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James Webb Space Telescope Project

Performance Specification

for

James Webb Space Telescope
Micro-Shutter Assembly
Actuator Units

February 06, 2006

JWST GSFC CMO

February 6, 2006

RELEASED

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Greenbelt, Maryland

National Aeronautics and Space Administration

CM FOREWORD

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JAMES WEBB SPACE TELESCOPE PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

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List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
1	Section 2.2.2, Page 2-1, 2-2	ICD Drawing number	S. Schwinger/ GSFC	3/01/2006
2	Section 2.2.8, Page 2-2	ICD drawing number	S. Schwinger/ GSFC	3/01/2006
3	Section 2.5.3, Page 2-4	ICD Drawing number	S. Schwinger/ GSFC	3/01/2006

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1.0 INTRODUCTION

1.1 SCOPE

This specification describes the electrical, mechanical, operating environment, and verification testing requirements for Engineering Test Unit (ETU) Actuator Units for a National Aeronautics and Space Administration (NASA) payload, the James Webb Space Telescope (JWST). The Actuator Units shall implement general spacecraft requirements that cover a rotary actuator unique to the Micro-Shutter Assembly (MSA) of the Near-Infrared Spectrograph (NIRSpec) instrument, one of several instruments aboard JWST.

1.2 DEFINITIONS

Maximum Internal Friction Torque (TF int max): The internal friction that the motor must overcome to move the output with no load on the output shaft at the beginning of life (BOL).

Motor Torque: Torque available at the motor rotor with optimal sinusoidal commutation at a specific rms current.

Torque Ripple: A variation in torque, with optimal sinusoidal commutation, that is usually expressed in percent of total torque.

Motor Constant, KM: This is a constant that describes the motor efficiency. Its units can be Newton-meters / sqrt (watt) or ounce-inches / sqrt (watt).

Torque Constant, KT: This is a constant that describes the relationship between current and torque. Its units can be Newton-meters / amp or ounce-inches / amp.

Commutation Sensor: This relatively low-resolution position sensor attached to the motor shaft that when excited and demodulated, has sine and cosine position signals that match the required sine and cosine actuation waveforms of the motor, thus providing sinusoidal commutation signals for both motor phases. It is actually a resolver, but in this application is referred to as a phase director.

Resolver: This is a position sensor that when excited and demodulated, has sine and cosine position signals that can be processed by a Rotary to Digital (R to D) converter, which provides a digital signal proportional to angular position of the resolver shaft. The resolver that is geared to the output shaft is a relatively high-resolution device.

Actuator Unit: Also referred to simply as "actuator," this is the harness, output flange, mounting flanges, motor, commutation sensor, gearbox, bearings, mechanical interfaces, and output shaft position sensor as described herein.

Engineering Test Unit (ETU): Non-flight hardware that simulates flight hardware in form, fit and function for a specific test. The ETU is not required to have flight-like certification, and it will not be used for flight.

Qualification Unit: Unit used to qualify a flight design. See prototype and protoflight component definitions.

Prototype Unit: Hardware intended to qualify flight hardware of a new design. The unit is not intended to fly. The hardware is subject to Qualification Test levels and durations.

Flight Unit: The Flight Unit is hardware that will be used operationally in space.

Acceptance: The verification process that justifies that a Certificate of Compliance can be issued that certifies that the Actuator meets the specified requirements.

Qualification: The verification process that demonstrates that a design (not each individual flight unit) will function properly under conditions more severe than it will experience in orbit. It also serves as a quality control screen to detect deficiencies. Qualification tests are performed to Limit Level with a qualification test factor, e.g. 1.25 X Limit Level for static loads and sine vibrations and ±10 degrees Celsius beyond flight predictions for thermal tests.

Life Test: A test to demonstrate that a component or subsystem will operate within design specifications while subject to the predicted use. This includes all pre-flight qualification testing, launch conditions, and on-orbit operation and environment. The test article must perform without failure for a minimum of 2.0 times the expected number of operations or cycles expected.

