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# TWO-PLANE BALANCE AND SLIP-RING DESIGN

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## ABSTRACT

A 3.25-cm (1.28-in.) two-plane balance and eight-channel slip-ring assembly has been designed to measure and transmit the thrust (667-N;150-lb) and torque (135-N-m;100-lb-ft) components produced by wind-tunnel model turboprops and drive motors operating at 300 Hz.

## INTRODUCTION

An Advanced Turboprop Program is currently under development at Ames Research Center. The purpose of the program is to investigate and develop the use of large-diameter, high-solidity propellers (turboprops) as an economical and efficient means of aircraft propulsion. The possible fuel savings that could be attained from using turboprops can be as high as 15%. This is especially important to commercial airlines since the cost of fuel is about 50% of their operating expenditure.

The program will feature a fully powered, .084-scale, wind tunnel model of a modified Douglas DC-9 transport aircraft.

Some of the model's versatile characteristics include:

- wing-mounted power plants
- plyon-mounted power plants secured to the tail
- interchangeable wings which may be mounted in three different locations along the fuselage
- interchangeable horizontal tails with adjustable angle of attack settings

Each power plant consists of eight .304-m-diam (1-ft) graphite composite propeller blades driven at 300 Hz.(18,000 rpm) by a small, 149- KW (200-hp) air motor. The air motor requires air at 3.45 MPa (500 psi) and 1.36 kg/s (3 lb/s).

In order to measure the thrust and torque components produced by the propeller blades, a two-plane balance and slip-ring assembly will be used. As shown in figure 1, the inner sleeve of the balance will be pinned to the forward end of the air motor shaft, and the slip-ring assembly will be secured to the aft end of the air motor shaft. The central portion of the balance

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outer sleeve will then be pinned to a hub which secures the propeller blades. Instrumentation wires from strain gages on the balance will be routed to the slip-ring assembly through the center of the hollow air motor shaft.

The sizes of the balance and slip-ring assembly were defined by the anticipated thrust and torque loads, and the geometrical contraints imposed by the size of the air motor nacelle. This paper will describe the design of the balance and slip-ring assembly.

Two-Plane Balance Design

The two-plane balance, developed at Ames Research Center several years ago, is shown in figure 2. It consists of an outer sleeve attached at its extremities to an inner, hollow sleeve by a brazing/heat treatment-process. Nicoro braze wire (.127-cm-diam) is wrapped around the inner sleeve grooves (two at each end) prior to the outer sleeve/inner sleeve assemblage. The gap between the two sleeves is equalized by setscrews located at each end of the outer sleeve. An inert gas vacuum furnace is used to braze the two sleeves together while the balance is supported in a vertical position. The brazing cycle also serves as the condition A heat treatment. Afterwards, the balance is cooled to room temperature and then reheated to attain the precipitation-hardening phase of the heat treatment.

The outer sleeve has eight identical flexures, four at each end, arranged symmetrically in two parallel planes, perpendicular to the longitudinal axis. The flexures are instrumented with strain gages and can detect loads along any of the three axes in addition to moments about the three axes. A load along the longitudinal axis (thrust load) will be equally distributed among the eight flexures and will produce a bending stress in each flexure. The torsional load will also be equally distributed among the eignt flexures, but it will produce a column-type (compression/tension) stress in each flexure. For a further description of a two-plane balance, refer to NASA Technical Memorandum X-1278.

By adapting this basic design to suit the needs of this program, a two-plane balance was designed specifically to

- o measure a 667-N (150-lb) maximum thrust load
- o measure a 135-N-m (100-lb-ft) maximum torsional load
- o have a 3.25-cm (1.28-in.) outside diameter
- o have a 1.91-cm (0.75-in.) inside diameter
- o withstand an out-of-balance radial load of 8.9 KN (2000-lb) caused by an accidental loss of four of the eight propeller blades
- o utilize flexures with natural frequencies about and along all axes greater than 900 Hz (three times the exitation frequency) to prevent dynamic excitation

The size of each flexure, shown in figure 3, is determined by the following factors:

- o sensitivity (strain level) to each design load
- o interactions between design loads
- o adequate surface area to bond miniature strain gages
- o geometrical constraints

The geometry of the balance is such that the length (L) and width (B,C) of each flexure are inversely related to each other, while the thickness (H) is an independent variable. Consequently, each flexure may be either long and narrow, or short and wide, and may have any thickness.

