SMALL TRANSPORT AIRCRAFT TECHNOLOGY

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ABSTRACT

The commuter airlines have experienced very high growth rates during the past two years. This strong growth is anticipated to continue as the U.S. air transportation system is reshaped by deregulation. The regulatory changes, coupled with the increasing market for commuter air travel have resulted in a strong demand for new, improved small transport aircraft and have significantly improved the opportunities for the application of advanced technology to the design of these aircraft.

This paper reviews NASA's recent and proposed research on Small Transport Aircraft Technology (STAT). The results of contracted studies identifying the potential benefits of advanced technology are presented. Current in-house studies and research efforts are discussed. An overview of the proposed technology elements in STAT research is presented.
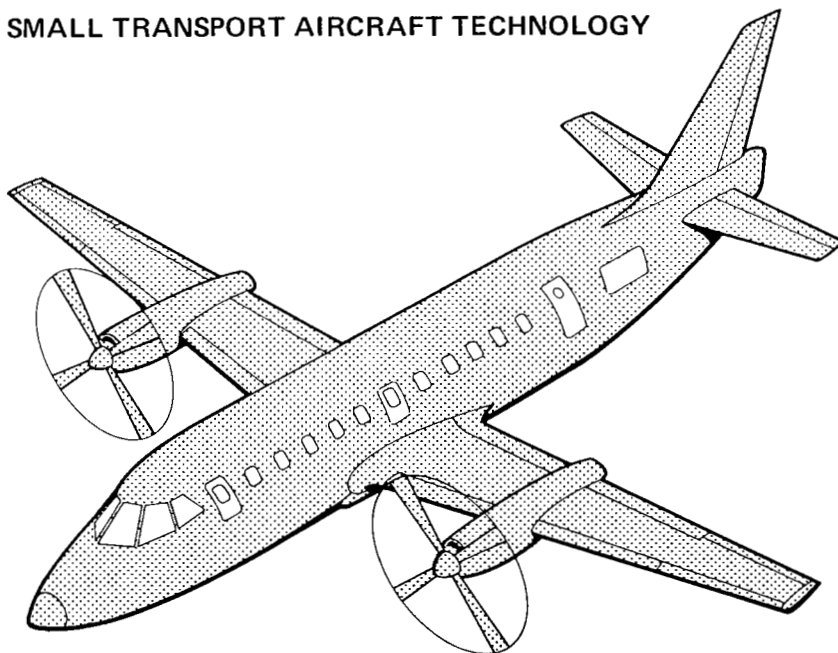
SMALL TRANSPORT AIRCRAFT TECHNOLOGY

Figure 1 shows the growth in U.S. commercial air transport service dating from the Ford Tri-motor era, with the introduction dates of some of the more significant transport aircraft. The Civil Aeronautics Board (CAB) has been instrumental in the classification of carriers. The Civil Aeronautics Act of 1938 granted certificates to the carriers in operation at that time which formed the cadre of trunk airlines. As the trunk airlines grew, they obtained larger aircraft and reduced service to smaller communities. In response, the CAB instituted the "local-service" airlines experiment in 1944 to provide better air service to the smaller communities. Following the pattern of the trunk airlines, the local-service airlines expanded and upgraded their fleet to larger jet-powered aircraft. Again because these larger aircraft are inefficient for short-haul, low density air service, a number of the smaller communities were faced with a loss of air service. In 1969 the CAB established the "Commuter Carriers" classification for operations with aircraft of less than 5674 kg (12,500 lb) gross weight. Whereas local-service carriers were able to start service in the 1940's with aircraft the same size as the trunk airlines (the DC-3's), commuter airlines were restricted to the 12,500 lb takeoff weight limit. In late 1972, the CAB restriction on commuters was revised to allow up to 30 passengers or 3404 kg (7500 lb) payloads. The "Airline Deregulation Act of 1978" and subsequent rulings have raised the limitations on commuter air carriers up to 60 passengers or 8170 kg (18,000 lb) maximum payload. Rising fuel costs and deregulation have resulted in trunk and local service carriers continuing to abandon the lower density, short-haul routes.

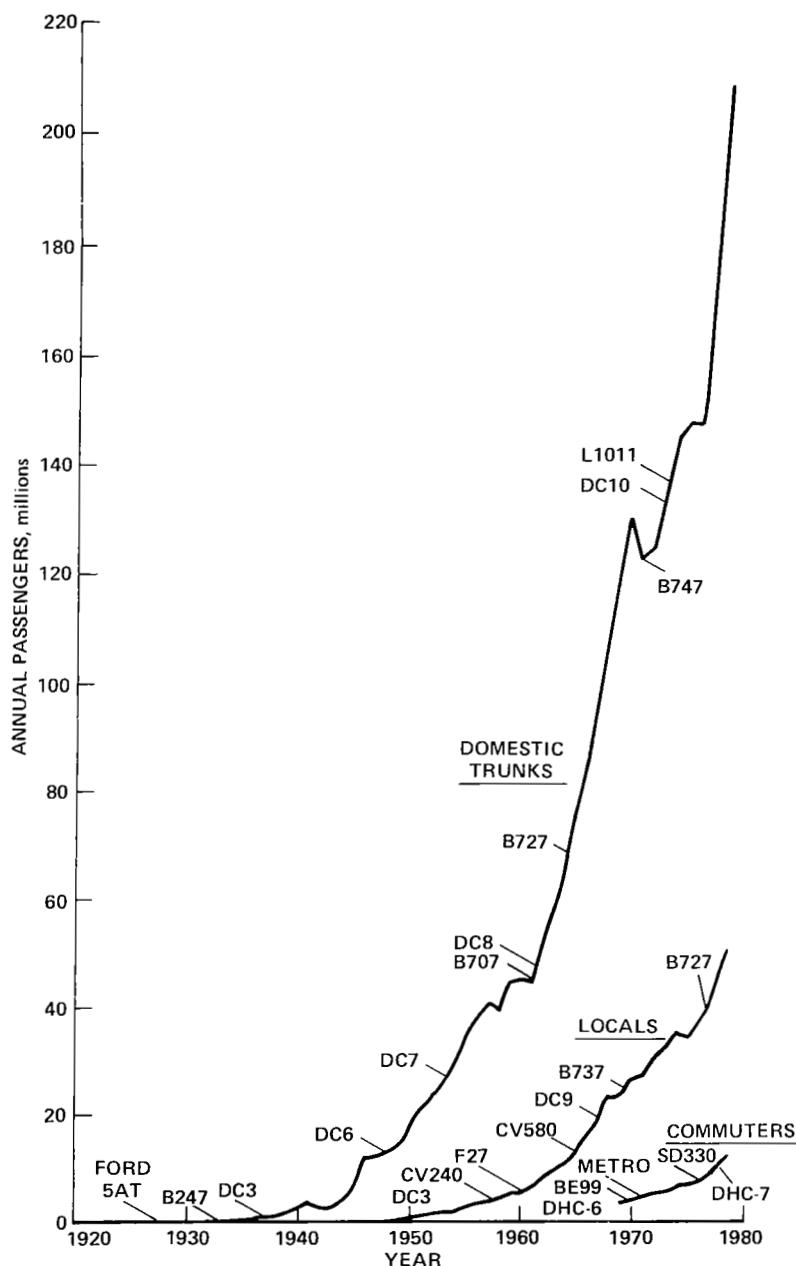**HISTORY OF U.S. COMMERCIAL AIR TRANSPORTATION**

Figure 1

The U.S. trunk airlines have now transitioned completely to jet powered transport aircraft and three-fourths of the local service airlines fleet is jet powered. Unfortunately, jet transport aircraft are less energy efficient for short flights than longer flights where the speed and altitude capability of the jet engine can be used more effectively. The reduced fuel efficiency of jet transport aircraft for short-haul service was tolerable at cheap fuel prices. However, from 1973 to 1979 the average price of jet fuel for the U.S. trunk airlines has increased (figure 2) from 3.4 cents/liter (13 cents/gal) to over 18.5 cents/liter (70 cents/gal). In 1973, fuel accounted for about 25% of the direct operating cost for a B727-200 aircraft. By 1979 this percentage had risen to over 50% of the direct operating cost.

