



# AEROSPACE RECOMMENDED PRACTICE

ARP5754™

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## Electromechanical Actuators Specification Guide

### RATIONALE

As electromechanical actuators (EMAs) are being more frequently used for safety critical aerospace applications, there is a need for a document providing comprehensive guidelines for specifying their design requirements. This document meets this need.

### FOREWORD

To draw attention to the different scopes applicable to statements in this document, the description “complete electromechanical actuation system” is used to describe the full scope of an EMA including its control and monitoring electronics, whereas the description “electromechanical subsystem” is used to describe the electromechanical actuation system without the control and monitoring electronics. Nevertheless, consideration of impact of all requirements to any subsequent development program is recommended. Appendix A is provided as additional information describing the various elements of an electromechanical actuation system and their characteristics to provide context to the reader.

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## 1. SCOPE

This Aerospace Recommended Practice (ARP) provides general characteristics, requirements, and design data to be recommended for inclusion in a procurement technical specification of an electromechanical actuator (EMA), including its control and monitoring.

### NOTES:

1. This document is limited to design requirement recommendations only.
2. U.S. military specifications created using this document as a guideline should use MIL-STD-961 as a guide for preparation of the specification.
3. Appendix A provides supplementary information to assist in the compilation of an EMA technical specification.

### 1.1 Purpose

This document is intended to be used by actuation system specifiers and actuation system integrators who may wish to specify the complete electromechanical actuation system or subsystem requirements of an EMA to a lower level. The reader of this document may therefore wish to select the level of requirements specified.

## 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 +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

|             |                                                                                                             |
|-------------|-------------------------------------------------------------------------------------------------------------|
| AMS-A-21180 | Aluminum-Alloy Castings, High Strength                                                                      |
| AMS-A-22771 | Aluminum Alloy Forgings, Heat Treated                                                                       |
| AMS-F-7190  | Forging, Steel, For Aircraft/Aerospace Equipment and Special Ordnance Applications                          |
| AIR4543     | Aerospace Hydraulics and Actuation Lessons Learned                                                          |
| AIR6127     | Managing Higher Voltages in Aerospace Electrical Systems                                                    |
| ARP4058     | Actuators: Mechanical, Geared Rotary, General Specification For                                             |
| ARP4386     | Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies                   |
| ARP4754     | Guidelines for Development of Civil Aircraft and Systems                                                    |
| ARP4761     | Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment |
| ARP5311     | Aerospace-Interface Definition for Mechanical Actuation Subsystems                                          |

|         |                                                                                                                            |
|---------|----------------------------------------------------------------------------------------------------------------------------|
| ARP5724 | Testing of Electromechanical Actuators, General Guideline For                                                              |
| ARP5812 | Actuators, Linear Mechanical, General Specifications For                                                                   |
| AS4716  | Gland Design, O-Ring and Other Elastomeric Seals                                                                           |
| AS5857  | Gland Design, O-ring and Other Elastomeric Seals, Static Applications                                                      |
| AS6235  | Face Seal Gland Design, Static, O-ring and Other Seals for Aerospace Hydraulic and Pneumatic Applications                  |
| AS8879  | Screw Threads - UNJ Profile, Inch Controlled Radius Root with Increased Minor Diameter                                     |
| AS22759 | Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy                                                          |
| AS50151 | Connectors, Electrical, Circular Threaded, AN Type, General Specification For                                              |
| AS50881 | Wiring Aerospace Vehicle                                                                                                   |
| AS94900 | Aerospace - Flight Control Systems - Design, Installation and Test of Piloted Military Aircraft, General Specification For |
| CMH17   | Composite Materials Handbook                                                                                               |

#### 2.1.2 AIA Publications

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

|           |                                                                         |
|-----------|-------------------------------------------------------------------------|
| NASM20995 | Wire Safety or Lock                                                     |
| NASM24665 | Pin, Cotter (Split)                                                     |
| NASM33540 | Safety Wiring, Safety Cabling for Cotter Pinning, General Practices for |

#### 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](http://www.astm.org).

|              |                                                                                                                                                        |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| ASTM B381    | Standard Specification for Titanium and Titanium Alloy Forgings                                                                                        |
| ASTM D149-09 | Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies |

#### 2.1.4 European Standards

Available from European Standards Store, [www.en-standard.eu](http://www.en-standard.eu).

