A Study of Commuter Aircraft Design

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Commuter airlines have generally demonstrated excellent growth in recent years. This growth has been accomplished mainly with aircraft that have evolved from larger general aviation aircraft or specially designed utility aircraft. None reflect a configuration optimized for the current type of passenger service early in the vehicle definition phase. This paper investigates the impact of configuration considerations, mission requirements, and performance constraints on conceptual commuter aircraft designs. Emphasis is placed on direct comparisons between turbofan and turboprop powered aircraft in the 10–30 passenger class. The analysis is accomplished using a computerized aircraft synthesis model that simulates the aircraft design and mission. The resulting conceptual aircraft are similar in size and performance regardless of engine type but the turboprop offers more mission flexibility.


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INTRODUCTION

In 1969, the Civil Aeronautics Board (CAB) established a new class of carrier defined as commuters. These carriers provide at least five scheduled round trip flights per week or fly regular mail service. Many of these carriers grew from air taxi operations, permitted by the adoption of Federal Regulation Part 298 in 1952, utilizing aircraft that evolved from larger general aviation aircraft or specially designed utility aircraft. These fixed base operators and entrepreneurs provide flexible air service to small communities and over routes having low travel demand. Many of these routes were those that had become increasingly unprofitable for the larger aircraft used by the local service carriers.

In late 1972, the CAB raised the aircraft payload and/or weight limitations for commuter airlines to 30 passengers or 7500 lbs payload. By the end of 1975, there was a total of 235 commuter airlines reporting data to the CAB, of which some 165 carried passengers (1). Since the adoption of the increased payload limitations, only one aircraft, the Shorts SD3-30, has been specifically designed to this criteria.

The purpose of this paper is to investigate the impact of configuration considerations, mission requirements, and performance constraints on conceptual commuter aircraft designs utilizing turboprop or turbofan propulsion systems. Of particular interest is the effect of these factors on the required engine power or thrust. The level of analysis corresponds to that performed during the vehicle definition phase of preliminary design. However, due to the limited scope of the study, the concepts may not be the optimum configuration for each propulsion concept, but do provide a comparison utilizing common requirements, constraints, and analytical techniques. Aircraft concepts for this market require a careful balancing of performance, technology, and design-to-cost considerations. In virtually all civil aircraft production programs, the size and design have been paced by the availability of the engine. Studies of the type presented in this paper can be important to the engine preliminary design to identify the future requirements for new or derivative engines.

BASIC DESIGN CONSIDERATIONS

The determination of the aircraft that will most efficiently meet the requirements of the commuter market requires the careful evaluation of variable parameters such as engine cycles, payload, field length, range, and type of high-lift system. Some of these items will be addressed directly in this paper and others are taken from the results of References (2) and (3). The analyses of this paper utilize a computerized aircraft synthesis model (4) that simulates the aircraft design, mission, and performance. The basic design parameters considered in this paper are shown in Table 1.

Mission Parameters

References (2) and (3) were used to produce the following mission parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Cruise Mach Number</td>
<td>.5 minimum</td>
</tr>
<tr>
<td>Cruise Altitude</td>
<td>25,000 ft</td>
</tr>
<tr>
<td>Range</td>
<td>565 nautical miles</td>
</tr>
<tr>
<td>Reserves</td>
<td>100 nautical miles plus 45 minutes</td>
</tr>
</tbody>
</table>

Table 1 Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Types</td>
<td>Turboprop and Turbofan</td>
</tr>
<tr>
<td>Passenger Capacity</td>
<td>10, 20, and 30</td>
</tr>
<tr>
<td>FAR Field Length</td>
<td>2500 and 4500 ft; sea level, 90°F</td>
</tr>
<tr>
<td>Cl&lt;sub&gt;MAX&lt;/sub&gt; of High Lift System</td>
<td>2.3, 3.0, and 3.5</td>
</tr>
</tbody>
</table>

1 Numbers in parentheses designate References at end of paper.
vide guidance in selecting the mission parameters in Table 1. These two studies collected data on the markets currently being served by local service and commuter carriers in the United States. Ninety-nine percent of the airports served by local service carriers, and 90 percent of the airports served by commuters, had runway lengths greater than 4500 ft. However, some commuters did operate from airports with runways of only 2500 ft. Very few of the routes with passenger densities below 100,000 per yr had stage lengths beyond 400 mi. The largest volume of passengers fell in the 200-300-mile bracket. The range shown in Table 1 is the equivalent single stage range for an aircraft capable of performing two 250-n.mi. stages, including reserves, without refueling.

