AEROSPACE RECOMMENDED PRACTICE

ARP4058™ | **REV. B**

Issued 1988-08
Revised 2017-05
Reaffirmed 2023-04

Superseding ARP4058A

(R) General Specification Guide for Mechanical Geared Rotary Actuators

RATIONALE

At Revision B, this document has been updated to include additional technical information and editorial corrections.

ARP4058B has been reaffirmed to comply with the SAE Five-Year Review policy.

TABLE OF CONTENTS

1. SCOPE 4
1.1 Purpose 4

2. REFERENCES 4
2.1 Applicable Documents 4
2.1.1 SAE Publications 4
2.1.2 ASME Publications 5
2.1.3 ASTM Publications 5
2.1.4 ISO Publications 5
2.1.5 NAS Publications 5
2.1.6 Battelle Memorial Institute Publications 5
2.1.7 RTCA Publications 5
2.1.8 U.S. Government Publications 5
2.1.9 FAA Publications 6
2.2 Definitions 6

3. REQUIREMENTS 7
3.1 Configurations 7
3.2 Interface Definition 7
3.3 Operating Characteristics 7
3.3.1 Performance 7
3.3.2 Integrated Components 8
3.4 Physical Characteristics 8
3.4.1 Dimensions 8
3.4.2 Mounting 8
3.4.3 Moisture Pockets 9
3.4.4 Interchangeability 9
3.4.5 Weight 9
3.4.6 Stiffness 9
3.4.7 Backlash (Freeplay) 9
3.5 Structural Characteristics 10
3.5.1 Strength 10
3.5.2 Damage Tolerance 10
3.5.3 Loads 10
3.5.4 Operating Life 12
3.6 Design and Construction 13

3.6.1 Sealing 13
3.6.2 Bearings 13
3.6.3 Lubrication 14
3.7 Materials, Processes, Assembling, and Parts 14
3.7.1 Materials 14
3.7.2 Metals 14
3.7.3 Metal Characteristics 14
3.7.4 Castings and Forgings 14
3.7.5 Material Quality Control 15
3.7.6 Conductivity Tests 15
3.7.7 Shot Peen 15
3.7.8 Processes 15
3.7.9 Metal Coatings 15
3.7.10 Detail Assembling Requirements 15
3.7.11 Use of Standard Parts 16
3.8 Environmental Conditions 16
3.8.1 Environmental Criteria 16
3.8.2 Exposure 17
3.9 Corrosion Protection 17
3.9.1 Faying Surfaces, Bearing, Bolts, Metal Seal Cases, etc. 17
3.10 Identification and Marking 17
3.10.1 Identification 17
3.10.2 Marking and Serialization 17
3.11 Workmanship 18
3.11.1 Quality 18
3.11.2 Interchangeability 18
3.12 Handling Safety 18
3.13 Reliability Requirements 18
3.13.1 Quantitative Reliability 18
3.13.2 Reliability Analyses 19
3.13.3 Reliability Verification 19
3.14 Maintainability 20
3.14.1 Maintainability Characteristics 20
3.14.2 Maintenance Concept 20
3.14.3 Quantitative Maintainability 20
3.14.4 Maintainability Verification 20
3.14.5 Ground Support Equipment (GSE) 21
3.15 Documentation 21
3.15.1 Analysis Requirements 21
3.15.2 Drawings 21

4. QUALITY ASSURANCE PROVISIONS 21
4.1 General 21
4.2 Test Requirements and Options 21
4.3 Classification of Tests 21
4.3.1 Acceptance Tests 22
4.3.2 Preproduction Tests 22
4.3.3 Development Tests 22
4.3.4 Qualification Tests 22
4.3.5 Test Matrix 22
4.4 Test Procedures 22
4.4.1 Acceptance Test Procedure 22
4.4.2 Preproduction Test Procedure 23
4.4.3 Development Test Procedure 23
4.4.4 Qualification Test Procedure 24
4.5 Test Conditions 24
4.5.1 Environmental Conditions 24
4.5.2 Test Instruments 24
4.5.3 Test Fixtures 24
4.6 Acceptance Tests 25
4.6.1 General 25

4.6.2 Examination of Product 25
4.6.3 Backlash (Freeplay) 25
4.6.4 No Load Torque 25
4.6.5 Efficiency 25
4.6.6 Weight 25
4.6.7 Rejection and Retest 25
4.7 Verification Tests 25
4.7.1 Verification Test Methods 25
4.7.2 Sampling and Tests 25
4.7.3 First Article Inspection 26
4.7.4 Post-Verification Test Acceptance Testing 26
4.7.5 Endurance Test 26
4.7.6 Fatigue Test 26
4.7.7 Static Load Tests 26
4.7.8 Environmental Tests 26
4.7.9 Additional Tests 28
4.7.10 Performance Tests 28
4.8 Test Reports, Design Changes and Data 29
4.8.1 Preproduction and Qualification Test Reports 29
4.8.2 Design Changes 29
4.8.3 Qualification Approval of Similar Units 29
4.9 Preproduction and Qualification Test Failures 29

5. PREPARATION FOR DELIVERY 29
5.1 Preservation and Packaging 29

6. NOTES 29
6.1 Revision Indicator 29

Figure 1 Load versus deflection hysteresis loop: stiffness and backlash 9
Figure 2 Example of a general actuator coordinate system 10

Table 1 Standard format: static design limit loads 11
Table 2 Standard format: fatigue loads (one cycle) 11

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides a guide for preparation of requirements for general design, performance, and testing of mechanical geared rotary actuators intended to be used for applications requiring motion control in response to manual or automatic power control system inputs.

1.1 Purpose

This recommended practice is to be used as a guide in preparing a detail specification for mechanical geared rotary actuators and is applicable to all military and commercial aerospace vehicles.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4841 (outside USA), www.sae.org.