|         |                                                 |
|---------|-------------------------------------------------|
| EN 2282 | Characteristics of aircraft electrical supplies |
|---------|-------------------------------------------------|

### 2.1.5 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, [www.easa.europa.eu](http://www.easa.europa.eu).

|       |                                                    |
|-------|----------------------------------------------------|
| CS-23 | Normal, Utility, Aerobatic and Commuter Aeroplanes |
| CS-25 | Certification Specifications for Large Aeroplanes  |
| CS-27 | Certification Specifications for Small Rotorcraft  |
| CS-29 | Certification Specifications for Large Rotorcraft  |

### 2.1.6 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, [www.faa.gov](http://www.faa.gov).

|           |                                                                                       |
|-----------|---------------------------------------------------------------------------------------|
| 14 CFR 23 | Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes. |
| 14 CFR 25 | Airworthiness Standards: Transport category airplanes                                 |
| 14 CFR 27 | Airworthiness Standards: Normal Category Rotorcraft                                   |
| 14 CFR 29 | Airworthiness Standards: Transport Category Rotorcraft                                |

### 2.1.7 Battelle Publications

Available from 505 King Avenue, Columbus, Ohio 43201, Tel: 1-800-201-2011, [www.battelle.org](http://www.battelle.org).

|       |                                                               |
|-------|---------------------------------------------------------------|
| MMPDS | Metallic Materials Properties Development and Standardization |
|-------|---------------------------------------------------------------|

### 2.1.8 ISO Publications

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

|          |                                                                     |
|----------|---------------------------------------------------------------------|
| ISO 7137 | Environmental Conditions and Test Procedures for Airborne Equipment |
|----------|---------------------------------------------------------------------|

### 2.1.9 RTCA Publications

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

|        |                                                                                                                           |
|--------|---------------------------------------------------------------------------------------------------------------------------|
| DO-160 | Environmental conditions and Test Procedures for Airborne Equipment                                                       |
| DO-178 | Software Considerations in Airborne Systems and Equipment Certification                                                   |
| DO-254 | Design Assurance Guidance for Airborne Electronic Hardware Considerations in Airborne Systems and Equipment Certification |

### 2.1.10 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

|                  |                                                  |
|------------------|--------------------------------------------------|
| AFAPL-TR-75-41   | High voltage Design Guide for Airborne Equipment |
| AFSC DH 1-6      | System Safety Design Handbook                    |
| AFWAL-TR-82-2057 | High voltage Design Guide: Aircraft              |

|               |                                                                                                                                                                                                                                            |
|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| JSC 29129     | Electrical Auxiliary Power Unit (EAPU) Corona Design Guideline                                                                                                                                                                             |
| NAVSO P-3641  | Navy Power Supply Reliability Design & Mfg Guidelines                                                                                                                                                                                      |
| MIL-A-8625    | Military Specification: Anodic Coatings for Aluminum and Aluminum Alloys                                                                                                                                                                   |
| MIL-C-5541    | Chemical Conversion Coatings on Aluminum and Aluminum Alloys                                                                                                                                                                               |
| MIL-DTL-26482 | Electrical Connectors                                                                                                                                                                                                                      |
| MIL-DTL-38999 | Detail Specification: Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, And Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification For |
| MIL-HDBK-454  | Military Handbook: General Guidelines for Electronic Equipment                                                                                                                                                                             |
| MIL-HDBK-470  | Department of Defense Handbook: Designing and Developing Maintainable Products and Systems                                                                                                                                                 |
| MIL-STD-810   | Environmental Engineering Considerations and Laboratory Tests                                                                                                                                                                              |
| MIL-HDBK-838  | Lubrication of Military Equipment                                                                                                                                                                                                          |
| MIL-PRF-8805  | Performance Specification Switches and Switch Assemblies, Sensitive, Snap Action (Basic, Limit, Push Button and Toggle Switches), General Specification For                                                                                |
| MIL-STD-130   | Department of Defense Standard Practice: Identification Marking of U.S. Military Property                                                                                                                                                  |
| MIL-STD-461   | Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment                                                                                                                                   |
| MIL-STD-464   | Department of Defense Interface Standard, Electromagnetic Environmental Effects Requirements for Systems                                                                                                                                   |
| MIL-STD-704   | Aircraft Electrical Power Characteristics                                                                                                                                                                                                  |
| MIL-STD-889   | Dissimilar Metals                                                                                                                                                                                                                          |
| MIL-STD-961   | Military Specification and Associated Documents Preparation of                                                                                                                                                                             |
| MIL-STD-1472  | Human Engineering                                                                                                                                                                                                                          |
| MIL-STD-7179  | Finishes, Coatings, and Sealants for the Protection of Aerospace Weapons Systems                                                                                                                                                           |

## 2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

### 2.2.1 European Commission Documents

Available from the European Union, <http://ec.europa.eu/environment>.

