# MODERN AIRCRAFT BRAKING SYSTEMS

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DOI: 10.19062/2247-3173.2023.24.19

***Abstract:*** *This paper presents some problems concerning the present trends in the field of aircraft braking systems. New solutions like electro-mechanical or electro-hydrostatic actuators are considered the future, but some big aircraft producers do not renounce yet to classical electro-hydraulic braking systems. New solutions are not generally accepted, they have to prove their reliability and that they bring considerable more advantages than penalties.*

***Keywords:*** *aircraft, braking systems, electro-hydraulic, electro-hydrostatic, electro-mechanical*

## 1. INTRODUCTION

Hydraulic braking systems were used on aircraft relatively early on the aircraft. First hydraulic braking system appeared in the beginning of 1930s. Their function was only to stop the aircraft on the ground at the landing run. They developed rapidly and become more and more sophisticated once the aircraft evolved. Additional functions appeared, as the aircraft turning on the ground by differential braking of the main landing gears wheels. Gradually, this solution was replaced on big aircraft by the steering of the nose wheel, but some small aircraft still use this solution.

Once the flight speed increased and also the aircraft mass became necessary to use stronger braking. The problem to avoid the wheel blocking in the braking process became acute. Hydraulic braking systems were provided with anti-skid function, which release the brakes when the wheels begin to slide on the ground. By this way, a better aircraft control at the landing run is achieved and also the tyres wearing reduced. The first anti-skid systems were implemented with simple mechanic-electric-hydraulic devices. Development of the analogical electronic devices and later digital electronic devices led to improved anti-skid systems, controlled by analogical or digital computers. Better performances regarding the wheels sliding and landing run decrease were obtained, maintaining acceptable tyres wear.

Later, parking brake was introduced on aircraft. Aircraft have a big surface reported to their mass and for this reason wind gusts can easily move the aircraft on the ground. Before that, using braking logs in front and behind wheels prevented this phenomenon. Now, this function is accomplished also by the braking system.

In order to reduce more rapidly the landing speed, in present, many systems as jet reverser, propeller windmill regime, aerodynamic brakes and spoilers and braking parachutes. In this manner, the braking system stress reduces.

Hydraulic braking systems use the hydraulic pressure to press together the braking discs. Braking control is obtained by braking pressure control.

This control is realized using mechanic-hydraulic devices for braking systems controlled by the pilot pedals, or by electric-hydraulic devices when automatic brake is activated. We do not insist here on these aspects, well known in aeronautic world. An electro-hydraulic braking system is presented in Fig. 1 [1].

At the end of 20th century appeared the trend to move to “”More Electric Aircraft” and even “All Electric Aircraft”. This trend appeared after two aeronautic catastrophes. In that situations all aircraft hydraulic systems failed and aircraft control lost. First intention was to replace electric-hydraulic or mechanic-hydraulic servo-actuators for flight controls with electro-hydrostatic or electro-mechanic servo-actuators. Until now only electro-hydrostatic servo-actuators implementation succeeded.

