

**Aerospace Fluid Power
Electrohydrostatic Module, Design, Performance and Test Recommendations**

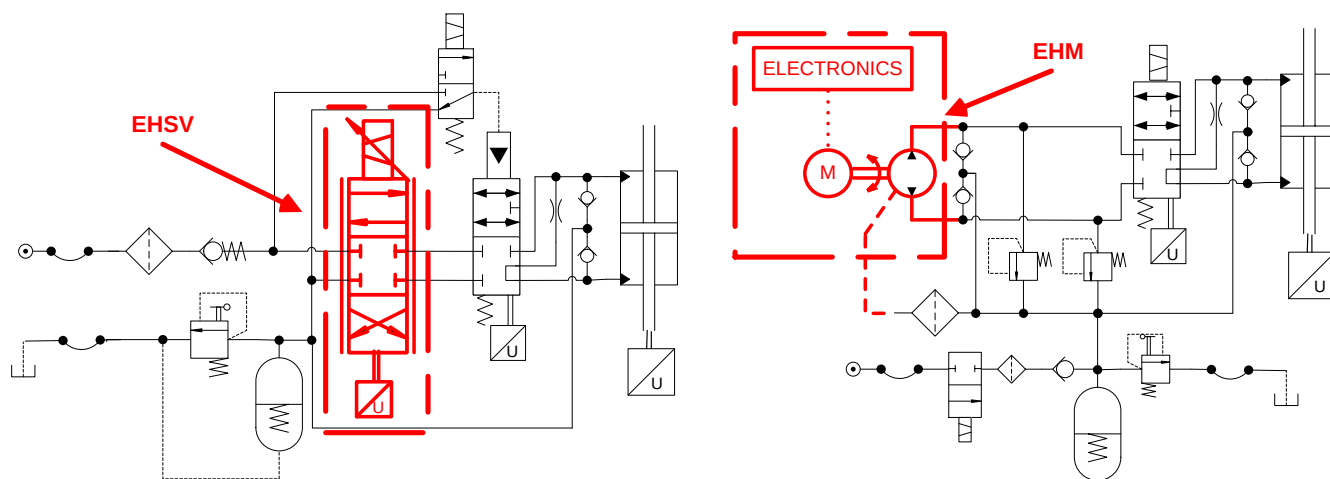
RATIONALE

There is a need for a document that provided design, performance and test requirements for an Electrostatic Module (EHM) that is comparable to existing documents for an Electrohydraulic Servo Valve (ARP490) or a Direct Drive Valve (ARP4493). This document meets this need.

FOREWORD

The key component of the existing regular Fly By Wire servo controls are the Electrohydraulic Servovalves (EHSV) which are designed in compliance with ARP490 which defines standard characteristics and interfaces to a level which makes possible to define families of components with significant commonality and to ensure the interchangeability of products from different manufacturers. This level of standardization, while still providing a lot of flexibility, has made possible to keep the cost of EHSV within certain limits.

An Electrohydrostatic Module (EHM) is a key component of an Electrohydrostatic Actuator (EHA) that is comparable to an Electrohydraulic Servovalve (EHSV) or a Direct Drive Valve (DDV) of an Electrohydraulic Servo Actuator (EHSA).



Electrohydraulic Servo Actuator hydraulic diagram (typical)

EHA hydraulic diagram (typical)

Figure 1 - EHSV and EHM hydraulic function comparison

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1. SCOPE

This Aerospace Recommended Practice provides general requirements for Electrohydrostatic Module (EHM) that is used in Electrohydrostatic Actuator (EHA) for aerospace applications.

This document includes design, performance and test (production and qualification) requirements.

1.1 Purpose

This document is intended to be used as a guide by the EHA manufacturer in preparing a detail specification for a specific EHM application. This document may be read in conjunction with ISO 22072 which defines the general characteristics, requirements and design data for an Electrohydrostatic Actuator (EHA).

The requirements contained in this document are confined to interface definition and input/output characteristics of an EHM. The information presented should be useful in standardizing:

- The terminology
- The specification of design and performance parameters, and
- The test procedures used in conjunction of these components.

The requirements do not restrict nor attempt to define the internal design characteristics of an EHM. As such the material is equally applicable to an EHM having:

- Different internal functioning
- Different ratings
- Different physical sizes, etc.

In certain instances, standards for an EHM design are recommended to achieve component interchangeability, for example, command signal polarity, mounting bolts and fluid ports location.

1.2 Field of Application

This document applies to both balanced and unbalanced area EHA and EBHA applications.

