16.50 Propulsion Systems
Spring 2011

Quiz 2 May 18, 2011

Two hours, open book, open notes

TRUE-FALSE QUESTIONS

Justify your answer in no more than two lines.
4 points for correct answer and explanation
2-3 points for a correct answer with only partially correct explanation
1-2 points for an incorrect answer with some valid argument
0 for an incorrect answer with an incorrect explanation, or <u>any answer</u> with no explanation

Statement	True	False
1. For a turbojet, a high $\theta_t = T_{t4}/T_{t0}$ gives a high thermodynamic efficiency η_{th} at any compression ratio π_c.		
2. The pressure ratio of the turbine does not change when the pilot changes the fuel/air ratio f.		
3. If the throat area A_7 of a turbojet decreases due to some obstruction, the compressor operating line moves closer to the stall line.		
4. The bypass ratio α of a turbofan engine is fixed by the geometry, and does not change with operating conditions.		
5. For a fixed compressor face Mach number M_2, the cowl lip of a subsonic inlet would choke if its area A_1 were less than $\bar{m}_2(M_2)A_2$, where $\bar{m}_2$ is the non-dimensional flow factor.		
6. The Euler equation is only valid for ideal, isentropic flow.		
7. The stall line on a compressor map can be pre-determined by flow matching conditions even before the specific compressor has been selected.		
8. In a multi-stage turbine in which each stage has the same isentropic efficiency η_{stage}, the overall turbine isentropic efficiency η_T is greater than η_{stage}.		

9. The nitrogen oxides produced in the primary zone of a jet engine burner are largely destroyed by the cooler secondary air that is injected downstream.		
10. A quadrupole made up of four monopoles emits less acoustic power than would each of the monopoles separately.		

PROBLEM 1 (30 points)

The design of a certain turbofan engine is such that the turbine inlet temperature at takeoff on a standard day ($T_0 = 288\ K, P_0 = 1\ atm$ is $1650\ K$, and the compressor-face Mach number is $M_2 = 0.5$. The compressor is designed to provide maximum thrust at that condition. A set of such engines provides the required thrust (including margin) for takeoff of a passenger jet plane.

Consider now a "hot day" situation ($T_0 = 305\ K, P_0 = 1\ atm$) for the same plane, with the same load and at the same take-off Mach number. How will the following quantities change from their design values?:

- Thrust F
- Normalized thrust $\varphi = \frac{F}{P_{t2}A_2}$
- Normalized peak temperature $\theta = {T_{t4}}/{T_{t0}}$
- Peak temperature T_{t4}
- Normalized flow rate $\overline{m}_2$
- Flow rate $\dot{m}$
- Fuel flow rate $\dot{m}_f$
- Compressor pressure ratio π_c

PROBLEM 2 (30 points)

In designing one of the identical stages of a compressor, we wish to maximize the stage temperature rise ΔT_t, so as to minimize the number of stages, while limiting the stage loading to avoid excessive losses. Assume a 50% reaction design, with the axial velocity *w* determined by a compressor-face Mach number $M_2 = 0.5$, and an inlet total temperature $T_{t0} = 250\ K$.

a) Show from the Euler equation that high ΔT_t per stage is favored by high wheel spin $\omega\bar{r}$ and low stator exit angle β_1 (or, for this design, $\beta_2' = \beta_1$). Assume the wheel speed is as high as allowed by hoop stress limitations on the rim (assumed to be self-sustaining, namely, the blade centrifugal pull is compensated by the disk tension). The rim material is a Titanium alloy with working stress $\sigma = 6 \times 10^8\ Pa$, and density $\rho = 4500\ kg/m^3$. Take the blade ratio ${}^{r_H}/_{r_T} = 0.8$, so that ${}^{\bar{r}}/_{r_H} = 9/8$. Calculate $\omega\bar{r}$.

b) Draw the velocity triangle and show that the flow turning angle δ (the angle between V_1 and V_2, or between V_1' and V_2') increases as β_1 decreases. Values of β_1 that are too small will therefore lead to excessive blade losses, and possibly to stall. Choose the smallest β_1 that keeps $\delta \geq 15°$.

c) With these choices, calculate the temperature rise ΔT_t per stage. How many stages would be required to achieve an overall pressure ratio $\pi_c = 21$?