European Union Directive, Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS)

## 2.3 Definitions

ARP4386 contains the terminology, nomenclature, and definitions appropriate for use in actuation and control technologies.

For the purposes of this document, the following terms and definitions apply in addition to ARP4386.

**FAILURE:** This is any malfunction causing a performance degradation outside the limits as defined in the detailed specification.

**FREE PLAY OR BACKLASH:** This is the lost motion measured between two equal and opposite loads of sufficient magnitude to seat all bearings and contact points within the load path, but sufficiently low to allow elastic deformations of the actuator structure and bearings to be ignored.

**LOAD:** This is the force applied to the output of a linear actuator or as the torque applied to the output of a rotary actuator occurring as a result of the position or movement of the output.

**NOTE:** Since an EMA may have either linear or rotary outputs, the term load should be used throughout this document to represent either force or torque as applicable to the application.

## 2.4 Abbreviations and Acronyms

The abbreviations and acronyms used in this document are defined below.

|      |                                                                        |
|------|------------------------------------------------------------------------|
| dBa  | Decibels of sound pressure weighted to the A scale                     |
| EMC  | Electromagnetic compatibility                                          |
| EMA  | Electromechanical actuator                                             |
| LVDT | Linear variable differential transducer                                |
| MCE  | Motor control electronics (the EMA control and monitoring electronics) |
| MTBF | Mean time between failure                                              |
| PLOF | Probability of loss of function                                        |
| PWM  | Pulse width modulation                                                 |
| RoHS | Restriction of hazardous substances                                    |
| RVDT | Rotary variable differential transducer                                |
| VAC  | Volts alternating current                                              |

### 3. RECOMMENDED REQUIREMENTS

#### 3.1 General

EMAs covered by this document should be designed in accordance with a detailed specification. The detailed specification should specify the requirements necessary to satisfy the particular application.

The format, elements, and detailed procedures or values contained in this ARP are strongly recommended for use in the detailed specification of an EMA and its subsystems. The methods set forth herein for the preparation of a specification should be used as a guide. AIR4543 should also be consulted for lessons learnt that are applicable to EMAs.

Each of the requirements set out in the detailed specification should be defined in its own individual statement and uniquely identified within the specification by an alphanumeric tag relating it to the specifier's requirements database.

The requirements defined in the detailed specification should be met under all rated operating conditions over the specified service life.

##### 3.1.1 Associated SAE Documents

Linear mechanical screw transmissions should be specified in accordance with ARP5812.

Geared rotary transmissions should be specified in accordance with ARP4058.

#### 3.2 Electromechanical Actuator Description

It is recommended that the detailed specification includes a brief overview of the purpose, functions, and context of the EMA within the wider system and the end application. The description should not contain any requirements.

The end use of the actuator along with the criticality of the end application for loss of control and uncommanded motion, as well as normal and failure modes of operation for the EMA should be summarized.

The various configurations or reconfigurations and specific modes of the EMA should be described.

Recommendations for inclusion in the general description are:

- The electrical/mechanical/structural redundancy.
- Monitoring (speed, position, temperature, etc.).
- The prevention of back driving (no-back).
- The brake.
- The disconnect/clutch.
- The damping device.
- The dissipation of generated energy.
- The force/torque and/or speed limitation.
- The end stops.
- The heating of any stand-by unit.

The interfaces to the EMA should be briefly described including mechanical, electrical, and any command and feedback interfaces including data busses. A context diagram is often helpful in summarizing the interfaces and interactions of the system.

### 3.3 Electromechanical Actuator Scope

The required scope of the subject EMA should be defined in detail in the specification. The line replaceable unit(s) making up the EMA should be also defined.

