Ensuring Optical Stability: Developing a Precision Mirror Mount

For the SHIMCO Sounding Rocket Mission

February 18, 2026

Abstract

Precise optical alignment in sounding rocket missions requires mirror mounts that resist vibration and minimize displacement. This study evaluated two initial mount designs using SolidWorks simulations to measure static displacement, vibrational displacement, and resonant frequency across multiple materials. Mount #2 (1045 steel) performed best among the initial designs due to lower vibrational displacement and a higher resonant frequency. Two more designs (Mounts #3 and #4) were then developed. Both final mounts significantly reduced displacement and increased resonant frequency above 2,000 Hz, exceeding the normal vibration range experienced during launch. Mount #4 achieved the lowest vibrational displacement overall.

These results demonstrate that structural optimization improves launch survivability and optical stability for the SHIMCO sounding rocket mission.

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Introduction

SHIMCO Mission Overview

The Spatial Heterodyne Interferometric Molecular Cloud Observer (SHIMCO) sounding rocket mission, targeting launch in mid-2027, from White Sands Missile Range, will study the properties of the ρ and ζ Ophiuchi molecular cloud complexes, two nearby active star forming regions. SHIMCO will be launched into the thermosphere (~350 km) to observe far-ultraviolet fluorescence emissions from molecular hydrogen in that region. Hydrogen is the largest component of these star-forming molecular clouds; however, it is rarely directly observed because molecular hydrogen emission occurs in the far-ultraviolet range which is invisible to the unaided eye and difficult to measure from Earth due to atmospheric absorption (Corliss et al., 2022; Meyer et al., submitted)

The SHIMCO mission will use a highly specialized optical instrument known as a Reflective Spatial Heterodyne Spectrometer (RSHS). An RSHS is an ultra-high-resolution spectrograph designed for space-based spectroscopy, meaning that it can observe light from space to learn about the properties and behavior of celestial objects. This instrument works by separating different wavelengths of light, similar to how prisms separate white light into a rainbow (i.e., a spectrum). However, instead of using a simple prism, an RSHS separates colors using a system of mirrors and gratings which create patterns of light. These light patterns, called interference fringes, can then be analyzed to infer the exact wavelengths present in the light, corresponding to different colors that reveal information about the materials that produced them (Corliss et al., 2022).

In the case of the SHIMCO mission, researchers will be searching for information on hydrogen's far-ultraviolet wavelength emissions in the ρ and ζ Ophiuchi molecular cloud complexes. The position of the components, like the mirrors, in this type of instrument must be precisely aligned to get accurate measurements. Adjusting the positions can change the bandpass of light that is measured, meaning the range of light wavelengths that the instrument can collect data on. This precise tuning capability allows the instrument to be adjusted to capture specific hydrogen emission lines (Corliss et.al., 2022).

Ensuring Optical Stability

Since SHIMCO relies on measuring very small shifts in ultraviolet wavelengths, around 161 nm for molecular hydrogen, even tiny changes in the optical mounts can affect performance (Corliss et.al., 2022). For example, in high-precision optical instruments, the optical path length (the distance the light travels) should remain stable within one part in a million. In other words, for an optical path length of approximately one meter, the system should remain stable within a micron (±0.001 mm). This required level of stability becomes especially important for instruments that are sensitive to thermal expansion, vibration, and other mechanical errors (Yoder, 2008).

The instrument's fine-tuning ability relies on the mounts to ensure that the optical components, such as the mirrors and grating, are in the correct alignment. The need for these precise adjustments becomes a challenge in space missions due to the environment that the instrument will be exposed to during the launch and while in space. Some of the key environmental considerations for optical instruments in space are vibration, pressure, and temperature (Yoder, 2008). These factors must be kept in mind while designing mirror mounts.

There are changes that can be made to mount designs which help mitigate some environmental concerns that can change the reliability of optical instruments in space. As the temperature in the sounding rocket changes, materials will expand or contract based on their coefficients of thermal expansion. If multiple parts in the mounts are made of different materials, they may change size at different rates, which can warp, loosen, or damage parts, including the mirrors. When the rocket is placed in vacuum, the materials may also change in volume and in some extreme cases they will completely break down. Any closed pockets of air may also cause damage or explode because of the pressure difference in the air pockets and the inside of the rocket. Some materials that are often used for optical mounts because of their low coefficients of thermal expansion and their vacuum compatibility are stainless steel, titanium, and invar (Yoder, 2008).

