DESIGN STANDARD

MECHANISMS

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Japan Aerospace Exploration Agency

This is an English translation of JERG-2-330. Whenever there is anything ambiguous in this document, the original document (the Japanese version) shall be used to clarify the intent of the requirement.

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Contents

1. Scope

1.1 Purpose

This design standard describes the requirements for the design, quality control and testing of mechanism assemblies (hereinafter referred to as "mechanisms") used in spacecraft (such as artificial satellites and probes) and aims to ensure a high reliability in all the mechanisms with mechanical actuation.

1.2 Scope of application

The requirements to be handled in this design standard shall be applied to the mechanisms installed in the spacecraft. In addition, the mechanism for rocket and manned space equipment are not treated in this document.

2. Related documents

2.1 Applicable documents

The following documents shall be applicable in the scope defined by this design standard. If a contradiction arises, priority shall be given to this design standard unless otherwise specified.

(1) JERG-2-000 Spacecraft (Artificial Satellite and Probe) Design Standard
(2) ASTM E 595 Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
(3) JERG-2-200 Electric Design Standard
(4) JERG-2-310 Thermal Control System Design Standard
(5) MIL-HDBK-5 Metallic Materials and Elements for Aerospace Vehicle Structures
(6) JMR-001 System Safety Standard

2.2 References

The reference documents related to this design standard shall be as follows:

(1) JERG-2-141 Space Environment Standard

3. Terminology, definitions and abbreviations

3.1 Terms and Definitions

(1) Mechanism
Assembly of machine elements connected mutually to accomplish relative motion; mechanism assembly
(2) Outgassing
Emission of gas produced by material in a vacuum
(3) Interface
Mechanically, thermally, electrically and operationally common boundary between two elements in a system
(4) Acceptance test
A test to verify that the systems, subsystems, components or function parts are capable of satisfying the specifications defined in the purchase specification and the

performance requirements specified in other documents and that the items are free from manufacturing defects

(5) Contamination
Adhering of contaminants on the target surface or the state of adhesion

(6) Lubrication
Use or application of a material with specific surface characteristics between two surfaces in contact or in relative motion in order to reduce friction, wear or adhesion.

(7) Redundancy
Duplication of components or means for accomplishing specified functions. No upper items will fail even if some parts fail.

(8) Debris
A French term meaning fragment. Refers to abrasion powders produced by the operation of mechanism parts. Also refers to man-made dust and fragments drifting in space such as wreckage of man-made satellites.

(9) Total Ionizing Dose
Total dose of radiation absorbed in parts or materials up to a specific time

(10) Tribology
Science and technology on two mutually interfering surfaces in relative motion and related problems and on-site application

(11) Qualification test
A test to verify that the design of a mechanism or of mechanism parts is capable of satisfying the specified performance requirements under the operation environment with the margin specified

(12) Maintainability
A characteristic of design and facility of equipment for promoting checking, testing, inspection, service, repair and overhaul to accomplish the operational purposes with the minimum time, expertise and resources under a specified maintenance environment

(13) Misalignment
Geometric position error between machine elements and parts (such as translational displacement, inclination, torsion)

(14) Mission
To achieve the purpose of the program by carrying out consistent investigation or operation in space

(15) Latching or locking
When no restrictions are imposed on one or more degrees of freedom of a mechanism, latching or locking means to restrict such degree of freedom intentionally. In such cases, some sort of operation must be performed to release the mechanism.

3.2 Symbols and abbreviations

(1) EMC Electromagnetic compatibility

4. General requirements

The requirements shall be applied to the design and design verification of mechanisms.

4.1 System performance

The functional performance of mechanisms shall comply with the performance requirements of the system.

4.2 Mission

In designing a mechanism, the requirements shall be applied throughout the entire period of the mission specified in individual programs. All the requirements and environment conditions in each phase of the mission shall be satisfied.

4.3 Function

(1) Regulations on mechanism action shall be made.
(2) Regulations shall be made on the mechanical interface, action accuracy and speed including tolerance. It shall be required to verify that the specified requirements are satisfied.
(3) The action envelope area of mechanism components shall be specified. The envelope area shall not interfere with other on-board equipment or spacecraft.