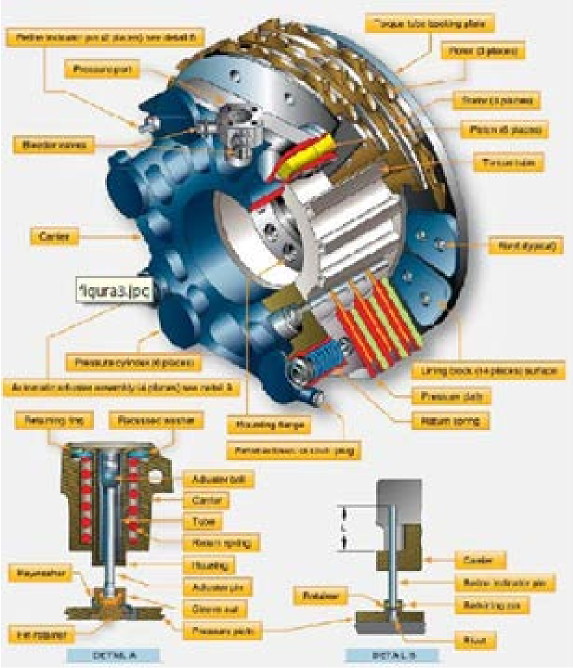


**FIG. 1** Multi-disc electric-hydraulic braking system [1]

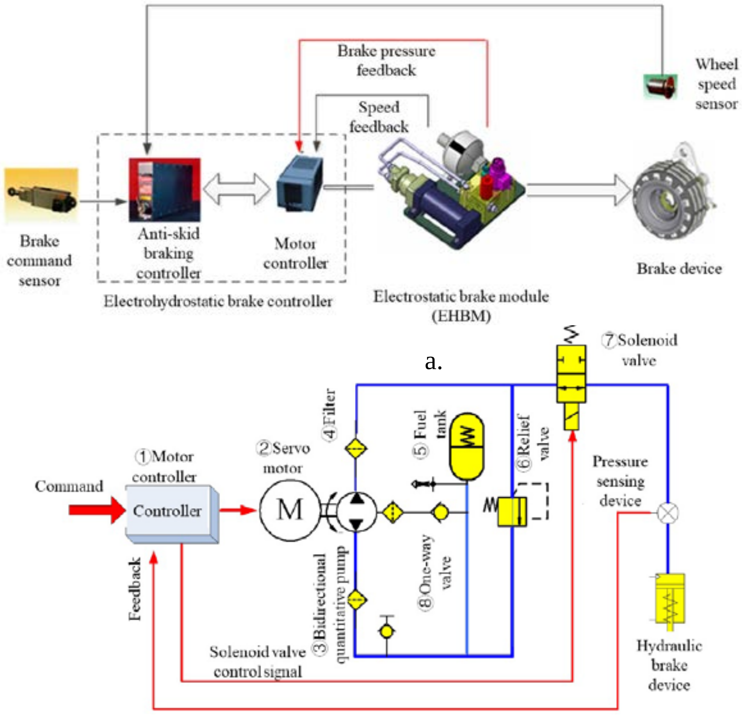
The main aims were to improve the flight controls reliability, to reduce production and maintenance costs, to simplify maintenance procedures. Another aim is to reduce the aircraft drives mass, but this fact is doubtful. Electro-hydrostatic servo-actuators are heavier than electro-hydraulic servo-actuators but the pumps and pipes are eliminated. Instead, electrical energy converters and electrical cables are necessary. We cannot say precisely overall electro-hydrostatic drives are less heavy than the classical electro-hydraulic drives.

In the last period the intention is to replace all the classical hydraulic drives with new drives, preferably electro-mechanic or electro-hydrostatic drives but also other solution for on board drives are studied.

## 2. ELECTRO-HYDROSTATIC AND ELECTRO-MECHANICAL BRAKING SYSTEMS

Electro-hydrostatic and electro-mechanical braking systems are very alike with electro-hydraulic once. The main difference is the manner to obtain the pressing force between the braking disks. In this case electro-hydrostatic and electro-mechanical servo-actuators develop this force. A braking system with electro-hydrostatic servo-actuators is in Fig. 2 [2].

Electro-hydrostatic servo-actuators present the advantage of lacking of centralized hydraulic system on aircraft. Necessary pressure in hydraulic system is produced by a local pump driven by an electric motor fed either from the 28 VDC electric system, either the 270 VDC electric system.



a.

b.