U.S. TRUNK AIRLINE JET FUEL PRICE
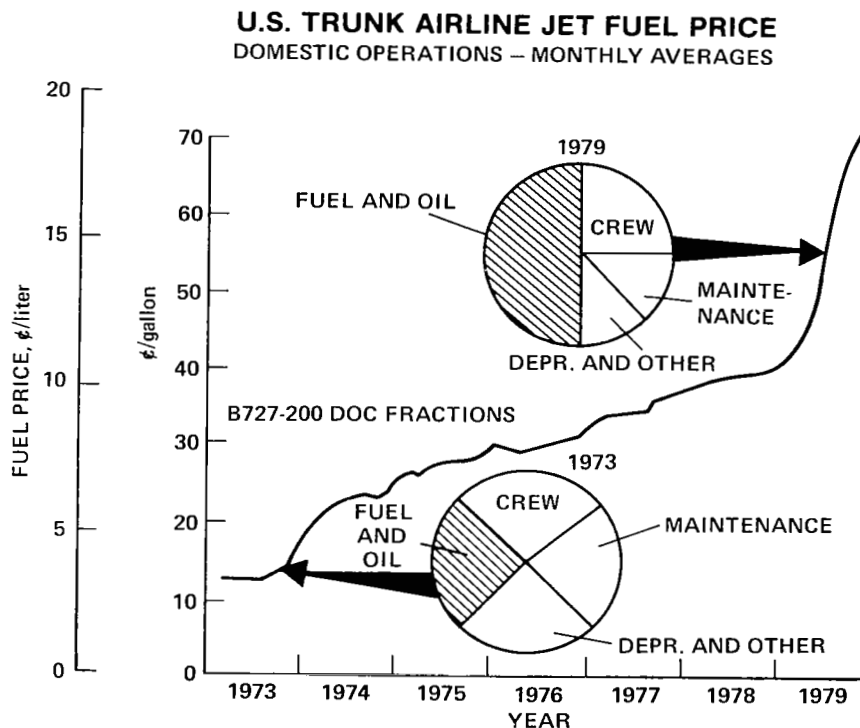DOMESTIC OPERATIONS – MONTHLY AVERAGES

Figure 2

The effect of fuel cost on the trunk airline direct operating cost elements is shown historically in figure 3 (reference 1). The influence of fuel price and its dominance since 1973 over the other direct operating cost elements is clearly evident. Because fuel costs are expected to continue to dominate aircraft operating cost, increasing aircraft fuel efficiency has become the major new transport aircraft design objective.

INFLUENCE OF FUEL PRICES

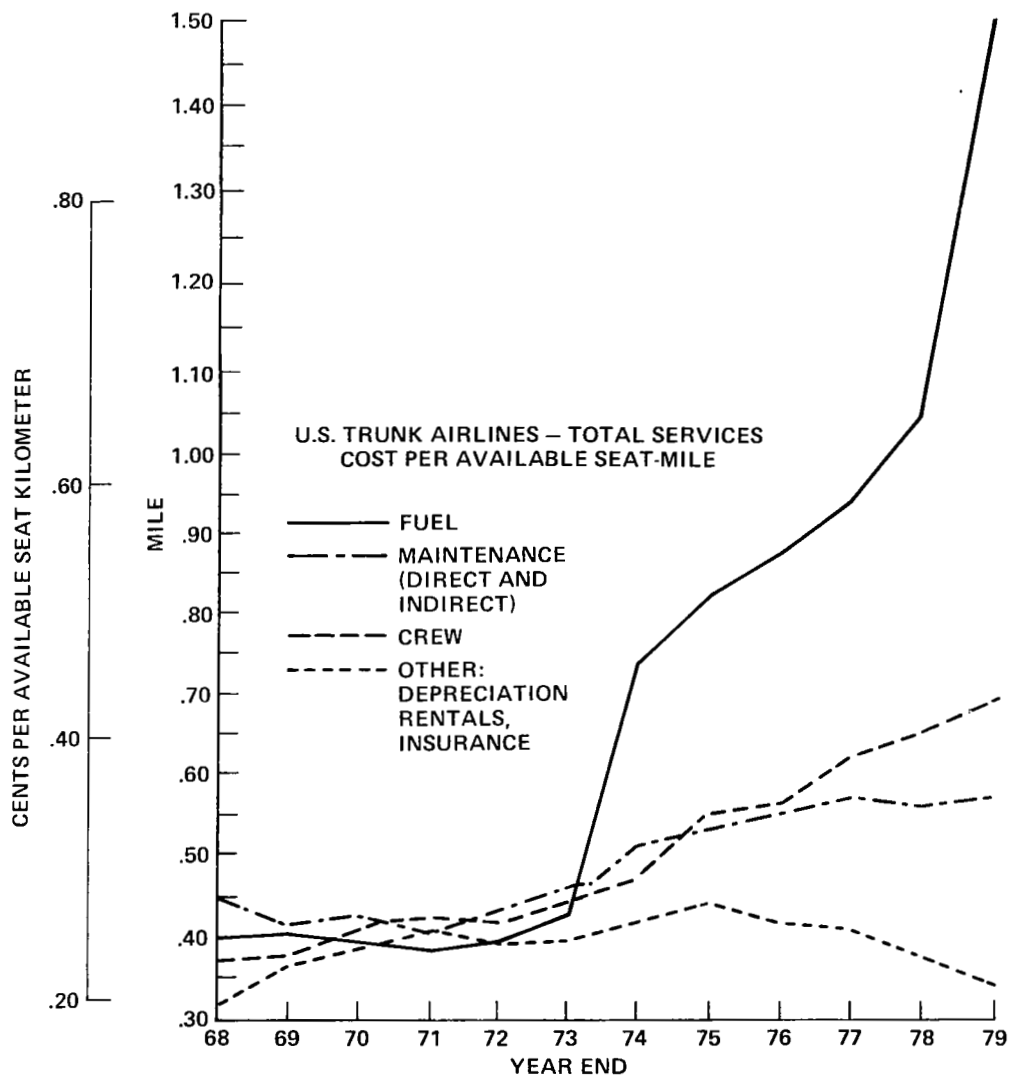DIRECT OPERATING COST ELEMENTS

Figure 3

The Airline Deregulation Act of 1978, bringing with it easier market entry and exit provisions, along with the sky-rocketing fuel costs, have resulted in trunk and local service airlines improving their operating efficiency by moving their jet transport aircraft to the longer, high density routes where they are more efficient. This transition is most noticeable by the increase in average stage length (figure 4, from Reference 2) since deregulation. This transition has resulted in the smaller communities being faced with more reductions in service by the carriers using the larger jet powered transports.

AVERAGE STAGE LENGTH

U.S. TRUNK AND LOCAL SERVICE CARRIERS
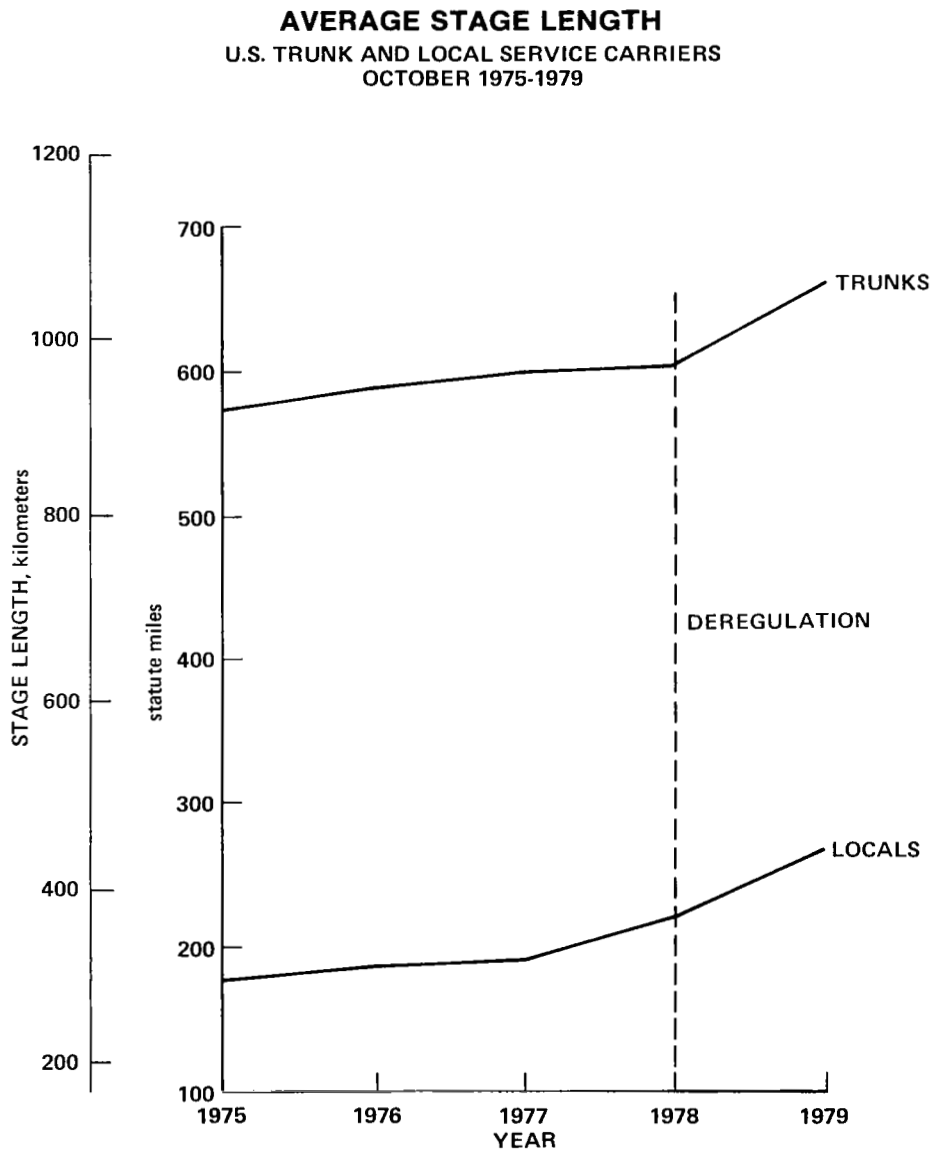**OCTOBER 1975-1979**

Figure 4

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 (Figure 5) has made them the fastest growing segment of air transportation. In 1979, commuter airline activity increased by 27.6% in passengers carried and 7.4% in cargo. The transition to commuter airlines and smaller commuter aircraft for short-haul air transportation is evident at most airports. The dramatic expansion in short-haul service with turboprop-powered 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.

