Propulsion System Integration Configurations for Future Prop-Fan Powered Aircraft

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Previous studies conducted by NASA, Pratt & Whitney, and other aircraft industry companies have indicated that a new high-speed propeller, the prop-fan, coupled with an advanced turboprop engine, can lead to a 20-30% reduction in fuel burned and a 10-13% reduction in direct operating costs relative to a comparable technology turbofan-powered aircraft. Under a recently completed NASA-sponsored study, numerous propulsion system integration options were investigated, including the gearbox, engine inlet, oil cooling, and mounting concepts. The advanced technology turboprop engine can be combined with a single- or counter-rotation prop-fan, installed either as a pusher or a tractor configuration on the wing or attached to the fuselage. The pros and cons of these combinations are discussed from an engine designer's point of view. In addition, critical technology questions that must be answered before industry will commit itself to a development program are addressed.

Introduction

PREVIOUS studies conducted by NASA, Pratt & Whitney, and other companies in the aircraft industry have shown that a new high-speed propeller, the prop-fan, when coupled with an advanced turboprop engine, can play a significant role in reducing fuel consumption and operating costs for aircraft scheduled to go into service in the early 1990s. These studies showed that the most promising application for prop-fan propulsion is in 100-120 passenger aircraft for short- to medium-range applications.

The recently completed NASA-sponsored Advanced Prop-Fan Engine Technology (APET) Definition Study[1] had three objectives: 1) to define an advanced technology turboprop engine to be combined with a single-rotation prop-fan, 2) to compare this propulsion system to a comparable technology turbofan system in a short-range aircraft, and 3) to identify key propulsion system technologies that must be verified prior to an industry commitment to the design, development, and certification of a prop-fan-powered aircraft. The study objectives were achieved. A single-rotation advanced technology turboprop system showed a 21% fuel burn and 10% direct operating cost advantage over a comparable turbofan propulsion system. In another NASA contract,[2] a counter-rotation prop-fan system exhibited an additional 9% fuel burn advantage and nearly 3% improvement in direct operating costs. Clearly, the prop-fan has significant potential fuel and cost savings for the future.

Most of the information presented in this paper was developed in the recently completed NASA studies. The topics to be discussed include: 1) the identification of a promising single-rotation prop-fan propulsion system in an over-the-wing tractor installation, 2) the impact of counter-rotation on an over-the-wing tractor propulsion system installation, 3) the impact of other installation options, and 4) a summary of critical technology questions arising from the concepts investigated.

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While the final selection of the propulsion system concept will result from integrated engine/aircraft company efforts, the advantages and disadvantages of these installation concepts are discussed from an engine manufacturer's point of view.

Base Propulsion System Installation Configuration Selection

The recently completed NASA APET and Counter Rotation Propeller/Gearbox Studies[1,2] identified the propulsion system component options for both single- and counter-rotation prof-fan systems.

The propulsion system component options investigated included: two- and three-spool turboprop engines; in-line and offset gearboxes; air/oil and fuel/oil heat rejection systems; annular, trifurcated, bifurcated, and chin inlets; mounting of propulsion system; engine and aircraft mounted accessories; and propulsion system control. Pratt & Whitney considered the critiques and comments on the various options from such aircraft companies as Boeing, Douglas, Lockheed-California, and Lockheed-Georgia in the final selection process.

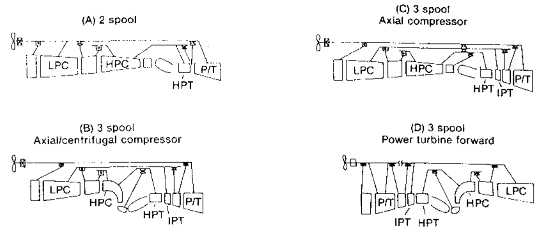
Engine Configurations

Four candidate turboprop engine configurations (Fig. 1) were selected to provide a variety of approaches to turboprop propulsion. They encompassed the use of two and three spools, axial and axial/centrifugal compressors, and free and nonfree power turbines. The two-spool configuration was studied to explore the potential of using a turbofan-type high spool for a turboshaft application. In this configuration, the power turbine drives both the low-pressure compressor and the prop-fan. The low compressor has been designed to permit constant prop-fan speed at the critical takeoff, climb, and cruise operating conditions. Two three-spool configurations permitted an evaluation of a free-power turbine relative to the two-spool nonfree turbine configuration and of the relative merits of axial and axial/centrifugal compressors. A novel three-spool, power turbine forward arrangement permits evaluation of unconventional aerodynamic and mechanical installation concepts. Among the potential benefits of this configuration are a simplified prop-fan/inlet integration because the inlet is aerodynamically remote from the prop-fan flowfield and the ability to design a two-spool engine with a free-power turbine without a third concentric shaft. Unfortunately, the duct losses resulting from the turning of the inlet and exhaust gases were prohibitive.

