



## Approximate estimation of drag of windmilling propellers

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## APPROXIMATE ESTIMATION OF DRAG OF WINDMILLING PROPELLERS

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## APPROXIMATE ESTIMATION OF DRAG OF WINDMILLING PROPELLERS

### 1. NOTATION AND UNITS

|                    |                                                                                                                                                                                                                           |                      |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| $AF$               | activity factor per blade = $\frac{10^5}{16} \int_{0.2}^{1.0} \frac{c}{D} \left(\frac{r}{R}\right)^3 d\left(\frac{r}{R}\right)$                                                                                           | —                    |
| $c$                | chord of blade at radius $r$                                                                                                                                                                                              | ft                   |
| $C_{L_{des}}$      | design lift coefficient at $0.7R$ (This is obtained by integrating the design pressure distribution at zero incidence around the section at $0.7R$ with respect to the chord and dividing by chord $\times$ dynamic head) | —                    |
| $C_P$              | power coefficient = $P \times 550 / (\rho n^3 D^5)$                                                                                                                                                                       | —                    |
| $C_{P_{350}}$      | power coefficient of “standard” propeller of $TAF = 350$                                                                                                                                                                  | —                    |
| $C_T$              | thrust coefficient = $T / (\rho n^2 D^4)$                                                                                                                                                                                 | —                    |
| $C_{T_{350}}$      | thrust coefficient of “standard” propeller of $TAF = 350$                                                                                                                                                                 | —                    |
| $D$                | propeller diameter                                                                                                                                                                                                        | ft                   |
| $J$                | advance ratio <sup>†</sup> = $1.688 \times V / (nD)$                                                                                                                                                                      | —                    |
| $N$                | engine rotational speed                                                                                                                                                                                                   | rpm                  |
| $n$                | propeller rotational speed                                                                                                                                                                                                | rps                  |
| $P$                | power absorbed by propeller ( $-P$ = power transmission from propeller to engine)                                                                                                                                         | hp                   |
| $R$                | propeller radius                                                                                                                                                                                                          | ft                   |
| $T$                | thrust ( $-T$ = windmilling drag)                                                                                                                                                                                         | lbf                  |
| $TAF$              | total activity factor (= $AF \times$ number of blades)                                                                                                                                                                    | —                    |
| $V$                | airspeed, TAS                                                                                                                                                                                                             | kn                   |
| $\theta_{0.7}$     | blade angle measured from section chord line at $r = 0.7R$                                                                                                                                                                | degree               |
| $(\theta_{0.7})_S$ | blade angle measured from section chord line plotted in graphs applicable to “standard” propeller with zero lift angle at $r = 0.7R$ of $3.1^\circ$                                                                       | degree               |
| $\epsilon_x$       | zero-lift angle taken as $7.3 C_{L_{des}}$                                                                                                                                                                                | degree               |
| $\rho$             | density                                                                                                                                                                                                                   | slug/ft <sup>3</sup> |

<sup>†</sup> The factor 1.688 is the conversion from knots to ft/sec.

## 2. NOTES

This Data Item presents a simplified method for the estimation of the drag of windmilling propellers. It must be emphasised, however, that the curves should only be used to provide a first estimate. A comparison of answers obtained by this method with those obtained for various cases by a more rigorous method suggests that this Item will yield solutions to within  $\pm 10\%$  of those predicted by the more rigorous method in 60% of cases. The remainder lie within  $\pm 20\%$ . However, it is assumed in this comparison that the blade angle when windmilling is known. Also, if the value of  $|C_P|$  involved, lies in the range  $-0.02 < |C_P| < 0$ , the percentage error may be higher. If it is required to investigate small magnitudes of thrust and drag, as, for example, in consideration of zero thrust for stall tests, it will be necessary to consult the propeller manufacturer.

Figures 2a, 2b, 3a and 3b are propeller characteristic charts plotting power coefficient and thrust coefficient, respectively, against blade angle at 0.7 radius for various values of advance ratio. The curves are plotted for a standard propeller of  $TAF = 350$  and no-lift angle at 0.7 radius of  $3.1^\circ$ . If the propeller under consideration has a zero-lift angle  $\varepsilon_x$  at 0.7 radius which differs from  $3.1^\circ$ , then the value of the true blade angle at 0.7 radius is related to the value used on the graphs by

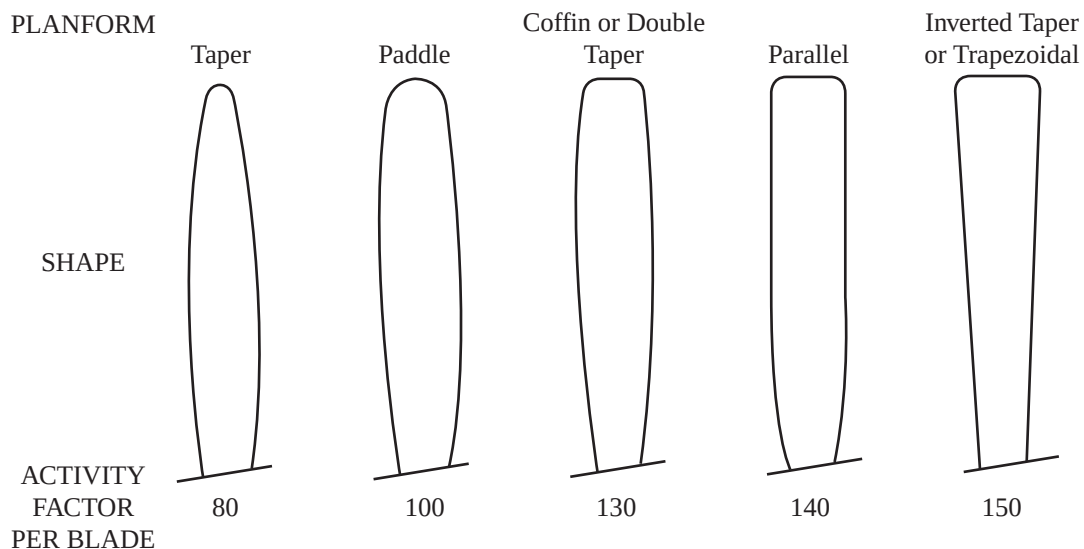
$$\theta_{0.7} = (\theta_{0.7})_S + 3.1 - \varepsilon_x .$$

Similarly, if the propeller has a total activity factor which differs from 350, the values of power and thrust coefficients applying to the propeller are related to those used in the graphs by

$$C_P = C_{P_{350}} \times \frac{TAF}{350} \quad \text{and} \quad C_T = C_{T_{350}} \times \frac{TAF}{350} .$$

Typical values of  $\varepsilon_x$  at  $0.7R$  are  $3^\circ$  for propellers designed for high cruise efficiency,  $4^\circ$  for propellers designed to give good mean performance at take-off and during cruise and  $5^\circ$  for propellers designed for high take-off thrust.

The activity factor is a function of blade planform and, if unknown, it is suggested that the values in Sketch 2.1 be taken as a guide for single blades.



**Sketch 2.1 Relationship between activity factor and blade planform**

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