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Probe Interference on Flow Measurements in Propeller near Slipstream

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Introduction

THE use of pressure probes for flow surveys has long been an accepted practice and has been applied to propeller flowfield measurements.[1-5] The question of probe or probe support interference on the flow measurements appears not to have been addressed in published literature, apart from a limited discussion in Ref. 5.

In connection with a flow survey in the near slipstream of a propeller, nacelle mounted on a semispan model,[5] using the five-hole probe assembly shown in Fig. 1, it was discovered that the power requirement for a given propeller rpm was sensitive to the angular orientation of the rakes. Furthermore, it was found that with the assembly removed, the power requirement was substantially reduced from that required with the rakes present.

These findings suggested that the five-hole probe assembly interfered with the flow it was designed to measure. For instance, the swirl angle, that is directly related to the torque/power, should consequently be higher with the rakes present than without the rakes for a given rpm. Intuitively, one would think that the presence of the rakes would reduce the swirl angle.

Experimental Technique

An investigation was thus launched to obtain a measure of the possible interference the rake assembly could have on the swirl angle. The tests were performed on an "isolated" nacelle, that was strut-mounted on the wind-tunnel sidewall balance (Fig. 2). Two similar 15-in.-diam propellers were used, one with the blade angle set at 52 deg (at 75% radius), and the other at 58 deg.

Flow measurements were performed using the rake assembly shown in Fig. 1. In addition, a single nonintrusive five-hole probe was used, matching the most inner probe of one of the rakes at 45% radius ($r/R = 0.45$) (Fig. 2). In both cases the probe heads were positioned 1 in. behind the propeller plane. Propeller torque was measured by a torque meter, integral with the propeller drive shafting.

Probe	Distance Probe ℄ to Nacelle ℄ |r|	Ratio r / R
1	3.375	0.450
2	5.250	0.700
3	6.000	0.800
4	6.750	0.900
5	7.312	0.975

R = 7.50" Prop Radius

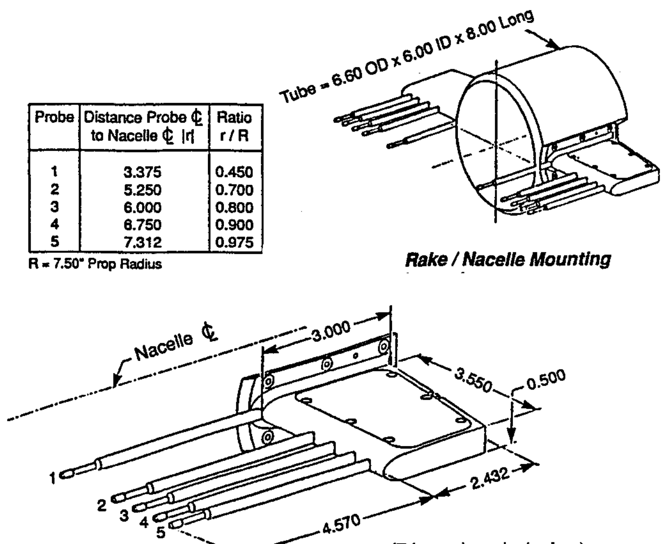

Fig. 1 Five-hole probe rake assembly.

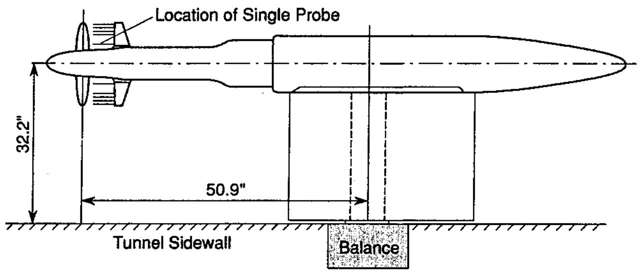

Fig. 2 Propeller test rig with flow survey rakes.

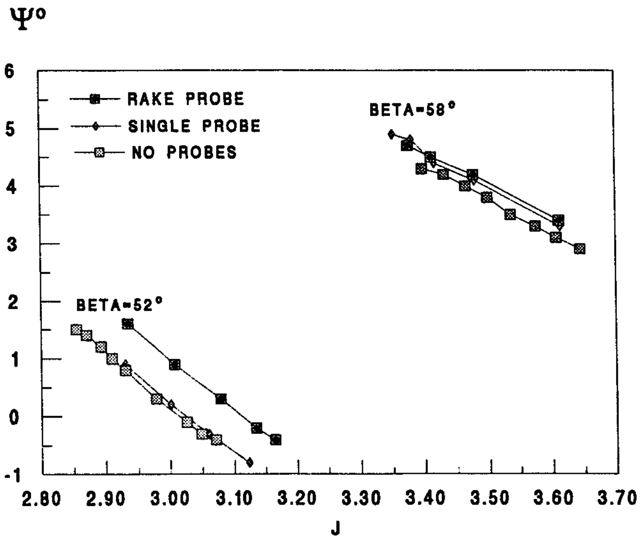

Fig. 3 Comparison of swirl angle data between single probe, rake probe and no probes, $r/R = 0.45$, $M = 0.7$

The investigation was carried out in the IAR 1.5-m × 1.5-m wind tunnel and restricted to Mach number 0.7 and a Reynolds number of 5.6×10^6/ft.

