Advanced Single-Rotation Propfan Drive System

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Abstract

ECONOMIC and strategic incentives to reduce aircraft fuel consumption have prompted significant government and industry interest in advanced turboprop aircraft for the 1990s. Scale-model wind tunnel testing has shown that large improvements in propulsive efficiency are achievable with a propfan at the high-speed flight conditions of advanced turbofan-powered aircraft. The propfan design concept shown in Fig. 1 is a full-size system for test evaluation in NASA's Propfan Test Assessment (PTA) flight research program in mid-1987.

The work described herein is the single-rotation gearbox phase[1] of Allison's Advanced Propfan Engine Technology (APET)[2] study sponsored by the NASA Lewis Advanced Turboprop Office.

Today, with the propfan approach of thin-swept highly loaded blades, the flight envelope for commercial turboprop aircraft can be extended in speed and altitude to include the turbofan cruise points. The APET study established the engine cycle trades for an extended turboprop flight envelope. Cost/benefit analyses based on the specific fuel consumption advantages of a high-pressure-ratio cycle showed the advantage of operating in the 30:1 to 40:1 range, which is compatible with 1990's component technology. Turbine inlet temperatures on the order of 2500°F would complement the high pressure and, at the same time, not compromise hot-section life. The APET study also showed that the advanced turboprop propulsion system should be designed using modular concepts to enhance maintenance of components and auxiliary systems. The following discussion describes the preliminary design of a single-rotation (SR) propfan gearbox.

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Configuration Selection

The SR gearbox conceptual study focused on two configurations for a 10,000-shp-class advanced production system. These included an offset and an in-line arrangement. Dual-compound idler gearing was selected for offset systems. For the in-line system, star gearing was selected. These arrangements are shown schematically in Fig. 2.

The conceptual study was expanded to define state-of-the-art and advanced gear-box versions of the offset gearbox. The decision to further evaluate the offset was based on a comparative analysis considering design parameters and weight factors. The results are shown in Table 1. This comparison showed that an offset arrangement with dual-compound idler gearing was favored over the in-line gearbox for the APET wing-mounted tractor aircraft.

SR Gearbox Preliminary Design

A preliminary design arrangement of state-of-the-art and advanced technology versions of the offset gearbox is shown in Fig. 3. The same advanced technology propfan and pitch change system was applied. Criteria for the comparison assumed the advancements in component technology level as outlined in Table 2.

Having established the gearing configuration and technology criteria to be used, the two preliminary designs were developed. Each shared the common design goal of 30,000 hr mean time between unscheduled removals for gearbox inherent failures. This goal represents a significant improvement over current operational systems. It was achieved primarily through improved bearing life. Gear sizes were based on the allowable stress levels for a 30,000-hr system life. Experience justifies this approach since bearings are typically the weak component in large aircraft gearboxes.

Conventional straight spur first-stage gearing was used in the state-of-the-art design. The advanced gearbox incorporated high-contact-ratio gears in the first stage. Helical gears were selected to enhance load sharing in the compound second stage of both designs. High-capacity tapered bearings were chosen in both cases for the propshaft.

The compound idler shaft thrust bearings are mounted on interconnected hydraulic pistons to balance axial forces and, therefore, balance the tangential gear forces. Both designs incorporate the modular concept for the oil pump, prop brake, and accessory drives.

The design of bearings was determined to be the most critical step in the design process. Allison's experience indicates that 50% of unscheduled gearbox removals are due to bearings. Of these bearing failures 10% are typically associated with contact stress fatigue. Approximately 50% of the bearing fatigue failures discovered at disassembly did not cause removal. This experience allows the establishment of

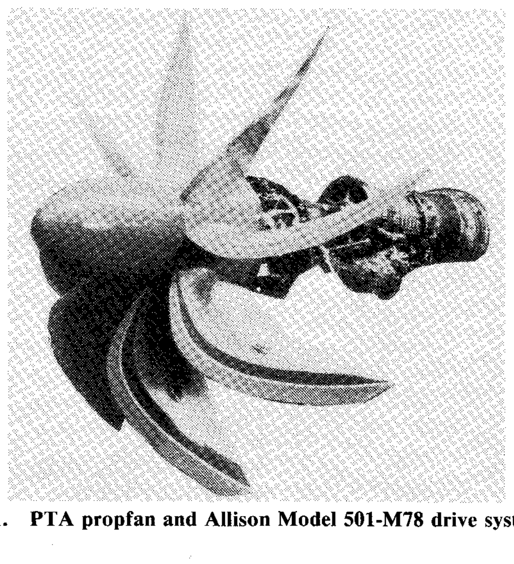

Fig. 1. PTA propfan and Allison Model 501-M78 drive system.