Fuel burn and direct operating cost are the most important factors in ranking the configurations. Engine performance (TSFC) and weight are the key factors in the fuel burn comparison. TSFC, weight, acquisition cost, and maintenance cost are the important factors in evaluating the direct operating cost of the engine. Several factors judged to be either comparable or of a second order of importance were also assessed and used in the engine configuration selection. Some of these factors included engine performance deterioration modes, component performance and matching, starting requirements, variable geometry complexity, engine acceleration/deceleration, and prop-fan matching.

Based on the evaluation, in which the aircraft fuel burn and direct operating cost were most heavily emphasized, the two-spool engine with all-axial compression and the three-spool engine with axial/centifugal compression were selected for continued studies with the airframe companies and NASA.

The two-spool engine had the best fuel burn, while the three-spool engine exhibited the lowest direct operating cost. Engine cross sections for each concept are shown in Fig. 2.



	(A) Axial 2-spool	(B) Axial/cent. 3-spool	(C) Axial 3-spool	(D) Reversed axial/cent. 3-spool
Fuel burn, %Δ	Base	+1.5	+1.1	+5.6
DOC, %Δ	Base	−0.9	−0.1	+0.8

Fig. 1 Four turboprop engine configuration candidates.

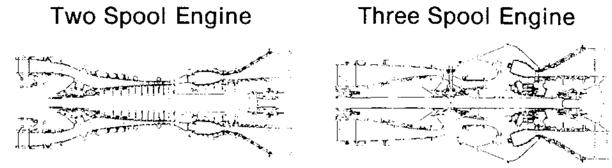


Fig. 2 Two engines selected for continued study.

Reduction Gear Concepts

Pratt & Whitney, in conjunction with other divisions of United Technologies Corporation, conducted extensive studies on numerous reduction gear configurations. These studies identified the split path configuration as the best in-line candidate and the compound idler concept as the best offset candidate for the single-rotation prop-fan gearbox.[3] Prop-fan pitch control considerations were and will continue to be an integral part of these gearbox configuration evaluation studies. The aircraft manufacturers have indicated that both gearbox concepts should be included in future single-rotation engine/aircraft integration studies. Therefore, both configurations are considered viable candidates for single-rotation prop-fan propulsion systems. The compound idler offset reduction gear concept is illustrated in Fig. 3. The impact of opposite-hand rotation on the offset compound idler reduction gear configuration is also shown in Fig. 3. The in-line split-path reduction gear concept is shown in Fig. 4.

The design of both gearboxes includes an aircraft accessory pad, a prop-fan brake, and subassemblies that can be removed for inspection and/or repair without removing the entire gearbox from the aircraft. The removable subassemblies include the prop-fan pitch control (all modules for the offset gearbox concept and two of the three modules for the in-line gearbox concept); power takeoff shaft for the airframe accessory drive; prop-fan brake assembly, input shaft coupling, seal, and mating rings; prop-fan shaft, seal, and mating rings; mount pads and bushings; oil supply/scavenge pump module; oil filters; breather filters; oil jet screens; the majority of the oil jets; and condition monitoring components (i.e., chip detectors and vibration/noise monitoring devices).

Numerous in-line and offset gearbox concepts for counter-rotation prop-fan systems were investigated, as reported in Ref. 4. Of all the concepts evaluated, the in-line differential planetary configuration was the most efficient, lightest, most reliable, and least expensive. The in-line differential planetary reduction gearbox is illustrated in Fig. 5. The counter-rotation prop-fan configuration reduces the prop-fan gyro moment 80 to 100% relative to single-rotation prop-fans.

