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Engine Design Project

The goal of this project was to write a code for a real engine cycle analysis. This code would then be used to design an engine that would minimize fuel burn of a 3500 nautical mile cruise climb starting at 37,000 feet where the temperature is constant as the plane rises. Some of the constraints of the engine are that the maximum total temperature the engine can reach is 3400 R, the temperature the engine should run at long periods of time is a maximum of 3150 R, the lift to drag ratio is constant at 24, the fan pressure ratio is constant at 1.3, and the engine must be able to produce 18,800 lbs of thrust for take-off. From these constants, it is necessary to determine the diameter of the fan (D), the bypass ratio, the total temperature in the combustion chamber (Tt4), and the overall pressure ratio (OPR).

For each design parameter for the engine, the effect they have on the fuel flow rate has to be taken into consideration. For example, a higher fan diameter would increase the weight of the plane, meaning it would need more thrust, and more fuel to carry the extra weight. However, the larger diameter of fan there is increases the amount of air flow that can be used as thrust which would decrease the amount of fuel necessary. Each part of the engine had to be designed like this, and it means that optimizing the fuel flow rate would require checking each component for a range of values to find what combination of design parameters would provide the required amount of thrust and the optimal amount of fuel burn.

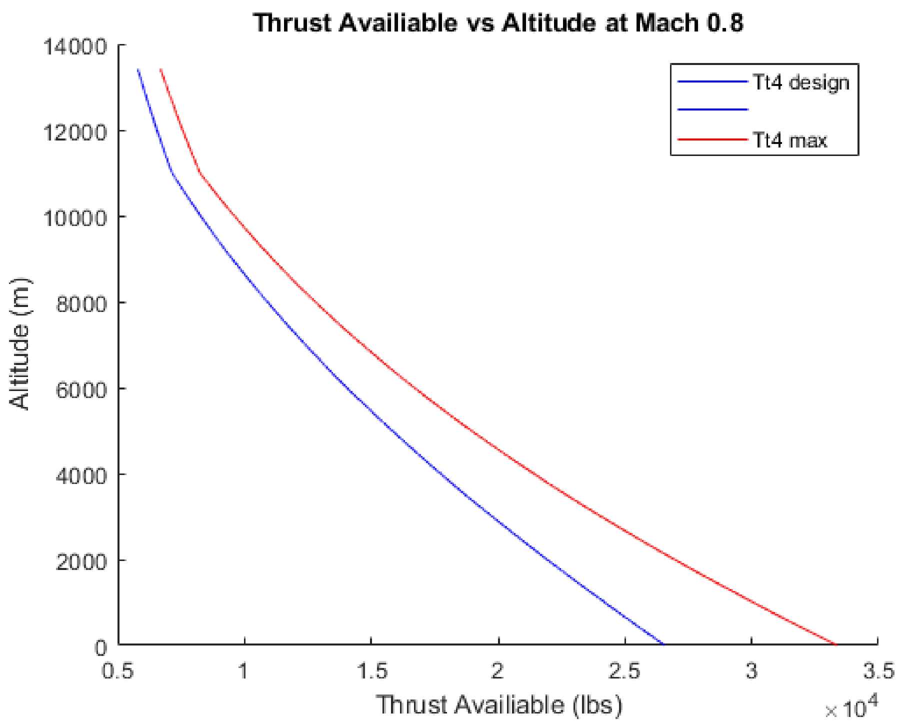
To do this, a MATLAB function was created that went through a cycle analysis of an engine that plugged each of the four design parameters into the cycle analysis. It then calculated the total amount of thrust that each combination of these parts was to see if it was equal to the required thrust for cruise climb. For this required thrust, with two engines and a constant L/D of 24, the required thrust is the total weight of the plane and the fuel divided by 48. So, if the thrust was equal to W/48 for any combination, the code would then check if that engine could produce enough thrust to take-off. Lastly, if each of these conditions were met, it would display the values of Tt4, BPR, D, and OPR along with the mass flow rate of fuel (mf) at that configuration. It is then possible to go through each of these configurations that meet the conditions of the required thrust and find the lowest mass flow rate of fuel. This is because the lower the mass flow rate of the fuel is, the less total amount of fuel is needed.

After taking each of these steps, it was found that the optimal configuration of the design parameters is as shown in **Table 1**. From this design configuration, it was calculated that the total fuel burn for this flight would be 62,074 lbs of fuel.

Design Configuration		
Condition	**Value**	**Units**
Tt4	3035	R
OPR	47	
D	52	inches
BPR	2	
mf (11 km)	0.071	sl/s

