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Internship Report on Static Test Pad Design for Solid Rocket Motor at STAR – Space Technology and Aeronautical Rocketry

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ABSTRACT

This paper outlines the process and considerations involved in designing a static test pad dedicated to rocket motor testing. The static test pad serves as a crucial facility to assess the performance, stability, and safety of rocket motors before actual flight applications. The paper discusses the key aspects of the design, including safety protocols, instrumentation, data acquisition systems, and infrastructure requirements.

This study emphasizes the importance of safety in static testing, highlighting the implementation of strict protocols to protect personnel and equipment during the test.

Furthermore, the abstract delves into the selection and installation of suitable instrumentation and data acquisition systems to capture essential parameters during the test, such as thrust, chamber pressure, burn time, and exhaust plume characteristics. The integration of reliable sensors and advanced data acquisition technology ensures accurate and real-time data collection, enabling engineers to make informed decisions and refine the rocket motor's design.

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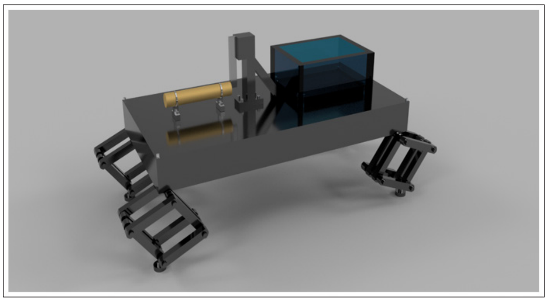


1. Problem Statement

To design a Rocket Motor Static Test Pad for testing and acquiring the required data for the performance analysis of the high powered rocket motors.

2. Introduction- Static Test Pad

A Rocket Motor Static Test Pad is a test pad used in the aerospace industries to visualize and calculate the specific impulse, thrust generated and other parameters which are important to annotate the perfect propulsion system of a rocket.

Designing a Rocket Motor Static Test Pad refers to creating a dedicated facility for conducting static tests on high-powered rocket motors. This facility is specifically designed to gather data and analyze the performance of these rocket motors.

2.1 Different Designs of STP

1. Fixed Test Stand- This is the simplest design, where the rocket motor is mounted on a rigid, fixed structure. It is cost-effective and easy to set up. However, it may have limitations when it comes to testing different thrust levels or angles.

2. Gimbal Test Stand - In this design, the rocket motor is mounted on a gimbal, allowing engineers to control and adjust the motor's orientation during testing. This design enables testing at various thrust levels and angles, mimicking different flight conditions.

3. Horizontal Test Stand - Rocket motors can also be tested horizontally, where the thrust generated propels the rocket against a restrained mechanism, effectively canceling out the forces.

4. Vertical Test Stand - The vertical test stand is the most common design for static test pads. Rocket motors are mounted vertically and secured to the ground during testing. This setup is useful for vertical takeoff rockets like those used in most space launch vehicles.

5. Throttleable Test Stand - Some static test pads are designed to accommodate throttleable rocket engines. These engines can vary their thrust levels during the test, allowing engineers to study their performance across different operational conditions.

Figure 2.1: Vertical Stand

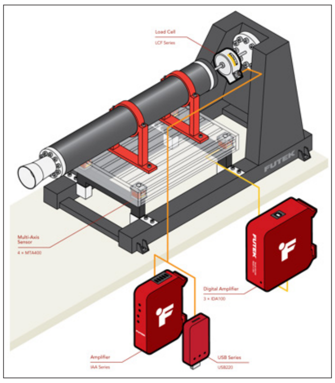


Figure 2.2: Horizontal Stand

3. Basic working principle of STP

The basic principle of a static test pad for rocket motors is to evaluate the performance and behavior of a rocket engine or motor while it remains stationary. The test pad provides a controlled and safe environment for conducting static tests, where the rocket motor is fired while securely mounted to the ground. The main components and principles of a static test pad include the following:

1. Fixed Position - The rocket motor is firmly fixed or mounted to the test pad to ensure it remains stationary during the test. This is typically achieved using strong structural elements or clamps to secure the motor in place.

2. Thrust Measurement - The test pad is equipped with thrust measurement devices to accurately measure the force or thrust produced by the rocket motor during the test. These measurements provide critical data about the motor's performance and help validate its design specifications.

3. Safety Measures - Safety is of utmost importance during rocket motor testing. The test pad is designed with safety protocols and mechanisms to handle the potential risks associated with testing rocket engines, such as containment structures to handle a potential explosion and safety shutdown systems.

4. Data Acquisition - Various sensors and instruments are installed on the rocket motor and the test pad to gather data during the test. These data include thrust, pressure, temperature, and other relevant parameters that aid in the analysis of the rocket motor's performance.

5. Ground Support Equipment - The static test pad is equipped with ground support equipment to supply propellants (such as liquid fuel and oxidizer) and other necessary resources to the rocket motor during the test. It is not required for a solid motor test.

6. Control and Monitoring Systems - The test pad is integrated with control and monitoring systems that allow engineers to initiate, control, and terminate the test safely. These systems also enable real-time monitoring of data, ensuring that the test is proceeding as planned.

7. Test Sequence - The test follows a predefined sequence, which includes pre-test checks, ignition, steady-state operation, and post-test data analysis. The test engineers carefully manage each step of the sequence to obtain reliable and accurate results.

4. Why to make STP?

1. Performance Verification - Static test pads allow engineers to evaluate the rocket motor's performance, ensuring it meets the design specifications and provides the expected thrust and specific impulse.

2. Safety Validation - Before integrating rocket motors into flight vehicles, engineers need to ensure their safety. Static tests help identify potential issues or anomalies, preventing hazardous situations during actual flights.

