Project Vulcan

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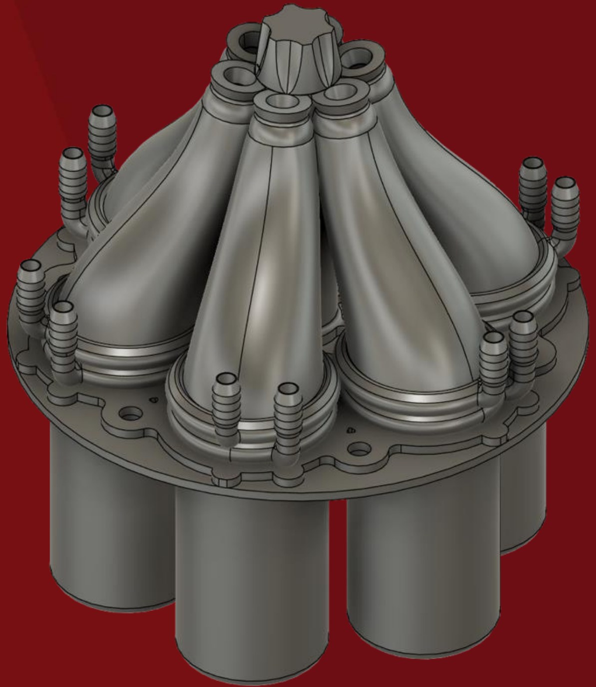
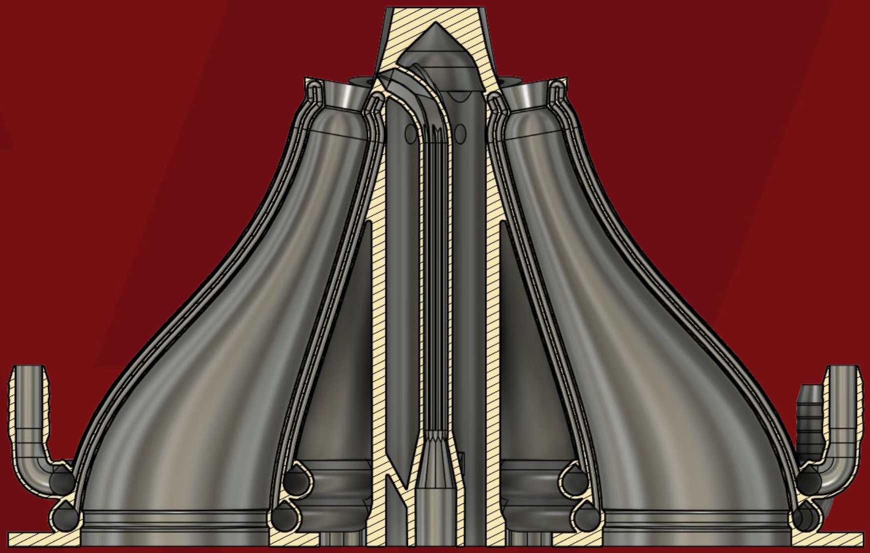
PROJECT OBJECTIVES

Objective #	Objective	Rationale
OBJ-01	The aerospike shall withstand a 3-second static fire test with solid rocket motors, simulating real-world flow conditions.	To assess the aerospike engine's aerodynamic efficiency and durability under operational conditions, ensuring it withstands the demands of repeated testing.
OBJ-02	The aerospike shall be fabricated using additive manufacturing technologies.	Leveraging 3D printing enables intricate design fidelity and rapid prototyping, ensuring optimal structural integrity and performance.
OBJ-03	The aerospike shall be compatible with the custom-designed test stand.	Ensuring compatibility with the dedicated test stand will streamline testing and validation, minimizing the need for additional adjustments.
OBJ-04	An altitude-simulating shroud shall be designed and fabricated to integrate with the aerospike system.	The shroud will simulate varying atmospheric conditions, allowing for accurate performance assessments across different altitudes, supporting data-driven insights.
OBJ-05	The aerospike shall incorporate a LITVC system.	Integrating LITVC will enable control over the thrust vector by injecting liquid into the exhaust flow, enhancing thrust direction precision and expanding control capabilities.

