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**DESIGN AND DEVELOPMENT
REQUIREMENTS FOR MECHANISMS**

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FOREWORD

This standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities.

This standard establishes uniform design and development requirements across NASA Centers for the design of mechanisms whose correct operation is required for safety or program success. Housing them in a NASA standard allows each NASA program to rely upon an established set of practices that have proven heritage and that have been developed from lessons learned across the spectrum of design applications, from flight systems to ground support equipment.

Requests for information, corrections, or additions to this standard should be submitted via “Feedback” in the NASA Technical Standards System at <http://standards.nasa.gov>.

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1. SCOPE

1.1 Purpose

The purpose of this standard is to establish common design and development requirements across National Aeronautics and Space Administration (NASA) Centers for the design of aerospace mechanisms whose correct operation is required for safety or program success. Collecting the requirements in a NASA standard allows each NASA program to rely upon an established set of practices that have proved heritage and that have been developed from lessons learned across a spectrum of design applications. This standard is designed to be applied to flight mechanisms that are designed, built, or acquired by or for NASA, though it may also serve as a useful guidance document for other systems such as ground support equipment (GSE). This document addresses technical functional requirements only and specifically does not address human factors requirements.

1.2 Applicability

This standard may be cited in contract, program, and other Agency documents as a technical requirement. When this standard is applied, individual provisions of this standard may be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program/project needs and constraints. When requirements are noted as mandatory (indicated by use of the word “shall”), tailoring shall be formally documented and approved as part of program/project requirements.

Adherence to this standard in and of itself does not exempt a mechanism from any safety, fault-tolerance, or hazard control requirements. Any such reduction in requirements must be established and approved at the program’s inception by the appropriate technical authority of the program invoking this standard.

2. APPLICABLE DOCUMENTS

2.1 General

The documents listed in this section contain provisions that constitute requirements of this standard as cited in the text of section 4. The latest issuances of cited documents shall be used unless specified by version control descriptor. The applicable documents are accessible via the NASA Technical Standards System at <http://standards.nasa.gov>, directly from the Standards Developing Organizations (SDOs), or other document distributors.

2.2 Government Documents

NSTS 08307 – Criteria for Preloaded Bolts

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2.3 Non-Government Documents

NASM23460 – Pin, Quick-Release, Self-Retaining, Positive Locking

2.4 Order of Precedence

In the case of conflict, the technical requirements of this standard take precedence.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms

ABEC	Annular Bearing Engineering Council
AFBMA	Anti-Friction Bearing Manufacturing Association
AIAA	American Institute of Aeronautics and Astronautics
EVA	extravehicular activity
GSE	ground support equipment
LLC	liquid locking compound
MIP	mandatory inspection point
NASA	National Aeronautics and Space Administration
SDOs	Standard Developing Organizations

3.2 Definitions

Contact Ellipse: The area formed between a bearing ball loaded against the ball track of a race ring in a ball bearing assembly.

Flight Article: The hardware, firmware, and software unit that is used operationally in a flight environment. This unit is designed and manufactured under strict quality control, with complete records of unit manufacturing, testing, shipping, and handling.

Holding Torque/Force Margin: The margin provided by a mechanism to prevent inadvertent operation.

Mechanism: A system in which one mechanical part moves relative to another mechanical part.

Operating Torque/Force Margin: The margin provided by a mechanism to ensure adequate actuation capability to drive a specified inertia or mass at a specified rate.

Proto-Flight Article: A flight unit used for qualification testing in lieu of a dedicated test article. This use of the flight unit for qualification testing often requires reduced test levels

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and/or duration and post-test hardware refurbishment.

Truncation: The condition in which a portion of a ball bearing's contact ellipse extends beyond the edge of the raceway due to excessive loading.

Qualification Article: A hardware, firmware, and software unit which is identical to the flight unit in form, fit, and function, as well as in manufacturing processes, parts, and quality control. This unit is used for verification and certification credit for all environmental requirements and performance requirements as needed.

Structural Fastener: A fastener that is used for structural purposes only, which is installed on the ground only, and whose configuration is not altered during flight, e.g., a bolt that acts as a hinge pin or a screw that holds a close-out panel onto a mechanism housing. Fasteners that are designed to be actuated during flight such as extravehicular activity (EVA) bolts or lead screws that act as fasteners, though they may perform structural functions, are not considered “structural fasteners” for the purposes of this document and may need to be evaluated as stand-alone mechanisms.

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4. REQUIREMENTS

4.1 Binding/Jamming/Seizing

Designs shall include provisions to prevent binding, jamming, or seizing. Appropriate provisions vary depending on the application. However, examples of possible provisions include dual rotating surfaces or other mechanical redundancies; robust strength margins such that self-generated internal particles are precluded; shrouding and debris shielding; proper dimensioning and tolerancing; thermal analysis; proper selection of materials and lubrication design to prevent friction welding, galling, etc.; and testing to determine detrimental contamination levels.

