9.26

9.26 An airplane flies at a speed of 400 mph at an altitude of 10,000 ft. If the boundary layers on the wing surfaces behave as those on a flat plate, estimate the extent of laminar boundary layer flow along the wing. Assume a transitional Reynolds number of $Re_{xcr} = 5 \times 10^5$. If the airplane maintains its 400-mph speed but descends to sea level elevation, will the portion of the wing covered by a laminar boundary layer increase or decrease compared with its value at 10,000 ft? Explain.

At 10,000 ft:

(a) $Re_{x_{cr}} = \frac{U x_{cr}}{\nu}$, where $U = 400\,mph\left(\frac{1\,hr}{3600\,s}\right)\left(\frac{5280\,ft}{mi}\right) = 587\,\frac{ft}{s}$

and from Table C.1, $\nu = \frac{\mu}{\rho} = \frac{3.534\times10^{-7}\,\frac{lb\cdot s}{ft^2}}{1.756\times10^{-3}\,\frac{slug}{ft^3}}$

$= 2.01\times10^{-4}\,\frac{ft^2}{s}$

Hence, with $Re_{x_{cr}} = 5\times10^5$,

$$x_{cr} = \frac{\nu Re_{x_{cr}}}{U} = \frac{(2.01\times10^{-4}\,\frac{ft^2}{s})(5\times10^5)}{587\,\frac{ft}{s}} = \underline{\underline{0.171\,ft}}$$

At sea-level:

(b) $Re_{x_{cr}} = \frac{U x_{cr}}{\nu}$, where $U = 400\,mph\left(\frac{1\,hr}{3600\,s}\right)\left(\frac{5280\,ft}{mi}\right) = 587\,\frac{ft}{s}$

and $\nu = 1.57\times10^{-4}\,\frac{ft^2}{s}$

Hence,

$$x_{cr} = \frac{\nu Re_{cr}}{U} = \frac{(1.57\times10^{-4}\,\frac{ft^2}{s})(5\times10^5)}{587\,\frac{ft}{s}} = \underline{\underline{0.134\,ft}}$$

The laminar boundary layer occupies the first 0.134 ft of the wing at sea level and (from part (a) above) the first 0.171 ft at an altitude of 10,000 ft. This is due mainly to the lower density (larger kinematic viscosity). The dynamic viscosities are approximately the same.

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