5. Design requirements

5.1 Interfaces

(1) Structural interfaces
Mechanisms shall conform to the structural interface conditions and requirements defined in the specification.
(2) Thermal interfaces
Mechanisms shall conform to the thermal interface conditions and requirements defined in the specification.
(3) Thermomechanical interfaces
Thermomechanical interfaces shall be designed in consideration of induced stress.
(4) Electric interfaces
Mechanisms shall conform to the electric interface conditions and requirements defined in the specification.
(5) Physical interfaces
The mass of a mechanism shall conform to the requirements defined in the specification.
(6) Other interfaces
Mechanisms shall conform to the interface conditions of optical (visual field), mounting alignment, accessibility during operation, envelope area, clearance with other equipment and ground-based equipment defined in the specification.

5.2 Environmental design standard

Mechanisms shall conform to the environmental condition requirements defined in the specification.

5.2.1 Ground environment

(1) Mechanisms shall satisfy the required performance even under ground handling environment conditions such as ground test, assembly, storage and transportation.
(2) It shall be required to consider the ground test environment including temperature, vibration, sound, shock, different atmospheric gases, pressure, humidity, cleanness and corrosive environment.

5.2.2 Launching environment

(1) Mechanisms shall satisfy the required performance after being exposed to rocket-launch environment conditions.
(2) As to the launching environment, changes in the parameters such as temperature, vibration, sound, shock, pressure and humidity shall be considered.

5.2.3 Orbital environment

(1) Mechanisms shall satisfy the required performance under orbital environment conditions until the end of their required operating life is reached.
(2) As to the orbital environment, such factors as vacuum, temperature cycle, vibration, shock, radiation, ultraviolet and atomic oxygen shall be considered. Consideration shall also be given to the effects of such space environment on the materials used in the mechanism.

5.3 Parts and materials

It shall be required to select mechanical parts, materials and processes which conform to the requirements for the functions, performance, environment conditions, quality and reliability of the mechanism and other requirements defined in the specification.

5.3.1 Requirements for parts

(1) Mechanical parts shall be selected from certified parts or registered parts if possible and proper.
(2) It shall be required to select mechanism components which conform to the mechanism requirements
(3) Mechanical parts shall be standardized to the possible and proper level.

5.3.2 Requirements for materials

(1) It shall be required to select mechanism materials which conform to the mechanisms requirements.
(2) In selecting metallic materials, consideration shall be given to corrosion resistance, galvanic corrosion resistance, stress corrosion cracking, and as-needed surface modification treatment in addition to physical and mechanical properties.
(3) In selecting mechanism materials which are to be exposed to the space environment, be sure that they have the tolerance to radiation, ultraviolet, atomic oxygen and debris as well as the low outgassing characteristics which conform to the applicable mission requirements.
(4) It shall be required to select materials for which change in characteristics due to temperature change and temperature cycle is within the required limit of the mechanism
(5) If environmental factors such as radiation, ultraviolet, atomic oxygen and temperature environment may have a synergetic effect on the materials to be selected, it is required that the effect on the materials under such complex environment fall within the required limit of the mechanism.
(6) When using hygroscopic or swellable materials, it is required that the change in material characteristics due to moisture absorption and swelling fall within the required limit of the mechanism.

5.4 Mechanism design

This section specifies general design review items with respect to the mechanism design such as parts and assemblies.

5.4.1 Accuracy control design

For mechanisms which require accuracy control, a proper error budget shall be reviewed and designed for the following items.

