

Single-shaft turbo-jet: RR Viper (page 48, fig 5.1)

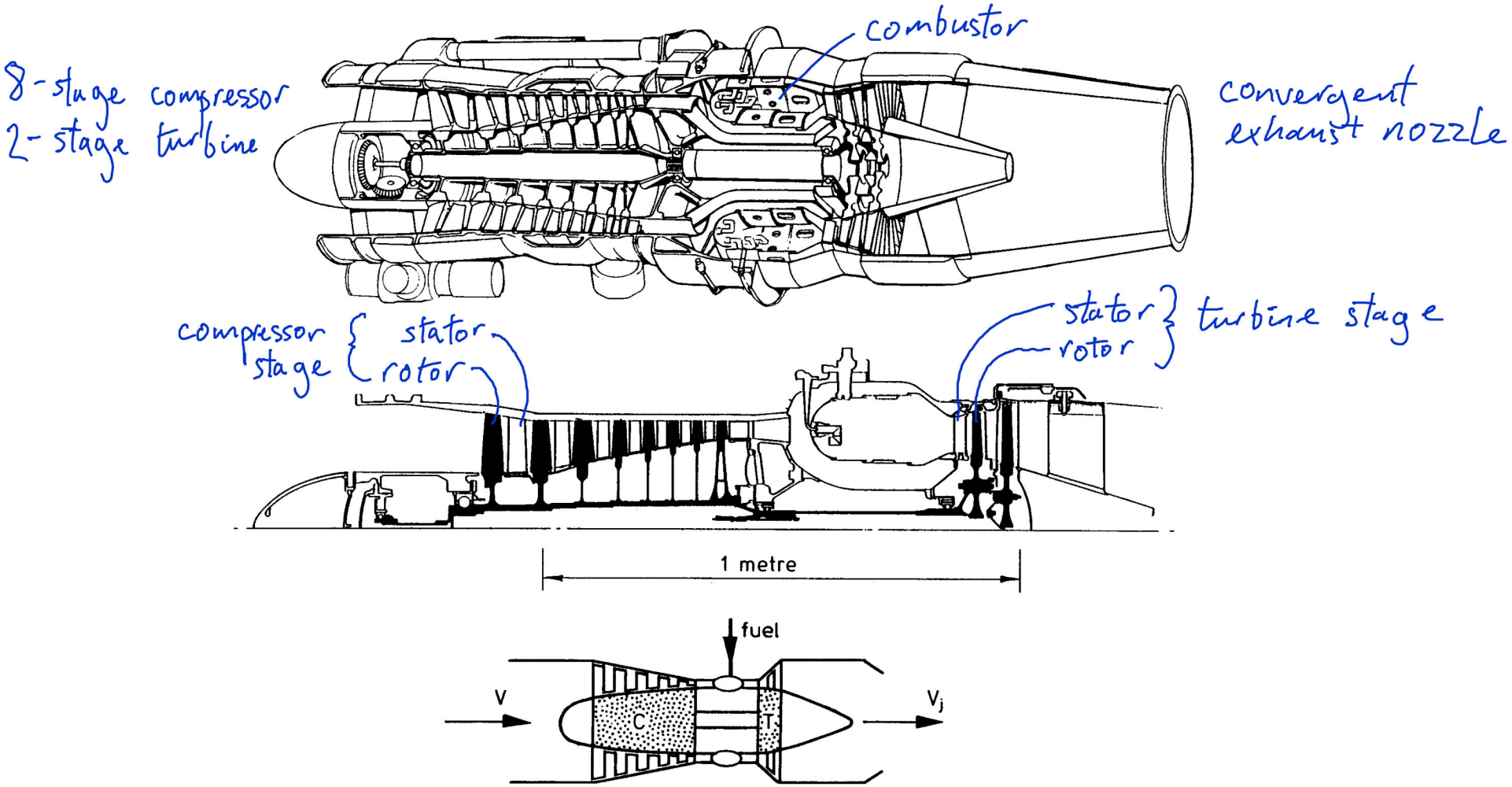


Figure 5.1. The Rolls Royce Viper Mark 601 single-shaft turbojet shown as a cut-away, in simplified cross-section and as a schematic

Two-shaft turbo-jet: RR Olympus 593 (page 48, fig 5.2)