The specification information is directed towards an EHM for use in aircraft flight control systems. However, it shall be recognized that it may also be applicable to many other control systems, for example, landing gear actuation and steering systems. Unless otherwise indicated in the rest of this document, EHA term is used to describe actuators using EHM concept.

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.

ARP490	Electrohydraulic Servovalves
AS595	Aerospace – Civil Type Variable Delivery, Pressure Compensated, Hydraulic Pump
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
ARP1383	Aerospace - Impulse Testing of Hydraulic Components
AIR1922	Aerospace - System Integration Factors That Affect Hydraulic Pump Life
AS4059	Aerospace Fluid Power - Contamination Classification for Hydraulic Fluids
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
ARP4493	Aerospace - Direct Drive Servovalves
AS4941	Aerospace - General Requirements for Commercial Aircraft Hydraulic Components
ARP5879	Aerospace – Test Methodology for Electrohydrostatic Actuators
AS5994	Pump Units, Hydraulic, Electric Motor Driven, Variable Delivery
AS8775	Hydraulic System Components, Aircraft and Missiles, General Specification For

2.1.2 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org> or available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO2669	Steady-State Acceleration
ISO2678	Insulation Resistance and High Voltage Tests for Electrical Equipment
ISO22072	Aerospace – Electrohydrostatic Actuator (EHA) – Characteristics to be defined in procurement specifications

2.1.3 Radio Technical Commission for Aeronautics Documents

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160	Environmental Conditions and Test Procedures for Airborne Equipment
RTCA/DO-178	Software Considerations in Airborne Systems and Equipment Certification
RTCA/DO-254	Design assurance Guidance for Airborne Electronic Hardware Considerations in Airborne Systems and Equipment Certification

2.1.4 U.S Government

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

MIL-PRF-83282 Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft, Metric, NATO Code Number H 537

MIL-PRF-87257 Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft & Missile

MIL-STD-704 Aircraft Electric Power Characteristics

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

2.2 Definitions

Terms used in this document are defined in ARP4386. Where new terms are used, the definitions are presented below.

An Electrohydrostatic Module is a subsystem consisting of a PDE (Power Drive Electronics), an electric motor and a fixed displacement hydraulic pump, powered by aircraft electric power, with a closed loop electric motor velocity control, capable of providing hydraulic output flow when suitably supplied with hydraulic fluid.

The case drain pressure is the pressure at pump drain port, usually expressed in psi or kPa.

The electric motor torque is the electromechanical motor torque used to react the hydraulic pump load, usually expressed in lbf.in or N.m.

The electric motor velocity is the electromechanical motor velocity used to control the hydraulic pump, usually expressed in rpm or rad/s.

The limit cycle is defined as the maximum acceptable motor speed or output flow oscillation when the EHM is commanded at null speed.

The load pressure drop is the differential pressure between the EHM output ports, expressed in psi or (kPa).

The Power Drive Electronic is the electronic unit used to convert AC or DC electric power supply into pulse width modulated voltages to drive a motor.

The system pressure is the pressure at the entrance of the system, generally A/C hydraulic circuit pressure.

2.3 Symbols and Abbreviations

The symbol and abbreviations used in this document are listed below:

AC	Alternate Current
A/C	Aircraft
AT	Acceptance Test
ATP	Acceptance Test Procedure
AR	Amplitude Ratio
A _{RMS}	Ampere Root Mean Square
CE	Control Electronics
CIV	Corona Inception Voltage

DC	Direct current
deg	degree
EBHA	Electrical Back-up Hydraulic Actuator
EHA	Electrohydrostatic Actuator
EHA	Electrohydrostatic Actuator
EHSV	Electrohydraulic Servo Valve
ESD	Electrostatic Discharge
ESS	Environmental Stress Screening
FCC	Flight Control Computer
FH	Flight Hours
FHA	Failure Hazard Assessment
GSE	Ground Support Equipment
h	hour
HALT	Highly Accelerated Life Test
HASS	Highly Accelerated Stress Screening
HIRF	High Intensity Radio Frequency
M	Mega (prefix)
MBU	Multiple Bit Upset
MeV	Mega electron Volt
MTBUR	Mean Time between Unscheduled Removals
n	neutron
PA	Phase Angle
PD	Partial Discharge
PF	Power Factor
rpm	revolution per minute
SEU	Single Event Upset
TBA	To Be Answered
TBC	To Be Confirmed
TBD	To Be Determined

TBO	Time Between Overhaul
USL	Upper System Level
V	Volt
VAC	Volt Alternate Current
VDC	Volt Direct Current
V _{RMS}	Volt Root Mean Square
μ	micro (prefix)
Ω	Ohm

3. PROCUREMENT SPECIFICATIONS

This section is intended to be a guide for the preparation of an EHM specification.