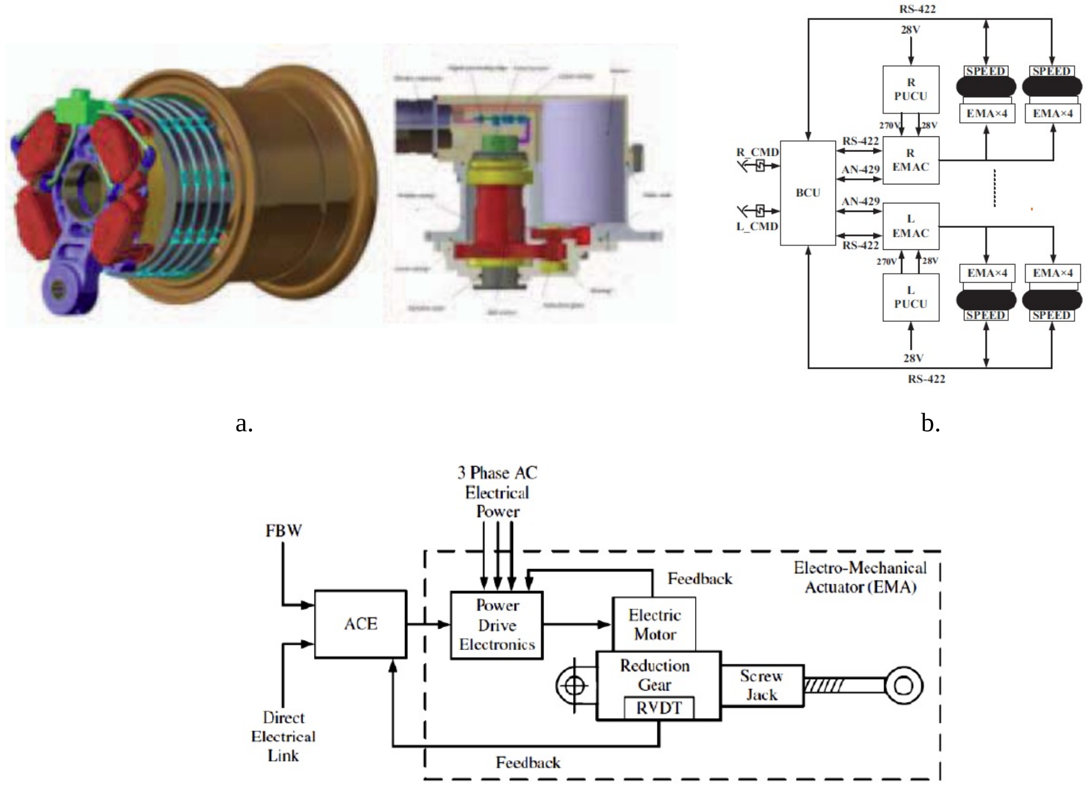
**FIG. 2** a. Structure of a a braking system with electro-hydrostatic servo-actuators [2];
b. Principle scheme of a electro-hydrostatic servo-actuator [2]

This solution avoids all the difficulties concerning manufacturing and maintenance of the centralized hydraulic system. However, electro-hydrostatic servo-actuator is heavier than electro-hydraulic servo-actuator. Electro-hydrostatic servo-actuator system has a hydraulic accumulator, valves and filters in addition to electro-hydraulic servo-actuator. Are also necessary a power conversion electronic system and two feedback loops for braking control.

Figure 3.a [3] shows an electro-mechanic braking system. Servo-actuators in this care are electro-mechanic. These servo-actuators have simpler construction than electro-hydrostatic servo-actuators. Electro-mechanic servo-actuators are also fed from the 28 VDC electric system or from the 270 VDC electric system. In most cases the 270 VDC is used as main feeding system and in emergency situation the 28VDC feed the servo-actuator through a power converter.

System in Fig. 3.b [3] contain two redundant control block for brake intensity (BCU), four controllers for the electro-mechanic servo-actuators (EMAC), four sensors for braking pedal positions (PUCU), 8 data acquisition systems from the wheels (SPEED) and 8 electric braking systems with electro-mechanic servo-actuators. Each wheel has a braking system with four electro-mechanic servo-actuators. Information is transferred between the control blocks through ARINC 429 and RS 422 digital data busses. Each servo-actuator has two control loops, one force loop and one position loop. System architecture allows implementing very efficient braking control algorithms.

Electro-mechanic braking system has the advantage of centralized hydraulic system absence, but electro-mechanic servo-actuators are still heavier than electro-hydraulic servo-actuators. Power electronic system is also a supplementary feature in this case.