Component: A functional subdivision of a subsystem and generally a self-contained combination of items performing a function necessary for the subsystem's operation. Examples are electronic box, transmitter, gyro package, actuator, motor, and battery. For the purposes of this document, "component" and "unit" are used interchangeably.

Unit: A functional subdivision of a subsystem, or instrument, and generally a self contained combination of items performing a function necessary for the subsystem's operation. Examples are electronic box, transmitter, gyro package, actuator, motor, and battery. For the purposes of this document, "component" and "unit" are used interchangeably.

Assembly: A functional subdivision of a component consisting of parts or subassemblies that perform functions necessary for the operation of the component as a whole. Examples are a power amplifier and gyroscope.

Part: A hardware element that is not normally subject to further subdivision or disassembly without destruction of design use. Examples include resistor, integrated circuit, relay, connector, bolt, and gaskets.

Instrument: A spacecraft subsystem consisting of sensors and associated hardware for making measurements or observations in space. For the purposes of this document, an instrument is considered a subsystem (of the spacecraft).

Survival Temperature: A non-operational temperature at which the unit must dwell to verify its ability to withstand this temperature extreme without causing damage.

Hot/Cold Start: The powering on and driving of an actuator at a given temperature extreme (after dwelling at that temperature). The actuator is not required to meet the performance specifications at this temperature and exposure to this temperature must cause no permanent damage to the unit.

2.0 REQUIREMENTS

All of the written requirements in this document shall apply at the end of spacecraft (SC) life (EOL), which will occur no earlier than 5 years post launch (if Launch=2008, then EOL=2008+5=2013) except as otherwise noted.

2.1 DESCRIPTION

The Actuator Unit shall have a six-pole permanent-magnet two-phase brushless DC motor with redundant windings driving a two-stage speed reducer driving a load-carrying output shaft. Position knowledge shall be via an integral redundant resolver as defined in section 2.5 of this document. Commutation signals shall be via a six-pole integral redundant phase-director as defined in Sections 2.3.1 and 2.3.6 of this document.

There shall be two configurations of actuator units, with each unit of a configuration be identical to one another. One configuration will be exempt from all the environmental requirements specified in this document, unless specifically stated to apply to that configuration. The other configuration will comply with all environmental requirements. The two configurations are as follows:

1. Exempt from non-specific environmental requirements, referred to as the Ambient Temperature Actuator (ATA)
2. Complies with all environmental requirements, referred to as the Helium Cryogenic Actuator (HCA)

2.2 PHYSICAL CHARACTERISTICS

Detailed envelope and interface drawings (mechanical and electrical) shall be supplied to the government. All Contractor drawings prepared for this unit shall conform to the requirements of MIL-DTL-31000B. The Interface Control Drawing shall include specific information regarding all of the following parameters:

2.2.1 Mass

Total as delivered, each actuator mass shall be less than or equal to 1.15 kg (2.5 pounds). The Contractor shall also indicate the mass and the approximate center of mass on the Interface Control Drawing.

2.2.2 Dimensions

Interface locations and physical envelope should be within the ranges specified in Goddard Space Flight Center (GSFC) Drawing No GX XXXXXXX (TBD). The Contractor Interface Control Drawing shall include specific details and dimensions including but not limited to

- Size, location and tolerance of mounting holes
- Flange thickness

- Reference surfaces
- Overall physical envelope
- Variations from the dimensions shown in GSFC Drawing No GX XXXXXXX (TBD)

2.2.3 Wires

The wire from the stepper motor shall be of the M22759/11 Teflon insulated type, sized according to the derating schedule found in EEE-INST-002, using the requirements found in section 2.4 of this specification. Each primary and redundant side of the motor shall require four wires, each carrying less than 2 amps. Each primary and redundant side of the position sensor shall require six wires, each carrying less than 0.5 amps. Each primary and redundant side of the phase director shall require six wires, each carrying less than 0.5 amps. The total count of wires of an actuator unit shall be 32 wires. Lead lengths of all wires shall be no less than 122 cm (48 inches).