3.1 Description and Interfaces

3.1.1 Item Definition

An EHM includes:

- An electric motor
- A hydraulic pump
- A Power Drive Electronic (PDE)
- Electrical connectors (the number of connectors used should be defined in order to achieve a good segregation between high and low power signals and between command and monitoring signals)
- Internal electrical connectors for the motor and sensors (if any)
- Thermal, speed and motor current information sensors
- Three or four hydraulic connection ports (see 3.1.4.1.2)
- An electrical independent heating device (if required)

NOTE: Pump anti-cavitation valves and pressure relief devices are not included in EHM design, but are part of the EHA manifold. Although pressure relief devices are primarily dedicated to protect actuator against overload, they also protect pump against overpressure. Additionally, for EHM optimization consideration, the pump anti-cavitation valves should be also be part of an EHA manifold in order to simplify the EHM integration on actuator.

3.1.2 Item Functions

The EHM performs at least the following functions:

- Conversion of electrical energy to hydraulic energy
- Provides output hydraulic flow as a function of speed command
- Electrical interface with upper system level:
 - EMC/lightning protection, signals filtering, etc.
 - Electrical energy dissipation (Aiding load and deceleration, if specified)
 - Power limitation (if specified)
- Mechanical interface with A/C and with hydraulic actuator
- Monitoring of EHM operation:
 - Temperature
 - Motor speed
 - Motor current

The EHM shall also perform internal monitoring and report the status to the upper level control system (FCS computer or other). The action resulting from fault detection shall be limited to system safety aspects.

Depending on system architecture (segregation rules, optimization requirements...) auxiliary control functions associated with the A/C system management (i.e., mode selection, re-configuration ...) may be performed by the PDE or by an EHA Control Electronics. This CE may be power-supplied by the PDE of the EHM. In this case, the interfaces to the PDE shall be detailed in the corresponding chapter.

3.1.3 EHM Key Design Drivers

EHM design and sizing are directly dependent upon the following key EHA specification requirements:

- The EHA maximum operating output force generally determines the maximum operating pressure differential between EHM output ports. In some cases, the maximum loaded rate could be the determinant of the maximum EHM output port differential pressure.
- The maximum EHA velocity, which determines the maximum EHM output flow
- The EHA loaded rate requirements, determining EHM loaded rate requirements and power consumption
- The load conditions critical to the thermal design of the EHM, such as:
 - The EHA maximum continuous holding force
 - And/or the maximum operating output force
 - And/or the maximum operating load and associated time duration
 - And/or specific duty cycle (time domain load and velocity) requirements
 - All with associated EHA thermal bay environment (air flow, temperature, convection coefficients, etc.)

While the above requirements determine the EHM output port differential pressure and EHM motor torque requirements, the available supply voltage to the PDE and the EHM motor commutation algorithm implemented in the PDE also influence the EHM motor design, which shall be considered in the overall optimization of the EHM.

EHM mechanical design from endurance standpoint is dependent upon the EHA endurance requirements and the number of EHA cold starts during life.

3.1.4 Interface Definition

An EHM typically interfaces mechanically and hydraulically with the EHA for control and output power and with other aircraft systems for power input, built-in test (BIT) and support equipment. All interfaces shall be described within EHM detailed specification or on the interface control document (ICD).

3.1.4.1 Hydraulic Interface

3.1.4.1.1 Hydraulic Fluid

The applicable hydraulic fluid specifications shall be stated and marked in the EHM name plate. Hydrocarbon based fluids per MIL PRF-83282 and MIL-PRF-87257 are typically used in military and space applications while phosphate-ester based fluids per AS1241 are used in most commercial and some military transport aircraft. The exposure to other fluids, such as preservative oil or alternate test fluids shall also be noted.

The EHM performance presented in the following sections are based on phosphate-ester fluid characteristics per AS1241. For alternative fluids, the EHM performance can be estimated by modulating the proposed figure with used fluid density and viscosity and other fluid characteristics.

Some special precautions are necessary, however, in the fluid system. Care shall be taken to remove all traces of water from the operating fluid. If ice particles form at low temperatures, EHM performance can be affected. Likewise, care shall also be taken to motor pump bleeding because the presence of air within the pump can adversely affect its functioning (see 3.1.5.8).