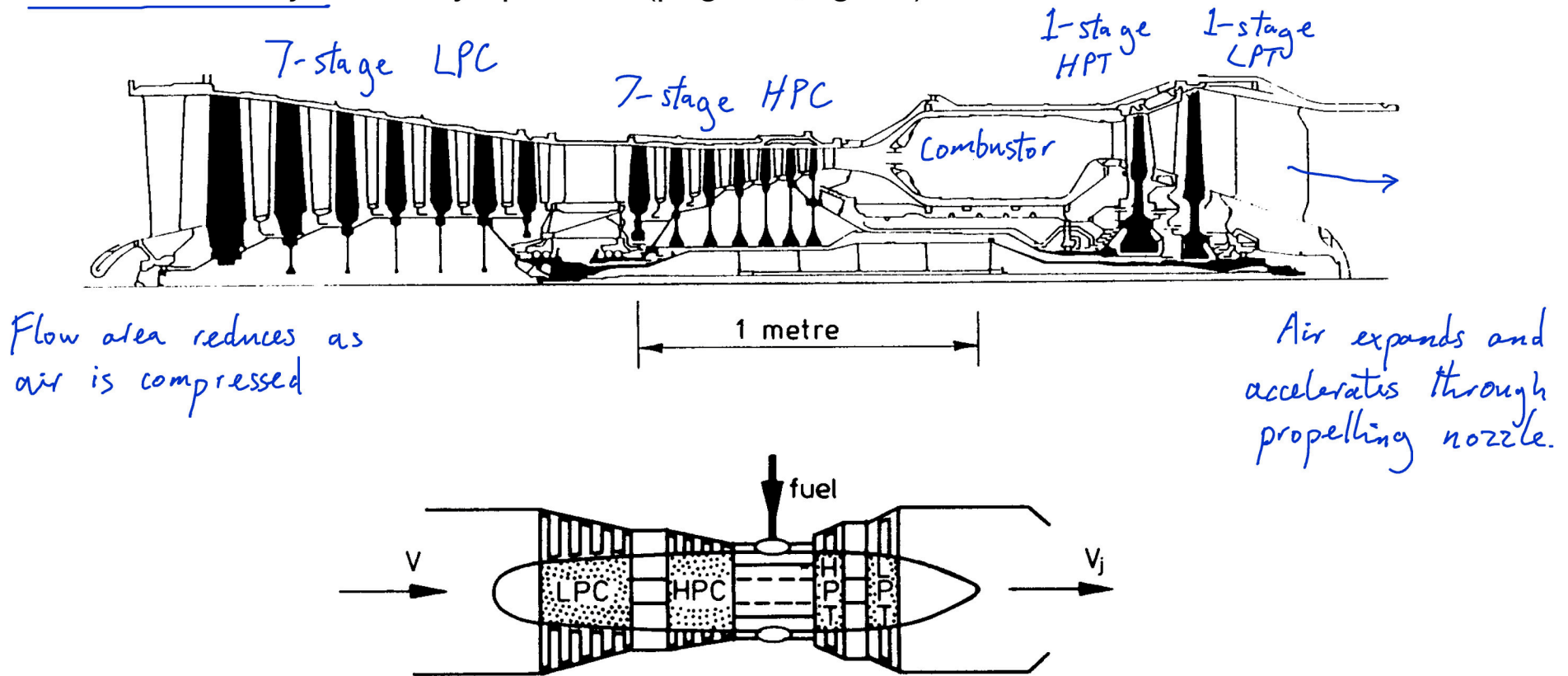
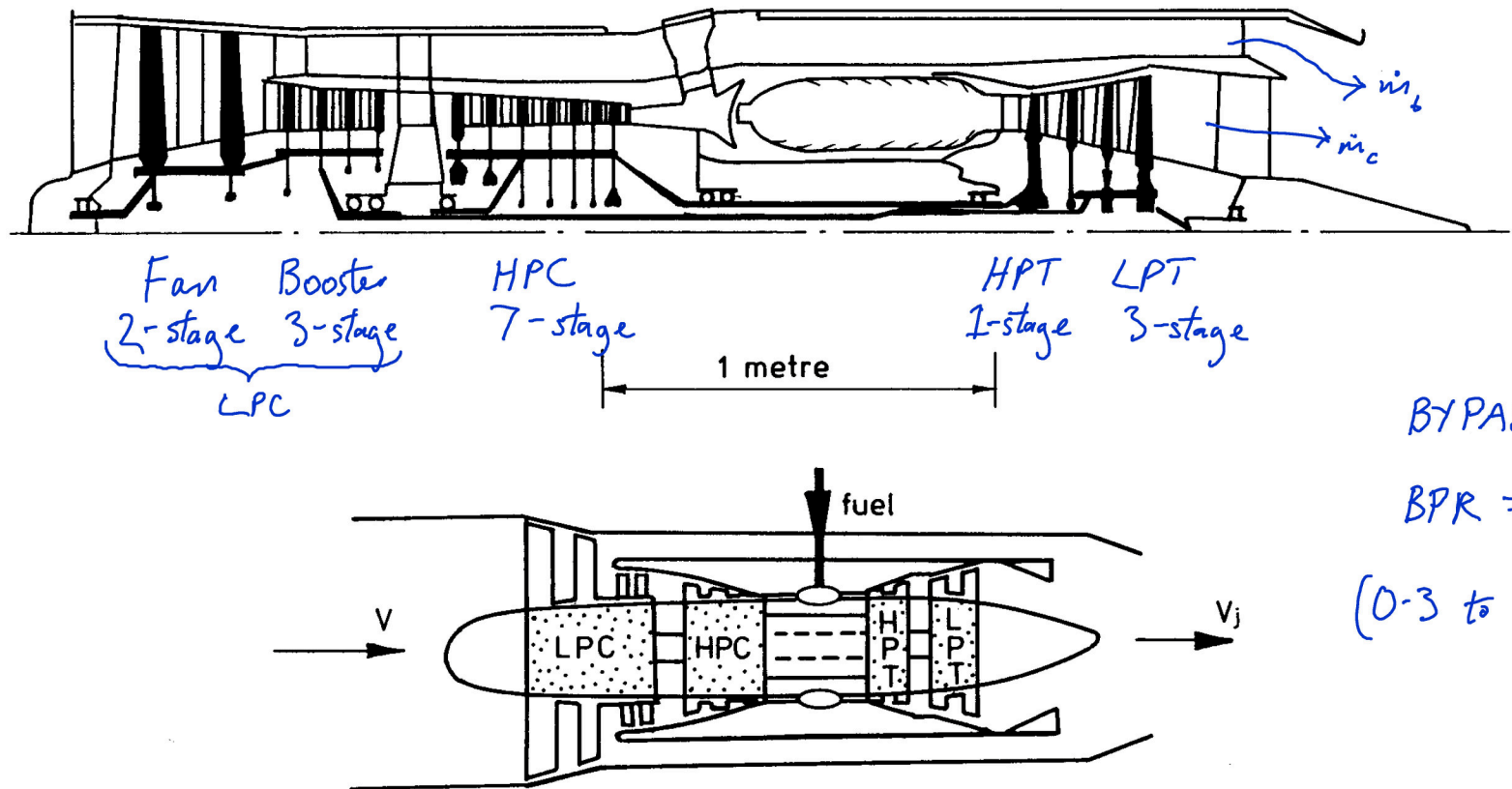


