

APPROXIMATE PARAMETRIC METHOD FOR PROPELLER THRUST ESTIMATION

ADDENDUM A: APPLICATION TO FIXED-PITCH PROPELLERS

1. INTRODUCTION

This Addendum extends the method of Item No. 83001 to direct-drive fixed-pitch propellers. The method gives estimates of uninstalled thrust for fixed-pitch propellers operating at airspeeds up to 250 kn, with the following ranges of applicability.

$P/\sigma D^2$		V_{tip}		TAF
kW/m ²	hp/ft ²	m/s	ft/s	
16 to 64	2 to 8	200 to 300	700 to 1000	160 to 540

However, for the majority of light aircraft with fixed-pitch propellers, $2 < P/\sigma D^2 < 6$ hp/ft² ($16 < P/\sigma D^2 < 48$ kW/m²) and $160 < TAF < 240$.

2. DATA REQUIRED FOR USE IN THE METHOD

- The variation of engine power^{*}, P , with rotational speed, N , at full-throttle, or fixed part-throttle, settings.
- The propeller diameter, D , and total activity factor, TAF , or, for a systematic study, ranges of values of these.
- The forward speed, $V_{N_{max}}$, at which the propeller maximum rotational speed, N_{max} , is achieved (see Section 4 for guidance).

3. METHOD OF THRUST ESTIMATION FOR FIXED-PITCH PROPELLERS

The variation of thrust with forward speed for a fixed-pitch propeller logically divides into two parts. The dividing point is $V_{N_{max}}$ and estimation methods for speeds below and above this are given in Sections 3.1 and 3.2.

3.1 Method of Estimating Thrust for $V \leq V_{N_{max}}$

- Estimate $\Delta N_s/N_{max}$ from Figure 1.
- For airspeed ratios, $V/V_{N_{max}}$, in the range 0 to 1.0, use Figure 2 to estimate $\Delta N/\Delta N_s$ and hence the

* In general, P is roughly proportional to N but wide variations of engine speed-power characteristics exist even for engines of similar power output. Engine manufacturers' data may include a "full-throttle" variation of P with N , i.e. the maximum shaft power available at each value of N , and, in addition, the variation of P and N when a "standard" fixed-pitch propeller is fitted. Such "propeller-load" data are not suitable for use with this Item.

corresponding propeller rotational speeds using,

$$N = N_{max} \left(1 - \frac{\Delta N}{\Delta N_s} \times \frac{\Delta N_s}{N_{max}} \right). \quad (3.1)$$

- (iii) For each value of N obtained from (ii) determine the corresponding value of:

engine power, P , from engine curves,

propeller disc-loading parameter, $P/\sigma D^2$,

propeller tip speed, $V_{tip} = \frac{\pi}{60} ND$,

forward speed, $V = \frac{V}{V_{N_{max}}} \times V_{N_{max}}$.

- (iv) For the required value of TAF use the method of Section 3 of Item No. 83001 (*i.e.* steps (ii) to (v) and Figures 1 to 6) to estimate thrust for each set of values of $P/\sigma D^2$, V_{tip} and V , obtained in (iii) above.

3.2 Method of Estimating Thrust for $V > V_{N_{max}}$

- (v) It is assumed that for $V > V_{N_{max}}$ the engine is throttled to maintain constant rotational speed. For a fixed-pitch propeller operating at constant rotational speed in the range of forward speeds where $V > V_{N_{max}}$, the variation of thrust with forward speed, $\partial T/\partial V$, is nearly linear. Figure 3 gives values of $[(1/D^2)(\partial T/\partial V)]_{const N}$ from which values of thrust lapse and thrust for $V > V_{N_{max}}$ may be calculated as follows:

$$\left[\frac{\partial T}{\partial V} \right]_{const N} = \left[\frac{1}{D^2} \frac{\partial T}{\partial V} \right]_{const N} \times D^2, \quad (3.2)$$

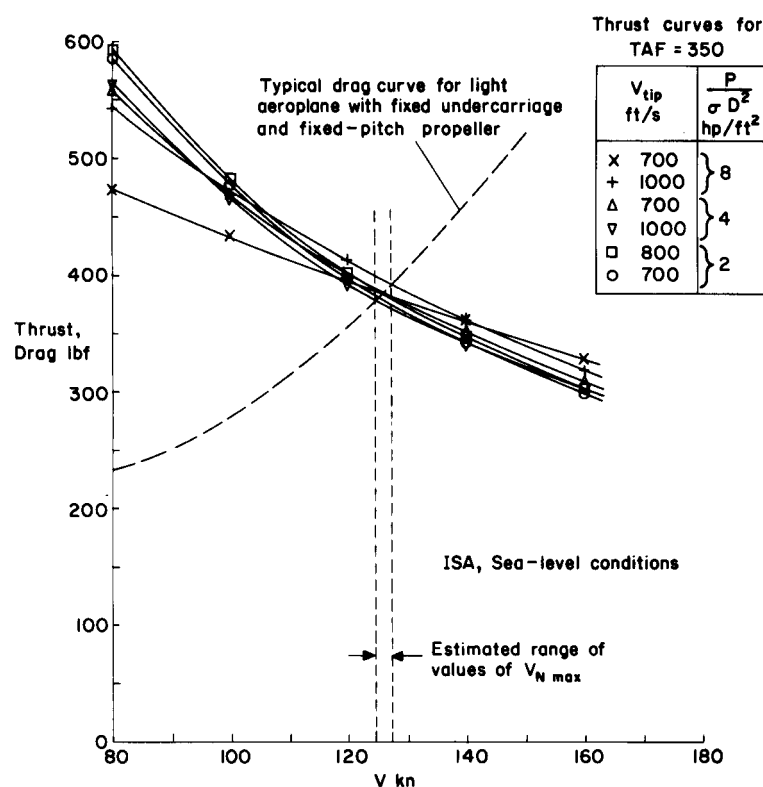
$$T = T_{N_{max}} + \left[\frac{\partial T}{\partial V} \right]_{const N} \times (V - V_{N_{max}}). \quad (3.3)$$