4.1.1 Clearances

a. Static and dynamic clearance requirements between the mechanism and any other structure, component, thermal covering, and field of view shall be established and maintained.

The established clearance requirements shall account for the following:

- (1) Manufacturing, assembly, and alignment tolerances
- (2) Temperature
- (3) Temperature gradients
- (4) Vibration
- (5) Distortion and relaxation due to the acceleration field
- (6) Distortion and relaxation due to depressurization
- (7) Ascent loads
- (8) Operational loads
- (9) Descent loads
- (10) Other internally and externally applied loads

b. The established clearances shall be maintained during transportation and all operational modes of the system and space vehicle.

4.1.2 Tolerancing

Dimensional tolerances on all moving parts and intentional interference-fit parts shall be established and documented via a tolerance stack-up/clearance analysis to ensure that proper functional performance is maintained under all natural and induced environmental conditions and configurations including, but not limited to the following:

- a. Thermally induced in-plane and out-of-plane distortions
- b. Differential thermal growth and shrinkage
- c. Deflections due to internal and externally applied loads
- d. Mechanical adjustment (rigging)

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4.1.3 Installation and Adjustment Sensitivity

An understanding of the sensitivity of mechanism performance as a function of installation/integration and mechanical adjustment (rigging) variables shall be demonstrated by test and/or analysis.

4.1.4 Lubricant Compatibility

Lubricants used in the mechanism shall be compatible with the following:

- a. Interfacing materials (including components and fluids)
- b. Other lubricants used in the mechanism
- c. All natural and induced environments encountered by the mechanism
- d. Outgassing/creep requirements (e.g., for nearby optical surfaces), if applicable
- e. Hygroscopic requirements, if applicable
- f. Clean room requirements, if applicable

4.1.5 Lubricant Quantities

The proper quantities of lubricant needed for all functions, their respective environments, and design lives shall be explicitly specified. The determination of the proper quantity shall include both of the following:

- a. Enough lubricant is available to perform as desired.
- b. The lubricant quantity is not over-specified such that it will produce detrimental effects, e.g., spreading into undesired areas, increasing viscosity, causing interferences, contaminating clean room environments, etc.

4.1.6 Lubricant Life

The selection of lubricant for use in the mechanism shall be based upon development tests of the lubricant that demonstrate its ability to provide adequate lubrication under all specified operating conditions over the design lifetime.

- a. If life testing cannot provide proof of lubricant availability based on evaporation over the required life of the mechanism, an analysis shall be performed to show that there is an adequate amount of lubricant available to the system (not including degradation) for the duration of the mechanism life with a margin greater than 10.
- b. Lubricant availability analyses based on degradation rates shall be verified through life testing.

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4.1.7 Pulleys

All pulleys shall use pulley guards that extend to the tangency points of the cable to prevent the cable from slipping off the pulley.

4.2 Quick-Release Pins

Quick-release pins, sometimes referred to as “pip-pins,” shall be considered individual mechanisms and thus subject to all program requirements applicable to mechanisms, including all of those contained in this standard. (See notes on Use of Quick-Release Pins, section 5.2.)

4.2.1 Quick-Release Pins with Zero Fault Tolerance

Quick-release pins shall not be used in zero fault-tolerant catastrophic hazard applications. (See notes on Use of Quick-Release Pins, section 5.2.)

4.2.2 Quick-Release Pin Standards

Quick-release pin design shall be qualified by inspection and test to the provisions of NASM23460 or equivalent.

4.2.3 Quick-Release Pin Acceptance Testing

Quick-release pins shall be subjected to environmental acceptance testing.

4.2.4 Quick-Release Pin Qualification Vibration Testing

Quick-release pins shall be vibration tested to qualification levels while in place in their respective hardware locations during the qualification test of the assembly or shall be tested alone in a component test to the predicted qualification levels at the hardware location.

4.2.5 Quick-Release Pin Qualification Thermal Testing

Quick-release pins shall be subjected to thermal qualification testing.

4.3 Springs

4.3.1 Spring Application

In applications where spring failure would result in a hazard, or partial or complete loss of mission, the springs shall be

- a. Redundant or
- b. Designed, evaluated, and used under an acceptable fracture control program if the governing program utilizes fracture control. (See notes on Spring Failure, section 5.3.)

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4.3.2 Spring Type

Where possible, compression springs shall be used in lieu of tension or torsion springs. (See notes on Spring Failure, section 5.3.)

4.4 Dampers

4.4.1 Viscous Damper Filling

All viscous dampers shall be vacuum filled to preclude entrapment of air.

