

Standard

Moving Mechanical Assemblies for Space and Launch Vehicles

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Standard

Moving Mechanical Assemblies for Space and Launch Vehicles

Sponsored by

American Institute of Aeronautics and Astronautics

Approved

30 June 2005

Abstract

This standard specifies general requirements for the design, manufacture, quality control, testing, and storage of moving mechanical assemblies (MMAs) to be used on space and launch vehicles. This standard is applicable to the mechanical or electromechanical devices that control the movement of a mechanical part of a space or launch vehicle relative to another part. The requirements apply to the overall MMA as well as to the mechanical components and instrumentation that are an integral part of these mechanical assemblies.

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Foreword

This standard is based on Military Specification MIL-A-83577B, Moving Mechanical Assemblies (MMA) for Space and Launch Vehicles, which was cancelled by the Department of Defense in the mid 1990s. It is most recently based on a Technical Operating Report prepared by Brian W. Gore of The Aerospace Corporation with support from the Air Force Space and Missile Systems Center (SMC) and the National Reconnaissance Office (NRO).

This standard is the result of contributions received from many individuals, most notably those on the AIAA MMA Committee on Standards (CoS).

At the time of approval, the members of the AIAA MMA CoS were:

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The above consensus body approved this document in June 2005.

The AIAA Standards Executive Council (Mr. Amr ElSawy, Chairman) accepted the document for publication in June 2005.

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Introduction

This standard is intended to incorporate those requirements that are common to most Moving Mechanical Assemblies (MMAs) for space and launch vehicles. The requirements stated are a composite of those that have been found to be cost-effective for high reliability space and launch vehicle applications.

Not all requirements stated herein are of equal importance or weight. They have been divided into three categories of importance, ranging from requirements that are imposed on all applications to examples of acceptable designs, items, and practices. The relative weighting of requirements is an important consideration when tailoring this standard to specific applications and in making trade studies of alternatives. The weighting factors that are incorporated in this standard are as follows.

“Shall” designates the most important weighting level, the mandatory requirements. Unless specifically tailored out or modified by the contract, they constitute the firm contractual compliance requirements. Any deviation from the contractually imposed mandatory requirements requires the approval of the procurement authority.

“Shall, where practical,” designates the second weighting level. Alternative designs, items, or practices may be used for specific applications when the use of the alternative is substantiated by documented technical trade studies and/or test. These trade studies shall be made available for review when requested or provided to the customer in accordance with the contract provisions. Unless required by other contract provisions, deviations from the “shall, where practical” requirements do not require approval of the procurement authority.

“Preferred,” “should,” or “may” designates the lowest weighting level. Unless required by other contract provisions, deviations from these preferred requirements do not require approval of the procurement authority and do not require documented technical substantiation.

1 Scope

This standard specifies general requirements for the design, manufacture, quality control, testing, and storage of moving mechanical assemblies (MMAs) to be used on space and launch vehicles. This standard is applicable to the mechanical or electromechanical devices that control the movement of a mechanical part of a space or launch vehicle relative to another part. The requirements apply to the overall MMA as well as to the mechanical components and instrumentation that are an integral part of these mechanical assemblies.

When this standard is used to specify general requirements for MMAs to be used on launch vehicles, injection stages, reentry vehicles, or other vehicles, the term “space vehicle” is to be interpreted as the applicable vehicle.

2 Tailoring

Where possible, the requirements in the standard are stated in terms that are self-tailoring to each application. However, additional tailoring of the requirements should be considered throughout the acquisition process within the constraints of the major program elements. These elements typically include performance, testing, reliability, schedules, production costs, operating costs, maintenance costs, and other high-cost drivers in the projected life cycle. Contractors are encouraged to identify to the procurement authority, for program office review and reconsideration, any requirements imposed by this standard that are believed excessive. However, contractors are reminded that deviations from contractually imposed requirements can be granted only by the procurement authority.

The use of the weighting factors (see Introduction) in the standard is intended to assist in the tailoring of requirements to specific applications and to assist contractors in the design process. Because the implications of the weighting factors vary with the type of contract and with other contract provisions, it is important to provide clear contractual language, particularly regarding design reviews and the resolution of any subsequent actions.