AMS2419	Plating, Cadmium-Titanium
AMS-A-21180	Aluminum-Alloy Castings, High Strength
AMS-A-22771	Aluminum Alloy Forgings, Heat Treated
AMS-C-8837	Coating, Cadmium (Vacuum Deposited)
AMS-C-26074	Electroless Nickel Coatings
AMS-F-7190	Forging, Steel, For Aircraft/Aerospace Equipment and Special Ordnance Applications
AMS-H-6088	Heat Treatment of Aluminum Alloys
AMS-QQ-C-320	Chromium Plating (Electrodeposited)
AMS-S-13165	Shot Peening of Metal Parts
AMS-STD-2175	Castings, Classification and Inspection of
ARP926	Fault/Failure Analysis Procedure
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP5311	Aerospace-Interface Definition for Mechanical Actuation Subsystems
AS1701	Lubricant, Solid Film

AS5272	Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting, Procurement Specification
AS8879	Screw Threads - UNJ Profile, Inch Controlled Radius Root with Increased Minor Diameter
AS9100	Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations

2.1.2 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

ASME Y14.100	Engineering Drawing Practices

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E1417	Standard Practice for Liquid Penetrant Testing
ASTM E1444	Standard Practice for Magnetic Particle Testing
ASTM E1742	Standard Practice for Radiographic Examination

2.1.4 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/.

ISO 10012	Quality Assurance Requirements for Measuring Equipment

2.1.5 NAS Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NASM33540	Safety Wiring and Cotter Pinning

2.1.6 Battelle Memorial Institute Publications

Available from Battelle Memorial Institute, 505 King Avenue, Columbus, OH 43201, Tel: 614-424-6424, www.mmpds.org.

MMPDS-07	Metallic Material Properties Development and Standardization

2.1.7 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160	Environmental Conditions and Test Procedure for Airborne Equipment

2.1.8 U.S. Government Publications

Available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6396, http://quicksearch.dla.mil/.

MIL-HDBK-275	Guide for Selection of Lubricant, Fluids, and Compounds for Use in Flight Vehicles and Components
MIL-HDBK-831	Preparation of Test Reports
MIL-HDBK-838	Lubrication of Military Equipment

MIL-STD-130 Identification Marking of U.S. Military Property

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

MIL-STD-889 Dissimilar Metals

MIL-STD-1537 Electrical Conductivity Test for Verification of Heat Treatment of Aluminum Alloy, Eddy Current Method

MIL-A-8625 Anodic Coatings, for Aluminum and Aluminum Alloys

MIL-STD-31000 Technical Data Packages

MIL-I-8500 Interchangeability and Replaceability of Component Parts for Aerospace Vehicles

MIL-PRF-46010 Lubricant, Solid Film Heat-Cured, Corrosion-Inhibiting NATO Code - S-1738

TT-P-1757 Primer coating, Alkyd Base, One Component

2.1.9 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 23-13A Fatigue, Fail-Safe, and Damage Tolerance Evaluation of Metallic Structure for Normal, Utility, Acrobatic, and Commuter Category Airplanes

AC 25.613-1 Material Strength Properties and Material Design Values

2.2 Definitions

Refer to ARP4386 for general system terms that are used in this Aerospace Recommended Practice.

MECHANICAL GEARED ROTARY ACTUATOR: A geared torque amplifier placed at the output of rotary actuation drive systems, or integrated directly with motor drive elements, used to rotationally position aerodynamic control surfaces, doors, or other moveable aircraft structures. These devices are configured to primarily transmit torque but may also carry axial and shear loads.

ACTUATOR SLICE: A compound planetary gearset consisting of a sun gear, planet gears and fixed and moveable ring gears that form one geared rotary actuator subassembly. They may be combined with other identical gearsets in parallel to multiply the torque capacity of the device approximately in proportion to the number of slices combined. They typically pertain specifically to power hinge (hinge output) style rotary geared actuators.

SLICE-TO-SLICE MAL-DISTRIBUTION: The degree to which loads vary between the slices of a given actuator assembly.

EXTERNAL LOADS: The loads imposed on the actuator output. They typically include air loads originating at the moveable surface or structure, inertia loads of the surface or structure and intermediate linkages and mechanisms being moved, along with their friction, damping, etc.

TARE LOSSES: Torque losses due to friction and drag inherent in the actuator which are independent of output loading, originating at seal interfaces, gear meshes, and any other areas where relative motion between parts, or motion through lubricant, exists that produces resistance to motion. Seal friction and drag losses are examples of tare losses.

STIFFNESS: The ratio of the applied torque to the load path deflection expressed in in-lb/rad (Nm/rad). Unless otherwise specified by the design specification, the deflection for static stiffness should be considered the elastic load path unidirectional deflection excluding freeplay.

DESIGN LIFE: The summation of a specified number of operational service lives which form the design and analysis criteria for determining life dependent characteristics and safety margins.

LOSS OF FUNCTION: Damage resulting in fracture or failure of a particular component sufficient to prevent the unit from meeting the specified performance, strength, or reliability requirements. When a component has suffered damage of an extent which renders the part unacceptable for continued use, it is considered to have failed.

3. REQUIREMENTS

Requirements are outlined covering the designs of mechanical geared rotary actuators which may be integrated into a detail specification to be prepared by the procuring agency.

3.1 Configurations

There are numerous configurations of mechanical geared actuators which comprise various types of gearing and to which this ARP applies. This includes mechanical spur or helical geared rotary actuators that are either of the simple or compound planetary type, or a combination of both types. Often, a simple planetary gearset is combined in series with a compound planetary type actuator in order to achieve higher ratios. Additional types of mechanical geared rotary actuators include worm/wheel gearsets, harmonic drives, offset or cluster gearsets, trochoid gearsets, cycloidal gearsets, bevel gearsets, and right-angled drives.

3.2 Interface Definition

The geared rotary actuator serves as the output device for a rotary actuation system, or an integrated rotary actuator. A typical actuation system or integrated rotary actuator may contain one or more of the following components with which the geared rotary actuator assembly may interface directly:

1. Prime Mover (Hydraulic, Pneumatic, Electric)
2. Connecting Members (Torque Shafts, Angle Gear Boxes, Couplings, U-Joints)
3. Safety Devices (No-Backs, Torque Limiters, Brakes)
4. Sensors (RVTs, RVDTs, Tachometers, Hall Effects, Encoders, Limit Switches)
5. Miscellaneous Devices (Clutches, Sequencers, Accessory Drives, etc.)

These components may be configured and specified apart from, or integrated with, the rotary actuator assembly.

When installed, the actuator also becomes an integral part of the aircraft, reacting surface loads into the aircraft structure. All applicable structural, mechanical, and electrical interfaces and their relevant characteristics should be defined. A list of associated equipment should be added using part and assembly identifying numbers and who is responsible for them. It should include the geometry interface with allocated envelope.

