Non-dimensional treatment of thrust (page 83):

The net thrust is determined by:

$$F_N = F_G - \dot{m}_a V$$

Now the flight velocity is independent of the engine operation and so we should concentrate on the gross thrust (Eqn. 8.2):

$$F_G = \dot{m}_a V_j = \dot{m}_a V_{19} + (p_{19} - p_a) \times A_N$$

This can be rearranged as (Eqn. 8.3):

$$F_G + p_a \times A_N = \dot{m}_a V_{19} + p_{19} \times A_N$$

The right-hand side is comprised of terms ($\dot{m}_a$, V_{19}, p_{19}, and A_N) which, because the exit nozzle is choked, are purely set by the aeroengine operation.

Thrust is a force so can be best made non-dimensional by $D^2 p_{02}$ (**NOT** $D^2 p_a$).

Engine parameters can be expressed in terms of non-dimensional fuel flow (page 84):

$$\frac{F_G + p_a A_N}{D^2 p_{02}} = \frac{\dot{m}_a V_{19} + p_{19} A_N}{D^2 p_{02}} = \text{function}\left(\frac{\dot{m}_f \, LCV}{D^2 p_{02}\sqrt{C_p T_{02}}}\right)$$

Hence, non-dimensional "corrected" gross thrust (page 79):

$$\frac{F_G + p_a A_N}{D^2 p_{02}} = \text{function}\left(\frac{\dot{m}_f \, LCV}{D^2 p_{02}\sqrt{C_p T_{02}}}\right) = \text{function}\left(\frac{T_{04}}{T_{02}}\right) = \text{function}\left(\frac{ND}{\sqrt{\gamma R T_{02}}}\right)$$

The above allows the "corrected" gross thrust to be determined, once the non-dimensional engine operating point is known.

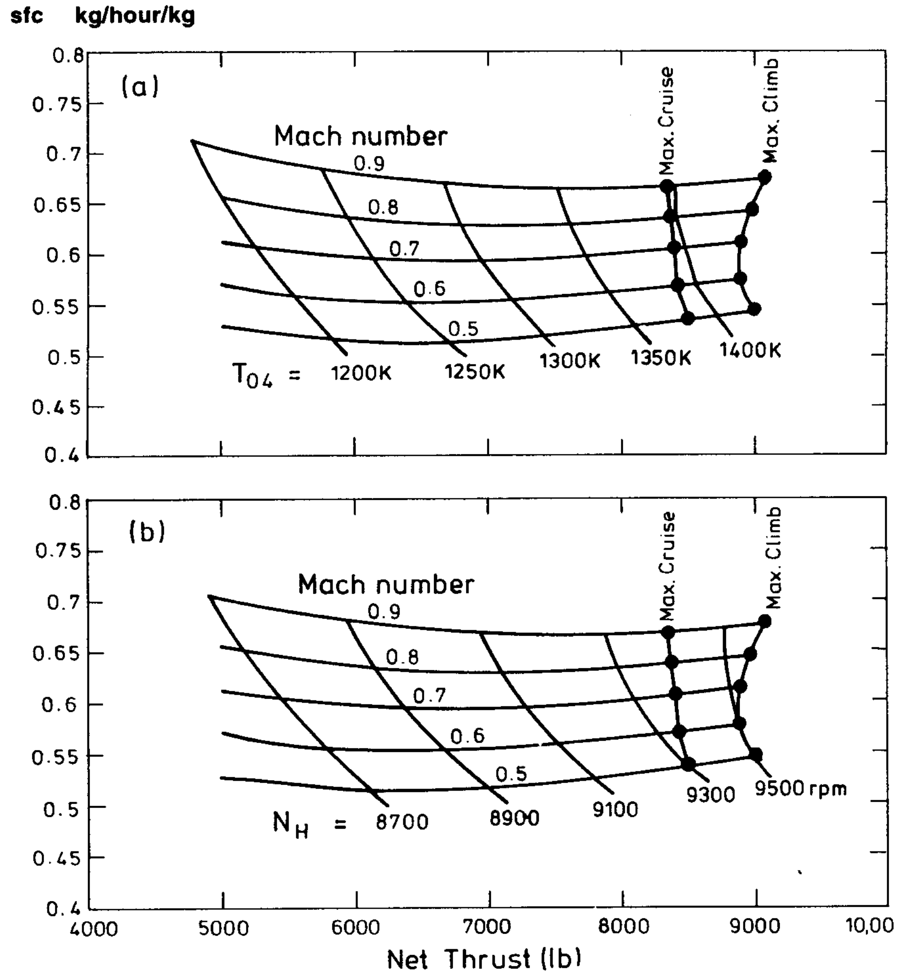
If the flight conditions are known (V and p_a) then the net thrust may be calculated:

$$F_N = F_G - \dot{m}_a V$$

Net thrust and sfc relationship (page 85, fig 8.2):