4.4.2 Viscous Damper Construction

All viscous dampers shall allow changes in fluid volume and viscosity with temperature.

4.4.3 Viscous Damper Fluid Containment

Viscous dampers shall not leak fluid during the design life of the mechanism in which they are used.

4.5 Bearings

4.5.1 Bearings as a Current Path

Bearings shall not be used for ground current return paths or to carry electrical current.

4.5.2 Bearing Quality

Bearings shall meet Annular Bearing Engineering Council (ABEC) 7, 7P, or 7T tolerances (or better) in accordance with Anti-Friction Bearing Manufacturing Association (AFBMA) standards. Nonstandard bearings or thin sectioned bearings where AFBMA tolerances do not apply shall have the manufacturer's precision level most nearly equivalent to ABEC 7.

4.5.3 Bearing Hertzian Contact Stress

The mean Hertzian contact stress in a bearing shall not exceed the appropriate values in table 1 when subjected to the yield load.

Table 1 — Allowable Contact Stress for Bearing Materials Under Yield Loads

NOTE: For hybrid bearings using silicon nitride balls with steel rings, the allowable contact stress will be that of the steel used.

Bearing Material	Mean Hertzian Contact Stress Quiet Running	Mean Hertzian Contact Stress Non-Quiet Running
440C Steel	335 ksi (2310 MPa)	400 ksi (2760 MPa)
52100 Steel	360 ksi (2480 MPa)	430 ksi (2960 MPa)
M62 Steel	550 ksi (3790 MPa)	590 ksi (4070 MPa)

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4.5.4 Bearing Hardness

Rolling element bearings shall have a minimum hardness of Rockwell C58.

4.6 Switches

4.6.1 Inadvertent Prevention of Mechanism Actuation

When switches are used as indicating devices for mechanisms, the design of the switch mounting and the switch orientation shall be such that maladjustment of the switch shall not physically impede mechanism travel.

4.6.2 Switch Actuation

Switch actuation shall be accomplished such that the switch is capable of being actuated only within its acceptable operating range (e.g., cam-operated switches using ramps that level off, or use of indirect switch-release levers).

4.7 Fastener Retention

4.7.1 Fastener Retention Redundancy

Each fastener that performs a structural function either shall incorporate two separate verifiable locking features or shall be positively retained or captured. Preload may be used as one of the locking features combined with conventional vibration-rated aerospace secondary locking, so long as the preload level is adequate to produce the intended locking effect. (See notes on Fastener Preload, section 5.4.)

4.7.2 Structural Fasteners Subject to Rotation

Structural fasteners used in joints that are subject to rotation in operation shall either

- a. Utilize at least one non-friction locking device, or
- b. Utilize a self-locking nut with a shoulder bolt or a standard bolt in a sleeve, wherein the grip length or the length of the sleeve shall ensure that sufficient end play is provided to preclude binding when the self-locking nut is tightened.

4.7.3 Use of Snap Rings and Cotter Pins

- a. Snap rings and cotter pins shall not be used where other acceptable retention methods are possible.
- b. Where use of snap rings or cotter pins cannot be avoided, new snap rings or cotter pins shall be used once the previous snap ring or cotter pin is removed.

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4.7.4 Use of Non-Verifiable Structural Fastener Retention Methods

a. Non-verifiable retention methods such as liquid locking compounds (LLCs) shall not be used where other acceptable fastener retention methods are possible.

b. When no other acceptable fastener retention methods can be used, the use of a liquid locking compound shall require a validated process addressing the following LLC sensitivities:

- (1) Quantity and coverage of LLC
- (2) Fastener and joint material
- (3) Thread size
- (4) Fastener preload
- (5) All environmental conditions
- (6) Specified process for cleaning threads
- (7) Specified process for application of primer to threads
- (8) Specified process for applying LLC to threads
- (9) Break-torque strength in comparison with LLC's manufacturer-stated capability

4.7.5 Locking Feature Verification

Installation procedures shall require functional verification of locking features, such as measurement of running (self-locking) torque or visual inspection of lock wire integrity to be performed and recorded for each individual structural fastener.

4.7.6 Structural Fastener Torque Specification

a. Preload torques and running torques, along with their acceptable ranges, shall be specified on the drawings controlling their installation.

b. The required torque for fasteners with locking features shall be clearly specified on the drawing as "above running torque."

4.8 Performance Analysis, Strength Analysis, and Fracture Control

4.8.1 Structural Requirements

a. The structural design of mechanisms shall adhere to the structural requirements of the parent program.

b. The stress analysis shall include considerations of structural stiffness including that of the mounting interface; elastic and/or plastic deformations; and thermal distortions, alignment/tolerance induced displacements, and minimum material thickness/tolerance considerations.