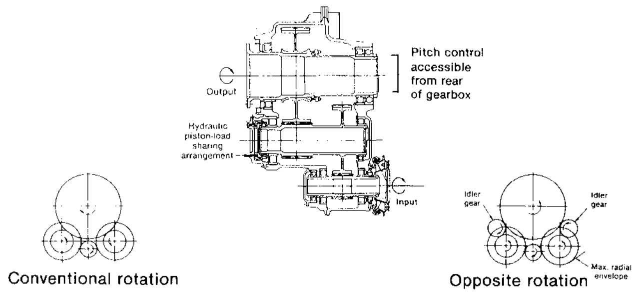


Fig. 3 Compound idler offset single-rotation gearbox concept.

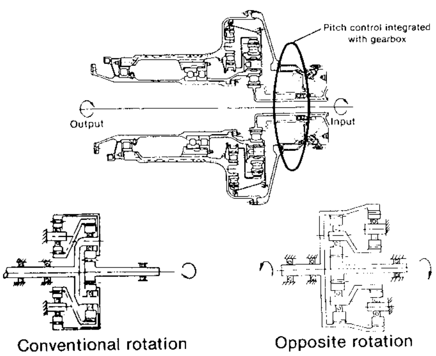


Fig. 4 Split path in-line single-rotation gearbox concept.

Heat Rejection Concepts

An effective gearbox lubrication and cooling system must be designed to ensure that the prop-fan reduction gear operates efficiently and has good reliability and durability. During gearbox operation, power is lost due to sliding and rolling contact in the gear tooth meshes, bearing rolling contact, windage effects, and oil churning. A cooling system must be provided to dissipate the heat generated by this power loss and to prevent the oil from breaking down at the critical high-power and high-speed operating conditions. At reduced-power conditions such as cruise, the full flow of oil is not required; therefore, the oil flow rate can be reduced, eliminating some of the unnecessary oil churning losses. By using such a system, the maximum power conditions will size the gearbox heat rejection system.

Five heat rejection concepts were air/oil heat exchangers that imposed penalties in weight and drag to varying degrees. Fuel was also considered as a heat sink for the gearbox oil. However, the small amount of fuel being consumed by the highly efficient engines does not have sufficient capacity to dissipate the heat generated by the reduction gear. Thus, a heat rejection concept in which the fuel in the aircraft tanks is used as a heat sink was evaluated.

Based on comments from the airframe manufacturers, the concept of a fuel/oil cooler with a supplementary air/oil cooler (Fig. 6) was selected. The supplementary air/oil cooler dissipates the gearbox heat rejected during operating conditions when the fuel in the aircraft tanks is below the level required to absorb the gearbox heat rejection.

Inlet Concepts

Since the interaction between the prop-fan and the inlet is a key factor in designing an efficient 0.7-0.8 *Mn* cruise turboprop propulsion system, numerous inlet configurations were evaluated. Annular, trifurcated, bifurcated, and chin (single) inlet concepts were considered for an in-line gearbox installation. Chin and bifurcated inlets were considered viable candidates for the offset gearbox installation. A quantitative assessment was made of the inlets on the basis of inlet throat height, total inlet pressure losses, and the required length between the inlet and engine compressor inlet face for two- and three-spool engine configurations. For engines of $\approx 12{,}000$ hp, the maximum inlet throat height increases from ≈ 1.6 in. for the annular configuration to ≈ 10 in. for the chin (single) inlet configuration. For the annular inlet, the inlet pressure losses due to the prop-fan spinner boundary layer are very significant because the inlet throat height is so small. On the other hand, circumferential compressor face distortion is less of a concern with the annular inlet concept than with any of the other inlet concepts. A qualitative assessment of the inlets was made on the basis of engine compressor airflow distortion, prop-fan back pressure effects, foreign object (bird/dirt) damage, angular airflow sensitivity, inlet anti-icing, and compatibility with the gearbox. Based on this assessment and consultation with the airframe manufacturers, the chin inlet was selected for the offset gearbox installation and the bifurcated inlet was selected for the in-line gearbox installation. Industry and NASA are pursuing solutions to technical questions related to the inlet.[5]

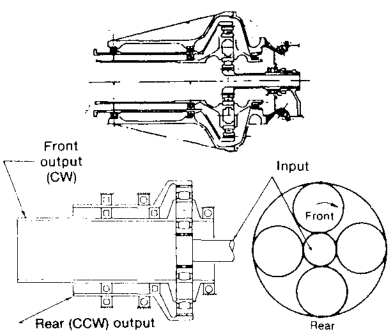


Fig. 5 Differential planetary in-line counter-rotation gearbox concept.