Figure 5.2. The Rolls Royce Olympus 593 shown as a simplified cross-section and as a schematic

Two-shaft low bypass ratio engine: P&W JT8D-1 Viper (page 49, fig 5.3)



BYPASS RATIO,  

$$BPR = \frac{\dot{m}_b}{\dot{m}_c}$$
 (0.3 to 1.5 here)

Figure 5.3. The Pratt & Whitney JT8D-1 shown as a simplified cross-section and as a schematic

The high bypass ratio engine (Chapter 5)

$$\eta_o = \eta_p \times \eta_{th}$$

Get high  $\eta_{th}$  by having high  $T_4/T_2$  and high pressure ratio.

$$\eta_{th} \approx 0.47 \text{ for } T_4/T_2 = 5.5 \text{ and } P.R. = 40$$

However:

Large work output.

⇒ High jet velocity for a simple turbojet.

High jet velocity gives a low propulsive efficiency.

For the NLA core cycle, (Exercise 4.4)  
 $V_j \approx 830 \text{ m/s}$  if all  $w_x \rightarrow \Delta KE$   
 $\Rightarrow \eta_p = \frac{2V}{V_j + V} \approx \underline{0.47}$

Hence the simple turbojet at subsonic flight speeds has poor overall efficiency.

$$\eta_o \approx 0.47 \times 0.47 = \underline{0.22}$$

Solution is to use a high bypass ratio engine where the large work output from the core is used to drive a large fan to give a low pressure rise, and hence low jet velocity, to a large flow of air.

Thus,  $\dot{m}_a \uparrow$  and  $(V_j - V) \downarrow$

High bypass ratio engine: Rolls-Royce Trent 884 (page 50, fig 5.4a)