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4.8.2 Mechanism Structural Interface Boundary Conditions

To ensure mechanism structural integrity and performance, the mechanism analysis shall include consideration of the structural mounting boundary conditions, including the following:

- a. Stiffness/flexibility
- b. Mounting alignment tolerances
- c. Temperature-induced distortions
- d. Load-induced distortions

4.8.3 Structural Integrity During Stall

Mechanism components and linkages shall have sufficient strength to tolerate an actuation force/torque stall condition at any point of travel and still maintain a positive margin of safety with the appropriate program-levied ultimate factor of safety applied.

4.8.4 Mechanical Stops

a. Mechanical stops shall be designed to a yield factor of safety of 2.0 and an ultimate factor of safety of 3.0 based on static analysis for maximum impact loads that occur upon full actuation of the mechanism. However, if it can be shown that the dynamic analysis inherently accounts for dynamic load amplification as a result of the impact, the nominal structural factors of safety shall be used.

Impact loads shall account for the following variables:

- (1) Variables in inertia properties
- (2) Actuation force/torque
- (3) Drive train resistance
- (4) Environmental conditions
- (5) Uncertainties in model parameters, analysis methodology, and other effects such as amplified inertia loads that may be transmitted through gear trains.

b. The mechanism analysis shall demonstrate that the stop transients do not overstress any gear teeth or drive mechanisms in the drive train.

4.8.5 Bearing Performance and Strength Analysis

a. Bearings shall have analysis demonstrating acceptable material, mounting, preload, performance, and structural integrity, accounting for the following conditions:

- (1) Maximum combined axial, radial, and moment loads sustained during ground handling, launch, on-orbit, or other operational modes
- (2) System stiffness requirements

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- (3) Effects of temperature, temperature gradients, fits, tolerances and initial preload on torque, stiffness, and life
- (4) Lubrication
- (5) Wear
- (6) Smoothness of operation
- (7) Friction torque, considering breakaway and running , in the installed state
- (8) Reliability and life
- (9) Effects of alignments, fits, tolerances, thermal, and load-induced distortions on preload, stress, and bearing shoulder height requirements

b. The design of each bearing installation shall be substantiated by analysis and tests for the specific application conditions.

c. Bearing fatigue life calculations shall be based on a survivability probability of 99.95 percent when subjected to maximum time varying loads.

d. The upper and lower extremes of the contact ellipses shall be contained by the raceway, or the effects of truncation shall be assessed.

4.8.6 Gear Performance Analysis

Gear trains shall have analysis demonstrating acceptable performance after accounting for the following conditions:

- a. Precision of gearing, including position errors and transmission errors (smoothness of motion)
- b. Gear train stiffness
- c. Gear train inertia
- d. Lubrication utilized
- e. Friction and friction variation (torque ripple)

4.8.7 Gear Strength Analysis

Gear trains shall have analysis demonstrating positive margins of safety for strength and wear, accounting for the following conditions:

- a. Tooth pitting, Brinelling, and bending stresses under nominal and peak operating loads
- b. Impact tooth loads from maximum combined axial, radial, and moment loads sustained during the full life cycle of the mechanism
- c. Backlash
- d. Effects of temperature and temperature gradients on quality of lubrication and gear contact pattern
- e. Effects of tooth geometry
- f. Undercutting and tooth profile modifications

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- g. Gear mounting, misalignment, face load distribution
- h. Variation in operating center distance

4.8.8 Inadvertent Contact Loads

If remote manipulator systems, payload operations, extravehicular or intravehicular activities, or other situations presenting a risk of inadvertent contact are present, then exposed mechanism components, protective shrouds and covers, and mounting structure shall be designed to accommodate inadvertent impact loads from these sources. Care in this manner will ensure adequate margins against deformation that could cause a binding or jamming condition or inadvertent operation of the mechanism, using full factors of safety.

4.8.9 Preloaded Bolt Criteria

a. Bolted connection margins of safety may be assessed without fastener preload, yield, or gapping considerations provided that all of the following requirements are met:

- (1) The joint is not a tension joint in which gapping cannot be tolerated. A “tension joint” is defined as a joint in which the largest component of the applied load is tension.
- (2) Fastener prying effects are correctly accounted for.
- (3) The fastener is in a local pattern of two or more fasteners.
- (4) The fastener is a high-quality military standard, national aircraft standard, or equivalent commercial fastener that is fabricated and inspected in accordance with aerospace flight quality hardware specifications.
- (5) The fastener preload is well controlled, using test-verified torque-tension relationships and nominally 65 percent of F_{ty} . Exceptions shall be documented with rationale, such as secondary structural application.
- (6) The joint fittings are metallic.
- (7) No significant thermal loading that changes preload is present during mechanical loading.
- (8) The joints are not for pressure containment, including crew module environmental containment, or hazardous material containment.

