Design of a Cold-Gas Propulsion System for the STARI Mission

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***Abstract*—The STarlight Acquisition and Reflection toward Interferometry (STARI) mission is a NASA-funded joint project led by the University of Michigan with Georgia Institute of Technology, Stanford University, Rensselaer Polytechnic Institute, and NASA's Jet Propulsion Laboratory (JPL) as participants. The mission aims to demonstrate the first transfer of starlight between spacecraft by utilizing two estimated 6U sized CubeSats that will be developed by the universities. The satellites will be separated by approximately 100 meters in Low Earth Orbit , aiding in developing technology applicable to future interferometry missions that require the high angular resolution needed to effectively search for nearby planets that reside in habitable zones around stars.**

As the propulsion system provider, the Georgia Tech Space Systems Design Lab (GT SSDL) will design, manufacture, and deliver cold-gas propulsion units for each spacecraft. The project builds upon Georgia Tech's experience working on similar formation flying missions such as the SunRISE, VISORS and SWARM-EX missions. In particular, the Virtual Super-Resolution Optics using Reconfigurable Swarms (VISORS) mission features two 6U formation flying CubeSats, and as such, it is the initial baseline for the STARI propulsion system design. Utilizing the design heritage of the VISORS mission aids the STARI mission in both timeline and budget constraints while providing an opportunity to improve the propulsion system design.

The main design change that the team is exploring during Phase A of the STARI mission is the addition of a heater to the cold-gas propulsion system. The GT SSDL's cold-gas propulsion systems, such as the VISORS propulsion system, traditionally feature a two-tank design that allows fluid to completely vaporize before exiting the nozzles. Historically, the propulsion system has produced variable thrust based on environmental conditions that must be compensated for by the control system. A goal of the heater in the STARI propulsion design is to improve upon the heritage system by providing a more consistent and repeatable thrust and impulse.

This paper presents the design process for the STARI propulsion system to highlight the development of major performance parameters such as delta V, required propellant mass, and specific impulse. It also examines the design changes from the VISORS propulsion system, such as the addition of the heater, and discusses lessons learned from prior missions.

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1. INTRODUCTION

University CubeSat missions provide opportunities to conduct useful science operations and test new technological concepts on a smaller, faster, and more affordable scale than larger missions. As CubeSats and small spacecraft become more prevalent in the space industry, some projects are focused on how to apply technologies used on larger spacecraft to these smaller, less expensive platforms. The Virtual Super-Resolution Optics using Reconfigurable Swarms (VISORS) and the Starlight Acquisition and Reflection toward Interferometry (STARI) missions are two such projects that aim to demonstrate the miniaturization of larger satellite technology.

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The STarlight Acquisition and Reflection toward Interferometry (STARI) mission is funded by the National Aeronautics and Space Administration (NASA) as part of the Astrophysics Research and Analysis Program (APRA). STARI addresses NASA's strategic interest in developing space interferometry capabilities. The project is a joint mission between the University of Michigan, Georgia Institute of Technology, Stanford University, Rensselaer Polytechnic Institute, and NASA's Jet Propulsion Laboratory (JPL). Georgia Tech is responsible for providing the propulsion system for STARI, which is an enabling technology for multi-satellite interferometry.

Interferometry is a technique that allows for high angular resolution of telescope images by combining light beams from an array of telescopes at different locations. Interferometry on the ground is a commonly used measurement technique, but it is limited by geography, weather, and atmospheric variations. A space-based interferometry system could be used to identify planets with similar atmospheres to Earth's by improving the measurement quality relative to Earth-based interferometry networks [1]. Currently, there have been no system-level demonstrations of formation flying space-based interferometers at the precision needed for this application due to the high costs and risks associated with such a mission. The STARI mission provides an ideal platform for a technology demonstration towards interferometry due to the relatively low cost of CubeSat missions. The two estimated 6U sized CubeSats, currently referred to as STARI-1 and STARI-2, require relative position knowledge within millimeters while co-orbiting the Earth at separation distances between 10 to 100 meters apart [2].

The VISORS mission, an earlier project supported by the National Science Foundation (NSF), was initiated from the CubeSat Ideas Lab in 2019 and aims to image the solar corona at high resolution using two 6U CubeSats. The two satellites act as a distributed diffractive telescope using an optics spacecraft (OSC) and a detector spacecraft (DSC) positioned approximately 40 meters apart during science operations [3]. Each CubeSat contains an additively manufactured cold-gas propulsion system which was designed, assembled, and tested by the Georgia Tech (GT) Space Systems Design Lab (SSDL) to allow for positional maneuvering during orbit. VISORS is currently undergoing spacecraft integration and testing at NASA's Goddard Space Flight Center.

