PRESENTATION OF TEST RESULTS ON ELECTRICALLY ACTUATED NOSE LANDING GEAR

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Abstract

New generation of A/C (A380 & B787) already integrate some electrical functions. Some of them are critical, like flight control or braking. Research work are ongoing to replace other existing hydraulic functions, including landing system, to increase next generation of single aisle global performances.

Global architecture trade-offs are ongoing, with the A/C manufacturers, to select the optimum solution. MELANYII project, launched in 2006 by Messier-Dowty & Messier-Bugatti with the help of French DGAC, is part of the actuation technology basement studies.

The objectives of the project was to show that electrical actuators (Electro-Hydro-static Actuation or Electro-Mechanical Actuation) are suitable for landing gear actuation functions : Extension/Retraction of gear & doors, locking/unlocking of gear & doors, Steering of nose wheel.

The paper details the prototype of Electro-Hydro-static Actuation system developed for a Nose Landing Gear (based on A320 specification) & tested early 2009 on a specific system test rig developed with CEAT.

1 General Introduction

Nose landing gear actuation systems usually consists in :

- Landing gear extension / retraction,
- Nose wheel steering,
- Landing gear door opening / closing (except if the door are mechanically linked to the gear).

Today, these systems are connected to the aircraft main hydraulic power. Landing gear and door systems are "on/off" systems, driven by selector valves. For steering system, the angular position of the NLG is controlled by a servovalve within a position loop.

On classical hydraulic A/C, the hydraulic power units (hydraulic pumps) are located close to the wing area.

So, for Nose Landing Gear actuation, using electrical actuation will allow a significant part of hydraulic piping to be replaced by electrical harnesses, lighter and easy to integrate in the A/C structure.

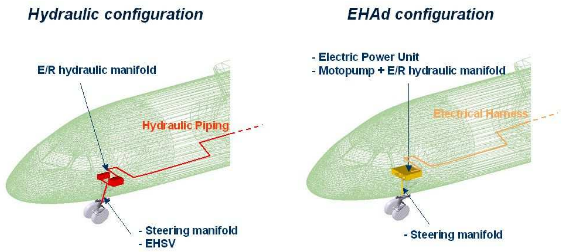

Figure 1

Furthermore, one of the advantages of a landing gear system driven with electrical actuation is the reduced power consumption, simply due to the "power on demand" architecture.

Two main technologies could be used for electrical actuation:

- one based on Electro-Mechanical Actuators (EMA),
- one based on Electro-Hydrostatic Actuators (EHA).

Trade-off are in progress through research projects to evaluate the feasibility and the performances of each solution.

The Electro-Hydrostatic Actuation technology uses lots of already mature hydraulic or electro-hydraulic components : wet motor pump technology is already used on flight control actuators (EHA & EBHA), embedded motor control, hydraulic actuators, etc.

A system based on this technology has then been designed and tested first in the scope of MELANYII project.

The paper details the prototype of Electro-Hydrostatic Actuation system developed for a Nose Landing Gear (based on A320 specification) & tested early 2009 on a specific system test rig developed with CEAT.

2 Presentation of the prototype

2.1 Main objectives

2.1.1 General

The following figure shows the functioning phases of actuation at landing gear level (Steering & Extension/Retraction of Doors and Gear) :

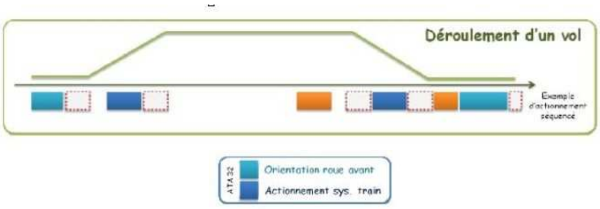

Figure 2

As the Extension/Retraction function & steering function are never used at the same time, the actuation power supplies could be mutualized to reduce system weight & increase reliability (less components).

The same motor-pump energizes both extension / retraction and steering systems.

A set of selector valves dispatches hydraulic power either on doors opening / closing, gear extension / retraction or steering hydraulic actuators.