NOTE Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards.

3 Applicable Documents

The following applicable documents contain provisions that, through reference in this text, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements made on the basis of this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

In the event of a conflict between the text of this standard and the references cited herein and the vendor’s ISO 9001 or AS 9001 quality systems, the text of this standard shall take precedence. Nothing in this standard, however, shall supersede applicable laws and regulations unless a specific exemption has been obtained.

AFBMA Standards	<i>AFBMA Standards for Ball and Roller Bearings and Balls</i>
AGMA Handbook	<i>American Gear Manufacturer’s Association Handbook</i>
AIAA-S-110-2005	<i>Space Systems – Structures, Structural Components, and Structural Assemblies</i>
AIAA-S-113-2005	<i>Criteria for Explosive Systems and Devices Used on Launch and Space Vehicles</i>

ASTM F 2094	<i>Standard Specification for Silicon Nitride Bearing Balls</i>
MIL-STD-1686	<i>Electrostatic Discharge Control Program For Protection Of Electrical And Electronic Parts, Assemblies And Equipment (Excluding Electrically Initiated Explosive Devices)</i>
MIL-HDBK-83575	<i>Wiring Harness, Space Vehicle, Design and Testing, General Specification for</i>
MIL-PRF-46010	<i>Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting</i>
MIL-STD-1522	<i>Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems</i>
SAE-AMS-QQ-S-763	<i>Steel, Corrosion Resistant, Bars, Wire, Shapes, and Forgings</i>
Aerospace Corp. TR-2004(8583)-1	<i>Test Requirements for Launch, Upper-Stage, and Space Vehicles (to be superseded by MIL-STD-1540E and subsequent versions)</i>

4 Vocabulary

For the purposes of this document, the following terms and definitions apply.

Addendum

the radial height of an involute gear tooth above the pitch line

NOTE A long addendum modification is often specified on a pinion gear to balance the tooth bending stress between the pinion teeth and gear teeth.

Approach Action

in gearing, the involute action before the point of contact between the meshing gears has reached the pitch point

NOTE In spur gearing, pinions with a long addendum modification working with a gear with no addendum modification will have less approach action. If the gear teeth are somewhat inaccurate, a gear set with lower approach action will run more smoothly.

Back EMF

the voltage generated in an inductive coil or motor winding when the inductor or coil moves through a magnetic field

Cold Welding, Friction Welding, and Galling

adherence of same or similar material parts, such as fasteners or cup-cone fittings, under high interface contact pressures, extended periods in vacuum conditions and/or where small motions are induced at the preloaded interface

Contact Ellipse

the area formed by a bearing ball loaded against the ball track of a race ring in a ball bearing assembly

Contact Ratio

the number which indicates the average number of pairs of teeth in contact

NOTE The contact ratio can be calculated by the arc of action (circumferential length along the pitch diameter from one tooth to the corresponding point on the next tooth) divided by the pitch.

Critical Component or Assembly

an item not backed up by a redundant unit or function, or the failure of which could cause complete loss of the space vehicle or the loss of a primary portion of the mission

Dedoidal Condition

a condition in harmonic drives in which the flexspline is not concentrically engaged with the circular spline as can occur during installation, mishandling, or torque overload

Deployable

a device that is moved by a moving mechanical assembly from a stowed position on the space vehicle to an extended position adjacent to the vehicle

NOTE Solar arrays, antennas, experiment booms, or sun shields are classified as deployables where they meet the above description. The term “deployable” should be interpreted as inclusive of all devices that are deployed, retracted, or stowed.

Dynamic Torque (Force) Margin

the ratio of the drive torque minus resisting torque (torque required to overcome friction, wire harness bending, etc.) divided by the torque required for acceleration, minus one

NOTE 1 The dynamic torque margin expressed in percentage is calculated as follows:

$$\% = \left[\left(\frac{\text{drive torque} - \text{resisting torque}}{\text{torque required for acceleration}} \right) - 1 \right] \times 100$$

NOTE 2 For linear devices, “force” replaces “torque” in the definition so that the dynamic force margin is defined as the ratio of the drive force less the resisting forces, divided by the force required for acceleration, minus one.

