"MORE ELECTRIC" CONTROL SURFACE ACTUATION, A STANDARD FOR THE NEXT GENERATION OF TRANSPORT AIRCRAFT

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Abstract

For a long time the control surfaces of transport airplanes above a certain weight have been hydraulically powered. The most recent generation of in-service commercial transports is showing generalization of the electrical signaling of the hydraulic flight control actuators, known as Fly By Wire systems. The very new Airbus aircraft generation, A380 and A400M, presently under development, now features a mixed flight control actuation power source distribution, associating electrically powered actuators with conventional FBW hydraulic servocontrols.

The intent of this paper is to highlight the drivers for this evolution, to discuss the presently selected electrical actuator technology and the future of this “More Electric” configuration.

1. Flight control actuation basics

1.1. Control Surfaces

Flight controls of transport category airplanes usually include so called “primary flight controls”, dedicated to the control of the attitude on the roll, yaw and pitch axes, and the trajectory of the aircraft, and “secondary flight controls”, also identified as “high lift system”, dedicated to the control of the lift of the wing.

The roll control is generally achieved by one or several pairs of ailerons complemented with several pairs of roll spoilers, the yaw control is achieved by a single or a double panel rudder and the pitch control is achieved by one or two pairs of elevators and a movable horizontal stabilizer. Duplication of the aileron, rudder or elevator surfaces on very large airplanes is primarily intended to cope with the bending of the flexible supporting structures of the wing and empennages rather than providing control system redundancy.

The high lift system generally includes leading edge slats which generate an aerodynamic effect making possible the use of high angles of attack and trailing edge flaps that basically increase the area on the camber of the wing, and as a consequence the lift provided at a given angle of attack.

![Fig 1. A380 flight control surfaces](image-url)
1.2. Power requirements

The concept of power applied to hydraulic flight control actuation could be misleading. Hydraulic actuators are better characterized by a stall load and a no load rate, the available mechanical power being dependent on the operating point and derived from the above characteristics. As an example the variation of the characteristics of actuators as a function of the size of the airplane is the following. The rudder actuator is usually the largest actuator for a given aircraft model.

Rudder actuator stall load / no load rate

<table>
<thead>
<tr>
<th>Model</th>
<th>Stall Load</th>
<th>No Load Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320</td>
<td>45 KN</td>
<td>110 mm/s</td>
</tr>
<tr>
<td>A340</td>
<td>94 KN</td>
<td>135 mm/s</td>
</tr>
<tr>
<td>A340-600</td>
<td>155 KN</td>
<td>160 mm/s</td>
</tr>
<tr>
<td>A380</td>
<td>225 KN</td>
<td>100 mm/s</td>
</tr>
</tbody>
</table>

These hydraulic actuators are supplied from an hydraulic generation system not necessarily sized for flight controls only, the landing gear also being a major consumer. However the maximal “power” figure, product of the nominal system pressure and the maximal flow of all the “normal”, ie not “emergency”, pumps supposed to be simultaneously active, gives a good idea of the available power for actuation purposes.

<table>
<thead>
<tr>
<th>Model</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320</td>
<td>125 KW</td>
</tr>
<tr>
<td>A340</td>
<td>240 KW</td>
</tr>
<tr>
<td>A340-600</td>
<td>290 KW</td>
</tr>
<tr>
<td>A380 (3H)</td>
<td>500 KW</td>
</tr>
</tbody>
</table>

1.3. Actuation architecture definition drivers

The architecture of the flight control system, in terms of number of actuators per surface, number and distribution of power sources and flight control computers, is primarily driven by safety considerations.

The safety objectives, as defined by the current regulations, require failures, or combinations of failures, resulting in the loss of the airplane to be demonstrated as Extremely Improbable. This means that their failure rate shall not exceed a probability of $10^{-9}$ per flight hour.

Complete loss of power supply to a fully powered flight control actuation system, which would result in loss of control, falls in this category. As a consequence the flight control actuation system shall be supplied from several redundant power sources. Practically, taking into account the current reliability of secondary power sources, three independent sources are required.

Trailing edges control surfaces, if unbalanced, are prone to flutter if left free to rotate, in the event of failure of their driving system. Flutter may be a diverging phenomenon leading to structural rupture. For this reason redundancy of actuation systems and power sources at each trailing edge surface is required, either to keep the loss of control as Extremely Improbable, or to provide damping to the surface in the event of loss of its control, making Extremely Improbable the condition where it would be free to rotate with no damping.

