AER 710: Aerospace Propulsion

Semester Project: Supersonic Engine Design

Due March 25, 2024 by 5:00 p.m. ● 20% of the final grade

This individual (not group!) assignment, for 20% of your overall grade in AER 710, is as follows:

1. Project Description

As a new engineer at a large aerospace company, you are assigned a position in the engine design division. There is a renewed interest to design a commercial supersonic aircraft, which would fly from New York to London in under three hours. You are given the task to compare two competitive systems for thrust delivery in a preliminary design approach. One engine under consideration should be "fictional" (vs. off-the-shelf), whose main attributes are based on your principal design requirements from the mission definition (additional "nuts and bolts" stuff to complete the engine can be added later, or alluded to more briefly). The second engine should be an off-the-shelf one and two engines should be compared in a trade-off study. That is, the differences in performance characteristics should be explained based on design inputs of the fictional, i.e., design, engine.

As an aircraft-based project, you may wish to review (and use) your AER 615 *Aircraft Performance* notes to assist in mission definition. Bear in mind, however, that the main emphasis of this project is on the design and analysis of your propulsion systems, not the whole vehicle.

The design process is broken down into two phases. First, you will need to design and optimize a supersonic inlet for your "fictional" engine using the Oswatisch principle (as explained below), and after that, you will complete a comprehensive parametric cycle analysis study for performance parameters. Finally, you will use your findings in your preliminary design. A detailed comparison of both engines is required.

1.1. Part I: Supersonic Inlet Design

Your first task is to preliminary design the inlet of your "fictional" engine for high supersonic flight. In a supersonic intake, the freestream is decelerated to subsonic speed through a suitable shock system. The number of oblique shocks is a matter of designer choice. Higher flight Mach numbers require a greater number of oblique shocks.

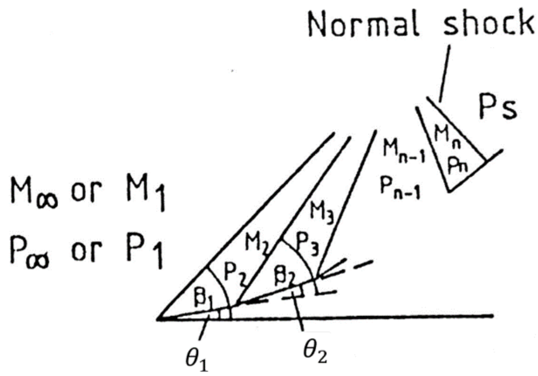

Figure 1. Multi shock compression for Oswatisch optimization (Goldsmith, 1993).

Your primary concern is to optimize the inlet for the **pressure recovery ratio ($\boldsymbol{\pi_d}$)** across the entire inlet. According to Oswatitsch's principle (Oswatitsch, 1947), the pressure recovery in a system of $(n-1)$ oblique shocks followed by the n^{th} normal shock (see Fig. 1) is maximum when the shocks are of equal strength, i.e., that is upstream Mach numbers normal to the oblique shocks are equal:

$$M_1 \sin\beta_1 = M_2 \sin\beta_2 = \ \ldots = M_{n-1} \sin\beta_{n-1} \tag{1}$$

Above equation combined with the oblique shock relations, that are $M_{\text{downstream}} = f(M_{\text{upstream}}, \gamma, \beta)$ and $\theta = f(M, \gamma, \beta)$, the resultant system of equations can be numerically solved to calculate for M_1 to M_{n-1}, β_1 to β_{n-1}, θ_1 to θ_{n-1}, and π_1 to $\pi_{\text{n}-1}$.

1.1.1. Part I: Project Deliverables

Your task is to design a supersonic ramp inlet that maximizes π_{d}. You need to design an optimal shock system consisting of 3 oblique shocks followed by a normal shock.

Inputs:

- Number of shocks: 4 (3 oblique shocks + normal shock)
- Flight Mach number M_1= 3.2
- The normal shock up-stream Mach number $(M_n) = 1.3$
- Gamma $\gamma = 1.4$

Outputs:

Your results should include the Mach numbers (M_2 to M_{n-1}), oblique shockwave angles (β_1 to β_{n-1}), flow deflection angles (θ_1 to θ_{n-1}), stagnation pressure ratios across the individual oblique shock and the normal shock (π_1 to π_n) and finally the intake pressure recovery ratio (π_d). You must also include a rendition of the resultant inlet geometry.

You also will submit a working version of your code, along with operator instructions.

1.1.2. Hints

1) There are multiple solutions to the systems of equations. For example, depending on the initial guess you can get negative values for Mach numbers. You need to limit your domain to physically realistic values.

2) You will need to solve several equations simultaneously. However, you do not need to write code to do this, e.g., see the Matlab fsolve or vpasolve function.

1.2. Part II: Parametric Cycle Analysis

Apply one-dimensional parametric cycle analysis to calculate the performance parameters of your "fictional" engine(s). Analyze both engines as part of the supersonic mission requirements and draw conclusions based on a trade-off study.

