Low Reynolds Number Propeller Performance Data: Wind Tunnel Corrections for Motor Fixture Drag

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The correction method begins with the standard definitions where here the prime notation is used to denote quantities depending on the net axial force $(T - D_{fixture})$:

$$J = \frac{V}{nD} \tag{1}$$

$$C'_T = \frac{T'}{\rho n^2 D^4} \tag{2}$$

$$C_P = \frac{P}{\rho n^3 D^5} \tag{3}$$

$$\eta' = J \frac{C'_T}{C_P} \tag{4}$$

where D is the propeller diameter and should not be confused with the motor fixture drag $D_{fixture}$.

The following equations outline the method of calculating the corrected thrust coefficient C_T. An interative process is employed to calculate C_T.

$$T' = T - D_{fixture} \tag{5}$$
$$T' = \rho n^2 D^4 C'_T \tag{6}$$

Thus, the corrected propeller thrust is given by

$$T = \rho n^2 D^4 C'_T + D_{fixture} \tag{7}$$

The drag of the motor fixture can be estimated using

$$D_{fixture} = qSC_D \tag{8}$$

$$q = \frac{1}{2}\rho(V+v)^2 \tag{9}$$

where the propeller-induced velocity, v is calculated using classical momentum theory assumptions. The induced velocity is given by

$$v = \frac{1}{2}\left[-V + \sqrt{V^2 + \left(\frac{2T}{\rho A}\right)}\right] \tag{10}$$

Therefore

$$T = \rho n^2 D^4 C_T' + \frac{1}{2}\rho(V+v)^2 SC_D \tag{11}$$

For the interative method, T is initially calculated by assuming v to be 0. An iterative process is then employed until T coverges. The final v value is also obtained. Finally the corrected thrust coeffiecient is calculated using

$$\begin{aligned} C_T &= \frac{\rho n^2 D^4 C_T' + D_{fixture}}{\rho n^2 D^4} && (12)\\ &= \frac{\rho n^2 D^4 C_T' + \frac{1}{2}\rho(V+v)^2 SC_D}{\rho n^2 D^4} && (13)\\ &= C_T' + \frac{\frac{1}{2}\rho(V+v)^2 SC_D}{\rho n^2 D^4} && (14)\\ &= C_T' + \frac{1}{2}\frac{(V+v)^2 SC_D}{n^2 D^4} && (15) \end{aligned}$$

The final determination of the corrected thrust coefficient C_T depends on the dimensions and drag coefficient C_D of the motor fixture. The C_D could be estimated by CFD analysis of the propeller fixture CAD model shown in Fig. 1 or from experimental measurements. Based on the drag coefficient of various 3D bodies in Ref. 1, an approximate C_D value of 1 is reasonable.

References

[1]Hoerner, S. F., *Fluid-Dynamic Drag*, Hoerner Fluid Dynamics, Brick Town, NJ, 1965.