Both the STARI and VISOSRS missions require precise satellite maneuverability to conduct their scientific operations. Therefore, the design of an effective propulsion system for precision CubeSat position control is necessary to meet the mission success criteria. The focus of this paper is on the design of the additively manufactured STARI propulsion system, which includes lessons learned from the earlier VISORS mission and other past cold-gas propulsion systems built by the GT SSDL that have informed the design.

2. HERITAGE DESIGN

Past cold-gas propulsion systems developed by the GT SSDL share many common features. Units are characterized by a two-tank design with a main tank for propellant storage and a plenum tank used to vaporize the propellant. All designs use the refrigerant R-236fa for propellant, which was initially selected for its volumetric efficiency and safety advantages, and is now well characterized by the lab. More specifically, R-236fa can be stored as a liquid, allowing for high volumetric efficiency at a fixed volume. It is also chemically non-reactive, which is beneficial for both safety planning and spacecraft interaction [4]. Additionally, its saturation pressure at 50°C is less than 100 psi, which allows for the tanks to be certified for launch vehicles more rapidly than higher pressure vessels which require additional fracture analysis and testing.

In the main tank, the propellant is kept at its saturation pressure, where it is stored in a saturated liquid-vapor mixture state. A single solenoid valve connects the main tank to a smaller tank called the plenum. The plenum tank is smaller than the main tank, but as it is not used to store propellant, the pressure in the plenum tank is lower than that in the main tank. For example, on the VISORS propulsion systems, the plenum was 17% of the main tank volume on the OSC and 28% of the main tank volume of the DSC. On both VISORS spacecraft, the plenum pressure is kept between 80-95% of the main tank pressure.

Ideally, when propellant enters the lower pressure plenum, it vaporizes completely and can then be directed through any one of the other valves and nozzles on the propulsion system, providing thrust in various directions. Filling the plenum is accomplished through a closed loop refill process, where the operator sets a plenum pressure threshold, prompting the system to refill the plenum in small intervals to ensure the propellant in the plenum is maintained in a gaseous state [5]. The VISORS complete system features seven solenoid valves, with six valves accompanying orthogonal nozzles to provide impulses to the system in different directions. Figure 1 shows an example of the fluid flow pathways on the VISORS propulsion system in a piping and instrumentation diagram (P&ID) and illustrates the directions that each nozzle may provide an impulse. Nozzles may be fired in pairs to allow for null torque impulses in the desired direction [3].

The propellant tanks are additively manufactured from Somos PerFORM material using stereolithography (SLA), which involves curing a resin material layer by layer throughout the printing process [5]. Additively manufactured tanks allow for complex internal geometries to efficiently use the overall volume that the propulsion system occupies on the satellite. Mainly, this process allows for the creation of internal fluid pathways that would be extremely difficult or impossible to manufacture by other means. The overall shape of the tank can also be easily modified to allow for the best placement of the propulsion system within the spacecraft bus.

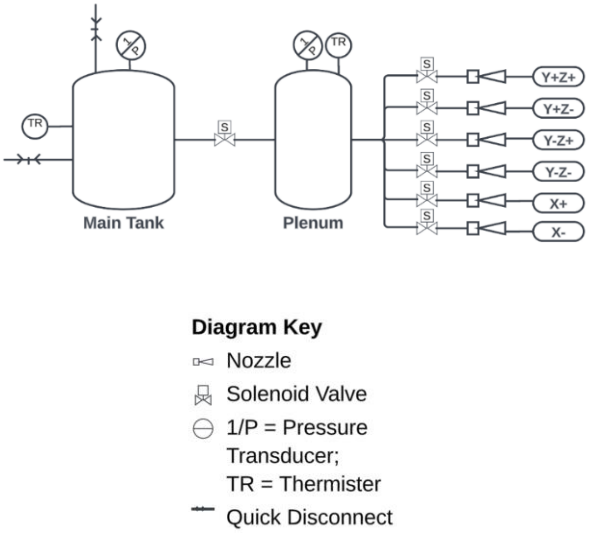

Figure 1. VISORS flow pathway schematic.

However, it is imperative that any residual debris from the SLA process is minimized or completely removed after fabrication. Small, unwanted resin particles that cling to the structure are an unavoidable aspect of the printing process. These particles pose a risk to the system's performance should they cause any blockages in nozzles or valves or reduce the effectiveness of sealing surfaces which can cause leaks. Following the post-machining process, the units are flushed repeatedly with isopropyl alcohol (IPA) and bathed in an ultrasonic cleanser to remove any leftover debris from the fabrication [5].