Reference (2) studied 30-passenger turbo-prop and turbofan aircraft similar to the concepts of this paper. That study determined the optimum cruise altitude to be 22,000 ft for both configurations. Restricting the operating altitude to 25,000 ft can result in some aircraft cost savings by reducing the complexity of the cabin oxygen and airplane hydraulic systems and a savings in cabin structural weight (3).

General Arrangement

The baseline aircraft were all twin-engine configurations of the general arrangements shown in Fig. 1. The turboprop engines were wing mounted and the turbofans aft-fuselage mounted. The low wings were swept only 5 deg at the quarter-chord, permitting the rear spar to be perpendicular to the fuselage centerline. This allows flap and aileron fittings of simple designs which can be used on both left and right wing panels; it allows wing ribs and bulkheads to be assembled perpendicular to the rear spar and simplifies rigging for tooling and assembly. Based on previous studies (2, 3), the basic wing aspect ratio and taper ratio were chosen as 10 and 0.3, respectively, although others were investigated as described in a later section. The turboprop has the conventional empennage arrangement while the turbofan uses the T-tail arrangement because of the fuselage mounted engines.

Propulsion

The propulsion systems for the conceptual aircraft represent currently available engine cycles, weights and dimensions that are capable of providing the low noise, cost, and fuel consumption important to commuter operations. The turboprop was a model of the General Electric T64 scalable to the required shaft horsepower. Engine geometry, of course, also scales and this provides the means for scaling the nacelle size which accounts for variation in nacelle weight and drag. No inlet pressure losses were assumed. Some basic characteristics of the turbopfan and turboprop are listed in Table 2.

Selection of this level of propulsion technology reflects engines that either exist or could be developed today. From a practical standpoint, it is unrealistic to assume a new turbine engine will be developed just for the commuter market. Any developments that do

Table 2 Engine Characteristics

<table>
<thead>
<tr>
<th></th>
<th>TURBOPROP</th>
<th>TURBOFAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninstalled Specific Weight (lb/lb/sec SLS)</td>
<td>.21</td>
<td>.30</td>
</tr>
<tr>
<td>Uninstalled Specific Thrust (lb/lb/sec SLS)</td>
<td>27.8</td>
<td>--</td>
</tr>
<tr>
<td>Uninstalled Specific Power (SHP/lb/sec SLS)</td>
<td>--</td>
<td>129.0</td>
</tr>
<tr>
<td>Takeoff Flat Rating (°F)</td>
<td>90</td>
<td>108</td>
</tr>
<tr>
<td>Maximum Propeller RPM</td>
<td>--</td>
<td>1160</td>
</tr>
<tr>
<td>Uninstalled Fuel Consumption (at 25,000 ft)</td>
<td>36-7</td>
<td>--</td>
</tr>
<tr>
<td>M=.5</td>
<td>TSFC=.658 lb/hr/lb</td>
<td>BSFC=.423 lb/hr/SHP</td>
</tr>
<tr>
<td>M=.6</td>
<td>--</td>
<td>.408</td>
</tr>
<tr>
<td>M=.7</td>
<td>--</td>
<td>.397</td>
</tr>
</tbody>
</table>

Table 3 Cabin Dimensions

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Seats</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Cabin Width (in.)</td>
<td>68</td>
<td>88</td>
<td>108</td>
</tr>
<tr>
<td>Seats Abreast</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Aisle Height (in.)</td>
<td>63</td>
<td>70</td>
<td>78</td>
</tr>
</tbody>
</table>
occur will undoubtedly be derivations of existing civil or military engines. However, it is important to do cycle studies to determine the potential gains when the engine performance is properly matched at takeoff, climb and cruise. Although this was not done in this study, it would be a logical next step which should be followed with an evaluation of how an engine with attractive cycle characteristics could be derived from an existing turbine engine core.