Another critical factor in mount design is resonant frequency, which is the natural frequency at which a structure vibrates the most. If a structure is excited at its resonant

frequency, displacement can increase significantly. Therefore, it is important to design structures so that their resonant frequencies lie outside the frequency ranges that the rocket experiences. Launch vibration data from a NASA sounding rocket study indicates that the highest concentration of vibration frequencies experienced for the Aerobee 150A sounding rocket occurs below 2,000 Hz, particularly during the early portion of launch (Nagy & Coble, 1964). Above 2,000 Hz, the vibration levels are significantly reduced in both the longitudinal and lateral frequency plots (Nagy & Coble, 1964). Based on this data, designing mirror mounts so that the mount's natural resonant frequency exceeds 2,000 Hz helps reduce displacement and improve the stability of the optical system throughout launch.

Design Options

There are two mount designs being considered for the SHIMCO mission; each comes with its own advantages and disadvantages. In a spring-based mount, the mirror is held against the mount with a spring. Screws are inserted at multiple points on the mount which push against the mirrors and can be adjusted to position the mirror appropriately. Glue can be applied to the end of the screws to adhere them to the mirror. The spring-based mount is good for precise adjustments; however, it is less practical for rocket flights because the spring can vibrate during launch. Locking mounts eliminate this problem by using screws both for positioning and locking but require custom fasteners, making the design more expensive than spring-based mounts. These custom screws consist of two parts: (1) a high thread count positioning screw used to adjust the mirror, and (2) a locking screw which inserts into the positioning screw and holds the mirror in place (see Figure 1). The outer screw has a high threads-per-inch (TPI) count, which allows for finer, more precise adjustments and increases resistance to loosening under vibration due to the greater friction between the screw and the mount (Ramey & Jenkins, 1995). Like the spring-based design, there are multiple screws around the back of the mount that can be adjusted to align the mirror. This project focuses on fabricating and testing these mount designs for the SHIMCO sounding rocket to address challenges in maintaining optical alignment throughout the mission and to ensure stable performance under launch and space conditions.