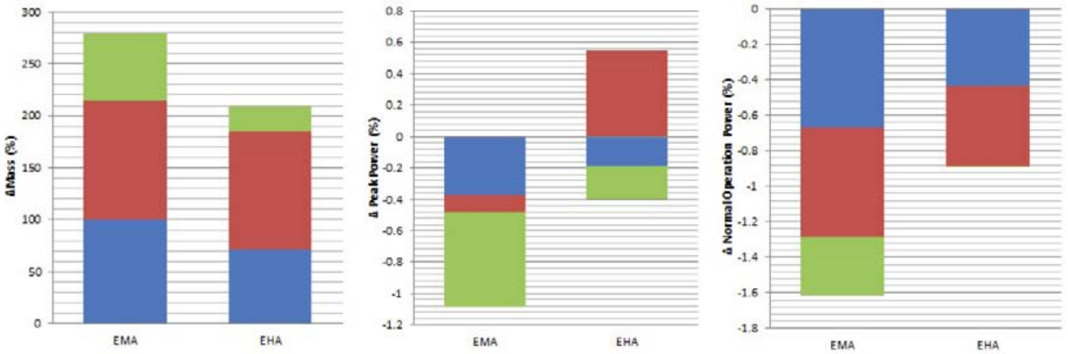
a. b.

c.

**FIG. 3** a. Electro-mechanic braking system [3];
b. Control scheme for electro-mechanic braking system [3];
c. Electro-mechanic servo-actuator structure [3]

Both electro-hydrostatic and electro-mechanic braking systems use the energy from electric system. All the power from the hydraulic system used by the electro-hydraulic braking system is now transferred now to the electric system. In this manner, the electric systems load increases very much. This is one of the big problems for More Electric Aircraft and All Electric Aircraft.

In [4] we find a comparison between electro-mechanic servo-actuators (EMA), electro-hydrostatic servo-actuators (EHA) and classical electro-hydraulic servo-actuators considered as base level.

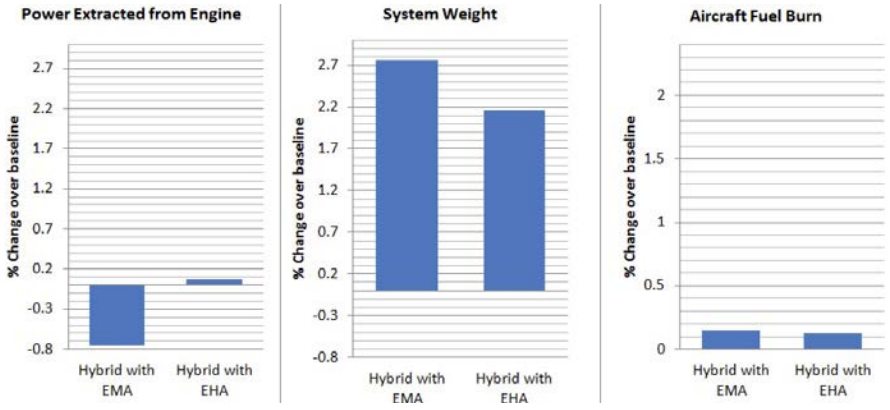


a. b. c.

**FIG. 4** Comparison between EMA, EHA and classic electro-hydraulic servo-actuators (base level)
a. Mass variation [4]; b. Maximum power variation [4]; c. Variation of normal functioning power [4]

We notice EHA is twice heavier than electro-hydraulic one and EMA is 2.7 times heavier (Fig. 3.a). Peak power is 1 % lower for the EMA and .4 % higher for EHA (Fig. 3 b). Normal operation power is 1.6 % lower for EMA and 0.8% lower for EHA. In conclusion, for braking systems, overall advantages of EMA and EHA are doubtful. They are much heavier, but the power difference is negligible.

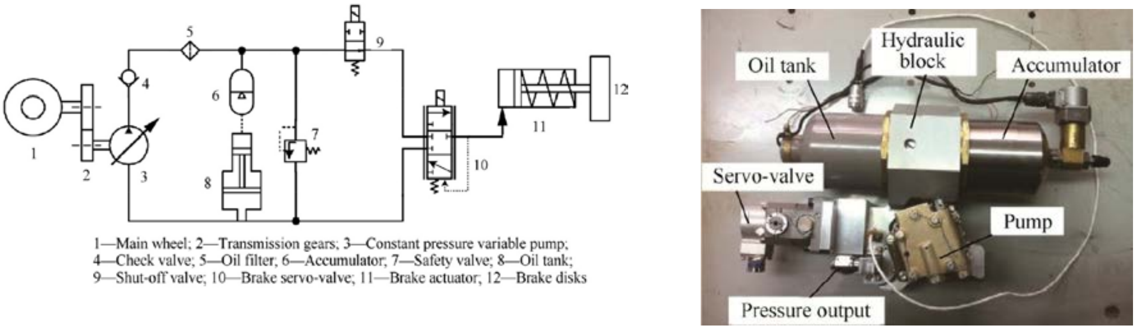
In [4] we find also a comparison between the entire braking system, in classical version, with EMA and with EHA.



a. b. c.