The dynamic force margin expressed in percentage is calculated as follows:

$$\% = \left[\left(\frac{\text{drive force} - \text{resisting force}}{\text{force required for acceleration}} \right) - 1 \right] \times 100$$

Elastohydrodynamic Lubrication Regime

situation in which the rolling element and race generate a film between them of sufficient thickness, based on load and speed, while they are elastically deformed under load; asperity contact may or may not exist in the EHD regime.

Failure

an event or condition that causes the device or system to perform outside of its specification limits

NOTE The failure modes include those associated with functional performance, premature operation, failure to operate at a prescribed time, failure to cease operation at a prescribed time, and others that are unique to the device or system.

Hunting Tooth

a condition in which the number of teeth on the driven and driving gears is selected so that the same two teeth do not mesh with each revolution of the larger of the two gears

NOTE The number of teeth on each gear should be selected, within the limits of the gear ratio requirement, to maximize the number of revolutions before meshing of the same two teeth.

Limit Load

highest predicted load or combination of loads that a component or MMA may experience during its service life

Movable System

a device or system that requires a moving mechanical assembly to orient, rotate, track, scan, or otherwise control position or motion

NOTE Movable systems include, but are not limited to, antennas, telescopes, sensors, control-moment gyroscopes (CMGs), momentum wheels, and reaction wheels. A deployable is a type of movable system.

Moving Mechanical Assembly (MMA)

a device that controls the movement of a deployable or other movable system of a space or launch vehicle

NOTE Moving mechanical assemblies include, but are not limited to, deployment mechanisms, sensor mechanisms, pointing mechanisms, drive mechanisms, de-spin mechanisms, separation mechanisms, momentum and reaction wheels, control-moment gyros, gimbals, and other mechanisms required to perform specific functions.

Procurement Authority

the individual with the authority to enter into, administer, or terminate contracts and make related determinations and findings

NOTE The term includes authorized representatives of the procurement authority acting within the limits of their authority as delegated by the procurement authority.

Pull-in Torque

maximum friction load under which a stepper motor can start at a given step rate.

NOTE 1 pull-in torque is specified in relation to a specific drive circuit and a specific inertia.

NOTE 2 Pull-in torque includes detent torque and motor bearing friction.

Pyrotechnically Actuated Device

a mechanism that employs the energy produced by an explosive charge to perform or initiate a mechanical action

Recess Action

in gearing, the involute action after the point of contact between meshing gears has passed the pitch point

NOTE In spur gearing, pinions with a long addendum modification working with a gear with no addendum modification will have greater recess action. If the gear teeth are somewhat inaccurate, a gear set with higher recess action will run more smoothly.

Service Life

all operational usage and non-operational time, including unit, subsystem, and vehicle acceptance tests

Single-point Failure

the failure of a system element that causes the failure of the entire system

NOTE A single-point failure mode within a redundant device of a system is therefore typically not a single-point failure mode of that system. If it is, the devices are not completely redundant.

Static Torque (Force) Margin

the ratio of the drive torque available divided by the resisting torque (torque required to overcome friction, wire harness bending, etc), minus one

NOTE 1 The static torque margin expressed in percentage is as follows:

$$\% = \left\{ \left[\frac{\text{drive torque}}{\text{resisting torque}} \right] - 1 \right\} \times 100$$

NOTE 2 For linear devices, "Force" replaces "Torque" in the definition so that the static force margin is defined as the ratio of the drive force available divided by the resisting force, minus one.

NOTE 3 The static force margin expressed in percentage is as follows:

$$\% = \left\{ \left[\frac{\text{drive force}}{\text{resisting force}} \right] - 1 \right\} \times 100$$

Step Integrity

the ability of a stepper motor to achieve the number of steps commanded without loss or gain of steps

Stopping Load

the deceleration load or impact load imparted to the MMA and/or the surrounding structure

NOTE The maximum stopping load can occur at end of travel or at intermediate points of travel, as in the case of damper dead band.