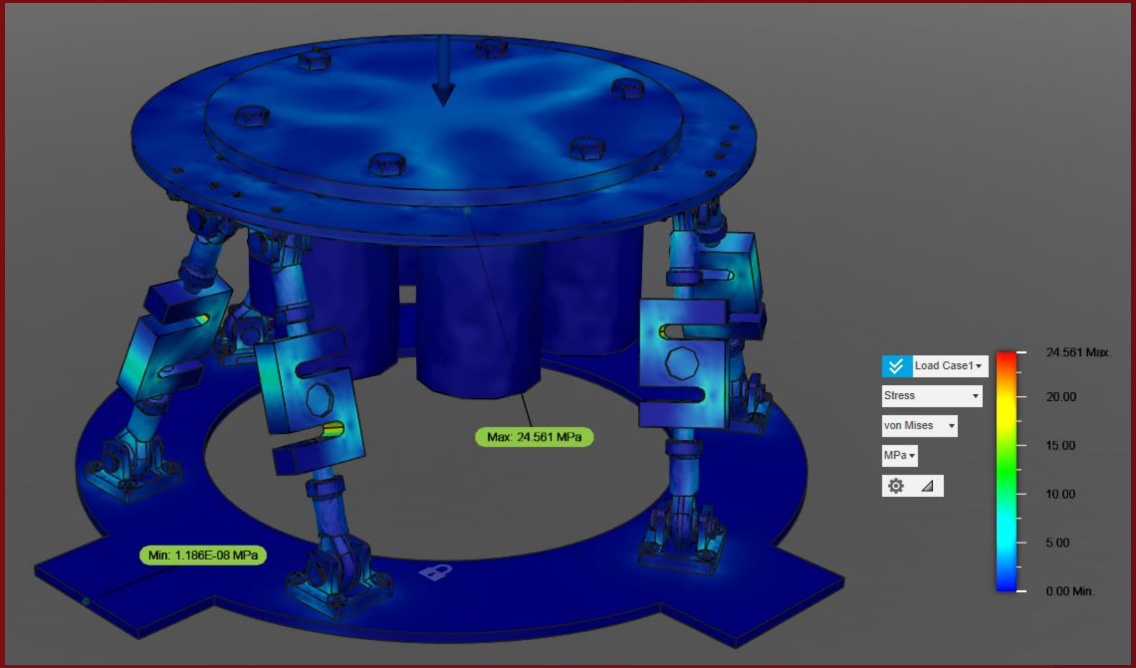
METAL 3D-PRINTED AEROSPIKE

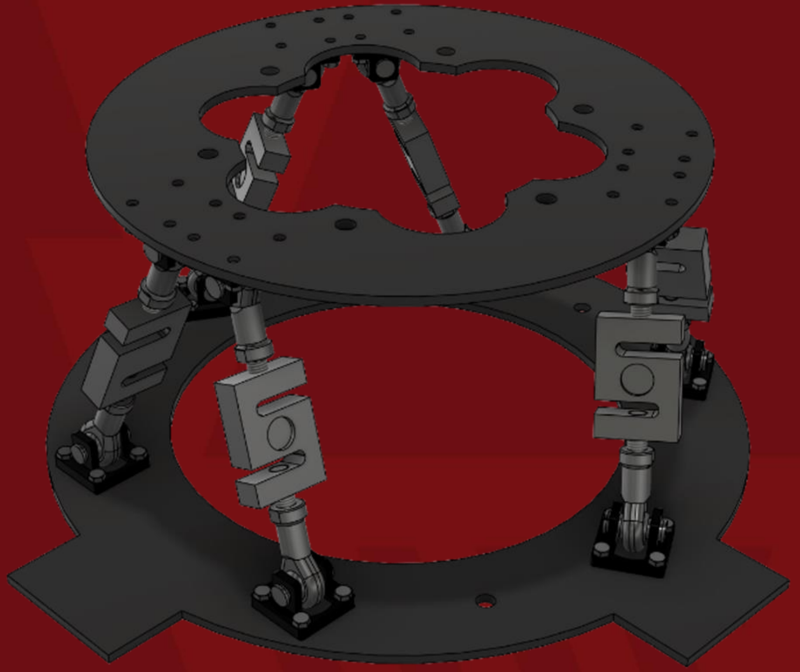




The metal 3D-printed radial aerospike engine represents a complex integration of advanced manufacturing, fluid dynamics, structural resilience, and data acquisition, culminating in a system designed for high-temperature, high-pressure static fire testing. The system-level components have been carefully developed to ensure a seamless and controlled testing environment at the Vaya Space facilities.