**FIG. 5** Comparison between classic hydraulic braking systems,, hybrid systems with EMA and hybrid systems with EMA. a. Power absorbed from the aircraft engine; b. System mass; c. Fuel consumed by the aircraft [4]

We notice here hybrid system with EMA absorbs 0.8 % less power and hybrid system with EHA absorbs 0.1% more power. Entire system mass is 2.7% higher for systems with EMA and increases 2.2% for systems with EHA. Aircraft fuel consumption is 1.5% higher both for systems with EMA and systems with EHA. An interesting solution we find in [5]. In order to reduce the power consumed by the braking systems with EHA, it is used a hydraulic pump driven by the landing gear wheels.

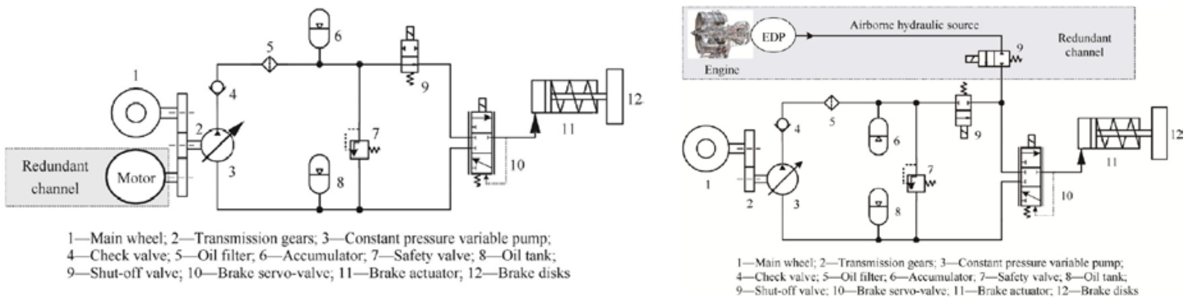


a. b.

**FIG. 6** EHA Servo-actuator for braking system with pump driven by the landing gear pump [5]. a. Servo-actuator scheme [5]; b. Servo-actuator prototype [5]

In this case, the braking system consumes from the aircraft electric system only the control power that is low. The high power needed to drive the servo-actuator pump is obtained from the landing gear rotating wheels. At high aircraft speed, the pump driven by the wheels feed the hydraulic cylinder and fill the hydro-accumulator. At low speeds and for parking brake, hydro-accumulator energy ensures the braking process. Prototype of this type of servo-actuator is in Fig. 6.b [5].

In [5] we find also versions of this servo-actuator with pump backup drive from an electric motor or from the aircraft hydraulic system (Fig. 7.a and 7.b [5]). Mainly the disk brakes dissipate the aircraft kinetic energy. The servo actuator pump absorbs also a small quantity of the aircraft kinetic energy.



a. b.

**FIG. 7** EHA servo-actuator with aircraft wheels driven pump and electric motor backup [5]; b. EHA servo-actuator with backup hydraulic feeding from the aircraft hydraulic system [5]