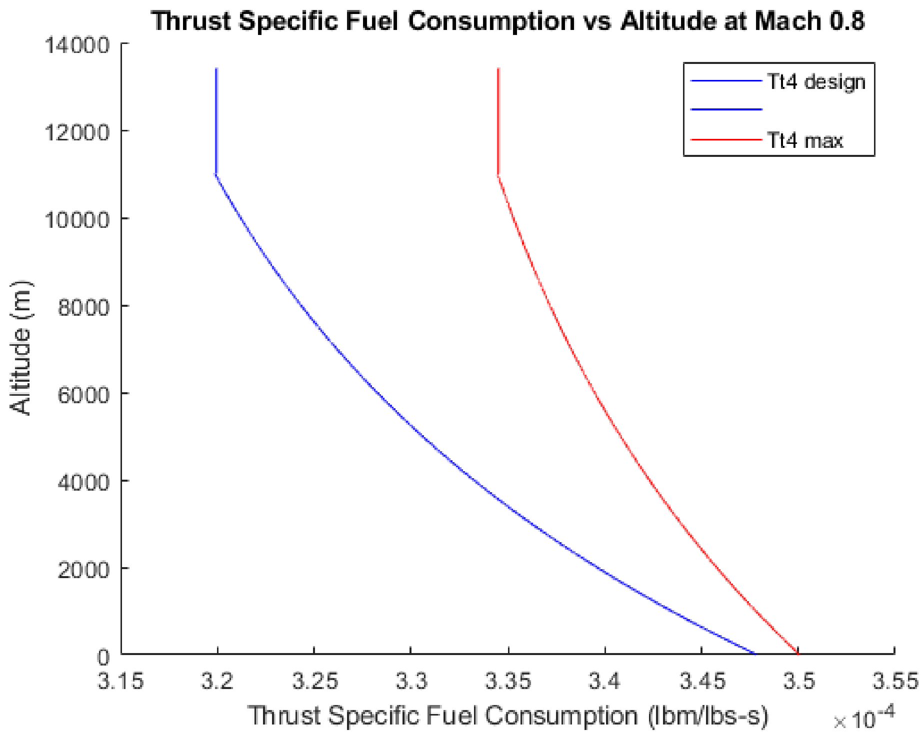
With these values, the takeoff at thrust can be up to 42,925 lbs of thrust with a Tt4 of 3400 R, and a thrust specific fuel consumption (TSFC) of 0.6298. In cruise climb at an altitude that begins at 37,000 feet, the thrust each engine produces at the start of the climb is 7,144 lbs of thrust, and each engine produces 4,077 lbs of thrust by the end of the climb. This decrease in thrust is due to the density of air decreasing as altitude increases, and thus the amount of total mass of air the engine is able to pull in is smaller at higher altitudes. However, this also means the engine burns less fuel to keep the same mass to fuel ratio constant, and it turns out that the TSFC is constant at these altitudes where temperature is constant at 1.1519 lbm/lbs/hr. This principle only applies when there is a constant temperature. The TFSC changes along with the thrust when there is a change in temperature as the plane climbs in altitude. **Figure 1** and **Figure 2** below show the thrust and the TSFC with respect to altitude for a Tt4 of the design temperature of 3035 R and the maximum Tt4 of 3400 R.

Figure 1



With the chosen design configuration, the thrust available is much lower at high altitudes where the density of the air is low. As the altitude decreases, the available thrust increases at a higher and higher rate, meaning that there is much more thrust as the plane gets closer to the ground. However, this does not mean that flying lower to the ground is more efficient because the drag increases at lower altitudes. It can also be seen that the TSFC is constant after 11km.

Figure 2



The next two figures (**Figure 3** and **Figure 4**) show the thrust available and the TSFC at varying Mach numbers. As can be seen by the graphs, the thrust available decreases as the Mach number increases and the TSFC increases as the Mach number increases. This happens because the mass flow rate of fuel coming into the engine is assumed constant, therefore as the aircraft speeds up, the only factor that affects the thrust is the incoming flow. In the thrust equation, the incoming flow is multiplied by the amount of air coming in and subtracted from the rest of the values, meaning as the incoming flow increases (and the rest stays constant), the thrust produced by the engine decreases. Therefore, as the thrust decreases, the TSFC increases as the mass flow rate of the fuel is not affected much by the increase in speed. It can also be noted that the thrust at the maximum Tt4 temperature is higher than at design temperature and the TSFC is lower at the higher Tt4.

Figure 3

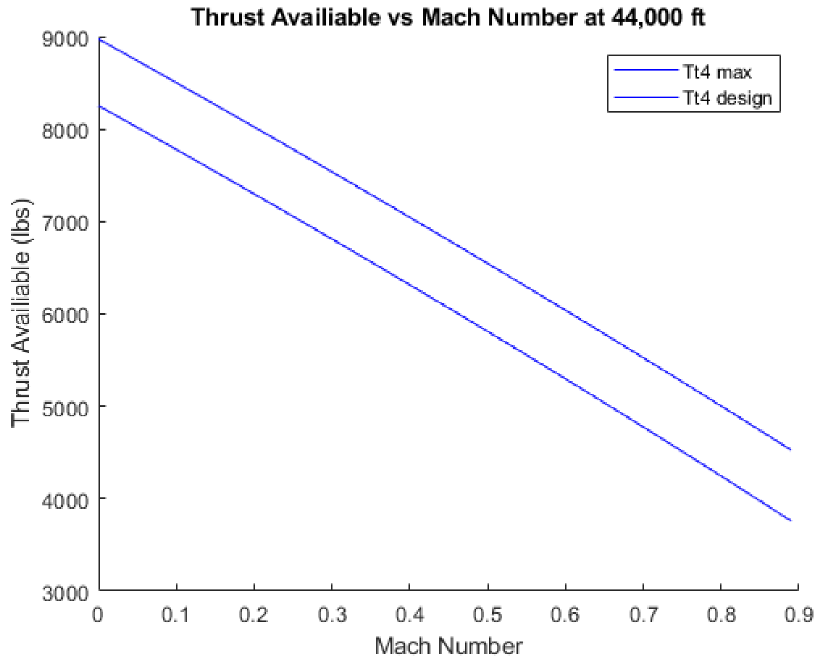


Figure 4