Results and Discussion

A comparison of swirl angle data from the single probe and the corresponding rake probe measurements for the two propellers is shown in Fig. 3 as function of the advance ratio J. For a blade angle BETA = 52 deg, the difference between the rake probe and single probe data is very pronounced, with

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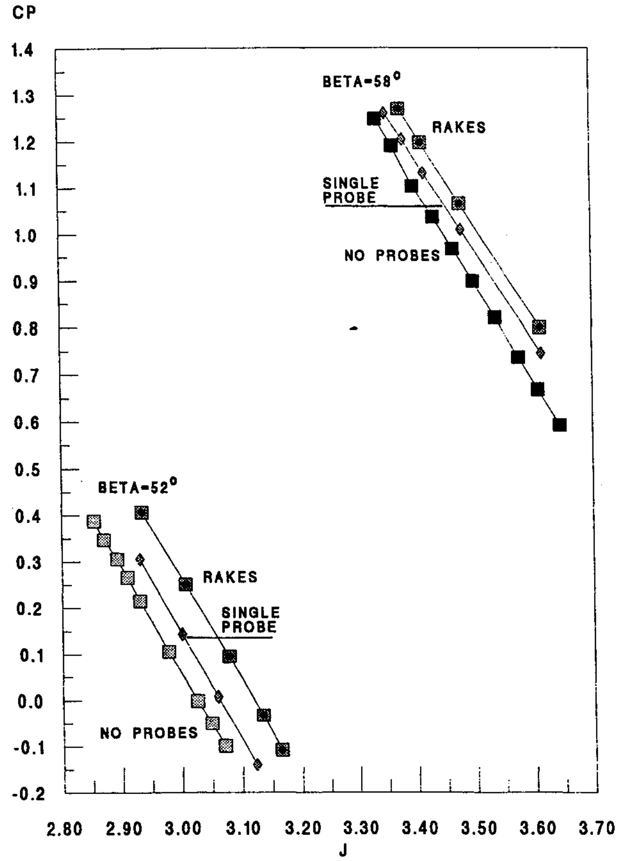

Fig. 4 Flow survey rake/single probe interference on the power coefficient at $M = 0.7$.

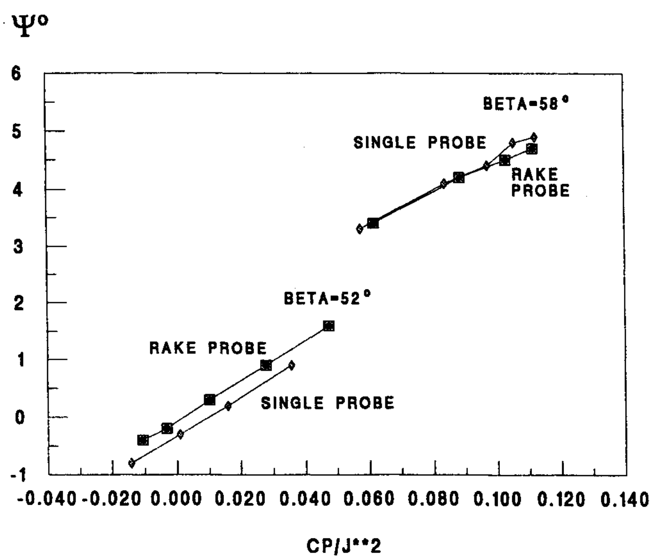

Fig. 5 Comparison of swirl angle data between single probe and rake probe at $r/R = 0.45$ vs CP/J**2, $M = 0.7$.

the rake probe showing about 0.8 deg larger swirl than the single probe. For the blade angle BETA = 58-deg case, the difference is very small.

These data are consistent with the power coefficient (CP) data depicted in Fig. 4. For the BETA = 52-deg case the power is reduced by 25% or more, when the single probe is substituted for the rakes. The corresponding reduction for the BETA = 58-deg case is of the order of 5%. A further small reduction in CP is obtained in both cases when the probe mounting is removed, suggesting that the single probe was not as nonintrusive as thought. It is believed that the probe mounting, which increased the nacelle diameter by 10%, rather than the probe itself, was the cause of this residual interference.

Since flow survey measurements that are free of interference are desirable for correlation with propeller theoretical data, the question arises whether the five-hole probe rake data can be corrected to give interference-free, or near interference-free data.

In Fig. 5, the swirl angle has been plotted vs the parameter CP/J^2. The rake probe and the single probe data more or less collapse onto a single line for each of the two propellers, although there is still a small difference for the propeller with the 52-deg blade angle. This "collapse" is not surprising since the power coefficient is a direct measure of the angular momentum, which is directly proportional to the angular velocity, imparted by the propeller to the freestream. The swirl angle is directly related to the angular velocity.

The power coefficient can be expressed as an integral of the product of the local mass flow, angular velocity, and radius, multiplied by the advance ratio squared:

$$CP = \text{const} \times J^2 \int\int \text{mass flow} \times \text{angular velocity} \times \text{radius}$$

where the integral is performed over the surveyed flowfield, which may exceed the propeller disc area. It follows that CP/J^2 rather than CP is the proper similarity parameter for the angular velocity (swirl angle). Although the mass flow will vary with change in angular velocity, such variations are of second-order compared to the angular velocity changes.

Consequently, rake probe data can be used to obtain nominally interference-free data by interpolating or extrapolating the data using the parameter CP/J^2 to values of the parameter with no probes present.

Following this procedure, the swirl angle data for the "no probes" CP values given in Fig. 4 have been obtained and superimposed on the directly measured data in Fig. 3. The no probes values are about 0.2 deg below the measured data for the propeller with 58-deg blade angle and close to the single probe data for the lightly loaded propeller with 52-deg blade angle. The same procedure could be applied to all rake probes to obtain nominally interference-free swirl angle data for the entire surveyed flowfield.

Although the investigation has been limited to a freestream Mach number of 0.7, the interference aspects of the flow survey equipment can be considered to be of a general nature.

In conclusion, it appears that the type of flow survey equipment here employed, when complemented with torque measurements, can be used to obtain meaningful swirl angle data near the propeller plane by applying the described correction procedure.

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