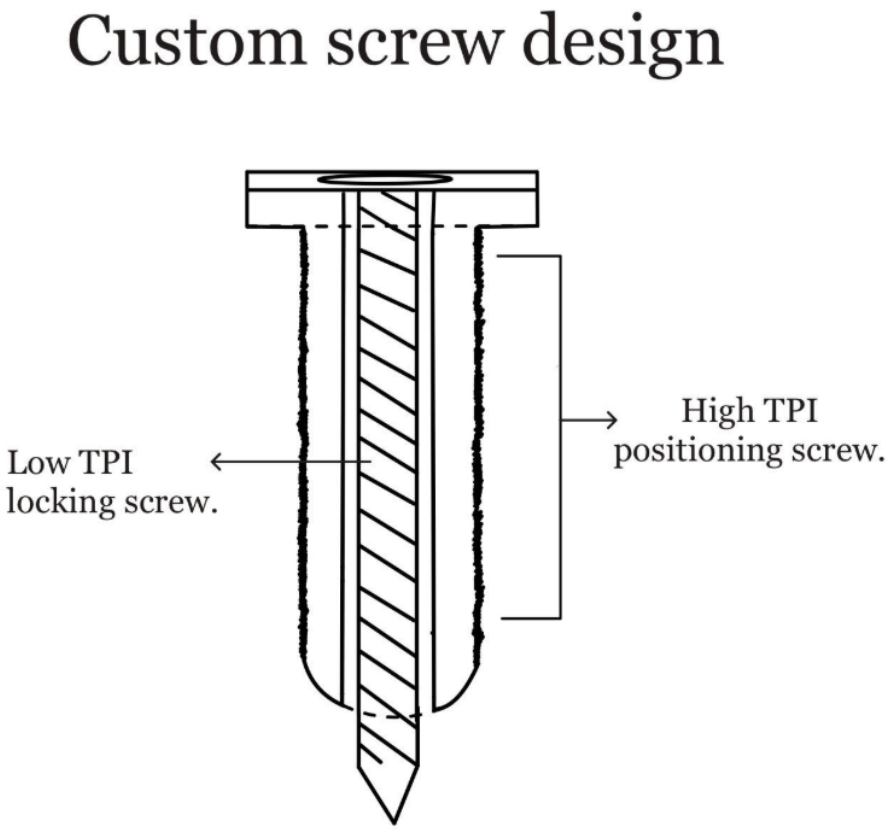

Figure 1 *Cross section of the custom screw design.*

Project Goal

The primary goal of this project is to develop a mount design that balances stability with adjustability, allowing the mirror to remain precisely positioned even in the presence of intense environmental conditions, in a way that supports the SHIMCO mission goals. This is important to make sure that data collected about the ρ and ζ Ophiuchi molecular cloud complexes during the SHIMCO mission is reliable, accurate, and useful for future scientific advancement.

Methods

As part of this research process, two different mount designs were modeled and analyzed to determine how effectively they would maintain alignment and resist deformation. Past testing of optical mounts has involved testing the materials used to examine the coefficients of thermal expansion, their resistance to humidity, and the life

of the mount before they become unreliable (Yoder, 2008). However, this specific project also emphasizes the mechanical elements of a mount design that make it stable. Due to the custom design requirements, getting the mounts manufactured to test was not realistic given time and budget constraints.

SolidWorks was used to model and conduct simulations on the mounts. The measurements of the mirror that will be flown on SHIMCO were used to create the models. Both models included unique structural features intended to influence the stability of the mirror (see Figure 2).

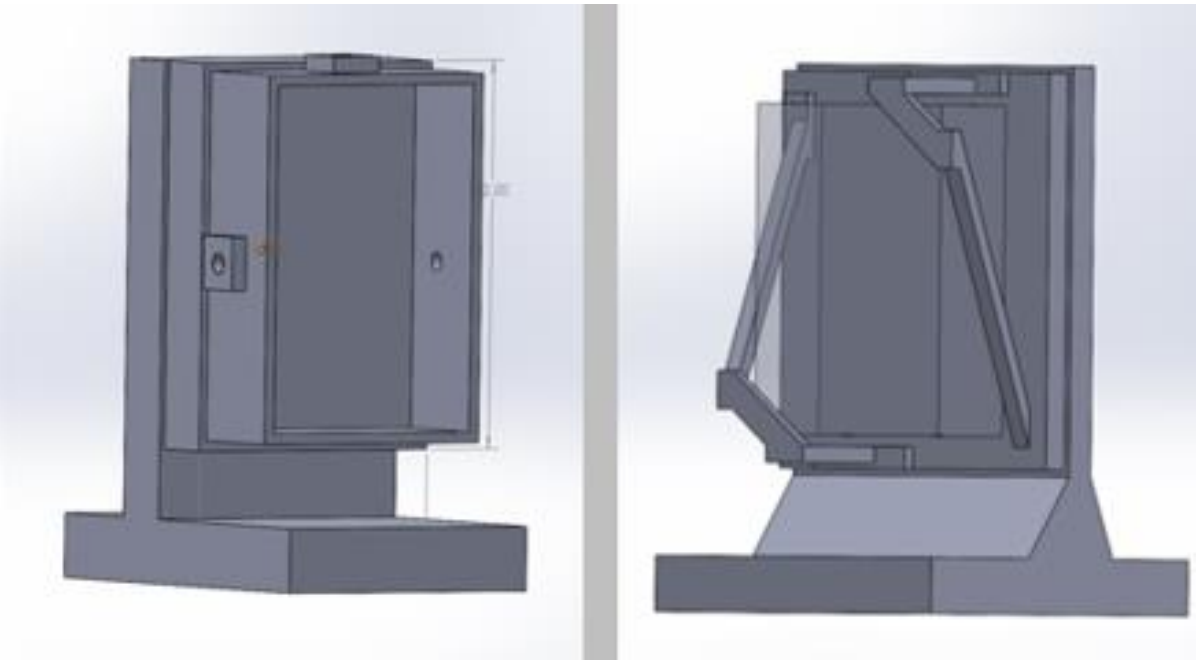

Figure 2 *Two initial mount designs.*

Following this, the mounts were run through a series of three simulations using different materials: 316 stainless steel, 1045 carbon steel, 6061 aluminum alloy, and copper 182. These metals were selected based on their range of mechanical properties, thermal behavior, and typical use in optical components (Yoder, 2008). The first simulation evaluated the displacement from the force of the mirror, calculated to be (1.23N). The second simulation evaluated the maximum displacement along the y-axis due to vibrations that move the mount along the x-direction. The third simulation determined the resonant frequency of the design. In addition, the coefficient of thermal expansion for each material was also considered to account for thermal deformation.

