ME EN 5830/6830: Aerospace Propulsion
Problem Set #7: Airbreathing Propulsion VI and V
Due date: 03/06/2025 by 11:59pm

Submission

Assignments can only be submitted on Gradescope, which can be accessed through Canvas. If you have any questions about submission, please email the class TA, John Gardner at john.w.gardner@utah.edu. Submissions will be automatically locked at the due date given above.

Introduction

This problem set primarily covers the material from Lectures 14 and 15. The goal is for students to analyze a compressor stage at design conditions, and analyze adjustments needed for off-design conditions, as well as compare modern combustor technologies. After completion of the assignment, students should be able to:

- Design the geometry of a compressor stage based on flow conditions and pressure requirements.
- Modify compressor properties to avoid stall.
- Discuss the benefits of modern combustor technologies.

Assignment

Problem #1: To meet a specified design requirement, a hypothetical individual compressor stage must provide a stagnation pressure rise of a factor of $p_{t3}/p_{t1} = 1.5$ at the design point. The upstream inlet guide vanes provide an incoming absolute velocity with an axial component $C_{z1} = 150$ m/s and an angle of $\alpha_1 = 10\,°$ with respect to the axial direction. The static temperature entering this stage is $T_1 = 335$ K. The rotational speed of the compressor is $\omega = 10{,}000$ rpm (revolutions per minute) and the average radius of the stage is $r = 0.3$ m. This stage has an isentropic efficiency of $\eta_{cs} = 0.9$. For this problem, you may assume that $\gamma = 1.4$ and $R = 287$ J/kg-K. **You can also assume that the velocity magnitude and angle entering the rotors (1) equals that exiting the stators (3).**

Filling in the following table may help you proceed through the problem:

State	α	C	C_θ	C_z
1				
2				
3				

a) Calculate the rotor velocity at the mean radius U in m/s. *Hint: The units of ω are rev/min, but the units of U need to be m/s. Make sure you properly convert all units. In particular, you will need a factor of $2\pi/rev$ (conversion of revolutions to radians) to get rid of the rev units.*

b) Compute the incoming absolute velocity C_1 and azimuthal component of the axial velocity $C_{\theta 1}$.

c) Compute the stagnation temperature of the incoming flow T_{t1}.

d) Compute the azimuthal component of the absolute velocity after the rotor $C_{\theta 2}$. *Hint: You were given a required stagnation pressure increase across the stage.*

e) What is the value of the axial component of the absolute velocity after the rotor C_{z2}. *Hint: Don't think too hard about this one.*

f) Compute the angle of the absolute velocity relative to the centerline α_2 and the absolute velocity C_2 after the rotor.

g) What are the absolute velocity components and angle after the stator $\alpha_3, C_3, C_{\theta 3}, C_{z3}$?

h) In the previous problem set, you analyzed the PW1000G-JM which had 3 low-pressure compressor stages and 8 high-pressure compressor stages. In that problem, the overall compression ratio across all stages was $r_p = 60$. Assuming the 3 low-pressure stages have an overall compression ratio of $r_{lp} = 8$, how many of the stages designed in this problem would be required in the high-pressure compressor to reach an overall compression ratio $r_p = 60$? Round up to the nearest number of stages.

Problem #2: Consider the compressor stage from the previous problem. While that stage was designed assuming conditions at the design point (e.g., at cruise altitude and speed), the conditions will vary from take-off to landing. To minimize the potential for boundary layer separation and stall, the turning angle in the rotor should be minimized. Thus, in this problem, assume the absolute flow angle after the rotor is limited to $\alpha_2 = 38.42°$ (compared to $\alpha_2 = 49.83°$ in Problem 1). Other than this geometric change, you can assume conditions before the rotor (state 1) are identical to Problem 1. Note that because of this new angle, conditions at state 2 will differ from those in Problem 1.

a) Compute the various velocities at state 2 ($C_2, C_{\theta 2}, C_{z2}$).

b) With this design, what is the stagnation pressure increase across a single stage of our compressor?

c) In part b, you should have computed a stagnation pressure increase lower than what we originally required ($p_{t3}/p_{t1} = 1.5$). Assume our isentropic efficiency, air temperature (and therefore c_p), airflow velocity, and swirler vane geometry cannot be changed. What other quantity can we modify to reach our required pressure ratio of 1.5?

d) Calculate the value of the rotor velocity U that would give the required pressure ratio.

e) Calculate the rotational speed ω that would give the required pressure ratio.

Problem #3: The two main low-emission combustor technologies currently used in commercial aviation are RQL and LPP. Fill out the following table with whether each technology is "better" or "worse" in each category, compared to the other.

	RQL	LPP
Flame Stability		
Soot Emissions		
NOx Emissions		

a) Which technology is better for flame stability? Why?

b) Which technology is better for soot emissions? Why?

c) Which technology is better for NOx emissions? Why?