When the specification is prepared by the actuation system integrator, several specifications may be prepared with separate subsystem scopes. For example, a separate specification may be prepared for the MCE and one for the electromechanical subsystem including sensors. Whilst general descriptions explaining the context of the EMA are useful, the specific scope of supply addressed by the specification should be clear.

### 3.4 Functional Requirements

The detailed specification should define the functions of the EMA including the type of motion, any external support or structural functions, sensing, and monitoring. The functional requirements should only focus on the need and required behavior and not define the method of implementation.

#### 3.4.1 Stroke/Rotation

##### 3.4.1.1 Electrical (Working) Stroke/Rotation

The detailed specification should provide a quantitative definition of the working stroke or rotation of the output, with tolerances, in a defined reference frame and sign convention, relative to a known datum and/or reference frame.

##### 3.4.1.2 Mechanical (Stop to Stop) Stroke/Rotation

The detailed specification should provide a quantitative definition of the mechanical stroke or rotation of the output, with tolerances, in a defined reference frame and sign convention, relative to a known datum and/or reference frame.

If an end stops function is required, this should be specified (the loads for which are defined in 3.12.3).

3.4.1.3 The requirements for any mechanical and/or electrical rigging functions and capabilities should be specified compatible with the maintenance requirements of 3.15.2, including total available stroke for rigging and maximum acceptable resolution of the rigging.

#### 3.4.2 Hold Function

The detailed specification should define any requirements for an output position hold function, such as a brake, that operates independent of the motor acting as a position servo.

#### 3.4.3 Disconnect Function

The specification should define any requirements for a disconnect function. The specification should specify the output performance when disconnected e.g., free movement and friction levels.

The means whereby the disconnect function is activated (for example, the system commanding the disconnect function such as the MCE, or vehicle control system) and the latency of activation should be defined.

The specification should define the requirement to support the output shaft when disconnected, e.g., all loads specified in this document should be supported when the EMA drive is disconnected.

The specification should state whether or not shear pins are an acceptable means of achieving a disconnect.

The requirements, if any, to reconnect the EMA after a disconnect and a definition of the operating conditions under which the EMA can be reconnected should be specified; for example, as a maintenance operation or automatically by the system itself.

#### 3.4.4 Backdriving

The ability of the EMA to be backdriven by the load or whether it is an irreversible actuator should be specified.

When a no-back device is expected to be used, the response time and maximum reverse displacement of the no-back should be specified.

#### 3.4.5 Power-Off Function

The detailed specification should define whether the EMA is required to perform a function with no power applied; for example, move freely.

#### 3.4.6 Degraded Function

The detailed specification should define any allowable reduction in performance or functioning acceptable under failure or overtemperature conditions.

#### 3.4.7 Measurements

Measurements required to provide a function for the higher level system or vehicle control should be listed and their purpose described.

##### 3.4.7.1 Feedback Measurements

Where required, specify the position, speed, acceleration, and force/torque feedback measurements functions to be provided. Identify any discrete motion/position sensing switches. When a separate specification is developed for the electromechanical subsystem of the EMA, the control feedbacks to the MCE should be specified. The recommended characteristics of the sensors to be specified are listed in 3.9.

##### 3.4.7.2 Monitor Measurements

Monitoring functions may be provided by the actuator to the vehicle systems including, for example, an integrated health monitoring system. When a separate specification is developed for the electromechanical subsystem of the EMA, the monitoring feedbacks to the MCE should be specified.

The requirements for monitoring measurements including motor temperature, position, speed, acceleration, and force/torque feedback measurements and mode of operation sensing should be specified.

Any required discrete motion/position sensing requirements, such as limit switches, should be identified.

The recommended characteristics of the sensors to be specified are listed in 3.9.

##### 3.4.7.3 EMA Parameter Storage and Access

To reduce set-up, rigging, and control parameter tolerances, it may be advantageous to provide local storage of important parameters on the EMA. The requirement for this function should be specified.

#### 3.5 Load Characteristics Specification

The definition of load given in 2.3 and Appendix A should be considered when specifying the load.

The detailed specification should define the output load actuated by the EMA and its characteristics including:

- The load inertia.
- The geometry and output load transmission kinematics.
- Additional external loads applied to the load that are transmitted to the EMA output.