3-shaft turbofan  
 $BPR = \frac{m_b}{m_c} \approx 6.0$

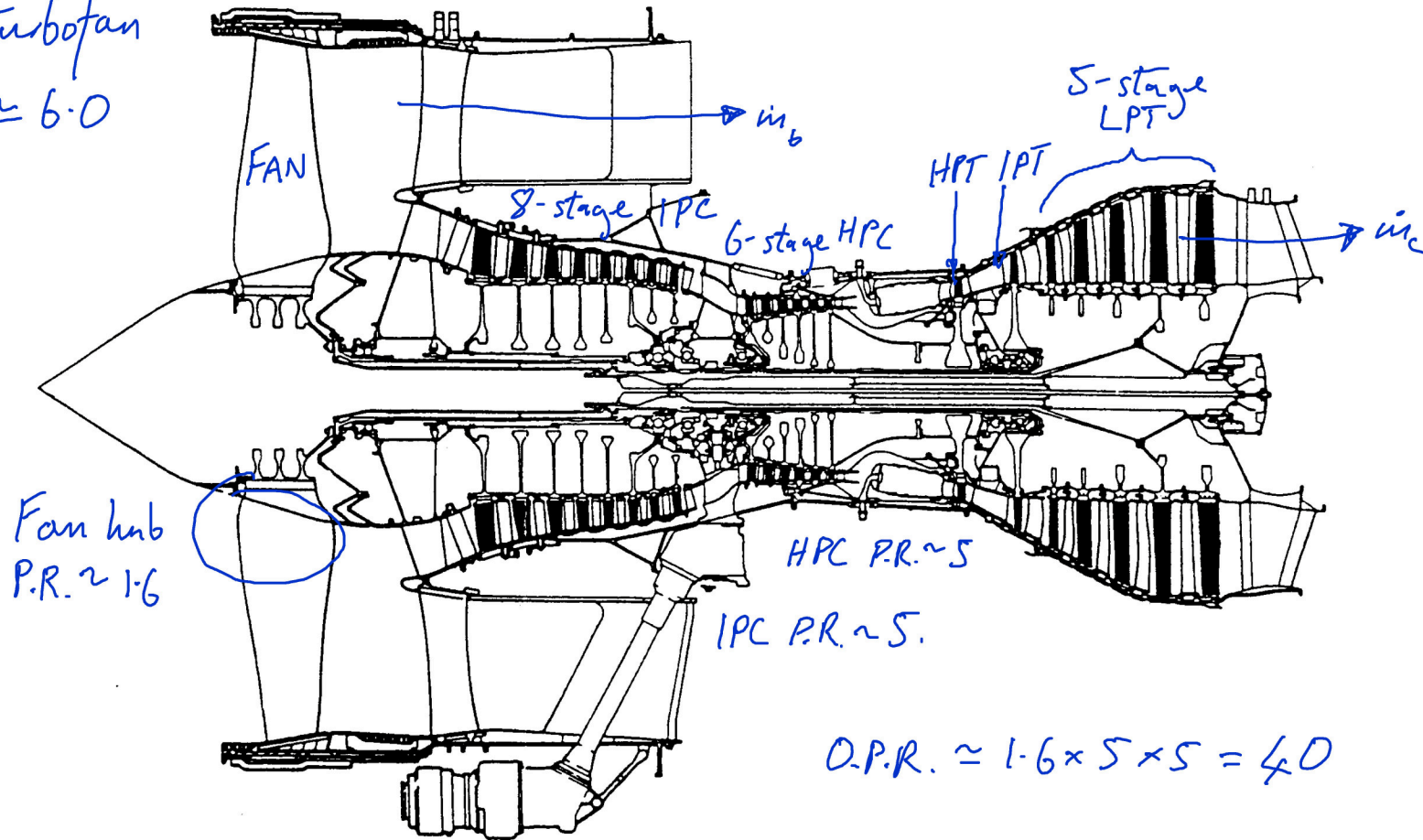


Figure 5.4(a) The Rolls Royce Trent 884  
 (Fan tip diameter 2.79 m)

High bypass ratio engine: Pratt & Whitney PW4084 (page 51, fig 5.4b)

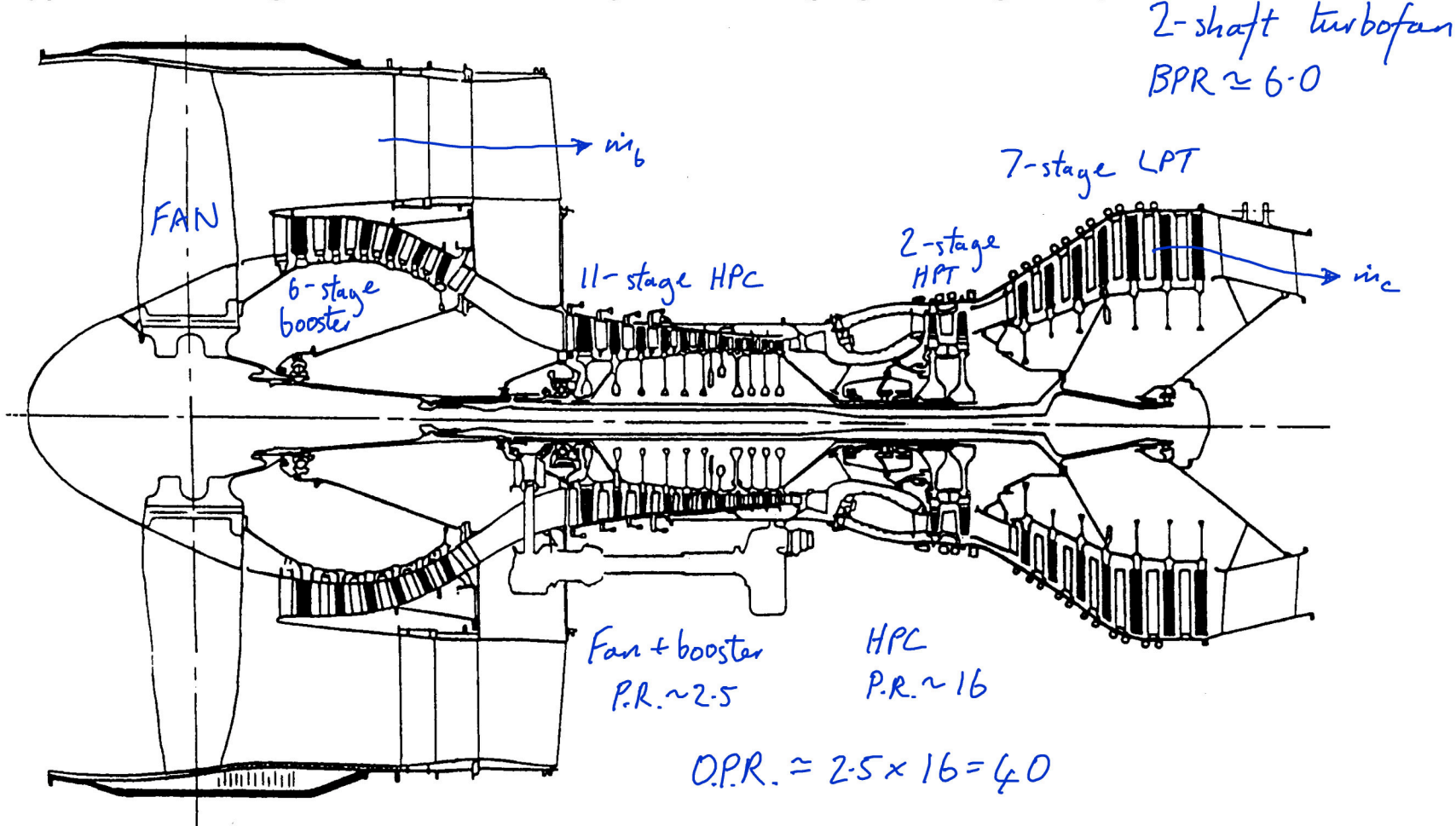


Figure 5.4(b) The Pratt & Whitney 4084 (Fan tip diameter 2.84 m)