2.1.2 Functional requirements

The following distributed architecture (EHAd) has then been selected for the prototype :

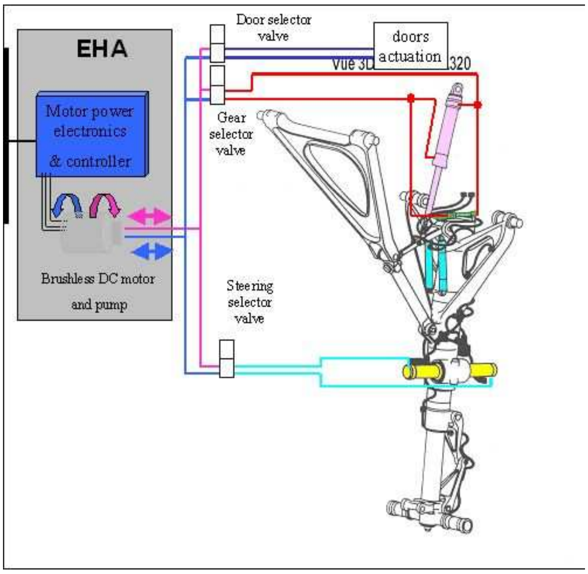

Figure 3

The system will have to ensure :

- Extension/Retraction of landing gear & doors in normal & emergency modes :

- sequence management,

- normal retraction & extension speed management, including end of stroke,

- emergency in free fall configuration (gear or door extended by gravity),

- uplocks fully electrically actuated, independently of the EHA system,

- Steering of nose wheel in normal mode (wheel position control) & free-to-castor mode (wheel free to rotate & damped).

2.2 Distributed EHA for landing gear Actuation system

This chapter will discuss about the main technical issues to be solved for this technology.

2.2.1 Motor control for the moto-pump

For extension/retraction function, an open loop control system (at actuators level) is sufficient. So, a Local Electro-Hydraulic Generation System (pressure controlled), easy to control, will be the most suitable solution. But this solution is not optimized for steering function.

For Steering function (closed loop position control), a flow controlled EHA is the best solution in term of weight (no servo valve), control management complexity, transients management, efficiency (power on demand).

A trade-off have been conducted between these solutions. A flow controlled EHA with a fixed displacement pump have been selected as the best compromise in term of weight and complexity.

2.2.2 Hydraulic components

The EHA technology is optimized for high pressure level (Lower actuator area => Lower pump displacement and motor speed => Lower drag losses in the motor air gap => Lower torque demand => Reduce the motor size). The prototype is not optimized on this criteria because it is based on existing A320 hydraulic actuators and so the pressure has been limited to 206 bar.

The actuation system is completely autonomous, without any connection to external hydraulic circuit. So a specific attention has been paid on dissymmetric flow management (mainly linked to dissymmetric actuators) & reservoir sizing (leakage, temperature variation, …).

A specific motor-pump manifold and a selector manifold have been designed.

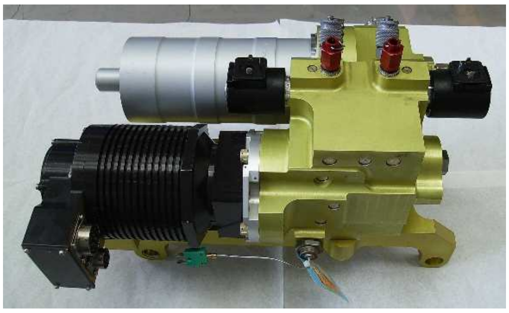

Figure 4

The selector valves will be based on electrically piloted direct drive components (no high pressure available to pilot the valve due to the power on demand system).

The doors shall remain open, without any power supply, during landing extension or retraction. A specific lock valve has been implemented to keep the pressure into the door actuator opening chamber and then to maintain the doors open while actuating the gear.