Additionally, the length and width are futher defined by the inner and outer diameter of the outer sleeve. Since the outer diameter is fixed (3.25-cm), the inner diameter (to some extent) is a variable. It is bounded by the size of the inner sleeve.

The maximum bending stress produced by the thrust load (P) occurs at the flexure base. This stress is $\sigma = 3PL/8CH^2$, where L is the flexure length, H is the thickness, and C is the base width. In order to produce an adequate strain level, the flexure should be thin and long (and consequently narrow) because of the moderate thrust load.

The column-type stress produced by the torsional load (T) on each flexure is $\sigma = T/4HBD$, where D is the outer sleeve mean diameter, and B is the width. The large torsional load coupled with the small diameter requires a flexure with a large cross-sectional area (HB) to prevent the flexure from being overstressed.

The above parameters demonstrated that designing to the torsional load required a flexure with a large width or thickness. However, the thrust load required a flexure with a large length (i.e., a small width) and small thickness. Consequently, the design of the flexures and of the related outer sleeve inner diameter was an iterative process.

The final size of the flexures and strain levels produced by the design loads are as follows:

- o length (L) = 9.12-mm (.359-in.)
- o thickness (H) = 2.28-mm (.090-in.)
- o width (B) = 1.78-mm (.070-in.)
- o base width (C) = 3.45-mm (.136-in.)
- o 610 microstrain for the 667-N thrust load
- o 1440 microsrain for the 135-N-m torsional load

Some other features of the 3.25-cm, two-plane balance include the following:

- o a stop nut to prevent the propeller blade hub from separating from the nacelle in case the balance/hub shear pins fail

- a stop nut to prevent the balance and propeller blade hub from separating from the nacelle in case the balance/air motor shaft shear pins fail

- soldering pins embedded through the forward end of the balance to ease and improve the strain-gage wire-soldering procedure

- a phenolic cover on the forward end of the balance which protects the instrumentation wires

- a spiral groove on the exterior surface of the outer sleeve to ease balance/propeller hub installation and removal by providing a cavity for dirt particles since the gap between the balance and the propeller hub is only .003-mm

Slip Ring Assembly Design

A slip ring assembly was designed to transmit the electrical signals from the balance strain-gages to a data-acquisition system while operating at 300 Hz. The constraints governing the design were that the slip-ring assembly had to interface with the existing air motor shaft, fit within an exit guide vane set located at the aft end of the air motor, and provide a means for delivering an air/freon mixture for cleaning and cooling the contacts.

The slip ring assembly, shown in figure 4, is secured to the aft end of the air motor shaft and consists of the following major items:

- a hollow kevlar shaft
- coin silver contact discs
- silver, graphite, molybdenum-disulfide brushes
- phenolic brush housing and sleeve
- exit guide vane set
- stainless steel retaining and adapter nuts

The contact discs are positioned over the kevlar shaft and sandwiched between phenolic spacers to orient them with respect to the shaft's longitudinal axis. Instrumentation wires are soldered to the contact discs and routed through the hollow kevlar shaft to its aft end. Before the kevlar shaft is inserted into the hollow air motor shaft, the lead wires from the balance strain-gages are routed througn the center of the hollow air motor shaft and connected to the lead wires from the contact discs.

The kevlar shaft, which has a key on the surface of its flange, is inserted into the air motor shaft so that the key fits into a slot in an adapter nut at the end of the air motor shaft. The kevlar shaft is retained by a nut which fits over the flange and threads onto the adapter nut. The retaining nut and key prevent the kevlar shaft from slipping. The kevlar shaft must always rotate at the same speed as the air motor shaft so that the instrumentation wires are not damaged.

The phenolic brush housing is then placed over the kevlar shaft/disc assembly. An alignment screw is threaded into the closed end of the brush housing and slides into the hollow kevlar shaft. This screw helps hold the brush housing concentric to the kevlar shaft while the brushes are being inserted and fastened to the brush housing.

Instrumentation wires are connected to each brush leg and run along the brush housing to soldering pins located at the closed end of the brush housing. Once the connections are complete, a phenolic sleeve is slid over the brush housing. This sleeve covers the holes in the brush housing through which the brushes are inserted and protects the instrumentation wires.

