

# Air Breathing Propulsion Field Exam Questions

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*Do both Parts 1 and 2*

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## Part 1 (Weighted 50%)

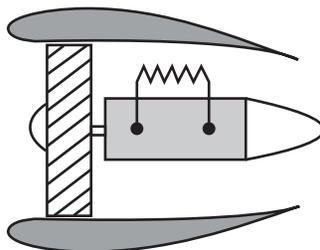
Electrification of aviation is one of the mega-trends in aerospace engineering where propulsion systems using a combination of gas turbine components and electric machines are being considered by industry and the technical community. One configuration that is being assessed are fans powered by electric motors. In this first part of the question you are asked to estimate the electric motor shaft power that would be required if a turbofan engine were replaced by an electric motor driven fan.

Consider a single-aisle aircraft with two turbofan engines, each providing 15,000 lbf (66.6 kN) of thrust. The fan pressure ratio is 1.4 and the isentropic fan efficiency is 0.9. During take-off the aircraft travels at a Mach number of 0.2. In the following analysis you can assume the bypass ratio to be large enough so the thrust provided by the core jet can be neglected. Ambient conditions can be taken at 1bar and 300K and air can be modeled as an ideal gas with  $\gamma = 1.4$  and  $R = 287$  J/kg-K.

- Sketch the propulsor, label all relevant stations, state your assumptions, and draw the streamlines into and out of the propulsor at the take-off condition described above.
- Determine whether the fan nozzle is choked or not. What is the fan jet Mach number?
- What is the propulsive efficiency at take-off?
- Find the mechanical power put into the flow (the change in kinetic energy flux through the turbofan engine).
- Determine the required fan shaft power an electric motor would have to provide if it were to replace the core gas turbine engine.
- What is the fan diameter if the fan face Mach number is 0.6?

## Part 2 (Weighted 50%)

Now consider an engine using the same fan, but with the core gas turbine engine replaced by an electric motor. The electric motor has an efficiency of 90% and a heat exchanger is used in the fan duct to provide cooling for the electric motor as shown below (sketch is not to scale).



You can assume an ideal heat exchanger (all of the lost work of the electric motor is rejected as heat to the fan flow) and that the blockage is negligible. The fan air flows *with friction* along the heat exchanger with a friction coefficient of  $C_f = 0.05$ . The length of the heat exchanger is half the hydraulic diameter of the fan duct. The hydraulic diameter is defined as  $4 \times$  area over the wetted perimeter. The inlet and nozzle can be assumed ideal.

- For the Mach number to *remain constant* along the heat exchanger, does the fan duct area have to increase, decrease or stay constant with distance along the duct? Why? A qualitative answer is expected here, bolstered by an equation or two.
- Sketch the process in the fan stream at take-off conditions from far upstream to far downstream in the  $h$ - $s$  diagram below. For all stations indicate both static and stagnation states.
- Consider the fan map below with the operating point from Part 1 marked by the dot for the take-off condition. If the fan pressure ratio of the electric motor driven fan is again 1.4 and the fan nozzle area is the same as in Part 1, how does the fan operating point rematch due to the presence of the heat exchanger? Sketch the change in operating point in the fan map below. A qualitative answer is expected, bolstered by an equation or two.
- Determine whether the fan nozzle is choked or not at the take-off condition. The fan exit Mach number is 0.4 and you can assume the same fan pressure ratio and isentropic efficiency as in Part 1 and a constant hydraulic diameter of the fan duct. What is the fan jet Mach number?