An Interface Control Drawing (ICD) should be generated to clearly define and document all rotary actuator assembly interface features and characteristics.

ARP5311 may be used for guidance in interface definition.

3.3 Operating Characteristics

3.3.1 Performance

The detail specification should specify the performance requirements of the geared rotary actuator with respect to its function within the mechanical actuation system. As a minimum, the following performance criteria should be specified:

1. Gear Ratio - Specify actuator gear ratio where applicable. This could be customer provided if the actuator is a stand-alone procured component, or defined by the supplier based on the performance requirements of an overall system.

2. Output Travel Authority - Angular output travel range of actuator

3. Maximum Output Rate

4. Efficiency - Specify as necessary according to system performance requirements. Different efficiency figures may be specified for different purposes. Examples include:

   - Minimum efficiency required to meet system power performance requirements over temperature

   - Efficiency versus temperature

   - Maximum efficiency as the worst case for downstream component sizing and

   - Minimum and maximum backdriving efficiency for reversible systems, etc.

   An alternative to specifying efficiency directly is to specify minimum or maximum input torques associated with operation at particular output loads, speeds and temperature conditions.

5. Tare Losses at Specific Operating Point(s) to define no-load performance, including forward and backdriving conditions if critical to the application, over temperature and at particular speed conditions

6. Direction of Rotation, including direction of output rotation relative to input rotation

7. Operating Temperature Range (Environment)

8. Output Torque - Static (Holding) and Dynamic (Driving)

9. Static Reversibility - This specifies whether or not the actuator input is allowed to be back-driven via application of a prescribed torque at the output when the actuator is in a static (stationary) condition

10. Dynamic Reversibility - This specifies whether or not the actuator output is allowed to continue motion when loaded at the output, following the cessation of torque application to the actuator input

Other performance requirements specific to the application should be included as necessary.

3.3.2 Integrated Components

Specify performance characteristics of components integrated into the actuator assembly as required by the system configuration. Examples of components often integrated into the actuator assembly include torque limiting and no-back devices.

3.4 Physical Characteristics

3.4.1 Dimensions

The detail specification should specify the maximum permissible envelope dimensions of the geared rotary actuator and related parts when installed and operated.

3.4.2 Mounting

Mounting provision for the geared rotary actuator should be in accordance with the detail specification. Specific dimensions and tolerances of the attachment hardware should be included when applicable. Suitable clearances should be provided between the geared rotary actuator, structure, and other components to preclude binding or jamming due to possible combinations of temperature effects, loads and deflections (including structural deflections). The actuator should be designed to be installed using standard Ground Support Equipment (GSE) and hand tools.

3.4.3 Moisture Pockets

External housing designs which could result in pockets, wells, traps, etc., into which water or other liquids can drain into and collect should be avoided. If such designs are unavoidable, provisions for draining moisture from these pockets should be incorporated.

3.4.4 Interchangeability

Parts, components, subassemblies, and assemblies having the same part number should meet the requirements of MIL-I-8500 and be interchangeable in form, fit, and function with other parts bearing the same part number.

3.4.5 Weight

The detail specification should specify the maximum wet weight compatible with specification requirements. Every consideration should be given to achieving a minimum weight in accordance with good design practices.

3.4.6 Stiffness

The detail specification should specify the minimum rotary actuator stiffness required in in-lb/rad (Nm/rad) as defined per the Load versus Deflection hysteresis loop shown in Figure 1. Most typically this is specified at the output; however, it could also be specified at the actuator input. Stiffness may vary with output position, and so the output positions of interest should be specified as necessary. For rotary actuator assemblies that include through-shafts, the detail specification should also specify the minimum rotary actuator stiffness required at the through-shaft as necessary.

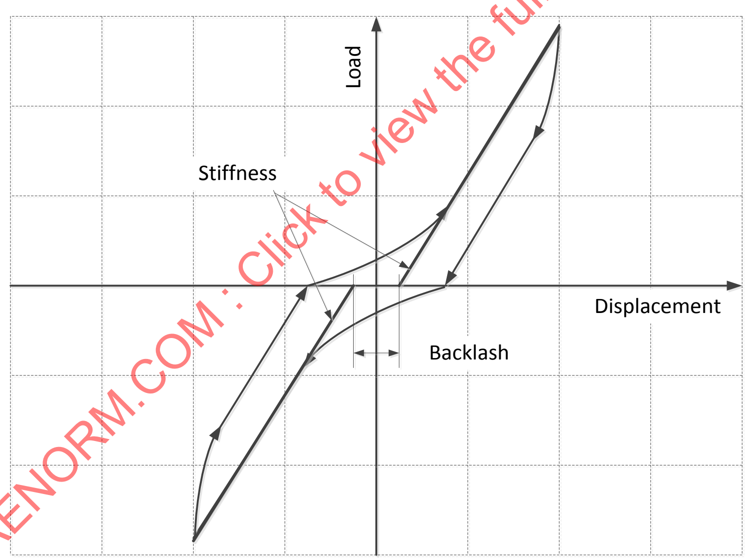

Figure 1 - Load versus deflection hysteresis loop: stiffness and backlash

3.4.7 Backlash (Freeplay)

The detail specification should specify the maximum backlash requirements, as defined per Figure 1. Most typically, this is specified at the actuator output; however, it could be specified at the actuator input. The specification should state whether the attachment hardware is to be included in the requirement. It is important to note that tighter backlash requirements measured at the output become difficult to achieve and add to cost. Allowance for wear may be specified by stipulating allowable actuator backlash after one life of actuator use.

3.5 Structural Characteristics

3.5.1 Strength

Unless otherwise specified, geared rotary actuators should be designed using the material properties of MMPDS-07 or proprietary material properties data which meets the appropriate statistical reliability requirement for A-Basis, B-Basis, or Nominal probability and confidence as defined in the MMPDS-07.

3.5.2 Damage Tolerance

The structural attachment elements of a geared rotary actuator that are essential to safety should be fully defined in the procurement specification. Actuators should incorporate materials, stress levels, and structural configurations to minimize crack initiation, and to minimize failure due to the propagation of undetected material flaws, cracks, or other damage. Where safety and criticality considerations dictate based on the application, requirements should be stated pertaining to the ability of the actuator to operate for a given number of operating cycles or period of time prior to failure with an initial flaw of specified size and characteristics.