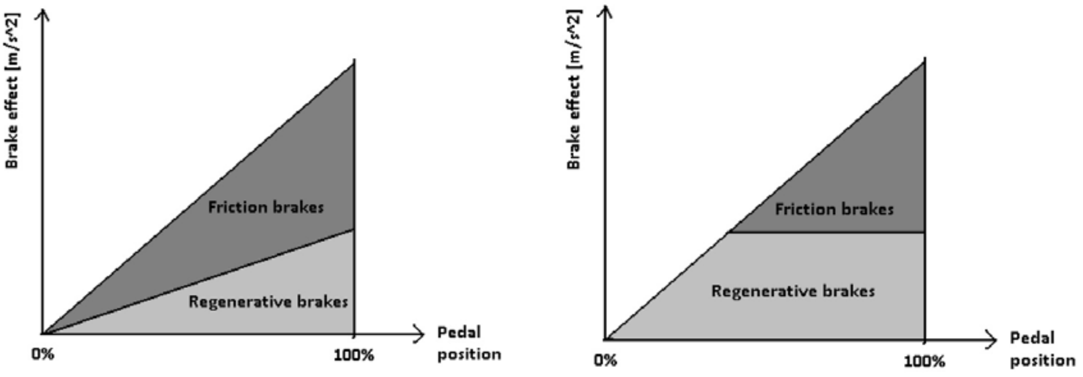
## 3. ALTERNATIVE BRAKING METHODS

### 3.1 Electromagnetic Braking Systems

Regenerative braking systems for aircraft appeared by analogy with regenerative braking systems for railway trains and auto vehicles. In those situations, the electric drive motor is switched in generator regime in the braking period. Generator produced energy is in fact absorbed from the kinetic energy of the vehicle and pushed back in the feeding network or stored in batteries. However, in many situations the braking torque is much higher than the generator drive moment. For this reason the regenerative braking system coexist with classical disk braking system. Nearly the same problems appear at the aircraft landing run braking.

Two regenerative braking strategies exist: parallel regenerative braking and series regenerative braking. In first case both regenerative and disk brakes work in parallel all the time. This solution ensures a smoother braking, without acceleration bounce. System control is easier but recovered energy is smaller.

The second solution, for braking accelerations below boundary level, uses only the regenerative brake and for accelerations above the boundary level, both regenerative and disk brakes are used together. Figure 8 [6] shows these situations.



a. b.

**FIG. 8.** a. Parallel regenerative braking; b. Series regenerative braking [6]

For aircraft regenerative braking, it is necessary to install on the main landing gear wheels and possibly on the nose landing gear wheels, electric machines working in generator regime during the landing run. In aircraft landing run, the dissipated energy is much higher than the case of auto vehicles braking. For this reason supplementary batteries or even dissipation electric resistor could be necessary. The braking intensity is controlled by the brakes electronic control system. Because the disk brakes has to remain on the landing gear it is difficult to install this system on the wheels. One solution is presented in Fig. 9 [6].

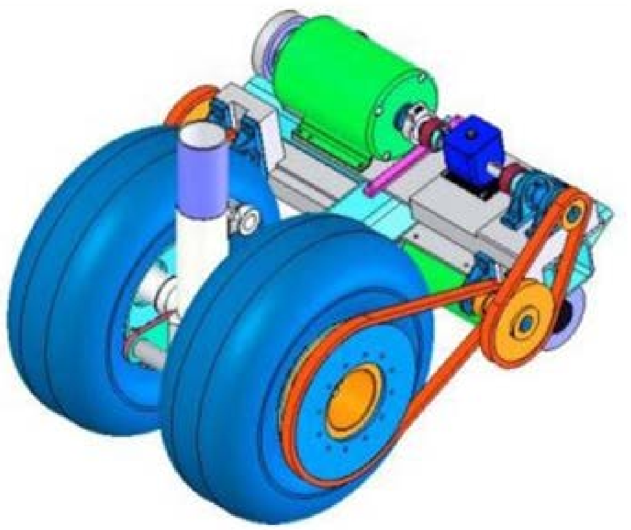


**FIG. 9** Regenerative braking system installed on the landing gear [6]

This system has as an important disadvantage a big additional mass and it is much bulky than the disk brakes. One advantage is in taxi run the electric machine could be switched in motor regime and used for aircraft drive in this period. In this manner aircraft engines can be stopped in the taxi period, both at take-off and landing. Less toxic emission will be produced on the airport and less fuel burned. For short and medium range aircraft, the taxi burned fuel represents an important fraction from the total fuel consumed. On the congested airports, when the take-off expecting time can be long, stopping the aircraft engine in this period saves an important quantity of fuel, even in this period the engine is idle.

