

INFORMATION ON THE USE OF DATA ITEMS IN THE SERIES WINGS 02.04.

Data Item Nos Aero W.02.04.01 to 03 deal with the calculation of profile drag of aerofoils at low C_L . That part of the total drag that depends on lift is not dealt with here (but see Item No. 66031).

Profile drag, which derives from the presence of the boundary layer, is sometimes divided into two components. These are: boundary layer normal pressure drag (or form drag) which results from the change in the pressure distribution due to the effective modification of the aerofoil shape caused by the presence of the boundary layer, and surface friction drag which is the resultant in the drag direction of the shear stresses at the surface of the aerofoil.

Surface friction drag is dependent upon the conditions of the flow, and in general is very much less when the flow in the boundary layer is laminar than when it is turbulent.

Laminar boundary layer flow is most readily maintained by a continuously falling pressure. This is the state of affairs at the nose of an aerofoil, and the so-called low drag or laminar flow aerofoils extend this falling pressure as far back as possible along the chord at the chosen lift coefficient, called the design lift coefficient. This leads to sections for which the maximum thickness is far back.

To calculate the profile drag accurately, the pressure distribution around the aerofoil must be known; it is found, however, that for a given type of section a good estimate is obtained by multiplying the drag of a flat plate at zero incidence by a factor depending on the type of section, the position of the transition point and the thickness/chord ratio. Item Nos Aero W.02.04.01, 02 and 03 give the drag coefficients of flat plates and the multiplying factor for various types of aerofoil section (conventional, low-drag convex, low-drag cusped and low-drag with straight trailing edges). The effect on the profile drag of varying trailing-edge angle and position of maximum thickness independently has not yet been calculated over a sufficient range to enable Data Items to be produced.

To use the Items, the mean position of the transition points on the upper and lower surfaces must be known. Knowledge of the pressure distribution for the aerofoil is desirable, since transition will occur in the most favourable cases slightly downstream of the first minimum pressure peak, the aerofoil being assumed to be aerodynamically smooth and free from waviness. Turbulent flow will tend to shift the transition point forward. Failing a knowledge of the pressure distribution, the assumption of transition at the point of maximum thickness will be conservative for low-drag aerofoils at the design lift coefficient. At other than the design lift coefficient, the pressure distributions will be modified but low-drag properties will be maintained in many cases over a lift coefficient range that will vary from 0.1 on either side for thin aerofoils to 0.3 on either side for moderately thick aerofoils. It should be noted that a very high standard of freedom from waviness, skin joints, and contamination from dust, flies, *etc.*, is required if these values are to be achieved. Outside this range the drag of all aerofoils should be calculated on the assumption of mean transition point at, say, the leading edge or 0.1 of the chord from the leading edge.

Item Nos Aero W.02.04.01, 02 and 03 apply only to aerodynamically smooth surfaces. Some degree of roughness or waviness may exist without increase in drag; Item Nos 73016 and Aero W.02.04.11 give the best available information as to permissible limits. Both roughness and waviness may increase drag by causing a breakdown of laminar flow; roughness exceeding the permissible limit will increase the drag in turbulent flow, apart from any increase due to change in transition point.

It is desirable here to remark in more detail on the limitations and assumptions of the Items dealing with surface roughness. They are based on certain hypotheses given in the References to the Items, and on the classic experiments of Nikuradse on pipes roughened with sand grains, these experiments being the only comprehensive series on roughness that have as yet been made. There are certain difficulties however in drawing general conclusions from these tests. There are experiments on flat surfaces by Schlichting (Ingenieur-Archiv), which give some support to the deductions made from Nikuradse's work. From an aerodynamic point of view the boundary layer thickness and the height from trough to crest of the particles when stuck to the surface are the important parameters. Nikuradse defined the roughness in terms of the grain size, and showed that the grain size in his experiments was in fact equal to the height from trough to crest.

In the case of isolated particles, the effective grain size is the height of the individual particles above the smooth surface; but in the case of, say, camouflage paint it will not be safe to assume that the effective roughness height is equal to the size of its grains. On a painted surface there will usually be a wide variation in the height of the excrescences, which will not be that of the grains of the paint. Tests have been carried out to establish an equivalent roughness height (see Item No. 73016) for such surfaces, and the results and methods to obtain an equivalent roughness height for a given surface are given in RAE Rep. Aero 1977 (1944). Since the tests were made on the surface of a wing alone, the possibility of interference effects being enhanced by roughness was not investigated.

Item No. 73016 defines the limit of roughness that has no effect on flat plate mean skin friction in turbulent flow and allows the increase in skin friction drag to be calculated if the limit is exceeded.

The maximum roughness that will have no effect on the transition point is defined in Item No. Aero W.02.04.09. If this value is exceeded the transition point will move forwards towards the nose of the aerofoil or body. The equivalent limit for waviness is given in Item No. Aero W.02.04.11 and if this limit is exceeded it should be assumed that transition takes place at the most forward wave that exceeds the limit.

Little information is available on the interaction of surface waviness and roughness. The effect is likely to be small unless one of these approaches the limit and the other is appreciable, in which case some movement of the transition point may be expected.

An examination of Item Nos Aero W.02.04.09 and 73016 indicates that the limiting grain size affecting drag in turbulent flow is roughly one fifth of that causing movement of the transition point. In cases where the former limit is exceeded the increase in skin friction drag can be calculated from Item No. 73016 but, where both are exceeded, allowance should also be made for the movement of the transition point. However, it should be noted that it is the average height of the grains that affects the skin friction drag in turbulent flow but the maximum height that determines the transition point. A small number of comparatively large excrescences can therefore cause an increase in drag due to transition point movement, although their effect on turbulent flow skin friction drag is small.

The effects on the drag of a flat plate due to small surface imperfections (excrescences) such as grooves, steps, ridges, cavities and rivets, together with other components such as circular cylinders, stub wings and half-body fairings are considered in a series of Data Items (Nos 74036, 75028, 75031, 76008, 83025 and 84035). The effects of non-uniform pressure distribution are dealt with by means of drag magnification factors calculated by the method of Item No. 91028. For wings with controls, the drag due to control gaps and the effect of sealing is considered in Item No. 92039. Practical examples of the application of the data to the prediction of the excrescence drag of typical wing components on a subsonic transport aircraft at the cruise condition are given in Item No. 93032.