Both tanks on the VISORS propulsion system include a thermistor and a pressure transducer that provide the necessary state information for the temperature and pressure of the propellant to perform precise maneuvers. These sensors are introduced to the tanks through traditionally machined metal plates that are bolted to the structure. Similarly, a stainless-steel valve manifold block is bolted to the top of the propulsion system. Control avionics boards are soldered to the valve manifold structure. For example, Figure 2 shows a CAD image of the VISORS propulsion system on the OSC Spacecraft. The DSC Spacecraft propulsion unit is nearly identical to the OSC unit in functionality, with geometry changes to account for the differing volume constraints of the two spacecraft.

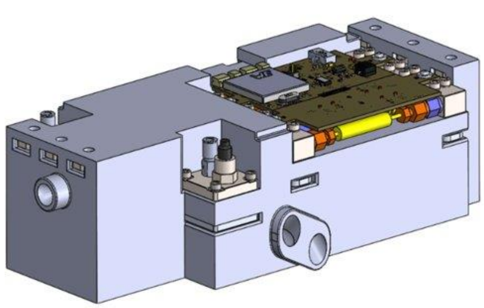

Figure 2: VISORS OSC propulsion unit.

3. ASSEMBLY, INTEGRATION, AND TEST OF PROPULSION UNITS AT GEORGIA TECH

Along with designing cold-gas propulsion units, the GT SSDL has a breadth of experience in assembling and testing propulsion systems "in-house". All flight hardware is handled and assembled in an ISO Class 8 cleanroom to limit the introduction of foreign object debris (FOD) to the hardware. After assembly, propulsion systems undergo performance and environmental testing in the SSDL's thermal vacuum (TVAC) chamber. The TVAC chamber can reach pressures as low as 1E-6 Torr during high vacuum and has an operating temperature range of -10°C to +60°C. These capabilities allow for system bakeouts, thermal cycling tests, leak checks, and performance testing of the flight units. Performance testing the propulsion units involves the use of a torsional thrust stand which allows the thrust and impulse of the nozzles to be characterized [5]. Figure 3 shows the VISORS propulsion system on the torsional thrust stand ready to transmit its performance data in the TVAC chamber. The STARI propulsion systems will follow the same testing process as the VISORS systems, using the same TVAC and thrust stand lab equipment, as well as the same test procedures.

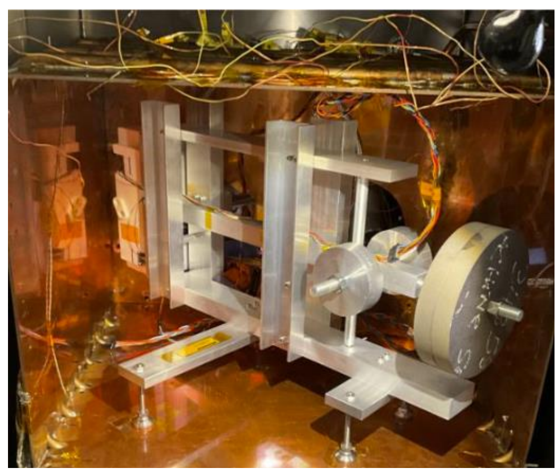

Figure 3: VISORS propulsion unit (left side of photograph) on SSDL torsional thrust stand.

4. LESSONS LEARNED AND FUTURE DESIGN IMPROVEMENTS

Due to the similarity of the VISORS project to the STARI mission, and the valuable characterization of the VISORS propulsion systems gained throughout their design, assembly, and testing, the VISORS design is being used as the baseline design for the STARI propulsion system. However, there are several lessons learned from VISORS and past propulsion projects that will benefit the STARI propulsion system design. One of the main areas that the design of the STARI propulsion system aims to improve is the consistency of thruster performance with the addition of a heater or propellant management system.

Most of the cold-gas propulsion systems produced in the

SSDL have operating temperature bounds from about 0°C to 50°C. In the case of the VISORS propulsion system, the lower bound was derived from electronics limits, while the upper bound is imposed by structural design limitations. Since the SSDL cold-gas thrusters are pressure-fed, variations in temperature will affect the performance of the systems. Through thermodynamic relationships, the temperature of the gas has a direct relationship to its specific impulse. Furthermore, specific impulse and thrust are related. As such, at higher temperatures, a higher specific impulse and higher thrust can be expected from the system. With the current propulsion system design, the pressure and temperature readings from both the main tank and the plenum allow operators to determine how long to conduct a "firing" (actuation) to achieve the performance desired for a particular maneuver in orbit. Providing automatic thermal control on these cold-gas propulsion systems could greatly improve the repeatability and thus the life of the spacecraft, as it could reduce the amount of propellant usage needed per maneuver.