(1) Machining and assembly tolerances, misalignment
(2) Bending (deflection), torsion
(3) Thermal deformation
(4) Mechanical interference (movable envelope)
(5) Frictional force and variation in frictional force, hysteresis
(6) Variation in driving force (motor, spring, electromagnetic solenoid)
(7) Control transient phenomena (resonance, overshoot)
(8) Performance errors ascribable to other error variations

5.4.2 Driving design

A proper margin (allowance) shall be provided to mechanisms with a driven section. Consideration shall be given to the following items:

(1) For frictional forces, consideration shall be given to not only dynamic friction force during steady drive but also to static friction force and hysteresis during activation and inverse driving.
(2) For motor driving, each motor shall have a torque (or force) margin which meets the requirements for expected changes in operational temperature and speed. The driving current shall be in agreement with the power resource.
(3) In reviewing (calculating) the required driving force (drive resistance), it is required to review the worst-case combination of operationally expected changes in temperature and speed with respect to each resistance element (such as bearing, gears, harness cables, latches and dampers). If necessary, the calculated values shall be checked for validity through testing at the element and subassembly level.
(4) For drive mechanism elements using a redundant system, a proper torque (or force) margin shall be ensured in case an element fails under the worst-case conditions.
(5) For deteriorated drive mechanism elements with a redundant system, the margin of other mechanism elements shall be evaluated in consideration of the possibility that the deteriorated mechanism will develop resistance force.

5.4.3 Operating life design

The operating life of a mechanism shall correspond to the expected sum total of nominal ground test and orbital operation. It is required that the mechanism be designed so that it can reach the required operating life under the proper environment conditions.

5.4.4 Tribology

(1) In designing a mechanism, it is required that the mechanism conform to its performance requirements and that the sliding and rolling surfaces be properly lubricated to prevent adheasion and reduce wear over the entire duration of the required operating life.

(2) Requirements on the storage, handling and operation of the mechanism shall be clarified in order to maintain the soundness of the lubricating surfaces of the mechanism.
(3) The rate of outgassing in the lubricant used to lubricate the mechanism shall be measured in accordance with a predetermined measurement method. (See ASTM E 595 Standard Test Methods for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment.)

5.4.5 Not Used

5.4.6 Other requirements

5.4.6.1 Replaceable mechanism

(1) It is desirable that replaceable mechanisms be designed with error proofing to ensure installation in the correct direction.
(2) Mechanisms using a crash damper shall be designed to be assembled only in the correct direction.

5.4.6.2 Latching or locking

It is required that latching mechanisms for locking be designed properly to prevent accidental release caused by vibration or shock generated during mission implementation.

5.4.6.3 End stops

In order to drive the operation items properly and prevent interference with the interface equipment, a mechanism in which movement or rotation is restricted shall be provided with a normal or emergency mechanical end fastener which regulates the mechanism's ultimate motion or movement to the maximum position.

5.4.6.4 Separable contact surface

The adhesion force between contact surfaces in which separation is likely to occur shall be smaller than the specified value.

Contact surfaces in the joint shall be designed considering the contact conditions, material characteristics and surface roughness.

5.4.6.5 Venting

(1) It shall be required to design a proper means for venting during launching and orbital operation unless the mechanism is air-tight or designed to deal with the forming of internal pressure in terms of function and performance.
(2) The venting method shall be designed properly to minimize the contamination of bearing, optical equipment and other high-sensitive equipment.
(3) For ventilation outside the lubricated portions, the lubricant shall conform to the contamination requirements for other applicable spacecraft materials.

5.4.6.6 Resetting and locking devices using explosive devices or other actuators

The operation of a releasing device shall conform to the cleanness requirements.

The releasing device shall be designed with a proper method for trapping debris.

5.5 Structural design

5.5.1 General requirements related to structural design

The structural design of a mechanism shall conform to the requirements.

Mechanisms shall be provided with the required functions and performance under the expected thermal environment conditions throughout their entire operating life. Transitional conditions shall be included in the thermal environment conditions.

5.5.2 Allowable values of materials

(1) The permissible design standard for structure is generally specified in MIL-HDBK-5 Metallic Materials and Elements for Aerospace Vehicle Structures.
(2) If the required design strength or other mechanical, physical or thermal reliabilities are not proper, it is required to make a new specification and perform evaluation or testing for assurance.

5.5.3 Strength safety margin

(1) Mechanisms shall satisfy the mechanical interface and performance requirements and withstand the expected environment during handling, transportation, test, storage, launching and orbital operating life without damage or deterioration.
(2) Mechanisms shall have a positive safety margin for all environments.