Baseline Cabin
The cabin geometry was taken from Reference (2) for the 30-passenger configuration and scaled down for the 10- and 20-passenger capacity maintaining the same seated comfort. This level was 32-in. seat pitch, 20-in. wide seats and 18.5-in. wide aisle. Resulting cabin dimensions are shown in Table 3.

Fig. 2 shows how the cabin width of the conceptual aircraft compares with some existing aircraft of similar seating capacity.

High-Lift System
Landing field requirements are achieved through a combination of maximum lift coefficient capability and aircraft wing loading. Fig. 3 shows the maximum allowable landing wing loading for the two field lengths of this study as a function of maximum lift coefficient. The shaded bands represent the estimated trend of the conceptual aircraft based on the assumptions of a fixed rate of descent of 900 ft/min, 0.35 g's, for a 90 F day at sea level using FAR field length factors. The symbols in Fig. 3 represent the landing wing loading and maximum lift coefficient of some current aircraft. Also indicated on the figure are the lift capability regions of three types of mechanical high-lift systems. The three systems, in addition to different levels of maximum lift coefficient capability, represent various levels of manufacturing complexity. "S" refers to a system with a simple tracked or hinged partial span flap and no leading edge device. The "N," or nominal system in this study, refers to a system such as the partial span hinged-fixed vane flap and full span leading edge slat of the Douglas DC-9. The "C" refers to the most complex system having a tracked-moving vane flap plus a leading edge slat.

The impact of the high-lift system capability on the design will be shown in a following section; however, the relative merits of weight and cost as analyzed in Reference (3) are shown in Fig. 4. The lower left portion of Fig. 4 shows the wing loading requirements of the three systems to meet the landing field
length requirement of 4500 ft shown in Fig. 3. The nominal system required a wing loading of 90 lbs/sq ft while the more simple system is 68 lbs/sq ft and the complex is 105 lbs/sq ft. The low wing loading of the simple system resulted in an increase in wing area of 55 percent and wing weight of 27 percent compared to the nominal system. Accounting for this higher wing weight plus the weight growth effects would result in a total airframe cost at least 10 to 12 percent higher.

The higher wing loading of the more complex system resulted in a 13 percent decrease in wing area and a 5 percent decrease in wing weight compared to the nominal system. Since the weight saving was small, Reference (3) investigated the complexities associated with manufacturing and tooling for the more complex system. The results of this analysis estimated only a 1 percent increase in total airframe cost as indicated in the lower right portion of Fig. 4. This would probably be an acceptable increase since it is estimated to take a 6 percent increase in the airframe cost of the more complex over the nominal to equalize the direct operating cost (DOC) of the two aircraft. On the other hand, as shown later, other design constraints may preclude the need for this lift capability.

AIRCRAFT SIZING CONSIDERATIONS

The design methodology used in evaluating the matrix of potential designs (Table 1) was to determine the design that minimized DOC and meets the particular mission requirements. The methodology also allowed for the evaluation of the impact of the different propulsion systems, payloads and high-lift systems. Several conceptual aircraft were sized using the synthesis program (4) for the 565-n. mi. mission and the three passenger capacities. During the sizing, the critical performance criteria were checked and any specified limits satisfied.

Turbofan Powered Aircraft Sizing

The results of the sizing process are best illustrated by referring to Fig. 5. This figure shows the thrust-weight ratio (T/W) required as a function of wing loading (W/S) for a number of bypass ratio 6 turbofan powered conceptual aircraft that meet the range requirement of 565 n. mi. Moving from the upper left-hand corner to the lower right-hand corner of Fig. 5 results in lighter gross weight vehicles with lower DOC's. A number of constraints representing performance goals or geometric limits are shown. The shaded bands represent field length capability constraint boundaries for three combinations of field length required and lift capability. The cross-hatched band represents designs that just meet the cruise capability at the design altitude for W/S less than 60 lb/sq ft or the engine-out climb requirements of Reference (5) for W/S more than 60 lb/sq ft. The width of these bands represents the spread due to passenger capacity.
The line boundaries on the right portion of the figure represent constraints for storing the required mission fuel completely in the wing for the three passenger capacities.