An exit guide vane set (which contains a nacelle supported by a stator) is fitted over the phenolic sleeve and into the aft end of the air motor. The geometry of the nacelle creates a plenum chamber around the sleeve. The air/freon mixture (which will be delivered through an air line in the stator) will pressurize the nacelle to .69-MPa (100-psi). This mixture will be directed to the areas where the brushes contact the discs via eight 1.067-mm-diam (.042 in.) orifices through the brush housing and sleeve. The instrumentation wires at the soldering pins will be routed out of the nacelle through another hole in the stator.

Once the exit guide vane set encases the brush housing, the concentricity between the kevlar shaft and the brush housing is maintained by the nacelle. Thus the alignment screw (which is through the brush housing and kevlar shaft) is no longer needed. This alignment screw must be removed because the kevlar shaft rotates while the brush housing remains stationary. Removing a threaded cap on the end of the nacelle provides enough room to remove the alignment screw. The threaded cap is then replaced and a retention screw is installed through the cap and brush housing. The retention screw prevents the brush housing from moving forward with respect to the nacelle and prevents an excessive amount of the air/freon mixture from leaking into the aft end of the nacelle.

Previous testing has shown that this brush/contact disc system works well. Since each contact disc has opposing brushes, any vibrational displacement that lifts one brush leaves the other brush in contact. Thus, a "clean" signal is consistently provided.

## SUMMARY

Although the two-plane balance and slip-ring assembly are small parts of the whole wind tunnel model that will be used in the Advanced Turboprop Program, they play an important role in the program. They will measure the turboprop loads and transmit the electrical signals which will eventually aid in determining the effectiveness of using large-diameter, jet-driven propeller blades to propel an aircraft.