Another important aspect in the performance of the SSDL cold-gas propulsion thrusters is the phase of the propellant leaving the nozzle. Ideally, by the time the saturated mixture reaches the valves, it has transitioned to a purely vapor form. The function of the plenum is to vaporize any fluid that enters the tank due to its lower pressure. However, the success of this operation depends partially on the temperature in the plenum being the same or higher than the temperature in the main tank. If the plenum temperature drops below the temperature of the saturated mixture, some of the propellant could condense into a liquid state when it reaches the plenum [6]. Temperature control can also be used to mitigate this issue. While vaporization could be expected with higher confidence by the addition of a heater on the main tank, it is non-ideal to place a heater on the main tank in the current design, as it could potentially lead to over-pressurization and structural failure. More likely, the STARI design will utilize a heater in the plenum tank or near upstream of the nozzles to ensure that the propellant enters the valves in a gaseous state.

5. Analysis Methodology, Assumptions, and Parameters

The STARI mission recently completed Phase A, where teams established preliminary design information and conducted trade studies. Phase A concluded with a System Requirements Review (SRR) presentation that was given to an external panel of experts in December 2025. This section describes the process of developing the preliminary design for the STARI propulsion system.

Before beginning the design of the STARI propulsion system, the Georgia Tech team conducted a trade study on possible options for the STARI propulsion system that examined the use of low thrust electrosprays as an alternative technology, procuring a commercial propulsion system, and designing the propulsion system in-house. Ultimately, while there are pros and cons for each propulsion option the team could pursue, designing the propulsion system in-house was determined to be cost-effective and provide more design flexibility than purchasing or customizing a commercial cold-gas system. The cold-gas propulsion systems produced in the SSDL are cost effective and volume efficient due to the propellant characteristics and storage methods, while providing the directions of thrust necessary for precision three-axis position control. The combination of these features can be difficult to procure affordably in an off-the-shelf propulsion system, making the GT SSDL cold-gas propulsion systems the best known option for the STARI project. One of the contributing factors to the STARI propulsion system's technology readiness level (TRL) is the design heritage described previously in this paper, specifically from the delivered VISORS propulsion system.

Preliminary design calculations were completed using MATLAB scripts that can be easily altered if design inputs, such as delta-V, spacecraft mass, and propulsion system volume from the larger STARI team change, or if changes need to be made to the propulsion system. This methodology encourages flexibility if any of the assumptions used in the analysis change. In this analysis, when two state variables were known, the publicly available CoolProp software tool was used to readily determine other state properties of the propellant [7].

The STARI propulsion system's nozzle geometry is common with VISORS and other past SSDL cold-gas systems. This nozzle geometry has been characterized in the past through performance testing and has proven to be a successful geometry for systems of this magnitude. Furthermore, it will allow for ease of comparison between the STARI system and test data that has been accumulated from past SSDL propulsion projects.

The delta-V budget is determined based on how many maneuvers the two spacecraft must perform to achieve science goals over the mission lifetime. Overall estimated spacecraft mass (including the mass of the propulsion system itself) and delta-V are very closely related as shown in the following results section. The propulsion system volume determines the amount of propellant that the STARI propulsion system can store. A greater propellant storage volume will increase mission lifetime.

The initial delta-V analysis assumes a satellite mass of 12 kg as a reference point, which is the current STARI spacecraft mass estimate. Future analysis iterations will include higher mass estimates to build in as much margin, volume permitting, into the propulsion system design as possible. This analysis is conducted assuming a main tank and a plenum tank where a heating element is applied in the plenum tank, so gas going through the nozzle is at a consistent temperature of 50°C if sufficient time is allotted to heat the gas in the plenum tank before operation. This temperature was selected for the initial analysis as it is the maximum temperature that the systems are designed to operate. However, this temperature will be refined as the analysis continues. To better visualize the placement of the heater for the analysis discussed in this paper, consider the system design shown Figure 1 with a heating element in the plenum tank (likely attached to one of the walls that does not contact the main tank). By placing the heater in the plenum tank, the assumption becomes that the initial, or stagnation temperature, of the plenum tank is equal to the temperature of the heater.

6. STARI PRELIMINARY DESIGN CALCULATIONS

Prior to conducting the performance analysis, initial estimates for delta-V and specific impulse (Isp) are established. Estimates are set at values that would be considered ideal for this system in order to derive a preliminary volume for the main tank. Using the initial estimates for delta-V (Δv), specific impulse (I_{sp}), and initial mass (m_0), the required propellant and system dry masses are derived.

$$\Delta v = u_e \ln \frac{m_0}{m_f} \tag{1}$$

$$m_{prop} = m_0 - m_f \tag{2}$$

This propellant mass can be used to find the volume of the main tank where the propellant is stored as a saturated vapor-liquid vapor mixture. The stored propellant is primarily liquid, with some gas existing in the mixture in the form of an ullage bubble. It is useful to maintain the storage tank at the propellant saturation pressure and temperature since it allows the system to remain in equilibrium and makes it simple to understand the conditions of the main tank at any given time based on the temperature and pressure readings in the tank. The density of the saturated liquid R-236fa at a temperature of 50°C and the associated saturation pressure are used for calculations [8]. It is assumed that in these conditions, the majority of the propellant is a liquid, which allows for maximum propellant mass storage.