4. SELECTION OF $V_{N_{max}}$

The value of $V_{N_{max}}$ is chosen to suit the performance and role of the aeroplane*. In some cases, for example glider tugs or aerobatic aeroplanes, $V_{N_{max}}$ might be chosen so as to maximise excess thrust or excess power. However, it is common practice to make $V_{N_{max}}$ equal to the aeroplane maximum level speed.

If $V_{N_{max}}$ is near the maximum level speed, it can be estimated by equating thrust to drag, as shown in Sketch 4.1. For this calculation approximate values of propeller thrust are obtained by taking representative values of $P_{N_{max}}$ and V_{tip} and making the following assumptions,

- that the method of Item No. 83001 may be used (since at $V_{N_{max}}$ a fixed-pitch propeller gives the same performance as the corresponding constant-speed propeller),
- that the thrust may be estimated from Figures 1 and 6 only of Item No. 83001 (since the effect of TAF at speeds near $V_{N_{max}}$ is small – see Sketch 11.2 of Item No. 83001).



Sketch 4.1 Example of estimation of $V_{N_{max}}$ (see Section 4)

* Examination of flight-manual data for a number of light aeroplanes showed values of $\Delta N_s/N_{s_{max}}$ between 0.06 and 0.18 (for these cases, $2.5 \leq P_{N_{max}}/\sigma D^2 \leq 4.5$ hp/ft²).

5. NOTES ON THE CORRELATIONS

The method of estimation presented in this Addendum is based on the correlation of data for various propeller and engine types. The figures were generated using the data of Reference 8 and Derivation 2 of Item No. 83001. For Figure 1 the analysis involved 40 engine-propeller combinations covering wide ranges of values of $P_{N_{max}}/\sigma D^2$, TAF and V_{tip} . For Figure 1, 80 per cent of the data used correlated to within ± 15 per cent over the ranges of values of $P_{N_{max}}/\sigma D^2$ and $\Delta N_s/N_{max}$ shown. The spread of data in Figure 2, which utilised 15 different engine-propeller combinations, is represented by the hatched area on which a recommended working line is indicated. In the case of Figure 3 the curves given for thrust lapse correlated the data used to within ± 10 per cent. These data were taken from propeller-performance charts after assuming that N remained constant with changes in V or J .

6. EXAMPLE

Fixed-Pitch Propeller for a Small Single-Engined Aeroplane

For the direct-drive engine-propeller combination described below, estimate the uninstalled thrust available from 0 to 150 kn at ISA sea-level conditions ($\sigma = 1$) if $V_{N_{max}} = 125$ kn (see Sketch 4.1). The engine speed-power curve is shown in Sketch 6.1.

Propeller: $n_b = 2$ (fixed-pitch)
 $AF = 80$ ($TAF = 160$, $TAF/350 = 0.457$)
 $D = 6.3$ ft

Engine: $N_{max} = 2700$ rev/min
 $P_{max} = 180$ hp

Estimation of Thrust for Airspeeds Less than $V_{N_{max}}$

Following the procedure of Section 3.1, step (i) requires the estimation of $\Delta N_s/N_{max}$. From the given data

$$\frac{P_{N_{max}}}{\sigma D^2} = \frac{180}{1 \times (6.3)^2} = 4.535 \text{ hp/ft}^2.$$

From Figure 1a for two-bladed propellers with $P_{N_{max}}/\sigma D^2 = 4.535$ hp/ft² and $V_{N_{max}} = 125$ kn,

$$\Delta N_s/N_{max} = 0.161 \text{ (and so } N_s = 2265.3 \text{ rev/min).}$$

The results of steps (ii) to (iv) of the calculation sequence are presented in Table 6.1 and are plotted in Sketch 6.2.

Estimation of Thrust for Airspeeds above $V_{N_{max}}$

The method described in Section 3.2 is used. The tip speed at N_{max} is

$$V_{tip} = \frac{\pi}{60} N_{max} D = \frac{\pi}{60} \times 2700 \times 6.3 = 890.6 \text{ ft/s.}$$