



AEROSPACE INFORMATION REPORT

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Electrohydrostatic Actuator Applications on Aircraft Programs

RATIONALE

There is a need for a general overview of the applications of electrohydrostatic actuators (EHAs) on aircraft programs as a source of information for flight control actuation system architecture designers. This document meets this need.

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1. SCOPE

This SAE Aerospace Information Report (AIR) has been compiled to provide information on:

- a. The particularities of EHAs and their derivatives that make their implementation useful to meet some specific system requirements, solve some system architecture issues, or provide system optimization within the flight control actuation and hydraulic generation/distribution perimeter
- b. System architecture drivers and basic schematic diagrams, actuator principle schematic diagrams, and basic characteristics, for various civil and military aircraft

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.

AIR1083 Airborne Hydraulic and Control System Survivability for Military Aircraft

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

2.1.2 ISO Publications

Copies of these document are available online at <https://webstore.ansi.org/>.

or, if using the Switzerland address:

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.

ISO 22072 Aerospace - Electrohydrostatic actuator (EHA) - Characteristics to be defined in procurement specifications

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 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.

ARP6154 Aerospace Fluid Power Electrohydrostatic Module, Design, Performance and Test Recommendations

2.3 Abbreviations

AC	alternating current
APU	auxiliary power unit
DC	direct current
EBHA	electric backup hydraulic actuator
EHA	electrohydrostatic actuator
EHM	electrohydrostatic module
EMA	electromechanical actuator
FCAS	flight control actuation system
FH	flight hours
GSE	ground support equipment
HSA	hydraulic servo actuator
I/B	inboard
LVDT	linear variable differential transformer
M	middle
MCE	motor control electronics
MTBF	mean time between failures
O/B	outboard
PFCAS	primary flight control actuation system
PHM	prognostics and health monitoring
REU	remote electronic unit
RPM	revolutions per minute
UERF	uncontained engine rotor failure
VAC	AC voltage
VAC VF	AC voltage variable frequency
VDC	DC voltage

3. EHA OVERVIEW

3.1 General

The term “EHA” may be understood as a generic term covering various configurations. In this document, it refers to the ISO 22072 document, 3.1 and Figure 1.

Basically, an EHA is an electrically powered actuator that includes one or several hydraulic rams. The chambers of each ram are connected to an integrated hydraulic fluid reservoir and a bidirectional, fixed-displacement pump driven by a variable-shaft-speed, bidirectional electric motor controlled by an electronic module including power electronics, mounted on the actuator or remotely, and considered a part of the actuator. The pump/motor/motor control electronics assembly is known as the electrohyrostatic module (EHM). More details are available in ISO 22072.

3.1.1 EHA Types

Existing applications include:

- EHAs, or “simplex” EHAs, as shown in Figure 1 of ISO 22072
- Electric backup hydraulic actuators (EBHAs) that comprise an EHM installed on a hydraulic servo actuator (HSA) with a mode selection device
- Duplex EHAs that comprise two independent EHM/reservoir/manifold assemblies installed on a tandem cylinder and piston assembly

3.2 EHA Features

This section briefly discusses the characteristics of EHAs that make their implementation useful to meet some specific system requirements, solve some system architecture issues, or provide system optimization within the flight control actuation and hydraulic generation/distribution perimeter. Possible drawbacks or significant differences with other types of actuators are also discussed.

3.2.1 Impact on Hydraulic System Generation and Distribution

EHAs are electrically powered actuators that do not require hydraulic power from an external source; hence, hydraulic generation and distribution equipment, such as pumps, reservoirs, filters, piping, etc., are not needed.

EHAs could be either fully autonomous with no connection to centralized hydraulic systems, or they could incorporate for maintenance purpose an integrated ground-filling function to automatically compensate for a certain amount of external leakage or to renew hydraulic fluid. In the event of a hybrid power source configuration with hydraulic actuators and EHAs, this can be achieved with a small-diameter piping connection to an adjacent component supplied by a hydraulic system.

In the case of the EBHA, the actuator is powered from the central hydraulic system in normal operation and operates as an EHA in the event of failure on the central hydraulic portion of the actuator. In this case, the central hydraulic system may maintain the fill on the EHA side during normal operation.

3.2.2 Impact on Power Generation

If high-power EHAs are required, they are supplied from high-voltage sources, such as:

- 3 phase 115 VAC 400 Hz or variable frequency
- 270 VDC
- 3 phase 230 VAC variable frequency
- 540 VDC

On civil aircraft, the flight control actuators are used intermittently and/or in back-up mode, with a relatively low average power demand. The electric power generation is sized for commercial, noncritical, unloadable loads such as galleys, ovens, refrigeration, entertainment systems, etc. In this context, using electrically powered flight control actuators does not require extra power generation capability.

