Compact Dynamometer System That Can Accurately Determine Propeller Performance

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Abstract

AN advanced, compact propeller dynamometer measurement system has been developed that determines propeller performance values to within ±5% error. Propeller thrust is found to within ±3.2% with a linearly variable differential transformer that measures dynamometer shaft extensions, torque to within ±1.5% using an optical torque transducer, and rpm to within ±0.003% by an optical digital resolver. The system was tested in a low-speed wind tunnel using marine and remotely piloted vehicle propellers to assess its operational capability. Results reveal that the thrust and torque coefficients and efficiency can be determined to within ±3.45, ±2.08, and ±4.2%, respectively.

Contents

Introduction

An advanced propeller dynamometer system has been developed to characterize propeller performance in air. This system is compact and capable of providing accurate performance measurements to within ±5% error over a wide range of operating conditions. It can be used in wind tunnels with marine propellers in ducted and unducted configurations and also with small-scale propellers, such as those used by remotely piloted vehicles (RPVs).

Overall System Design

A schematic of the propeller dynamometer measurement system is presented in Fig. 1. (See Asson[1] for a complete description.) The system is comprised of three major components: a servomotor that drives the system and contains an optical resolver that measures rpm, an optical torque transducer that measures the torque input required to drive the propeller, and a linearly variable differential transformer (LVDT) that measures propeller axial displacement, which is related to its thrust. These components are housed within an aluminum nacelle, which is mounted in a wind-tunnel test section. One of two interchangeable propeller adapters can be fitted to the dynamometer shaft assembly to accommodate either marine or RPV propellers. The overall dimensions of the system are 40 in. (length) and from 2.0 in. (outside diameter) near the propeller adapter to 3.5 in. at the motor's location. Because of the compact size of this system, it can be used directly inside a full-scale RPV for in-flight testing. Each instrument within the dynamometer is linked to its own signal conditioning unit, which in turn is interfaced with an A/D acquisition board within a Macintosh II computer. In this manner, propeller thrust and torque coefficients and efficiency can be displayed in real time to show performance trends.

Major Components

A compact, 2.0-in.-diam., 8.38-in.-long, brushless, Pacific Scientific model R23HENA-R1-NS-NV-00, samarium-cobalt, permanent magnet servomotor is mounted in the rear of the dynamometer. The motor is equipped with an optical resolver, which converts small angular movements to digital signals, yielding very accurate position (±0.001 rev) and speed (±0.01 rpm) control over the motor's operating range from 0 to ±8000 rpm.

The motor shaft is connected to a Vibrac Series 1 TQ100DS optical torque transducer by a solid aluminum shaft coupling. The transducer is equipped with two optical disks that are mounted on a torsion bar within the unit. Rotation of the disks relative to each other produces a current output proportional to torque. The transducer has a full-scale torque rating of 100 oz-in. with linearity, hysteresis, ripple, and calibration accuracies of ±0.25% of full scale each and an overall accuracy of ±1.0% of full scale.

Another aluminum shaft coupling connects the optical torque transducer to the dynamometer shaft. The shaft extends through the LVDT coil assembly and transmits torque to the propeller shaft via a transverse shaft. The LVDT, a Schaevitz Engineering model 503XS-A, has a linear range of ±0.5 in. (±0.5% of full scale) and a sensitivity of 0.6 mV/V excitation/0.001 in. displacement. High precision, New Hampshire Ball Bearings, Inc., RI-542KF torque bearings allow the propeller shaft to rotate as a unit with the dynamometer shaft, whereas the Miniature Bearings, Inc., Rotolin ML500-875-1 precision linear bearings allow the propeller shaft to translate in the horizontal (axial) direction within the dynamometer shaft. The LVDT core is fixed to the end of the propeller shaft so that the propeller displacement can be measured by the LVDT.

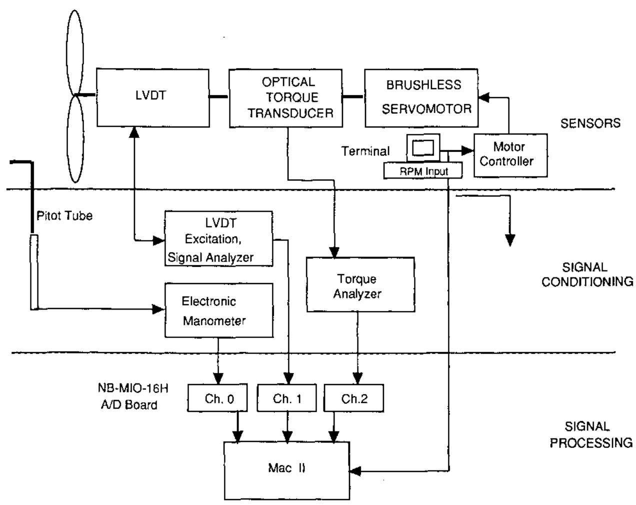

Fig. 1 Schematic drawing of the propeller dynamometer measurement system.

Received April 30, 1990; Synoptic received Dec. 20, 1990; accepted for publication Dec. 27, 1990. Full paper available from AIAA Library, 555 W. 57th Street, New York, NY 10019.