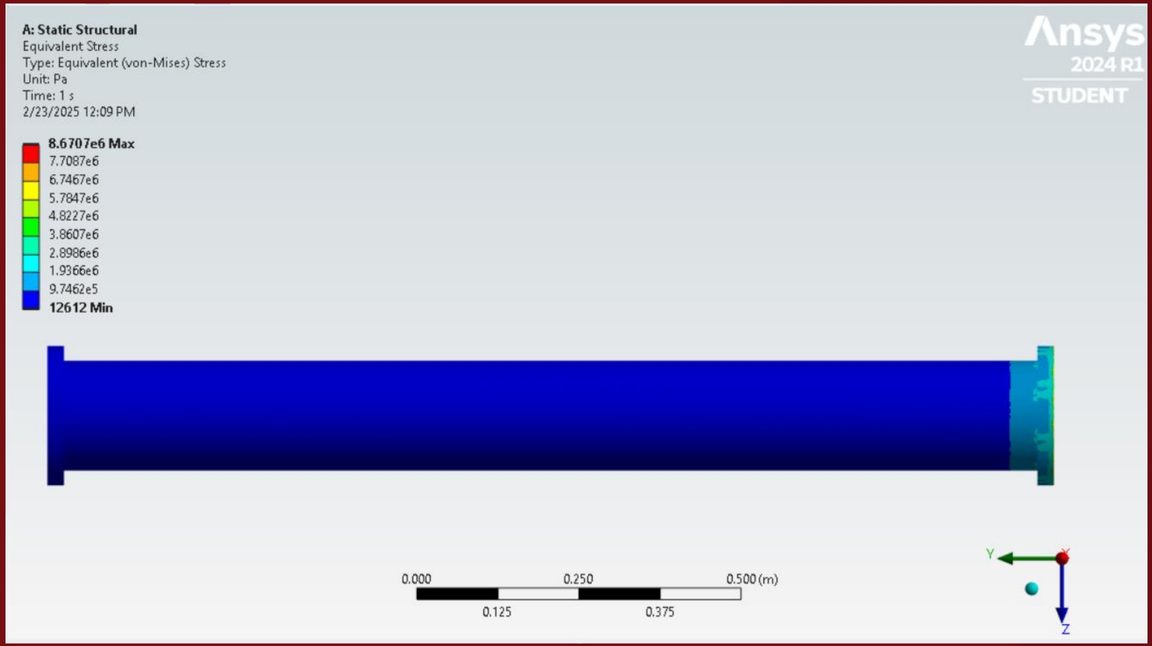
TEST STAND CONFIGURATION

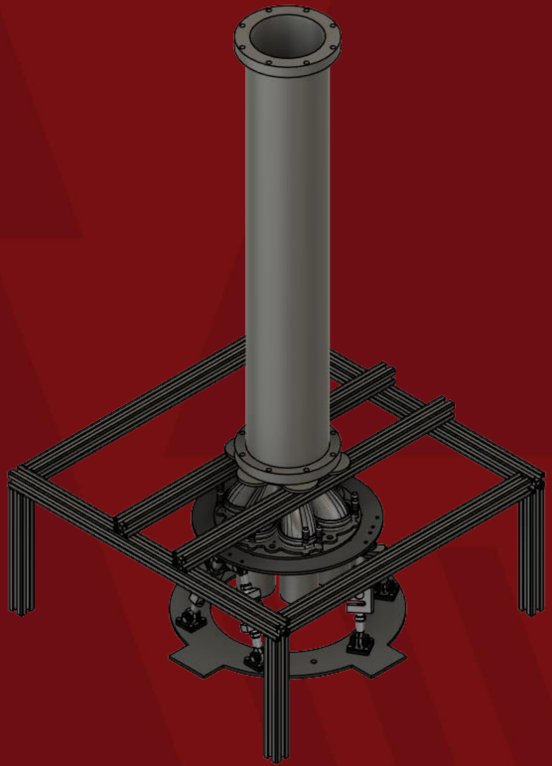




The custom-built test stand replicates a Stewart Platform and serves as the structural foundation for the aerospike engine, securing it against thrust forces up to 1.5 kN. The stand incorporates two steel plates, clevis brackets, spherical brackets, and load cells, ensuring accurate force measurement and stability. Two rings of M12 and M10 bolts are used to secure the model flange to the test stand for maximum structural integrity. The base is then bolted to the concrete floor at the Vaya Space test site during firings to ensure secure stabilization. The test stand was specifically designed to take measurements in 6 degrees of freedom (DOF). This is done to avoid constructing two different test stands for thrust and LITVC.