COMMUTER AIRLINE GROWTH
DECEMBER 1970 TO 1979*

(a) PASSENGERS CARRIED

(b) CARGO CARRIED
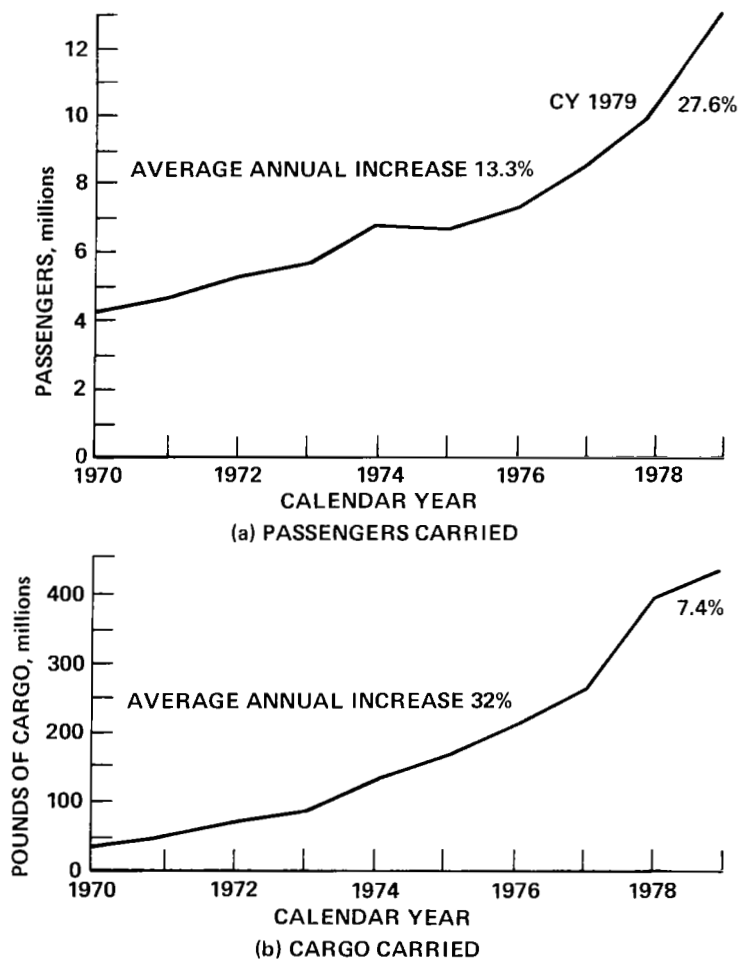
*1979 VALUES INCLUDE CARRIERS THAT WERE COMMUTERS IN 1978 AND OBTAINED CERTIFICATES IN 1979

Figure 5

The current turboprop powered commuter aircraft, although representing older technology and some sacrifices in passenger comfort, use 15 to 25% less fuel per seat mile at short stage lengths then the larger jet transports they are replacing. This efficiency improvement coupled with the smaller aircraft ability to provide a better match with passenger demand results in a significant overall system efficiency improvement. In recognition of the expanding role of the U.S. commuter airlines, several manufacturers have initiated the development of new, improved commuter transport aircraft. One of the most recently announced new aircraft development is the Fairchild/Saab-Scania 30-34 passenger aircraft shown in Figure 6. Scheduled for introduction into service in 1984, this aircraft will incorporate the best current technology available and will be powered by the General Electric CT7-5 turbo-prop engine.

FAIRCHILD/SAAB-SCANIA 30 PASSENGER
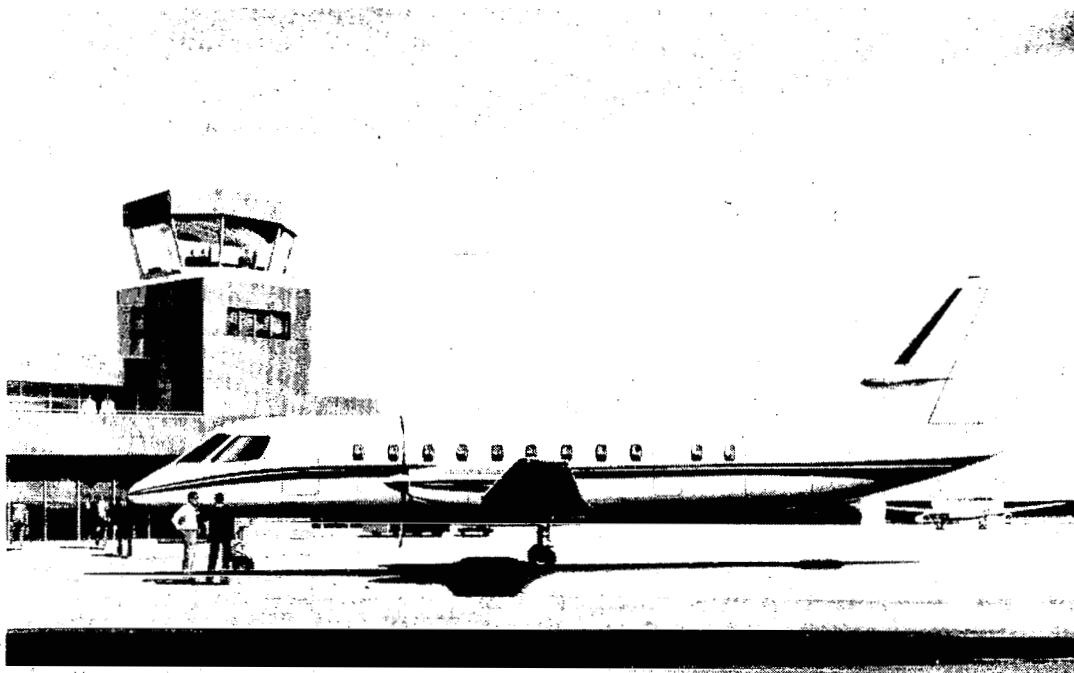## COMMUTER AIRCRAFT

Figure 6

In order to develop the advanced technology that can be applied to future small transport aircraft, focused research and technology efforts are required. NASA has initiated a Small Transport Aircraft Technology (STAT) aeronautics research activity to provide this focus. Figure 7 depicts the elements of this activity to enhance the development of significantly improved small short-haul transport aircraft. Technologies that can improve public acceptance and operational economies are important research areas.

SMALL TRANSPORT AIRCRAFT TECHNOLOGY (STAT)

IDENTIFY AND DEMONSTRATE THE COST-EFFECTIVE APPLICATION OF ADVANCED TECHNOLOGY TO ALLOW THE DEVELOPMENT OF SIGNIFICANTLY IMPROVED SMALL SHORT-HAUL TRANSPORT AIRCRAFT