Truncation

situation in which a portion of a bearing ball's contact ellipse extends beyond the edge of the raceway due to excessive loading

Ultimate Load

the product of limit load and the ultimate factor of safety

Yield Load

the product of the limit load and the yield factor of safety

5 General Design Requirements

5.1 Performance Requirements

5.1.1 General Performance Requirements

Deployables and other movable systems shall, where practical, be designed so that they are self-supporting when placed in any orientation relative to gravity, while in either the stowed or deployed configuration. They shall be designed with sufficient motive force to permit full operation during ground testing without depending on the assistance of gravity to demonstrate deployment. Off-loading devices to simulate a zero "g" condition are allowed so that the movable system is adequately supported. Off-loading devices should have minimal effect on deployment; these effects shall be included in operational analyses. Where a device rotates after deployment, as in sun-tracking solar arrays, the design shall, where practical, be such that the center of gravity of the device is coincident with the axis of rotation to preclude the need for counterbalancing during functional testing. For all deployables, the deployment motion shall, where practical, be controlled for the full range of travel. For all deployables, rebound of the deployable after contacting the stops should be minimized. Kick-off springs or other suitable devices shall, where practical, be used to initiate deployment motion. If used, these devices shall, where practical, have a stroke long enough to ensure complete disengagement of the deployable from its retention mechanism. Where acceleration loads are applied to a deployed assembly, such as those generated by space vehicle spin or propulsion forces, the design should preferably be such that the accelerations tend to drive the deployable into its deployed latched position. Positive retention provisions shall, where practical, be provided for deployables in the stowed and deployed positions.

Where two or more deployables are used on a space vehicle, the deployment/operation of one shall, where practical, be independent of the successful deployment/operation of the other. Where this sequential dependency cannot be avoided, and the deployable that could be obstructed is mission critical, a mechanically and electrically redundant release device shall, where practical, be provided for the deployable that by its failure could prevent successful deployment of the mission critical deployable. Deployables and other movable systems that require discrete sequential motions, each initiated by separate commands, or any mission critical deployable shall, where practical, have a backup ground command for each event.

5.1.2 Force/Torque Margins

MMA's should be designed with the highest practical torque margin or, for linear devices, the highest practical force margin. Two components of margin shall be considered: (a) the static torque or force margin that applies to the torque or force required to overcome drive resistance and (b) the dynamic margin that applies to the torque or force required to impart acceleration.

Minimum available driving capability and maximum load determination shall be verified by test and analysis; each element of resistance shall be characterized in this test program. The performance sensitivity of MMA's to environmental variations such as temperature, pressure, acceleration, vibration, and radiation shall be evaluated. Adequate torque or force margins shall be demonstrated throughout the MMA's full range of travel.

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. The MMA should be designed such that the resistive forces or torques as a result of broken springs are minimized.

The calculation of the force or torque margin in assemblies with viscous dampers shall include, but not be limited to, the seal friction due to mechanical compression of elastomers, fluid pressure on the elastomers, and possible changes in static and dynamic friction due to storage time.

For MMA's that use devices such as gearboxes and/or harmonic drives, torque margin requirements shall be met before and after the gear train.

5.1.2.1 Static Torque or Force Margin

The static torque margin is defined as the ratio of the drive torque available divided by the resisting torque (torque required to overcome friction, wire harness bending, etc), minus one.

The static torque margin shall be expressed in percentage and is calculated as follows:

$$\% = \left\{ \left[\frac{\text{drive torque}}{\text{resisting torque}} \right] - 1 \right\} \times 100$$

For linear devices, "force" replaces "torque."

The static margin is calculated by using the minimum driving torque or force and maximum static resisting torques or forces. Minimum available driving capability shall be determined by including the worst-case combination of factors such as supply voltage, motor and controller parameters, and minimum available drive torque or force. *Typically the drive torque includes the effects of magnetic detent or cogging torque within the motor.* Note that the minimum torque/force output (from the spring, motor, etc.) may be further limited by other components of the MMA, such as a gearbox. Maximum static resistance determination shall include the worst-case combination of factors such as static friction, alignment effects, latching forces, return springs, wire harness loads, damper drag, and variations in lubricity. Worst-case thermal conditions and vacuum shall be considered when determining margins.

Static torque or force margin shall be at least 100% at any position of motion. For new designs, the margins in Table 1 should be used. For those systems where the observed values of the driving and resisting torques or forces are extremely low, poorly characterized, or highly variable, higher margins than those specified in Table 1 should be used.