

JWST NIRSpec Cryogenic Light Shield Mechanism

Kathleen Hale* and Rajeev Sharma*

Abstract

The focal plane detectors for the Near-Infrared Spectrometer (NIRSpec) instrument on the James Webb Space Telescope (JWST) require a light tight cover for calibration along with an open field-of-view during ground performance testing within a cryogenic dewar. In order to meet the light attenuation requirements and provide open and closed fields of view without breaking vacuum, a light shield mechanism was designed. This paper describes the details of the light shield mechanism design and test results. Included is information on the labyrinth light path design, motor capability and performance, dry film lubrication, mechanism control, and mechanism cryogenic performance results.

Background

A light tight cover mechanism design and development is discussed for ground testing the Near Infrared Spectrometer Instrument's focal plane detectors on the James Webb Space Telescope. The NIRSpec focal plane detectors require a light tight cover for calibration along with an open field-of-view during ground performance testing within a cryogenic dewar. These tests include exposing the detectors to infrared light for calibration in "darkness" while under vacuum at approximately 20 Kelvin (-253°C). The darkness requirement is to maintain light levels less than 0.001 electron/sec/pixel at the detectors. In order to provide this low light level during calibration and also allow the detectors to be exposed to the required light sources when needed, the light shield mechanism was developed.

Requirements

The light shield mechanism is required to attenuate light in the chamber to a level less than 0.001 electron/sec/pixel before it reaches the detectors. Volume space allotted to the mechanism is 27.9 cm in diameter by 15.2 cm high (Ø11 in x 6 in). The shield must be able to open or close within about 60 seconds, operate in a vacuum (10^{-6} Torr) at 20 Kelvin, and in any gravitational orientation. The lifetime requirement for the shield is a few thousand cycles where one cycle is open and close.

When open, the shield door is to remain outside the 76-degree cone angle of the detectors' field of view. The light shield door range of rotation is about 124 degrees from open to close.

Shutter Light Path Design

A labyrinth light path is created, Figure 1, by the aligning of teeth-like protrusions on the shutter door with teeth cut outs into the plate covering the detector housing, hereafter referred to as the dewar bulkhead. The door and dewar bulkhead protrusions are separated by a gap of 0.64 mm (0.025 in) to prevent any contact debris from being created during the opening and closing operation of the door. This gap allows light entrance to the path, however, the labyrinth design combined with the proper material selection and treatment forces any light entering to bounce many times off the path's walls and thus be absorbed to levels below the requirement. Aluminum 6061, which is bead blasted and black anodized, makes up both the door and dewar bulkhead.

