



Thrust and drag accounting for propeller/airframe interaction

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THRUST AND DRAG ACCOUNTING FOR PROPELLER/AIRFRAME INTERACTION

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THRUST AND DRAG ACCOUNTING FOR PROPELLER/AIRFRAME INTERACTION

1. NOTATION AND UNITS

		SI	British
C_P	power coefficient, $P/\rho n^3 d^5$ (P in N m/s or ft lbf/s)		
D	aircraft drag, propellers-on	N	lbf
D_{p0}	aircraft propellers-off drag, including effects of flow through engines and any auxiliary intakes	N	lbf
ΔD	correction to aircraft propellers-off drag to allow for interference effect between propeller flow and particular airframe component, see Equation (3.3)	N	lbf
d	propeller disc diameter	m	ft
F_{G0}	free-stream momentum force (ram drag), per powerplant (gauge stream force far upstream in inlet streamtube for "core engine", see Reference 6)	N	lbf
F_{G9}	standard gross thrust, per powerplant (gauge stream force at nozzle exit plane, see Reference 6)	N	lbf
F_N	standard net thrust of "core engine" ($F_{G9} - F_{G0}$, see Reference 6), per powerplant	N	lbf
f	empirical factor in propulsive thrust to allow for increase in nacelle drag due to slipstream		
h	fractional reduction in flow through propeller due to nacelle blockage		
J	advance ratio, V_0/nd		
N	number of powerplants (= number of propellers*)		
n	propeller rotational speed	rev/s	rev/s
P	power input to propeller	N m/s	ft lbf/s
T	total installed thrust for aircraft	N	lbf
T_{EX}	excess thrust for aircraft, $T - D$	N	lbf
T_{FA}	free-air thrust per propeller*; axial force exerted by propeller blades in uniform flow field undisturbed by nacelle or other structure	N	lbf

For footnote refer to end of Notation

T_{mb}	minimum-body thrust per propeller*, see Section 2.3 and Section 4 of Reference 11	N	lbf
T_N	net thrust per propeller*, see Section 2.3 and Equation (3.6)	N	lbf
T_P	propulsive thrust per propeller*, Equation (4.5); shaft thrust diminished by extra zero-lift drag due to slipstream of those parts of aircraft immersed in it	N	lbf
T_S	shaft (or “apparent”) thrust per propeller*, Equation (4.3); axial force exerted by propeller blades in flow field in which they are situated on aircraft	N	lbf
ΔT	correction to propeller free-air thrust to allow for presence of particular airframe component, see Equation (3.2)	N	lbf
V_0	free-stream velocity	m/s	ft/s
η	propeller efficiency		
ρ	air density	kg/m ³	slug/ft ³

Subscripts

<i>axial</i>	denotes effect due to increased axial velocity in propeller streamtube
<i>b</i>	denotes blockage effect of airframe component, in changing effective axial velocity at propeller
<i>e</i>	denotes effective value
<i>f</i>	denotes fuselage
<i>g</i>	denotes effect due to pressure gradients in propeller streamtube (buoyancy)
<i>i</i>	denotes induced effect, due to upwash or downwash at propeller
<i>L</i>	denotes lift-dependent effect on drag
<i>n</i>	denotes nacelle (or fuselage for nose-mounted powerplant) complete with engine intake and nozzle and any auxiliary inlets attached to nacelle and their associated mass flows; also denotes “in presence of”, e.g. as in T_{Sn}
<i>py</i>	denotes powerplant mounting pylon
<i>st</i>	denotes stabilisers (tailplane or foreplane and fin)
<i>swirl</i>	denotes effect due to rotational velocity in propeller streamtube

For footnote refer to end of Notation

uc	denotes undercarriage unit
v	denotes effects due to increased velocity in propeller streamtube
w	denotes wing, including high-lift devices and any auxiliary inlets together with their associated mass flows
0	denotes effect on drag at zero lift

* In this Item the word “propeller” refers to either a single-rotation propeller or a counter-rotating pair.

2. INTRODUCTION

2.1 General

Item No. 85015 (Reference 11) provides an introduction to the various propeller/airframe interference effects on thrust and drag. The purpose of the present Item is to act as a companion to that Item in setting up an overall framework by means of which all the interference effects of installing propellers on an airframe may be accounted for in terms of thrust and drag. Such a system of thrust and drag accounting, commonly and appropriately called “book-keeping”, is necessary in aircraft performance calculations and in the analysis of flight and wind-tunnel test data in order to ensure that no component is overlooked and that none is counted twice. Chapter 2 of Reference 6 and Appendix A of Reference 13 provide detailed thrust and drag accounting schemes for turbo-jet and turbo-fan propulsion systems and Reference 4 defines the various thrust components involved. For a detailed understanding of thrust and drag accounting in general, and for the particular cases of turbo-jets and turbo-fans, the user is advised to refer to References 6 and 13.

2.2 The Framework

In the framework in this Item it will be assumed that the designer has a knowledge of at least a good approximation to free-air thrust for each propeller. Such information will be either in the form of estimates of free-air thrust or wind-tunnel data for minimum-body thrust or net thrust, see Section 2.3.

The propeller is then assumed to be added to the nacelle (operating with a given mass flow) which is itself assumed to be already attached to the aircraft. The drag of the nacelle, “propeller-off”, complete with intake, nozzle, oil-coolers *etc.* and their associated mass flows is part of the aircraft drag, propellers-off, which is assumed to be known. The propeller-off effects, as far as the nacelle itself is concerned, arise from the flow around the nacelle, plus the flow around the engine, for an air-cooled reciprocating engine, or through it for a turbine engine. There will also in general be present some exhaust thrust, oil-cooler and other cooling mass flows with their associated effects, particularly on drag.

The “propellers-on”[†] effects on propeller thrust arise from the interference effects due to the presence of the airframe while the effects on drag arise from the propeller flow around the airframe. A detailed discussion of the various interferences is given in Section 5 of Item No. 85015 (Reference 11).

For the purposes of this Item the thrust and drag framework is couched in terms of “thrust minus drag”, commonly called “excess thrust”, or, as applied to turbo-jet and turbo-fan engines in Reference 6, “net propulsive force”.

[†] In this Item “propellers-on” means “propellers are fitted and are producing thrust”.