AERODYNAMICS

SYSTEMS

- ECONOMICS
- EFFICIENCY
- PERFORMANCE
- ENVIRONMENT
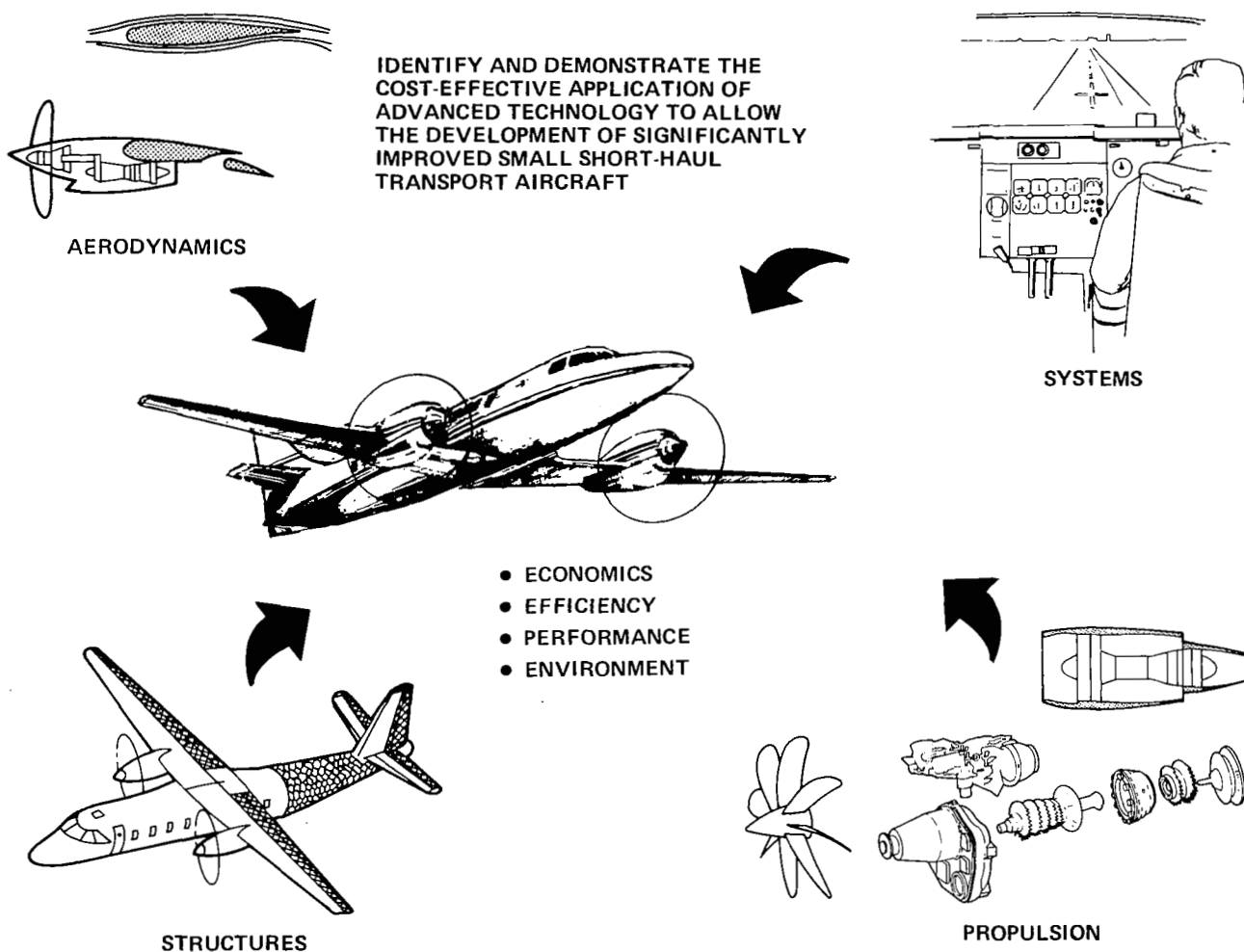
STRUCTURES

PROPULSION

Figure 7

To assist in formulating the STAT research activity, a broad range of advanced technology application studies have been initiated with airframe, engine, and propeller manufacturers. Recently completed studies by Cessna (unpublished), General Dynamics-Convair (Reference 3), and Lockheed-California Company (Reference 4) investigated small transport aircraft designs with 19, 30, and 50 seat capacity. Initially, current technology baseline designs were established for use as a reference against which the benefits of advanced technology could be measured. Figure 8 shows the general arrangement of each manufacturer's 30 passenger baseline. Cessna's design has stand-up headroom, a cruise speed of Mach 0.456 (250 KIAS), Citation business jet airframe technology, Pratt & Whitney of Canada PT6 turboprop engine technology, and has been optimized to minimize direct operating cost (DOC) for fuel at $1.00 per gallon. However, the design did not consider meeting the jet transport interior noise goals of the specification. Cessna also studied a 19 passenger configuration. General Dynamics-Convair designed 30 and 50 passenger current-technology baseline aircraft similar to Cessna's except for the addition of acoustical cabin wall treatment to achieve the interior cabin noise goal of 85 overall sound pressure level, typical of current jet transports. The acoustical treatment weight was estimated to be 1044 kg (2300 lb) for the Convair 30 passenger design of Figure 8. Lockheed-California chose higher design cruise speeds of Mach 0.6 and 0.7 for their 30 and 50 passenger aircraft respectively.

BASELINE AIRCRAFT CONFIGURATIONS
30 PASSENGERS 1219 m (4000 ft) FIELD LENGTH

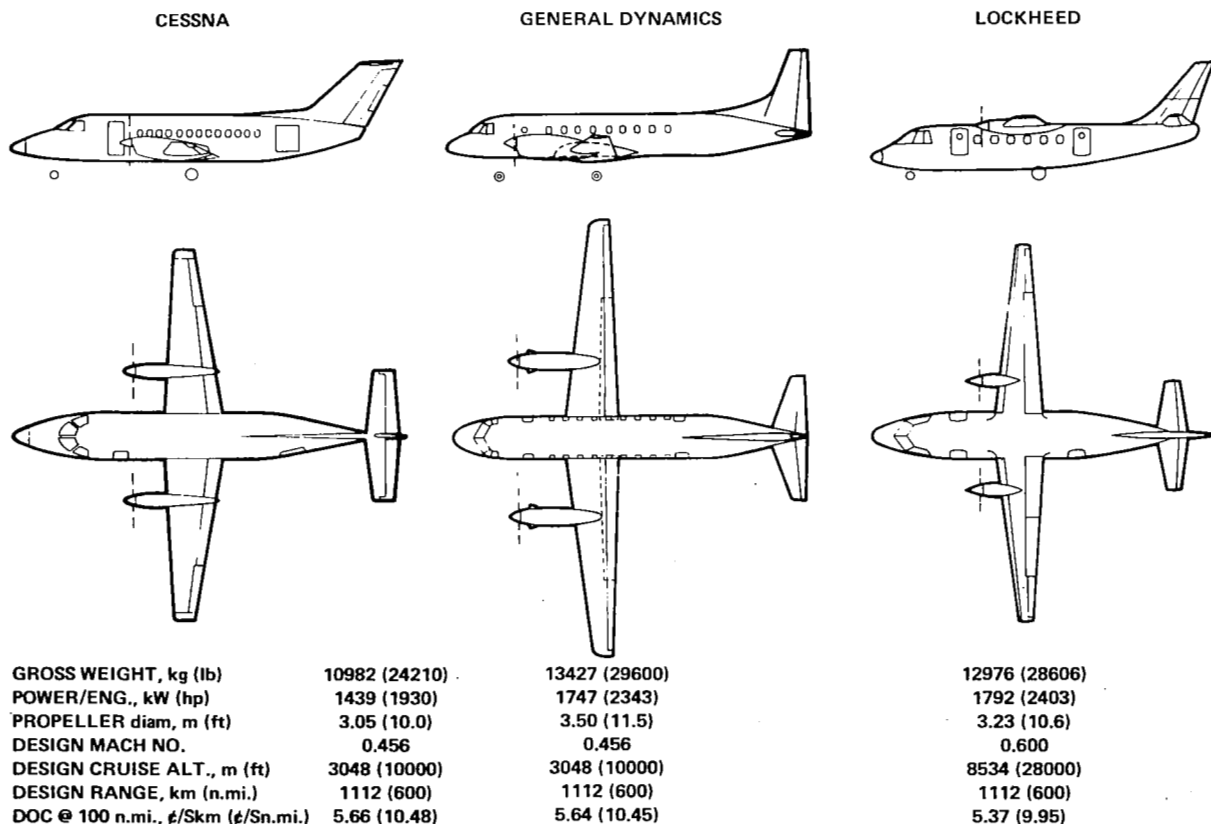|	CESSNA	GENERAL DYNAMICS	LOCKHEED
GROSS WEIGHT, kg (lb)	10982 (24210)	13427 (29600)	12976 (28606)
POWER/ENG., kW (hp)	1439 (1930)	1747 (2343)	1792 (2403)
PROPELLER diam, m (ft)	3.05 (10.0)	3.50 (11.5)	3.23 (10.6)
DESIGN MACH NO.	0.456	0.456	0.600
DESIGN CRUISE ALT., m (ft)	3048 (10000)	3048 (10000)	8534 (28000)
DESIGN RANGE, km (n.mi.)	1112 (600)	1112 (600)	1112 (600)
DOC @ 100 n.mi., ¢/Skm (¢/Sn.mi.)	5.66 (10.48)	5.64 (10.45)	5.37 (9.95)

Figure 8

93

Figure 9 shows the improvement in fuel usage and direct operating cost for Cessna's 19 and 30 passenger advanced technology designs. The utilization of bonding along with the use of composites in secondary structural components had the major impact on improving aircraft weight, cost and operating economics. The major improvements resulting from advances in propeller, engine and aerodynamic technology were in fuel usage followed by significant savings in direct operating cost. Combining all the technologies resulted in advanced technology aircraft designs that used 38 to 40% less fuel on a 100 n.mi. trip compared with the current technology baseline. These improvements resulted in a 21% reduction in direct operating cost on the 100 n.mi. trip. The general arrangement of Cessna's advanced designs are the same as their baseline configurations. As such, the 2 abreast 19 passenger design does not offer the passenger comfort levels of the 3 abreast 30 passenger design.