ALTITUDE SIMULATION SHROUD





An altitude-simulating shroud compatible with the aerospike design will be placed around the nozzle. This shroud will create controlled, localized pressure drop, simulating ambient atmospheric conditions experienced at various altitudes during a rocket launch. Thrust and pressure data will be recorded to validate the performance of the shroud and to evaluate how the aerospike performs under reduced ambient pressure, assessing its altitude-compensating efficiency.

TEST PLANS

Test Number	Test Name	Test Description	Requirement to be Verified by Test
01	3D Printed PLA Model and Test Stand Fitting	Validation that the aerospike design fits the test stand as designed before moving forward with metal 3D printing. It is also to validate that the test stand is correctly assembled.	SYS.03, SYS.05, STRUCT.04, and SAF.01.
02	Test Stand Data Collection and Electronic System Verification	Verification that the test stand was calibrated correctly, that the sensors record and report accurate data for the force and moment that will be generated by the aerospike design, and that the Python script works properly.	SYS.05, CONTR.02, and SAF.01.
03	Six Solid Rocket Motor Configuration Test Fire with E-Match Ignitor	Validation that a singular A8-3 solid rocket motor can be lit using an MJG Firewire Initiator then further validated by lighting a six A8-3 solid rocket motor configuration simultaneously using six MJG Firewire Initiators.	CONTR.01, SAF.01, SAF.03, SAF.04, and SAF.05.
04	LITVC Wet Dress Rehearsal	Validation that the LITVC system is integrated and functions as designed and that the data being collected is recorded and accurate.	SYS.03, PROP.03, CONTR.03, SYS.05, SAF.01, SAF.03, and SAF.05
05	Fully Integrated Metal 3D Printed Aerospike Including LITVC System and Altitude Shroud Simulation	Validation that the fully assembled metal 3D printed aerospike ignites safely and properly using the six solid rocket motor configuration, fuel grain, and test stand while recording the required data, that the LITVC system efficiently imposes lateral thrust for the aerospike, and that the altitude shroud that is being simulated records the thrust at an altitude of 25 km.	PROP.01, PROP.02, PROP.03, PROP.04, STRUCT.01, STRUCT.04, SYS.03, SYS.05, CONTR.02, CONTR.03, SAF.01, SAF.02, SAF.03, SAF.04, and SAF.05.