2.2.4 Wiring Configuration

Power wires shall be grouped and kept separate from signal wires.

2.2.5 Materials and Finish

All materials and processes shall be in accordance with spaceflight standards and approved by the Government. All parts shall be passivated and external surfaces shall be conductive, with a maximum resistance of 10^9 ohms/square. Aluminum parts shall be finished with iridite per MIL-C-5541, Class 3. Titanium surfaces shall be finished per AMS 2488 and conductive surfaces identified in the design shall be masked.

2.2.6 Cleanliness

The assembly and integration shall be performed in a class 100 environment. The test operations should be performed in a clean, dust-controlled environment such that performance is not compromised. The units shall be inspected after test and re-cleaned if necessary.

2.2.7 External Leakage

There shall be no external leakage of lubricant.

2.2.8 Identification and Marking

Each unit shall be permanently marked with the part number and a unique sequential serial number in the area designated on the interface drawing, GX XXXXXXX (TBD), in a manner to be approved by the Government.

2.3 MECHANICAL CHARACTERISTICS

Actuator assemblies shall have the following physical and nominal performance characteristics, except as otherwise noted.

2.3.1 Motor Configuration

The motor shall be of a two-phase design with six-poles. The phase director shall also be of a two-phase design with six-poles. The phase director shall be aligned such that its sine and cosine signals closely match the actuation waveform required by the motor windings such that the phase director signals can be used for sinusoidally commutating the motor.

2.3.2 Motor Torque Ripple

The motor torque ripple shall be less than 3 percent when applying sinusoidal commutation.

2.3.3 Reduction Gear Ratio

The reduction gear ratio shall have two stages with a combined reduction ratio of 20:1.

2.3.4 Actuator Rotation Profile

The actuator shall be operated such that the output shaft, beginning from home rotates 125 degrees to end of travel, then rotating back to home, thus being one cycle of operation. Each half-cycle shall be of approximately 5 seconds in duration. Operational holds times of up to 2000 seconds may occur before the beginning of a new cycle.

2.3.5 Resolver Gearing

The resolver shall be geared to the output shaft such that between 90 and 95 percent of the maximum range of the resolver is utilized for the full range of the output shaft as specified in paragraph 2.3.4.

2.3.6 Phase Directors

The phase directors, primary and redundant, shall be driven by the motor shaft and be aligned so as to meet or exceed performance requirements.

2.3.7 Shaft Load Capability

The actuator shall be capable of achieving the performance required in this specification after exposure to the loading given in Table 2-1 and assuming a 0.15 kg mass is coupled to the output shaft.

2.4 ELECTRICAL CHARACTERISTICS AND PERFORMANCE

2.4.1 Motor Type

The motor shall be a six-pole, two-phase, sinusoidally commutated, permanent-magnet brushless DC motor.

2.4.2 Redundancy

Motor windings shall be redundant. A short or break in any winding shall not affect the redundant winding in any way and vice versa. There shall be redundant phase directors and redundant resolvers as well.

2.4.3 Motor Constant

The motor constant shall be at least Km = 4.8 oz-in/sqrt (watt) at room temperature.

2.4.4 Torque Constant

The torque constant shall be Kt = 66.8 oz-in/amp, plus zero, minus 5%.

2.4.5 Electrical Time Constant

The electrical time constant shall be less than 1.2E-03 seconds.

2.4.6 Dielectric Strength

Dielectric material between mutually isolated electrical circuits shall withstand a test voltage of at least 200 VAC for 60 seconds without exceeding a current of 1.0 ma.

2.4.7 Insulation Resistance

Insulation resistance between mutually isolated electrical circuits shall be at least 100 megaohms at a test voltage of at least 500 Vdc for 60 seconds minimum.

2.5 POSITION KNOWLEDGE

2.5.1 Type Description

A resolver with full redundancy shall be integral to the actuator assembly. It shall be geared to the output shaft such that nearly the full dynamic range of the resolver is utilized over the full-intended operational range of motion of the output shaft. Refer to paragraphs 2.3.5 and 2.3.6 for specifications.