Rotary actuators may include multiple or redundant load paths in applications where failure of a single load path is deemed insufficiently safe based on the hazard and criticality analysis. If required, redundant load paths should be specified accordingly.

3.5.3 Loads

3.5.3.1 Load Specification

The detail specification should include the static design loads, the fatigue load spectrum, impact loads, and the environmental loads particular to the application. All potentially damaging loads should be specified for each of 6 degrees of freedom using an actuator coordinate system appropriate to the application, an example of which is shown in Figure 2.

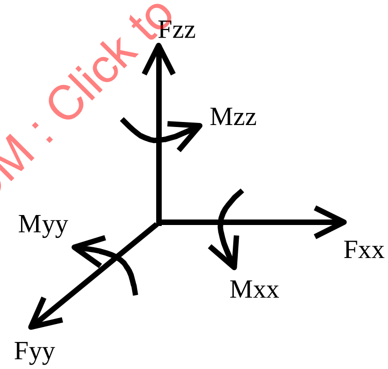

Figure 2 - Example of a general actuator coordinate system

The detail specification should specify magnitude, direction, and type of all externally applied loads. If travel limiters or stops are incorporated, load paths resulting from bottoming should be considered and tested. All possible combinations of loading should be specified, together with the diagram of the operational geometry. A standard table format should be used for the specification of loads; see Tables 1 and 2 for examples of such formats.

Table 1 - Standard format: static design limit loads

Limit Load F (pound or N) M (inch-pound or Nm)	Actuator Angular Position xx (Degrees)	Corresponding Load at Limit Load F (pound or N) M (inch-pound or Nm)					
		Fxx	Fyy	Fzz	Mxx	Myy	Mzz
Fxx =		-					
Fyy =			-				
Fzz =				-			
Mxx =					-		
Myy =						-	
Mzz =							-

Table 2 - Standard format: fatigue loads (one cycle)

Actuator Angular Position xx (Degrees)	Fxx (pound or N)	Fyy (pound or N)	Fzz (pound or N)	Mxx (inch-pound or Nm)	Myy (inch-pound or Nm)	Mzz (inch-pound or Nm)
Start of Cycle						
.						
.						
.						
End of Cycle						

3.5.3.2 Limit Loads

The detail specification should specify the maximum output limit load required and number of limit load applications in each of six degrees of freedom without permanent deformation of parts. For the limit load associated with each individual degree of freedom, the corresponding loads for the remaining 5 degrees of freedom under the same condition should be specified so their combined effects are accounted for. The output limit load is typically the highest external load applied to the actuator output under any condition, and could be a static holding or dynamic operating condition. The limit load could result from normal operating conditions, or from failure conditions such as a disconnect of other actuation system or interfacing aircraft components. Additionally, limit loads may result from system dynamic considerations such as a torque limiter engagement resulting from a downstream jam or external obstruction.

When only dynamic operating loads are known, the corresponding limit load is typically specified as 1.25 times the maximum operating load; however, this could vary depending upon the responsible design authority.

The actuator should be capable of meeting the limit load requirements over the full operating temperature range. Unless otherwise specified, the rotary actuator should meet all of the other requirements of the specification after the application of limit load.

3.5.3.3 Ultimate Load

The detail specification should specify that the actuator should withstand a load 1.5 times the limit loads specified in 3.5.3.2 without failure for a specified period of time. The actuator should be capable of meeting the ultimate load requirement over the full operating temperature range. There may be permanent set in parts, but failure or rupture is not acceptable. Note that at the discretion of the procurement agency the Ultimate load may be specified as 1.25 times limit load under worst case conditions of material properties and dimensional tolerance or as 1.5 times limit load at nominal conditions of material properties and dimensional tolerance.

3.5.3.4 Durability and Fatigue

The actuator should be designed to withstand all loading requirements for its specified application and duty cycle without loss of function during its specified useful life. This should include dynamic operating cycles, as well as dynamic fatigue cycles occurring from buffeting during motion that form a dynamically oscillatory component additive to the operating loads, and static fatigue cycles due to buffeting airloads which may occur when a surface is maintained in an extended or intermediate deflection position.

3.5.3.5 Mal-Distribution

On multiple slice hinged rotary actuators; mal-distribution of load between slices exists due to variations in vehicle structural stiffness, attachment fit-up between the vehicle and actuator lugs, etc. The effect of this mal-distribution of loads between slices can be handled in two different manners in the specification and design analysis.

a. If only the total actuator load is known and specified in Tables 1 and 2, a factor should be applied to the 6 degree of freedom limit loads defined in Table 1 and to each 6 degree of freedom spectrum load of Table 2 to account for actuator slice load mal-distribution in order to compute the maximum load for any individual actuator slice, which then becomes the design load for all identical actuator slices. This factor can be determined from analysis and/or test measurement of similar devices. The peak slice loads should be used for design and analysis of the individual slices for the actuator and should be calculated as follows, per Equation 1:

$$\text{Actuator Peak Slice Load} = \frac{(\text{Limit, Ultimate or Fatigue Loads}) * (\text{Mal - distribution Factor})}{\text{Number of Slices}} \quad \text{(Eq. 1)}$$

b. Alternatively, if the load on individual slices is known from analysis or measurement, these loads should be specified in Tables 1 and 2 and the design and analysis of the individual slices should be in accordance with the most highly loaded slice within the actuator assembly. Whereas other actuator components (input planetaries, through shafts, etc.) are sized by the total actuator load, these components should be designed based on the total actuator load obtained by summing the loads which are applied to each slice of the actuator. For this approach, no additional mal-distribution factor need be applied in the design and analysis.

3.5.3.5.1 Side Loads

Loads specified along the rotational axis of the actuator produce additional mal-distribution to the individual slices of a multi-slice actuator. Mal-distribution is increased due to axial play between actuator attach lugs and the mounting structure attachment hardware. As the principal function of the actuator is the amplification and transmission of torque in a rotary motion, mounting arrangements should be selected to minimize axial loading.

3.5.4 Operating Life

3.5.4.1 Operational Service Life

The specification should specify the operational service life in flight hours, and the associated on-aircraft and off-aircraft ground hours.