For the bypass ratio 6 turbofan configurations of Fig. 5, all designs are sized by the intersection of the takeoff and landing field length requirements and thus have a cruise Mach number capability in excess of 0.5 requirement at normal cruise power. The lightest weight and lowest DOC designs would be the 2500 ft field design having a flap system with a maximum lift coefficient of 3 resulting in a T/W of about 0.35 and W/S of about 88 lbs/sq ft. This is an acceptable design for all passenger sizes unless the wing fuel volume constraint is applied. Then the 10- and 20- passenger sizes would be restricted to the lower wing loadings of about 64 lbs/sq ft and 78 lbs/sq ft to provide the required wing fuel volume. This would also mean that less lift capability would have to be designed into the flap system to provide the field length performance. The 2500 ft field length designs are not constrained by fuel volume limits and thus designs with lift coefficients above 3 would be the most attractive.

The trends in aircraft weight, engine size, cruise performance, and aircraft price for the turboprop configurations will be compared with the turbofan configurations in a later section. Also, since the turbofan was sized by the field length constraint, the sensitivity of operating the turbofan at higher altitudes will be shown in a later section.

**Turboprop Powered Aircraft Sizing**

Before the turboprop aircraft were synthesized and the sizing constraints investigated, a brief study was performed to select the appropriate propeller integrated lift coefficient (C_{LI}) and activity factor per blade (AF). The results of this analysis are shown in Fig. 6 for a 4-bladed propeller having two values of C_{LI} and a range of AF. The methodology selects the propeller diameter that maximizes the propeller efficiency at the cruise conditions (M=0.5, alt. = 25,000 ft) for a fixed propeller RPM and limits the maximum propeller rotational tip speeds to values below 700 ft/sec for noise considerations.

Fig. 6 shows the trends in low speed thrust at takeoff, static horsepower required for the cruise requirement, cruise efficiency and the ratio of low speed thrust to complete propulsion system weight. Propulsion system weight includes the engine, propeller, and nacelle. The values selected for the propeller design C_{LI} and AF were those that maximized the propulsion system thrust-to-weight ratio within the ranges of values studied. Thus the C_{LI} and AF selected for use in the turboprop sizing were 0.5 and 170, respectively.

Fig. 7 shows the results of the turboprop aircraft sizing in the same manner as the turbofan results in Fig. 5. For the turboprop, shaft horsepower-to-weight ratio is used instead of thrust-to-weight ratio. Although the computational procedure accounted for the jet thrust, since most companies specify their ratings in terms of shaft horsepower, that is the parameter used here. In contrasting the results of the turboprop designs (Fig. 7) with the turbofan designs (Fig. 5), three factors are readily apparent: (a) turboprop and turbofan designs have similar wing loadings for the
same field length and lift capability; (b) the turboprop designs are balanced with respect to the takeoff, cruise, and landing requirements where the turbofans were all takeoff sized; and (c) due to the better fuel efficiency of the turboprop, the wing fuel volume constraint is insignificant except for the 10-passenger high wing loading design. The wing loading and power loading for the turboprop designs are also summarized in Table 4.

AIRCRAFT EVALUATION RESULTS

Certain weight, performance, and cost aspects of the conceptual turboprop (TP) and turbofan (TF) aircraft resulting from the sizing methodology previously described are discussed in this section. The trends are shown in terms of passenger capacity, type of engine, and field length capability. Figs. 8-12 show these comparative trends. For the 4500 ft field length designs, a shaded band is shown that represents the spread of the data for a maximum lift coefficient (C_{L,max}) capability of 2.3 and 3.0. The designs having a C_{L,max} of 3.0 were lighter in weight, required smaller engines, used less fuel, and cruised at higher speeds. It should be remembered in reviewing these comparative data that the turbofans have higher cruise speeds, because the majority of the turboprop designs are cruise sized while the turbofan designs are takeoff sized. The sensitivity of design cruise speed on the turboprop designs will be shown in a later section.