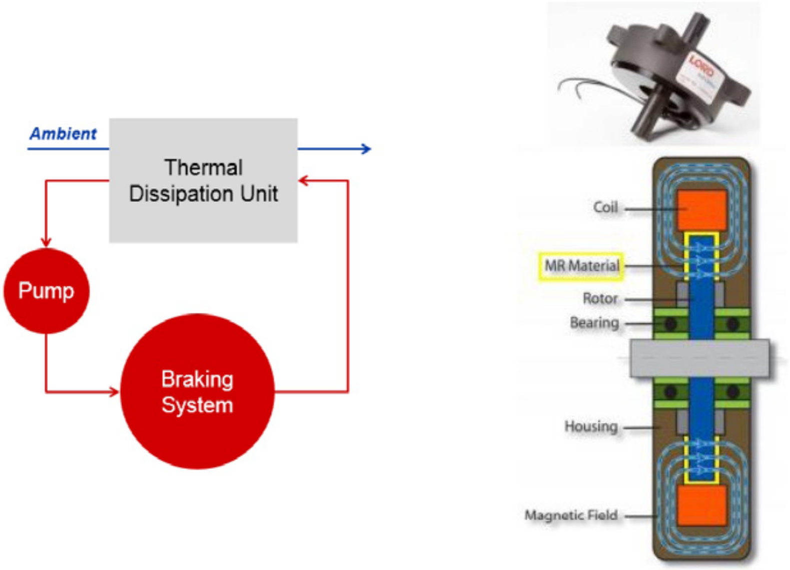
### 3.2 Fluidic Brake Systems

This braking system development started from the idea the kinetic aircraft energy is transformed in heat energy. This heat energy is dissipated usually on the brake disks. In some emergency braking, brake disks temperature can rise above admitted limits and to endanger other aircraft components. In [8] authors propose another solution to dissipate this energy.

The braking system has a hydraulic pump that circulates a magnetorheological fluid. This fluid is used to generate the braking torque in the braking system. The energy produced in the braking process dissipates on a heat exchanger. Magnetorheological liquid evacuates better the heat generated than the braking disks. Fig. 10 [8] presents this system.

Magnetorheological fluids increase their viscosity when a magnetic field is applied. Braking system consists in a chamber filled with magnetorheological fluid. One chamber wall is linked with the brake stator and the opposite wall is linked with brake rotor.

Liquid flow between these walls produces a big brake torque when the magnetic field is applied. Fluid viscosity increases proportionally with the magnetic field. By consequence, the braking intensity increases proportionally with the magnetic field. The pump circulates the fluid out of the brake chamber and passes it through the heat exchanger.



a. b.

**FIG. 10** a. Architecture of the fluidic brake system; b. Section through the fluidic brake system [8]

## 4. ENHANCED SOFTWARE BRAKE SYSTEMS

Airbus implemented already on aircraft Airbus 380 and Airbus 320, as optional system, the “Brake to Vacate” (BTV) system. This system is provided as standard feature on Airbus 350. BTV system aims the automatic management of the braking process and is a supplementary selection in classical automatic braking system. The classical automatic brake management allows the pilot to select only the brake intensity between many levels, in concordance with the airplane type (Fig. 11 [9]). It is a software implemented system that allows pilot to select during the approach phase the landing speed and desired runway exit. Using the GPS, airport navigation system, electronic data base with airport maps, auto-pilot and automatic braking system, BTV optimizes the braking intensity in order the airplane reach the taxi speed when it arrives at the desired runway exit. Between optimization criteria are passengers comfort and tyres and brakes wear.

On the navigation display appears a supplementary page for BTV set-up. From this page the pilot can select the parameters in order to the landing run evolves according the selected plan. Pilot makes the set-up according to the traffic control indications. During the landing run it is used the optimum combination of all the braking devices: jet reverse, aerodynamic brakes, spoilers and brake system.

This system proved useful especially on the congested airports. As main advantage, BTV avoid the situation the pilot misses the runway exit indicated by the traffic control. This means the medium Runway Occupancy Time (ROT) reduces. This situation frequently appears in low visibility landings and requires redefining the taxi trajectory to the allocated terminal, and by consequence taxi time increases.

