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An introduction to aircraft excrescence drag



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THE PREPARATION OF THIS DATA ITEM

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AN INTRODUCTION TO AIRCRAFT EXCRESCENCE DRAG

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AN INTRODUCTION TO AIRCRAFT EXCRESCENCE DRAG

1. NOTATION AND UNITS

		SI	British
A_{ref}	reference area for excrescence	m^2	ft^2
C_D	excrescence drag coefficient, based on q_∞ and S_{ref}		
C'_D	“clean” aerofoil drag coefficient, based on q_∞ and c		
C'_{De}	drag coefficient of aerofoil with excrescence		
$\Delta C'_D$	increase in C'_D due to excrescence, $C'_{De} - C'_D$		
C_{Dfp}	drag coefficient for excrescence mounted on flat plate with uniform pressure distribution, based on q_{10} and A_{ref} (c in Section 3.3.1)		
C_{f0}	local skin friction coefficient at excrescence location, in absence of excrescence		
c	aerofoil chord	m	ft
h	excrescence height	m	ft
K	factor on C_{Dfp} to allow for differences between geometry and orientation of excrescence as tested in wind tunnel and as located on aircraft, see Section 3.1		
l	characteristic length of excrescence	m	ft
M	Mach number		
M_∞	free-stream Mach number		
m	power law index in Equation (3.3)		
m_d	drag magnification factor		
q	kinetic pressure, $\frac{1}{2}\rho u^2$	N/m ²	lbf/ft ²
q_∞	free-stream kinetic pressure, $\frac{1}{2}\rho_\infty u_\infty^2$	N/m ²	lbf/ft ²
R_c	aerofoil Reynolds number, $u_\infty c/\nu_\infty$		
R_l	excrescence Reynolds number, in absence of excrescence, $u_{10} l/\nu_{10}$		
S_{ref}	aircraft wing reference area	m^2	ft^2

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u	velocity	m/s	ft/s
u_{∞}	free-stream velocity	m/s	ft/s
$u_{\tau 0}$	friction velocity at excrescence location, in absence of excrescence, $(\tau_{w0}/\rho_{w0})^{1/2}$	m/s	ft/s
x	distance from leading edge, measured along aerofoil surface	m	ft
x_0	value of x at excrescence location	m	ft
y	distance measured from surface and normal to it	m	ft
δ	local thickness of boundary layer (where local velocity reaches $0.99 \times$ velocity at edge of boundary layer, in absence of excrescence)	m	ft
θ	momentum thickness, in absence of excrescence	m	ft
$\Delta\theta$	increment in momentum thickness due to excrescence	m	ft
ν	kinematic viscosity	m ² /s	ft ² /s
ν_{w0}	wall value of ν at excrescence location, in absence of excrescence	m ² /s	ft ² /s
ν_{∞}	free-stream kinematic viscosity	m ² /s	ft ² /s
ρ	density	kg/m ³	slug/ft ³
ρ_{w0}	wall value of ρ at excrescence location, in absence of excrescence	kg/m ³	slug/ft ³
ρ_{∞}	free-stream density	kg/m ³	slug/ft ³
τ	shear stress	N/m ²	lbf/ft ²
τ_{w0}	wall value of τ at excrescence location, in absence of excrescence	N/m ²	lbf/ft ²

Subscripts

imm	denotes value for part of excrescence immersed in boundary layer
$proj$	denotes value for part of excrescence projecting from boundary layer
T	denotes value at aerofoil trailing edge
$\delta = 0$	denotes inviscid flow (zero boundary-layer thickness)
0	denotes value at excrescence location, in absence of excrescence
1	denotes value at edge of boundary layer, in absence of excrescence

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2. ASSESSMENT OF THE PROBLEM OF EXCRESCENCE DRAG

2.1 Role of Drag in Performance

The increasingly competitive nature of the aircraft industry is forcing the designer to guarantee the performance of a new aircraft at an ever earlier stage in its design. The performance of an aircraft is very dependent on its drag which, for the most aerodynamically efficient design, needs to be as small as possible for a given configuration and flight condition. For a transport aircraft low drag is important for good fuel efficiency which, in an era of increasing fuel cost, contributes very significantly towards the maintenance of low operating cost. For a combat aircraft even very small reductions in drag can translate into what might be crucial improvements in performance.

2.2 Definition of Excrescence Drag

The ideal aircraft has an aerodynamically smooth^{*}, continuous exterior surface which is by definition sealed against air leakage through any part of its boundary. A carefully prepared wind-tunnel model (but without representative flying controls) provides a close approximation to that ideal. The drag of the ideal aircraft at any angle of attack would be dependent on the flight conditions of Mach number and Reynolds number which, given an aerodynamically smooth surface, govern the extent of laminar flow on each airframe component. In practice, the constraints of economic manufacturing techniques, the necessity for control clearances, the installation of external communications antennae and the provision of inlets and outlets for cooling air are typical factors that conspire against the attainment of the ideal aircraft. Each of these practical considerations leads to a component of drag additional to that of the ideal aircraft. The total of such components is commonly called the “excrescence drag” for the aircraft. The term “excrescence drag”, as used here, is one that is all-embracing and includes the drag due to such things as pressurisation leaks, leaks due to unsealed control gaps and momentum changes in the flow of air through a flush inlet, the internal system and its related outlet. An alternative to “excrescence drag” is the term “parasite drag”. This is not used here, however, as it has historical associations with the drag due to those sources other than the lifting surfaces. In that context the total fuselage and nacelle drags would be considered as parasite drag, for example.

