DEVELOPMENT OF AN ELECTRO-HYDROSTATIC NOSE LANDING GEAR ACTUATION AND STEERING SYSTEM

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Abstract

Environmental aspects gain significantly in importance with every new generation of aircraft and must be seriously considered for the development of new systems solutions.

Some aspects are known to contribute to the goal of greener air transportation with reduced emissions, decrease of fuel consumption and smaller life cycle environmental footprint. Examples are the electrification of aircraft systems, alternative fluids with smaller environmental impact and solutions less prone to disposal in maintenance activities.

System architectures in future aircraft are already evolving toward higher degrees of electrification. The development of solutions capable of efficiently using this available electric power is therefore necessary. Pure electro-mechanical actuation is an obvious candidate and became state-of-the-art in some aircraft systems like for instance secondary flight controls. These are for landing gear applications however prohibitive from a weight and envelope point of view, given the high power levels associated with its operation.

Liebherr-Aerospace proposes a self-sufficient solution to perform all functions of the nose landing gear of an aircraft based on electro-hydrostatic actuation (EHA) technology, including steering, landing gear extension and retraction, unlocking and operation of landing gear doors. The system works solely on electric power, and thus is an important brick for the electrification of future aircraft.

This approach takes benefit of the high power density of hydraulic solutions at a fraction of today's required hydraulic fluid volume. By doing so, the landing gear actuation system itself remains conventional with hydraulic actuators for extension, retraction and steering. Therefore, minimum installation impact, if any, is expected. This approach also reduces the overall technological risk of introducing this new concept. All the individual elements are known and have proven maturity, being their integration for landing gear applications novel.

Electro-hydrostatic actuation for the nose landing gear is part of Liebherr's strategy for hydraulic power generation in aircraft of the next generation, where electrically driven, de-centralized high-efficient power packs (HEPP) provide the applicable consumers with pressurized fluid necessary for their operation. These self-sufficient solutions can also be optimized independently from the rest of the aircraft, opening opportunities for power on demand, higher pressure levels with the associated smaller weight, in addition to alternative, environmentally friendly fluids.

A system test campaign was performed at Liebherr-Aerospace allowing technology readiness level (TRL) 6 at equipment level to be reached. TRL 6 at aircraft level is planned after completion of tests at an aircraft representative rig, which are ongoing, followed by aircraft ground tests.

Keywords: EHA; high-efficient; landing gear; actuation; more electric aircraft

1. Introduction

On a conventional airplane, the energy sources of various on-board systems are numerous and complex. These are typically pneumatic, electric and hydraulic. Conventional transport category aircraft usually have three hydraulic systems to comply with the applicable hazard classifications [3] [1]. Two of these systems are powered by each of the engines through an engine driven pump (EDP) located at the engine auxiliary gearboxes. The third hydraulic system is often powered by an electro-motorpump (EMP) [1]. This configuration is represented in Figure 1 and is referred to as 3H [4]. It results in a hydraulic system installation, which is complex, requires considerable installation space, is heavy and is difficult to maintain.