As confirmation that the above scaling arguments are correct, the relationship between sfc and net thrust is plotted as a function of turbine inlet temperature (T_{04}) and as a function of the high-pressure shaft speed (N_H).

The plots are similar confirming the above arguments.



Loss of one engine at take-off (four engines down to three) (page 88):

At take-off:

$L/D \approx 10.0$, $\sin\theta = 0.03$, mass = 636×10^3 kg

$$F_N = \left(\frac{1}{L/D} + \sin\theta\right)\times W = (0.1 + 0.03) \times 636\times10^3 \times 9.81 = 811 \text{ kN}$$

Each of three remaining engines must produce a net thrust of:

$$F_N = 270 \text{ kN}$$

At cruising condition ($T_{04}/T_{02} = 5.6$) the non-dimensional thrust is:

$$\frac{F_G + p_a \times A_N}{p_{02} \times A_N} = \frac{207.3\times10^3 + 28.7\times10^3 \times 3.14}{46.0\times10^3 \times 3.14} = 2.06 \text{ (no units!)}$$

Cruising condition represents a “safe” maximum (provided T_{04} is acceptable).

At take-off (sea level, 90 m/s, $T_{04}/T_{02} = 5.6$) (page 88):

$T_a = 288$ K, $p_a = 101.3$ kPa, $T_{02} = 292.0$ K, $p_{02} = 106.3$ kPa, $\dot{m}_a = 1121.4$ kg/s

Hence:

$$F_G = 2.06 \times p_{02} \times A_N - p_a \times A_N$$

$$= 2.06 \times 106.3 \times 10^3 \times 3.14 - 101.3 \times 10^3 \times 3.14 = 369.5 \text{ kN}$$

Ram drag = $\dot{m}_a V$ = 1121.4×90 = 100.9 kN

Net thrust = gross thrust – ram drag = 369.5 – 100.9 = 268.6 kN

This is almost exactly the required thrust of 270 kN per engine.

Hence the four-engined plane has no problems if one engine fails during take-off.

Loss of an engine during cruise (page 90):

As the weight remains fixed and the aircraft has the same L/D ratio, the drag remains the same: Total thrust unchanged!

Each engine must produce more net thrust:

$$F_N = F_G - \dot{m}_a V$$

So, the flight speed must be reduced.

To maintain the optimal lift coefficient:

$$C_L = \frac{L}{\frac{1}{2}\rho A V^2} \quad \text{ie} \quad \rho V^2 = \text{constant}$$

The aircraft must descend to increase the ambient density.