3. Design Validation - Engineers use static test data to validate their designs and refine them if necessary. It helps improve the efficiency and reliability of rocket motors.

4. Thrust Vector Control (TVC) Calibration - For rockets that require TVC for steering during flight, static test pads help calibrate and verify the performance of TVC systems.

5. Qualification Testing - Before a rocket motor can be certified for flight, it must undergo extensive qualification testing. Static test pads facilitate this process, ensuring that the motor is reliable and meets all the necessary requirements.

6. Cost-Effective Testing - Conducting tests on a static test pad is often more cost-effective than conducting in-flight tests, especially during the early stages of rocket development.

Static test pads for rocket motors are crucial tools in the rocket development process. They allow engineers to verify performance, ensure safety, validate designs, and qualify rocket motors for flight, all in a controlled and cost-effective environment. These tests are essential for the success of any space launch program, helping to identify and rectify potential issues before rockets are used in actual space missions.

5. Design

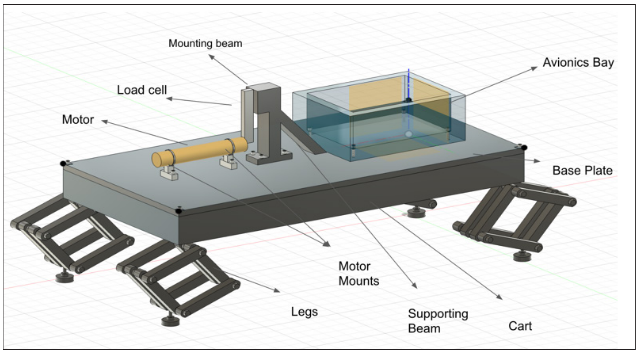


Figure 5.1: Static Test Pad

- The final model design of STP includes a rectangular beam which is carried on the top of a cart with foldable legs. Initially after doing the calculations, I beam was considered to support the whole structure which was finally replaced by a rectangular after getting feedback from mentors. The strength difference is not much in both structure and for our system, it has to sustain stress of about 500 N and a rectangular beam is strong enough to sustain that.

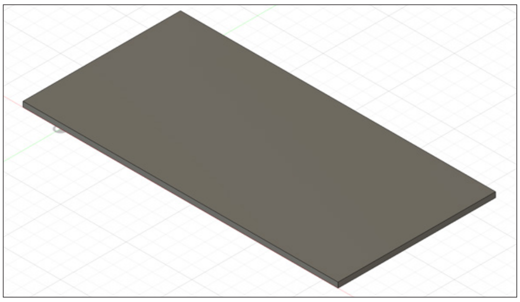


Figure 5.2: Base Plate

The cart is attached to the foldable legs which makes the system more flexible and portable.

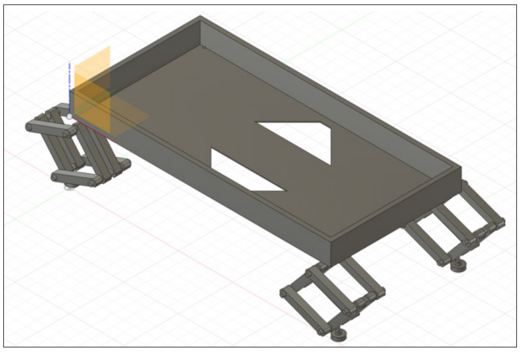


Figure 5.3: Base Plate

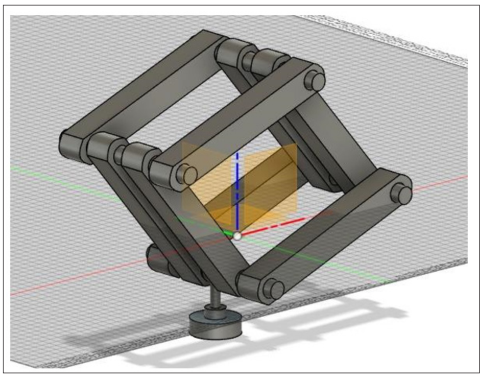


Figure 5.4: Legs

- Modularity of system was a priority to make it more mobile so that it is easy to assemble and disassemble. This flexible design of test stand is capable of testing motors of length in the range of 15-20cm which exerts maximum force of 500N.
- There are holes in the base plate to adjust the motor mounts according to the motor's length.
- Motor mounts has bearing on the inside and they are tied with screws to make it more adjustable for different motor diameter sizes.
- Bearing inside the motor clamp allows the axial movement, so that motor pushes on the load cell and it gives accurate measurements.

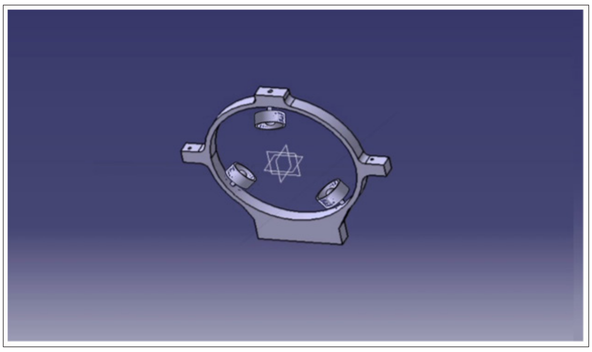


Figure 5.5: Motor Mount

- Load is fixed on a beam which is fixed to the stand using nuts and bolts. which is further supported by an inclined beam structure to make the design more stable.
- Avionics bay is place on one edge of the stand to keep all the electronics component needed for testing procedure. Avionics components are discussed a later section of this report.