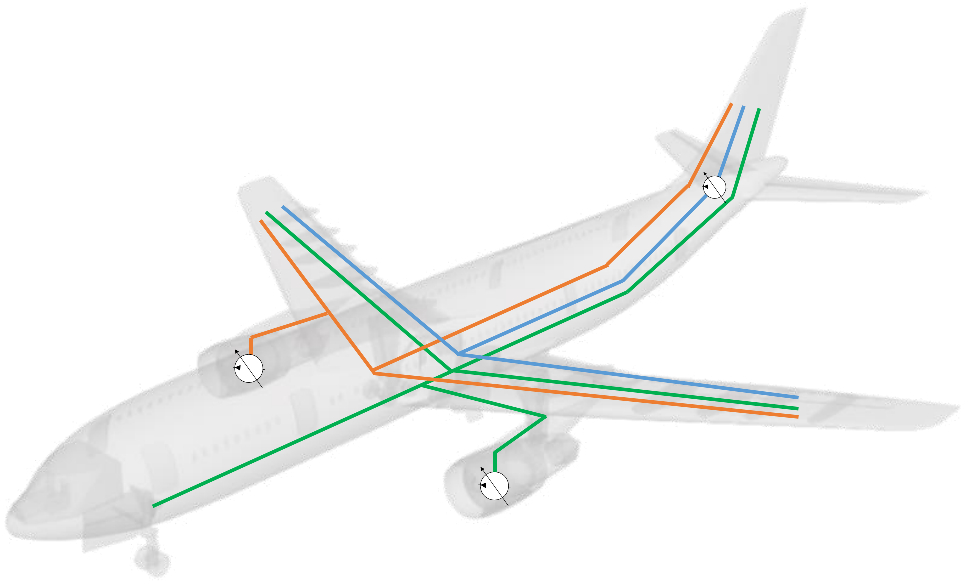

Figure 1 - Simplified representation of conventional hydraulic systems

System architectures in future aircraft are evolving toward higher degrees of electrification. Electrical power is generated by the engines and the auxiliary power unit. The optimized use of power generation is possible by an overall and flexible electric power management [1]. Additionally, an easier fault isolation and reconfiguration of power paths can be achieved in architectures with full electric distribution system [2].

Further, the electrification of aircraft systems tends to improve dispatch reliability of the aircraft as the number of hydraulic lines and connections and thus potential leakage sources are reduced.

In the case of the hydraulic generation system, the adoption of alternatives to the conventional 3H architecture is considered. The Airbus A380 for instance features a “more electric” concept in which one hydraulic system was eliminated and replaced by a set of electrically powered actuators. This power source distribution features two hydraulic systems and two electric systems. It is known as 2H/2E [5].

A pure electro-mechanical architecture for the operation of the landing gear is a solution for smaller aircraft and helicopters, as already implemented for instance in the Airbus H160 [7]. For larger aircraft, trades have shown that for now the additional weight becomes prohibitive.

Recent studies consider a move toward local hydraulic power generation, with two central electric systems in the aircraft and a series of local electrically powered high-efficient hydraulic power packs [6]. The high power density of hydraulically operated consumers results in smaller weight. This approach additionally allows for keeping conventional landing gear actuation and steering with the benefit of their robust design, in-service maturity, and known failures modes.

This configuration is represented in Figure 2. Additional EHAs and/or EMAs for flight controls, necessary to comply with applicable hazard classifications, are not represented in the figure.

The functions in the nose landing gear do not require a constant pressure system. In this case, an electro-hydrostatic actuation approach is adopted, benefiting from the maturity and robustness, which this technology has shown in flight controls applications. The NLG EHA system is referenced as ESTER in this work, short for **E**lectrical **ST**eering, **E**xtension and **R**etraction system.

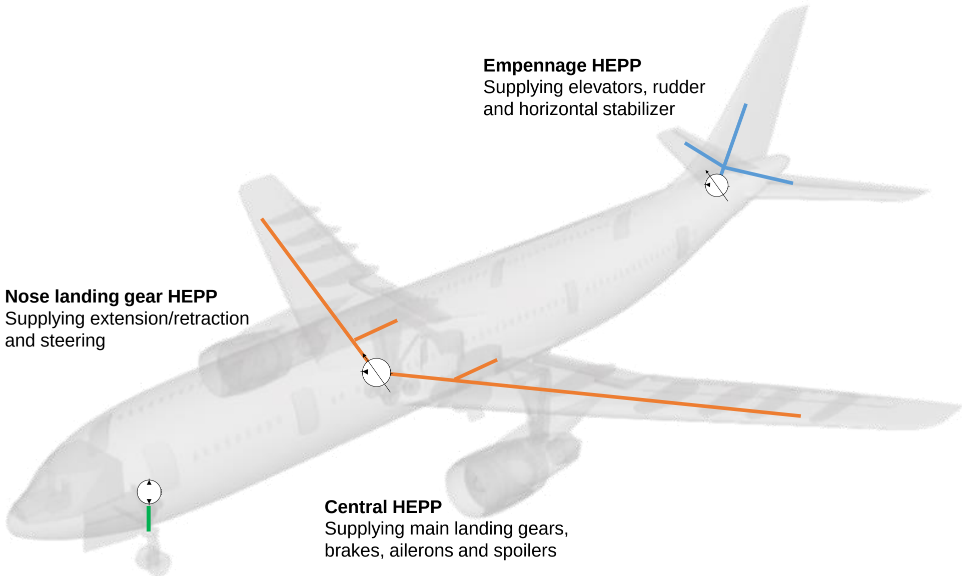

Figure 2 - Simplified representation of local hydraulic generation

2. Description of the ESTER solution

The core of the ESTER solution is its electro-hydrostatic approach. As in any EHA, the hydraulic pressure in the actuators is a reaction to the external loads. A fixed displacement pump is driven by an electric motor, which is speed controlled by a dedicated motor control electronics. The rate of command is determined by the motor angular speed. The direction the consumers are operated is determined by the motor sense of rotation [8]. A simplified representation is shown in Figure 3.