5.5.4 Stiffness design

If there are requirements for natural frequency to correspond to the machine environment during launching or requirements for ensuring orbital flexible structure characteristics, the mechanism shall be designed with rigidity to meet the requirements.

5.6 Thermal design

The thermal design of a mechanism shall conform to the requirements specified in JERG-2-310 Thermal Control System Design Standard. Mechanisms shall meet the following requirements.

Mechanisms shall be provided with the required functions and performance under the expected thermal environment conditions throughout their entire operating life. Transitional conditions shall be included in the thermal environment conditions.

5.7 Electrical design

5.7.1 Electrical design

Mechanisms shall be designed to meet the requirements for electrical performance and have stable electrical characteristics throughout their operating life cycle. Basically, JERG-2-200 Electric Design Standard.

5.7.2 Electric wires

(1) Fixed parts shall be used for portions which are likely to be affected by bending.
(2) Cables and electric wires shall be formed, arranged and supported considering the

following items:
(a) No electric wires, electric wire terminals or connectors shall be subject to mechanical stress exceeding their tolerance.
(b) Wiring shall be carried out at a distance from sharp edges or liquid pipe lines.
(c) In a vibration environment, damages and failures shall be prevented.

5.7.3 Electric connectors

Connector types and shapes (example: number of pins) shall be selected so as to avoid damage or coupling errors.

5.7.4 Insulation

The insulation of electric wires shall be designed in accordance with JERG-2-200 Electric Design Standard.

5.7.5 Grounding

Mechanisms shall be grounded at a mechanical interface point. Any components insulated from mechanical interface points shall be ground separately as needed.

5.7.6 Deformation of wiring

For electric wires which deform at movable portions, consideration shall be given to make shape change and reaction force repeatable.

5.8 General requirements

5.8.1 Reliability

(1) Mechanisms are an important component which can become a single point of failure in many cases. Due consideration shall be given to their reliability.
(2) The reliability of mechanisms can be increased by providing a large design margin or designing single points of failure with redundancy.
(3) For mechanisms that are indispensable to the success of mission, it is required to prove that the required reliability is satisfied through analysis or testing.
(4) For parts with a limited operating life, the operating life shall be verified through testing or analysis.
(5) It is required that the failure of a part will not cause nonconformance in other equipment or mechanisms.
(6) Reliability analysis shall be performed in accordance with JMR-004 Reliability Program Standard.

5.8.2 Redundancy

(1) All single points of failure in the mechanism shall be identified in the design phase. To minimize the number of single points of failure and satisfy the reliability requirements, the mechanism shall be designed with a redundant configuration where possible.
(2) If the entire mechanism cannot be designed with a redundant configuration, redundancy shall be accomplished at the mechanism component level.
(3) It is required that a failure in one subcomponent in the redundant system will not cause nonconformance in other functions or parts in the redundant system.

5.8.3 Safety

(1) In designing a mechanism, due consideration shall be given to safety so as to prevent harm to personnel and peripheral equipment in all phases including manufacturing, assembly, testing and transportation. Due consideration shall be given to prevent damage to the mechanism in all the phases.
(2) Safety design shall be performed in accordance with JMR-001 System Safety Standard.

5.8.4 Operability

(1) It is required that no operational restrictions are imposed on the mission in designing a mechanism. If imposing operational restrictions is inevitable, the conditions shall be identified.
(2) When off-nominal requirements are made from the system, it is required that a worst-case analysis be performed in the design phase considering off-nominal operation and that the system design be supported to minimize the sensitivity of design and operational performance to the changes in parameters.

5.8.5 Maintainability

(1) It is required that mechanisms be maintenance-free during storage or ground operation. If maintenance must be performed by necessity during storage or at the end of the ground operating life, it is required to record the number of actions, nonconformance identification and repair details, and thereby indicate the appropriateness of maintenance.
(2) Mechanisms shall be designed considering the replacement of critical parts if appropriate.

5.8.6 Interchangeability

It is required that mechanisms and parts be designed considering interchangeability where possible.