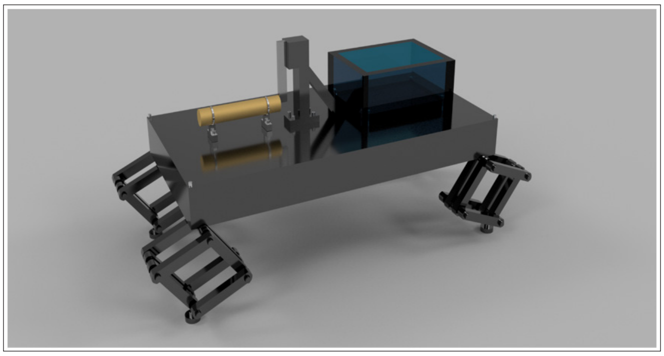


Figure 5.6: STP

5.1 Dimensions

The calculations for dimensions is done using Bending Moment equation, for a simply supporting beam

$$M = -w * (L-x)$$

M = The bending moment acting at x distance from the left end of the beam
w = The load acting at x distance
L = The length of the beam

This equation is used to analyse behavior of beam under different load conditions. Following are the dimensions of specific STP components after considering stress of 500N:

Beam - 60x60x1 cm
Cart - 60x30x8cm
Motor: Diameter: 25mm, length: 20cm (Dimensions considered in the CAD design)
Avionics Bay: 20x15x8cm

6. Software Required to Build Stp

1. **Fusion 360** - Used to design 3D model, static stress analysis and rendering the model. All the initial prototypes, components as well as final designs are made in this software.
2. **Proteus** - Simulation of sensors like load cell, thermocouple, vibration sensor with arduino is done in Proteus.
3. **Arduino IDE** - Used to program, compile and upload the code for whole STP testing process.

7. Materials

Below is the material comparison table, based on which final material for the test stand was selected.

Property	Steel	Aluminum	Hemp
Density	7850 kg/m^3	2700 kg/m^3	1500 kg/m^3
Strength	200-300 MPa	70-100 MPa	270 MPa
Modulus of elasticity	200 GPa	70 GPa	40 GPa
Weight	7.8 times heavier than aluminum	1/3 times lighter than steel	4.5 times heavier than aluminum
Corrosion resistance	Good, but can rust if not protected	Excellent, naturally forms a protective oxide layer	Fair, can be treated to improve resistance
Electrical conductivity	16.7 MS/m	38 MS/m	1 MS/m
Thermal conductivity	50 W/mK	205 W/mK	4.3 W/mK
Cost	More expensive than aluminum	Less expensive than steel	Less expensive than aluminum and steel
Sustainability	Recyclable, but energy-intensive to produce	Recyclable, relatively low-energy to produce	Sustainable, grows quickly and requires little water

The material selected for the STP for our specific thrust requirement is ALUMINIUM 6061 (Density 2700 kg/m3), because of the following features:

- Strength: Aluminum 6061 is a strong alloy that can be used in applications where strength is important. It is often used in structural applications, such as aircraft and boat frames.
- Formability: It is a very formable alloy that can be easily bent, shaped, and extruded. This makes it a good choice for a variety of applications, such as manufacturing car parts and creating custom products.
- Weldability: It is a weldable alloy that can be easily welded using a variety of welding methods.
- Corrosion resistance: It is a corrosion-resistant alloy that can be used in applications where corrosion is a concern.
- Cost: Easily available and cheaper than other proposed materials.

7.1 Manufacturing Process

Below is the manufacturing process of Aluminum:

- **Bauxite Mining**- Bauxite is the raw material used to produce aluminum. It is a type of rock that contains aluminum oxide, the main component of aluminum. Bauxite is mined in open-pit mines, and it is then processed to remove impurities.
- **Alumina Refining**- The purified bauxite is then processed to produce alumina, which is a white powder that is almost pure aluminum oxide. Alumina is produced using the Bayer process, which involves dissolving the bauxite in a hot solution of sodium hydroxide. The aluminum oxide is then precipitated out of the solution, and it is further purified by calcination.
- **Aluminium Smelting**- Alumina is then smelted to produce aluminum metal. This is done by passing an electric current through a molten bath of alumina and cryolite, a type of salt. The electric current breaks down the alumina, and the aluminum metal is released. The aluminum metal is then collected and cast into ingots or other shapes.

A future material HEMP is also proposed, it comes from Hemp plants and after cultivation, fibres are extracted and it can be used in the variety of products like textiles, insulation and composites. It has easy manufacturing process and is a sustainable material. Space companies including NASA and SpaceX are exploring this material for use in space exploration. Hemp fibres can be used to make more effective and sustainable insulation designs.

8. Cost Analysis

Cost analysis is done for the entire test pad.

```
cost of 12 screws approx..: - 12x1= 12 rupees
cost of the cart including the 4 wheels approx.: - 500
+ (4x1000) = 4500 rupees
cost of 6 bearings approx.: - 6x25= 150 rupees
cost of 2 clamps approx.: - 2x50= 100 rupees
cost of the base approx.: - 500 rupees
cost of the avionics bay with load cell mount approx.
: - 3000 rupees
cost of the motor frame:- 1000 rupees
machining cost approx.:- 2000 rupees
cost of other nuts , bolts and joints :- 250 rupees
miscellaneous cost :- 1000 rupees

TOTAL COST OF MANUFACTURING :- 12,512 rupees (approx.)
```