2.2.4 Hydraulic schematics of the prototype

The following architecture takes into account the previous technical issues :

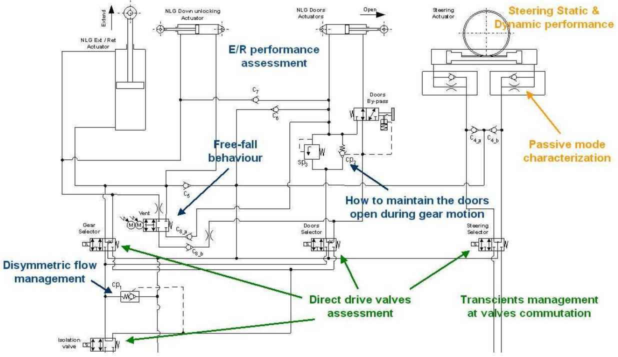

Figure 5

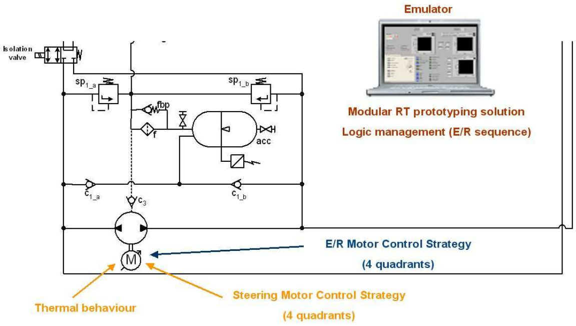

Figure 6

2.2.4 Safety/Reliability

The selected EHAd architecture leads to the following specificities :

- Safety :

  To prevent single failure leading to catastrophic event, end of stroke proximity sensors have to be redounded & end of stroke snubbing devices have to be kept on the actuators.

- Availability :

  According to availability requirements, power electronics & control could be easily redounded. The availability of the system is then closely linked to the hydraulic pump reliability.

2.3 Integration of actuation system on the prototype of Nose Landing Gear

3.3.1 Mechanical integration

The moto-pump group has been integrated directly on the main fitting of the landing gear. The hydraulic stiffness is then kept to its highest value : run-up time, bandwidth & steering performances are easier to be reached. This needs a global optimization of the moto-pump, hydraulic block & reservoir (envelope & weight) in a harsh environment.

The Extension/Retraction hydraulic block, with the dedicated selector valves, has been integrated in the landing gear bay, close to the actuators.

3.3.2 Architecture of the prototype

The following figure shows the global architecture of the prototype (emulation of “pilot orders”, actuation sequence management, motor power electronics, hydraulic system, landing gear dressing) :

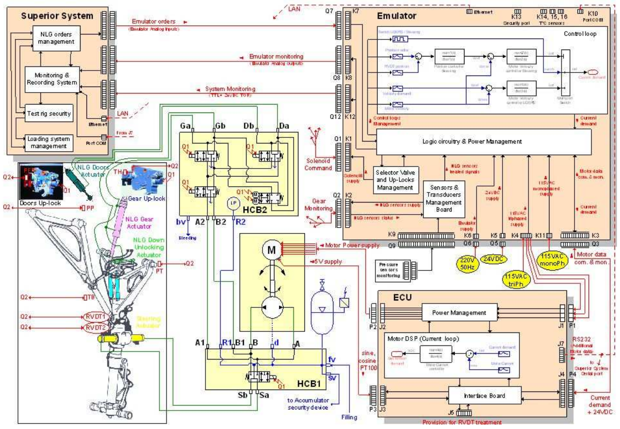

Figure 7

3.3.3 Presentation of the prototype

The prototype is build with existing A320 hydraulic actuator, specific moto-pump manifold, specific selector manifold (door/gear maneuver selector functions), power electronics (motor control), flexible pipes, existing prototype of electrically actuated up-locks.

The figure gives an overview of all the components integrated on the nose landing gear.