The pressure of the plenum is controlled to be between 80%-95% of the main tank pressure. After determining the volume and associated pressure of the main tank, the minimum and maximum expected pressure of the plenum tank can be readily calculated. These minimum and maximum pressures act as thresholds when refilling the plenum tank or firing the valves. Valves will never be fired for a duration such that the pressure of the plenum would drop below the minimum threshold, and the plenum will never be filled to more than the maximum pressure. These restrictions ensure a satisfactory pressure ratio across the valves while still providing an environment where the propellant fluid will vaporize upon entering the plenum. To size the plenum, an ideal value for the mass of propellant that should be able to exit the plenum and ideal volume of the plenum are evaluated. In the STARI guidance, navigation, and control (GNC) analysis, the largest single delta-V maneuver is estimated to be around 60 mm/s for transitions between different science operations. The propellant mass expelled in a single actuation is lower than the largest single delta-V maneuver, meaning the system will operate in a series of impulses to achieve larger maneuvers. Based on the estimated propellant mass expelled from the plenum, the total mass that the plenum should store given the changes in pressure before and after operation is calculated using the ideal gas law.

$$m_{plenum} = \frac{m_{expelled} \times P_{max}}{P_{max} - P_{min}} \tag{3}$$

Next, the Mach number at the nozzle exit is determined using the Newton-Raphson iterative solver method. This analysis employs an initial guess for the Mach number and iterates between the isentropic equation for Mach number at the nozzle exit and its derivative until there is negligible difference between the two values. In Equation 4, M_e is the exit Mach number, A^* is the cross-sectional area of the nozzle throat, A_e is the cross-sectional area of the nozzle exit, and γ is the ratio of specific heats.

$$M_e = \frac{A^*}{A_e} \cdot \left(\frac{\gamma+1}{2}\right)^{\left(\frac{-\gamma+1}{2(\gamma-1)}\right)} \cdot \left(1 + \frac{\gamma-1}{2} \cdot M_e^2\right)^{\left(\frac{\gamma+1}{2(\gamma-1)}\right)} \tag{4}$$

After finding the exit Mach number, the resulting pressure ratio is found using isentropic flow relations, which aids in calculating the exit velocity where the temperature of the propellant is equivalent to the temperature of the heater.

$$\frac{P}{P_0} = \left(1 + \frac{\gamma-1}{2} {M_e}^2\right)^{\frac{-\gamma}{\gamma-1}} \tag{5}$$

$$u_e = \sqrt{\frac{2\gamma}{\gamma-1} R T_0 \left[1 - \left(\frac{P_e}{P_0}\right)^{\left(\frac{\gamma-1}{\gamma}\right)}\right]} \tag{6}$$

Equation 6 is used to solve for the exit velocity (u_e), where T_0 is the stagnation pressure, or in this case, the temperature of the heating element, and the pressure ratio is calculated from Equation 5. The specific impulse is found using Equation 7, where g is the gravitational acceleration constant at sea level, 9.81 m/s^2. Finally, delta-V is derived from Equation 1 using the new specific impulse value.

$$I_{sp} = \frac{u_e}{g} \tag{7}$$

Using this analysis methodology with an assumed main and plenum tank temperature of 50°C, the achieved delta-V is approximately 14 m/s and the specific impulse is about 43 seconds. Knowing the specific impulse and delta-V, other useful parameters for the STARI system such as thrust and total impulse are calculated.

Given that the STARI propulsion system and overall spacecraft are still undergoing design changes, it is important to understand the relationships between how changes in the overall spacecraft will affect the design of the propulsion system. For example, if the spacecraft mass increases while the volume allotted to the propulsion system remains constant, the larger spacecraft mass produces less delta-V.

Similarly, the propulsion system lifetime is typically extended when more propellant can be loaded into the main tank. As such, when designing the propulsion system tank, the main tank volume will be maximized as much as possible while still ensuring proper wall thickness and space in the propulsion system volume for electronics and the plenum tank.

Figure 4 shows an example of the impact of temperature dependence on thrust. The analysis used to create this chart assumes a constant specific heat ratio and illustrates the positive relationship between temperature and overall thrust in the system, where the temperature is the temperature of the main tank fluid. The STARI propulsion system thrust analysis will continue to evolve with more detailed nozzle placement as the spacecraft design is completed.