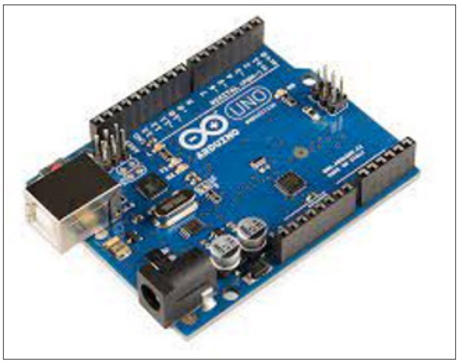
Figure 8.1: Cost Analysis

9. Avionics

9.1 Component Description- Introduction to Sensors Used for Static Test Pad

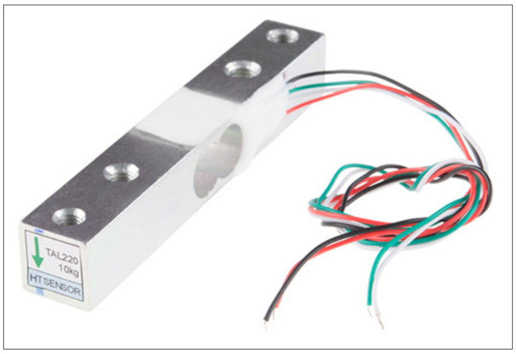
1. Arduino

Arduino is a popular open-source microcontroller platform used in static test pads to control and interface with various sensors and devices. It provides a flexible and easy-to-use development environment for managing data acquisition, signal processing, and actuation during the test.



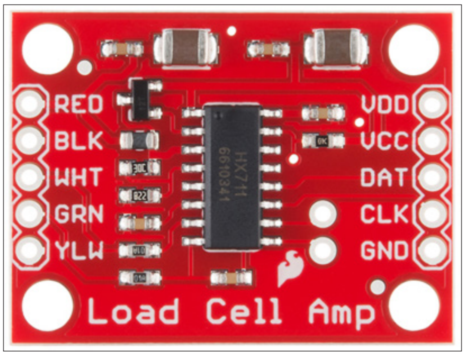
2. Load Cell

Load cells are sensors that measure force or load applied to them. In a static test pad, load cells are used to measure the thrust produced by the rocket motor during testing. They provide essential data to assess the rocket's performance and validate its design parameters.



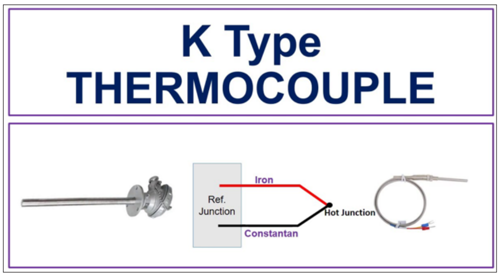
3. HX711

The HX711 is a specialized load cell amplifier and analog-to-digital converter (ADC). It is commonly used with load cells to convert analog force measurements into digital signals that can be processed and analyzed by the Arduino or other control systems.



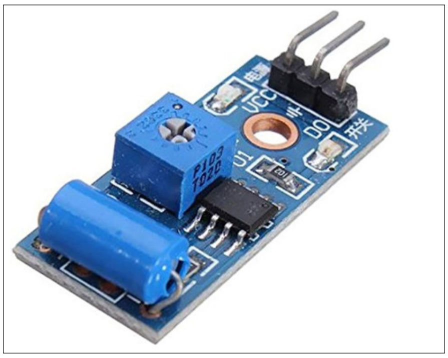
4. K Type Thermocouple

K Type thermocouples are temperature sensors capable of measuring a wide range of temperatures. In the context of a static test pad, these thermocouples can be employed to monitor the temperature inside the rocket motor or in critical components, ensuring that the temperatures stay within safe operating limits.



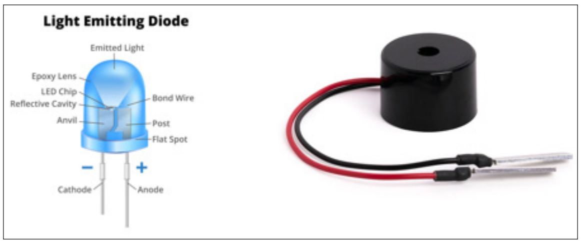
5. Vibration Sensors

Vibration sensors, such as accelerometers, are used to detect and measure vibrations or mechanical oscillations in the test setup. They help assess structural integrity and identify potential resonances or instabilities that may affect the rocket's performance.



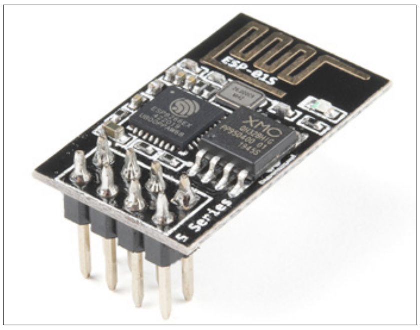
6. LED and Buzzer

LEDs and buzzers are simple output devices used for visual and audible indications during testing. They can be programmed via the Arduino to provide status updates, alarms, or warnings related to the test process or any detected anomalies.



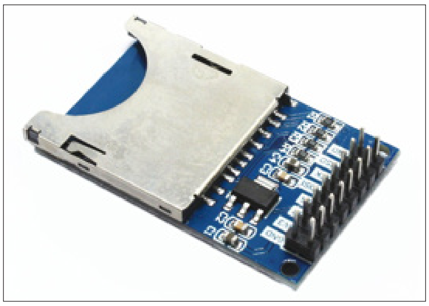
7. WiFi Module

WiFi modules enable wireless communication and data transfer between the static test pad and a remote computer or mobile device. This capability allows real-time monitoring and control of the test, enabling engineers to observe and respond to test conditions from a distance.



