PROJECT AETHERION

Student Names: Anuj Dahal, Kevin DiMattina, Oguzkhan Kutlan

Project Title: An Exploration of Rocket Structural Systems & Nose Cones at Maximum Dynamic Pressure

Research Problem: Stresses endured by rockets at maximum dynamic pressure are mitigated by throttling down, which reduces fuel efficiency and lengthens flow separation; this is necessitated by low-durability rocket components that cannot withstand max-q strain and stress levels.

Rationale:

Max q is the moment in a rocket's journey where dynamic pressure and its velocity reach their highest effects. This can cause incredible structural tension, compression, and stress. To counter this effect, rockets throttle down their engines to lower velocity in order to prevent structural damage from aerodynamic stress caused by max q. This in turn prolongs flow separation within the nozzle because of less pressure in the thrust of the nozzle and more time in dynamic pressure that is higher than the exit pressure. The pressure imbalance with the exit and dynamic pressures of the nozzle and atmosphere is unavoidable–that is, if we ignore the use of altitude adaptive nozzles which can reduce flow separation, although their use is limited due to complexity and higher maintenance costs.

However, we may be able to prevent the necessity of throttling down thrust output if we increase structural strength within the rocket's body, which would effectively allow it to handle higher aerodynamic loads, increasing efficiency throughout the rocket's launch. By testing various materials that follow the guideline for the operational standards list (listed below), and designing the structure in such a way that strengthens the rocket's body, we can ultimately reduce flow separation, lower costs, decrease fuel consumption, and reduce the time it takes for a rocket to reach orbit.

Research Questions:

1. How would changes in the **material** of a rocket's framework affect the stress and strain it faces at maximum dynamic pressure?
2. How would various **structural-system designs** differ in their effects on rocket integrity and strain-mitigation at maximum dynamic pressure?
3. How do the aerodynamics of the rocket, based on changes in **nose-cone model**, relate to the stresses faced by rockets at maximum dynamic pressure?
4. *Given the tested designs*, what would an **ideal** structural system and nose cone look like when minimizing max-q-induced stresses and strain?

Engineering Goals:

Our first goal is to *determine whether austenitic stainless steel, high-tensile-strength titanium alloy, or aluminum alloy 2024 is most effective in minimizing damages at maximum dynamic pressure.*

Our second goal is to *design and test three (3) different structural systems and five (5) different nose cones for their mitigation of max-q-induced stress and strain.*

Our third goal is to *physically model and test the optimal rocket design in a simulated maximum-dynamic-pressure environment for its true durability.*

Materials:

- Wind tunnel (LSE, GMU SciTech Campus)
- Polyethylene Terephthalate Glycol-modified Carbon Fiber (PETG-CF) filament
- Fiber-optic strain sensors

Procedure:

Notes: Much of the later stages of the procedure are dependent on data gathered in previous steps, meaning that precision in instruction is limited prior to beginning experimentation. Changes will be made in accordance with newfound discoveries as research progresses.

Due to budget and time constraints, the initial analysis will be performed computationally via ANSYS Finite Element Analysis (FEA). The final design will be modeled using the data gathered from these analyses and tested physically at the LSE, GMU SciTech. The procedure will be split into two (2) parts accordingly.

1. Material Selection

a. Using Ansys Granta Materials Data for Simulation (MDS), select the three (3) materials to be tested in a general, controlled test; austenitic stainless steel, high-tensile-strength titanium alloy, and aluminum alloy 2024 stand as the current selection.

b. Using Ansys SpaceClaim, model the geometry for a controlled structural system, carefully considering the size and shape of the cylindrical body, fairings, and fins; hand calculations must be conducted prior to modeling to tailor the design to Earth's outer-atmospheric conditions.

c. Generate a default mesh for the control model, using the Face Meshing tool afterwards to increase its accuracy. The mesh should be made fine in the Sizing menu, with its maximum size depending on the structural system's 3D geometry.

d. Define the material properties of the control model in the Material Models menu based on the material being tested (refer to Step 1a), ensuring that Structural is selected; the Linear, Elastic, and Isotropic settings should be selected on a case-by-case basis depending on which of the three (3) materials are being tested.

e. Select PIPE288 in the Element Type menu, ensuring that Solid is also selected to best simulate the situation. Stress with Thickness should be selected wherever possible to gather the desired data post-processing.

f. Perform a stress analysis on the object, noting the general stress and strain it faces along with specific points and paths where the studied material may behave differently than its counterparts.

g. Perform steps (b) through (f) for each of the three (3) selected materials.

h. Based on the data analysis from (f), decide on the material to be used in the final design.