Presented as Paper 84-1194 at the AIAA/SAE/ASME 20th Joint Propulsion Conference, Cincinnati, Ohio, June 11-13, 1984; received Aug. 6, 1984; synoptic received Feb. 22, 1985. Full paper available from AIAA Library, 555 W. 57th St., New York, N.Y. 10019. Price: Microfiche, $4.00, hard copy, $9.00. **Remittance must accompany order.**

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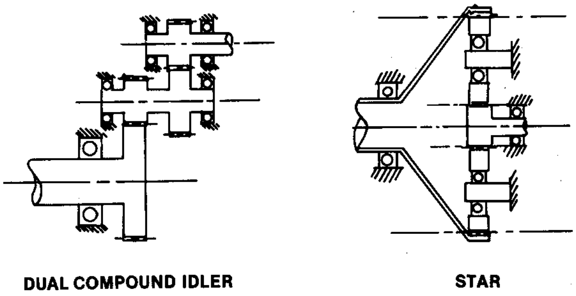

Fig. 2 Ofset and in-line gearing.

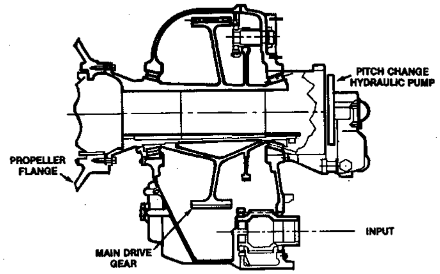

Fig. 3 Gearbox cross section.

bearing design life criteria consistent with achieving the 30,000-hr system goal. A comparison of the current and advanced technology designs in Table 3 shows the level of improvement expected.

The reduction in weight and frontal area resulted principally from the differences in gear and bearing allowable design stress levels. Since less material was needed and advanced manufacturing techniques such as powdered metal and near-net-shape forging were applied, acquisition cost was reduced for the advanced gearbox. The reductions in maintenance cost were primarily due to reduced parts cost and not a result of change in maintenance procedures

Allowable oil temperature rise of the advanced design resulted in reduced oil pump flow rate and power. However, this improvement was offset by the losses associated with higher sliding velocities in the high-contact-ratio first-stage gear set. Consequently, the advanced technology features did not result in efficiency improvements over the high level assumed for state-of-the-art design.

Technology Verification

The NASA/Allison APET study was expanded to include the preliminary design of a counter-rotation gearbox.

Table 1 Gearbox evaluation parameters

Evaluation parameter	Weighting factor
Efficiency	21
Maintenance	16
Acquisition cost	15
Pitch control accessibility	15
Weight	13
Design and development risk	10
Spatial envelope	5
Scaling	5

Table 2 Technology advancements

Evaluation parameter	State-of-the-art	Advanced technology improvement, %
Gear stress	Base	25
Gear finish	Base	40
Bearing material life factor	Base	200
Bearing finish	Base	50
Allowable oil temperature rise	Base	50

Table 3 Gearbox technology payoff

Parameter	State-of-the-art	Advanced technology improvement, %
Weight	Base	20
Frontal area	Base	17
Acquisition cost	Base	25
Maintenance cost	Base	18

Technology verification of many of the assumptions made in the single-rotation design described herein and counter-rotation design is being pursued in an Advanced Gearbox Technology program that includes the design and testing of a 13,000-hp gearbox. This joint NASA/Allison program will provide key technology improvements in analysis, design, and manufacturing.

References

[1]Anderson, R. D., Devlin, R. E., Novick, A. S., and Wagner, D. A., "Advanced Propfan Drive System Characteristics and Technology Needs," AIAA Paper 84-1194, June 1984.

[2]Anderson, R. D., "Advanced Propfan Engine Technology (APET) Definition Study Final Report," NASA-CR-168115, Nov. 1984.