5.8.7 Error proofing design

(1) It is required that mechanisms and parts be designed so as to prevent improper assembly.
(2) Mechanisms and parts shall be designed so that testing and inspections can be performed to check for proper assembly and mounting.

5.8.8 Other requirements

5.8.8.1 Identification nameplate

(1) Mechanisms and parts shall be identified by nameplates. Nameplates shall be attached to an outer surface so that no mechanism functions will be affected.
(2) Pasting, etching or direct display with regard to the article may be performed if there are no appropriate outer surfaces to which to attach a nameplate.

5.8.8.2 Non-flight display

Non-flight articles shall be distinguished from flight articles.

5.8.8.3 Measurement item

(1) It is required that mechanisms be designed so that important data which can ensure its performance and identify failures will be measured continually from the ground evaluation phase to orbital operation.
(2) Measurement data shall be obtained through a telemeter wherever possible.

6. Verification

(1) The development of a space mechanism shall include a verification process. Verification requirements shall be divided into analytical verification requirements and test verification requirements.
(2) A verification matrix shall be created.

6.1 Analytical verification

Analytical verification of mechanisms shall include the following items:

(1) Identification of the worst operational and non-operational cases through thermal analysis
(2) Structural analysis stiffness, stress caused by mechanical/thermal load, and fatigue)
(3) Performance analysis of operable functions under every applicable environment and operation condition (based on the worst-case conditions identified) in order to derive the load, time, shock, speed, dimensional stability and position accuracy.
(4) Dynamic margin
(5) Occurrence of shock and sensitivity
(6) Occurrence of external disturbance and sensitivity
(7) Lubrication analysis
(8) Operating life analysis
(9) Magnetic or electromagnetic analysis
(10) Radiation analysis
(11) Stress analysis

6.1.1 Identification of worst-case conditions

The operational and non-operational conditions under the mechanism worst-case conditions shall be set in accordance with the environment, load, functional performance of specific spacecraft and mechanisms.

6.1.2 Thermal analysis

Thermal analysis of mechanisms shall conform to the requirements specified in JERG-2-310 Thermal Control System Design Standard.

6.1.3 Structural analysis

Structural analysis of mechanisms shall conform to the requirements specified in JERG-2-320 Structure Design Standard.

6.1.4 Function and performance analysis

The requirements for function models shall be as follows:

(1) The analysis models or numerical models to be used as the basis for analysis shall have flight hardware mechanism interface conditions and spacecraft characteristics with respect to the following items:
   (a) Mass
   (b) Inertial force
   (c) Position of center of gravity
   (d) Structural stiffness
   (e) Application force or application torque
   (f) Resistant force

(2) The following items shall be performed on the model shown in Section (1).
   (a) Parametric study of mechanical variation factors
   (b) The analysis model shall be renewed through the design and test phases if necessary.
   The analysis results shall be verified in comparison with the related test results.

6.1.5 Analysis of dynamic margin

It shall be required to verify through analysis that mechanisms conform to the specified requirements related to the dynamic margin.

6.1.6 Occurrence of shock and sensitivity

It shall be required to verify through analysis that mechanisms conform to the requirements related to the occurrence of shock and sensitivity specified in the mechanism requirement specification.

6.1.7 Disturbance produced

It shall be required to verify through analysis that the operation of mechanisms conforms to the vibration-related (micro-vibration) requirements defined in the mechanism requirement specification.

6.1.8 Lubrication analysis

(1) It shall be required to verify that the selected lubrication system conforms to the application method or operating life.
(2) The quantity of lubricant shall be evaluated for conformity through analysis.

6.1.9 Operating life analysis

(1) Mechanisms with a limited operating life shall be identified.
(2) It shall be required to verify through analysis that mechanisms with a limited operating life conform to the operating life requirements.

6.1.10 Magnetic or electromagnetic analysis

It shall be required to verify through analysis that the EMC standard is satisfied.

6.1.11 Radiation analysis

It shall be required to perform analysis on radiation-sensitive mechanisms for total ionizing dose and verify that the mechanisms conform to the performance requirements including operating life.

6.1.12 Stress analysis

It shall be required to perform stress analysis on electric parts (including harnesses) to verify that the electric parts conform to the derating standard.