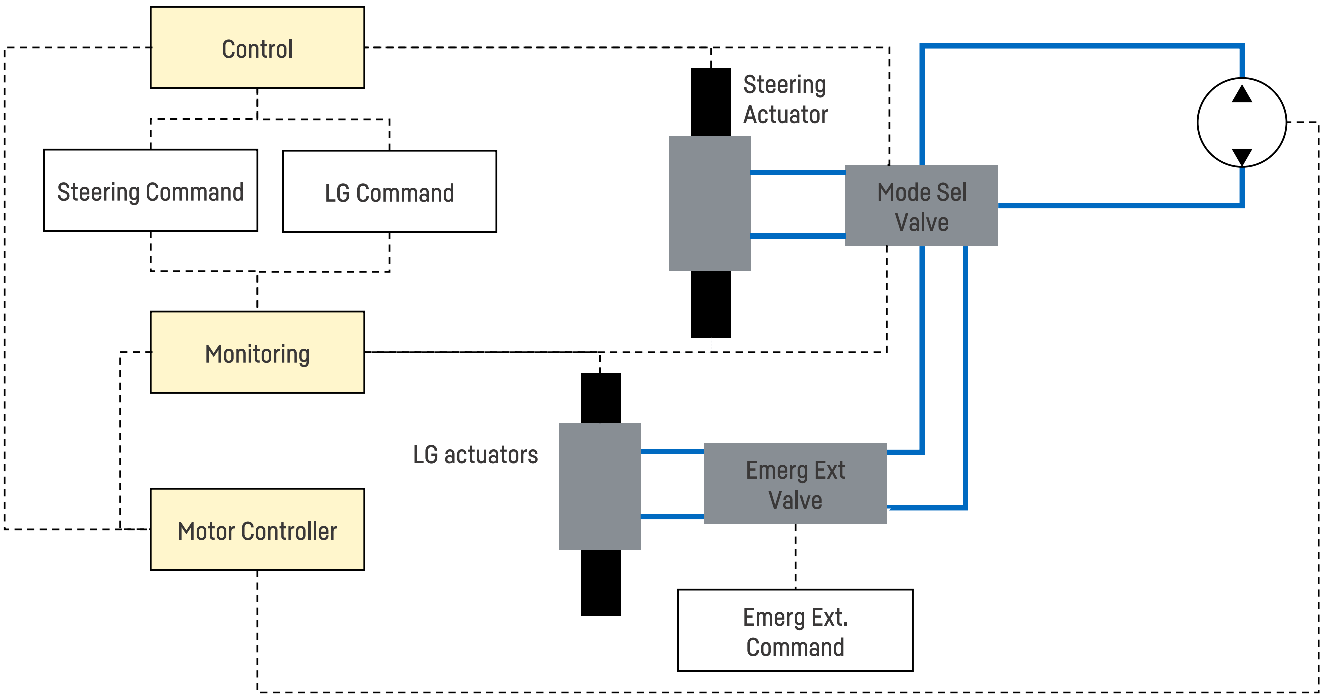

Figure 3 - ESTER simplified architecture

In a conventional system, the hydraulic pressure in the generation is constant and not a reaction to the load. Hydraulic valves are commanded to control operation of the consumers, e.g. a directional control valve for landing gear extension and retraction and an electro-hydraulic servo-valve for steering.