8. SD Card

An SD card can be used as a data storage medium to log test parameters, sensor readings, and other relevant data during the test. This information can be retrieved later for analysis, troubleshooting, or comparison with simulation results.



9. Igniter Relay
Igniter relays are used to control the ignition process of the rocket motor. They ensure a safe and controlled ignition sequence, allowing engineers to initiate and terminate the test safely from a distance.

These sensors and components play a crucial role in the functionality and safety of a static test pad. They allow engineers to collect vital data, monitor key parameters, and automate the test process, ultimately aiding in the validation and optimization of rocket motors before they are used in actual flight missions.

9.2 Working
Testing and Analysis Process of Static Test Pad

Step 1: Pre-Test Preparations
- Verify all safety measures and protocols are in place.
- Check the test pad's readiness and calibration of sensors and equipment.
- Load and configure the Arduino or microcontroller for data acquisition and control.

Step 2: Ignition Sequence
- Initiate the ignition sequence using the igniter relay.
- Monitor and verify that the ignition is successful.

Step 3: Thrust Measurement
- Start data acquisition for thrust measurement using load cells and HX711.
- Continuously monitor and record the thrust produced by the rocket motor.
- if the thrust exceeds a threshold value, turn on safety alarms

Step 4: Temperature Monitoring
- Activate K Type thermocouples to measure internal and critical component temperatures.
- Monitor and Record temperature data throughout the test.
- if the temperature exceeds a threshold value, turn on safety alarms

Step 5: Vibration Monitoring
- Turn on vibration sensors (accelerometers) to detect and measure mechanical vibrations.
- Record vibration data during the test.
- if the vibration exceeds a threshold value, turn on safety alarms

Step 6: Real-Time Monitoring and Display
- WiFi module to establish a wireless connection for real-time data transmission.
- Display relevant data on a remote computer or virtual terminal for live monitoring.

Step 7: Data Logging
- Store all collected data on the SD card for further analysis.

Step 8: Test Completion
- Monitor the thrust and other parameters until the desired test duration is reached.
- Safely terminate the test when complete.

Step 9: Post-Test Analysis
- Retrieve data from the SD card for detailed post-test analysis.
- Analyze thrust curves, temperature profiles, and vibration patterns.

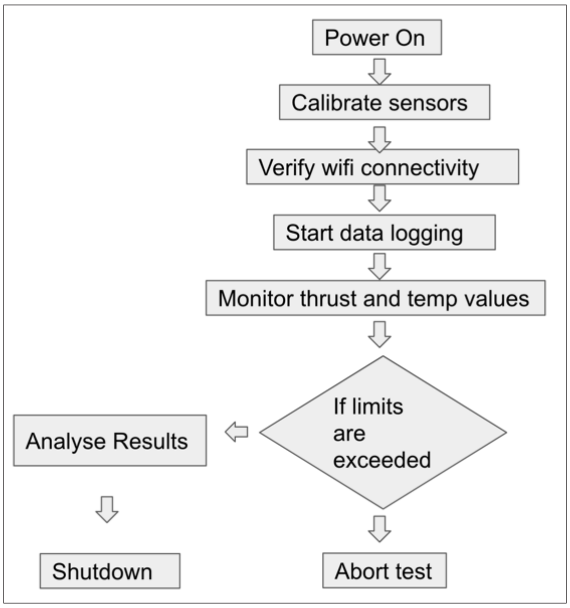
Step 10: Performance Evaluation
- Compare test data with simulation results and design specifications.
- Evaluate the rocket motor's performance, including thrust levels and temperature characteristics.

Step 11: Identifying Anomalies
- Identify any anomalies, irregularities, or unexpected behavior from the data.
- Investigate the causes of any deviations from expected performance.

Step 12: Improvements and Adjustments
- Based on the analysis, make necessary adjustments to the rocket motor's design or test setup.
- Implement improvements to optimize performance and safety.

This series of steps provides a general outline of the testing and analysis process for a static test pad. The avionics flowchart in the next section visually represents these steps and their interconnections for a more intuitive understanding of the entire process.

9.3 Architecture
Flowchart for the testing procedure of STP



10. Procedure to build STP

Below is the series of steps to be followed in order to assemble test pad.

- First cart is attached to the base plate with 4 nuts and bolts at each corner.
- Legs are attached with screws to adapt the uneven terrain.
- Motor is now fixed in the motor mounts which allows an axial movement of the motor. Tightly fix the motor mounts with the screws to fit the motor diameter.
- Attach the load cel to the supporting beam with the 2 bolts. Supported vertical and inclined beam are fixed to the stand using 2 more screws.
- Lastly Avionics bay is paced near the edge behind load cell and fixed to the stand using 4 screws.