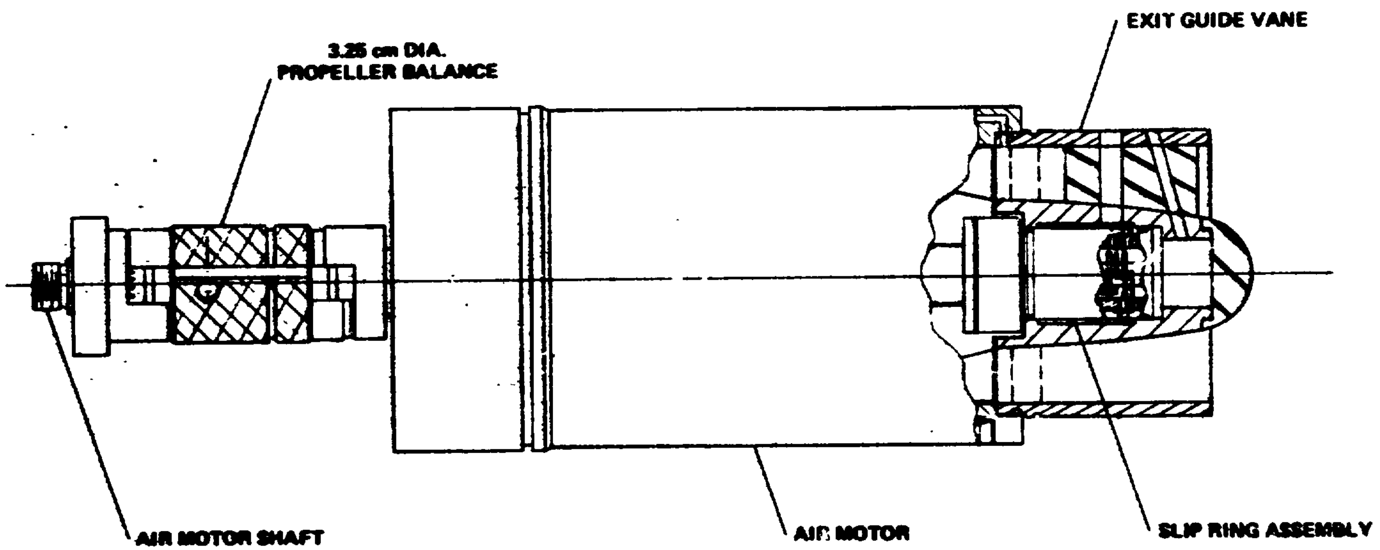


Figure 1. Balance/Motor/Slip-Ring

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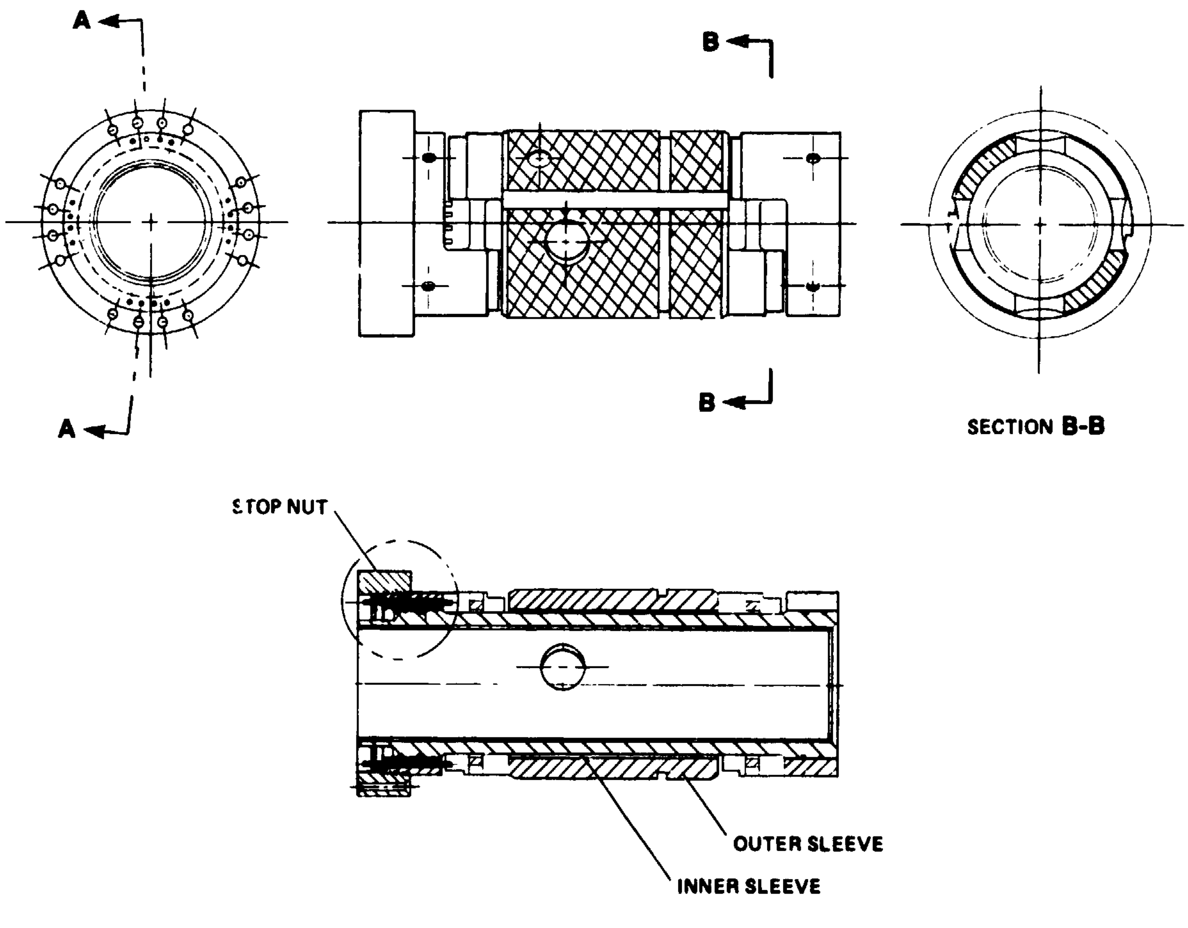