*NASA Goddard Space Flight Center, Greenbelt, MD

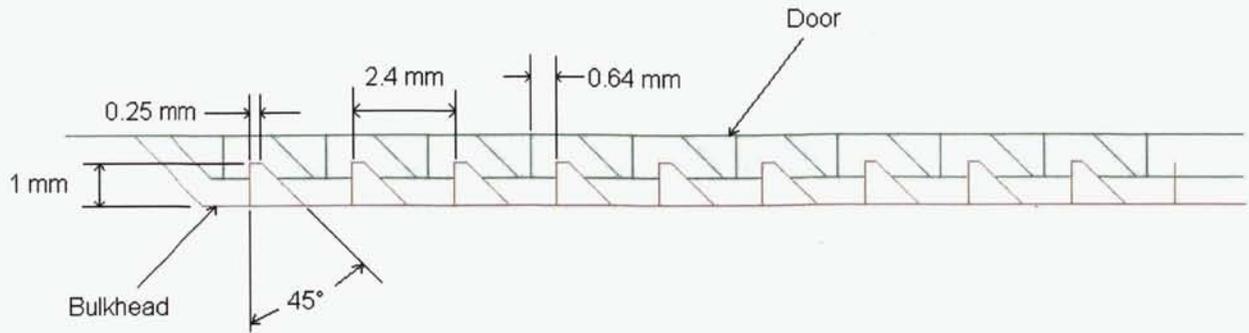


Figure 1. Light- Path Labyrinth Cross-Section View

Fabrication of parts was completed on the Micron 600U 5-axis high-speed milling machine as shown in Figure 2. The small sizes and angles of the light path protrusions make it necessary to use this machine. An additional advantage of the high-speed machine is the extremely low amount of stress that is added to the part by the machining as opposed to the level normally added by typical machines. Stress is a concern due to the fact that cryogenic temperatures can cause the part's stress to increase and warp the movable door. Therefore, as well as using the high-speed machine, Aluminum 6061-T651 is used to minimize stress. Aluminum 6061-T651 is heat treated to stress relieve the material.

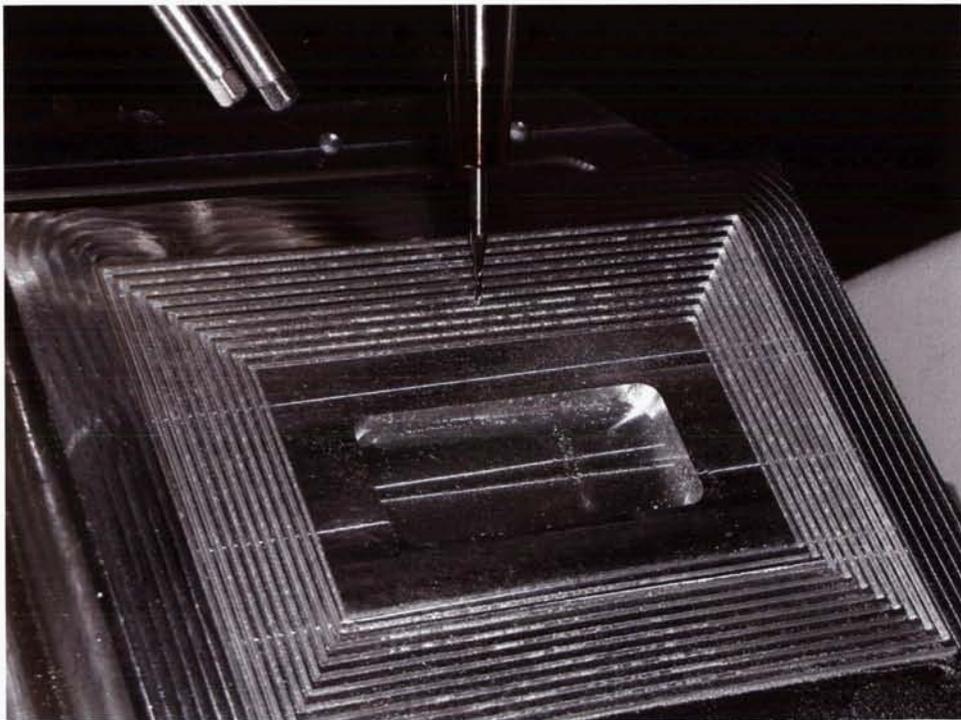


Figure 2. Picture of door being cut on Micron machine

After rough-cut fabrication, the door is taken and soaked in liquid nitrogen to determine if part warping at cryogenic temperatures is an issue. Key measurements taken before and after this process are compared and it is found that the door's critical dimensions do not permanently move any significant amount. Therefore, it is determined that the cryogenic environment will not warp the door and affect its operations.

Next, the dewar bulkhead plate is fabricated. Aluminum 6061- T651 is again used to minimize stress. Figure 3 shows the exploded isometric view of the mechanism.