3.5.4.2 Design Life

The specification should define a design life as the number of operational service lives to design to, together with a probability and confidence interval. Each operational service life consists of the complete operational and fatigue load duty cycle expected to be applied to the actuator in its intended application. The design life requirement, together with probability and confidence interval, infers the statistical likelihood with which the actuator will perform without failure within the application for the entire operational service life of the aircraft as established to satisfy the safety requirements per the operational criticality of the actuator, and the maintenance or ownership cost targets.

3.5.4.3 Operational Cycles

The detail specification should define an operating spectrum of output rotation and load versus number of cycles for the actuator, which should be commensurate with its operational service life using the standard format specified in 3.5.3.1.

3.5.4.4 Static Fatigue Cycles

The detail specification should specify the total number of static fatigue cycles (also referred to as static buffeting cycles) the actuator will be subjected to at the most critical output position (for example fully retracted, fully extended, or an intermediate position) using the standard format specified in 3.5.3.1.

3.5.4.5 Bottoming Out Cycles

If stops are incorporated, specify the number of bottoming cycles, speed, input side torque and inertia, driveline stiffness, the load and the load stiffness and inertia during the stop impact. Inertia should include actuator inertia.

3.5.4.6 Extended Fatigue Life

Additional fatigue life, beyond the Design Life specified above, may be specified to ensure sufficient fatigue margin of the structural components in the primary load paths of the actuator. For this requirement, bearings and seals may be considered consumables and changed out as needed, and improved lubrication may be provided. The details of the conditions and requirements concerning extended fatigue testing may vary per a particular customer's requirements and should be described in the specification.

3.5.4.7 Useful Life

The actuator should have a specified useful life (in years), under any combination of operating and storage life durations, to which specified performance and integrity are expected.

3.6 Design and Construction

The actuator should be designed and constructed to meet the operational requirements in the detail specification.

3.6.1 Sealing

The rotary actuator should be configured to prevent loss of lubricant or contamination of lubricant from outside agents. If condensation can occur inside the actuator, then all internal parts are to be adequately corrosion protected and provision made to prevent entrapping water inside.

3.6.2 Bearings

3.6.2.1 Antifriction Bearings

Ball, roller, or needle bearings in accordance with approved Military or Aerospace Standards should be used, except as indicated in the following paragraphs. Sealed bearings are preferable over shielded bearings in an atmospheric environment.

3.6.2.2 Journal Bearings

Where freeplay and efficiency are not major considerations, journal or plain bearings may be used in accordance with approved Military or Aerospace Standard.

3.6.2.3 Integral Bearings

Where integral bearings are used between the fixed and movable gears of a compound planetary gear stage, ball loading plugs should be adequately retained to prevent their loss and subsequent loss of the bearing balls.

3.6.3 Lubrication

Customer specifications should be referenced when available to define lubrication requirements. When not available, MIL-HDBK-275 and MIL-HDBK-838 may be used for guidance. Solid or dry-film lubricants should be in accordance with MIL-PRF-46010, AS1701, AS5272, or an approved equivalent. Lubricant type and fill quantity should be selected to address performance requirements with respect to efficiency over temperature and gear durability consistent with the fatigue requirements on the aircraft and for the verification test program. Grease, oil or semi-fluid lubricants may be selected consistent with these performance requirements. Lubricants and lubrication design features should be in accordance with the specified aircraft maintenance concept. Anticipated greasing equipment should be identified and specified where appropriate. Minimum allowable service intervals for lubrication should be specified, however, permanently lubricated components should be provided whenever possible.

3.6.3.1 Lubrication Fittings

Suitable lubrication and drainage fittings are to be supplied when required. Appropriate access to lubrication fittings should be considered in the design.

3.7 Materials, Processes, Assembling, and Parts

3.7.1 Materials

The materials used in rotary geared actuators should be suitable for the service and purpose intended and should conform to the applicable government specifications when such specifications exist for the type of material being used. Non-specification materials may be used provided it can be demonstrated that their use will result in a superior product. The use of each material in its application should be substantiated. Use of materials for critical structural applications should be approved by the procuring agency.

3.7.2 Metals

MMPDS-07 should be used as the authority for strength of all actuator metals. AC25.613-1 should be referenced when using metals not otherwise covered by the MMPDS. All metals should be compatible with the lubricants used and with the intended temperature, function or service, and storage conditions to which the components will be exposed. The metals used should possess adequate corrosion resistant characteristics or should be suitably protected to resist corrosion which may result from such conditions as dissimilar metal combinations, moisture, salt spray and high temperature deterioration, as applicable. Contact between dissimilar metals as defined in MIL-STD-889 should be minimized during fabrication, installation or assembly. However, where contact cannot be avoided, measures defined in MIL-STD-889 should be taken to avoid galvanic corrosion.

3.7.3 Metal Characteristics

Use of vacuum melted steels should be encouraged, where cost effective. When ultra-high strength steels are employed, this is mandatory. Heat treatments and fabrication techniques which impart low residual stresses and maintain maximum dimensional stability are desirable.

3.7.4 Castings and Forgings

Castings and forgings should be designed to the criteria of the following listed specifications as applicable. Additional requirements for design not included in the listed specifications should appear on the part drawing.

a. AMS-A-21180

b. AMS-A-22771

c. AMS-F-7190

d. AMS-STD-2175

3.7.5 Material Quality Control

Sufficient controls over wrought, cast, or forged material should be exercised so that aircraft quality is maintained. Non-destructive and destructive tests such as X-ray, penetrant, magnetic particle, tensile tests, and chemical analysis must be performed in accordance with the applicable military specifications to ensure good quality. Minimum requirements for inspection are:

Forgings should be penetrant and/or magnetic particle inspected per ASTM E1417 and ASTM E1444 as applicable.

Castings should be X-rayed per ASTM E1742 and/or magnetic particle inspected and penetrant inspected per ASTM E1417 and ASTM E1444 as applicable.

Wrought product in the form of sheet, bar, tubing, or plate should be tested as specified in the applicable material specification.

Ferro-magnetic, high-stress parts should be subject to magnetic particle inspection in accordance with ASTM E1444. Non-magnetic, high-stress parts should be subject to fluorescent penetrant inspection in accordance with ASTM E1417. Cracks or other injurious defects disclosed by the inspection should be cause for rejection.