2.5.2 Resolution and Accuracy

The accuracy of the resolver shall be ≤ 3 arc minutes, over its full dynamic range.

2.5.3 Resolver Alignment

The resolver shall be aligned in relation to the output shaft index so that when the output shaft is at its beginning orientation, the resolver is at its beginning orientation. Variation of the positioning of the resolver of each actuator unit shall be within 1 degree. Refer to drawing GX XXXXXXX (TBD) for output shaft index orientation.

2.5.4 Electrical Interface

The resolver electrical interfaces shall be included in vendor's Interface Control Drawing. The total number of wires required to independently operate each resolver shall be six (6) per side, primary and redundant.

2.6 LIFE REQUIREMENTS

2.6.1 Duty Cycle

The actuator shall accommodate a duty cycle consisting of sweeping and hold modes that can run in either direction as described in paragraph 2.3.4. The HCA actuators shall support usage consistent with the required life at cryogenic temperatures.

2.6.2 Number of Cycles

The anticipated number of cycles for the HCA units is 200000. Refer to paragraph 2.3.4 for cycle definition. Units shall perform within specification after experiencing this number of cycles.

2.6.3 Mission Life

Mission orbit life shall be 5 years as defined in Section 2.0.

2.6.4 Shelf Life

Shelf life shall be 10 years when packaged using agreed-to procedures.

2.7 ENVIRONMENTAL REQUIREMENTS

HCA actuators shall be designed to meet all of the performance and other design requirements of this specification.

2.7.1 Static Loads

The actuator shall be capable of withstanding the inertial loads in Table 2-1, applied individually.

Table 2-1. Actuator Inertial Limit Loads

Direction	Acceptance (Limit) Loads	Qualification Loads
x	22.16 g	26.96 g
y	22.16 g	26.96 g
z	22.16 g	26.96 g

2.7.2 Dynamic

The actuator shall be capable of withstanding the random vibration levels shown in Table 2-2 and Figure 2-1. The actuator shall also be capable of withstanding the sine vibration levels of Table 2-3. The loads are considered to act in any of the three mutually perpendicular component axes.

Table 2-2. Random Vibration Spectral Density

(2 Minutes/Axis for Qualification Testing and 1 Minute/Axis Acceptance Testing)

Frequency (HZ)	Spectral Density (g^2/Hz)	
	Qualification (ETU) Levels	Acceptance (Flight) Levels (g^2/Hz)
20	0.01	0.01
20-50	+8.21 dB/oct	+ 6.31dB/oct
50	0.20	0.10
200	0.20	0.10
200-250	-22.3 dB/Oct	-16.97 dB/Oct
250	0.06	0.04
800	0.06	0.04
800-2000	-3.89 dB/oct	-3.01 dB/oct
2000	0.01	0.01
Overall Grms	8.99 G rms (1 σ)	7.39 G rms (1 σ)