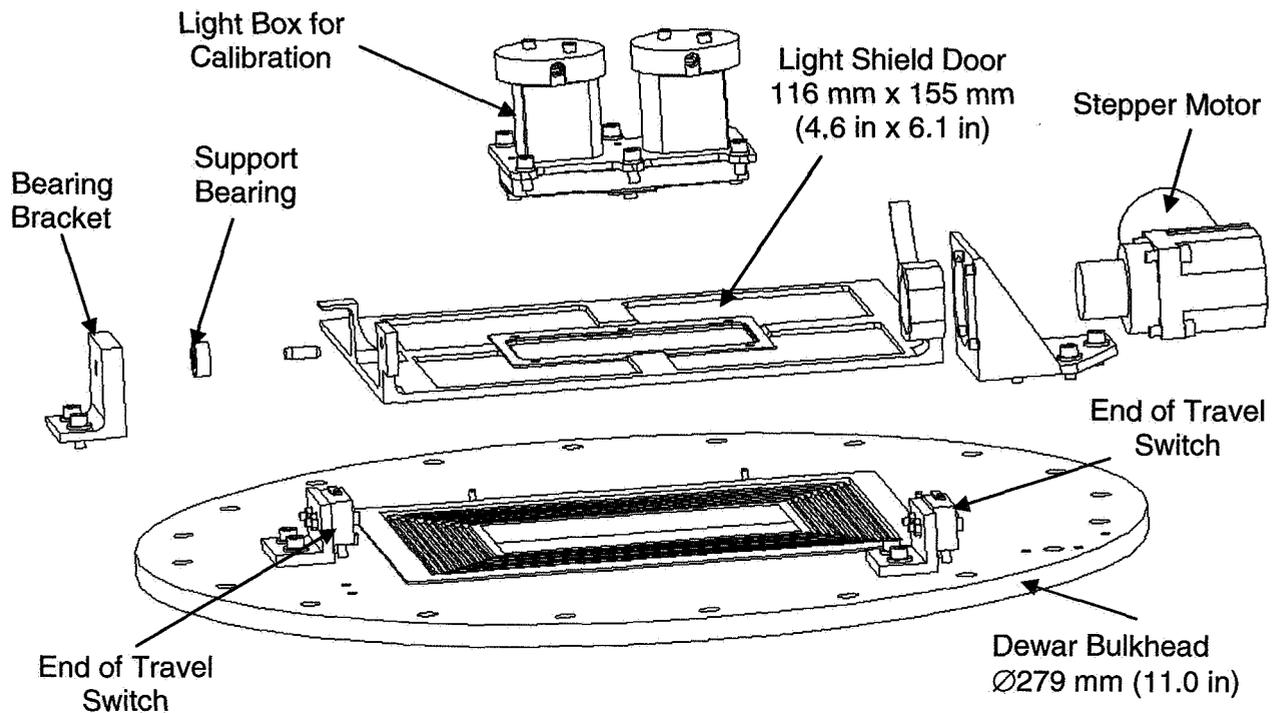


Figure 3. Exploded Isometric View of Light Shield Mechanism

Motor Selection

One cryogenic compatible stepper motor is used to drive the light shield door mechanism. The motor was procured from CDA Intercorp with a right angle gear head, a planetary gear train, dry film Molybdenum Di-Sulfide (MoS_2) coated parts, a motor shaft mounted resolver for position feedback, and a keyed motor shaft interface to the door. Motor design parameters are discussed below.

Torque

Analysis indicates the light shield mechanism requires, with margin, a maximum driving torque of $0.19 \text{ N}\cdot\text{m}$ ($1.67 \text{ in}\cdot\text{lb}$) in the worst-case gravity orientation. In this orientation, the door is required to be held open or closed against gravity by the motor detent alone as power must be disabled during detector tests. This motor detent torque with margin turns out to be the driving design parameter and calculates to $0.1 \text{ N}\cdot\text{m}$ ($0.88 \text{ in}\cdot\text{lb}$). A healthy factor of safety of 6 is used to bring the motor output detent torque to a $0.6 \text{ N}\cdot\text{m}$ ($5.3 \text{ in}\cdot\text{lb}$) value. The procured motor provides a measured detent torque of $0.75 \text{ N}\cdot\text{m}$ ($6.67 \text{ in}\cdot\text{lb}$).