3.7.6 Conductivity Tests

When aluminum alloy materials are employed, use of conductivity testing for alloy temper inspection is desirable. When specified, measurement should be in accordance with MIL-STD-1537 to the limits referenced in AMS-H-6088.

3.7.7 Shot Peen

Shot peening is strongly recommended for steels heat treated to 220000 psi (1520 MPa) ultimate tensile strength and above. Shot peening should be in accordance with AMS-S-13165 with 200% coverage required. Specific areas for bearings and bores and gear profiles are exempt as approved by the procuring activity.

3.7.8 Processes

Unless otherwise specified herein, processes or special tooling used in a rotary actuator should be as specified herein.

3.7.9 Metal Coatings

Ferrous alloys heat treated to 200000 psi ultimate tensile strength and above should utilize protective coatings which minimize or eliminate hydrogen embrittlement. These include, but are not limited to, vacuum deposited cadmium in accordance with AMS-C-8837, aluminum titanium cadmium in accordance with AMS2419, or chromium applied in accordance with AMS-QQ-C-320.

External surfaces of ferrous alloy parts need not be coated if the chromium content of the alloy is greater than 12%. Anodized coatings should be in accordance with MIL-A-8625, electroless nickel in accordance with AMS-C-26074.

3.7.10 Detail Assembling Requirements

3.7.10.1 Mechanical Joining

Individual parts may be mechanically joined with removable fasteners, or threaded connections, or by other qualified methods for permanent joining.

3.7.10.2 Joining with Removable Fasteners

Unless otherwise specified in the detail specification, all removable fasteners should be selected and used as follows:

a. Removable fasteners smaller than 0.25 inch (6 mm) should not be used to make single fastener connections, or connections essential to the structural performance of the actuator.

b. Removable fastener joints should use a positive method of retention such as self-locking nuts, plate nuts, lockwire, or cotter pins.

3.7.10.3 Threaded Joints

All threaded joints should be provided with adequate wrenching and holding provisions for assembly and disassembly of the joint before and after service use. Internal screw threads and external rolled threads should be in accordance with the thread form requirements of AS8879.

3.7.10.3.1 Retention of Threaded Joints

All threaded joints which carry critical loads should be positively locked in the assembled position so that load reversal at the threads is prevented. The use of jam locknuts is not a positive locking means unless otherwise restrained.

3.7.10.4 Retention of Removable Fasteners

Removable fasteners, unless restrained from moving by the attachment of adjoining parts, should incorporate a positive locking means or be safety wired.

3.7.10.5 Use of Retainer Rings

Retainer rings or pins should not be used to retain parts unless the rings are positively confined. They should not allow freeplay which could result in structurally destructive action or fatigue failure of the retained parts. Where used, retainer rings should be commercially available types which can be installed and removed with standard tools. Their use is subject to procuring agency approval.

3.7.10.6 Staking, Peening, and Swaging

Each application of staking, peening, and swaging, or any other means of permanent deformation for locking purposes, should be subject to procuring agency approval.

3.7.10.7 Safetying

Use of safety wire on threaded connections should be avoided if a reasonable alternative is available. Threaded parts should be safety wired when necessary in accordance with NASM33540.

3.7.11 Use of Standard Parts

Use of standard parts not specified in the detailed specification should be selected from established standards and specifications.

3.8 Environmental Conditions

3.8.1 Environmental Criteria

The actuator should not suffer any damage, deterioration, or degradation of performance when subjected to any environment or any natural combination of environments within the operational envelope as encountered during worldwide operations, as specified in MIL-STD-810 or RTCA/DO-160 and in the detail specification. The actuator should meet all the application specific requirements listed below:

a. Temperature, Ambient and Operating

b. Thermal Shock

c. Altitude

d. Humidity

e. Icing

f. Salt Spray or Salt Fog

g. Sand and Dust

h. Fungus

i. Vibration

j. Mechanical Shock

k. Explosive Atmosphere

l. Rain/Water Proofness

m. Fluids Susceptibility

The detail specification should specify, when applicable, the allowable damage and degraded performance after an extended life period of exposure to environments for the actuator.

3.8.2 Exposure

The actuator should not suffer any damage as a result of exposure to hydraulic fluids, fuels, de-ice fluids, cleaning solvents, etc., with which it may be expected to come into contact. The actuator should not suffer any damage to applicable chemical/biological (CB) contaminants or CB decontamination agents.

3.9 Corrosion Protection

In addition to the required metal corrosion protection, all external parts are to be painted with a prime coat and finish coat of epoxy or other approved material as specified by the detail specification. Holes in shafts and gears which are too small or too long to be adequately protected by plating must receive an approved corrosion protection.

3.9.1 Faying Surfaces, Bearing, Bolts, Metal Seal Cases, etc.

At assembly, the mating surfaces, ODs, IDs, etc., should be coated with wet primer per TT-P-1757 or approved equivalent for corrosion protection.

3.10 Identification and Marking

3.10.1 Identification

The identification requirements for the actuator should be as specified in MIL-STD-130 or as specified in the procurement specification.

3.10.2 Marking and Serialization

Each actuator should be marked and serialized. Placards should be the engraved or chemically etched type and mechanically secured to the component parts. Adhesive foil placards' use should be approved by the procuring activity and should be overcoated with a suitable clear material not softened by oils, grease, or cleaning solvents. Placards and data plates should be located such that they can be read when the component to which they are attached is installed in the application.

3.11 Workmanship

3.11.1 Quality

The supplier should exercise extreme care in fabricating, assembling, handling, and packing actuator units to assure that the components are clean and free of internal and external contaminants. All parts should be free from pits, rust, scrapes, splits, cracks, burrs, sharp edges, and discontinuities.

3.11.2 Interchangeability

Parts, components, subassemblies, and assemblies having the same part number should meet the requirements of MIL-I-8500 and be interchangeable in form, fit, and function with other parts bearing the same part number.

3.12 Handling Safety

The actuator and its components should be designed to provide a maximum level of safety to personnel during the course of installation and maintenance. Safety concerns like hazardous chemicals, high voltage, restrained energy sources, cutting edges, sharp points, etc., are design safety risks and should be identified and eliminated or mitigated to an acceptable level. This can be accomplished through good design practice, training, procedure implication, applicable warning labels and placards, and publication notes and warnings.