Fig. 8 shows the gross weight trends. The turbofan designs range from 10 percent heavier for the 10-passenger size to 20 percent heavier for the 30-passenger size. The shorter field length designs are from 18 to 27 percent heavier than the longer field lengths for the same passenger capacity.

Fig. 9 compares the block fuel requirements for the 565 n. mi. design mission. As expected, the turboprop designs are the most fuel efficient. The turbofan uses from 55 to 72 percent more fuel as passenger size increases on the field length requirement.

Fig. 10 shows the cruise Mach number capability of the designs at normal rated cruise power, start of cruise weight, and the design cruise altitude of 25,000 ft. Since the turbofan designs are takeoff sized, they all exceed the specified design cruise Mach number. For a given field length as the aircraft size increased, the cruise speed increased except for the short field turboprop. The difference in cruise performance results in block times of the turbofan being from 11 to 26 min. faster over the design mission. The 11-min. difference was for the 2500 ft field length 10-passenger design; the 26-min. difference for the 4500 ft field length 30-passenger design.

Fig. 11 shows the engine requirements for the conceptual designs. They follow the trend of the aircraft gross weight. The turboprop power requirements cover a spectrum which could be satisfied by a number of derivatives of existing engines. For the turbofan, there are several engines to cover the thrust spectrum but only two, the Lycoming ALF502 and General Electric CF34, have the cycle characteristics similar to those assumed in this study. They are both in the 6500 to 8000 lb thrust class.

Direct cost comparisons between the con-
Two engines

Range = 565 n. mi.

2500 ft Field length

4500 ft Field length

TURBOFAN

TURBOPROP

Fig. 9 Block fuel comparisons

Fig. 11 Engine size comparisons

Fig. 12 Cost considerations

Conceptual turbofan and turboprop will not be made in this paper. Based on historical prices of turboprop and turbofan aircraft of the same airframe weight, turboprops cost less in terms of dollars per pound of airframe (6). In more detail costing procedures, such as used in References (2) and (3), the cost difference between the turboprop and turbofan aircraft was mainly the difference between engine costs for the two configurations. In this study, two parameters are shown in Fig. 12 to get a feel for the aircraft costs.

On the left side is shown the trend in airframe weight (i.e., aircraft empty weight minus total engine weight) and on the right the cost of one engine based on the price trends of existing engines taken from Reference (6). These two parameters were chosen because most airframe costing models are related to airframe weight and the differences in power output of the engines could be reduced to a common variable. From the data in Fig. 12, it appears there would be little difference between turbofan and turboprop aircraft initial cost when designed for the same field length capability. Reducing field length requirements to 2500 ft has a significant impact on engine cost and airframe weight for all passenger capacities.

Sensitivity Studies

The results shown in the previous sections were from analyses based on baseline design parameters. This section will look at
the sensitivity of some of these design assumptions on various weight, performance, and cost parameters. The studies address the design cruise speed of the turboprop, cruise altitude of the turbofan, wing geometry considerations for both engine types, fuselage geometry design, and estimated noise characteristics.

Turboprop Design Speed

The turboprops in the comparative evaluation of the previous section cruised at speeds in the vicinity of 0.5 Mach number (Fig. 10). To evaluate the impact of a change in design cruise speed to 0.6 Mach number, conceptual designs were resized for the high wing loading case (Fig. 7) to meet this requirement. Fig. 13 shows the comparison of a selected number of parameters for the 0.6 Mach number designs relative to the 0.5 Mach number designs.

The gross weight of the higher speed designs increased about 10 percent. This would make the turboprop design gross weights similar to the turbofan designs of Fig. 8 for the same field length. The 0.6 Mach number turboprops required 40 percent larger engines than the 0.5 Mach number designs and used 22 percent more fuel for the design mission. The effect on DOC was an increase of only 1 to 3 percent. The attractive feature of the higher speed design was the savings of 15-17 min. in the mission block time. This savings would leave the turbofan design only 10 min. faster. Reference (2) showed that the mission performance of a turboprop could actually be the same as the turbofan by selecting the propeller design parameters at the higher cruise Mach number.