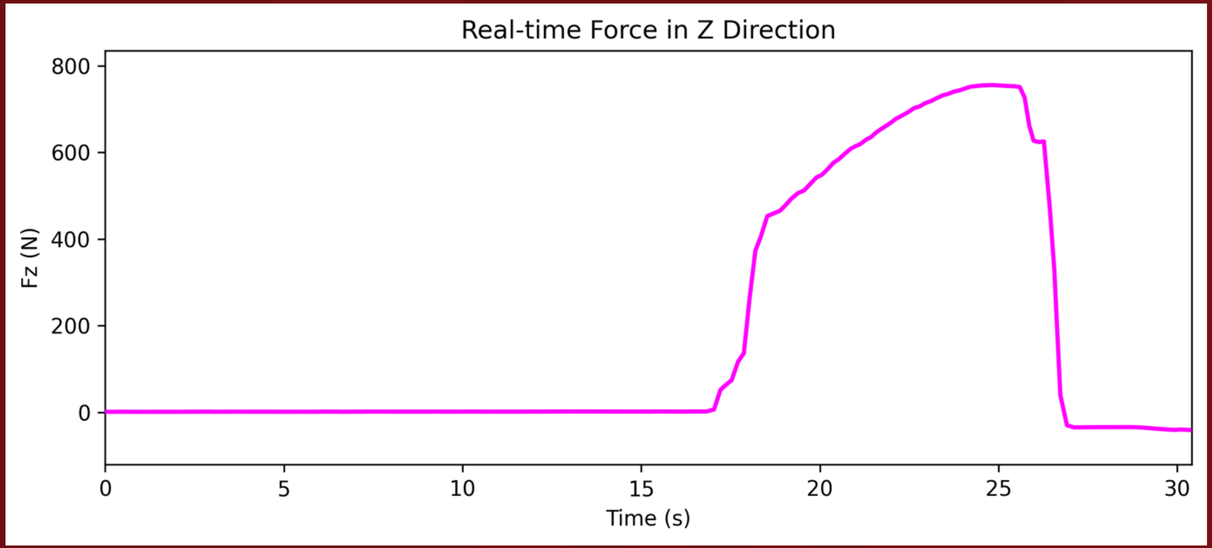
TEST FOOTAGE

Footage from Test Plan 3

TEST FOOTAGE

Footage from Test Plan 5

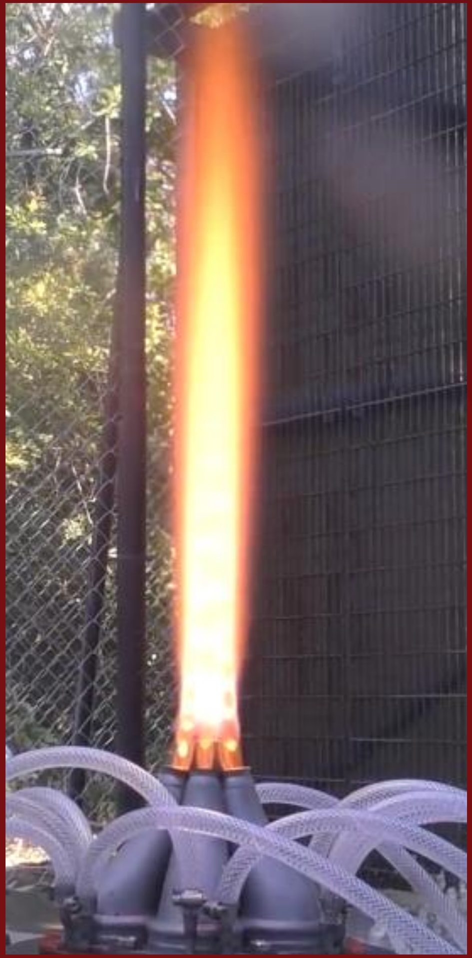
Test Run 1

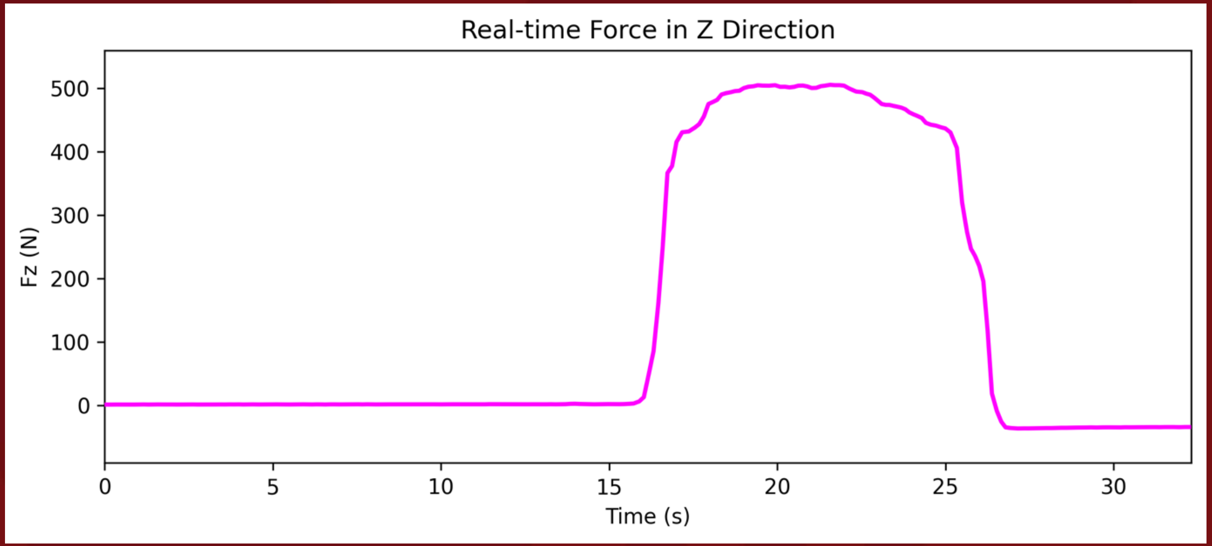


TEST FOOTAGE

Footage from Test Plan 5

Test Run 2



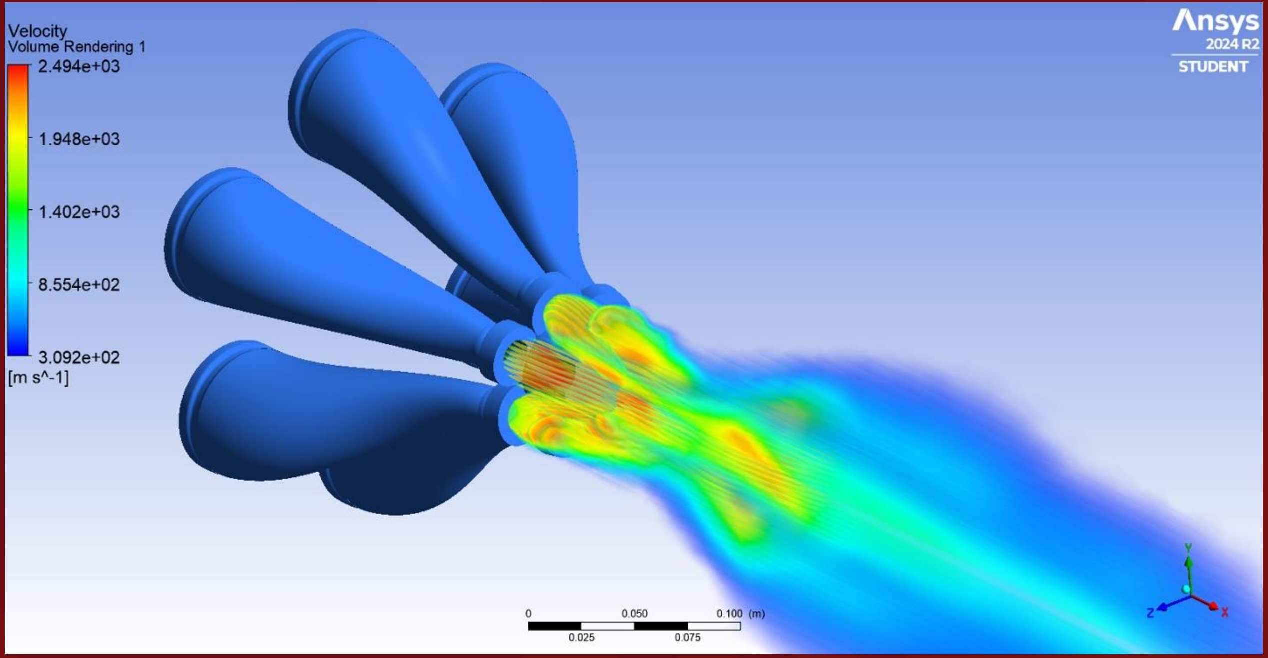


ADDITIONAL PHOTOS/FOOTAGE

ANALYSIS

The team utilized engineering tools and methods to validate the propulsion system and ensure the desired performance and survivability of the system. Computational Fluid Dynamics (CFD) simulations in ANSYS Fluent were employed to analyze flow behavior and predict pressure and thermal loads on the nozzle. Thermal survivability of the structure was verified using a combination of heat transfer data extracted from custom field functions written in Fluent and MATLAB-based heat transfer coefficient calculations. These coefficients were then applied in ANSYS Structural for a comprehensive thermal analysis. Subsequent structural simulations incorporated both thermal and pressure boundary conditions to confirm the system's integrity under expected operating conditions. The cooling system, critical to the survivability of the aerospike, was analyzed through a combination of MATLAB and CFD in Fluent to determine pressure losses and the required flow rate necessary to sustain effective heat removal.

The altitude-simulating shroud design incorporated pressure analyses using two methods: MATLAB-based calculations and Fluent CFD simulations. MATLAB employed simplified isentropic flow equations, combining nozzle throats into a single equivalent throat and predicting an internal pressure of approximately 6,334 Pa. In contrast, Fluent CFD simulations realistically modeled the geometry, capturing complex flow behaviors and interactions between individual nozzles, resulting in a higher internal pressure prediction of about 10,000 Pa. The 44.9% discrepancy between MATLAB and Fluent primarily arose from MATLAB's assumptions of ideal, frictionless, and isentropic conditions, and its simplification of multiple nozzles into one. Consequently, Fluent's higher predicted pressure was adopted as the simulated altitude condition.