If the above conditions are satisfied, then the fastener margin of safety may be assessed in the gapped condition in the usual manner for interacting shear, bending, and tension, as applicable, with the tension portion of the interaction calculated using the applied tensile load.

b. If the above criteria are not met, the preload analysis shall be conducted according to NSTS 08307.

4.8.10 Fracture Control

Mechanical assemblies shall be evaluated under an acceptable fracture control program if the governing program utilizes fracture control.

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4.9 Positive Indication of Status

All movable mechanisms shall provide positive indication that the mechanism has achieved its desired position (ready-to-latch, latched, etc.).

4.9.1 End-of-Travel Stops

End-of-travel stops shall be incorporated into all mechanisms.

4.10 Torque/Force Margins

Operating torque margin is defined as follows:

$$\textit{Operating Torque Margin} = \frac{\textit{Available Driving Torque}}{\textit{Total Resisting Torque}} - 1$$

Holding torque margin is defined as follows:

$$\textit{Holding Torque Margin} = \frac{\textit{Available Holding Torque}}{\textit{Torque Applied at Limit Load}} - 1$$

Dynamic torque margin is defined as follows:

$$\textit{Dynamic Torque Margin} = \frac{\textit{Available Driving Torque} - \textit{Total Resisting Torque}}{\textit{Torque Required for Acceleration}} - 1$$

For linear devices, “Force” replaces “Torque” in the above equations. These margins shall account for all worst-case factors in credible combinations, including but not limited to the following:

- a. Environmental conditions
- b. Frictional effects
- c. Possible changes in static and dynamic friction due to storage time
- d. Alignment effects
- e. Latching forces
- f. Wire harness loads
- g. Damper drag
- h. Thermally induced distortions
- i. Load-induced distortions
- j. Variations in lubricity including degradation or depletion of lubrication under worst case thermal-vacuum conditions, etc.
- k. Distortion effects due to mounting interface stiffness and mounting tolerances

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- l. Seal friction due to mechanical compression of elastomers
- m. Fluid pressure on the elastomers in viscous dampers
- n. Supply voltage, motor, and controller parameters
- o. Acceleration due to vehicle motion or maneuvers which can retard deployment
- p. Minimum available drive torque or force

4.10.1 Required Operating Torque/Force Margin

When test verified, an operating torque/force margin of 1.0 or greater is required at all applicable points of travel. Only verification by analysis shall require prior review and approval of the analytical approach and margin requirement by the appropriate technical authority of the governing program.

4.10.2 Verification of Operating Torque/Force Margins

All operating torque/force margins shall be acceptance-test verified for the most critical regions of operation unless another verification approach is approved by the appropriate technical authority of the governing program. (See notes on Torque/Force Margin, section 5.5.)

4.10.3 Required Holding Torque/Force Margin

When test verified, a holding torque/force margin of 1.0 or greater is required in all applicable holding configurations. Only verification by analysis shall require prior review and approval of the analytical approach and margin requirement by the appropriate technical authority of the governing program.

4.10.4 Verification of Holding Torque/Force Margins

All holding torque/force margins shall be acceptance-test verified for the most critical regions of operation unless another verification approach is approved by the appropriate technical authority of the governing program. (See notes on Torque/Force Margin, section 5.5.)

4.10.5 Required Dynamic Torque/Force Margin

The dynamic torque or force margin shall be greater than 25 percent at any position of motion unless it is demonstrated to be detrimental to the performance of the mechanism.

4.10.6 Verification of Dynamic Torque/Force Margin

All dynamic torque/force margins shall be acceptance-test verified unless another verification approach is approved by the appropriate technical authority of the governing program. (See notes on Torque/Force Margin, section 5.5.)

4.10.7 Electric Motor Actuation

Where mechanisms are driven by electric motors, a torque-versus-current relationship for each motor under minimum, maximum, and ambient thermal conditions shall be established. (For stepper motors, see notes on Torque/Force Margin, section 5.5.)

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4.10.8 Redundant Spring Actuation

In spring-driven mechanisms where redundant springs are used instead of a backup deployment mechanism, the mechanism shall have a positive torque or force margin for a one-spring-out case based on combining worst-case conditions.

4.10.9 Separation Nuts

Separation nuts shall not require preload or gravity in order to release their bolt.

4.11 Contamination

4.11.1 Assembly and Handling Requirements

Mechanisms shall be assembled and handled in an environment meeting the cleanliness requirements established for that mechanism.

4.11.2 Lubricant Migration

Lubricants used within the system shall not offgas, creep, or otherwise migrate to optical or other sensitive surfaces.

4.11.3 Dry-Film Lubricant Debris

Dry film lubricant debris shall be contained or shall be demonstrated to be non-detrimental to the operation of the mechanism.

4.11.4 Viscous Damper Fluid Cleanliness

Viscous damper fluids shall be clean to a level consistent with the damper design cleanliness requirements.

