Simplified Prediction of Propeller Inflow/Outflow Properties

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OVERVIEW

There are certain instances where an understanding of propeller inflow and outflow properties can be applied to the initial selection of propeller parameters. Two such instances are for the selection of counter-rotating propellers and the design of propeller ducts (nozzles).

Figure 1 illustrates the flow of the water "jet" through the propeller disk. This simplified approach relies on the well-used mass-flow (or momentum) methodology . As the mass of the water is accelerated through the propeller disk to a higher velocity, the Bernoulli effect causes a corresponding reduction of the diameter of the jet. The velocity and diameter of the jet at points along the propeller axis can be found with the equations shown below.

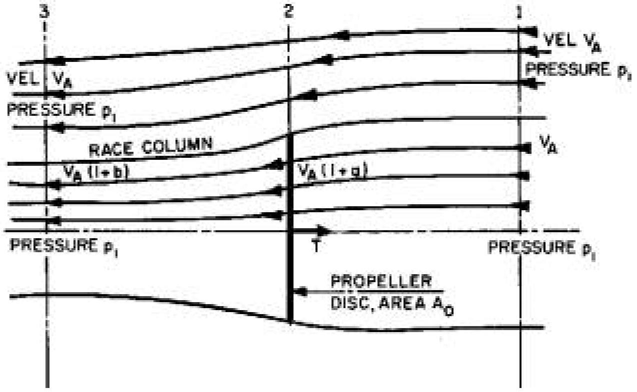

Figure 1. Propeller Jet Inflow-Outflow Properties
[SNAME, *Principals of Naval Architecture*]

WAKE FRACTION AND SCALE CORRECTION

It is important to note that the wake fraction generally includes the velocity profiles described in Figure 1. The prediction of effective wake fraction is derived by comparing the thrust loading in a circulating channel to that found behind the hull during a self-propulsion test – and solving for the corresponding velocity that would produce the measured thrust. In both cases, the jet will exhibit flow constriction and increases in local velocity. In other words, the V_A described above is the well-known V_A which is equal to $V(1\text{-}w)$.

Model- and full-scale propeller loadings will act differently, however, causing a slightly different distribution of the flow. The use of a wake fraction scale correction is a recommended step in all performance predictions.

INFLUENCE OF THE HUB

One of the initial components of this simplified methodology – the thrust loading – depends on the relationship between thrust, velocity and the area through which the water passes (i.e., the disk area). If the hub gets to be sizeable, as might be the case for a controllable-pitch or counter-rotating propeller, it may be appropriate to reduce the propeller disk area to be equal to the area outside of the hub.

For example, a conventional propeller with a hub of 18% of the diameter will only cause about a 3% reduction in disk area, but a 35% hub reduces the disk area by more than 12%.

EQUATIONS

Item	Equation	Variables	Comments
Thrust loading coefficient	$C_T = \frac{T}{\frac{1}{2}\rho A_0 V_A^2}$	T = open-water thrust A_0 = propeller disk area V_A = advance velocity	Make sure all units are compatible.
Ideal efficiency	$\eta_i = \frac{2}{1+\sqrt{C_T+1}}$	C_T = thrust loading coefficient	
Overall velocity factor	$a = \frac{1}{\eta_i} - 1$	η_i = ideal efficiency	This provides a way to estimate the overall change in velocity from inflow to outflow.
Local velocity multiplier	$k = \frac{2}{1+e^{-cX}}$	c = curve shape coefficient x = distance from propeller (in diameters, positive aft)	This provides a way to estimate velocities at specific axial locations. The "c" coefficient typically equals 3-4, with one reference using 3.3 as a representative value.
Local jet velocity	$V_X = V_A(1+ka)$	V_A = advance velocity k = local velocity multiplier a = overall velocity factor	This is the local jet velocity at any location (X) along the axis.
Local jet area	$A_X = \frac{V_A(1+a)A_0}{V_X}$	V_A = advance velocity a = overall velocity factor A_0 = propeller disk area V_X = local jet velocity	This is the local jet sectional area at any location (X) along the axis.
Local jet diameter	$D_X = \sqrt{\frac{4A_X}{\pi}}$	A_X = local jet area	This is the local jet diameter at any location (X) along the axis.

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