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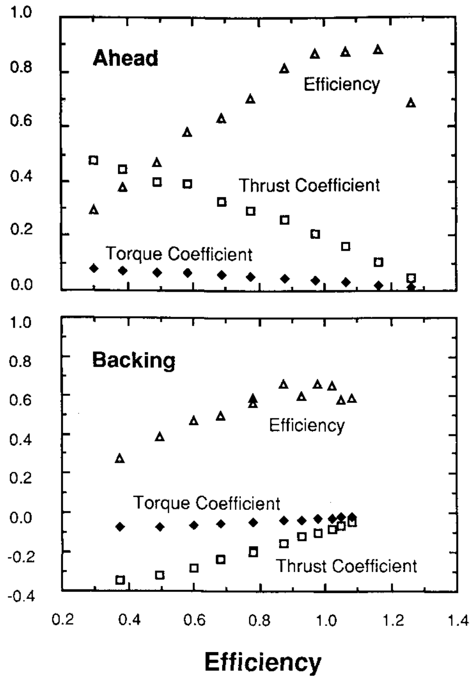

Fig. 2 Ahead and backing performance measurements for the marine propeller.

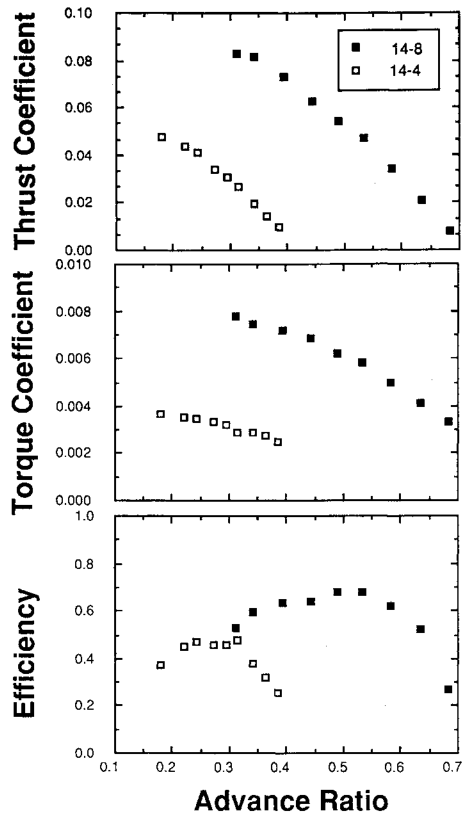

Fig. 3 Performance measurements for constant diameter, different pitch propellers.

The portion of dynamometer shaft that extends through the LVDT coil is made from phenolic material to avoid eddy current effects that interfere with the output of the LVDT. A spring and adjustable mounting nut on the propeller shaft keeps the assembly from extending out of the LVDT's linear range.

Located outside the test section are a Setra Systems Model 339H electronic manometer for measuring flow velocity, a Pacific Scientific model SC452-002-03 digital position and velocity motor control unit, the LVDT power supply and circuitry, and a Vibrac TM72-18 digital torque measurement instrument. The TM72-18 contains the circuitry for the torque transducer's optics and provides a digital torque output to within ±0.5% of full scale.

Error Analysis

Overall uncertainties of the thrust and torque coefficients and efficiency were determined using the uncertainty analysis method described by Kline and McClintock.[2] Estimates of uncertainty for all measurements and calibrations involved in determining thrust and torque coefficients and efficiency were considered. The resultant percentage errors in the thrust and torque coefficients and efficiency were ±3.45, ±2.08, and ±4.20%, respectively.

Results

One four-bladed marine and five two-bladed model airplane propellers were tested. The marine propeller had a 10-in. diam. with a pitch-to-diameter ratio of 1.262. This propeller was used in previous studies conducted in water by McDonald.[3] The model propellers included a 16-in. diam., 6-in. pitch Zinger propeller, designated with the notation of 16-6, and 14-8 Zinger, 14-6 Master Airscrew, 14-4 Zinger, and 13-7 Rev-Up model propellers.

Results obtained in determining the "ahead" and "backing" performance of the marine propeller are shown in Fig. 2. The best performance is achieved in the ahead configuration for which the propeller was optimally designed. These confirm McDonald's previous results[3] (to within experimental error). Data gathered using the Zinger 14-4 and 14-8 propellers are presented in Fig. 3. The effect of pitch on performance can be discerned accurately, where the larger pitch propeller is more efficient at higher advance ratios.

Acknowledgments

This work was performed under Contract N00014-89-J-1783 between the U.S. Office of Naval Research (S. G. Lekoudis, Scientific Officer, Fluid Dynamics) and the University of Notre Dame. The dynamometer components were purchased through the Jesse H. Jones Faculty Research Equipment Fund, Grant 2420-39322 MBA. We gratefully acknowledge R. Davis, who designed and built our first dynamometer, R. Strebinger, C. Klein, K. Peters, J. Preston, and M. Swadener for their efforts on the advanced dynamometer, T. Mueller for his encouragement and technical guidance, and W. Blake of the David Taylor Naval Ship Research and Development Center for several helpful discussions on marine propeller performance.

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