4.12 Qualification Testing

Each mechanism shall undergo qualification testing that assures that its design performance and safety margin meets all design requirements in all environments and situations that the mechanism may reasonably expect to encounter during its service life (including acceptance testing) according to governing program requirements. (See notes on Qualification Testing, section 5.6.)

4.12.1 Qualification Configurations

The mechanism shall be qualification tested in its launch, on-orbit, landing, and other operational configurations, both

- a. At the appropriate corresponding environmental extremes and
- b. With the mechanism in its appropriate passive or operating state

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4.12.2 Qualification Testing Interface Boundary Conditions

Mechanical system qualification testing shall be conducted with the appropriate mounting interface boundary conditions, including stiffness/flexibility, mounting alignment tolerances, and thermal and load-induced distortions to ensure mechanical system structural integrity and performance.

4.12.3 Pre- and Post-Qualification Inspection and Functional Testing

Inspection and functional tests shall be performed both before and after qualification tests.

The inspection and pass-fail criteria for the functional tests shall be established prior to the qualification test.

4.12.4 Qualification Level Adjustment for Proto-Flight Approaches

Adjustment of qualification test parameters to avoid excessive endurance or fatigue limit margin erosion for programs using proto-flight approaches shall not be made without prior approval by the governing program.

4.13 Design Life Verification Tests

Design life verification testing shall be performed on all mechanism functions to verify that all design life requirements have been met. Typical design life concerns include cycle life, endurance or fatigue limits, potential deterioration of lubrication, excessive wear, storage times, etc. (See notes on Design Life Verification, section 5.7.)

4.13.1 Design Life Verification Test Environment

Design life verification testing shall be conducted at the applicable environmental extremes of the mechanism unless otherwise approved by the appropriate technical authority of the governing program. (See notes on Design Life Verification Testing, section 5.7.)

4.13.2 Testing of Mechanical Stops

Design life verification testing shall include testing of mechanical stops by intentionally running the mechanism into the stops, whether or not the mechanism has limit switches to prevent contacting the stops in normal operation.

4.13.3 Design Life Test Factor

a. Human-rated mechanisms shall be life tested to at least four times the number of planned operational cycles plus four times the total number of ground cycles (including assembly, installation, and maintenance) plus four times the total number of functional, environmental, and run-in cycles. (See notes on Design Life Verification, section 5.7.)

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b. Non-human-rated mechanisms shall be life tested to at least two times the number of planned operational cycles plus four times the total number of ground cycles (including assembly, installation, and maintenance) plus four times the total number of functional, environmental, and run-in cycles. (See notes on Design Life Verification, section 5.7.)

4.13.4 Pre- and Post-Life Test Inspection and Functional Testing

a. Inspection and functional tests shall be performed both before and after design life verification tests.

b. Mechanical system components that are subject to wear shall be disassembled and inspected for degradation or other anomalies.

4.13.5 Design Life Level Adjustment for Proto-Flight Approaches

Adjustment of design life verification test parameters based on criticality or to avoid excessive endurance or fatigue limit margin erosion for programs using proto-flight approaches shall not be made without prior approval by the appropriate technical authority of the governing program.

4.13.6 Refurbishment for Proto-Flight Approaches

Proto-flight systems shall be refurbished after the design life verification tests and prior to reacceptance testing.

4.14 Acceptance Testing

All mechanisms shall be subjected to acceptance testing which incorporates functional, run-in, and environmental testing structured to detect workmanship defects that could affect operational performance. (See notes on Acceptance Testing of EVA Bolts, section 5.8.)

4.14.1 Functional Test Structuring

a. All functional tests for mechanisms shall be structured to demonstrate that the mechanism is capable of operating to satisfy all performance requirements.

b. All mechanism functions shall be exercised during functional testing.

4.14.2 Initial Functional Testing

Each mechanism designated as a flight or qualification test article shall undergo an initial functional test prior to undergoing any other acceptance testing.

4.14.3 Run-In Testing

A run-in test shall be performed on each mechanism after initial functional testing and prior to being subjected to further acceptance testing unless both of the following are true:

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a. It can be shown that this procedure is detrimental to performance and would result in reduced reliability, and

b. The appropriate technical authority of the governing program grants a waiver for the run-in test prior to the start of acceptance testing. (See notes on Run-In Testing, section 5.9.)

4.14.4 Run-In Test Duration

a. The run-in test shall be conducted for a minimum of 50 hours.

b. For items where the number of cycles of operation is a more appropriate measure of the capability to perform in a consistent and controlled manner, the run-in test shall be conducted for at least 15 cycles or 5 percent of the total expected service life cycle, whichever is greater.