High bypass ratio engine: General Electric GE90 (page 52, fig 5.4c)

2-shaft turbofan  
BPR  $\approx 9.0$

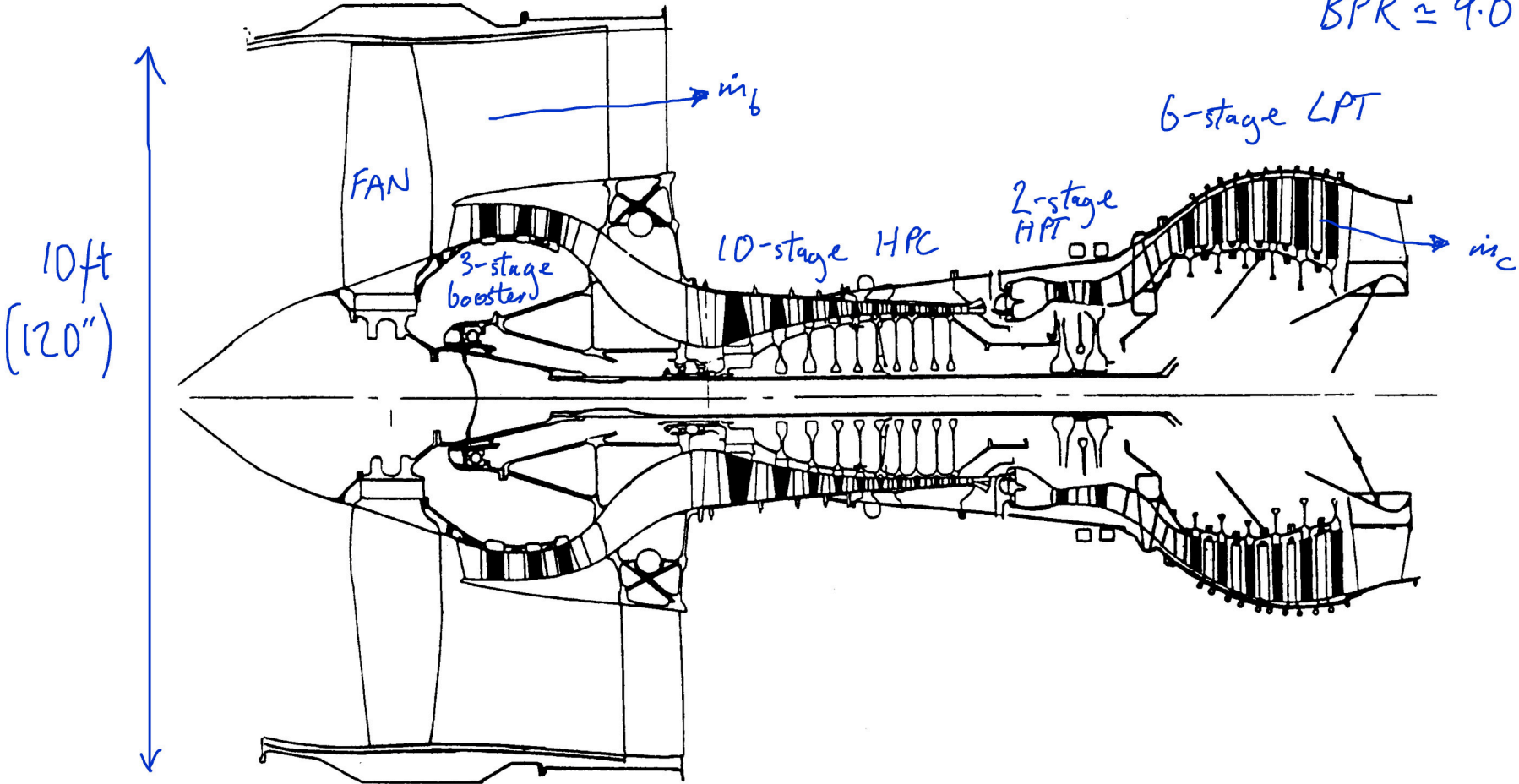
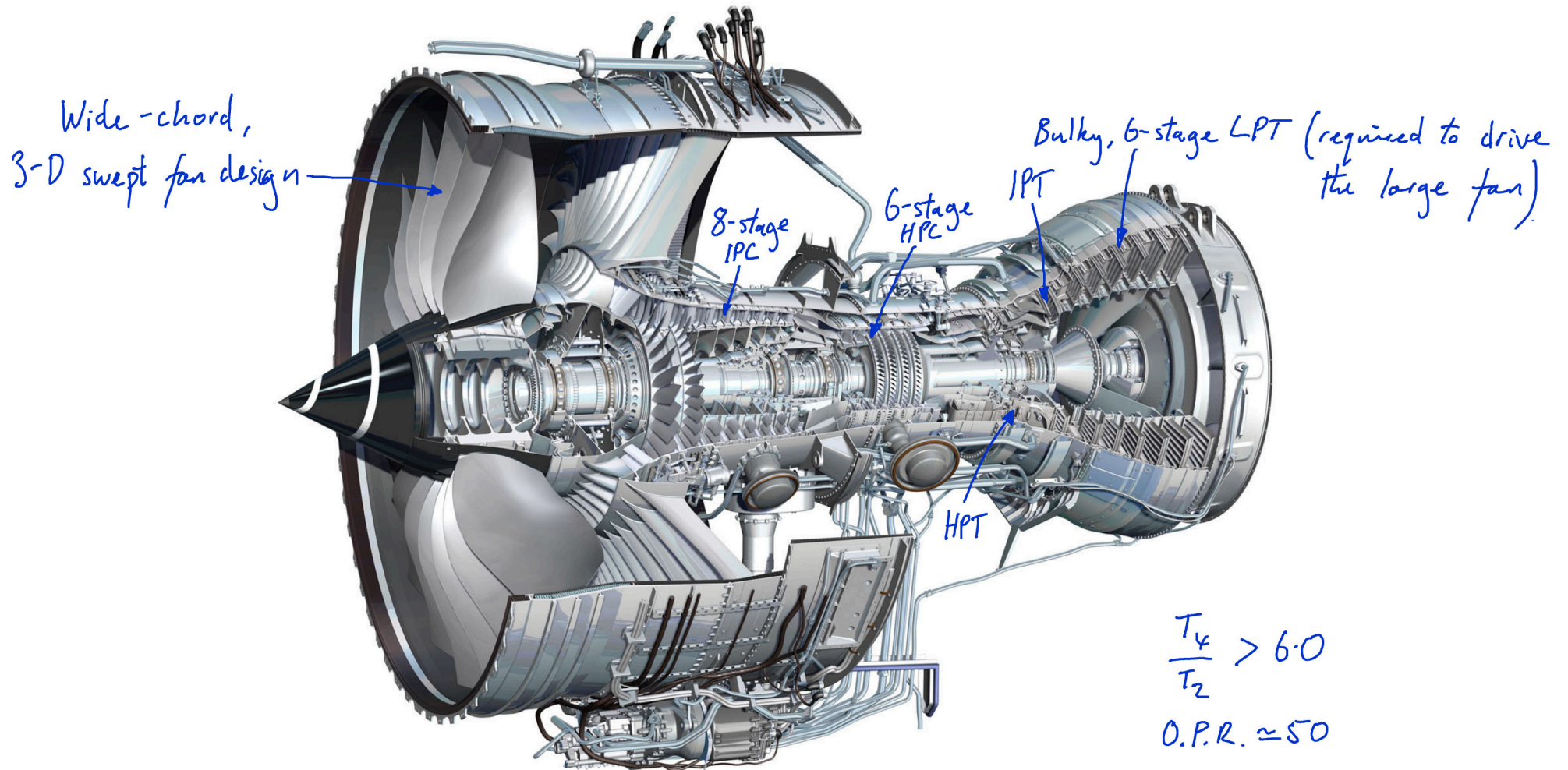