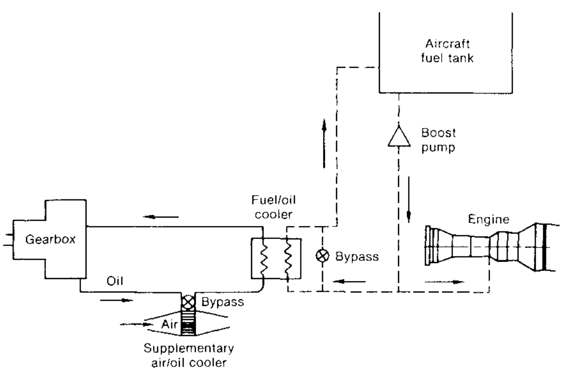


Fig. 6 Fuel/oil heat rejection concept with supplementary air/oil cooler.

Mounting Concepts

Three candidate propulsion system mounting arrangements were evaluated. An integrated nacelle system in which the gearbox and engine are mounted to a stiff frame that, in turn, is shock mounted to an airframe nacelle was the first system evaluated. A partially independent system, where the gearbox and engine require stiff mounting to an airframe to minimize deflections between the reduction gear and engine, was the second system investigated. The third system ties the engine and the reduction gear units together structurally to form a single functional unit.

Based on an analysis of each of the configurations and consultation with the airframe manufacturers, the mounting concept tying the engine and reduction gear together was selected for further evaluation. Engine/aircraft structural dynamic studies with the airplane manufacturers are required to 1) determine the optimum axial location of the engine relative to the wing, 2) evaluate shock isolation, and 3) assess the impact of these factors on wing flutter.

Accessories for Prop-Fan Propulsion

Various engine- and aircraft-related accessories and mounting locations were evaluated. It was determined the engine-related accessories (fuel pump, electronic control for propulsion system, lubrication pumps, electrical generators and starters) should be powered from the high spool of the engine. Preliminary studies favor engine-mounted aircraft accessories (hydraulic pumps and integrated-drive electrical generators) for the in-line gearbox installation because of the limited space around the gearbox and gearbox-mounted aircraft accessories for the offset reduction gear installation where more space is available. As indicated by the airframe manufacturers, the final selection of the aircraft accessory mounting location will require trade studies beyond the scope of those performed to date and should also include an evaluation of "all-electric" accessory technology.[6]

Propulsion System Control

The control system for the prop-fan propulsion system will incorporate electronic circuitry, fiber optics, and dual redundancy in the vital control paths. A dual-channel, full-authority digital electronic control will regulate the prop-fan and engine during normal and emergency operating conditions. The system will allow independent control of the propeller (for synchrophasing and other performance/acoustic optimization functions) and engine speed and power setting. Automatic control will be provided for steady-state and transient operation in both the forward and reverse thrust modes. Protective measures will be provided to limit the torque, temperature, overspeed, and possible faults in the system (which could lead to prop-fan feathering, windmilling, etc.). The major component in the system is an electronic unit that contains circuitry for digital computation, input and output conditioning, and electrical power regulation. This circuitry gathers information from the propulsion system sensors and modulates the various engine functions, including gas generator fuel flow, propeller pitch, variable compressor geometry, and active clearance control, if required. The electronic control also provides information to the aircraft for cockpit instrumentation display, diagnostics, and condition monitoring. Optic technology could be incorporated to reduce cabling and increase immunity to external electromagnetic interference. Integration of the propulsion system control with the various aircraft systems should be considered for the aircraft of the 1990s.[7]

Prop-Fan/Turbofan Aircraft Comparison

A single-rotation prop-fan propulsion system and a high-bypass-ratio turbofan engine incorporating 1988 engine technology were selected for aircraft evaluation. The engine size and cycle comparison is presented in Table. 1. The engines were evaluated in a 120 passenger Mach 0.75 cruise airplane over a simulated flight cycle during a typical mission. Cruise speed affects the comparison because the performance advantage of the prop-fan-powered aircraft increases as Mach number decreases. Mach 0.75 was chosen after consultation with airframe manufacturers as a representative for airplanes of 120 passenger capacity and short-range capability.

The key engine and aircraft sizing requirements and study assumptions are shown in Table 2. The effect of propeller slipstream swirl on wing aerodynamics has not been fully established and much more experimental work is required before a penalty or benefit can be assessed. For the baseline comparison, no benefit or penalty was assessed relative to a turbofan installation. The effect of a 3% prop-fan drag penalty was assessed separately. While beyond the scope of this study, bleed and power extraction from the turboprop gas generator (engine) for 100-150 passenger commercial aircraft will have a significant impact on propulsion system sizing and final selection of the product configuration.