ADVANCED TECHNOLOGY SMALL TRANSPORT
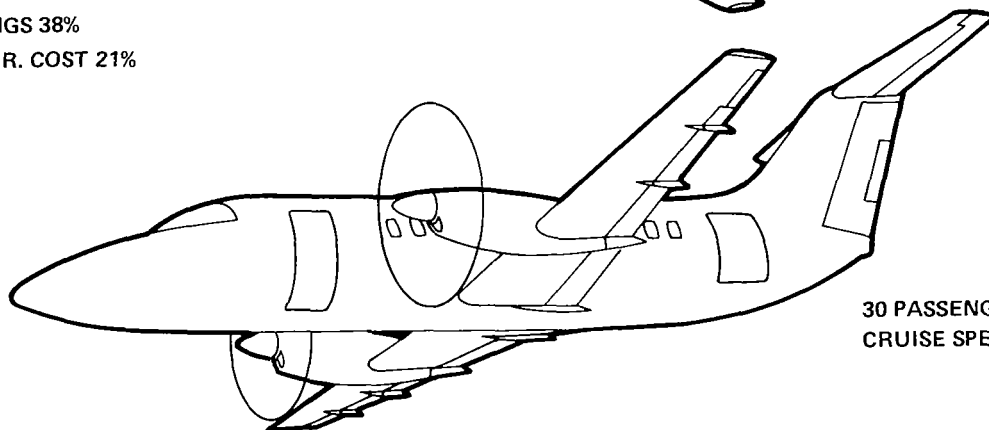## AIRCRAFT DESIGN
CESSNA AIRCRAFT
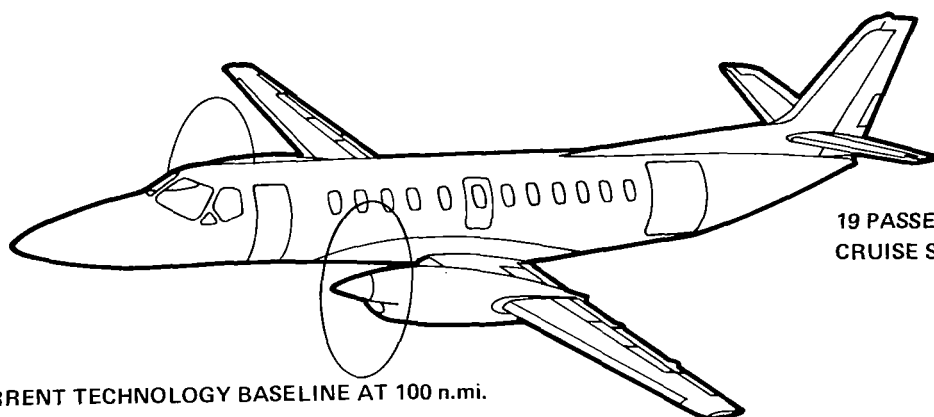
19 PASSENGER
CRUISE SPEED = 0.5 MACH

RELATIVE TO CURRENT TECHNOLOGY BASELINE AT 100 n.mi.
FUEL SAVINGS 38%
DIRECT OPER. COST 21%

30 PASSENGER
CRUISE SPEED = 0.5 MACH

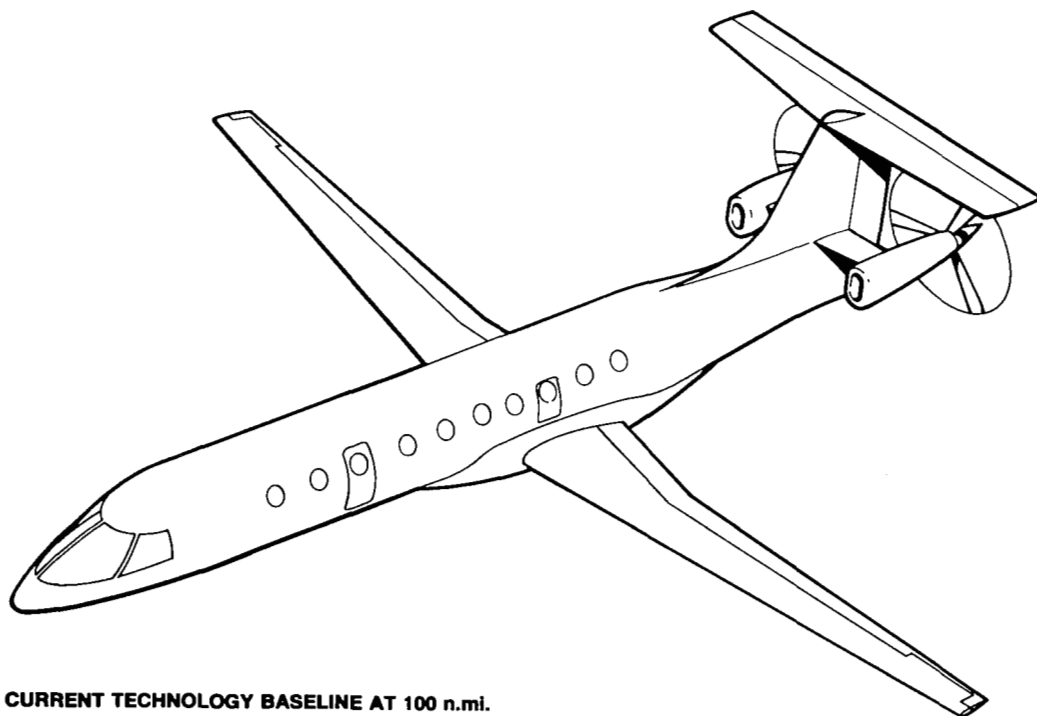RELATIVE TO CURRENT TECHNOLOGY BASELINE AT 100 n.mi.
FUEL SAVINGS 40%
DIRECT OPER. COST 21%

Figure 9

In the Convair study, advanced technologies in aerodynamics, structures, systems, and propulsion were applied individually and those with the greatest payoff were incorporated in a combined advanced technology design. All the Convair aircraft were designed for cruise speed of 250 knots indicated airspeed. The advanced 30 passenger short-haul aircraft design (Figure 10) incorporates a new high-lift wing design using low-drag airfoils, composite structure, active controls, and improved propeller/engine technology. Compared with the current technology baseline, the Convair advanced technology 30 passenger aircraft is 22% lighter in gross weight, has 51% less wing area, requires 37% less power, and uses 31% less fuel on a 100 n. mi. trip. These improvements result in a 24% reduction in direct operating cost for a 100 n.mi. trip with fuel at 26¢/liter ($1/gal). The advanced technology configuration has the engine mounted on pylons at the back of the fuselage. Because a major design goal is to provide a low cabin interior noise level equal to what the passenger is used to in large jet transports, the aft location avoids the large fuselage acoustic treatment penalties that are 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 and avoid damage from aircraft servicing equipment at the terminal.

ADVANCED TECHNOLOGY
SMALL TRANSPORT AIRCRAFT DESIGN
GENERAL DYNAMICS — CONVAIR

RELATIVE TO CURRENT TECHNOLOGY BASELINE AT 100 n.mi.
FUEL SAVINGS 31%
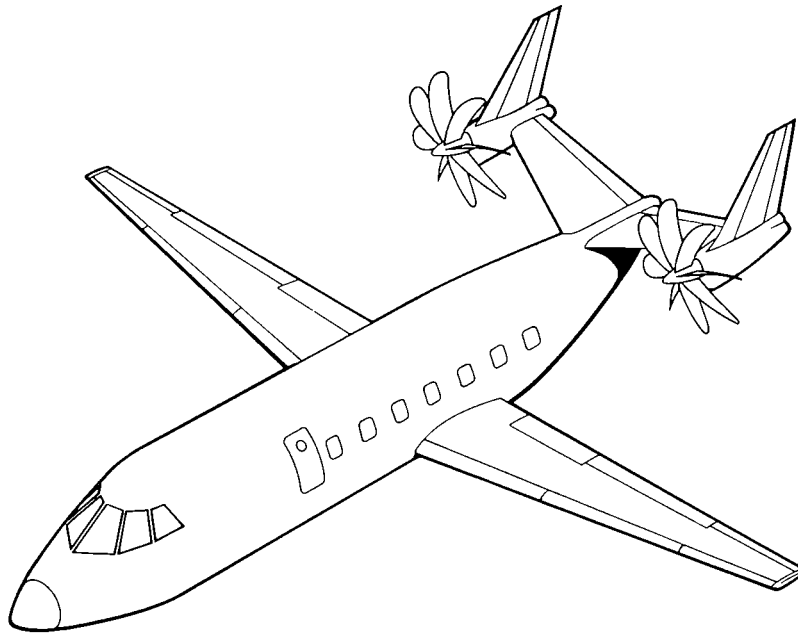**DIRECT OPERATING COST SAVINGS AT $1/gallon 24%**

30 PASSENGER
CRUISE SPEED = 0.5 MACH

Figure 10

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 compared to the skin-stringer aluminum structure of the baseline design. Lockheed's orthogrid or isogrid composite structural concept utilizing laminated bars built up of alternating layers of syntactic resin and high-strength fibers appears very attractive. Prepregged graphite and syntactic resin tape can be obtained in combined form so that both layers can be wound together on automatic machines. This manufacturing technology gives the structural designer considerable flexibility in choosing 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 saves both parts and labor. For a 30 passenger design this concept resulted in a 25% structural cost savings relative to conventional aluminum skin-stringer design practice. One of the most promising advanced technology designs resulting from this study (Figure 11) incorporates an improved high-lift, low drag wing design, composite structures, active controls and propulsion system improvements. 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% less fuel on a 100 n.mi. trip and has a 16% reduction in DOC over their current technology baseline.