3.1.4.1.2 EHA Hydraulic Interfaces

3.1.4.1.2.1 Balanced power ram

For a balanced EHA power ram, the EHM is hydraulically connected to the EHA hydraulic manifold by 3 hydraulic ports identified as follows:

- Pump port - A
- Pump port - B
- Pump case drain - D

3.1.4.1.2.2 Unbalanced Power Ram

For an unbalanced EHA power ram as for a spoiler actuator or for a rear ram of dual tandem actuators, the EHM is hydraulically connected to the EHA hydraulic manifold by 4 hydraulic ports identified as follows:

- Pump port - A
- Pump port - B
- Pump third port - C
- Pump case drain - D

Whereas Pump ports A and B are connected to power ram chambers, the third main port C of the pump is connected to the EHA reservoir to compensate for flow variations due to the difference of volume required at port A and B.

3.1.4.1.3 Pressure

3.1.4.1.3.1 Inlet Pressure

The inlet pressure corresponds to the pressure level of the flow entering the pump. The inlet pressure at pump ports is generally generated by a charged accumulator located in the actuator hydraulic circuit. Inlet pressurization shall be high enough to suppress cavitation in the pump (AIR1922 can be used as a guideline to define minimum inlet pressure) and shall be supplied whatever the operating conditions (temperature, speed, life...).

The maximum inlet pressure shall also be specified.

3.1.4.1.3.2 Case Pressure

It is recommended that the case pressure shall always be slightly higher than reservoir pressure, which is slightly higher than the inlet pressure in order to ensure positive flow out of the case at all times in the interests of filtration. It is the EHA manufacturer responsibility to ensure that this condition is fulfilled.

The maximum case pressure in normal operating conditions and in case of upper system level failure conditions (if different) shall be specified.

3.1.4.1.3.3 Maximum Outlet Pressure

The maximum pressure at pump outlet port is generally limited by pressure relief valves integrated in the EHA hydraulic control flow circuit. The pressure relief valves minimum cracking pressure, minimum shut off pressure and max flow point shall be specified on whole hydraulic fluid temperature range.

3.1.4.1.4 Hydraulic Fluid Temperature

The range of fluid temperature supplied to the EHM shall be specified. The EHM might not be active all the time (for example when the EHA is in damped mode) the operating air temperature range (surrounding conditions) of the EHM shall also be specified (see 4.2).

3.1.4.1.5 External Hydraulic System Pressure

Although the EHA is a self-contained hydraulic system, it shall be periodically connected to an external hydraulic system for refilling purpose (i.e., leakage compensation). This hydraulic system can be the A/C hydraulic system, separate GSE, or a Depot Maintenance.

The pressure characteristics of the external hydraulic fluid system supplied to the EHA shall be specified (i.e., rated and maximum supply pressures, rated and maximum return pressures) as well as its associated failure conditions if they might affect EHM operations.

3.1.4.2 Electric Interface

The EHM is electrically connected to A/C electrical power and upper level control systems. It receives:

- Electrical power supply
- Flow demand (command)
- Actuator mode status (active, stand-by, maintenance, etc...)
- Electrical power supply for heating device, if specified

The EHM provides monitoring information to upper level control system such as:

- Motor speed
- Motor current
- Motor temperature
- PDE temperature
- Fluid temperature information
- EHM internal monitoring status
- Command wrap
- Actuator mode status wrap
- Electrical power supply status (e.g., presence of power, loss of one wire...)
- Heater status, if specified

The use of serial digital data buses for liaison between EHM and upper level control system is generally preferred for monitoring information transmission, but analog signals can also be used.

3.1.4.2.1 Electric Power Interface

3.1.4.2.1.1 Electric Power Characteristics

The EHM/PDE is generally supplied with a high voltage electrical power source. This may be selected from:

- 115 VRMS three phases constant frequency (400 Hz)
- 115 VRMS/230 VRMS three phases variable frequency (360 Hz to 800 Hz)
- Directly from high voltage DC sources (270 VDC or other) - With or without possibility for the consumers to re-generate power on the electrical network
- Other appropriate power sources

The EHM shall meet all performance requirements, characteristics and limits defined in the electrical power supply specification (MIL-STD-704, RTCA/DO-160 or other specification).

The power specified is either AC or DC.

The voltage operating range shall be specified.

If desired, the maximum allowable power consumption may be specified in watts or in VA (Volt Ampere). The maximum current may be specified in amperes if necessary.

3.1.4.2.1.2 Electrical Interface to A/C Power Network

The EHM interface to A/C electrical power network interconnecting wires shall be specified. The connector type, size and location shall be included on the specification control drawing.