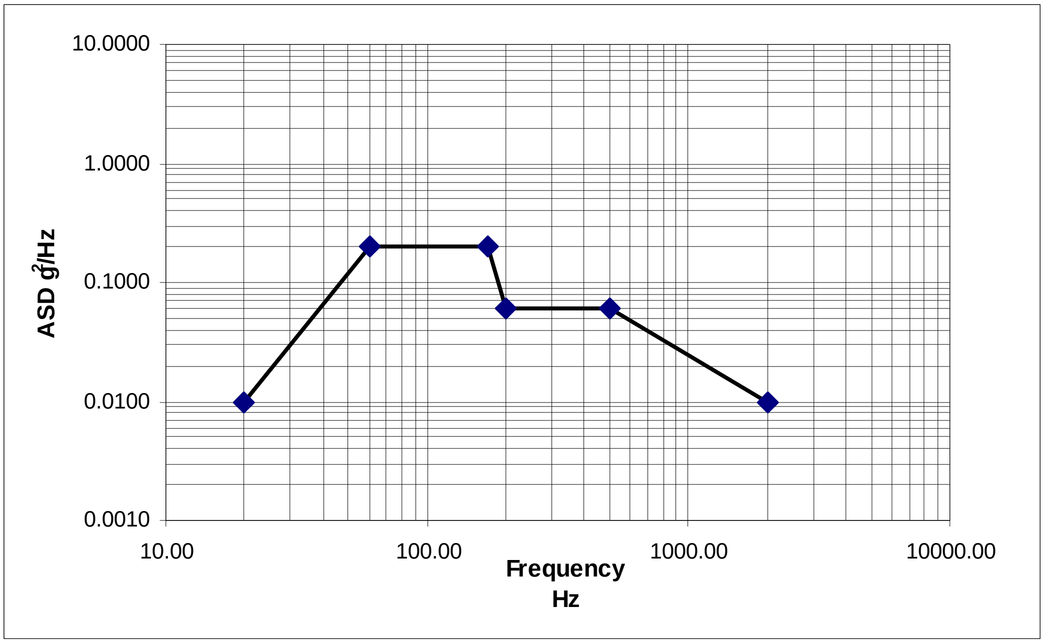

Figure 2-1. Random Qualification Vibration Profile

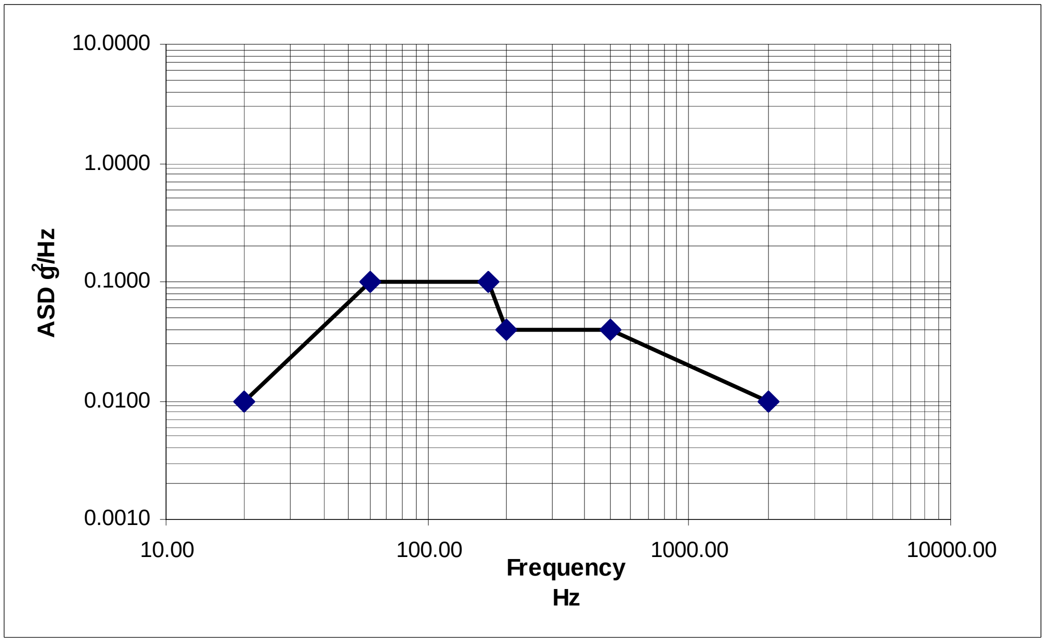

Figure 2-2. Random Acceptance Vibration Profile

Table 2-3. Sine Sweep Vibration Test Levels

(2 Oct/Min/Axis for Qualification Testing and 4 Oct/Min/Axis Acceptance testing)

Qualification		Acceptance	
Frequency	**Amp/Acceleration**	**Frequency**	**Amp/Acceleration**
5 – 20 Hz	± 15 mm	5 – 20 Hz	± 12 mm
20 – 100 Hz	20 g	20 – 100 Hz	16 g