3.13 Reliability Requirements

3.13.1 Quantitative Reliability

Reliability in actuator design will be determined by the ability of the actuator to achieve its operational requirements under all defined conditions in an effective and efficient manner.

In most cases an actuator is one of several components of a system, whereby the actuator is allocated a quantitative reliability objective as part of the larger system requirement.

The procuring activity will assign a quantitative reliability requirement defined in the specification. There are three different categories of quantitative reliability:

1. Operational requirements for the actuator parameters

2. Basic reliability requirements for the item design and quality

3. Statistical confidence/decision risk criteria for actuator reliability tests.

Various operational parameters or methods to define the quantitative reliability requirement are as follows:

a. Mean Life

b. Mean-time-between-failures (MTBF)

c. Mean-time-between-critical-failures (MTBCF)

d. Mean-cycles-between-failures (MCBF)

e. Mean-flight-hours-between-failures (MFHBF)

f. Mean-time-between-maintenance-actions (MTBMA)

g. Mean-time-between-unscheduled-maintenance-actions (MTBUMA)

h. Mean-flight-hours-between-unscheduled-maintenance-actions (MFHBUMA)

i. Mean-time-between-removals (MTBR)

j. Probability of Success

k. Failure Rate (FR)

l. Service life (with or without preventive maintenance)

m. Mean-time-between-unscheduled-removals (MTBUR)

These parameters can be applied singularly or applied in combination to define an actuator requirement. Industry specific parameters can also be used and tailored to meet objectives.

3.13.2 Reliability Analyses

A reliability analysis of the actuator should be performed. Specific quantitative and qualitative reliability tasks may be performed as follows:

a. Reliability Modeling/Block Diagrams

b. Reliability Allocations

c. Reliability Predictions

d. Failure Modes Effects Analysis (FMEA) with Criticality (FMECA)

e. Parts Standardization Program

f. Reliability Critical Items

g. Effects of Functional Testing, Storage Handling, Packaging, Transportation, and Maintenance

h. Loss of Function Criticality

The Reliability Analyses requirements should be specified by the procuring activity and can be a combination of analyses that best meet actuator reliability design objectives. Analyses requirements may include ARP926 and ARP4761, as specified.

3.13.3 Reliability Verification

Once reliability requirements have been defined, testing requirements defined in the specification may be used to demonstrate and validate the actuator reliability. Testing may include:

a. Reliability Development/Growth Testing (RDGT),

b. Qualification Testing,

c. Acceptance Testing,

d. Environmental Stress Screening (ESS),

e. Highly Accelerated Stress Screening (HASS) and/or

f. Highly Accelerated Life Testing (HALT), as applicable.

3.14 Maintainability

3.14.1 Maintainability Characteristics

The ultimate goal concerning maintainability in the actuator design is to eliminate maintenance requirements over the useful life of the actuator program. All attempts should be made, through detail specification definition, to eliminate scheduled preventive maintenance/servicing, inspection, and maintenance from the design. This greatly reduces life cycle cost over the life of the program.

If elimination of maintenance requirements is not feasible, then special attention should be given to component/subassembly design pertaining to its maintenance. It is in the design phase where actuator maintenance features should be addressed to reduce life cycle repair costs. Factors such as modularity, parts count reduction, complexity, accessibility, visibility, testability, simplicity, and interchangeability all influence maintenance cost.

3.14.2 Maintenance Concept

When an actuator design requires maintenance, the specification should state the desired maintenance and level of maintenance that will apply. All attempts should be made to mitigate requirements for maintenance labor hours, Aerospace Ground Equipment (AGE), personnel skills, and technical publications/data.

The level of maintenance should be classified/defined as:

a. Organizational Level or Flight Line

b. Intermediate or Hangar and/or

c. Depot /Repair Station.

3.14.3 Quantitative Maintainability

Each applicable level of maintenance should have a detailed mean/average time to repair stated in maintenance man-hours, personnel skill level, and support equipment requirements.

To assist in determining the maintenance specific quantitative and qualitative maintainability tasks. Analyses can be performed, which can consist of:

a. Maintainability Modeling

b. Maintainability Allocations

c. Maintainability Predictions

d. Failure Modes and Effects Analysis (FMEA) - Maintainability Information

e. Maintainability Analysis

f. Maintainability Design Criteria

The Maintainability Analysis requirements for a procuring activity can be a combination of two or more of the analyses that best meets the actuator maintainability design objectives.

3.14.4 Maintainability Verification

Once maintainability requirements have been defined, verification requirements defined in the specification can be used to demonstrate and validate the actuator maintenance features and repair times. Verification should be conducted under the auspices of the Maintainability Demonstration.

3.14.5 Ground Support Equipment (GSE)

The actuator should be designed to be installed, tested, serviced, and maintained using standard GSE and hand tools. Special tools should not be required for the Organizational/Flight Line and Intermediate/Hangar Levels of maintenance. Specialized GSE and tooling may be required for the Depot Level/Repair Station for complete teardown, inspection, repair and functional check.

3.15 Documentation

3.15.1 Analysis Requirements

The detail specification should indicate the general analysis approach and analysis procedures that are applicable to all actuator designs for the specific application. As a minimum, the following areas should be considered:

a. Performance: Substantiation of actuator performance and limits thereof.

b. Moving Parts Clearance: Demonstration of adequate clearance of all moving parts under all combinations of environments and loads and all combinations of manufacturing tolerances and wear.

c. Selection of Materials and Minimum Size of Structural Members: Justification should be provided for materials and processes employed and for all operational stress levels anticipated.

d. Qualification Analysis: When items, components, or complete actuators are qualified on a similarity basis, sufficient data, (that is, test or analytical, or both) should be furnished to the procuring activity to demonstrate that those part(s) can be fully qualified.

3.15.2 Drawings

Drawings applicable to parts, components, subassemblies, and the complete actuator assembly should be in accordance with ASME Y14.100 or MIL-DTL-31000 as specified in the procurement document.

4. QUALITY ASSURANCE PROVISIONS

4.1 General

The quality assurance provisions should be in accordance with the detail specification. The supplier should have a quality system which conforms to the requirements of AS9100. Except as otherwise specified, the supplier may utilize his own or any other inspection facilities and services acceptable to the procuring agency. Inspection records of the examination and tests should be kept complete and available to the procuring activity as specified in the contract.