The results were analyzed to determine which design features and material combinations most effectively minimized displacement. As the simulations were run, each design-material combination was placed on a bracket, and the highest-performing design moved forward. The winner of this bracket was then compared to a final optimized design, based on the observation made during the initial simulations. Unlike the initial two designs that were fully created and then tested to establish a baseline, the final design was periodically tested throughout the modeling process to maximize the overall improvement of the final design.

Results

Bracket Results

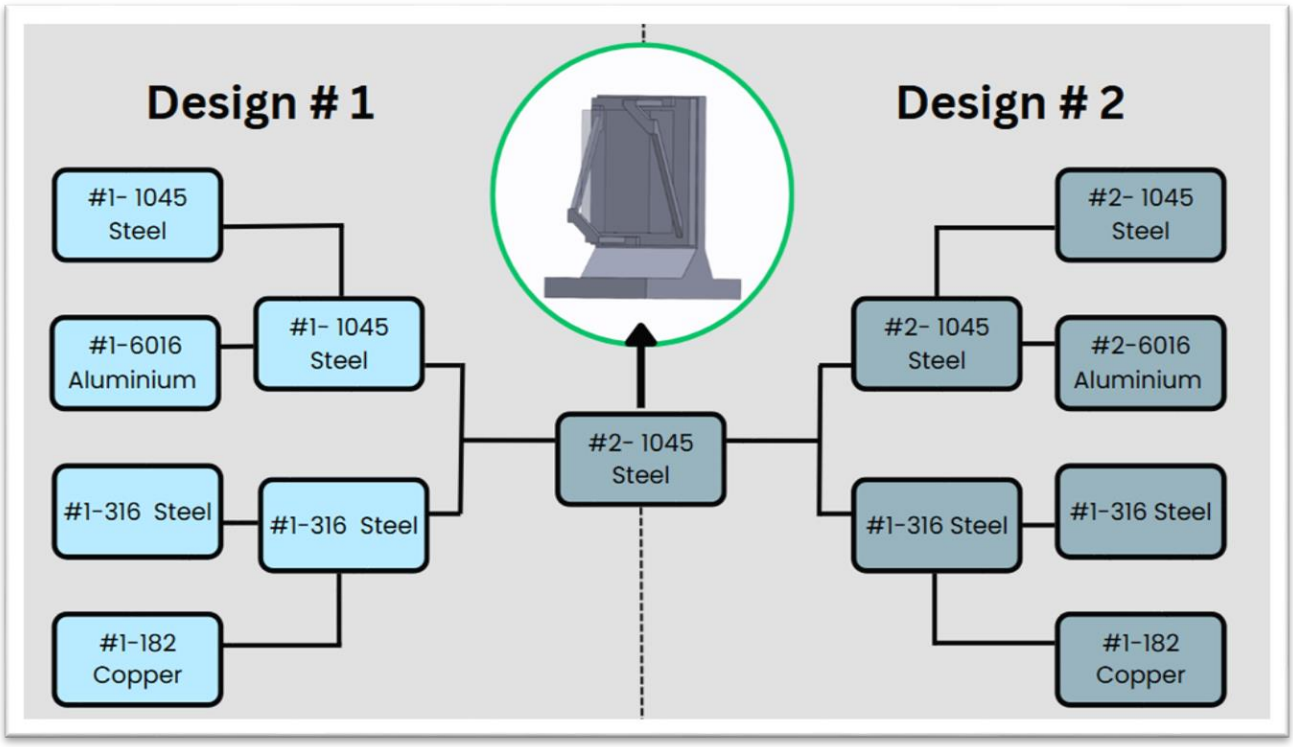

Figure 3 *Bracket results for original designs.*

Value	Mount #1	Mount #2	Mount #3	Mount #4
Average mirror displacement (mm)	5.61×10^{-5}	1.26×10^{-4}	2.30×10^{-5}	2.88×10^{-5}
Max vibration displacement, y-axis (mm)	3.96×10^{-2}	1.74×10^{-2}	4.44×10^{-3}	2.87×10^{-4}
Resonant Frequency (Hz)	1,017.8	1,130.7	2,609.1	2,216.2