2.3 Significance of Excrescence Drag

Excrescence drag is an important contribution to the total drag since it is in an area over which the designer does have a large measure of control by careful detail design, in spite of the manufacturing constraints. Indeed, because of its importance it is an area to which the industry, both in research and manufacturing (Reference 12, for example), has paid an increasing amount of attention in recent years. The reason for this is obvious when the penalties of poor design are considered.

Many studies concerning excrescence drag have been made over the years (References 2, 3 or 6, for example). A useful comprehensive survey of the information available on the drag due to surface imperfections is given in Reference 13. Although many studies concerning specific aircraft have been carried out within individual companies, it is understandable that only a few of these are widely available.

Reference 5 presents a review of three turbo-jet powered combat aircraft typical of the 1960s and shows that the excrescence drag varied between 10% and 20% of the total drag at subsonic speeds. A similar exercise carried out on two World War II piston-engined aircraft (Reference 11) provides a graphic illustration of the particularly severe penalties that can arise from cooling flows, unsealed controls and extraneous items of ancillary equipment. With regard to transport aircraft, a breakdown of various sources

^{*} Recent research has indicated that even with surfaces that can be classified as aerodynamically smooth (*i.e.* with roughness height less than the laminar sub-layer thickness) use of regular roughness in the form of longitudinal grooves (riblets) ideally aligned with the local flow can produce significant reductions in turbulent boundary-layer skin friction below that for a smooth surface.

of drag on a number of aircraft in Reference 9 indicates an excrescence drag contribution varying from 15% to 24% of the profile drag in the cruise, which could represent a variation of as much as 9% to 14% of the total drag (for a cruise speed about 20% above minimum drag speed). Although the aircraft surveyed in Reference 9 date from the 1960s, or earlier, figures for excrescence drag of about 10% of the total cruise drag are typical of all but the most recent generation of transport aircraft. In summary, various studies show that excrescence drag can be very significant if no special attention is paid to the problem at the design stage. The current view is that by close attention to detail-design and manufacturing tolerances, an excrescence drag below 5% of the total cruise drag should be attainable, at least for high-speed subsonic transports; and indeed this is essential for competitive operation. In order to tackle the problem the designer needs to know the penalties of poor design, and to this end a set of Data Items is available for predicting excrescence drag, see Section 3.2.

In order to achieve the excrescence drag target the manufacturer usually compiles a set of standards (often called something like “aerodynamic smoothness requirements”) to be adhered to in the construction of any new aircraft. These standards relate to the detail-design principles to be adopted in certain critical, or sensitive, areas of the airframe, within which excrescences cause the greatest amount of drag. Such areas are generally characterised by thin boundary layers and/or large local velocities and so include those parts of lifting surfaces (*e.g.* wings, tailplane, fin) around, and ahead of, areas of minimum pressure, the forward parts of non-lifting surfaces (*e.g.* fuselage, nacelles) and areas in which interference flows are present (*e.g.* lifting surface/fuselage junctions, pylons).

3. PREDICTION OF EXCRESCENCE DRAG

If the aircraft under consideration by the manufacturer is very similar in design and performance to its immediate predecessor (a “stretched” version, for example) for which an accurate assessment of excrescence drag is available, then it is quite common practice to base the estimate for the new aircraft on that value as a starting point. There are, of course, risks of error in such an exercise and it may be deemed prudent to repeat the full procedure; this would certainly be necessary for a radically different design. Currently, the only practical method for a new design is an empirical one in which the drag increments for each excrescence are estimated and summed for the whole aircraft.

3.1 General

The prediction process in broad outline involves, firstly, the use of correlations of wind-tunnel data for the drag of a range of idealised excrescence forms mounted on a flat plate (so that the velocity outside the boundary layer is constant and the pressure distribution is therefore uniform). Secondly, it is required to provide some allowance for non-uniform pressure distribution; and thirdly, a further allowance for any effects related to the differences between the wind-tunnel model for the excrescence, including its orientation in the flow, and the actual excrescence on the aircraft. Furthermore, the local flow conditions and boundary-layer data at the excrescence location, but in the absence of the excrescence, are required. Also, the basic flat plate data for the various idealised excrescences are by no means comprehensive. Indeed, for certain types of discrete excrescence, and especially proprietary items such as specialised fasteners and some antennae, recourse might have to be made either to manufacturers’ data, if available, or to specially commissioned wind-tunnel tests. A rigorous application of the method to a complete aircraft is a very difficult and time-consuming process, often calling for many approximations in order to achieve a result.

In summary, because of these difficulties, it is not currently possible to provide a detailed method for application to all aircraft. All that can be provided is an outline scheme that in principle is capable of application to any type of excrescence provided that sufficient data are available.