4.14.5 Run-In Test Environment

The run-in test conditions shall be representative of the operational loads, speed, and environment. The assembly may be operated at ambient conditions if both a and b are satisfied as follows:

a. The test objectives can be met and the ambient environment will not degrade reliability or cause unacceptable changes to occur within the equipment, such as the generation of excessive debris, and

b. The appropriate technical authority of the governing program grants permission for the run-in test to be conducted at ambient conditions prior to the start of run-in testing.

4.14.6 Run-In Test Monitoring

During the run-in test, sufficient periodic measurements shall be made to indicate what conditions may be changing with time and what wear rate characteristics exist.

4.14.7 Environmental Testing

a. Environmental acceptance tests for mechanisms shall demonstrate the mechanism's ability to achieve performance requirements when exposed to expected environmental extremes.

b. All mechanism functions that operate in that environment shall be exercised during environmental testing.

4.14.8 Functional Testing

Functional tests that exercise all mechanism functions shall be performed both before and after environmental tests in order to establish whether damage or degradation in performance has occurred.

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4.15 Mechanism Installation

Mechanisms shall either be designed to preclude installation in an incorrect orientation or be clearly labeled in a manner that indicates proper installation orientation and prevents improper installation.

4.16 Exceptions and Alternate Approaches

Any exceptions or alternate approaches to the requirements listed in this standard shall be justified with supporting technical rationale and formally approved by the proper NASA technical authority prior to implementation.

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5. GUIDANCE

This section contains information of a general or explanatory nature that may be helpful but is not mandatory.

5.1 Reference Documents

MIL-A-83577B (Cancelled)	Assemblies, Moving Mechanical, for Space and Launch Vehicles, General Specification for
MIL-STD-1540D	Product Verification Requirements for Launch, Upper Stage, and Space Vehicles
NASA TP 1999-206988	NASA Space Mechanisms Handbook
NASA TM-86556	Lubrication Handbook for the Space Industry

5.2 Use of Quick-Release Pins

Quick-release pins have an extensive history of failure and other problems, which is why they are subject to extra provisions. Their use in critical applications is strongly discouraged, and they should never be used in zero fault-tolerant critical hazard applications. Because they are considered as separate mechanisms, they require their own redundancy or hazard control measures. Before quick-release pins are used in catastrophic hazard applications, three failure modes must be addressed:

- a. Loss of locking ball(s)
- b. Premature failure of shank
- c. Failure of head

Loss of locking balls is nearly impossible to eliminate through design and manufacturing. The usual method of providing a control to that failure is a hitch pin. Quick-release pin vendors can eliminate failures a and b by design and manufacturing using the following combination of efforts:

- a. Design reviews by NASA and contractors of each quick-release pin design drawing to eliminate failure modes, and identify critical dimensions and critical processes.
- b. Process control (heat treating, welding, etc).
- c. Traceability of raw materials.
- d. Addition of mandatory inspection points (MIPs) for critical dimensions. MIP sign-off would be during process and manufacturing steps.
- e. Configuration control of the vendor's design and fabrication process.

In addition, quick-release pin structural integrity in a particular application should be addressed. The appropriate NASA technical authority should ensure that quick-release pin design and manufacturing, redundancy, structural integrity, and math model accuracy requirements are

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satisfied. Given the heavy scrutiny typically involved, the end result is that it might be easier to use some other method—launch bolts, screws, shear pins, latches, etc. Currently, only one quick-release pin has undergone such a process, Avibank “Space Pin” part number 56789. These pins received a site certification from Johnson Space Center in order to be approved for use on the Space Shuttle and Space Station programs. The use of this pin was still subject to quick-release pin-specific requirements similar to those in this standard, but the use of any other pin was subject to still further restrictions. This example does not imply endorsement of these pins by any other program, and their acceptability for use should be approved by each individual program’s appropriate technical authority.

5.3 Spring Failure

a. Failure of springs that are properly controlled under an acceptable fracture control program is typically considered non-credible. The design and use of a fail-safe spring or the use of a spring that maintains functionality with the loss of a single coil is acceptable.

b. Compression springs (including spring washer stacks) are desirable over extension and torsion springs because a compression spring may retain a portion of its functionality after the fracture of a coil, a condition which is generally not possible with other types of springs. However, in order for this functionality to be retained, the spring geometry must be such that space between coils is less than the spring wire diameter so that the broken halves cannot thread into one another. Such threading into one another would further reduce or eliminate the spring functionality.

5.4 Fastener Preload

Testing has shown that preloads in the ranges specified by most of the common standards such as MSFC-STD-486B (typically in the 70 percent Fty range and often specified by the preload torque) are usually (but not always—thus the requirement for secondary locking features) sufficient to prevent loosening during vibration. However, there is very little data for preloads under this range. For preloads less than those found in MSFC-STD-486B, developmental vibration testing for the specific application should be performed to demonstrate that the preload level chosen is sufficient to prevent loosening under flight vibration environments.