2. Design Instructions

For the final report, you are encouraged to apply your computer programming and/or spreadsheet skills in undertaking any parametric study, as evidence of your engineering design selection process towards the chosen system (where possible, avoid decisions via rough guesses, trial-and-error, intuition, and aesthetics; however, rules of thumb are acceptable as starting points in design).

Use and apply as many equations as possible from various sources, including your course textbook, notes, and other literature, as additional evidence of engineering techniques being applied in system selection. The knowledge you gain from this course should tell you if the numbers these equations give you are reasonable, or not. Where the respective propulsion system's performance seems good, or bad, or unrealistic, objectively discuss the design issues (e.g., as you learned in AER 404 *Intro to Aerospace Engineering Design*).

The efficiency of components should be chosen based on historical values and from a literature survey. This part of the analysis is as much a research project as a design project.

3. Project Report Requirements

The report is limited to 20 pages maximum cover-to-cover (1.5 line spacing) excluding the appendix. The final technical report should be typed, with any computer programming included as an appendix. Graphs where appropriate must be included in the main body of the report. Remember, simply having the descriptive text from the literature, and vague rationalizations for design choices, will not overly impress the marker. Show the numbers for your specific application.

Organize your project report as follows:

1. Title page
2. Problem description – Briefly restate the problem at hand in your own words.
3. Approach – Describe the system of equations that you solved and the method used to solve them.
4. Final Design – Present and compare the results of engine designs.
5. Conclusions – Explain the results and draw conclusions.

Originality and initiative will be rewarded. Do not reproduce examples you may come across in the literature. Make sure to work on your own to avoid similar submissions. **The reports will be checked for academic misconduct.** Plagiarism is punishable under the University's Academic Code of Conduct (minimum penalty: zero for the assignment; next level penalty if warranted: a course grade of F).

4. Design Code

You may use any programming language or solution method to design your engine. However, you must submit a self-contained routine that determines the optimal intake parameters and engine performance calculations. This can be a collection of Matlab files or an Excel workbook. Regardless, the code should be able to be run as submitted to produce the final inlet parameter. That is, one should be able to hit 'run' on a Matlab script file and have the code output the inlet design and produce the results. This script may call other functions (which should be included), but the 'front-end' is required.

5. Submission Instructions

You are **required** to submit your final report and all design code required to complete the project. The programming files and the report **must** be submitted **digitally** via the D2L Course website Assignments Section **by** March 25, 2024 by 5:00 p.m. **Late submissions of project will be penalized at the rate of 25% per day (maximum two-day delay).**

6. Frequently Asked Questions

Q: I have my capstone, quiz, lab submission, etc. on the same week. Can I get an extension?
A: No extension is granted because you have other evaluations commitments. The project description is made available at the beginning of the semester for you to plan around your personal and academic commitments. The earlier you start your project, the better it is.

Q: Then how can I get an extension?
A: Extensions will only be granted for circumstances listed in the *Senate Policy 167*. To be considered for an extension, students are required to submit to the department an Academic Consideration Request Form along with any documents necessary.

Q: Can you check my code/values for errors?
A: No.

Q: Not all values required for the parametric cycle analysis are specified here. What should I do?
A: You should research and find typical values from the literature. This is as much a research project as a design one.

Q: My code/hard drive was corrupted. Can I be excused from submitting my code?
A: No. You should have backed up your work. This is a habit that will save you a lot of headaches in the future.

Q: I am having technical problems submitting my documents to D2L. What should I do?
A: You should email your TA with all project documents attached. In this case, your email should be sent before the deadline.

7. Evaluation

The project will be marked based on the rubric below:

Design Report Evaluation Template

Course:					
Report Title:					
Date:	**Student Name:**			**Student Number:**	
Component:	**Excellent**	**Good**	**Satisfactory**	**Needs Improvement**	**Grade**
1. Technical writing (/12)					
Grammar, spelling					
Content is clear, concise, and relevant					
Effective use of computational tools (5a)					
Figures, tables, equations, are clear and labelled/captioned/numbered					/12
2. Proper use of citations/references (/12)					
All sources are cited.					
In text citations are properly used.					
Citation style is consistent throughout.					/12
3. Report formatting (/12) (GAI: 7a)					
Introduction and background					
Professional format and presentation					/12
4. Design process (/48)					
Identification of constraints, requirements and design objectives					/12
Breadth of solutions considered (4b)					/12
Depth of analysis					/12
Feasibility analysis and selection (4c)					/12
4. Outcome/conclusions (/16) (GAI: 1c)					
Achievement of design requirements					
Conclusion / final selection presentation					/16
Overall:					/100

8. References

Goldsmith, E. L. (1993). *Practical intake aerodynamic design.* AIAA.

Oswatitsch, K. (1947). *Pressure recovery for missles with reaction propulsion at high supersonic speeds.* NACA TM No 1140.