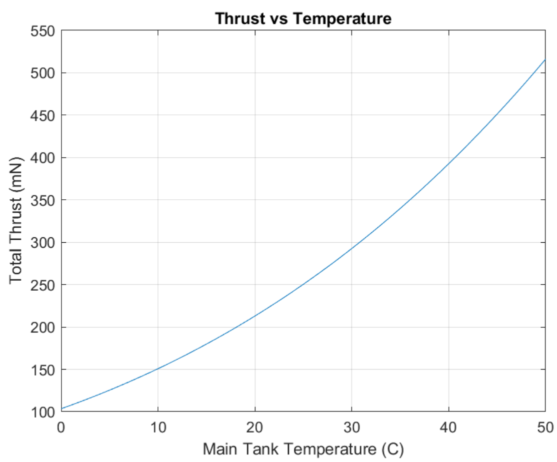

Figure 4: Thrust vs Temperature Plot.

The thrust, specific impulse, plenum temperature, plenum pressure, mass flow rate, and delta-V of a single maneuver are plotted in Figure 5 through Figure 8 as a function of time while the system is fired. In the following figures, the black 'x's' on the graphs indicate the time when the plenum firing must be concluded as to not drop below the specified minimum pressure ratio between the plenum and main tanks. The plenum is not empty at this point in the firing process, but operation of the thruster will cease until the plenum can be refilled. Longer elapsed time on the graphs demonstrate how thrust would be affected if the plenum continued to fire for a longer period of time. To examine the effect of main tank temperature on propulsion system performance, the analysis was conducted at different main tank temperatures of 0°C, 25°C, and 50°C.

The thrust of the propulsion system is mainly driven by the pressure and temperature of the main tank. The plenum tank is filled to satisfy a certain pressure percentage between it and the main tank. Typically, the plenum is filled to around 95% of the main tank pressure. The thrust that the system can produce is largely driven by the initial pressure of the main tank. As such, higher main tank temperatures produce more thrust, but adding a heater to the plenum tank does not have a significant effect on the thrust of the system.

While the thrust information presented in Figure 5 is unchanged by a plenum tank heater, the specific impulse, as shown in Figure 6 becomes uniform across main tank temperatures when a plenum tank heater is added. When a heater set to heat the gas in the plenum tank to 50°C is added to the system, the specific impulse will behave the same as the top, thicker yellow line in Figure 6, which is with a tank temperature of 50°C, since specific impulse is strongly affected by the stagnation temperature in the plenum tank, and therefore the exit velocity. It is also important to note from these figures that as time goes on, if the plenum was allowed to empty completely of mass, the performance efficiency per mass would be greatly reduced. This behavior is why operation is paused when the pressure ratio between the tanks drops below about 80 percent.

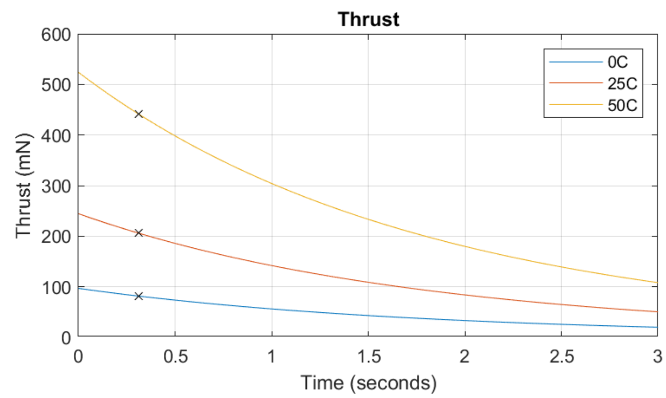

Figure 5: Thrust vs Time at different Main Tank temperatures.

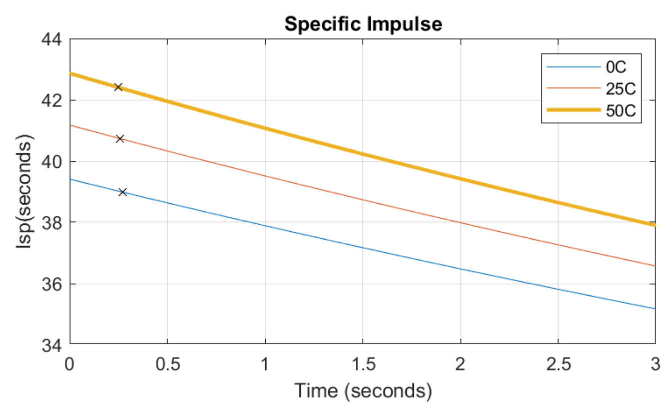

Figure 6: Specific Impulse vs Time at different Main Tank temperatures.