11. Proteus Simulation

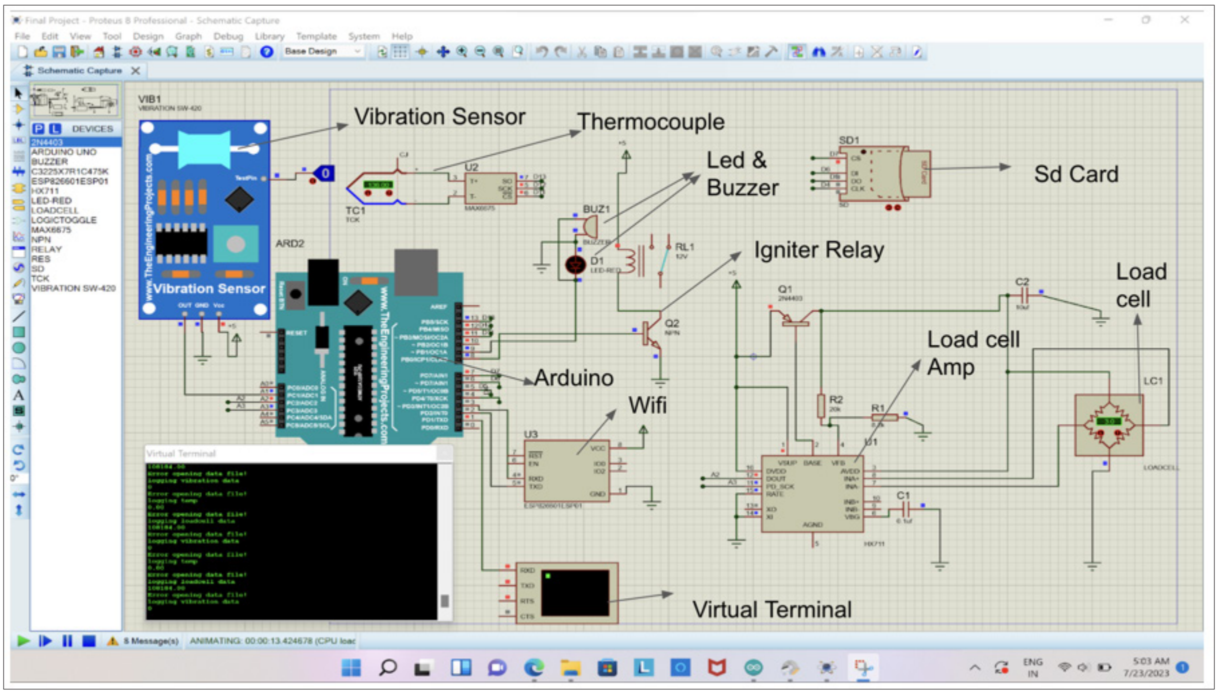


Figure 11.1: Screenshot of Proteus Simulation

12. Arduino Code

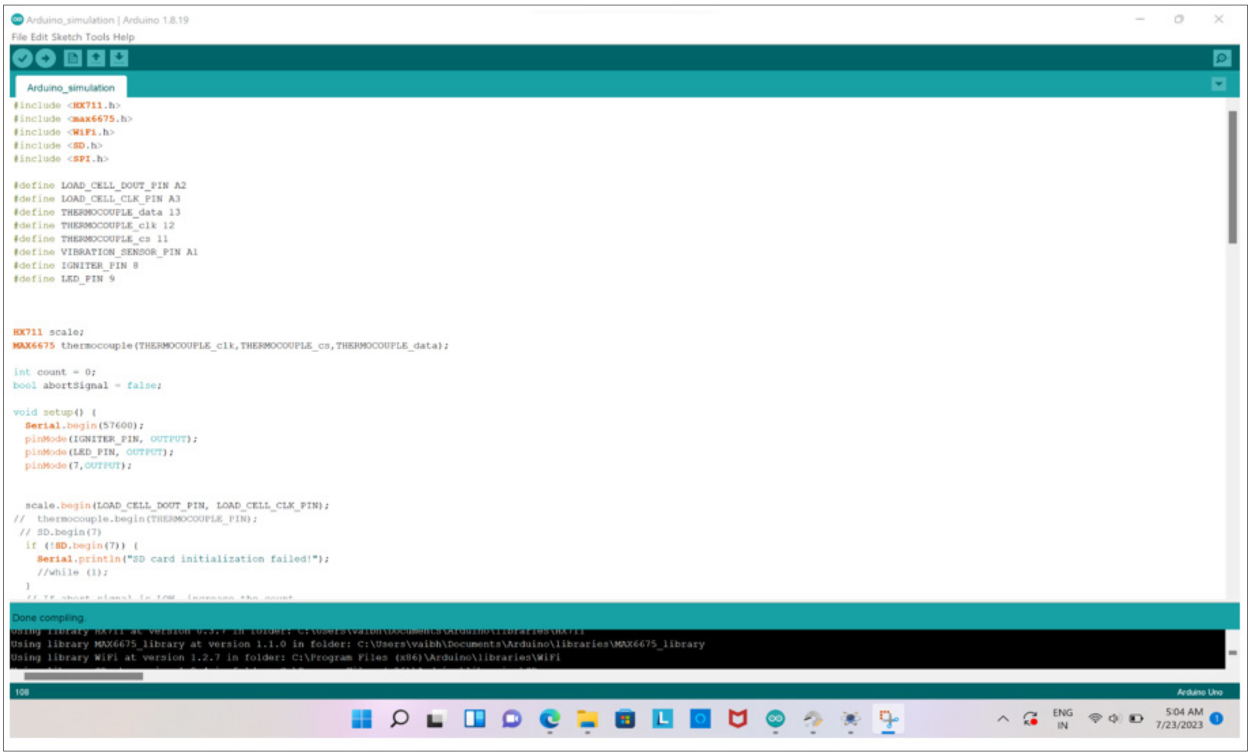


Figure 12.1: Screenshot of Arduino IDE

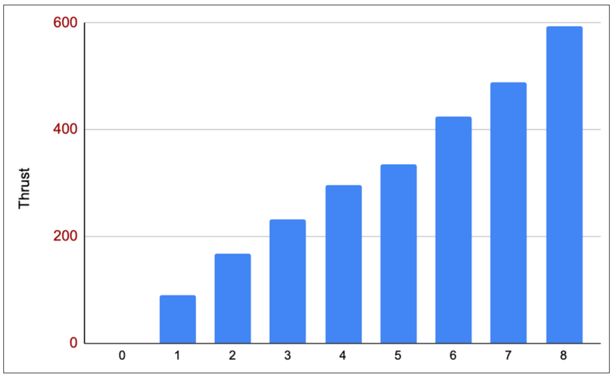
13. Observations

- All data acquisition systems and instrumentation were checked and calibrated for accurate measurements.
- As the test progressed, thrust steadily increased, reaching its peak within the expected range.
- No signs of anomalies, structural failures, or abnormal readings were identified.
- Static stress analysis report shows that the structure is strong enough to sustain our thrust requirement.
- Data collected from the sensors (loadcell, thermocouple, and vibration sensor) is logged and printed in the virtual terminal.