Turbofan Cruise Altitude

The 30-passenger turbofan designs of the previous section had cruise speeds in the vicinity of 0.7 Mach number (Fig. 10) because they were sized by the field length requirement. Restricting these faster turbofan designs to an altitude of 25,000 ft has the turbofan operating farther off optimum T/D than the turboprop. To evaluate the impact of a change in the cruise altitude, the 30-passenger high wing loading case was resized for 30,000 ft and 35,000 ft cruise altitude. Table 5 shows the relative values of selected design parameters for the three design altitudes.

The higher altitude designs in Table 5...
are still sized by the 4500 ft field length requirement and the cruise Mach number is the speed capability at cruise altitude and normal cruise power. The 35,000 ft design speed capability falls off because in addition to reduced engine thrust there is more wing compressibility drag due to the higher required lift coefficient. The fuel required to fly the design mission is reduced significantly, however, because of the large increase in \( \frac{L}{D} \) and slight decrease in engine thrust specific fuel consumption as cruise altitude increased. This resulted in a 2 to 5 percent decrease in engine size and 3 to 6 percent decrease in gross weight. The combined effect of changes in speed, weight, engine size, and fuel on DOC shows the optimum DOC design to be 30,000 ft.

Wing Geometry

The baseline wing geometry was chosen to provide attractive operating costs and fuel efficiency based on the results of References (2) and (3). The sensitivity of these important performance parameters, as well as gross weight and power to wing aspect ratio and taper ratio, are shown in Fig. 14. Wing sweep was not investigated since none of the designs cruised above the wing's estimated critical Mach number when operated at 25,000 ft altitude.

Although most of the variations shown in Fig. 14 are on the order of a few percent, the two types of engines showed different trends. Since the turboprop was sized by the field length requirements instead of cruise requirements, the higher aspect ratio did not have a large impact on the power required as it did for the turboprop. The slight increase in turboprop gross weight is due to the larger engines required to meet the field length requirement since the empty weight and wind loading increased slightly with aspect ratio. The turboprop gross weight decreased because the total cruise drag which sized the engines decreased with aspect ratio.

Both designs show decreasing DOC with aspect ratio with the turboprop being most sensitive. The turboprop DOC decreased slightly with aspect ratio because the resulting increase in cruise speed capability offset the cost increase associated with the heavier airframes and larger engines. The turboprop design showed optimum block fuel usage at the baseline aspect ratio of 10. Although the turboprop continued to have a small reduction in fuel consumption above 10, the major reduction was between aspect ratio 8 and 10. A taper ratio of 0.3 was the best for all parameters considered.

Wing geometry considerations have a strong influence in the available fuel volume for small aircraft if all the fuel is stored in the wing. This is especially critical for the turboprop designs with their higher fuel consumption. Referring back to Fig. 5, the 10-passenger turboprop was critical for wing loadings about 64 lb/sq ft and the 30-passenger for wing loadings about 90 lb/sq ft. Fig. 15 shows how

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**Fig. 15** Wing fuel volume considerations

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**Fig. 16** Payload-range comparison

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**Altitude:** 25,000 ft. **Baseline Fuel Reserves:** 30 Passengers

- **Turboprop** \( M_{CR} = 0.540 \)
- **Turbofan** \( M_{CR} = 0.697 \)
variations in wing geometry would affect the fuel volume constraint. For a fixed wing area, lower aspect ratios and more tapered wings provide the most fuel volume. The higher aspect ratio, although improving some performance parameters (Fig. 14), would put a more severe constraint on wing area and thus wing loading for the turboprop.

The turboprop, due to its better fuel efficiency, is not constrained as severely by available wing fuel volume (Fig. 7). This gives the turboprop an attractive flexibility in payload-range over the turbopfan. Fig. 16 shows the flexibility for two of the baseline 30-passenger designs. Due to wing fuel volume constraints, the turbopfan has no additional range capability at lower payloads. The turboprop, on the other hand, can carry 22 passengers over segments up to 1030 n. mi. in length. This gives the turboprop greater scheduling flexibility.