Table 1 *Comparison of Mount Designs in 1045 Steel. CTE for 1045 Steel is* 1.15×10^{-5} */K.*

As shown in Figure 3 and Table 1, Design #1 in 1045 steel demonstrated lower static displacement from mirror load (5.61×10^{-5} mm) compared to Design #2 (1.26×10^{-4} mm). However, Design #2 exhibited lower vibrational displacement along the y-axis (1.74×10^{-2} mm compared to 3.96×10^{-2} mm for Design #1). Additionally, Design #2 achieved a higher fundamental resonant frequency (1130.7 Hz) than Design #1 (1017.8 Hz). Both configurations shared the same coefficient of thermal expansion (1.15×10^{-5} /K), as they were simulated in the same material. Therefore, Design #2 in 1045 steel was selected as the bracket winner.

Final design

The final design was only modeled in 1045 Steel as it performed the best for the first two mounts. The final mount also had two variations created (mount #3 and mount #4) (see Figure 4). The mirror load displacement was applied to the design in two different ways and the total displacement was found to get a more well-rounded analysis of the designs (see Figure 5). This would depend on the orientation of the mount inside the rocket.

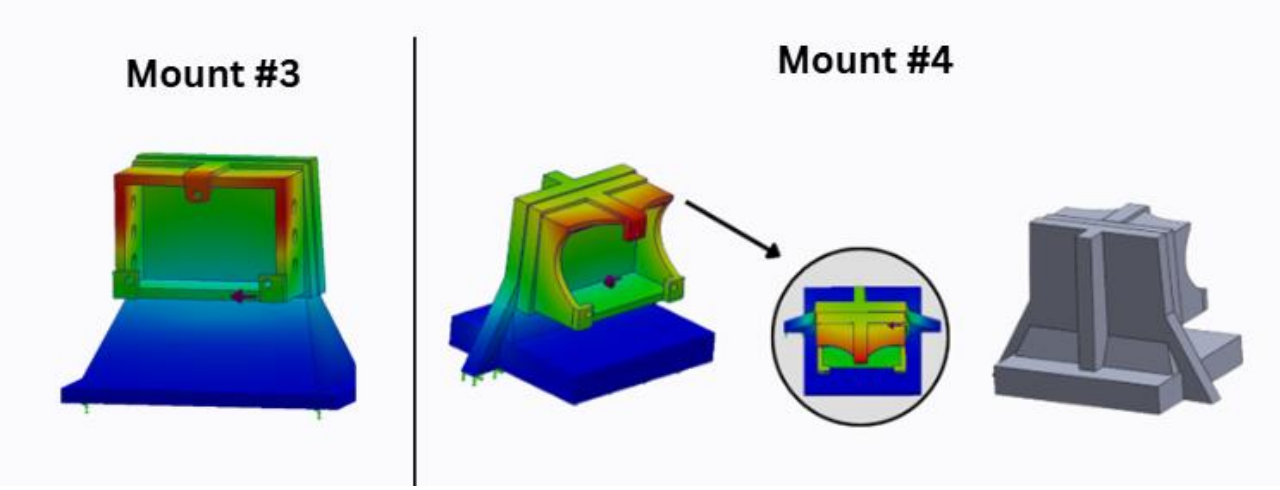

Figure 4 *Final mount designs, vibrational displacement simulation*.