14. Results

14.1 Thrust Plotting

Data measured through load cell is converted to thrust values using a calibration equation Thrust = f(load cell reading). This mathematical relationship is established by performing curve fitting or regression on load cell readings and reference thrust values.



14.2 Static Stress Analysis

- The stress analysis of a rocket motor static test pad involves evaluating the structural integrity and performance of the test pad under the loads and forces generated during rocket motor static testing.
- These loads include the weight of the rocket motor, thrust forces, pressure waves, vibrations, and any dynamic effects. Consider both the static and dynamic loads that occur during startup, operation, and shutdown.
- For our rocket test pad design, we assumed the max force that will be applied would be 500 N.
- Then we apply the identified loads to the model and simulate the static test conditions. Analyse the resulting stress, strain, and deformation distribution within the test pad structure. Evaluate the stress distribution within the test pad structure based on the results. Identify areas of high stress concentration and assess their impact on the structural integrity. Verify if the stress levels are within the acceptable limits for the chosen materials and design standards.
- Apply appropriate safety factors to the stress analysis results to ensure an additional margin of safety. These factors account for uncertainties in material properties, loads, and other variables that could affect the performance of the test pad.

Result report of stress analysis of the cart is attached at the end of this report.

Conclusion

The static test pad for rocket motor testing demonstrated successful results, with the rocket motor performing as expected within the design parameters. The ignition sequence, thrust build-up, steady-state operation, and burn time all aligned with the pre-test predictions, indicating that the motor's performance was consistent and stable throughout the test.

Clearance zones

It is advised to keep a distance of atleast 30 feet from the testpad as a precaution because it can be harmful for any person to be anywhere near that.

1. Take safe distance while testing the pad.
2. Don't try it in crowded area, but at a specific place which is meant for it.
3. Read the precaution label before use it.
4. Should have a moderator with you at least for the first time.

Precautions

1. Always wear appropriate PPE, such as hard hats, goggles, and hearing protection.
2. Be aware of your surroundings and be on the lookout for potential hazards.
3. Report any safety concerns to a supervisor immediately.
4. Do not enter the clearance zone unless you are authorized to do so.
5. Follow the instructions of the test stand operator.

Study Report

AUTODESK

Analyzed File	stress_analysis v1
Version	Autodesk Fusion 360 (2.0.16490)
Creation Date	2023-07-19, 10:16:22
Author	ramonadevi

Report Properties

Title	Studies
Author	ramonadevi

Simulation Model 1:1

Study 1 - Static Stress

Study Properties

Settings	Static Stress
General	2023-07-19, 10:10:05

Settings

General

Contact Tolerance	0.1 mm
Remove Rigid Body Modes	No

Damping

Mesh

Average Element Size (% of model size)	
Solids	10
Scale Mesh Size Per Part	No
Average Element Size (absolute value)	-
Element Order	Parabolic
Create Curved Mesh Elements	Yes
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

⊟ Adaptive Mesh Refinement

Number of Refinement Steps	0
Results Convergence Tolerance (%)	20
Portion of Elements to Refine (%)	10
Results for Baseline Accuracy	Von Mises Stress

⊟ Materials

Component	Material	Safety Factor
Body1	Steel	Yield Strength

⊟ Steel

Density	7.85E-06 kg / mm^3
Young's Modulus	210000 MPa
Poisson's Ratio	0.3
Yield Strength	207 MPa
Ultimate Tensile Strength	345 MPa
Thermal Conductivity	0.056 W / (mm C)
Thermal Expansion Coefficient	1.2E-05 / C
Specific Heat	480 J / (kg C)