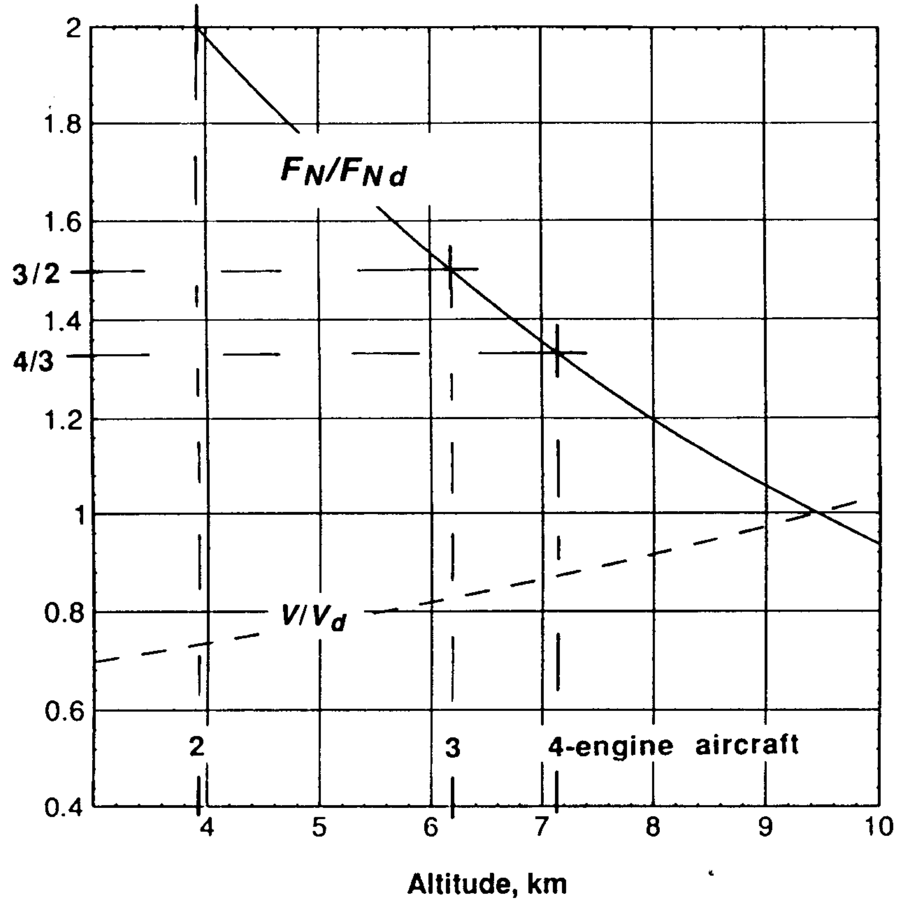


Fig 8.3

Two engined planes must descend further (page 91):

On a two-engined plane, the one remaining engine must produce twice the net thrust.

Hence the flight speed must be reduced more than for a four-engined aircraft.

Hence, two-engined planes descend further to gain a higher ambient density.

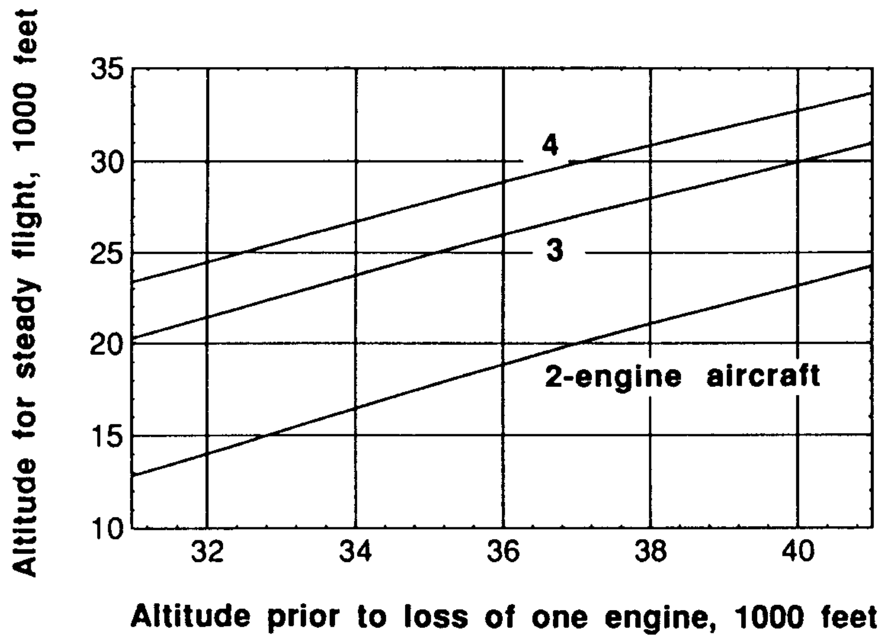


Fig 8.4

Problem: mountain ranges extend over 20000 ft!

Turbomachinery: compressors and turbines (page 94):

A turbomachine is a “steady flow” device (non-positive displacement) that converts between shaft-work and enthalpy by changing the tangential momentum of a fluid by passing it through stationary and rotating blade rows.

The blade row must provide the necessary flow turning to change the tangential momentum of the fluid:

The flow turning is related to work exchange (Δh_0).

The viscous effects within the boundary layers on the blade row generate entropy (a reduction in stagnation pressure) and leads to efficiencies that are less than 100%:

Blade boundary layers (irreversible flow) cause aerodynamic inefficiency.