LEVEL 1 SYSTEM REQUIREMENTS

Requirement #	Requirement	Rationale	Verification Method	Verification Strategy
SYS.01	The system shall employ a radial multi-engine vehicle-integrated aerospike design.	The aerospike design is critical for maintaining engine efficiency across a broad range of altitudes by naturally compensating for changes in atmospheric pressure.	Inspection	The design will be inspected to meet the qualifications of a radial multi-engine aerospike design and simulated to ensure efficiency.
SYS.02	The system and team shall comply with all safety requirements and implement the risk mitigation measures documented in this CDR document.	Safety standards, plans, and procedures as well as risk mitigation measures are required to be followed.	Inspection	Inspection of safety procedures and plans to verify that the requirements are being followed.
SYS.03	The system shall be compatible with an LITVC system.	The integration of a Liquid Injected Thrust Vector Control (LITVC) system within the aerospike design enhances thrust control, potentially lowering weight and increasing control precision compared to conventional gimbals.	Analysis, Test	Comprehensive analysis and testing will confirm the system's compatibility with the LITVC system.
SYS.04	The system shall be compatible with an altitude simulating shroud.	Simulating varying altitudes on the test stand shall provide data to further support aerospike efficiencies.	Analysis, Test	An all-encompassing shroud shall simulate a vacuum for the aerospike. Altering the shroud will dial in altitude estimations to simulate launch data.
SYS.05	The test stand shall house the aerospike design dimensions and sensors to accurately record test data.	The test stand must be designed to accommodate the aerospike's specific dimensions and integrate sensors to accurately capture the engine's performance metrics.	Inspection	Building and testing our custom test stand will allow us to ensure compatibility with the aerospike design and proper integration of sensors to record accurate and comprehensive performance data.

PROPULSION SUBSYSTEM REQUIREMENTS

Parent	Requirement #	Requirement	Rationale	Verification Method	Verification Strategy
SYS.01	PROP.01	The propulsion system shall be capable of supporting a burn duration of at least 3 seconds.	A continuous 3 second test duration provides sufficient time to observe and analyze steady-state plume interaction with the aerospike geometry, ensuring the system can withstand the propulsion environment.	Test	Verify that chamber pressure remains stable throughout the test, ensuring steady exhaust flow for the entire duration.
SYS.03	PROP.02	The LITVC system shall produce a thrust deflection of at least 3 degrees.	A lateral thrust deflection of 3 degrees provides directional control precision typical in aerospace applications without significantly impacting overall propulsion.	Test	Conduct controlled burns with the LITVC system to measure thrust vectoring effectiveness.
SYS.04	PROP.03	The altitude-simulating shroud shall be capable of simulating atmospheric pressure up to 25 km altitude.	Simulating up to 25 km altitude pressures is critical for evaluating the aerospike's performance in near-vacuum conditions, supporting efficiency studies at high altitudes.	Test	Measure static pressure during operation within the shroud, ensuring it matches the target pressure to replicate high-altitude conditions.

STRUCTURES SUBSYSTEM REQUIREMENTS

Parent	Requirement #	Requirement	Rationale	Verification Method	Verification Strategy
SYS.01	STRUCT.01	Spike structure shall withstand temperature cycles from ambient to operational extremes (up to 2,888 K).	The engine must withstand repeated cycles experienced during solid propellant ignitions without material degradation.	Inspection, Analysis	Thermal analysis and visual inspection will verify material integrity across repeated cycles, preventing potential failure from temperature-induced stresses.
SYS.02	STRUCT.02	Spike to engine/thrust stand mounting points shall maintain structural integrity under maximum expected thrust loads (up to 1.5 kN).	Mounting points must endure the full thrust of the engine to prevent structural failure during operation.	Analysis, Test	Load testing and finite element analysis (FEA) will confirm that mounting points can sustain these forces without deformation, ensuring operational safety.
SYS.01	STRUCT.03	All structural components shall be fabricated from materials compatible with solid propellant combustion byproducts.	Material incompatibility could lead to corrosion or weakening of structural elements, compromising safety and performance.	Inspection, Test	Material compatibility tests will be conducted with propellants and oxidizers to verify durability against exposure to combustion gases and residues.
SYS.05	STRUCT.04	Aerospike structure shall integrate with the propulsion system and custom test stand.	Ensuring compatibility with the custom test stand and propulsion equipment allows for smooth integration and reduces the need for modifications.	Inspection	A finite element load analysis will confirm the secure attachment and support of the six motors.

