ASE 376 K Homework#6 Spring 2008
(due Wednesday March 19)

Hill & Peterson Problems 5-9, 15, 16, 20.

S6-1 We wish to begin the thermodynamic design of a high bypass turbofan engine cycle with separate primary and secondary streams. One of the conditions at which the engine is working hardest is at the "top-of-climb", i.e. when climbing to the service ceiling of the airplane. The ambient temperature for the top-of-climb design point is 217 K, the corresponding ambient pressure is 19.3 kPa, and the Mach number is 0.80. The bypass ratio is 8, and the maximum allowable temperature in the engine is 1640 K. Assume an inlet adiabatic efficiency of 0.95 and primary and secondary nozzle efficiencies of 0.97. The enthalpy of reaction of the fuel is 45 MJ/kg, the burner efficiency is 0.99 and the stagnation pressure ratio across the burner is 0.95. Assume constant ***polytropic*** efficiencies of 0.92 for the compressor and fan and 0.93 for the turbine. Hot gas specific heat $\gamma_h = 1.33$.

NB: You can use the posted turbofan spreadsheet as starting point, but you have to modify it so that you use fixed polytropic efficiencies of compressor and turbine rather than fixed adiabatic efficiencies.

(a) What is the optimum fan pressure ratio for a cycle with a compressor pressure ratio of 40? What are the corresponding values of the specific thrust and TSFC?

(b) How do these values change if the compressor pressure ratio is increased to 45 keeping all other parameters the same. (Remember that the compressor and turbine adiabatic efficiencies change with pressure ratio for fixed polytropic efficiency.)

S6-2 We wish to analyze the off-design performance of the CF6 turbofan engine using the NASA engine simulator. A link to the program is on ERes [NASA engine simulator (ramjets, turbofans, turbojets]. You can also download the applet if you wish – it is one of the programs available from the ERes link "NASA Program Link".

A quick way to get started is as follows:

a. Switch from Design mode to Tunnel test mode.
b. Under Load my Design choose "Load CF6 model"
c. Choose "Metric Units"
d. Select Output "Engine Performance"
e. Select "Input Mach + Altitude"
f. Use option Gam(T), i.e. temperature dependent specific heat ratio $\gamma(T)$. Afterburner should be OFF (though I believe it is programmed not to affect the calculations for this engine model.)

In a spreadsheet record the program outputs: ambient temperature and pressure, Net Thrust $\Im$ (use *kN*), and Fuel Flow (*kg/hr*) for throttle settings $\xi = 75$ and 100%. Use the following matrix of flight conditions:

H= 0 m, M = 0, 0.1, 0.2, 0.3, 0.4, 0.5
H= 3000 m, M = 0.3, 0.4, 0.5, 0.6, 0.7
H= 6000 m, M = 0.5, 0.6, 0.7, 0.8, 0.9
H= 9000 m, M = 0.5, 0.6, 0.7, 0.8, 0.9
H= 12000 m, M = 0.5, 0.6, 0.7, 0.8, 0.9

Note that the *TSFC* computed and displayed by the program has units of $kg\ hr^{-1}/N$ and typically only shows one or two significant digits (three decimal places). You can compute a slightly better value in your spreadsheet using the displayed value of fuel flow rate and net thrust. Don't believe it is good to 5 digits – it is 3 max, e.g. $\Im$ = 55.0 *kN*, Fuel Flow = 2781 *kg/hr* ⇒ *TSFC* = 14.0 $mg\ s^{-1}/N$ (standard SI units for *TSFC*).

(i) For ξ = 100% plot $\Im$ as a function of M; show the $\Im$ *vs* M curves for all altitudes on a single plot. Similarly plot *TSFC vs M* at each altitude.

(ii) Generate the $\Im$ *vs* M and *TSFC vs M* plots for ξ = 75%.

Switch the output to "Component Performance".

(iii) What numerical check can you make to see that the values of pressure and temperature listed for each station are the stagnation values?

(iv) At any Mach number and altitude, what is the effect of changing the throttle setting ξ on turbine inlet temperature (T_{o4})? Does T_{o4} change if you vary M or H at fixed ξ? For M = 0.8, H = 6000 m, record and plot Fuel Flow rate and T_{o4} *vs* ξ, for ξ between 50 and 100%.

The engine performance is a function of a several variables (M, H, ξ). Engine performance variation with altitude is often presented in the form of "corrected" thrust ($\Im/\delta$), and "corrected" specific fuel consumption ($TSFC/\sqrt{\theta}$), where $\delta \equiv p_a / p_{SL};\ \theta \equiv T_a / T_{SL}$. Although a detailed model is best, we wish to see if there exist simple approximate altitude scaling relations for corrected variables. Consider the sea-level data for the CF6 engine at M = 0.8, ξ = 100%. Calculate the thrust at each altitude (3, 6, 9, 12 *km*) at fixed M (= 0.8) that corresponds to the same corrected thrust as the sea level value at ξ = 100%:

$$\left(\Im/\delta\right)_H = \left(\Im/\delta\right)_{SL} \Rightarrow \Im_H = \delta(H)\times\Im_{SL,\xi=100\%};\ \left(\delta_{SL}=1\right)$$

At each altitude determine the throttle setting that gives a computed thrust that matches this corrected thrust (to 3 digits). Record the throttle setting and fuel flow rate, and compute the corresponding corrected *TSFC*. How do throttle setting and corrected *TSFC* vary at fixed $\Im/\delta$?

(You can design your own engine and estimate its performance. The simplest way is to start with an existing design and make changes to the design. For example, load the CF6 model as a baseline design for civilian turbofan engines. You then switch to "Load My Design" and click on Inlet, Fan, Compressor, etc. on the graphic and change the performance parameters of each component. For example, you could put in reasonable non-ideal component efficiencies, change bypass ratio, fan pressure ratio, compressor pressure ratio, etc. Note that UNLIKE the convention we use in class, the program assumes that the compressor pressure ratio multiplies the fan pressure ratio for the core air stream. By clicking on the "size" button you can vary the engine size so that the thrust at sea-level static conditions is some desired value and then find cruise thrust at high altitude. Alternatively you can set a desired cruise thrust and determine the corresponding sea level thrust. You can then examine the engine performance as a function of speed at fixed altitude, and as a function of altitude at fixed speed, by going to the "Tunnel Test Mode" and changing simulated flight conditions. Note that if you specify a high compressor pressure ratio (say 20) and fan pressure ratio (say 2), then you cannot fly at high speed at sea level using ordinary materials because you will exceed maximum allowable temperature in the engine. However, you may be able to fly at this speed at 5000 *m* (say) because the incoming air is cold.)