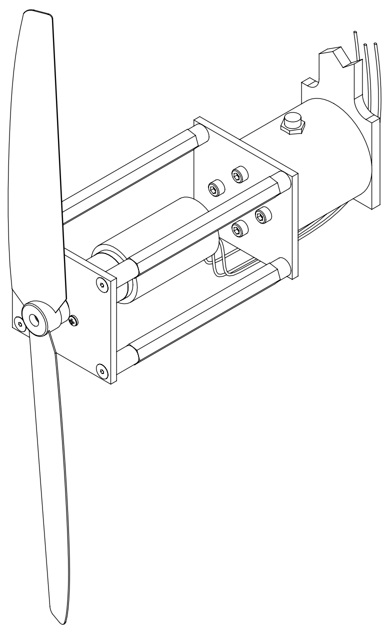
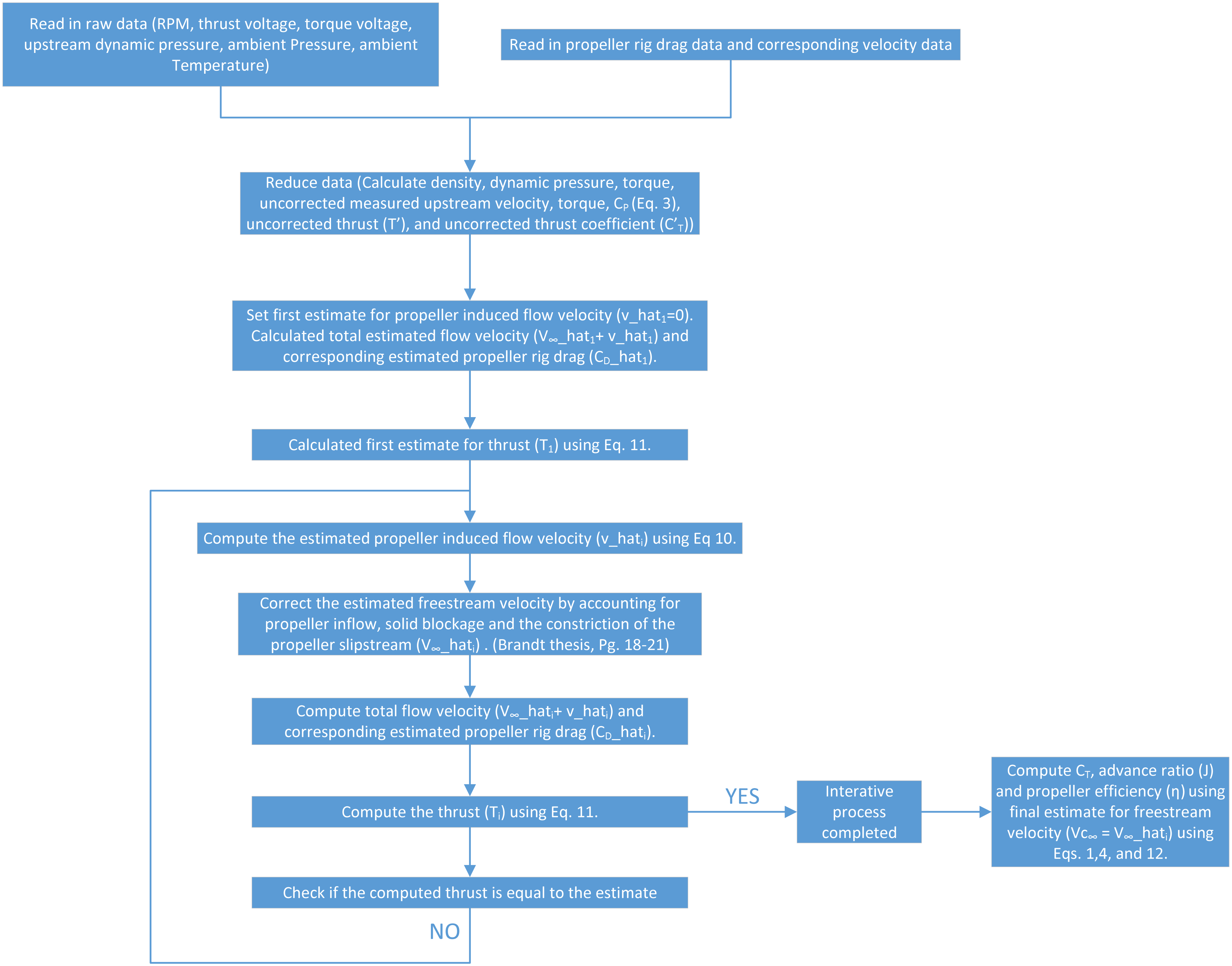


Figure 1. Propeller and motor fixture isometric rendering.



Read in raw data (RPM, thrust voltage, torque voltage, upstream dynamic pressure, ambient Pressure, ambient Temperature)
Read in propeller rig drag data and corresponding velocity data
Reduce data (Calculate density, dynamic pressure, torque, uncorrected measured upstream velocity, torque, C_P (Eq. 3), uncorrected thrust (T'), and uncorrected thrust coefficient (C'_T))
Set first estimate for propeller induced flow velocity (v_hat$_1$=0). Calculated total estimated flow velocity (V_∞_hat$_1$+ v_hat$_1$) and corresponding estimated propeller rig drag (C_D_hat$_1$).
Calculated first estimate for thrust (T_1) using Eq. 11.
Compute the estimated propeller induced flow velocity (v_hat$_i$) using Eq 10.
Correct the estimated freestream velocity by accounting for propeller inflow, solid blockage and the constriction of the propeller slipstream (V_∞_hat$_i$) . (Brandt thesis, Pg. 18-21)
Compute total flow velocity (V_∞_hat$_i$+ v_hat$_i$) and corresponding estimated propeller rig drag (C_D_hat$_i$).
Compute the thrust (T_i) using Eq. 11.
YES
Interative process completed
Compute C_T, advance ratio (J) and propeller efficiency (η) using final estimate for freestream velocity (Vc_∞ = V_∞_hat$_i$) using Eqs. 1,4, and 12.
Check if the computed thrust is equal to the estimate
NO