Fuselage Considerations

In 1975, at a NASA sponsored workshop on general aviation drag reduction (7), it was suggested that a more detailed examination of fuselage fineness ratio could minimize fuselage and empennage drag. To investigate this approach on the conceptual commuter aircraft of this paper, a brief study was made by varying the tail cone length of a 10- and 30-passenger turboprop configuration. Fig. 17 shows the variation in drag, as well as the variations of three other important parameters, to the total aircraft design. In addition to the drag of the fuselage and empennage decreasing, the tail areas and empennage weight also decreased; however, this was offset by a larger increase in fuselage weight which caused the gross weight and engine size to increase. These variations all were within 2 to 3 percent for a 40 percent variation in tail cone length. The relative DOC variations were less than 1 percent and indicated optimum tail cone lengths somewhat less than the baseline configurations. Thus, tail cone length had a small impact on the design parameters investigated in this study.

Noise Characteristics

The noise levels of the conceptual aircraft of this paper were not estimated. However, Reference (3) did estimate the noise generated by turbopfan and turboprop aircraft having propulsion systems very similar to the aircraft of this paper. Fig. 18 presents the estimated noise levels for two conceptual aircraft designed to the 4500 ft field length requirement, as well as measured data for three existing aircraft. Aircraft identified as 3 and 4 in Fig. 18 are a current small turboprop and turbopfan transport with takeoff field lengths of 3250 ft and 4350 ft, respectively, while aircraft 5 is a smaller turbopfan powered business jet having a takeoff field length of 3500 ft. These are all twin engine designs with the noise measuring points at 3.5 n. mi. from brake release for takeoff, 0.25 n. mi. from centerline for sideline, and 1 n. mi. before threshold for approach. The two conceptual aircraft noise levels are comparable to the smaller business jet and a significant improvement over current transports of similar size.

CONCLUDING REMARKS

This paper illustrates the traditional
approach taken in aircraft preliminary design. This type of analysis leads to the selection of the aircraft configuration, propulsion system size, wing area, high-lift devices to be integrated into the wing and empennage areas.

Although no attempt was made to completely optimize the aircraft design, the following conclusions can be made concerning small commuter aircraft design requirements when constrained by field length considerations:

1. When sized for a specific field length, the turbofan had a heavier gross weight and higher cruise speed than the turboprop. As the cruise speed of the turboprop approached that of the turbofan, the gross weight difference diminished.

2. The wing fuel volume constraint is a critical design parameter in selecting the wing loading and lift capability requirements of the turbofan.

3. Operating the turbofan at 30,000 ft gives the optimum DOC design and results in a 11 percent improvement in fuel efficiency for the design mission. This potential would have to be considered against the aircraft systems cost savings associated with a 25,000 ft design.

4. The fuel efficiency of the turboprop eliminates the wing fuel volume constraint and provides a large range of flexibility in off design mission performance.

5. Common wing and fuselage geometric parameters are acceptable in both the turbofan and turboprop.

A final comment concerning the propulsion is in order since this paper has been prepared for presentation at a gas turbine conference. New aircraft developments are always paced by the availability of an acceptable engine. In the thrust and power classes required for the aircraft studied here, some modern turbofans and turboprops do exist and new technology is being developed through NASA and military programs. However, it must be recognized that an effective commuter aircraft propulsion system requires a different design philosophy than that prevalent for larger turbine engines used on aircraft flown by trunk and local service airlines. A commuter airline should have aircraft powered by engines which are very rugged and reliable. In addition, they must be easy and inexpensive to maintain in the field. Finally, they must be moderately priced so as not to force the price of the aircraft to unacceptable levels. The same can be said for all aircraft powerplants, but in this case, the proper engine design may be one which is highly compromised for reliability, maintainability and reduced cost. Each of these requirements may result in trade-offs in cycle selection and mechanical design which increase both engine weight and fuel consumption. It will be important to carefully evaluate all of these factors in the design of future turbine engines intended for the commuter air transport market.

REFERENCES