The flight control actuators are used intermittently and very dynamically. The motors have a nonlinear operation with high-frequency switching, resulting in harmonic noise beyond current limits that can disturb the operation of other equipment powered by the network. This requires a consequent electronic filtering or the use of a “dirty” network dedicated to the actuators in order to be compatible with the rest of the aircraft electrical power supply and distribution.

The EHA system has a potential to create power that can be applied to the bus, when slowing down the actuator or when the control surface drives the actuator. Either the actuator controllers or the power system should take care of this regenerated power.

3.2.3 Power Line Routing Flexibility

Routing of hydraulic lines in passenger aircraft shall take into account that because the hydraulic fluids are toxic, hydraulic components or hydraulic lines shall not be installed in the passenger compartments. Therefore, in the fuselage and in particular in the zone exposed to engine burst, i.e., an uncontained engine rotor failure (UERF), the hydraulic circuits are to be routed only in the cargo compartments reserved for the freight containers. With the trend toward high bypass engines with large rotors, providing separation for UERF within the cargo bay is a challenge.

Such a restriction does not apply to electric power lines, making more space available in the fuselage cross-section for achieving segregation between supply lines.

3.2.4 Battle Damage Reduced Vulnerability

AIR1083 states, “The use of independent actuation means, such [...] electrohydrostatic actuators (EHAs) [...] can be a means of enhancing survivability where power and space requirements permit such installations. The remote independent hydraulic power source or actuator [...] provides for actuation redundancy. This is particularly true for aircraft with large distances between the control surfaces and/or the power sources, where a [...] EHA [...] can substantially reduce the vulnerable area of a system.”

3.2.5 Low Jamming Probability

As demonstrated in service, hydraulic servo actuators (HSAs) are known to show a low jamming failure rate, lower than 10^{-9} per flying hour, as long as chambers are not hydraulically locked. The same applies to EHAs since their cylinder and piston assembly is similar to the one of a conventional servo actuator.

This is a difference from other electrically powered actuators such as electromechanical actuators (EMAs), that could suffer a jam of the mechanical power transmission components such as gearboxes or screws.

3.2.6 Damping/Blocking Functions

Fail safe modes, damping, or blocking (i.e., very high damping) functions can be achieved without complexity, as implemented on HSAs.

3.2.7 Thermal Behavior

In a conventional system, HSAs are connected to pumps and other hydraulic equipment through long pipes. The heat generated by the actuator operation is rejected into the hydraulic fluid, and in many cases, the cooling provided by the fluid circulation in the piping means that heat exchangers are not required, even at the system level.

EHAs, as contained hydraulic systems, cannot benefit from this effect. Heat sources are the various losses of the actuator (frictions, internal leakage, electric and magnetic losses), plus the energy generated when the control surface drives the actuator under aerodynamic or inertia forces. Thus, unlike an HSA, even holding a load without movement requires energy and generates heat. Therefore, extra cooling other than “natural” convection, conduction, and radiation may be necessary.

3.2.8 Load Limitation Function

The design loads of the actuator, attachments, and supporting structures are based on the maximum load that can be generated or reacted by the actuator. This maximum load depends on the current through the motor armature windings and on the motor torque constant. The current can be accurately limited, but the motor torque constant scatter due to tolerances and temperature variation can be significant.

Moreover, a current higher than what would require the load limitation may be necessary to meet high frequency dynamic performance.

Therefore, a load-limiting function not only based on current limitation may become necessary.

3.2.9 Support in Operation Simplification

Moving to all-electric technology, eliminating central hydraulic generation and distribution functions, is considered by some users to simplify the aircraft maintenance, in terms of ground support equipment (GSE) and highly specialized staff.

3.2.10 Life and Reliability

The life-limiting component for EHAs is the pump. Pump wear results primarily in internal leakage, generating heat that may increase temperature beyond acceptable limits. Fluid contamination and fluid aging may be contributing factors, especially since, unlike in HSAs, the fluid is not renewed. The rotational speed (RPM) of the pump under load with no surface movement can be used as a monitoring parameter representative of the condition of the pump in a prognostics and health monitoring (PHM) context.

External leakage could also be a life-limiting factor for fully autonomous units. Some units incorporate an automatic refilling function. The frequency of refilling can be used as a monitoring parameter representative of the condition of the piston rod seals in a PHM context.

The motor control electronics can be the sizing item in terms of mean time between failures (MTBF).

3.2.11 Full-Time Operation versus Backup Only

The current demonstrated life of EHAs does not make them appropriate for being the normal operation actuation system in applications such as commercial aircraft (up to 150000 flight hours [FH] current requirement). However, the technology is suitable for applications such as fighter aircraft or as a backup for commercial or military transport aircraft.

3.2.12 Standardization Opportunities

The EHM subassemblies can fit various applications. They could be subjected to a standardization policy similar to the electrohydraulic servo valves of HSAs.