Gearing

A right angle gear-head is essential for this mechanism design as the volume space available to mount the motor and mechanism to the dewar bulkhead is limited. The total motor gear ratio is 187:1 implying one motor step equals the door motion of 0.16 degree. This small step size is required so that if during door motion the motor bounces back or misses a step near the fully closed position, the gap left "open" does not allow a significant amount of light to enter the light path. Analysis confirms the gap is not large enough to degrade the light shield capability of the mechanism.

Cryogenic Lubrication

Dry lubrication on the motor components is required for proper cryogenic temperature operation. A sputtered Molybdenum Disulfide (MoS_2) coating was used on the motor gears, bearings, and moving parts. MoS_2 was chosen for this mechanism based on the ability to provide any thickness needed and also its heritage on numerous previous flight programs such as COBE, Cassini, SIRTf, and others. Drawbacks in using many dry film lubricants, including MoS_2 are that the coating should be operated in a dry oxygen and water vapor free environment. Operation should not occur at humidity levels above about 40% due to the reactivity of the coating with oxygen and water vapor.

The MoS_2 dry film lubricant sputtering process was provided by Hohman Plating Inc. In a vacuum, at 149°C (300°F), an electron emitter breaks up the lubricant material into atomic size particles that bombard the parts. The coating particles adhere to the parts' surfaces and build up thickness over time. Coatings can be co-sputtered with different elements to improve crystalline structures and lower the friction coefficient. The majority of coatings are co-sputtered with Nickel giving a 0.02 friction coefficient. More advanced co-sputter options are Antimony O_3 ($\mu = 0.01$) or Antimony O_3 with Gold ($\mu < 0.01$). This project co-sputtered with nickel as the coefficient of friction meets the required amount and is less expensive than the other co-sputter options. Figure 4 shows the dry film thickness along the tooth of a motor gear part as seen in a cross-section view.