ADVANCED TECHNOLOGY SMALL TRANSPORT
AIRCRAFT DESIGN
LOCKHEED — CALIFORNIA COMPANY

30 PASSENGER
CRUISE SPEED = 0.6 MACH

RELATIVE TO CURRENT TECHNOLOGY BASELINE AT 100 n.mi.
FUEL SAVINGS 26%
DIRECT OPERATING COST SAVINGS 16%

Figure 11

General Electric, Garrett AiResearch, and Detroit Diesel Allison are investigating advanced engine technologies for engines in the 1000 to 5000 horsepower class for NASA's Lewis Research Center. Since these studies started well after the airframe studies, NASA utilized their in-house aircraft synthesis capability with airframe manufacture inputs to design optimized baseline aircraft. These aircraft were optimized around current technology engine cycles furnished by the engine companies and scaled to meet common aircraft design requirements. Figure 12 presents an example for cruise speed selection for the three different engine cycles representing different types of compressors and a range of turbine inlet temperature (TIT). Each contractor is now investigating engine cycle characteristics and component technologies that can increase engine life, improve fuel efficiency, and lower maintenance cost for this class of engine. Some of the advanced technologies being investigated for larger engines as part of NASA's ACEE program may be utilized. These studies will be completed in the next couple of months.

ENGINE INFLUENCE ON CRUISE MACH NUMBER SELECTION

50 PASSENGER 1219 m (4000 ft) FIELD LENGTH

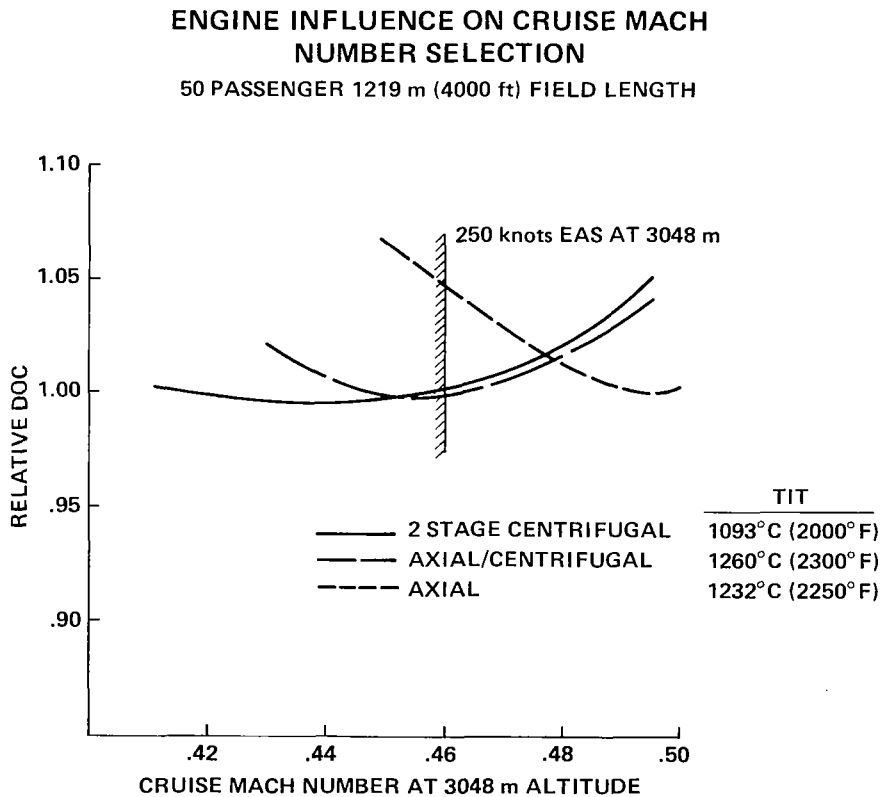|	TIT
———— 2 STAGE CENTRIFUGAL	1093°C (2000°F)
———- AXIAL/CENTRIFUGAL	1260°C (2300°F)
---- AXIAL	1232°C (2250°F)

Figure 12

Potential improvements in small transport aircraft propellers are being studied by United Technologies--Hamilton Standard Division and Cessna's McCauley Accessory Division. To compliment these studies, NASA has performed various trade-off studies to investigate the influence of noise goals, field length requirements and cruise speed capability on propeller selection. Figure 13 shows the influence of number of blades on some selected performance criteria and acoustical treatment weight requirements for 30 and 50 passenger configurations. The magnitude of weight to meet the 85 dB overall sound pressure level goal is about the same for both sizes. However, it represents 3-5.5% of the 30 passenger gross weight compared to 2 - 4% of the 50 passenger gross weight. The power is determined by the 1219 meter (4000 ft.) field length requirement for 3 and 4 blades, and the 250 knot indicated cruise airspeed for the 6 blade case. The 5 blade case is an equal match. In terms of minimum direct operating cost, the 30 passenger design shows a definite optimum with 5 blades while the 50 passenger is about the same for 4, 5, or 6 blades.

PROPELLER SELECTION

WING LOADING = 293 kg/m^2 (60 lb/ft^2)
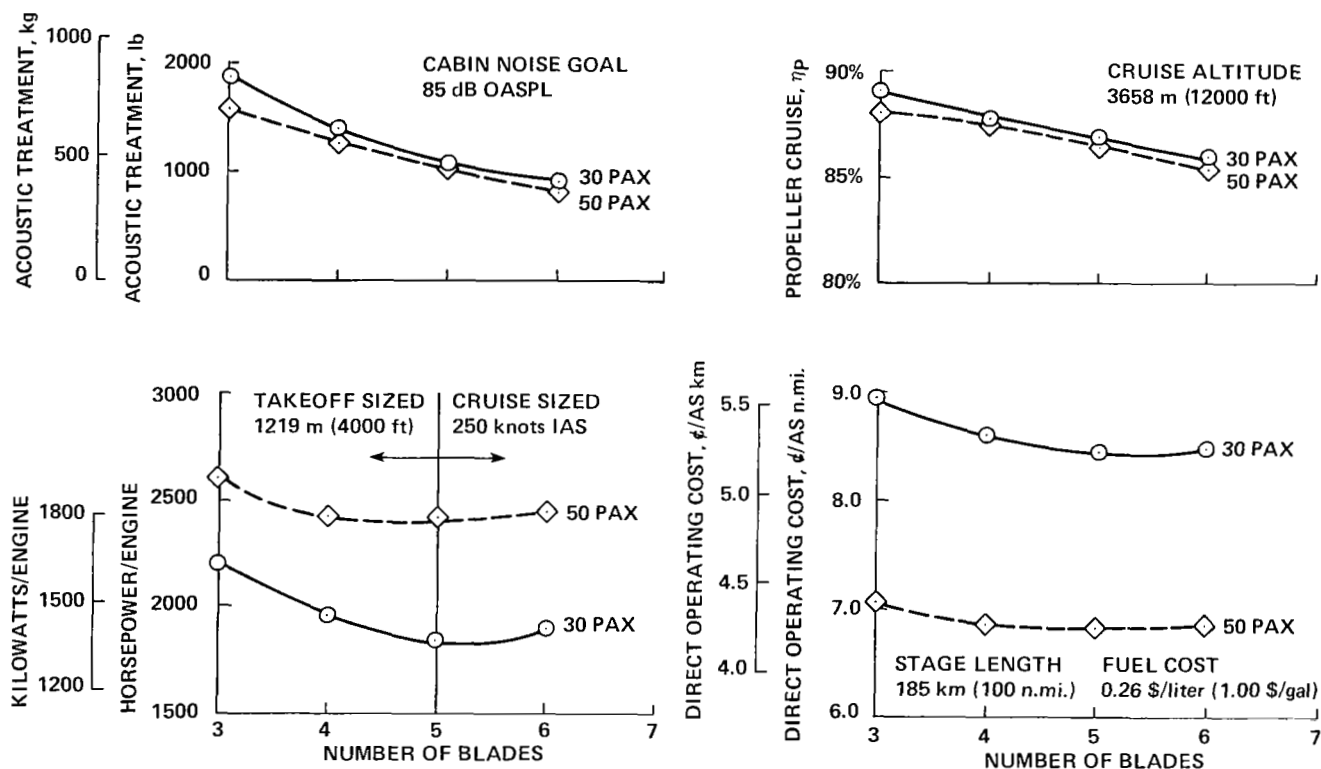DESIGN RANGE = 1112 km (600 n.mi.)