4.2 Test Requirements and Options

Appropriate testing, as outlined herein, should be conducted during the development and production of actuators to ensure proper design and performance, continuing quality and the degree of unit reliability expected in service.

At the option of the procuring organization, any of the test requirements specified herein may be waived, or modified, owing to design experience or operating considerations. The corresponding performance requirement may be verified by inspection, analysis, demonstration, or similarity to an already verified actuator. Request for waiver or modification of test requirements should be accompanied by complete detailed information, analysis and justification.

4.3 Classification of Tests

The following test programs, for the purpose of demonstrating compliance of actuators with the requirements of this specification, should be classified as follows:

4.3.1 Acceptance Tests

These tests, as specified in the detail specification, are performed on each actuator manufactured to demonstrate compliance with the nominal performance specified at nominal environmental conditions by the detail specification and the approved Acceptance Test Procedure.

4.3.2 Preproduction Tests

These tests are performed on the initial unit(s) to provide a basis for preliminary design approval to proceed with the production program. The preproduction test specimens should approximate as nearly as practicable the intended production units in design configuration, material, processing and production techniques. An assurance test, in addition to the acceptance tests, should be as specified in the detail specification and should include tests as outlined in 4.7.

4.3.3 Development Tests

The specifying agency may require that detailed characteristics of the actuator be measured to support computer simulation modeling, also referred to as virtual prototyping, in support of program objectives. This testing may be extremely critical regarding the effect of actuator characteristics on other system components and on the performance of the complete integrated actuation system the actuator is a part of. These tests may be dedicated development activities, or in some cases there may be overlap with testing required as part of the verification test pogram.

4.3.4 Qualification Tests

These tests are performed on production configuration actuators to confirm full compliance with the requirements of the detail specification. Each test specimen should initially and periodically throughout the qualification tests be subjected to the Acceptance Tests per 4.3.1. The number of qualification test units should be specified by the procuring agency.

4.3.4.1 Verification of Operational Service Life

The qualification test requirements should define the verification of operational service life through endurance testing as a test duration in terms of the number of lives to be tested (e.g., test for 1 life, or test for 2 lives, etc.) in order to demonstrate the design life requirement of 3.5.4.2.

4.3.4.2 Flight Worthiness

To demonstrate the flight worthiness of the equipment when the program schedule does not permit completion of the full endurance test prior to the first flight of the equipment, completion of the endurance test through anywhere from 10 to 25% of the total test spectrum, plus a certain subset of performance and environmental tests, must be successfully completed. This initial flight worthiness testing is sometimes referred to as Safety of Flight Testing. The specific requirements for demonstrating flight worthiness depend upon the criticality of the equipment, and should be specified by the procuring activity.

4.3.5 Test Matrix

Acceptance and Qualification test matrices should be included in the specification. Each matrix should provide a summary of the tests to be performed and a cross reference between the applicable Quality Assurance provision paragraph and the corresponding Requirements paragraph. This is principally a tool to ensure completeness of a document and to provide a general format for test plans.

4.4 Test Procedures

4.4.1 Acceptance Test Procedure

The acceptance test procedure should specify those tests which each actuator should satisfactorily complete as a condition for acceptance. The procedure should ensure that each actuator which is accepted meets the basic dimensional and performance requirements. It should describe tests in detail indicating the environmental conditions, specifying the test fixtures, equipment and instrumentation, the format of the individual unit test data sheet or test log, and the measurements and observations which should be recorded. The procedure should be updated when subsequent testing or usage indicates additional or modified tests should be incorporated.

4.4.2 Preproduction Test Procedure

The preproduction or safety-of-flight test procedure should specify those tests which are necessary to demonstrate that the actuator is satisfactory for limited life usage prior to formal qualification test completion. Cycle testing may be abbreviated to meet expected conditions.

4.4.3 Development Test Procedure

Development testing may be performed to more fully characterize actuator performance for purposes of designing interacting system components, or supporting computer simulation modeling of the complete actuation system within which the actuator is integrated.

Some recommended development test approaches are described as follows.

4.4.3.1 Internal Loads

Internal loads may be measured in order to understand the total input torque required to drive the actuator under all conditions. These internal tare losses typically include contributions from friction and speed dependent drag. A test program to establish the forward driving tare losses should include measurements of input torque at various speeds of interest in both directions of rotation, and over the range of required operating temperature.

In addition to forward driving measurements, measuring the torque on the output side required to backdrive the actuator when unrestrained on the input side at specific speeds and over temperature could be important for certain applications. In these cases, this should be measured as well.

4.4.3.2 Efficiency

For many applications, understanding the operating efficiency characteristics of the actuator over various conditions of operation is important. In these cases, testing for overall efficiency of the actuator should be performed over the full range of required combinations of speed, load, and temperature. This should include forward driving and backdriving conditions to capture all quadrants of actuator operation, as well as breakaway and stall conditions for applications for which these are critical.

Measuring the efficiency as described in the previous paragraph during backdriving, often referred to as aiding load conditions, provides a means to quantify the dynamic irreversibility by noting the input torque required to maintain motion at different levels of operating speed and aiding load.

The above noted loaded efficiency measurements can be combined with the measurement of internal loads to provide a comprehensive description of the actuator dynamic performance characteristics.

4.4.3.3 Irreversibility and Reversibility

For applications which require irreversibility or reversibility, it should be verified by test the degree to which the actuator will resist, or allow, being backdriven. Regarding irreversibility, it is important to note the two types are static and dynamic irreversibility.

For static irreversibility testing, the input side of the actuator is free, and a static load is applied to the output side; static irreversibility requires that the input side does not move. The applied output side load should be increased in steps to the maximum required irreversible load specified. As a vibrational or shock environment can affect the degree to which an actuator will not backdrive, it may be required to perform this test while vibrating the actuator, or applying a shock loading.

For dynamic irreversibility, the actuator is driven from the input side with an aiding load applied to the output side. The motive torque from the input side is suddenly removed, and dynamic irreversibility requires that the input and output side motion cease at the point in time the motive torque is removed.

Static reversibility is tested in a similar fashion; however, it requires that the input side does move when a load is statically applied to the output side. The applied load should be increased in steps to determine at what applied load backdriving will occur.