Turbulent Wake behind Slender Propeller-Driven Bodies at Angle of Attack

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Theme

MOST of the past work on axisymmetric wake flows has dealt with simple shapes in unpropelled configurations. The older work on propelled bodies was restricted to jets injected from circular disks.[1,2] Gran[3] studied the wake of a propeller-driven Rankine Ovoid at low Reynolds number. Extensive work on propeller-driven slender bodies has been published beginning in 1974 by a team at VPI & SU.[4-6]

In this report, several previously unstudied effects on the turbulent wake of propeller-driven bodies are examined. The first is the effect of body pitch angle on the wake properties. The second is the addition of an appendage such as a "sail" to an axisymmetric body. The third is the effect of replacing a single propeller by an equivalent set of side-by-side, counter-rotating propellers.

Contents

All tests were conducted in the VPI & SU 6-ft × 6-ft subsonic tunnel at a baseline condition of a dynamic pressure of 5.0 in. of water (approximately 157 fps) yielding a Re_D based on diameter 4.4×10^5. The model has an overall length of 72 in. and a fineness ratio of 12:1.

The first body had a single shaft which extended out the stern. The second body had twin shafts which flared out at a 7-deg angle through the stern. Both models had dc motors to drive the propeller shafts. The single shaft model was direct-drive, while the dual shaft model used a belt driven 1:1.5 step-up from the motor to the counter-rotating shafts.

The single shaft model used a 6-in.-diam., 3-bladed, model-airplane propeller, while the dual shaft model used two 4.375-in.-diam., 3-bladed propellers which were cut down versions (RH and LH) of the single propellers. All propellers were twisted to a higher pitch to operate more efficiently at the higher airspeeds used. The effective pitch of the larger propellers, as modified, was 2.46.

A strain-gage balance was used to determine self-propelled conditions. Note that the mounting strut clears the "sail" on the model. Forces on the sail, but not on the strut, are measured along with those on the main body.

The mean flow measurements were made using a three-dimensional Yawhead probe. The velocity fluctuations and Reynolds shear stress were obtained with an X-wire probe. Body boundary-layer measurements were made with a rake of pitot tubes.

It was decided that an adequate description of the wake could be achieved with three transverse cuts, one vertical and two horizontal, at each axial station. These traverses were made at $Z/D = 2$, 10, and 40 with the model at $\alpha_e = 0$ deg and $\alpha_e = -2$ deg for the single propeller model and at only $\alpha_e = 0$ deg for the dual propeller model.

Only results for the single-propeller model are presented here due to space limitations. The backup document has complete results. First, consider the mean-flow results at $\alpha_e = 0$ deg. In the near wake ($Z/D = 2$), there is a momentum defect at the center of the wake and a momentum excess region in the outer portion of the wake as shown in Fig. 1. The static pressure decreases in the wake of the propeller as in the case of a vortex. For the horizontal profiles, large variations in flow pitch are measured with very small changes in the flow yaw, but in the vertical profiles the substantial flow angularity is in the yaw direction.

At $Z/D = 10$ the momentum excess and defect regions have decreased and spread out. The static pressure variation has

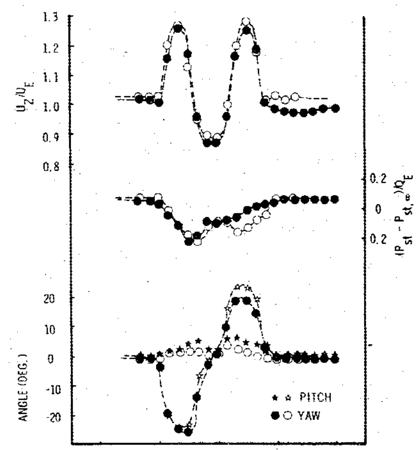

Fig. 1 Mean flow velocity, angularity, and static pressure; $Z/D = 2$ and $\alpha_e = 0$ deg; solid symbols show vertical profiles, open symbols show horizontal profiles.

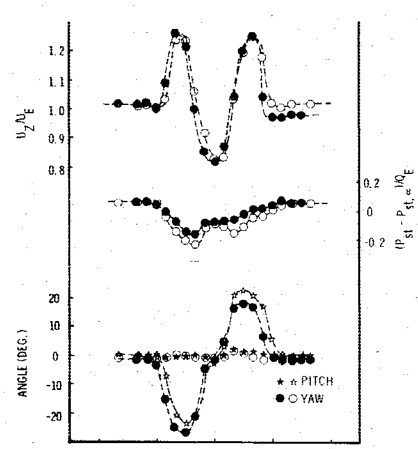

Fig. 2 Mean flow velocity, angularity, and static pressure; $Z/D = 2$ and $\alpha_e = -2$ deg; solid symbols show vertical profiles, open symbols show horizontal profiles.