6.2 Verification through testing

6.2.1 Basic principle

(1) In testing, it shall be required that the hardware conform to the requirements related to design, manufacturing and performance. Testing includes development tests, qualification tests, acceptance tests and operating life tests.
(2) The mechanism design shall conform to the ground operation under atmospheric environment conditions and thermal vacuum conditions. Restrictions on operation under allowable operations and environment conditions shall be defined.
(3) The mechanism design shall be performed with consideration given to conducting typical ground tests in an operable form. It shall be required that the mechanism design conforms to testing under the atmospheric environment and thermal vacuum environment conditions under gravity.

6.2.2 Development test

(1) A development test shall be planned and conducted as follows:
  (a) Input necessary to design and analysis (dynamic analysis in particular) shall be provide.
  (b) New designs shall be verified.
  (c) Verification shall be made on critical mechanisms.
(2) Testing
  Unless clearly verified based on the test data obtained from the past space application cases, the following verification tests shall be conducted on the mechanisms of the engineering model in the initial phase of the project.
  (a) Function and performance test
  (b) Vibration test and shock test (if necessary as verification of new design)
  (c) Thermal vacuum test or temperature test (if necessary as verification of new design)
  (d) Operating life test on mechanism elements with a critical operating life
(3) Critical mechanisms and parts which require a development test shall be identified in the initial phase of the design and development program.

6.2.3 Qualification tests

Mechanisms shall be qualified through testing.
Qualification tests shall be conducted according to typical procedures under a typical environment.

6.2.3.1 Structure test

In a structure test, verification shall be made in accordance with the structure-related

requirements specified in JERG-2-320 Structure Design Standard.

6.2.3.2 Thermal vacuum test

In a thermal vacuum test, verification shall be made in accordance with the requirements specified in JERG-2-310 Thermal Control System Design Standard.

6.2.3.3 Functional test

In a functional test, it shall be required to verify that the mechanisms conform to the function and performance requirements even after being exposed to the environment conditions (load and heat) of qualification test.

Mechanical and thermal stabilization shall be performed before conducting a test.

6.2.3.4 EMC test

When using an EMC-sensitive component with regard to the mechanism or when spacecraft-specific EMC requirements are imposed on the mechanism, it shall be required to verify the EMC performance of the mechanism.

6.2.3.5 Electrical test

In an electrical test, it shall be required to verify that the mechanism conforms to the electrical function and performance requirements.

6.2.4 Acceptance test

For products newly assembled based on the qualified design, it shall be required to verify through an acceptance test that the manufactured hardware is free from manufacturing errors. Acceptance tests shall be conducted at a level higher than the expected level at the time of launching but lower than the qualification level. Testing shall be conducted at a level which causes no damage to the hardware. No repair or adjustment after the acceptance test shall be necessary.

6.2.4.1 Test items

It is desirable that testing include the following items as well as the detection of workmanship errors.

The functions and performance shall satisfy the requirements.

It shall be verified that the electric wiring can withstand the required voltage without causing destructive discharge.

6.2.4.2 Running-in

It is desirable that running-in be performed on mechanisms unless it is harmful in terms of performance and can decrease the reliability.

6.2.4.3 Inspection

The dimensions, mass, appearance and identification marking of the machine shall be inspected properly after the acceptance test.

6.2.5 Operating life test

6.2.5.1 Operating life qualification

After going through an environment test at a level higher than that of the acceptance test, the design, operating life and performance of mechanisms shall be verified for conformity under the operating life test conditions simulating the ground and in-orbit environment conditions.

6.2.5.2 Requirements for operating life test conditions

The operating life test conditions shall properly represent the following parameters which impact the operating life.

(1) Thermal conditions, load conditions and motion profiles properly corresponding to operational conditions.
(2) When conducting an accelerated operating life test to verify the operating life performance of a mechanism, the conditions of the accelerated operating life test shall represent the worst-case environment in terms of deterioration.

6.2.5.3 Acceptance criterion of operating life test

In an operating life test, the functional performance of mechanisms shall conform to the design requirements after the test is finished.