Figure 13

In addition to the broad technology studies for small transport aircraft, NASA is also considering needs that may be met by results from on-going research efforts. Aerodynamic research on natural laminar flow airfoils and low-speed lift to drag improvements are examples. Figure 14 shows one of NASA-Ames most promising advanced natural laminar flow airfoils compared to the older NACA 65A laminar flow airfoil, along with analytically predicted pressure distributions and drag. The advanced airfoil design has a blunter nose, and its maximum thickness occurs farther aft than for the NACA 65A airfoil. The pressure distribution is shown for a Mach number of 0.65 and a lift coefficient of 0.588, which corresponds to the design point for the advanced airfoil. The drag comparison was determined from a viscous-flow computational code that accounted for boundary-layer growth. Transition was assumed to occur at the point where the upper-surface pressure gradient became unfavorable on the respective airfoils. The reduction in drag is about 28%. Recent boundary layer stability analysis by Lockheed-Georgia has indicated a stable boundary layer to 59% chord on the upper surface and 41% chord on the lower surface at the design Mach number and lift coefficient.
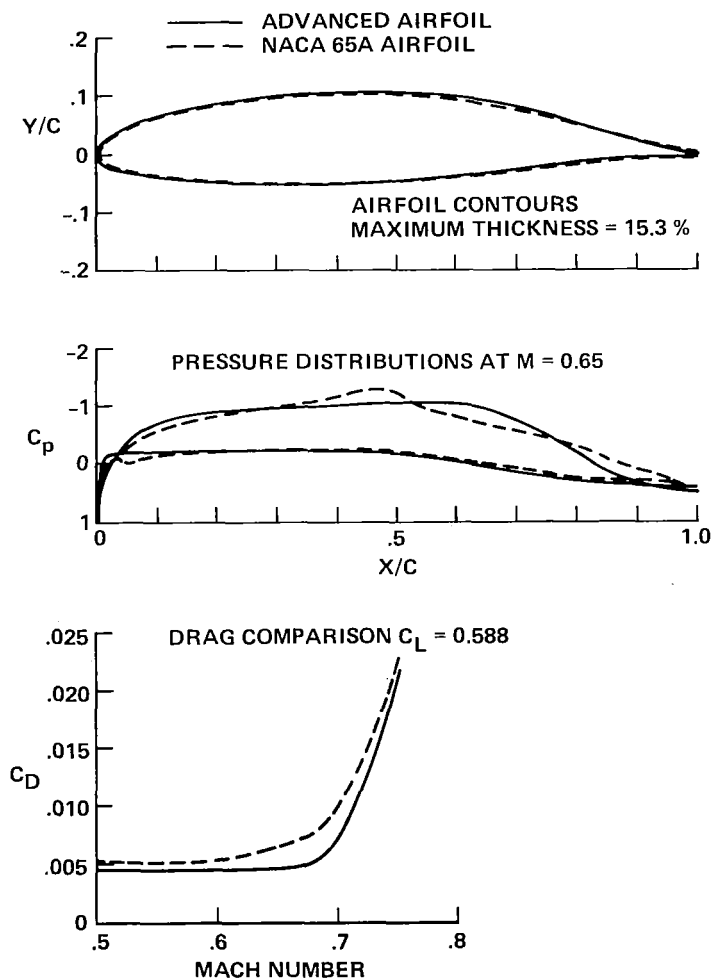
NATURAL LAMINAR FLOW AIRFOIL DESIGN

Figure 14

In order to validate the natural laminar flow airfoil design concept, utilizing practical manufacturing techniques, a large-scale, 1.27 meter (50 inch) chord, two-dimensional airfoil test is planned in the Ames 12-foot pressure wind tunnel. By using the bonded aluminum honeycomb structural concept, an airfoil can be constructed with a practical manufacturing technique that will maintain its shape and have a smooth rivet-free surface. Figure 15 shows an example of such a section built by the Boeing Commercial Airplane Co. (Reference 5). In connection with this airfoil research, a report (Reference 6) summarizing experience with natural laminar flow and the potential for resilient leading edges to reduce insect contamination was published in May 1979. Other concepts to protect the leading edge from contamination so that laminar flow can be maintained will also be evaluated. Some of these concepts have been investigated in NASA's ACEE program as part of the laminar flow control research.

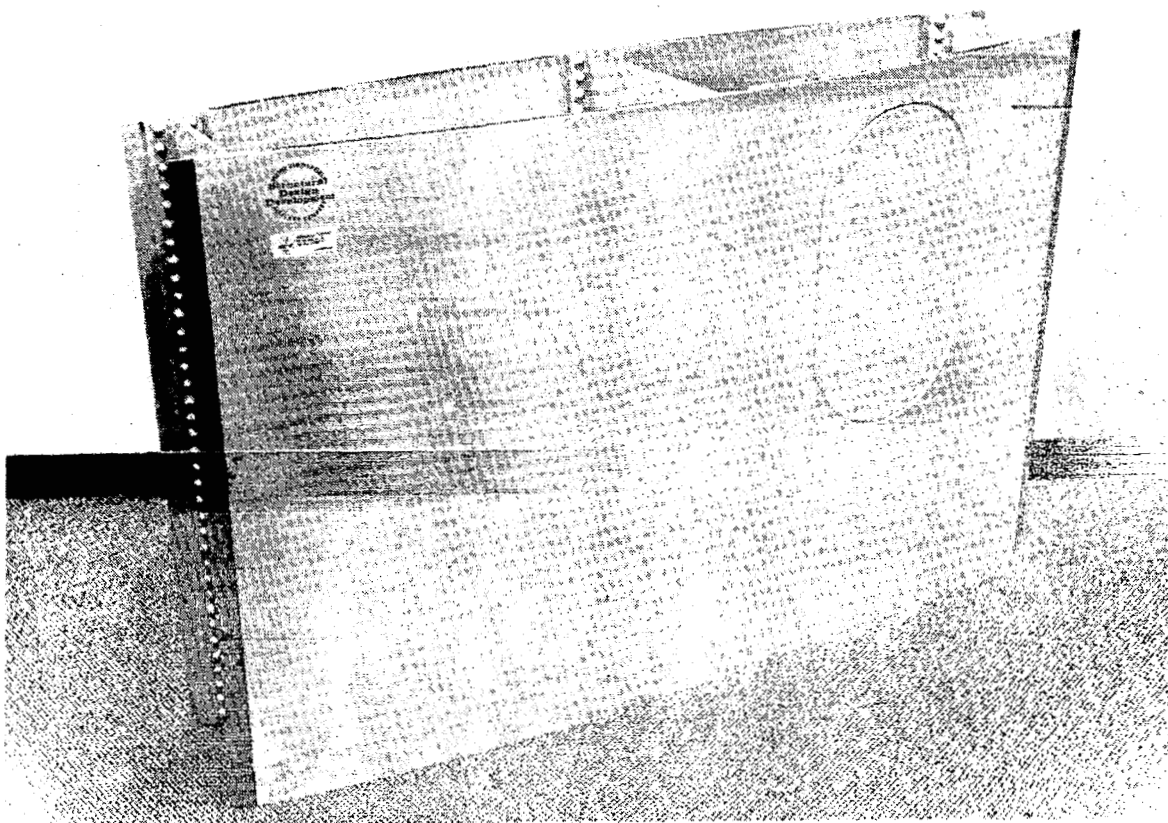## SAMPLE BONDED ALUMINUM HONEYCOMB CONSTRUCTION