Other safety considerations apply to events identified as “particular risks” which may generate common failure modes to supposedly independent systems: engine or tire burst, mid-air collision with limited structural damage, battle damage for a military transport, belong to this category. Geometric segregation of equipment and interconnection routes, introduction of isolation devices are required for minimizing vulnerability to these risks.

Other obviously fundamental criteria are the minimization of the maintenance costs and of the weight of the actuation system and power sources.

2. Airbus current flight control system technology

2.1. Typical FBW power source and actuator distribution

The current flight control system technology for large transport category airplanes is known as “Fly By Wire” (FBW). This concept has been introduced at Aerospatiale in the late 60’s with Concorde, at Airbus in the 80’s with the A320. It features 3 centralized hydraulic systems supplying redundant sets of electrically signaled hydraulic actuators. Control surfaces are fitted with 3, 2 or 1 actuators, depending on their criticality and sensitivity to flutter. A similar arrangement has been introduced at Boeing in the early 90’s with the B777.

As an example Fig 2 shows the Airbus A340 distribution of actuators, hydraulic systems identified as Yellow, Green and Blue, and Flight Control Computers over control surfaces.
2.2. Typical FBW servocontrol lay-out

The typical FBW actuation configuration, as selected for ailerons and elevators, consists in two electrically signaled servoactuators, also identified as “servocontrols”, supplied from two independent hydraulic systems, in an active / stand-by arrangement.

The active unit, connected to one or several Flight Control Computers and servoed by one of them drives the surface. The stand-by unit is driven in a by-pass mode that generates a certain velocity dependent opposing force. In the event of a failure of the normally active control chain, the stand-by becomes active and vice versa. In the event of a failure of both control chains, the actuators in stand-by mode provide the required surface damping.

Fig 3 shows the main components of a typical FBW servocontrol.
3. Airbus “More Electric” approach

3.1. Why challenging Flight Control Actuation power sources?

In terms of hardware, the primary flight control system in the Airbus FWB concept is now extremely simple: it basically consists in side stick controllers and pedals, digital computers and actuators. At this point it becomes difficult to identify further significant simplification of this system in its own. Major improvement is now to be searched for in its periphery, for example in the direction of the associated power sources.

On the other hand, technology advances in the design of brushless electric motors taking advantage of new magnetic materials, electronic controllers incorporating miniaturized power components and hybrid circuits are making electrical actuation more and more attractive from the power to weight ratio point of view.

This is the combination of this reflection on potential improvement areas together with the electric motor technology opportunity which has been the driver towards the introduction of some proportion of electrical actuation in the current Airbus flight control system concept for the next generation of commercial and military transports.

3.2. Basic concept

As mentioned above three independent power sources are required to make the complete loss of the flight control actuation system Extremely Improbable.

Now large transport category airplanes are currently fitted with three independent hydraulic systems plus two independent electric systems, which makes a total of five independent power sources.

The basic idea is then that one hydraulic system can be eliminated and replaced by a set of electrically powered actuators with no detrimental impact to the probability of loosing the flight control actuation system.

3.3. The “2H / 2E” power source distribution

The A380, currently under development and scheduled to fly in 2005, is the first “More Electric” flight control commercial transport. The selected power source configuration, identified as 2H / 2E in the trade-off studies, features two hydraulic systems, Green and Yellow, and two electrical systems, E1 and E2, as shown in Fig 4.

The current Airbus Fly By Wire actuation system is based on an active/stand-by actuator arrangement. The selected More Electric architecture keeps this principle, the normally active actuators still being regular servocontrols, the stand-by actuators being changed to Electrohydrostatic Actuators (EHA).

The A400M, the Airbus military transport, just launched and scheduled to fly end of 2007, is to be similarly architected.

![Fig 4. The A380 Power Source and Actuator Distribution](image-url)
3.4. EHA and EBHA

The selected type of electrically powered actuator is the Electrohydrostatic Actuator (EHA). As shown in Fig 5, it is basically a self contained hydraulic actuator incorporating a pump driven by a variable speed electric motor; by transferring the fluid from one cylinder chamber to the other, the pump and electric motor achieve the control of the position of the piston connected to the surface.

In some circumstances it may be beneficial to power a given actuator either from an hydraulic system, as a regular servocontrol, or from an electric system as an EHA. This is the purpose of the Electrical Back-up Actuator (EBHA), that gathers around a common cylinder and piston assembly the servovalve of the FBW servocontrol and the motor pump of the EHA.