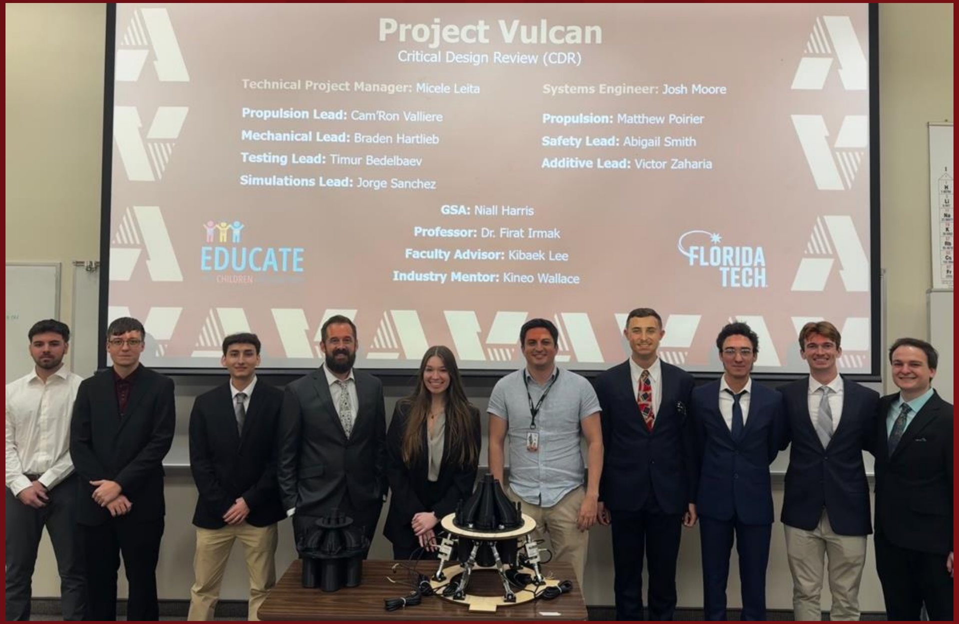
CONTROLS SUBSYSTEM REQUIREMENTS

Parent	Requirement #	Requirement	Rationale	Verification Method	Verification Strategy
SYS.05	CONTR.01	The control system shall be capable of initiating the engine start sequence remotely.	Remote start capability is crucial for operational safety, allowing controlled ignition initiation while ensuring personnel are safely distanced from the propulsion system.	Test	Perform remote ignition tests to verify the control system's start capability and operational safety.
SYS.05	CONTR.02	The control system shall record thrust data for engine performance parameters to a ground station.	Real-time thrust data is essential for monitoring engine performance and making informed decisions for post-flight analysis, enhancing system reliability.	Demonstration, Test	Demonstrate the system's capability to transmit accurate thrust data to the ground station during engine operations.
SYS.03	CONTR.03	The control system shall regulate liquid supply to the LITVC system during engine operation.	Precise control over the LITVC liquid supply is necessary to maintain stable and responsive thrust vectoring, ensuring effective maneuverability and control during testing.	Demonstration, Test	Verify liquid flow control functionality by testing system responses at various thrust vectoring angles.

SAFETY SUBSYSTEM REQUIREMENTS

Parent	Requirement #	Requirement	Rationale	Verification Method	Verification Strategy
SYS.02	SAF.01	The team shall meet all the safety requirements for Vaya Space and Florida Tech's Environmental, Health, and Safety Department (EHSD), the Cocoa Fire Department, and the City of Cocoa regarding safety training, PPE, hazardous material handling, and hot firing.	Required per Florida Tech EHSD and Vaya Space's safety procedures.	Inspection	Inspection of safety procedures and plans to verify that the requirements presented by Florida Tech EHSD and Vaya Space are being followed.
SYS.02	SAF.02	The system shall be constructed with a safety factor of 1.5.	The structural integrity under high-pressure and thermal loads associated with solid propellant combustion, a safety factor of 1.5 is applied.	Inspection, test, analysis	Demonstrate the system's capability to transmit accurate thrust data to the ground station during engine operations.
SYS.02	SAF.03	The system shall be tested in a safe operating zone at Vaya Space.	To prevent potential injuries or harm to any personal or surrounding environment.	Inspection	All personnel shall wear welding masks when directly viewing the test or remain in Vaya's control room.
SYS.02	SAF.04	The system shall include immediate containment protocols, including the availability of appropriate fire suppression equipment, to manage potential hazards during ignition.	Ensures rapid response to anomalies, providing containment measures to limit risk if an unexpected issue arises during burn.	Procedure Test	Verify the availability and readiness of fire suppression equipment and protocols through simulated emergency drills.
SYS.02	SAF.05	The safety system shall comply with regulatory standards and use the required personal protection equipment (PPE).	To prevent potential injuries or harm to any person as well as adherence to safety expectations.	Inspection	Documentation that specifies the required PPE that needs to be used and defined safety standards.

TEAM PHOTOS/FOOTAGE



TEAM PHOTOS/FOOTAGE

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