Figure 15

To establish an aerodynamic data base representative of current technology, unpowered and powered small transport aircraft wind tunnel tests of a 15%-scale model of the Swearingen Metro transport are being conducted by NASA-Ames under a cooperative research agreement with Swearingen Aviation Corporation. The first series of unpowered tests were completed in the Ames 12-foot pressure wind tunnel in June of 1980. These tests consisted of aircraft component drag build-up; low, mid, and high nacelle locations on the wing; modified wing leading edges; and an alternate flap design. A limited amount of wing flow visualization and pressure distributions (using pressure belts) was obtained with the engine nacelles on and off the wing. Figure 16 illustrates the aircraft drag build-up configurations and their contributions to total model drag. The body and wing have almost equal drag contributions, about 120 counts. The tail assembly added 48 counts and the nacelle contribution was mainly at the higher lift coefficients. When the landing gear was extended with the gear doors open, this added 548 counts of drag for the flaps up configuration.
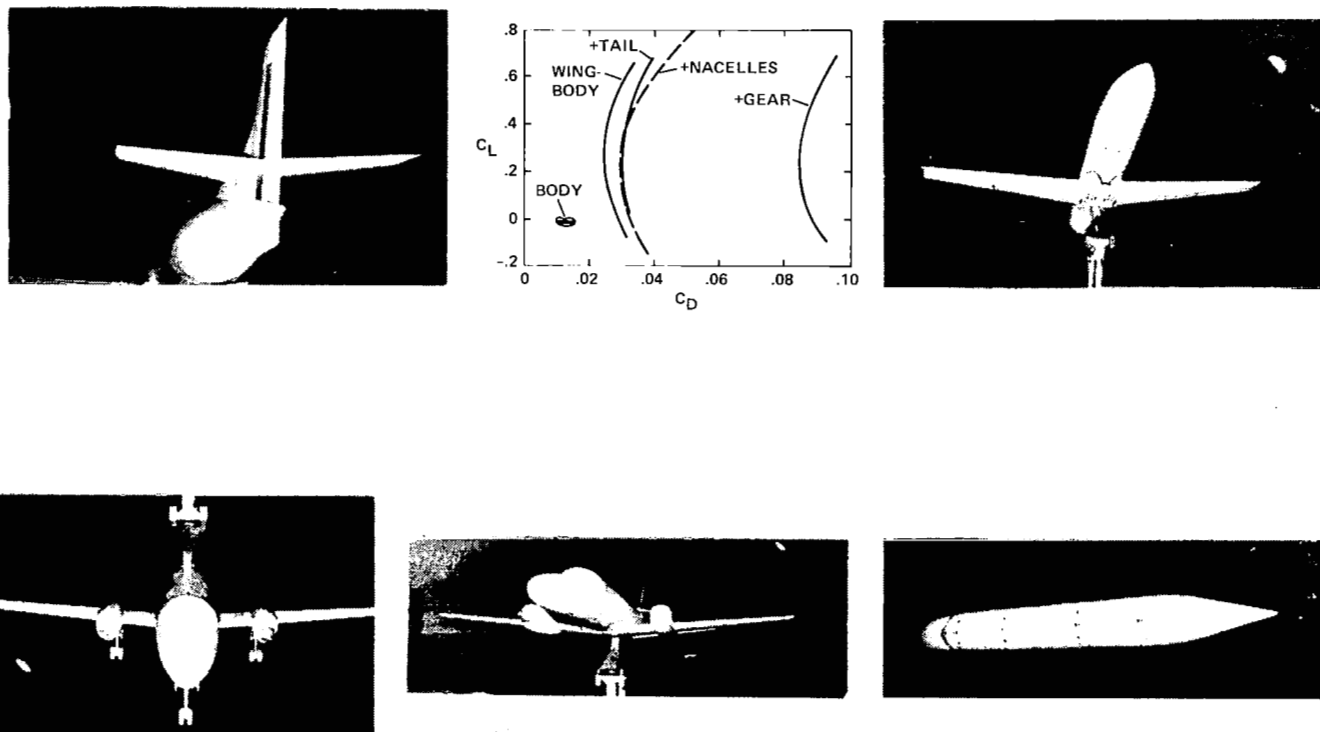
DRAG BUILDUP

Figure 16

During the testing of the basic Swearingen Metro configuration alternate engine nacelle locations were investigated for general research interest. Figure 17 shows the influence of the nacelle location on the maximum lift coefficient of the model. All nacelles had the same general shape except for the aft fairing. The low nacelle showed the least degradation in maximum lift compared to the clean wing. However, for a low wing configuration, the mid-nacelle location offers a more practical compromise for other design considerations.
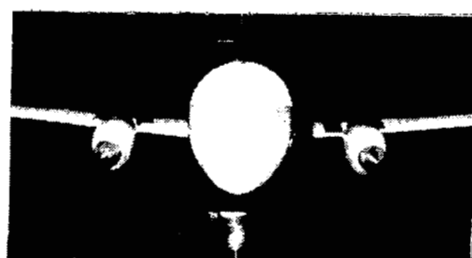
NACELLE LOCATION
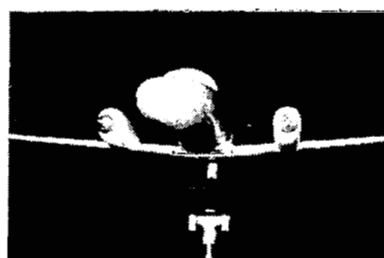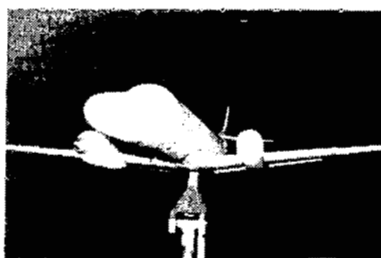
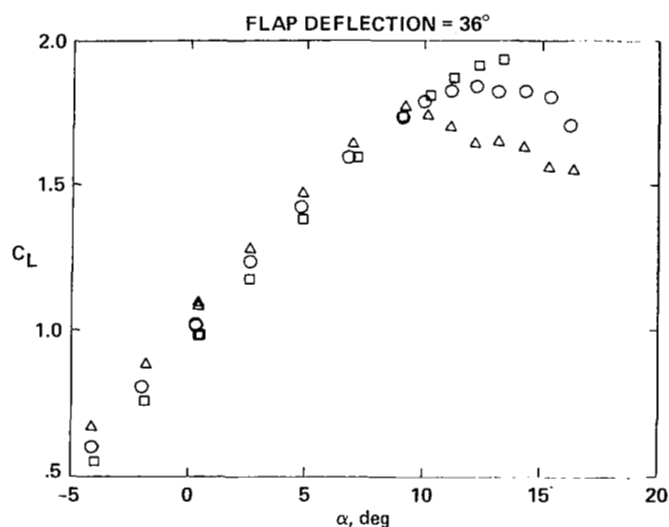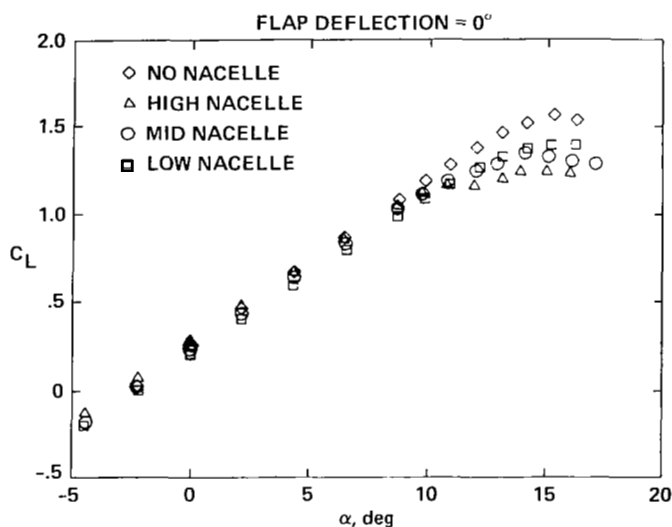HIGH NACELLE   MID NACELLE   LOW NACELLE

Figure 17

The STAT technology elements are along disciplines similar to the large aircraft technologies of the ACEE program. The short stage length and lower altitude operations, however, result in different design considerations. In aerodynamics, climb performance is as important as cruise performance. Turboprop installation aerodynamics and propeller efficiency are major propulsion system considerations. The small size of engine components results in different engine design limitations. In structure, minimum gage requirements mean different tradeoffs in composite utilization. Active control systems and icing protection can enhance ride quality and safety in the low altitude operating environment. Unconventional configurations such as aftmounted turboprops, lifting tails, or canards may offer significant benefits.

Recent studies have indicated advanced technology can offer aircraft with passenger space and comfort levels comparable to the larger jet transports with significant improvements in economics. Estimates in direct operating cost savings ranged from 16 to 24 percent with initial aircraft costs reduced from 5 to 18%. Fuel savings range from 26 to 40 percent.

IMPORTANT TECHNOLOGY ELEMENTS

AERODYNAMICS	PROPULSION	STRUCTURES	SYSTEMS
LOW DRAG AIRFOILS	PROPELLERS	COMPOSITES	ACTIVE CONTROLS
HIGH-LIFT DEVICES	ENGINE COMPONENTS	BONDING	ICING PROTECTION
ENGINE/AIRFRAME INTEGRATION	CONFIGURATION		CONFIGURATION

TECHNOLOGY BENEFITS

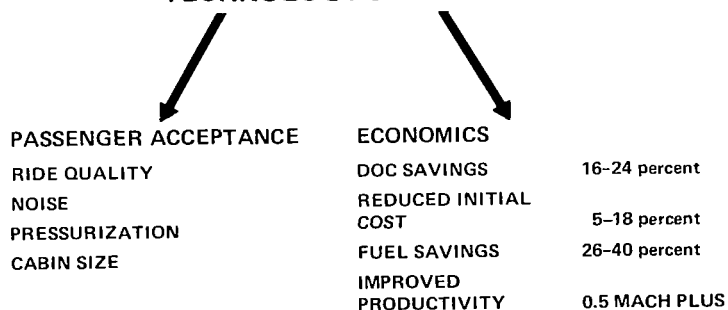| PASSENGER ACCEPTANCE	ECONOMICS	
RIDE QUALITY	DOC SAVINGS	16-24 percent
NOISE	REDUCED INITIAL COST	5–18 percent
PRESSURIZATION	FUEL SAVINGS	26-40 percent
CABIN SIZE	IMPROVED PRODUCTIVITY	0.5 MACH PLUS

Figure 18

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