Figure 5.4(c) The General Electric GE90  
(Fan tip diameter 3.12 m)

The latest three-shaft high bypass ratio turbofan (from [www.rolls-royce.com](http://www.rolls-royce.com)):



Trent 1000 (BPR=11, fan tip diameter 2.85 m)

Turbine entry temperature (page 54-58):

*Engine temperature constraints*

Thermodynamically the ratio  $T_4/T_2$  is important in cycle efficiency. *(previous lecture)*

Value of  $\approx 5.5$  chosen for cruise design point.

However, blade life depends on the actual temperature  $T_4$  of gas.

*-since this determines creep.*

Take-off only lasts a few minutes so a far higher temperature can be allowed whilst cruise can last for several hours and must be well within creep limit.

Compressor and turbine inlet temperatures (page 55, table 5.1):

	$T_2$	$T_4$	$\frac{T_4}{T_2}$
Take off (sea level) (Most demanding <u>mechanical</u> )	288.2 K	1700 K <i>High Temp &lt; 5 min</i>	5.90
<i>(Max. non-dimensional thrust)</i> Top-of-climb (31000 ft, M=0.85) (Most demanding <u>aerodynamic</u> )	259.5 K <i>lower <math>T_2</math> at high altitude.</i>	1575 K	6.07 <i>Max. Temp Ratio</i>
Start of cruise (31000 ft, M=0.85) (Most demanding <u>thermodynamic</u> )	259.5 K	1450 K <i>lower Temp ~ 8 hrs / flight</i>	5.59

Blade melting  
point  $\approx 1550$  K

$\frac{T_4}{T_2}$  is an important  
 $T_2$   
non-dimensional group  
(see later)

Extensive cooling technology and complexity is required to achieve an acceptable blade life from the hot components (page 55, fig 5.5).