5.5 Torque/Force Margin

Verification by test as specified in sections 4.10.2, 4.10.4, and 4.10.6 does not require a mechanism demonstration at greater than limit load conditions but rather requires a test verification of the amount of driving or holding torque or force available under conservative adverse conditions.

The stepper motor margin may be calculated one of two ways: using motor available torque (pull-in torque) and comparing to friction loads or performing a step stability analysis. Refer to AIAA S-114-2005, *Moving Mechanical Assemblies for Space and Launch Vehicles*, for details. For closed-loop control and micro-stepping applications, the static and dynamic margin equations of section 4.10 should be used.

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5.6 Qualification Testing

MIL-STD-1540D may be helpful in establishing an effective qualification test program.

5.7 Design Life Verification Testing

a. Design life tests for long-term missions often require accelerated testing. This testing needs to be approached carefully with knowledge of the failure mechanism being tested and potential undesirable consequences of accelerating temperature and/or speed. For example, increasing the speed of a gear train during testing to get the required number of cycles may aid the lubrication of a device intended for cryogenic application by local heating, which helps the flow (replenishment) of the lubricant, or the increased centrifugal force may deplete lubricant unrealistically, or the gearbox may encounter a resonant speed where the planet gears rattle between their opposite faces, destroying the gears rapidly. Care must be taken not to perform a test that is unrepresentative of the design conditions.

b. Test data has shown that certain dry-film lubricants (especially Molybdenum Disulfide-based lubricants) perform better and degrade less quickly in a vacuum than they do in an atmospheric environment. For this reason, life verification tests performed in atmospheric conditions may be conservative in this respect, but by the same token this increase in lubricity can have undesirable effects such as changes in achieved preload of EVA bolts. All effects of a vacuum on the mechanism in question need to be considered when picking the worst-case test environment.

c. It is often advisable to add some margin to the calculated number of life cycles to allow for anomaly investigations or other unforeseen needs. This margin allows for the mechanisms to be functioned during investigation without using up flight cycle life and exceeding the life certification. This margin is added before applying the test factor, i.e. (life cycles + test cycles + ground cycles + margin)*4.

5.8 Acceptance Testing of EVA Bolts

Sometimes, acceptance testing and wear-in of the removal of any EVA bolt with self-locking threads is not recommended. Some self-locking thread features and some lubricants have a very limited life. Therefore, they can be prematurely degraded by acceptance testing. In these cases, an alternate acceptance approach may be advisable. Such an approach could require some combination of the following:

- a. Rigorous torque margin analysis
- b. Increased attention to materials and lubricant selection
- c. Increased attention to process control and inspection of thread form, lubricant application, assembly, and running torque measurement
- d. Increased contamination control precautions

However, in some instances, depending on the materials and lubricants involved and the operational scenario, a preconditioning of the locking insert may be recommended. In this case,

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conditioning with one cycle has met with good success in the past because the torque in the inserts is typically reduced by about 50 percent after only one cycle.

5.9 Run-In Testing

One primary purpose of the run-in test is to detect material and workmanship defects that manifest themselves early in the component life and that are not commonly caught by acceptance vibration testing. Another purpose of the run-in test is to wear in parts of the assembly so that they perform in a consistent and controlled manner prior to subsequent testing and use. Satisfactory wear-in may be manifested by a reduction in running friction to a constant low level. Not performing wear-in for this reason can cause false “failures” in subsequent testing due to physical characteristics falling outside of acceptable parameters that were established without understanding true steady-state conditions. Test procedures, test time, and criteria for performance adequacy should be in accordance with a test plan that has been approved by the program’s appropriate technical authority. All gear trains using solid film lubricants should, where practicable, be inspected and cleaned following the run-in test.

5.10 MIL-A-83577B

Many of the practices in this standard were constructed from portions of MIL-A-83577B. However, that complete specification is far too broad to be applied to this application in its entirety, and that document is now cancelled. An American Institute of Aeronautics and Astronautics (AIAA) specification based on the cancelled MIL-A-83577B, designated AIAA S-114-2005, is an updated version of this resource. It makes for an excellent design guide.

5.11 Key Word Listing

<u>Key Word</u>	<u>Page Number</u>
Acceptance Testing	4, 6, 13, 22, 24, 25, 29
Bearings	5, 14, 15, 17
Contamination	5, 11, 22, 29
Dampers	4, 14, 21
Fastener Retention	5, 15, 16, 30
Gear Strength	5, 18
Lubricant	4, 5, 12, 22, 29, 30
Switches	5, 15, 23
Quick-Release Pins	4, 6, 13, 27
Tolerancing	4, 11
Torque/Force Margin	5, 6, 9, 20, 21, 28