Analysis of the STARI design also focuses heavily on the achieved delta-V of the system. Like specific impulse, delta-V is largely impacted by the heater temperature. For a varying main tank temperature and a constant heater temperature in the plenum tank, the total delta-V of the system is expected to be constant. For a constant main tank temperature, an increase in the plenum heater temperature would increase the total system delta-V linearly due to the higher pressure of the propellant exiting the plenum. The relationship between total delta-V and main tank temperature is shown in Figure 7.

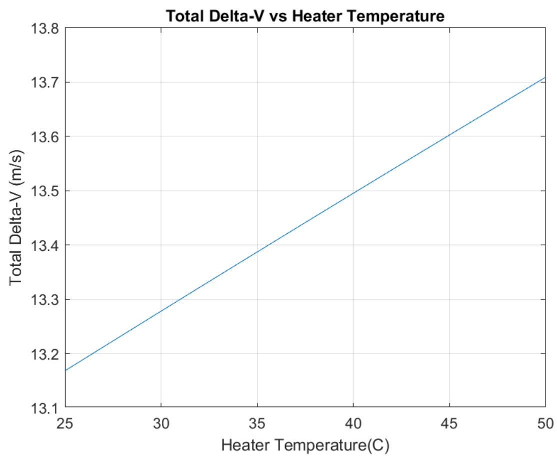

Figure 7: Total Delta-V vs Heater Temperature (constant Main Tank temperature).

However, it is also important to understand the delta-V impulse that can be obtained with each firing of the propulsion system. The delta-V obtained versus time is shown in Figure 8. This is not the total delta-V of the system, but a delta-V obtained from the instantaneous exit velocity and the propellant mass expelled from the plenum tank over time. Note that there are diminishing returns as the plenum is left open beyond its designed 80% pressure ratio refill threshold level (past the 'x' in the figure).

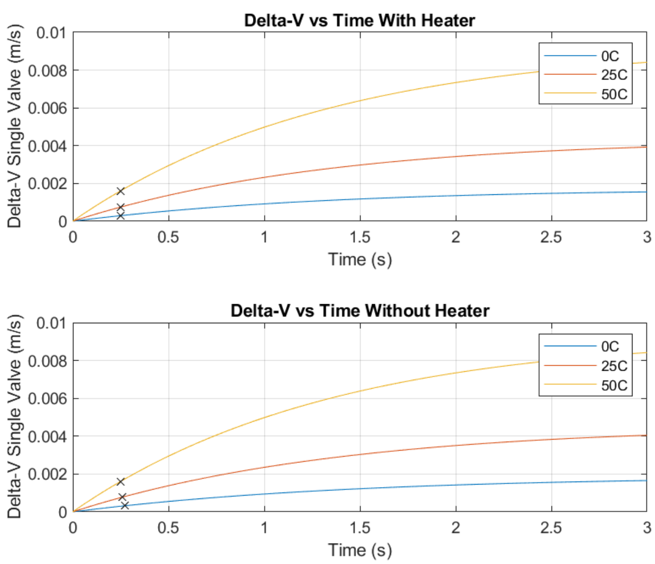

Figure 8: Single Maneuver Delta-V vs Fire Time at different Main Tank temperatures.

Based on the initial design parameters determined through this stage of analysis, an initial external model of one of the propulsion systems has been drafted to aid in the spacecraft mechanical design. As shown in Figure 9, this propulsion system model includes main features such as preliminary nozzle locations and cutouts for pressure and temperature sensors as well as an area dedicated to the valve manifold block. The mechanical design will be updated and refined as more information becomes available.

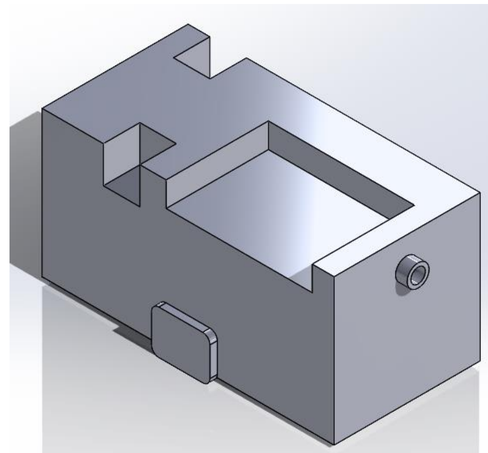

Figure 9: STARI External Features Model (draft).

7. Requirements

The STARI mission conducted its System Requirements Review (SRR) in December 2025. The current analysis for the propulsion system complies with the majority of the draft requirements currently set by the STARI team to conduct successful science operations. A portion of high priority propulsion system requirements are summarized in Table 1.