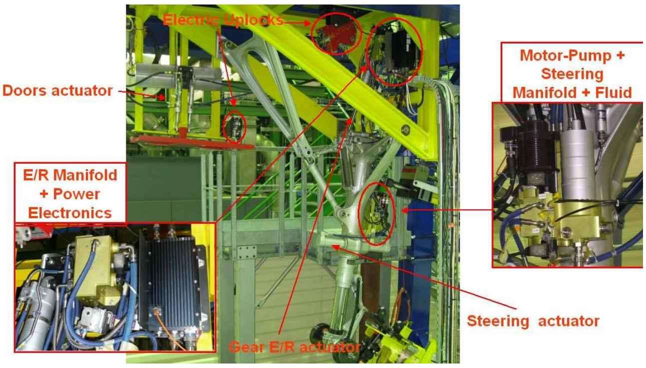

Figure 8

The actuation management (position loop, sequencing control end of stroke management, power management, system monitoring & safety) is performed by a specific electronic bay using industrial components (Labview Real Time environment).

3 Presentation of the system test rig

3.1 General presentation of the rig

A specific test rig has been designed & manufactured by DGA Techniques Aéronautiques (ex CEAT) to support the tests of the NLG actuation systems.

This rig is able to support a landing gear of the size of an A320 nose landing gear.

The following picture shows an overview of the rig during mechanical installation and set-up in the test area :

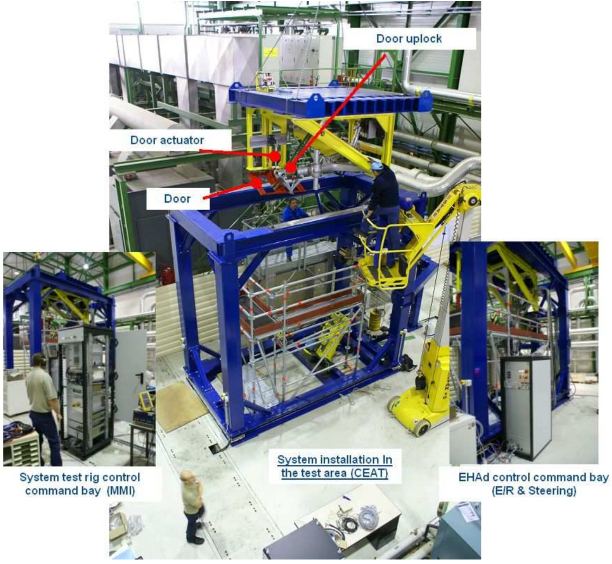

Figure 9

It is able to simulate aerodynamic loads on the landing gear & doors during extension/retraction phases and to simulate the steering load coming from the wheel tire/ground contact during A/C maneuvers. The rig will also generate the analog orders for the actuation system.

The main innovation of this rig for the DGA Techniques Aéronautiques is the rig management (safety, loading) by a real time system. This choice has been done to reach load control requirements.

3.2 Control & Loading systems

The control of the rig is made within Labview environment according to the following figure :

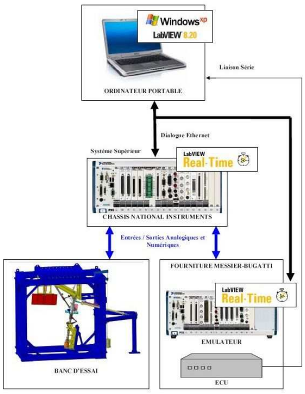

Figure 10

The MMI, supported by a PC, will allow the operator to control the test process, to generate the orders for the loading systems, generate the steering analog orders (position of the wheel), generate the macro-orders for extension/retraction maneuvers, manage the acquisition, recording and displays.

The loading systems are hydraulically operated.

The control of the axial forces (for door & landing gear loading) or torque (for steering loading) loops, the monitoring & safety management of the rig are realized under Labview Real Time environment by a PC installed in the rig control bay.

Data acquisition and recording are realized by the same PC under Labview Real Time environment.

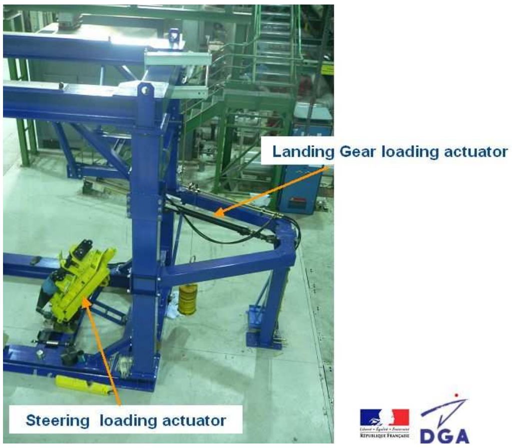

Figure 11

4 Presentation of tests results

4.1 Test program

The objectives of the actuation system test program was to demonstrate the feasibility and a good level of maturity of the Nose Landing Gear actuated by an EHAd (functional, integration) & to identify issues in order to generate some recommendations for the development of real system.

