

LIMIT OF SURFACE WAVINESS FOR LAMINAR FLOW OVER WINGS

1. NOTATION AND UNITS

		SI	British
b	wave length measured along profile parallel to plane of symmetry	m	ft
h	height of wave (trough to crest) measured normal to undistorted surface	m	ft
l	length of laminar boundary layer on undistorted surface measured parallel to chord	m	ft
R_l	Reynolds number based on length of laminar boundary layer, $U_1 l / \nu$		
U_1	local velocity outside boundary layer at position of wave crest but on undistorted surface	m/s	ft/s
ν	kinematic viscosity	m ² /s	ft ² /s

2. NOTES

The limiting value of the ratio of wave height to wave length, h/b , for the transition position to be unaffected by the wave in the surface is plotted in Figure 1 against Reynolds number, R_l , for various values of l/b .

The curves were derived (Derivation 1) from the formula

$$\frac{h}{b} = 9 \times 10^6 R_l^{-3/2} \left(\frac{l}{b} \right)^{1/2} \quad (2.1)$$

and apply strictly to a wave at a distance l from the leading edge. For a wave situated forward of this point, the critical value of h/b should be reduced in the ratio (wave distance from leading edge/ l)^{1/4}, according to theory, due to the fact that the laminar boundary layer is thinner towards the leading edge. However, because of the greater inherent stability of the laminar flow towards the leading edge due to the favourable effect of positive pressure gradient and the smaller Reynolds number of the boundary layer, this relation is unlikely to apply in practice. As a first approximation it is therefore suggested that the curves be used for waves anywhere in the laminar flow region except over the first ten per cent of the chord, where smaller tolerances are possibly required.

The Item is applicable to single ridges, hollows or waves in the laminar boundary layer on the upper or lower surface of an otherwise aerodynamically smooth wing. If several waves are present each one should be treated separately.

3. DERIVATION

1. FAGE, A. The smallest size of a spanwise surface corrugation which affects boundary layer transition on an aerofoil.
ARC R & M 2120, 1943.

4. EXAMPLE

Determine the maximum permissible height of a bulge of wave length 0.025 m in the laminar part of the boundary layer on the upper surface of the low-drag wing of chord 2 m of an aircraft designed to fly at 260 kt at a height of 3000 m ($v = 18.62 \times 10^{-6} \text{ m}^2/\text{s}$). The transition position is at 0.3 chord and the local velocity at the position of the bulge is 1.12 times the free-air velocity.

$$U_1 = 1.12 \times 260 \times 0.5144^* = 149.8 \text{ m/s}.$$

$$U_1 l = 149.8 \times 0.3 \times 2 = 89.88 \text{ m}^2/\text{s}.$$

Hence,
$$R_l = \frac{U_1 l}{v} = \frac{89.88}{18.62 \times 10^{-6}} = 4.83 \times 10^6.$$

Now
$$\frac{l}{b} = \frac{0.3 \times 2}{0.025} = 24.$$

Thus, from Figure 1, for $R_l = 4.83 \times 10^6$ and $l/b = 24$, $h/b = 0.00415$.

Therefore $h = 0.00415 \times 0.025 = 0.000104 \text{ m}$.

Thus, for a wave of length 0.025 m, the maximum height in order that the transition position may not be affected is approximately 0.1 mm.

* Factor to convert from kt to m/s.