Table 1: STARI Propulsion System Requirements and Allocations

Requirement	Value	Compliance
Total ΔV	≥12 m/s	13.7 m/s Compliant via analysis
Minimum Impulse	<2 mNs	TBD (Likely based on past VISORS data)
Degrees of Freedom	Three	Nozzle Placement analysis
Volume Constraint	1.5 U (1500 cm^3)	Working to this volume in analysis
Power Budget	15 W (in work)	This is an estimate based on preliminary heater sizing and valve usage

From the current requirements defined for the STARI system, the propulsion system calculated delta-V meets or exceeds the mission requirements. While the requirement for minimum impulse bit was originally set to be less than 0.4 mN·s, this requirement was relaxed to align with the VISORS measured minimum impulse bit of 1 mN·s that was measured during TVAC testing. The expected minimum impulse bit is due to the time delay in the opening and closing of the valve, as well as the time for the flow to reach steady flow through the valves. Steady flow conditions through the valve are not achieved until around 20 milliseconds after the valve actuation command, since transient effects of the valve will account for some reported impulse during testing but are not true performance values [4],[5]. Further analysis on minimum impulse bit will be conducted in the future to better refine this requirement. The new requirement is for an expected minimum impulse bit of 2 mN·s due to the expected impulse increase associated with operating at a higher temperature from the heater. Relaxing this requirement impacts the operational plan and capabilities of the mission as a spacecraft may not be able to move with as much precision as the current requirement would allow. This could require increased maneuvering to achieve the desired position, resulting in more propellant consumption per maneuver. Furthermore, nozzle placement and resulting thrust vector analysis is on-going with the STARI team, but the system will be able to meet the degrees of freedom requirement by replicating the VISORS nozzle pairing strategy.

Power budget analysis is also ongoing as the power draw of the propulsion system is heavily influenced by the heater that is selected for the design. In a preliminary power budget analysis, the expected power draw for constant operations is 15 W. The valves require a 12 V spike and a 1.6 V hold during operation, corresponding to around 14 W during valve actuation, but less than 1 W while holding the valve open. For a plenum heater that is capable of providing a 50°C temperature increase of the gas in the plenum, the required power is around 9 W for a 15 second hold time. The power required for this type of heater design will increase if the desired time to heat the gas is less than 15 seconds.

8. Conclusion and Future Work

The STARI propulsion system design will mature as the mechanical, GNC, and science requirements continue to develop. The STARI mission is a multidisciplinary project that spans multiple academic institutions. During Phase A, teamwide discussions on feasibility and goals of the mission were highly beneficial toward designing the propulsion system. The design process and work described in this paper serve as the foundation for the final STARI propulsion system. The analysis will continue to evolve along with the spacecraft design and mission concept of operations.

The volume of the plenum should not affect performance of the propulsion system, as it is designed to operate within a specific pressure range regardless of volume. However, the size of the plenum has a great effect on the maximum amount of delta-V the system can obtain during one valve firing. A smaller plenum tank may allow more room for the main tank to expand, but will require shorter, more frequent pulses to obtain the desired delta-V effect for a given orbital maneuver which affects the mission concept of operations. Overall, current analysis shows that the main benefit of including a heater in the plenum tank is repeatability of the thrust actuation. The addition of a heater in the plenum tank allows for greater confidence that the propellant in the plenum tank will be gas. It would be interesting to explore the possibility of a heating element in the main tank, as the initial pressure in the main tank is a main driver for the thrust performance parameter. If the temperature, and therefore pressure, of the main tank could be controlled, the thrust performance could be kept near the maximum allowable performance that occurs when the fluid is at 50°C. However, introducing a heating element to the entire main tank introduces a risk of over-pressurizing the main tank should the temperature of the main tank exceeds 50°C. Another interesting heater placement opportunity could be adding a heater at the external valve tubing on the valve manifold to determine if the gas exiting the main tank could be vaporized upon actuation. These two heater placement options will be explored during the Spring 2026 academic semester to both select a path forward for the heater option and reduce the risks with changing the VISORS design to add a heater.

During Spring 2026, design parameters for an engineering development unit (EDU) will be finalized. Further analysis includes selecting a heating element, choosing the desired temperature the heating element should apply to the exiting gas, conducting an analysis driven trade study on how to best allocate volume to the main tank versus the plenum tank, and quantifying available margins on performance parameters such as delta-V. Minimum impulse bit and further delta-V analysis will also continue to better inform mission design and operations planning. Finally, nozzle placement decisions will inform plume impingement analysis. Currently, the team is looking into placing the propulsion system in such a way that avoids plume interaction with the solar panels.

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BIOGRAPHY

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