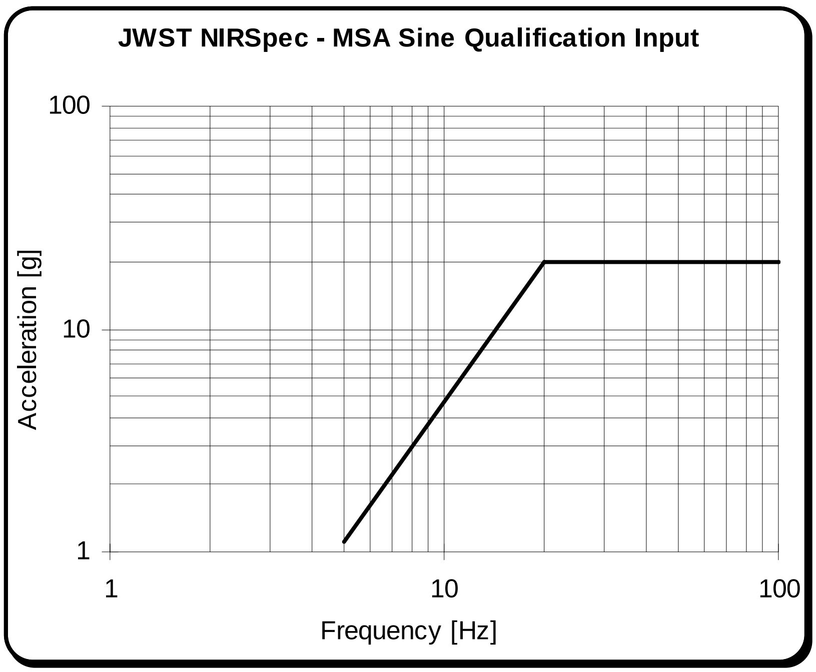

Figure 2-3. Qualification Sine Vibration Profile

2.7.3 <u>Shock</u>

During JWST spacecraft system level test and verification program as well as during launch, the actuator could be exposed to shock levels defined in Table 2-4 and therefore must be designed to withstand the maximum shock environment shown in Table 2-4.

Table 2-4. Maximum Expected Shock Environment

Frequency (Hz)	SRS (G peak)
100	20
1000	700
10000	700

2.7.4 Acoustic

The actuator will be subjected to acoustic levels at the spacecraft system level testing, as well as during launch, as defined in Table 2-5 and shall be capable of withstanding the acoustic environment.

Table 2-5. Acoustic Levels

Octave Band Center Frequency (Hz)	Noise Level (dB) re: 2 x 10^{-5} Pa		
	Qualification	Acceptance	Test Tolerance
31.5	132	128	-2, +4
63	134	130	-1, +3
125	139	135	
250	143	139	
500	138	134	
1000	132	128	
2000	128	124	
OASPL	146	142	-1, +3
Duration	Prototype 120 sec Protoflight 60 sec	60 seconds	-0, +5%

2.7.5 Thermal

HCA Actuators shall be capable of operation throughout a temperatures range of $20\text{ K} \leq T \leq 320\text{ K}$. On orbit operating temperature range is $25\text{ K} \leq T \leq 40\text{ K}$.

2.7.6 Vacuum

The HCA actuator shall be capable of meeting all performance requirements of section 2.3 at ambient as well as when exposed to a vacuum environment of 1 x 10^{-5} Torr.

2.7.7 Atomic Oxygen

Materials used in the construction of the actuator assembly shall not generate contamination products resulting from the interaction with an atomic oxygen environment. All operational requirements shall be satisfied during exposure to an atomic oxygen environment of 300 km (180 mile) perigee of transfer orbit for two weeks.

2.7.8 Radiation – Total Dose

The proposed JWST spacecraft will be positioned in a Lissajous L2 orbit. The total ionizing dose (TID) of radiation is not likely to exceed 42.5 krads.

2.7.9 Humidity

The actuator shall be capable of meeting the requirements herein after and during exposure to 20 to 70% relative humidity prior to launch.

2.7.10 Venting

The actuator shall survive external depressurization from one atmosphere to 10^{-5} Torr in 30 seconds. The actuator shall be vented to minimize lubricant loss and prevent internal pressurization during external depressurization of one atmosphere to 10^{-5} Torr in 30 seconds.

