ME 643 | Aircraft and Rocket Propulsion

ENGINE DESIGN PROJECT

Due: 11:59 pm on April 21, 2024

INSTRUCTIONS

1. This is a team project. Each team can consist of 3-4 members. The responsibility of forming the teams is with the students. However, each team should consist of a mixture of undergraduate and postgraduate students.
2. Each team should execute the project independently. Collaboration or discussion between teams is NOT permitted. After the engine designs are received from all the teams, a technical evaluation would be conducted.
3. Each team is required to submit the project report. Any standard document preparation system such as WORD, LaTeX can be used to prepare the project report. Handwritten reports will NOT be accepted.
4. Each team will be required to make a presentation after submission.

PROJECT STATEMENT

A request for proposal (RFP) has been published by an aircraft manufacturer inviting proposals from gas turbine engine manufacturers for supply of gas turbine engines for a specified modern civilian aircraft. Imagine that your team is working for a specific engine manufacturer such as Pratt & Whitney, General Electric. You are required to design a gas-turbine engine for the civilian aircraft given below:

Aircraft characteristics

Maximum gross takeoff weight	1,645,760 N
Empty weight	822,880 N
Maximum landing weight	1,356,640 N
Maximum payload	420,780 N (253 passengers + 196,000 N of cargo)
Maximum fuel capacity	716,706 N
Wing area	282.5 m^2
Engine needed	Turbofan engine (two engines per aircraft)
Maximum lift coefficient, $C_{L,max}$	2.0

Drag coefficients

$$C_D = K_1 C_L^2 + K_2 C_L + C_{D0}$$

M_0	K_1	K_2	C_{D0}
0.00	0.056	-0.004	0.0140
0.40	0.056	-0.004	0.0140
0.75	0.056	-0.008	0.0140
0.83	0.056	-0.008	0.0150

The twin-engine aircraft will cruise at 0.83 Mach and capable of the following requirements:

- Takeoff at maximum gross takeoff weight from an airport at 1.6-km pressure altitude on a hot day (38 °C) using a 3650-m runway. The aircraft is able to maintain a 2.4 % single-engine climb gradient in the event of engine failure at takeoff.
- It transports 253 passengers and luggage (90 kg each) over a still-air distance of 11,120 km.
- It should have 30 min of fuel in reserve at the end.
- It attains an initial altitude of 11 km at the beginning of cruise.
- To provide a reasonable-length landing gear, the maximum diameter of the engine inlet is limited to 2.2 m.

Part A: Mission Analysis

The mission profile consists of taxi, takeoff, climb and acceleration, cruise, descent, loiter, land and taxi. Some important information about the mission is presented in the table below:

Description	Distance, km	Thrust requirement, N	Fuel burn, kg
Taxi			
Takeoff			
Climb and acceleration	330		
Cruise	10,650		
Descent	140		
Loiter (30 min at 9 km altitude)	2		
Land and taxi			
Total	11,120		

Your team must first compute thrust and fuel burn for the mission. In order to compute the thrust force, you would need to use the aircraft performance equation that is relevant to each segment of the journey. The engine design that you propose should target to minimize the air ticket cost per passenger. For this project, you may assume that the air ticket cost is equal to the fuel cost for the journey per passenger. To obtain the total fuel burned during the journey, you would need the data of specific fuel consumption during each segment of the journey. The specific fuel consumption can be multiplied by the thrust requirement for each segment to get the fuel burn for each segment. However, since the specific fuel consumption is not available at this stage, you must begin with an average specific fuel consumption and use the same value for each segment to calculate the total fuel burn. The chosen specific fuel consumption should yield acceptable fuel burn. Note that the chosen specific fuel consumption is only a crude initial guess and should be refined through an iterative design process.

Part B: Parametric Cycle Analysis

Your team should now conduct the parametric cycle analysis to arrive at optimum set of parameters for the engine design. You must first begin by selecting a suitable design point. One possible option is the 0.83 March, 11 km altitude cruise condition, since the aircraft spends a large chunk of its journey time in cruise. The primary objective is to obtain the ranges of compressor pressure ratios, bypass ratios etc. that best meet the design requirements. Assume T_{t4} = 1560 K and h_{PR} = 42,800 kJ/kg for the analysis. In order to arrive at possible ranges of design variables, you must first determine the minimum uninstalled specific thrust and maximum allowable uninstalled thrust specific fuel consumption. The minimum specific thrust corresponds to maximum flow rate achievable for the given maximum engine inlet size, whereas the maximum specific fuel consumption is a result of mission analysis performed in part A of this project.

Plot thrust specific fuel consumption vs specific thrust. You should plot a curve for each bypass ratio, and cross-plot the values of compressor pressure ratio. The result is a carpet plot (a multivariable plot) for the cruise condition. Now draw a dashed horizontal line on the carpet plot corresponding to maximum allowable thrust specific fuel consumption and dashed vertical line for minimum uninstalled specific thrust. Determine ranges of design parameters that look promising and identify at least three possible engine design options.

Part C: Engine Performance Analysis

The third part of the project is to determine if the selected engine design options can “fly” the aircraft throughout the journey. For this, you will first need to “size” the engine. This is normally done for either the takeoff condition or one engine out condition. Once the engine is sized, the performance needs to be computed for all segments of journey to see if the thrust requirements are met. During the performance analysis, the actual specific fuel consumption is also computed, so the total fuel consumption can be readily obtained. This value needs to be compared with the initially assumed value of specific fuel consumption. Strictly speaking, the entire design is an iterative process. You would need to arrive the best possible engine design that meets the mission goals while minimizing the overall fuel consumption.