The turbofan engine installation is shown in Fig. 7; it is an installation that has evolved over many years of commercial transport experience. Typical turbofan and prop-fan-powered aircraft are shown in Fig. 8 and illustrate the engine location.

Engine Sizing Requirements and Assumptions

The engine requirements are:

1) FAR takeoff field length equal to or less than 7000 ft at sea level, 84°F.

2) Initial cruise altitude capability equal to or greater than 35,000 ft on design mission.

3) Emissions less than ICAO research goals for new engines.

4) 1988 technology availability.

5) 1992 engine certification.

The results of the fuel burn and direct operating cost (DOC) comparison between the turbofan and prop-fan-powered airplanes for a typical mission are illustrated in Fig. 9. The fuel burn advantage for the single-rotation prop-fan-powered aircraft is 21% and the DOC advantage is 10%. The majority of the DOC advantage results from fuel savings.

The influence of undefined factors (aircraft drag, acoustic treatment weight penalty, and fuel price) on the evaluation is illustrated in Fig. 10. The first bar shows the fuel burn/DOC advantage for the prof-fan from Fig. 9 with the assumptions from Table 2. Recall that in the evaluation ground rules, no interference drag penalty was imposed on the prop-fan-powered aircraft relative to the reference turbofan. The next bar shows the impact of a 3% drag penalty on the prop-fan-powered aircraft.

More wind tunnel testing of prop-fans installed on wings will be required to accurately assess the penalty or benefit of the propeller slipstream interaction with the wing. The third bar in Fig. 10 shows the effect of doubling the fuselage acoustic treatment weight in the prop-fan-powered aircraft. Under the guidelines listed in Table 2, the calculated acoustic treatment weight penalty for the prop-fan-powered aircraft was almost 2000 lb. Acoustic treatment weight has a larger effect on the DOC than engine weight because it includes the associated airframe cost increase, while engine weight and cost are treated separately. The fourth bar, seen only in the DOC evaluation, shows the effect of changing the fuel price from the baseline $1.50/gal to $1.00/gal and to $2.00/gal. It is im-

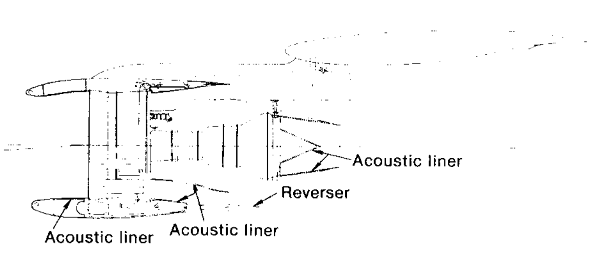


Fig. 7 Reference turbofan engine installation.

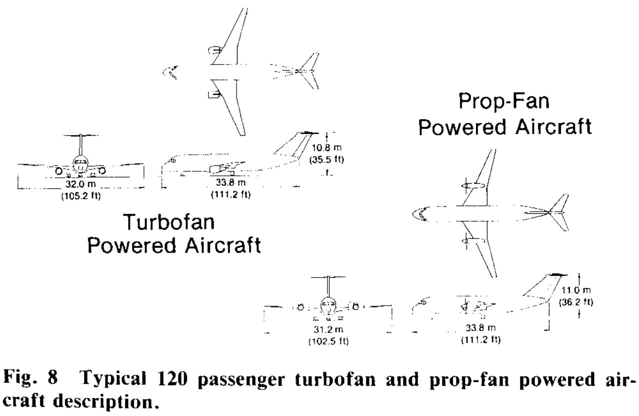


Fig. 8 Typical 120 passenger turbofan and prop-fan powered aircraft description.

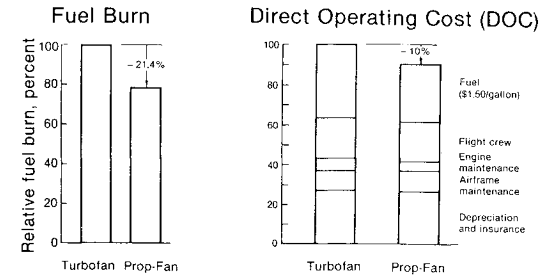


Fig. 9 Fuel burn and direct operating cost comparison (typical mission, 400 n.mi.).