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Index categories: Jets, Wakes and Viscid-Inviscid Flow Interactions; Marine Hydrodynamics, Vessel and Control Surface.

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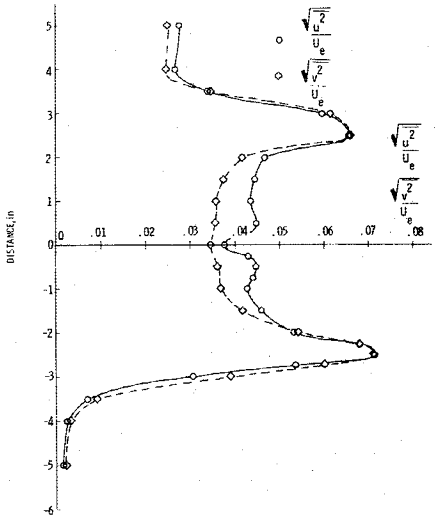

Fig. 3a Turbulence profiles at $Z/D=2$; $\alpha_e=0$ deg; axial and radial turbulence intensity profiles, vertical traverse.

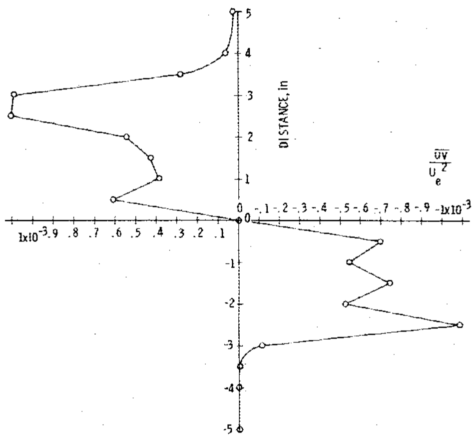

Fig. 3b Turbulence profiles at $Z/D=2$ with $\alpha_e=0$ deg; radial shear stress profile, vertical traverse.

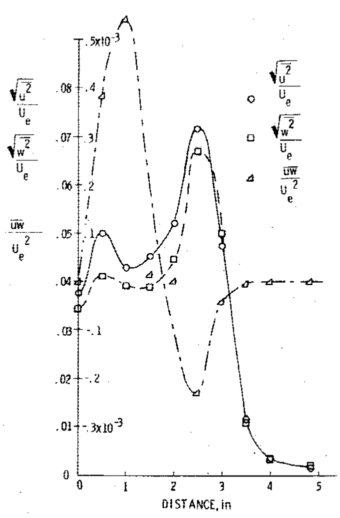

Fig. 3c Turbulence profiles at $Z/D=2$ with $\alpha_e=0$ deg; axial and peripheral turbulence intensity and peripheral shear stress profiles, horizontal traverse.

also decreased, and the swirl has decreased to the point that the flow angularity is only half the value measured at $Z/D=2$. By $Z/D=40$, there was only a small momentum excess in the wake. The data showed that the static pressure was uniform across the wake, and the swirl has completely diminished.

The mean-flow results for the pitched condition given in Fig. 2 show increased asymmetries in the vertical profiles. The flow angularity is decreased in the upper region of the vertical profile by 9 deg at the $Z/D=2$ station and by 6 deg at the $Z/D=10$ station.

The turbulence field is highly fluctuating in the near-wake (Figs. 3a-c). The velocity fluctuations are 7% of the freestream velocity behind the propeller tips. Note that the three turbulence intensities are essentially the same and that the peripheral shear stress is approximately one-half of that in the radial direction. The turbulence profiles become flatter with increasing distance from the propeller, and the maximum values fall first to about 6% ($X/D=10$) and 3% ($X/D=40$).

The effect of the sail on the mean flow and turbulence quantities was seen in the vertical profiles at each station. The sail produces a larger momentum deficit in the upper portion of the vertical profile which indicates the increased drag on the body due to the sail. The flow angularity is reduced in the region behind the sail, and the static pressure is increased substantially by the presence of the sail. The effect on turbulence intensities was to increase the level of turbulence in the vertical profile behind the sail.

From the results, several conclusions about the effects of appendages and nonzero pitch angles on the wake structure of a propeller-driven body can be asserted. First, a sail reduces the propeller swirl in its wake, and this causes an increase in static pressure. Second, the pitched condition further reduces the swirl and increases the static pressure in the region behind the sail. These effects are primarily confined to the vertical plane, and little change in the horizontal profiles is seen. Third, the effect of the sail on the drag coefficient is to increase it from $C_D=0.09$ as calculated for the body without sail[4] to $C_D=0.30$ with the sail.

The development of the boundary layer over the body on the side opposite the sail was also studied. By the last station considered, 11.17 diam back from the nose, the boundary layer had grown to approximately 1.5-in. thickness. The effects of the running propeller on the boundary layer were only detectable at the last station. The propeller accelerates the flow in the boundary layer and tends to decrease the boundary-layer thickness.

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