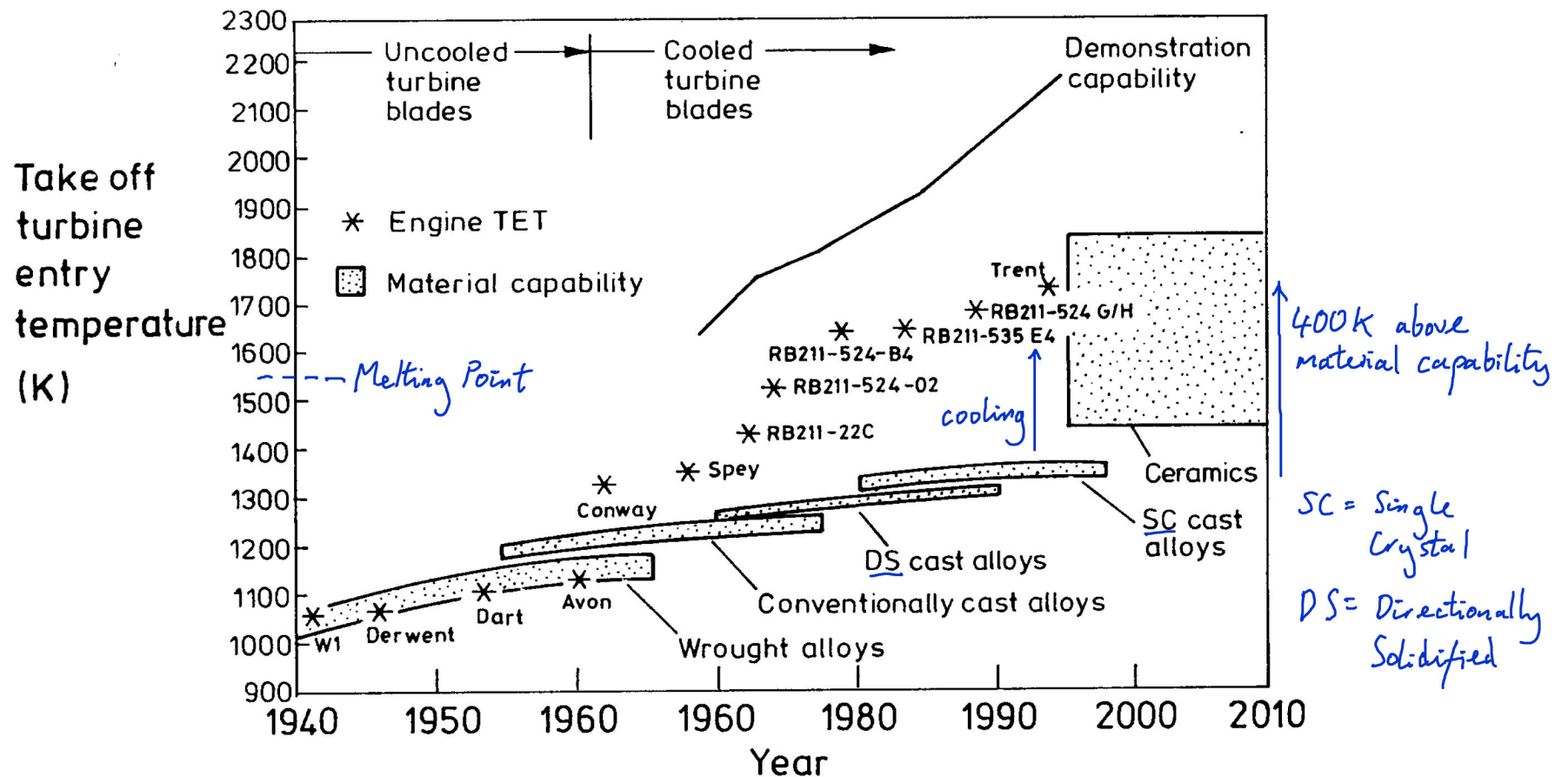


Figure 5.5. Rolls Royce high-temperature technology advances since 1940

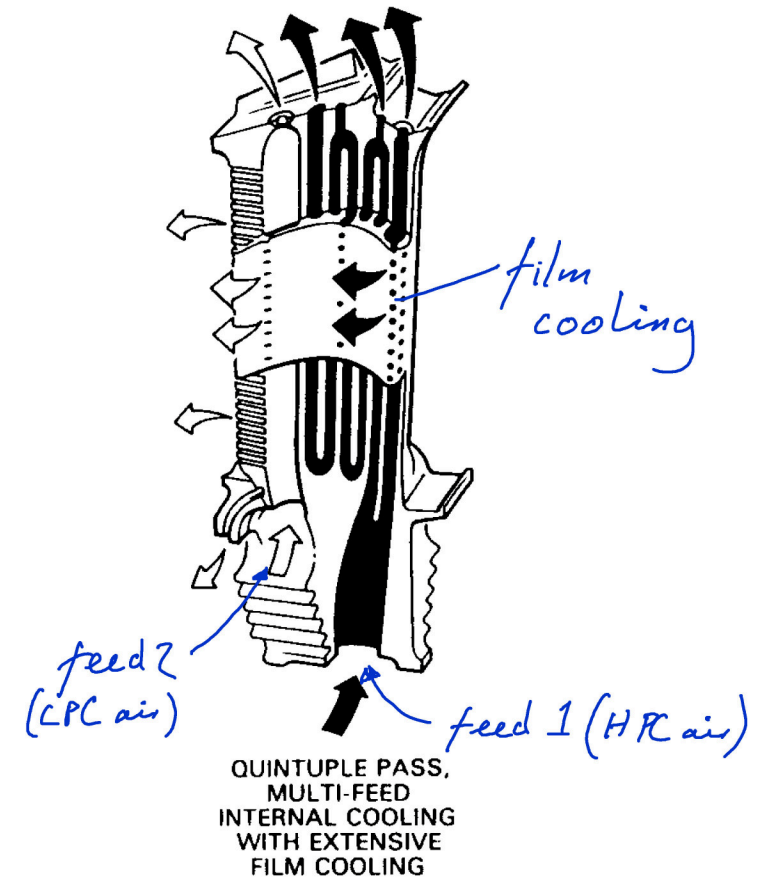
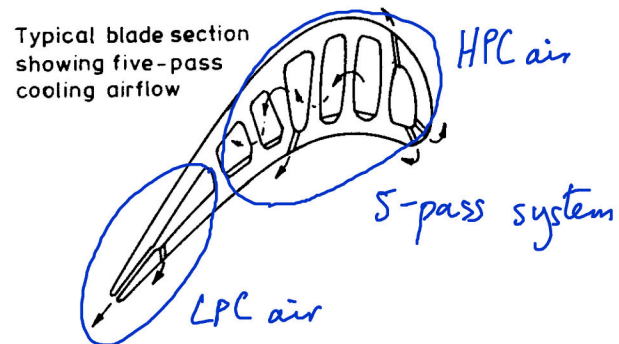
Blades have complex multiple-pass cooling passages (page 57):