Table 1 Turbofan and prop-fan engine size and cycle comparison (120 passenger aircraft)

Parameter	Turbofan	Prop-fan
Engine size (turbofan static thrust, prop-fan 0.3 *Mn* shaft horsepower at sea level standard plus 14°C)	17,000 lb	12,000 hp
Overall compressor pressure ratio	40.8	38.3
Bypass ratio	7	90
Maximum combustor exit temperature, °F	2660	2600
Fan/prop-fan diameter, ft	4.5	13.3

Table 2 Key engine/aircraft sizing requirements and study assumptions

Aircraft sizing requirements and assumptions
- 120 passengers
- Mach 0.75 cruise
- 1800 n.mi. design range with 120 passengers
- 400 n.mi. typical mission with 72 passengers
- No drag penalty for prop slipstream swirl (+3% evaluated)
- Prop-fan fuselage acoustic treatment weight penalty to attain turbofan cabin noise levels
- Noise at FAR 36 stations equal to or below stage 3 requirements

Engine sizing requirements and assumptions
- FAR takeoff field length equal to or less than 7000 ft at sea level, 84°F
- Initial cruise altitude capability equal to or greater than 35,000 ft on design mission
- Emissions less than ICAO research goals for new engines
- 1988 engine technology availability
- 1992 engine certification

portant to note that none of the undefined factors has a significant impact on the large advantage of the prop-fan over the turbofan.

Prop-Fan Propulsion System Installation Configuration Options

Numerous prop-fan propulsion system installation configuration concepts have been suggested in the past, some of which were evaluated in Refs. 8 and 9. A list of possible installation options include: single- and counter-rotation prop-fans, geared and gearless propulsion systems, over- and under-the-wing propulsion system mounting, fuselage and "tail" propulsion system mounting, and tractor and pusher propulsion systems. The final selection of the best propulsion system installation concept for a prop-fan-powered commercial aircraft will be the result of integrated government and industry efforts.

During the APET contract effort, the installation concepts were limited to over-the-wing, tractor-geared, single-rotation prop-fans; therefore, this system is used as the base configuration. To cover a broad range of technical issues, four major configuration concepts will be addressed: 1) the base configuration, 2) a counter-rotation prop-fan over-the-wing tractor, 3) a counter-rotation fuselage-mounted tractor concept, and 4) a counter-rotation fuselage-mounted pusher concept.

Single-Rotation Prop-Fan over-the-Wing Installation

Figure 11 illustrates typical single-rotation prop-fan over-the-wing installation concepts for both an in-line and offset gearbox. These installations are applicable to either the two-spool (nonfree power turbine) engine or the three-spool (free-power turbine) engine. The figure covers the conceptual nacelle, mounting, possible locations for airframe accessories, the bifurcated inlet for the in-line system, and the chin inlet for the offset system developed under the NASA APET contract. The in-line gearbox system is significantly lighter and offers the potential for a slimmer nacelle than the offset gearbox installation. The offset gearbox installation offers better access to the prop-fan pitch control, with the airframe accessories mounted on the prop-fan gearbox. The whole question of nacelle integration with the wing, be it above or below the wing, requires aerodynamic wind tunnel data for resolution. This technical issue is being addressed by NASA.[10,11]

The baseline propulsion system installation used for comparison with other systems is the in-line concept shown in Fig. 11. It includes a single-rotation tractor prop-fan, an in-line gearbox, bifurcated inlet, and an over-the-wing aircraft design approach.

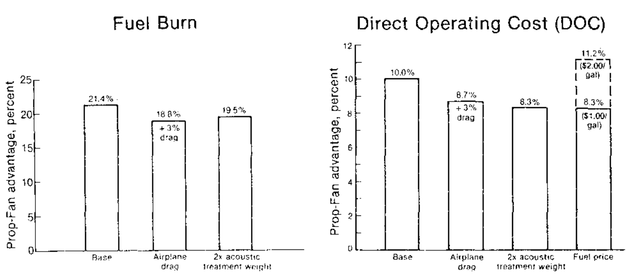


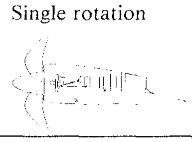
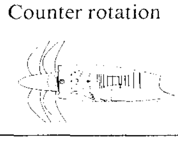
Fig. 10 Influence of undefined factors on evaluation (typical mission, 400 n.mi.).

