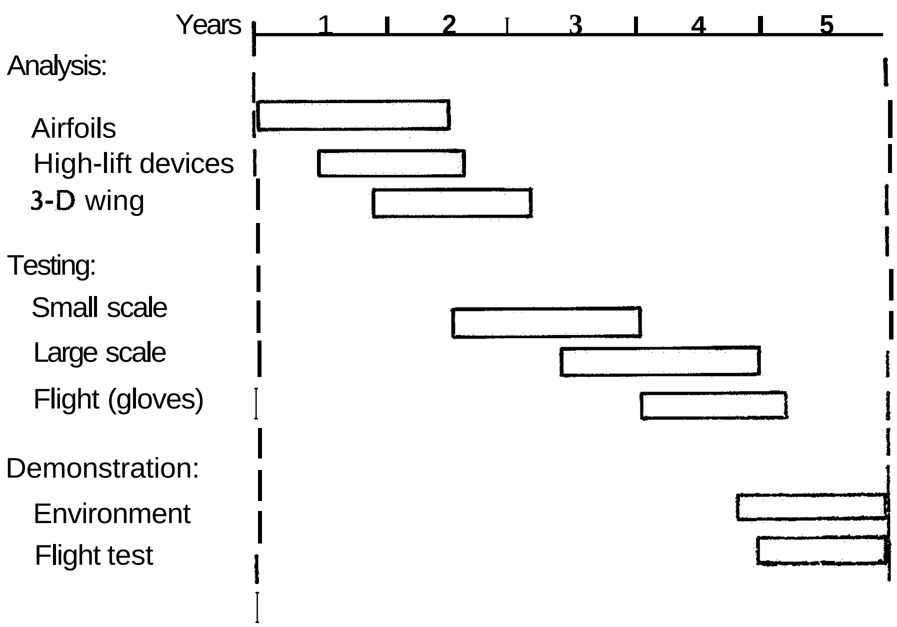
Leading edge devices
- Slipstream effects
- Insect shield

Configurations:

Aerodynamic loads
Stability and control
Certification

Example STAT Aerodynamics Program

Objectives: Demonstrate NLF airfoil feasibility using advanced materials, insect contamination prevention, and favorable aircraft configuration



STAT Aerodynamics Program Options

Small:		
Base R&T studies and small-scale wind tunnel test	3 years	$3 M
Medium:		
Large-scale fabrication and wind tunnel test	4 years	$4 M
Plus base R&T support		$7 M
Large:		
Flight test and evaluation (integrated with structures program)		$10 to $15 M

STAT Aerodynamics Issues

1. Focus on design requirements
   Cruise speed: $M = 0.5$ to 0.7
   Field length

2. Wing versus aft-mount props

3. NLF and low-drag turbulent airfoils

4. Testing requirements
   Small- and large-scale wind tunnel testing
   Flight environment

Appendix E

Candidate NASA STAT Systems Research

Cockpit displays	Control systems	Aircraft systems
Training simulator requirements	All-electric controls ● Digital data system ● Samarium cobalt motors ● Sensors ● Computers	Icing protection
Advanced displays ● Pilot workload reduction ● Aircraft health, maintenance requirements, center of gravity monitoring, and flight profile direction	Active controls ● Ride quality ● Stability augmentation	Pressure and air conditioning
Parameter identification for simulation modeling		Acoustic treatment