*ROTOR*

Forged blades were replaced by cast blades.

Cast blades were replaced by directionally solidified blades where crystals aligned to give good strength.

Now entire blades are single crystal!



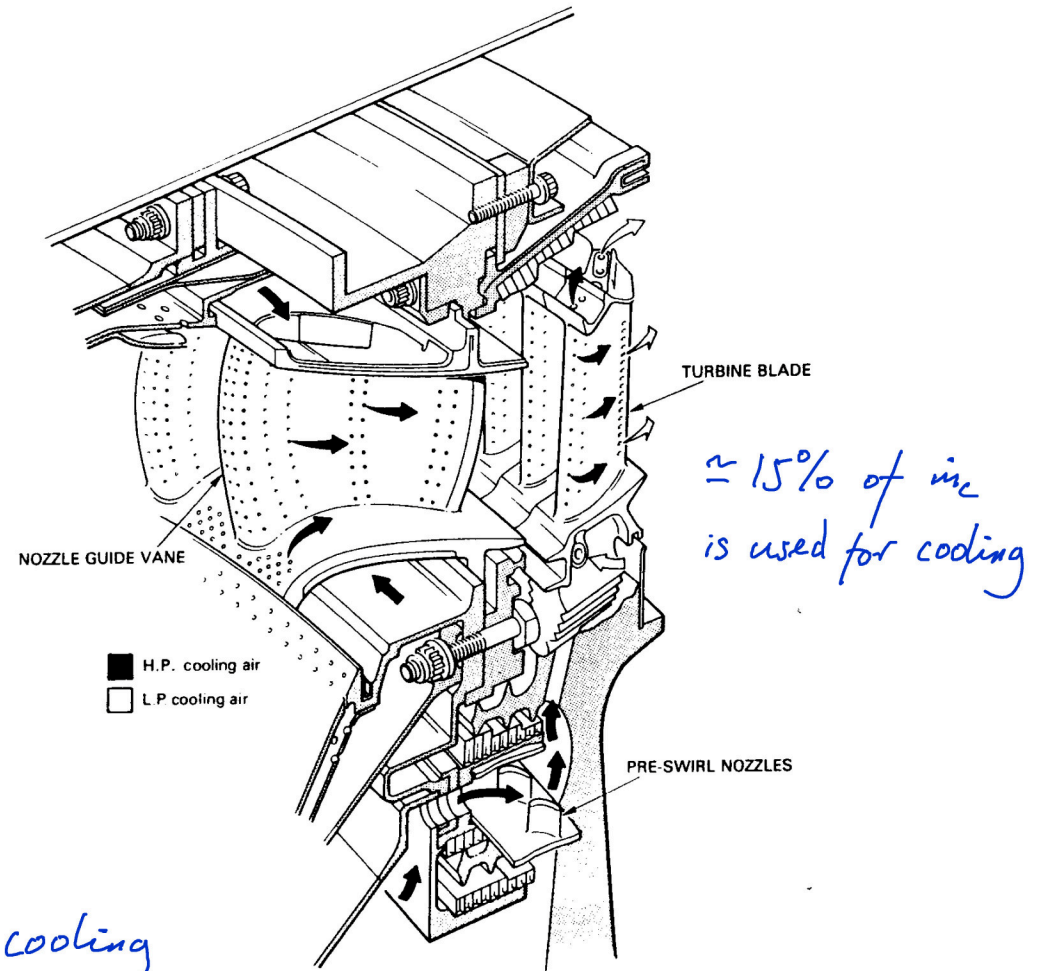
*Blade melts ~ 1550K*

*Air ~ 1700K at Take-off.*

Turbine blades include sophisticated cooling passages (page 57):

The cooling air must be at a high enough pressure to flow through the cooling passages. Thus the (relatively) cool air is taken from the compressor to provide just the correct pressure.

Here two different air supplies are used to minimise the efficiency loss associated with having to compress the cooling air.



*Trade-off: Amount of air used for cooling  
vs.*

*Increase in Turbine Entry Temperature ( $T_4$ )*