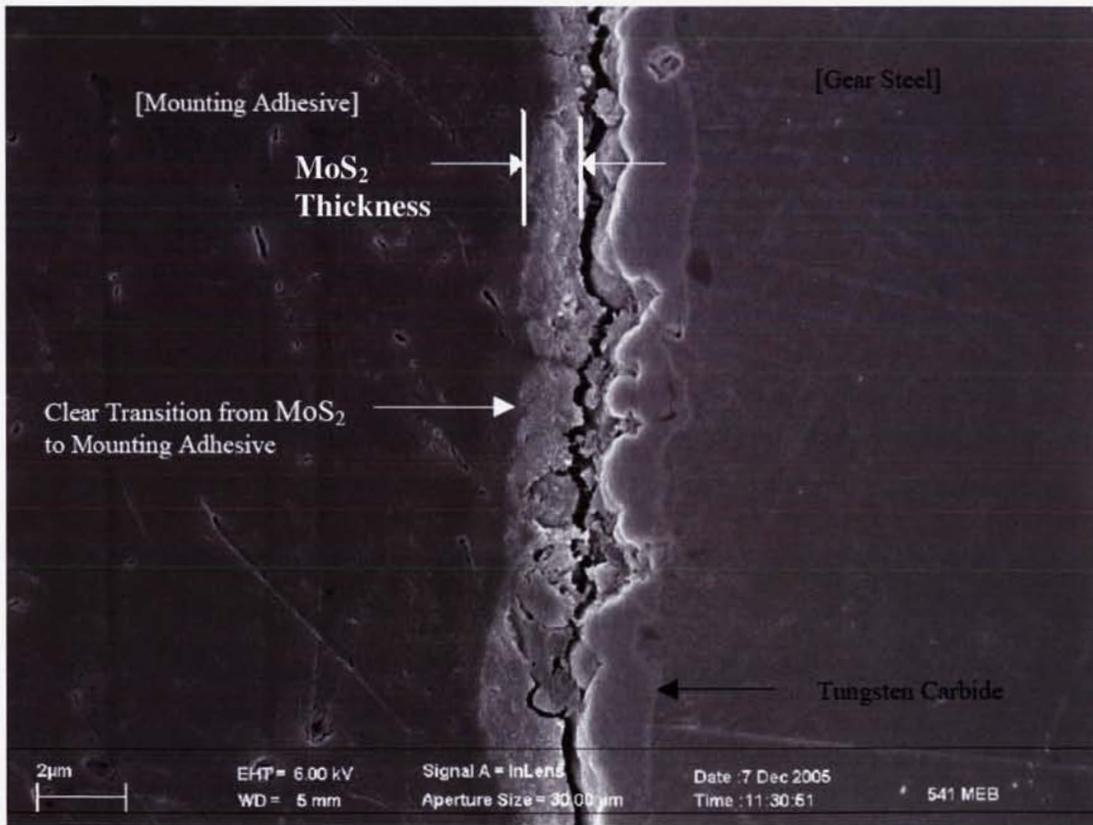


Figure 4. MoS_2 coating thickness measured along width of gear tooth near tooth tip of a representative motor gear part. Thickness measured from mounting adhesive to gap.

Nominally, Hohman plates parts to a thickness of 3000-10000 Angstroms (0.3 to $1 \mu\text{m}$ or 1.18×10^{-5} to 3.93×10^{-5} in) over 50 minutes. Considering the low life cycle requirements of the mechanism, the associated mechanical loads it would undergo, and margin, a MoS_2 coating thickness of $2.5 \mu\text{m}$ (0.0001 in) was considered. Initially, the relationship of lubricant coating buildup over time with the sputtering process was thought to be linear. However, through the coating of several sample gears, analysis shows

it to not be so. At first the thickness and time were extrapolated linearly to that for 2.5 μm (0.0001 in) which resulted in a 3-hour long application. Destructive analysis was performed on a sample gear by the materials group at NASA Goddard, and the average thickness of the coating was measured to be 17.8 μm (0.0007 in). Another gear sample was then coated at a lesser time of 70 minutes and the measured thickness of the coating ranged from 0.5 to 3.8 μm (2×10^{-5} to 1.5×10^{-4} in). Based on the gathered data shown in Figure 5, it was decided that an application duration time of 80 minutes would be sufficient for the light shield mechanism motor parts. All parts are coated for the 80-minute duration resulting in a thickness of 1.2 μm (0.00005 in). The final dry lube coating applied to the motor parts is based on the sample gear data and the minimum motor assembly tolerances for nominal fit. After the coating process was complete, all motor parts were successfully reassembled and tested.