Counter-Rotation Prop-Fan over-the-Wing Tractor Installation

By replacing the single-rotation prop-fan and gearbox with a counter-rotation prop-fan and an in-line differential planetary gearbox, a counter-rotation prop-fan over-the-wing tractor installation results. The counter-rotation prop-fan illustrated is the result of studies undertaken during the NASA-sponsored Counter Rotating Propeller/Gearbox Study[2] conducted by Hamilton Standard, Pratt & Whitney, and Lockheed-Georgia. Prop-fan loading studies for both single and counter rotation are shown in Fig. 12. Prop-fan loading is conveniently measured in terms of the shaft horsepower delivered to the prop-fan's divided by the diameter of the blades (shp/D^2). The maximum climb prop-fan loading is shown as a reference. The loadings for takeoff would be approximately twice the loadings at maximum climb. Using information for the takeoff, maximum climb, and cruise conditions, provided by Hamilton Standard,[12,13] the optimum loading for counter-rotation prop-fans appears to be 15-30% higher than the loading for single-rotation prop-fans. This results in a smaller diameter for the counter-rotation prop-fan, which can have a significant impact on the aircraft installation.

Relative to single rotation, the counter-rotation prop-fans have the potential for an 8% improvement in efficiency by removing the swirl from the exit flow of the first blades. This will, in turn, simplify the installation aerodynamics for a wing-mounted propulsion system. The source noise will be higher than single rotation because of the higher loading with counter rotation. As noted in Ref. 4, the far-field noise at takeoff may be 3-6 EPNDB higher than single rotation. However, with engine cutback, the Ref. 3 study indicated that the far-field noise for counter-rotation propellers could meet the FAR Part 36 stage 3 requirements. Also, counter-rotation prop-fans essentially remove the single rotation 1P moment

Table 3 Over-the-wing tractor comparison

Parameter	Single rotation 	Counter rotation 
Engine related		
Prop-fan performance (efficiency) and structure	Base	+ 8% efficiency (predicted)
Prop-fan/nacelle/inlet/compressor interaction	Base	Less risk (no swirl flow)
Mounting	Base	Better (reduced gyro moment)
Propulsion system "overhung" weight	Base	Slightly worse
Propulsion system commonality	Base	Better (common right and left gearboxes and prop fans)
Far-field noise	Base	Worse (+3-6 EPNdB)
Aircraft related		
Installation aerodynamics (wing/nacelle, etc.)	Base	Improved
Stability and control	Base	Unknown
Acoustic fatigue/structure-borne noise	Base	Worse
Cabin interior noise level (airborne noise)	Base	Worse (+1.6 dBA)

mounting requirement and the potential need for right- and left-hand (opposite rotation) gearboxes and prop-fans. This will improve propulsion system commonality compared to single rotation. However, counter rotation will require additional acoustic treatment in the aircraft because of the increased source noise. A comparison of single- and counter-rotation prop-fans in an over-the-wing tractor installation is presented in Table 3.

Many years of successful aerodynamic, acoustic, and wing-mounted wind tunnel model tests have been conducted for the base single-rotation prop-fan. However, this base is lacking for the counter-rotation prop-fan. Technology verification is required for the aerodynamic performance, noise, and wing aerodynamic integration, as well as an assessment of the impact of stability and control- and structure-borne noise on the aircraft before this concept can be considered a viable propulsion system candidate in the same context as the single-rotation system.

Counter-Rotation Tractor Fuselage-Mounted Installation

By removing the propulsion system from the wing and installing it aft in the fuselage, a clean aerodynamic wing can be obtained. With a clean wing, the potential benefits of laminar flow control now being evaluated by NASA can be realized. However, the potential benefits of wing laminar flow are applicable to either prop-fan- or turbofan-powered aircraft with rear-mounted propulsion systems.

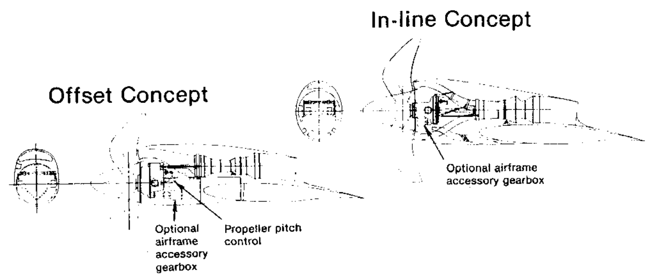


Fig. 11 Typical single-rotation over-the-wing installation concepts.