Data shall also be generated to be able to compare HA, EHA, EMA solutions in term of risks (mass, safety, reliability,…) and opportunities (power consumption, availability, maintainability, …)

4.2 Steering results

The performances of the EHAd system are compared to existing hydraulic A320 steering system :

- Deflection rate : higher than required because a higher motor velocity is required for the extension/retraction function.

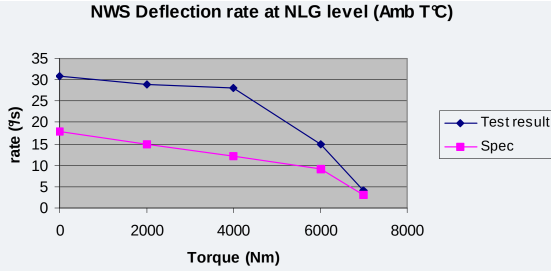

Figure 12

- Steady state performance : position accuracy is compliant, time to reach speed demand is compliant.
- Stability & frequency response: the performances are compliant, but the phase lag at 2Hz will be difficult to reach with a simple position loop.

		Objective	Test Results
Stability (No load)	**Gain margin**	**> 6 dB**	**10 dB**
	Phase margin	**> 45°**	**55°**
Frequency response (4000 Nm)	**Amp ratio (2Hz)**	**> -3dB**	**+ 0.5**
	Amp ratio (0.5Hz)	**> -3dB**	**+ 0.2**
	Phase lag (2Hz)	**> -55°**	**- 90°**
	Phase lag (0.5Hz)	**> -20°**	**- 16°**

Figure 13

- Steering Stiffness :

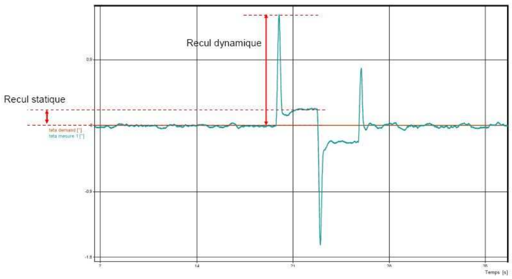

Figure 14

- Free castoring : same damping function than classical hydraulic one (same actuator & same damping restrictors)
- Thermal cycles : compliant

4.3 Extension/Retraction results

The following figure shows the positions of the gear & door during a retraction/extension sequence in nominal condition :

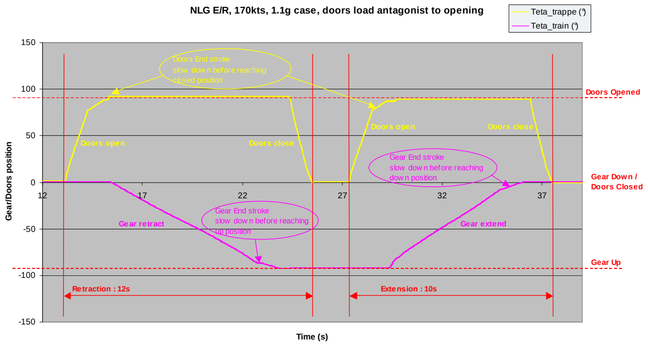

Figure 15

The extension/retraction performances (mainly the time of the global sequence) are compliant with the requirements :

Aero conditions		Objective	Test result (s)
Normal 170kts 1,1g	Doors Open	< 1,5s	1
	Doors Close	< 1,5s	2
	Gear Retract	< 8,5s	8,5
	Gear Extend	9-11s	6
	Global Retract	<11,5s	11,5
	Global Extend	12-14s	9
Limit 250kts 2g	Doors Open	No limitation / Stops allowed during retraction	1
	Doors Close		3
	Gear Retract		12
	Gear Extend		6
	Global Retract		16
	Global Extend		10

Figure 16

Emergency extension under gravity (free fall) performances are compliant.