4. EHA/EBHA APPLICATIONS ON COMMERCIAL AIRLINES

NOTE: The values shown in Tables 1 and 2 are rounded-up figures that are intended to give orders of magnitude rather than accurate actual data.

4.1 Airbus A380-800

The Airbus A380 is a four-engine, double-deck, long-haul civil airliner that made its first flight in 2005.

4.1.1 Airbus A380 Flight Control Actuation System (FCAS) Power Source Architecture Drivers

During the prelaunch phase, the Airbus A380 was initially designed as a conventional three hydraulic system primary flight control actuation system (PFCAS) power source aircraft due to the EHA technology risk at that time. When investigating the uncontained engine rotor failures, it was found that the three hydraulic system piping routes could not be properly segregated in the cargo compartments as achieved in other aircraft. This was because the size of rotor discs was significantly larger than on previous aircraft, and the number of engines to be considered, while the cross-section of the cargo compartments was not larger, being designed for the same standard containers. Moving from hydraulics to electrics for one power source made it possible to route the cables of the electric power source to any place in the fuselage cross-section, including passenger decks, to provide the appropriate segregation distances between the power routes.

To conclude, these are the requirements linked to the UERF that led to the use of EHAs/EBHAs on the Airbus A380. The significant weight saving announced (and achieved) has not been taken into consideration when making the decision.

4.1.2 Airbus A380 Actuator and Power Source Distribution Overview

The Airbus A380 actuators are powered by two 5000 psi (34500 kPa) hydraulic systems and two 115 VAC variable frequency electric networks. The distribution of these elements is shown in Figure 1.

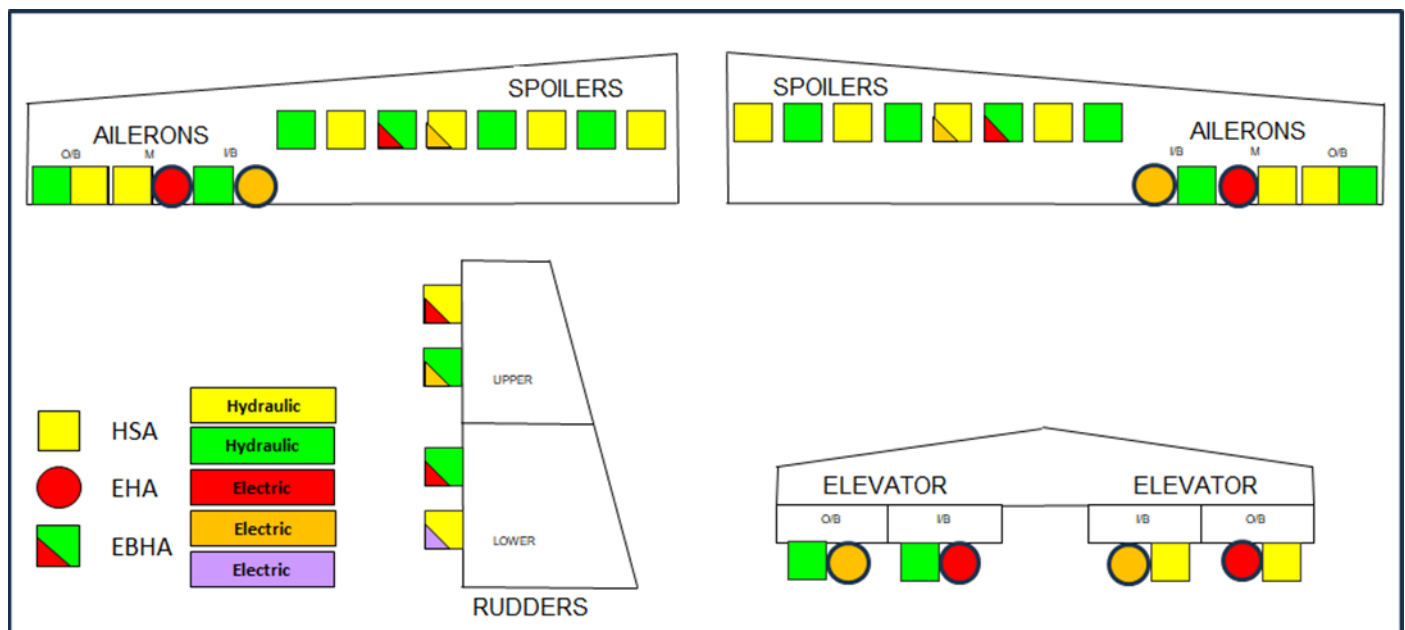


Figure 1 - Airbus A380 actuator and power source distribution overview

4.1.3 Airbus A380-800 EHAs and EBHAs

4.1.3.1 Schematic Diagrams

Figures 2, 3, and 4 are the top-level schematic diagrams of the Aileron and Elevator EHAs, the Rudder EBHA, and the Spoiler EBHA.