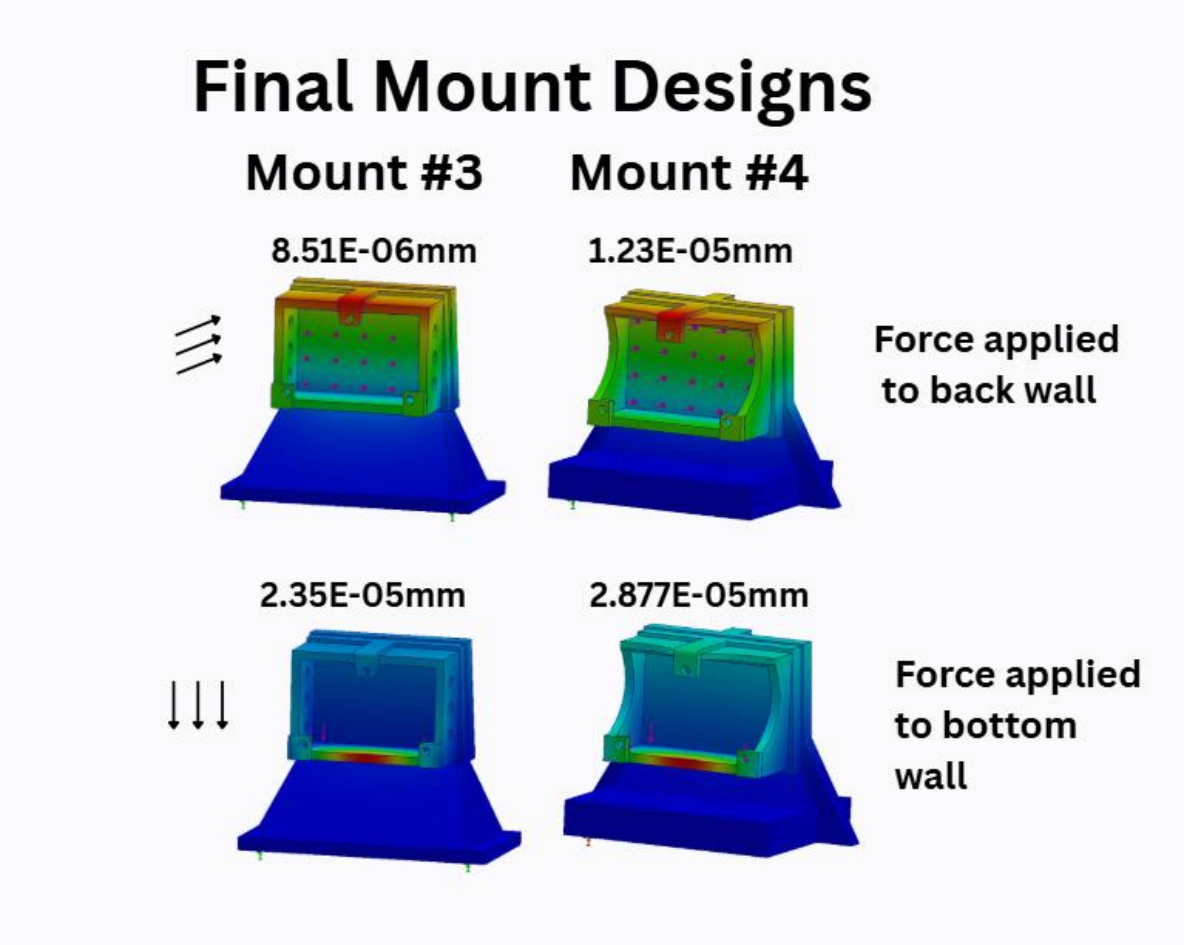

Figure 5 *Total Static displacement from mirror (1.23N), force applied in two different areas.*

The resonant frequency of the final designs, mounts #3 and #4, increased relative to Designs #1 and #2. Both exceeded the 2,000 Hz requirement. Mount #3 reached ~2,600 Hz and Mount #4 got to ~2,000 Hz.

Discussion

This study evaluated two initial mirror mount designs (Mount #1 and Mount #2) across multiple materials. Mount #2 in 1045 steel had the best overall performance among the initial designs. Although Mount #1 in 1045 steel demonstrated slightly lower static displacement from mirror (5.61×10^{-5} mm compared to 1.26×10^{-4} mm), Mount #2 showed significantly lower maximum vibration displacement (0.01744 mm vs. 0.03963 mm). Additionally, Mount #2 achieved a higher resonant frequency (1130.7 Hz compared to 1017.8 Hz), indicating greater stiffness. Because both designs were modeled in the same material, CTE was identical; therefore, Mount #2 was selected based on superior vibrational displacement and resonant frequency.

The final mount designs (Mount #3 and Mount #4) were developed to address weaknesses identified in the initial designs and to further improve stiffness and displacement control. Both final mounts demonstrated improvements over Mount #2. Mount #3 reduced static displacement to 2.30×10^{-5} mm and vibration displacement to 0.00444 mm, while also increasing the resonant frequency to 2609.1 Hz. Mount #4 achieved static displacement of 2.88×10^{-5} mm and dramatically reduced vibration displacement to 0.000287 mm, with a resonant frequency of 2216.20 Hz.