- The stiffness of the transmission to the load inertia.
- The load attachment stiffness to the surrounding mounting structure.
- Load friction to the extent it affects the force required from the actuator.
- The direction of the loads, whether aiding or resisting the EMA motion and under what circumstances these possible loading modes occur

### 3.6 EMA Design Constraints

The EMA is generally controlled by the MCE to meet static and dynamic performance and stability criteria.

To integrate with an MCE that is specified separately from the electromechanical subsystem, it may be necessary to specify the electrical parameters of the motor used within the EMA. In addition, the MCE will impose constraints on the electrical power supplied to the motor.

Nevertheless, such specifications should be used with care to avoid over constraint of the design solution. Consideration should be given to specifying the following parameters.

#### 3.6.1 Weight

The detailed specification should specify the maximum installed weight of the EMA. The maximum weight specified should be determined with regard to the lightest weight compatible with detailed specification requirements, cost, good design practices, safety, and vulnerability.

#### 3.6.2 Mechanical Interfaces

It is recommended that ARP5311 should be used as a guide in the preparation of the requirements relating to items called out in this section.

##### 3.6.2.1 Space Envelope

The detailed specification should specify the maximum permissible envelope dimensions (i.e., the maximum space allowed for components, linkages, connectors, and related parts when installed and operated) of the EMA when it is in its static condition, e.g., when it is being shipped and in its operating condition.

The envelope should include any space for the movement of the EMA and its components during its operation.

To clarify the space envelope, consideration should be given to the provision of a solid model in commonly interchangeable format(s) to allow three-dimensional comparisons of concepts to be assessed against the required envelope.

The specified space envelope should be determined after taking into account:

- The dimensions and tolerances of the mechanical connections or the dimensional standards if connections are achieved through standardized components.
- Access to mounting and attachment fixings for removal and fitting.
- Connector removal and fitting.
- Heat dissipation; for example, convection, heat sink, volume.
- Convection heating of the local environment.

Where a constraint is imposed by the openings available for removal and installation of LRUs, these should also be specified.

### 3.6.2.2 Mounting and Attachment Points

The size, location, and orientation of the required mounting and attachment points of the EMA should be specified in relation to the space envelope.

Mountings should resist forces and torques generated by the actuator including torques arising from acceleration/deceleration (including end stop impacts) of the motor (see also anti-rotation requirements in 3.18.11).

The detailed specification should define the maximum allowable load, in normal and failure conditions, for each attachment point.

### 3.6.3 Redundancy

The level of redundancy required in the EMA may be derived from the specified safety and reliability requirements. When redundancy concept and configuration is required for other reasons such as compatibility with the higher-level architecture, the redundancy requirements should be specified.

### 3.6.4 Motor Control Electronics Requirements

When the specification is for the complete electromechanical actuation system, the specific requirements for the MCE can be limited to interface, electrical power supply quality and constraints, performance, reliability, safety, and environmental requirements. Other performance, monitoring, and control requirements implicitly implemented in the MCE should be specified for the whole electromechanical actuation system as set out elsewhere in this document.

When the specification is for the electromechanical subsystem, the specification should be written so that the MCE requirements other than the interface to the electromechanical subsystem are not relevant, although other requirements set out in this document are necessary to achieve the correct overall EMA system performance. The interface specification to the electromechanical subsystem should mirror the MCE interface specification and include:

- The motor power connections (3.6.5).
- The motor position feedback sensor connections used for commutation (3.9.2).
- Motor speed sensors when required (3.9.3).
- Motor winding temperature (3.9.4).
- The output position sensors when these are excited and/or processed by the MCE (3.9.1).
- Limit switches (3.9.8).
- Other sensors such as force (3.9.5), acceleration (3.9.6).
- Control signals and power to other devices such as clutches (3.4.3), brakes (3.4.2), etc.

### 3.6.5 Motor Power Supply Constraints

The motor power is provided by the MCE. When the electromechanical parts of the EMA are specified without the MCE, or a separate specification for the motor is prepared, the power supply constraints for the motor should be specified.

When motor power supply constraints are dependent on operating, failure or environmental conditions, the power supply constraints should be defined for each condition under which the performance is specified. The power supply constraints may include:

- The maximum continuous current that may be drawn by the EMA motor.
- The maximum current that may be generated by the motor when back driven.