Estimating Propeller Forces for Blade Strength Analysis

A HydroComp Technical Report

Report 140

Overview

The definition of loads for the structural analysis of propeller blades, such as FEA (finite element analysis), would ideally be built from distributed pressures and forces. True distributions of these loads, however, are difficult to resolve and typically require flow codes (i.e., CFD) to determine their precise magnitude and location. This report provides a simple model for the estimate of propeller forces suitable for use in structural analysis.

The premise of the simplified model is that a) the forces can be modeled by a set of point loads rather than distributed pressures, and b) the magnitudes of these point loads can be estimated using a representative distribution for open propellers.

The graphic below illustrates how the three principal forces – thrust, torque, and centrifugal – are applied as point loads acting on a radial span of the propeller blade.

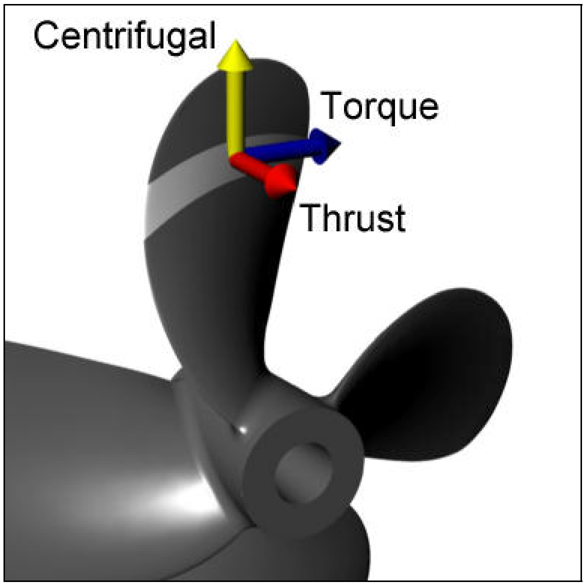

Figure 1 – Force diagram

Thrust and torque forces

Propeller thrust and torque are developed from local lift and drag of the propeller blade “foil” sections at their defined radial position. In other words, the total thrust of the propeller will be the integration of axial lift vectors for the sections from root to tip.

The influence of any particular section depends on its chord length and radial position. The velocity of any rotating section, of course, is a function of its radial position – the tip is traveling faster that the root due to its larger radial arm. However, as open propellers have a tip of nominally zero chord length, the tip section no longer has any effect on thrust or torque. (This is why propeller designers use a median radius, such as the 0.70 or 0.75 radius, as the nominal design figure. The combination of large chord and high radius gives it a predominant position.)

An assumed distribution

If we assume that most open propellers share a similar blade outline – such as that of a B-series or Gawn outline, for example – then we can use a single distribution model for thrust and torque loads. (This model will not be suitable for Kaplan-style propellers with wide blade tips, or for outlines vastly different from those described.) This also assumes that the pitch distribution is constant.

A suitable load distribution for a propeller with these conditions can be found in Schoenherr [1963]. The distribution provides a force per unit radial distance (e.g., pounds per inch) versus radial position.

HydroComp has converted these distributions into numerical expressions for F_T (axial thrust force) and F_Q (horizontal torque force) for the span between any two radial ordinates (e.g., 0.7 to 0.8).

$$F_{T(X1\text{-to-}X2)} = 3.5\ R\ k_T\ [a_T(x_2) - a_T(x_1)]$$
$$F_{Q(X1\text{-to-}X2)} = 3.5\ R\ k_Q\ [a_Q(x_2) - a_Q(x_1)]$$

where,

R = propeller radius (i.e., diameter/2)
$k_T = T / (z\ R\ c_H)$
$k_Q = Q / (z\ R^2\ c_H)$
x_2 = outer radial ordinate of span (i.e., 0.8)
x_1 = inner radial ordinate of span (i.e., 0.7)
$a_T(x)$ = thrust integration expression at x
$= (-2/105)(8 + 4x + 3x^2 - 15x^3)(1 - x)^{½}$
$a_Q(x)$ = torque integration expression at x
$= (-2/15)(2 + x - 3x^2)(1 - x)^{½}$

and,

T = propeller thrust
Q = propeller torque
z = number of blades
c_H = hub-to-tip integration expression
$= (1/15)(8 + 4x_H + 3x_H^2 - 15x_H^3)(1 - x_H)^{½}$
x_H = radial position of the hub (e.g., 0.20)

Using the estimate formula

Using a sample 20 inch propeller, we will find the thrust and torque force values for the span between the 0.70 and 0.80 radii (as is shown in Figure 1), given the following.

T = 1800 lbf
Q = 6000 lbf-in (500 lbf-ft)
R = 10 in
x_H = 0.20 (from a 2 in hub radius)
z = 4 blades

We calculate

$c_H = 0.5247$
k_T = 85.76 lbf/in
k_Q = 28.59 lbf/in

$a_T(0.8) = -0.04634$
$a_T(0.7) = -0.07433$
$F_{T(0.7\text{-to-}0.8)}$ = 84.02 lbf

$a_Q(0.8) = -0.05247$
$a_Q\ (0.7) = -0.08983$
$F_{Q(07\text{-to-}0.8)}$ = 37.37 lbf

Centrifugal force

The third force to be considered for the span is the centrifugal force of the rotating weight. Centrifugal forces are well understood, so they will not be described in further detail here – other than to say that the weight of each span can typically be found with whatever CAD software is used to develop the 3D model (e.g., slicing the blade up via intersecting cylinders).

Location and vector direction of point forces

Thrust forces are always axial in their direction (i.e., following the propeller shaft axis). Torque forces will be tangent to the radius arc. Centrifugal forces are normal to the axis.

The estimated point forces would be located at:

- mid-chord (i.e., halfway between leading and trailing edge)
- mid-span (e.g., 0.75R for a 0.7 to 0.8 span)
- on the generating-line pitch plane (typically at the pressure face), as this is a convenient design reference

For propellers with no skew, the force vectors will be in true X-Y-Z direction. With propellers of modest skew angle, the cosine effects will be small, so it is probably reasonable to neglect correcting them to be truly tangent and normal, and to simply use X-Y-Z direction.

References

Schoenherr, K.E., “Formulation of Propeller Blade Strength”, *SNAME Spring Meeting*, April 1963.

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