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Fig 5. Electrohydrostatic Actuator (EHA)

Fig 6. FBW Servocontrol, Electrohydrostatic Actuator (EHA) and Electrical Back-up Actuator (EBHA)
3.5. Benefits of the 2H / 2E arrangement

Benefits of the introduction of the electrically powered actuators in this "More Electric" architecture are identified in several areas:

In terms of safety several aspects can be highlighted: As far as power source redundancy is concerned the number is increased from 3 to 4 since 2 electrical systems replace 1 hydraulic system. Furthermore an additional margin of safety results from the introduction of the hydraulic/electric dissimilarity in the power sources. This provides further protection against common failures, such as maintenance errors which may affect all the hydraulic systems whatever is their number. Moreover the electrical power provides flexibility in routing resulting in an easier segregation of power distribution routes and an isolation and reconfiguration capability that hydraulic systems cannot offer.

The reduction in the total number of hydraulic components results in improvements of the MTBF, dispatch reliability, by elimination of potential leakage sources.

The elimination of the generation and distribution components associated to one of the hydraulic systems (pump, reservoir, filters, plumbing...) and the replacement of the associated servocontrols by EHAs / EBHAs results in weight and cost savings.

Another overall performance improvement results from the reduction of the electrical power required since the EHA efficiency is better than the one of combined electro motor pumps and servovalves of a third hydraulic system.

4. What future for electric flight control actuation?

4.1. EHA standardization

The key component of the existing regular FBW servocontrols are the Electro Hydraulic Servo Valves (EHSV) which are designed in compliance with a general requirement document 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.

Standardization of the pump/motor/power electronics sub-assembly, which is the key component of EHA, to the same level is as well a means to address the EHA cost issue and is presently under study.

4.2. EMA versus EHA?

The currently selected actuator configuration of the More Electric system arrangement is the Electrohydrostatic Actuator in which gearing and transmission are hydraulically achieved. The Electromechanical Actuator (EMA), in which the motor torque is mechanically amplified and transmitted to the control surface, using a gear set, a screw or other mechanical transmission devices can be seen as an alternative

As far as complexity, weight, reliability, maintenance requirement are concerned, EMA are potentially more attractive than EHA, at least for low power applications. In particular, all hydraulic technology relevant problems are obviously eliminated from the EHA configuration. However in the three following areas EHA are still preferable to EMA.

- The jamming probability of an EMA used in a primary flight control application is difficult to predict and substantiate from existing in-service experience. Jamming probability of an EHA, can be directly assessed from the current servocontrol experience, and shown as Extremely Improbable if properly by-passed. The jamming probability of mechanical systems incorporating hundreds of gear teeth and screw mechanisms is more a question mark and current experience in secondary flight control applications may not be directly transferable to primary flight controls, due to very different duty cycles in particular.

- The same applies to the prediction of the wear life. Wear of the mechanical transmissions components may result in control surface free-play or other non-linearities which may generate unacceptable limit cycles.

- The introduction of EHA in parallel with regular servocontrol in the basic More Electric architecture described above is easier than EMA. EHA can easily be made reversible in stand-by mode, they can incorporate identical damping devices to those currently used for flutter protection, they can be built with many components common with the adjacent servocontrol such as the piston, cylinder, associated position transducer or the accumulator.
4.3. Zero hydraulic systems?

The 2H / 2E More Electric arrangement makes possible to use electrically powered actuators in stand-by positions only, while conventional FBW servocontrols are kept as the normally active actuators. This somewhat limits the risk inherent to the introduction of the new technology.

A further reduction of the number of hydraulic systems would make necessary to use electrically powered actuators in normally active positions. This step will be considered when reliability of electrically powered actuators is substantiated from in-service experience of the presently implemented configuration.

5. Summary

For a long time the control surfaces of transport airplanes above a certain weight have been hydraulically powered. The state of the art standard for the flight control actuation systems of currently in-service large transport category aircraft is the digital control, from side stick signals, of hydraulically powered servoactuators supplied from centralized hydraulic generation and distribution systems.

The achieved simplicity of this FBW flight control actuation system hardware has presently reached such a level that further improvements were considered in the associated power sources rather than in the actuation system on its own.

The very new Airbus generation, A380 and A400M presently under development, now features a “More Electric”, mixed flight control actuation power source distribution, associating electrically powered actuators with conventional FBW hydraulic servocontrols.

The concept is based on the optimized utilization of existing on-board power sources, it presently takes advantage of the Electrohydrostatic Actuator technology.

It offers to the operators and passengers the performance and cost benefits associated to a reduced number of centralized hydraulic systems, together with the added margin of safety provided by more reliable and dissimilar flight control actuation system power sources.