2.8 ANALYSIS REQUIREMENTS

2.8.1 Stress

The actuator shall demonstrate positive margins of safety on ultimate failure modes using a yield F.S. of 1.25 and ultimate F.S. of 1.40 on flight limit levels shown in Table 2-1 in worst-case combinations. All margins of safety shall be verified by a detailed hand stress analysis of the actuator that assesses all primary and secondary structure, joints, fasteners, bearings and gear loads.

2.8.2 Fatigue

Fatigue life of the gear box shall be demonstrated with detailed analysis using the 95% reliability curves for the materials. The number of cycles to be used are per section 2.6 using a factor of two and a reference load on the harmonic drive of 11 N-m (100 in-lbs) of torque.

2.8.3 Wear

The wear life of all sliding or rolling surfaces, including the gearbox teeth, and bearings, shall be demonstrated with a detailed analysis or by similarity using appropriate margins of safety. The reference load on the output bearings should be no more than the axial preload. Reference cycles are listed in Section 2.6.

2.8.4 Lubrication

The Contractor shall provide analysis to show that sufficient lubricant is available throughout the life of the actuator so that it can meet the its specified performance and life requirements as defined in section 2.6. The Contractor shall also provide a stress-cycle, or ball-pass, analysis to support the lubricant choice.

2.9 TESTING

The contractor shall perform the tests listed in Section 3.0 of this document.

3.0 VERIFICATION

The contractor shall conduct a verification program that demonstrates the hardware design is qualified and meets all requirements contained in this document. The contractor shall provide a verification matrix defining the method of verification for each specific requirement of this document. Verification methods include inspection, analysis, test or a combination of these techniques.

3.1 INSPECTION

Verification by inspection includes visual inspection of the physical hardware, a physical measurement of a property of the hardware, or the documentation search demonstrating hardware of an identical design has demonstrated fulfillment of a requirement.

3.1.1 Visual Inspection

Visual inspection of the physical hardware by a customer appointed qualified inspector.

3.1.2 Physical Measurement

Physical measurement of hardware property (i.e. mass, dimensions, etc.) demonstrating the hardware meets specific requirement.

3.1.3 Documentation Search

Verification of requirements based on similarity shall include supporting rationale and documentation and shall be approved by the Government.

3.2 ANALYSIS

Verification of performance or function through detailed analysis, using all applicable tools and techniques, is acceptable with the following conditions.

For structural loads, design qualification by analysis requires that positive margins of safety be shown using factors of safety of 2.0 on yield and 2.6 on ultimate.

Government approval is required for verification by analysis.

3.3 TEST

The Contractor is required to only perform Acceptance Testing. The Contractor is not required to perform Qualification Testing, unless it is necessary to justify issuance of the Certificate of Compliance.

3.3.1 Acceptance Test

The verification process that demonstrates that hardware meets the specified requirements so that a Certificate of Compliance can be justifiably issued.

3.3.2 Test Failures

The MSA Program Representative shall be notified of any test failures within 24 hours of such occurrence. The test shall be completed to obtain as much information as possible. No replacement, adjustment, maintenance, or repairs are authorized during testing.

3.3.3 Test Procedure

The Government shall review and approve test procedures for all tests. Test procedures shall include pass/fail criteria and Mandatory Inspection Points (MIPs) for QA.

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
ATA	Ambient Temperature Actuator
BOL	Beginning of Life
DC	Direct Current
EOL	End of Life
ETU	Engineering Test Unit
GSFC	Goddard Space Flight Center
HCA	Helium Cryogenic Actuator
ICD	Interface Control Drawing
JWST	James Webb Space Telescope
MIP	Mandatory Inspection Point
MSA	Micro-Shutter Assembly
NASA	National Aeronautics and Space Administration
NIRSpec	Near-Infrared Spectrograph
R to D	Rotary to Digital
SC	Spacecraft
TF int max	Maximum Internal Friction Torque