Robustness tests have been successfully conducted to check the behavior of the system when submitted to gust loads (on gear or door), specifically in the area close to the end of strokes, or during command inversion.

More than one month of continuous operation (gear and door loaded operation & no load steering maneuvers) have been conducted without any need of hydraulic re-filling (no pressure loss & no leakage).

5 Conclusions

This study & the prototype developed in the scope of this study demonstrate TRL6.

The feasibility of the distributed Electro-Hydrostatic Actuation concept for the actuation of a Nose Landing Gear has been proved. The main requirements of steering function and Extension/Retraction function in term of performances and safety are reached.

This architecture is compatible with either electric or hydraulic up-locks (in normal mode).

5.1 Final assessment

5.1.1 Weight

Thanks to this prototype, a reliable weight of EHAd for nose landing gear has been evaluated. At system level, it is increased by about 35% compared to a hydraulic solution.

But the weight has to be assessed at A/C level to take into account benefits on centralized hydraulic generation.

5.1.2 Shimmy assessment

In a first approach & in the scope of this study, there is no difference between hydraulic & electro-hydrostatic actuation :

- In passive mode, same damping devices than hydraulic system,
- In active mode, moto-pump manifold is closed to the steering actuator.

5.1.3 Power consumption

The power consumption is improved & electrical power recovery could be possible.

The energy consumption comparison between Hydraulic Actuation & Distributed Electro-Hydrostatic Actuation is as follow :

	Normal hydraulic system	EHAd
L/G extension	Actuator sweep volume x inlet pressure	Null. Generation of electrical power to A/C is possible
L/G retraction		Power on demand : Mechanical energy * efficiency
Steering		Power on demand : Generation of electrical power to A/C is possible when the wheel returns to center position.

Figure 17

The expected efficiency of the global system is around 55 % at the maximum demand performance point :

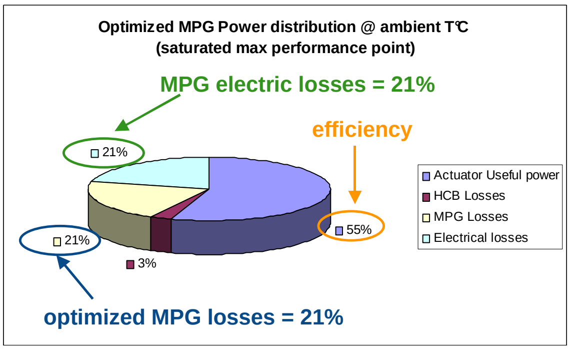

Figure 18

5.1.4 Maintainability

From maintenance point of view, the main remarks on the EHAd demonstrator design are :

1) The bleeding is still required in case of removal/installation of an item. This bleeding has to be done A/C on jack. Modular equipments design will avoid bleeding of the hydraulic items. Pure EHA solution (one per actuator) will bring that gain.

2) The NLG dedicated hydraulic circuit, without connection with other A/C hydraulic functions, would ensure less fluid pollution. But a monitoring of reservoir fluid level and fluid pollution is required.

This autonomous NLG hydraulic circuit also prevent a global hydraulic circuit re-filling and bleeding in case of NLG component replacement.

5.2 Recommendation / Open issues

For an optimized architecture, work has to be conducted on the following topics :

1) Moto-Pump manifold installed in the NLG bay to reduce its environmental constraints. The complete shimmy analysis has to be updated with all modelling hypothesis (landing gear structure, tire, hydraulic system, control, …).

2) Up-locks could be hydraulically supplied by the EHAd in normal mode (weight optimization),

3) Normal gear extend = free-fall (only gravity extension). The “door open” problematic will then be solved. One set of end of stroke sensor could be removed. The end of stroke management will be safer (according to “loss of gear damping” critical event) by keeping snubbing on the actuator. The gear selector valve is simplified (3/2 instead of 5/2).

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