Another advantages are the passengers comfort improving during the landing run, brakes wear reducing, allows the pilot to exit from the runway at a higher speed, avoids the runway outrun. From the traffic control point of view, runway occupancy time minimizes for each landing by avoiding the misses of the optimum runway exit. Even for a single flight this means only few seconds delay, on congested airports this delay can produce important traffic disrupt, especially in low visibility conditions. Small delay times added for many flights produces, overall, important delays and missing of the allocated time slot.

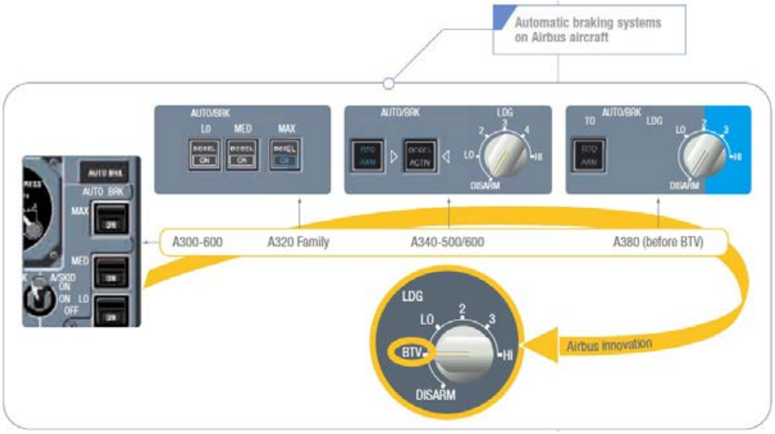


**FIG. 11** Automatic brake systems on Airbus aircraft [9]

## 5. PRODUCERS INTEREST FOR NEW INOVATION IMPLEMENTING

Aircraft producers' interest on the implementation of the innovation in the landing gear system is different taking into account in some situations overall advantages are doubtful. We can mention here the EMA and EHA brake systems. Boeing implemented on Boeing 787 Dreamliner EMA braking system from SAFRAN. The main advantage took into account was maintenance improvement and reduce of immobilization time of the aircraft on ground. However, according the comparison from paragraph 2, that shows a heavier brake system for EMA and EHA than the classical braking systems, and more fuel burned. Airbus choose the classical version, produced also by SAFRAN for Airbus 350 XWB [10]. Besides that, Airbus did not discard classical braking system neither for Airbus 380. For this aircraft Honeywell produces the braking system.

However, flight controls became to use EMA and EHA servo-actuators. Both Airbus and Boeing uses this kind of servo-actuators. Airbus 380 uses EHA and EBHA servo-actuators for the main flight controls. Boeing 787 Dreamliner secondary flight controls uses EMA servo-actuators. Fighters like F35, uses EHA servo-actuators for flight controls.

Electromagnetic and electro-fluidic braking systems presented in this work are in the research phase yet. Their advantages are not suitable to produce a trenchant choose of these solutions. They also increase the mass and volume of the braking system with consequences upon the fuel consumption. For long-range aircraft 0.2 % additional consumed fuel at a flight with 70 tones total consumption means 140 kg. This is a negligible quantity for that airplane, but a pretty big absolute value.

An important improvement introduces the BTV system, already implemented by Airbus. It is expected that other producers will introduce this feature.

## CONCLUSIONS

Gradually are implemented more and more improvements of the aircraft braking systems. This process implies careful studies on the innovations proposed. Hydraulic braking systems still present some advantages that were not crucially outdated by new technical solutions. Unlike flight controls, where all the big producers step by step move to EHA or EBHA servo-actuators, there in not such a trend for braking systems. Some big producers still prefer classical hydraulic brake systems.

Researcher investigate the possibility to implement some system from the railway trains or auto vehicles, but the landing gear configurations make difficult to adapt that systems. One problem is the huge kinetic energy of the aircraft that has to be dissipated in the landing run, comparing the auto vehicles situation.

Important improvements concerning the automatic braking management appeared in the last period. Airbus already implemented the BTV system that has as main advantages the reducing of the ROT, possibility to exit from the runway at higher speed, reducing of the brakes wears and enhancement of the passengers comfort, while the hydraulic braking system has no additional components.

Important research efforts are in development for aircraft break system improvement, but new solutions penetration is difficult. It has to prove the overall progress in relation to the classical hydraulic brake systems.

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