MoS₂ Coating Thickness vs. Time

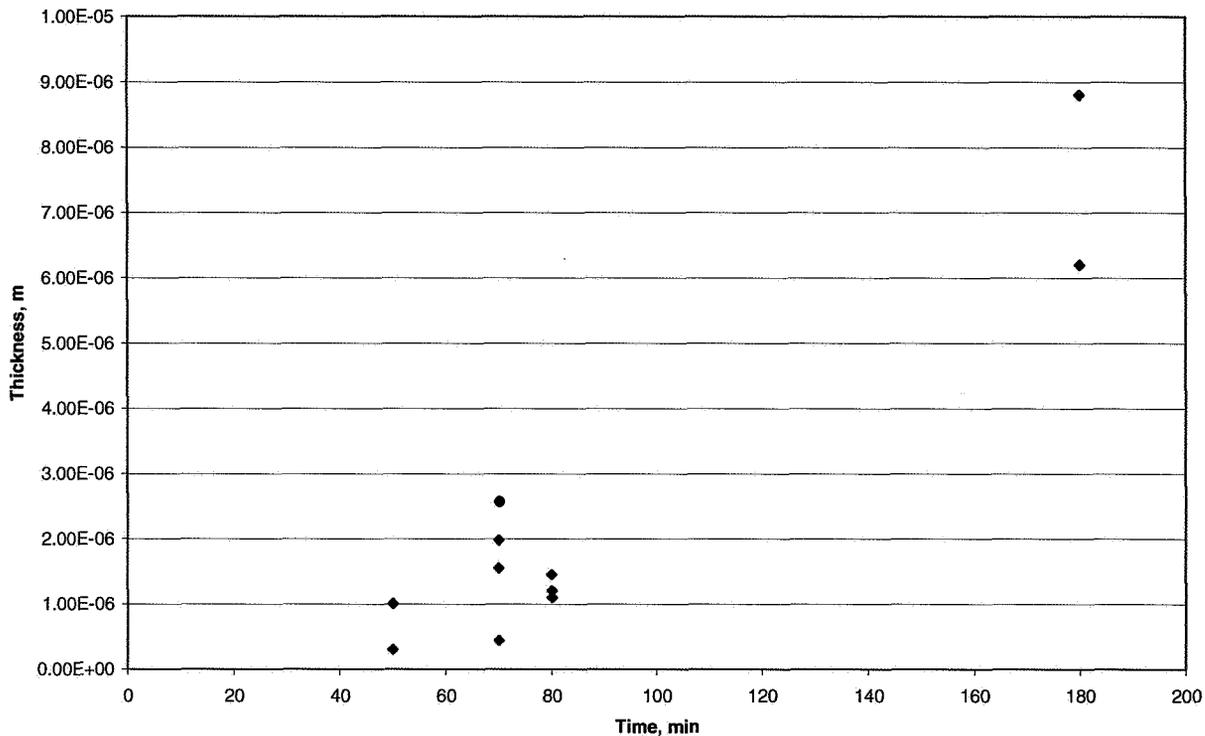


Figure 5. Measured MoS₂ Coating Thickness vs. Time on a typical motor gear part

The bearings in the motor are also dry lubricated with MoS₂. Lubrication thickness is the same as that for all other motor parts, 1.27 μm (0.00005 in). The support bearing on the opposite side from the motor on the bulkhead is a radial bearing and is not sputter coated. Instead, the support bearing is a “BarTemp” bearing from The Barden Corporation. “BarTemp” bearings have a cage made of a Teflon-coated, highly compressed material with very fine glass fibers and molybdenum disulfide impregnation. During operation, the rotation of the bearing causes the balls to rub off small amounts of the cage which coats the raceways with a thin lubrication layer.

Mechanism Control

The light shield mechanism motor is a two phase DC stepper motor with 30 degree steps and a total right angle gear ratio of 187:1. Nominal operation occurs at 24 VDC. Since the mechanism must operate at room temperature and at 20 Kelvin, a current controlled electrical drive system is used for maintaining proper performance margins under all operating conditions. A Newport 300 Series current control amplifier drives the light shield mechanism motor. Step pulse rate and phase current levels are settable

quantities through a front panel or macro driver software which controls the mechanism to open or close the light shield door in approximately one minute. Software time out and TTL limit switch interfaces allow electronically disabling motor power redundantly with this controller. Motor resolver analog signal is read and converted to a TTL quadrature signal that the Newport controller can read. Motor power is disabled when contact is made with one of the end of travel switches in either the open or closed position of the light shield door. The motor shaft resolver is used as a method of determining the door position.

Over Travel Analysis

As the light shield reaches its end of travel in either the open or close direction, it comes into contact with an end-of-travel switch. This switch then cuts off power to the motor and the door stops its motion. In the close direction there is a hard stop that does not allow the door to over travel. Travel in the open direction, however, does not have a hard stop. Therefore, stress analysis is performed on the tab that comes into contact with the switch to determine the maximum amount of force that can be handled. These calculations determine that the load felt on the tab is 20 times smaller than the yield load of the door material, including margin. Therefore, at the slow speed that the motor rotates, the tab contacting the switch will not yield if the motor attempts to continue to rotate, and the shield door will not over travel.

Cryogenic Testing

Before delivery to the project, the light shield mechanism is tested in a dewar at 20K in the operational configuration. The dewar bulkhead is attached to an interface plate to mate the mechanism to the chamber. Once assembly is complete, the chamber is closed and the then rotated 180° to orient the mechanism to its operational configuration. This places the mechanism so that gravity is acting to open the door from its closed position.

Test results are forthcoming and will be presented at the conference.

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