STAT Systems Program

Barriers preventing utilization of advanced technology now

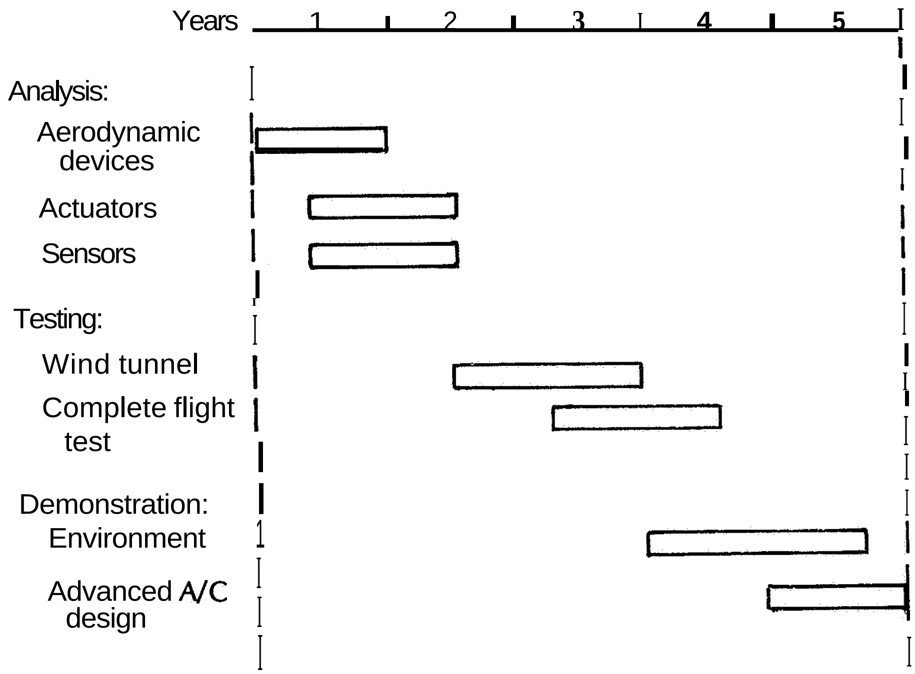
Cockpit displays:
- Currency requirements/simulation
- Display optimization
- Parameter identification and display techniques

Control systems:
- Redundancy requirements
- Certification

Aircraft systems:
- Icing - high technical risk on advanced low-power systems
- Acoustic treatment - lack of available research

Example STAT Control Systems Program

Objectives: Demonstrate the application of advanced all-electric technology to a non-flight-critical ride quality improvement system



STAT Systems Program Options

Small:		
Base R&T studies and small-scale tests	3 years	$ 3M
Medium:		
Simulation, brass board evaluation, and complete test	4 years	$ 8M
Plus base R&T support		$11M
Large:		
Flight test and evaluation		
installed on available aircraft	4 years	$15 M
Integrated with advanced aircraft design	5 years	$20 M

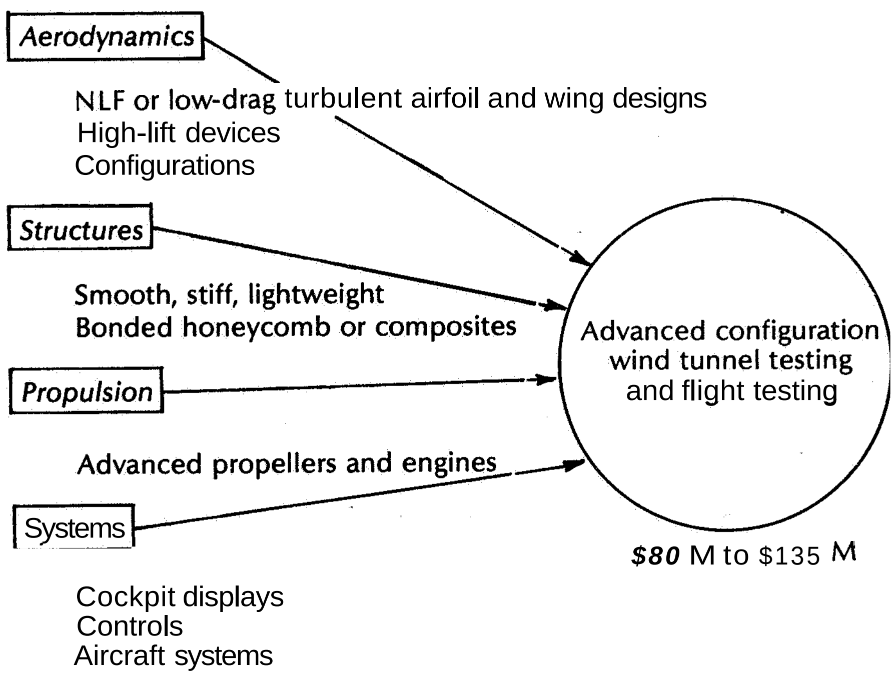
STAT Systems Issues

1. Handling qualities simulation requirements
   Emergency training usage
   Advanced display/systems evaluation

2. Control systems
   Redundancy
   Certification
   Repair and maintenance

3. Aircraft systems
   Relationship with other programs in icing protection and acoustic treatment
   NASA role in air conditioning and pressurization systems

Fitting It All Together



Appendix F

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