Compared to Mount #2, both final designs more than doubled the resonant frequency and significantly reduced vibrational displacement. Importantly, both mount #3 and mount #4 exceeded the 2,000 Hz threshold identified from NASA launch vibration data as the ideal range. This moves the final designs outside the most severe vibration range experienced during launch.

While Mount #3 achieved the highest resonant frequency, Mount #4 demonstrated the lowest vibrational displacement overall. Because minimizing vibrational displacement is critical for maintaining optical alignment Mount #4 represents the strongest overall design.

Overall, the progression from Mounts #1 and #2 to Mounts #3 and #4 demonstrates that design refinement significantly improved structural stability and reduced vibrational response. The final mount designs significantly improve structural stability and reduce vibrational response, increasing the probability of maintaining ±0.001 mm optical alignment during launch.

Limitations

This project relied entirely on SolidWorks simulations to evaluate performance. While simulations are useful for predicting behavior, they cannot perfectly replicate real rocket launch conditions. Launch vibrations are not perfectly uniform, as they were in these simulations. Additionally, the vibration studies were conducted without the mirror installed in the mount, meaning they provide only a simplified prediction.

The static displacement analysis was also simplified by assuming the mounts would be perfectly upright. In reality, the mount would be positioned at an angle inside the rocket, causing the direction of applied forces to be more complex. Furthermore, the mirror would be secured using screws, which would influence both vibration response and static displacement behavior. Additionally, thermal effects were considered only through the CTE, no simulations were performed to see the exact effects, so the exact impact of temperature changes on mount performance remains uncertain.

Future Work

To better understand how the mounts would behave under rocket launch vibrations, physical testing should be conducted in addition to the simulations performed in this project. One alternative method considered was shake-table testing to evaluate the mount's resistance to vibration. This approach would allow mirror displacement to be measured before and after exposure to random vibration, providing quantitative data on mount stability. An additional, more visual method using an ink grid placed between the mirror and mount was also considered to identify areas of relative movement (see Figure 8). However, this testing could not be performed because the available shake table was not working at the time. As a result, simulations were used to analyze mount performance.

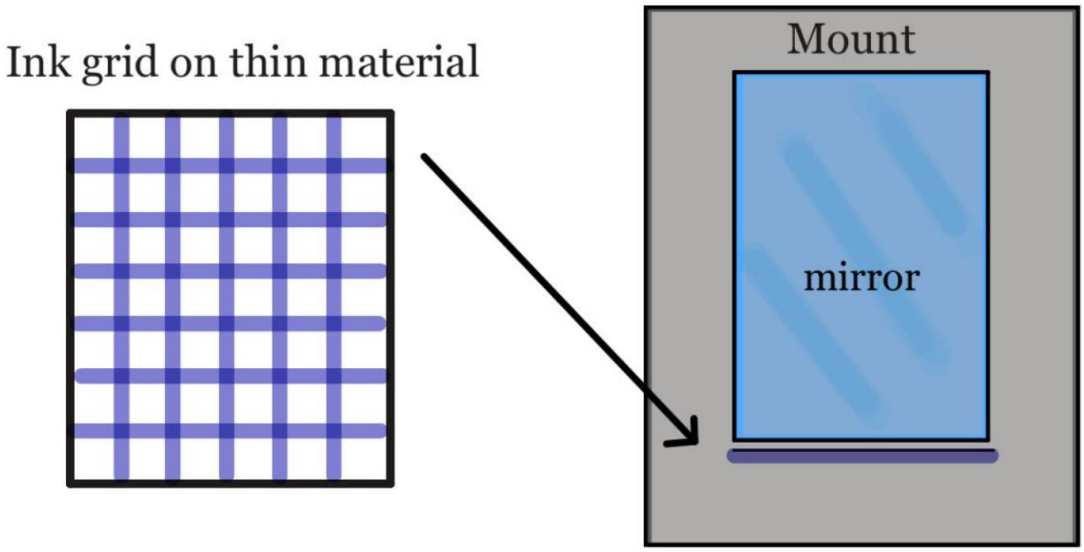

Figure 6 *Method for visualizing mirror movement in the mount.*

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