2. Structural-System Selection

a. Using Ansys SpaceClaim, model the geometry for three (3) structural systems, carefully considering the size and shape of the cylindrical body, fairings, and fins; hand calculations must be conducted prior to modeling to tailor the design to Earth's outer-atmospheric conditions. Make changes based on the variations in structural systems from primary literature, ensuring that each component is supported by adequate external research or physical principles.

b. Generate a default mesh for the studied model, using the Face Meshing tool afterwards to increase its accuracy. The mesh should be made fine in the Sizing menu, with its maximum size depending on the studied structural system's 3D geometry.

c. Define the material properties of the studied model in the Material Models menu based on the final material (refer to Material Selection), ensuring that Structural is selected; the Linear, Elastic, and Isotropic settings should be selected on a case-by-case basis depending on which of the three (3) materials is finally chosen.

d. Select PIPE288 in the Element Type menu, ensuring that Solid is also selected to best simulate the situation. Stress with Thickness should be selected wherever possible to gather the desired data post-processing.

e. Perform a stress analysis on the object, noting the general stress and strain it faces along with specific points and paths where the studied material may behave differently than its counterparts.

f. Perform steps (b) through (f) for each of the three (3) created structural systems.

g. Based on the data analysis from (f), decide on the system to be used in the final design.

3. Nose-Cone Selection

a. Using Ansys SpaceClaim, model the geometry for five (5) nose cones, emphasizing the angle of attack and fineness ratio. Make changes to these two variables based on the variations in nose cones from primary literature, ensuring that each new design is supported by adequate external research or physical principles; all nose cones should still be viable aerodynamically.

b. Generate a default mesh for the studied nose cone model attached to the final structural system (refer to Structural-System Selection), using the Face Meshing tool afterwards to increase its accuracy. The mesh should be made fine in the Sizing menu, with its maximum size depending on the studied nose cone's 3D geometry.

c. Define the material properties of the studied model in the Material Models menu based on the final material (refer to Material Selection), ensuring that Structural is selected; the Linear, Elastic, and Isotropic settings should be selected on a case-by-case basis depending on which of the three (3) materials is finally chosen.

d. Select PIPE288 in the Element Type menu, ensuring that Solid is also selected to best simulate the situation. Stress with Thickness should be selected wherever possible to gather the desired data post-processing.

e. Perform a stress analysis on the object, noting the general stress and strain it faces along with specific points and paths where the studied material may behave differently than its counterparts.

f. Perform steps (b) through (f) for each of the five (5) created nose-cone designs.

g. Based on the data analysis from (f), choose the nose cone to be used in the final design.

4. Final Design

a. To physically represent the final rocket nozzle design, export the SpaceClaim model file with the final material, structural system, and nose cone (refer to Martial Selection, Structural-System Selection, and Nose-Cone Selection) in .OBJ format and upload it to a 3D printer.

b. After printing the final design using PETG-CF filament, rig it with fiber-optic strain sensors and place it in the LSE Wind Tunnel at GMU SciTech, ensuring that the sensors are placed in areas where high levels of strain were measured during computational testing.

c. Set windspeeds equivalent to those faced by the controlled rocket design at maximum dynamic pressure to ensure accuracy in the simulation; thoroughly study the values being used, as precision is key to obtaining valid and supported strain data.

d. Analyze the results of the strain sensors and compare them to the expected computational analyses, alongside data gathered from primary literature sources.

e. If necessary, repeat step (a) to have a presentable, undamaged rocket design.

Risks and Safety:

Many aspects of the project are computational, with overheating of computer systems being the main risk involved; the likelihood of this occurring, however, is very low, effectively posing no threat to any researchers involved.

Part of the research will involve physical testing using a wind tunnel and 3D-printed objects, possibly causing bodily injury in the event of misused or malfunctioning equipment.

Computational power will be thoroughly considered when conducting nonphysical research, ensuring that overheating is prevented and excessive strain is not placed on the systems involved. Personal protective equipment (e.g., safety goggles, close-toed shoes, well-fitted clothing) will be worn by all on-site researchers to reduce the chances of bodily harm (due to rotating and moving parts) when conducting wind-tunnel experiments. High-quality, working-condition cords and electrical equipment will be used to mitigate the risk of harmful electric shocks. Permission will be granted for all potentially harmful activities, and safety will be prioritized in all facets of research and analysis.

Data Analysis:

The significant results of steps (a) to (f) in Material Selection, Structural-System Selection, and Nose-Cone Selection are the levels of strain faced by the studied models, which directly correspond to their durability at maximum dynamic pressure. Thus, the most durable model will be that whose average strain is the greatest (with consideration of peak strain where applicable/necessary). To determine the cause and locations of differing strain levels, the contour graphs and various values produced by the simulations can be studied. Areas of peak strain will be pinpointed visually and analytically after the computational *and* physical simulations; we will be focused on different types of flows caused by the nozzle designs that lead to these thrust losses.

Expected Outcomes:

Based on present-day rocket-design principles, **high-tensile-strength titanium alloy**[*] is expected to be the most effective material in withstanding max-q stresses and strain.

Furthermore, the structural system with the **most aerodynamic**[†] **fins and framework** is predicted as the most durable at maximum dynamic pressure.

Similarly, the nose cone with the **lowest fineness ratio and greatest angle of attack** is hypothesized to be the optimal choice for max-q damage mitigation.

Finally, it is expected that the physical experiment conducted using the final design will produce **approximately equivalent results** to those found computationally.

**After final selection of the three (3) studied materials, this term will be clarified with a specific alloy.*

[†] *Based on primary literature and hand calculations without external physical testing.*