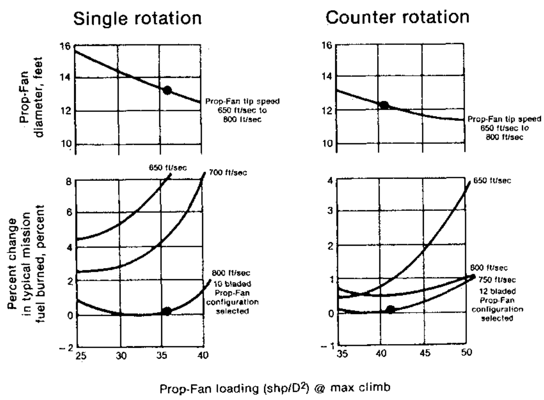


Fig. 12 Prop-fan loading selection trade study.

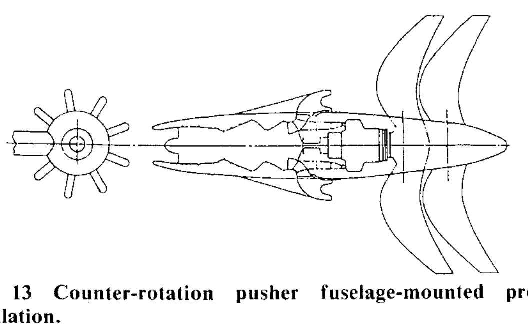


Fig. 13 Counter-rotation pusher fuselage-mounted prop-fan installation.

Another benefit of the aft installation is that cabin noise is reduced significantly because the noise source is moved further to the rear of the passenger compartment. Therefore, the aircraft acoustic weight penalty can be reduced substantially. With a fuselage-mounted propulsion system, maintenance actions are easier than with an over-the-wing installation because of the improved access to the engine components. The weight and balance of the aircraft is a problem to be dealt with because the propulsion system is mounted in the rear of the aircraft.

A major unknown in the fuselage installation is the stability and control of the aircraft and the impact of reverse thrust. NASA is performing model tests in these areas.

Counter-Rotation Pusher Fuselage-Mounted Installation

Figure 13 shows a counter-rotation pusher fuselage-mounted propulsion system installation. With this installation, the prop-fan could be located behind the rear pressure bulkhead and fuselage acoustic treatment would not be required for the passenger compartment. The potential benefits of this installation are: 1) a clean aerodynamic wing that permits the potential use of wing laminar flow control, 2) the elimination of an aircraft acoustic weight penalty to meet cabin noise requirements, and 3) the problem of weight and balance for the aircraft is reduced by being able to locate the propulsion system further forward than with a tractor fuselage-mounted configuration. However, this concept imposes a structural environmental problem associated with hot engine exhaust gases surrounding the gearbox, prop-fan spinner, and inner portions of the prop-fan blades. To alleviate this problem, a multilobe mixer could be used to reduce the 1000°F turbine exhaust gas temperature to an acceptable 300-400°F level. Bleed air from the engine compressor could be used to ensure that an acceptable temperature is attained for the gearbox and prop-fan. An in-depth study of engine/aircraft pusher installations is needed. At the present time, it is not known how the weight and performance debits incurred by the requirement to cool the gearbox and prop-fan blades compare to the acoustic and balance weight benefits. This engine/aircraft study should also evaluate other propulsion system concepts, such as remote and multiple gas generators with and without gearboxes and straight prop-fan blades. As in the counter-rotation tractor fuselage installation, the stability and control of the aircraft is an unknown. NASA testing of this installation concept is planned.

Critical Technology Questions To Be Answered

Numerous technical questions remain unanswered. The first is the structural integrity of the large swept prop-fan blade. This question can be answered only in the NASA large-scale advanced propfan (LAP) and propfan test assessment (PTA) programs, which should have high priority in the NASA aeronautic programs.[14,15] Second, swept counter-rotation prop-fans appear to have the highest potential. Scale-model aerodynamic, acoustic wing installation, stability, and control tests should be completed for a direct comparison with the single-rotation prop-fan test data. Third, full-size gearbox tests should be run to demonstrate the efficiency and reliability of a large-size modern technology reduction gear. And last, the issue of a pusher or tractor fuselage installation with and without reduction gearing should be thoroughly investigated on a total system fuel burn and direct operating cost basis.

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