Figure 2. Two-Plane Balance

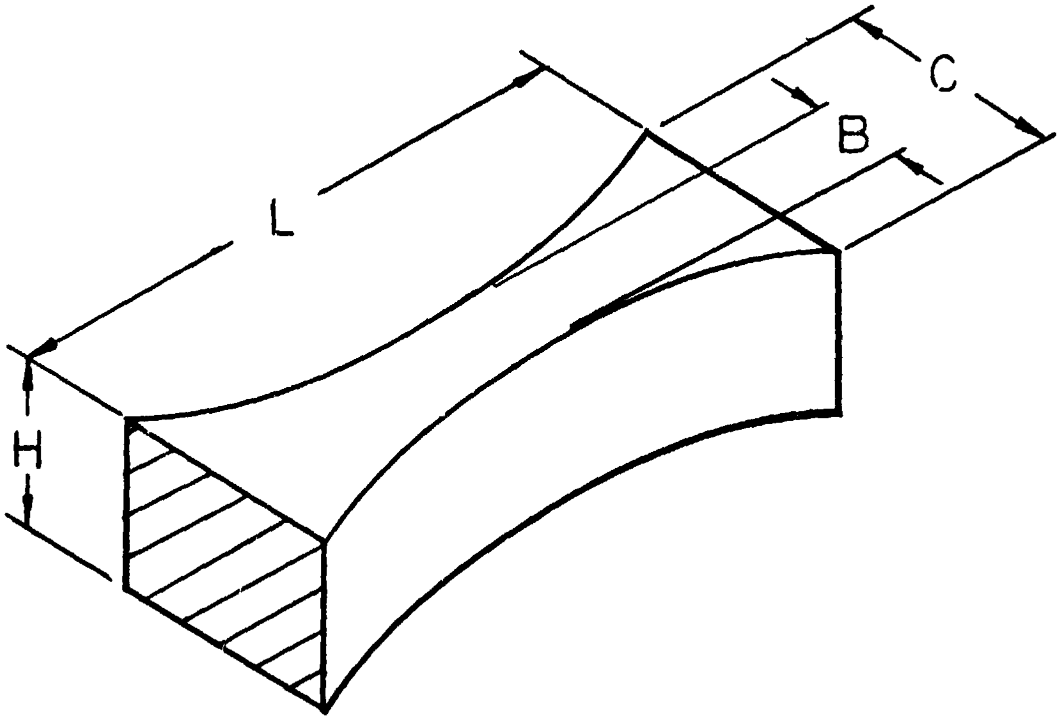


Figure 3. Flexure

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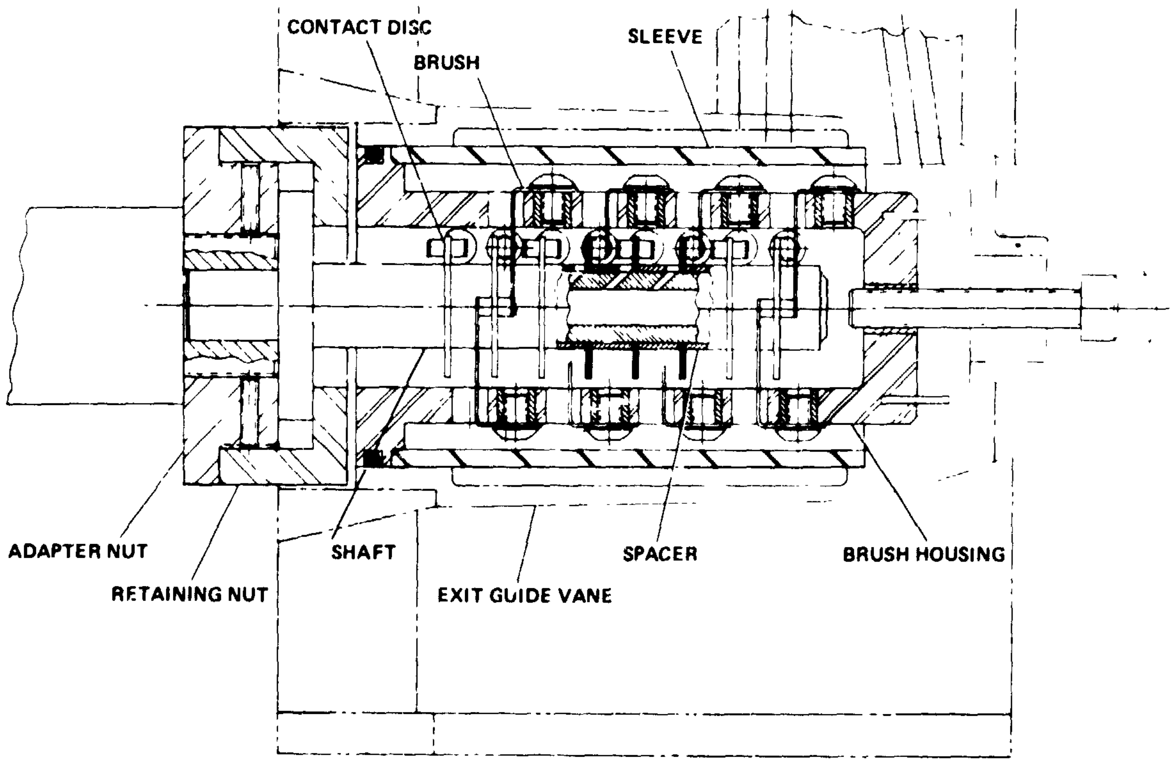


Figure 4. Slip-Ring Assembly