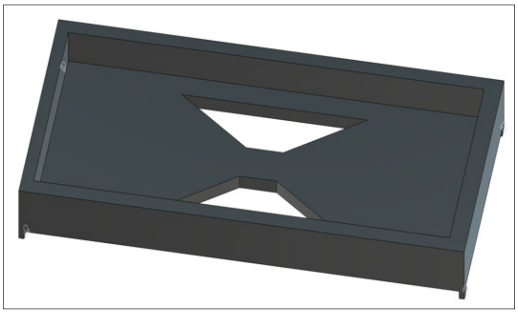
⊟ Contacts
⊟ Mesh

Type	Nodes	Elements
Solids	2164	968

⊟ Load Case1
⊟ Constraints
⊟ Fixed1

Type	Fixed
Ux	Fixed
Uy	Fixed
Uz	Fixed

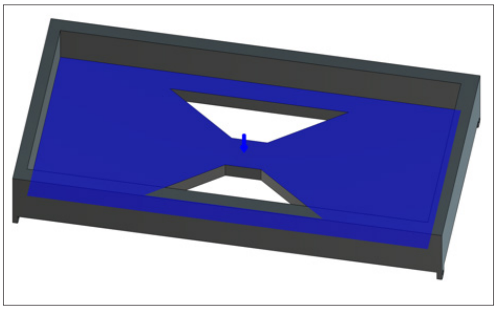
⊟ Selected Entities



⊟ Loads
⊟ Force1

Type	Force
X Value	0 N
Y Value	0 N
Z Value	-500 N
Force Per Entity	No

⊟ Selected Entities

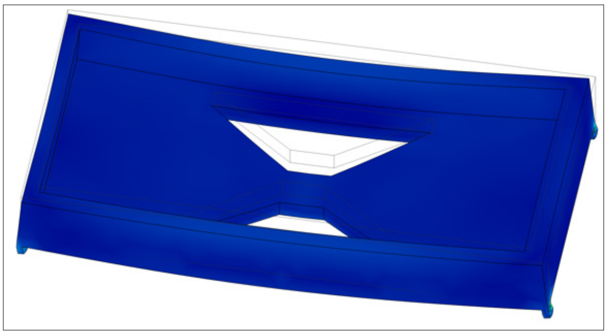


⊟ Results
⊟ Result Summary

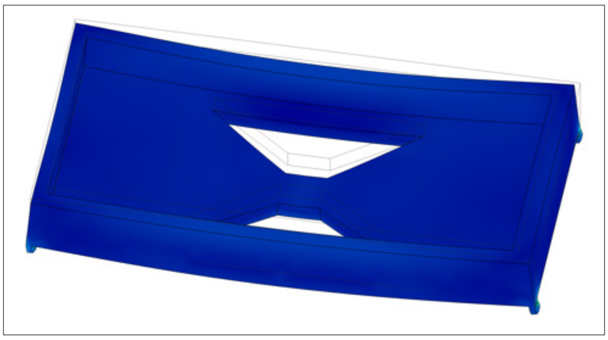
Name	Minimum	Maximum
Safety Factor		
Safety Factor (Per Body)	6.304	15
Stress		
Von Mises	0.01325 MPa	32.84 MPa
1st Principal	-2.415 MPa	23.53 MPa
3rd Principal	-28.42 MPa	3.045 MPa
Normal XX	-7.02 MPa	14.64 MPa
Normal YY	-3.767 MPa	5.649 MPa
Normal ZZ	-26.43 MPa	19.44 MPa
Shear XY	-3.671 MPa	2.951 MPa
Shear YZ	-4.923 MPa	11.35 MPa
Shear ZX	-3.484 MPa	11.75 MPa
Displacement		
Total	0 mm	0.00563 mm
X	-0.001439 mm	5.204E-04 mm
Y	-0.00102 mm	5.55E-04 mm
Z	-0.00561 mm	0 mm
Reaction Force		
Total	0 N	142.8 N
X	-34.26 N	66.06 N
Y	-9.374 N	24.16 N
Z	0 N	129.9 N
Strain		
Equivalent	8.054E-08	2.277E-04
1st Principal	6.995E-08	2.006E-04
3rd Principal	-2.195E-04	-3.306E-08
Normal XX	-1.762E-05	6.126E-05
Normal YY	-1.783E-05	2.915E-05
Normal ZZ	-1.169E-04	7.679E-05
Shear XY	-4.545E-05	3.654E-05
Shear YZ	-6.095E-05	1.405E-04
Shear ZX	-4.313E-05	1.455E-04
Contact Force		
Total	0 N	0 N
X	0 N	0 N
Y	0 N	0 N
Z	0 N	0 N

⊟ **Safety Factor**
⊟ **Safety Factor (Per Body)**

0 8

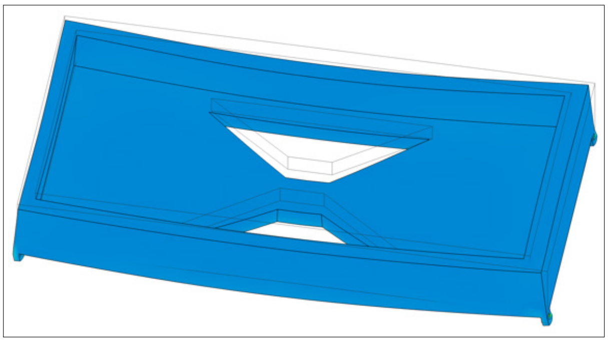


⊟ **Stress**
⊟ **Von Mises**
[MPa] 0.01 32.84



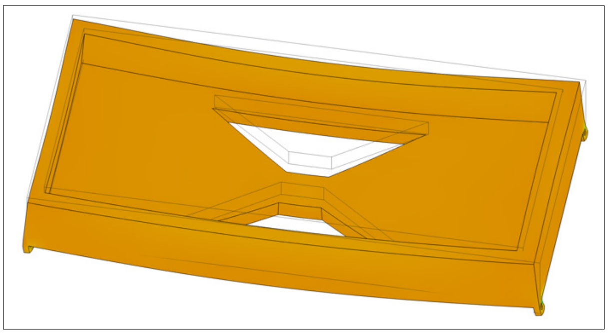
⊟ **1st Principal**

[MPa] -2.41 23.53

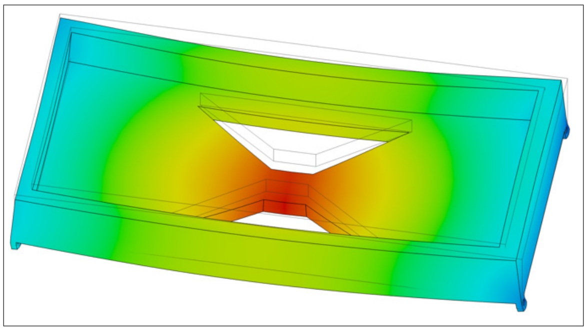


⊟ **3rd Principal**

[MPa] -28.42 3.04



⊟ **Displacement**
⊟ **Total**
[mm] 0 0.00563



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