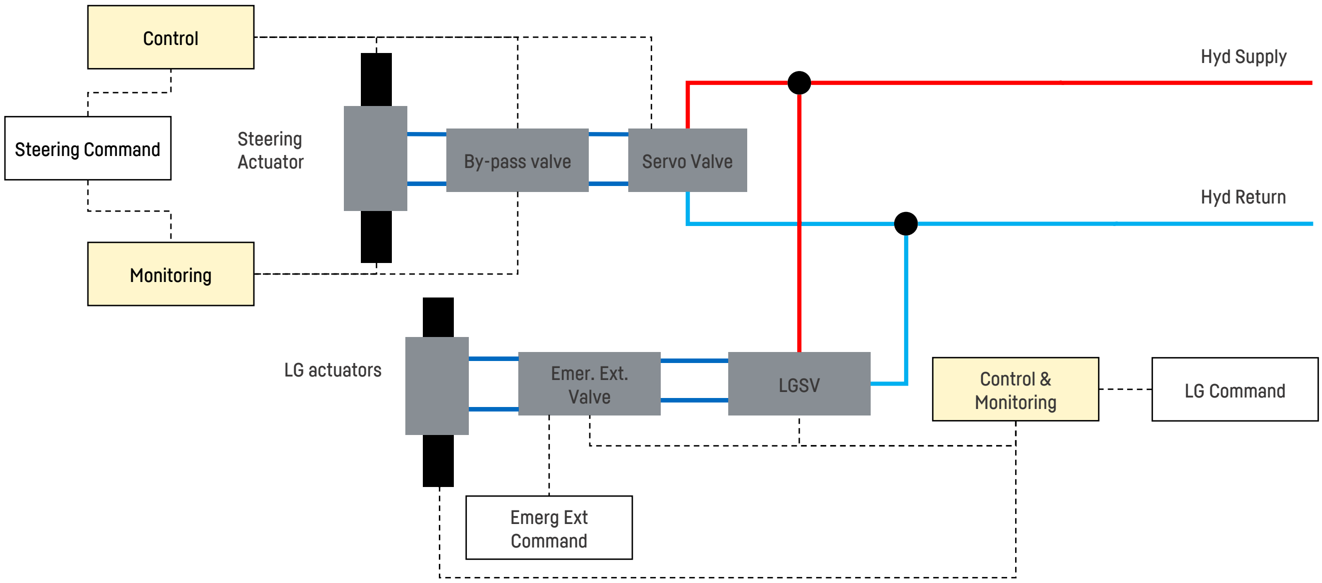

Figure 4 - Conventional NLG actuation

A variation of the option above is the usage of a high-efficient constant pressure system [6]. In this case, a fixed displacement pump is speed controlled by a PMSM motor and motor control electronics combination. Pressure transducers monitor the system pressure and provide feedback to close the pressure control loop. The motor control electronics adapts the motor speed according to the measured pressure levels, maintaining it constant, so that the generation system behaves as the one shown in Figure 4. A possible architecture is shown in Figure 5, and a possible concept is shown in Figure 6.

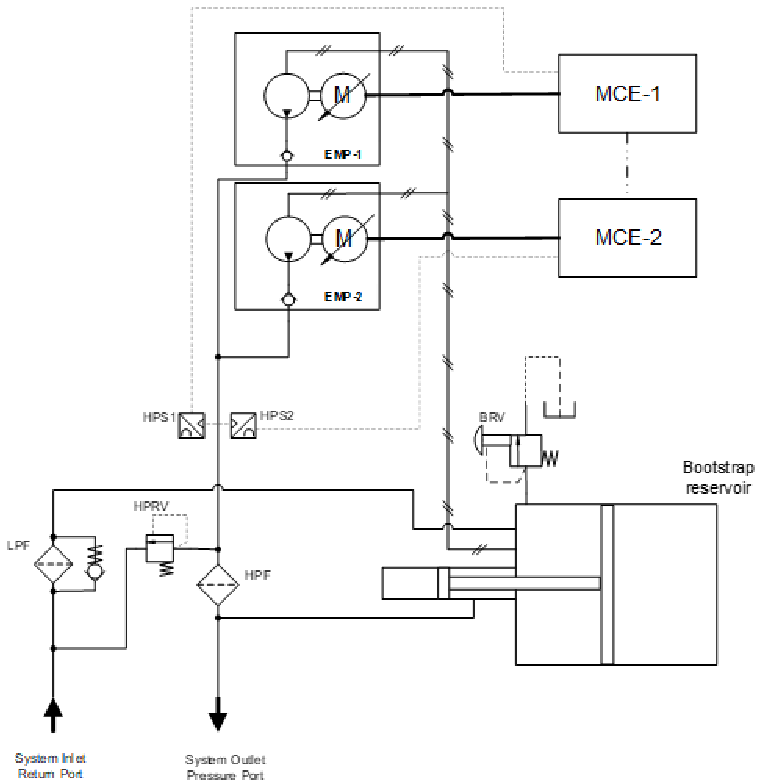

Figure 5 – High-efficient power pack architecture

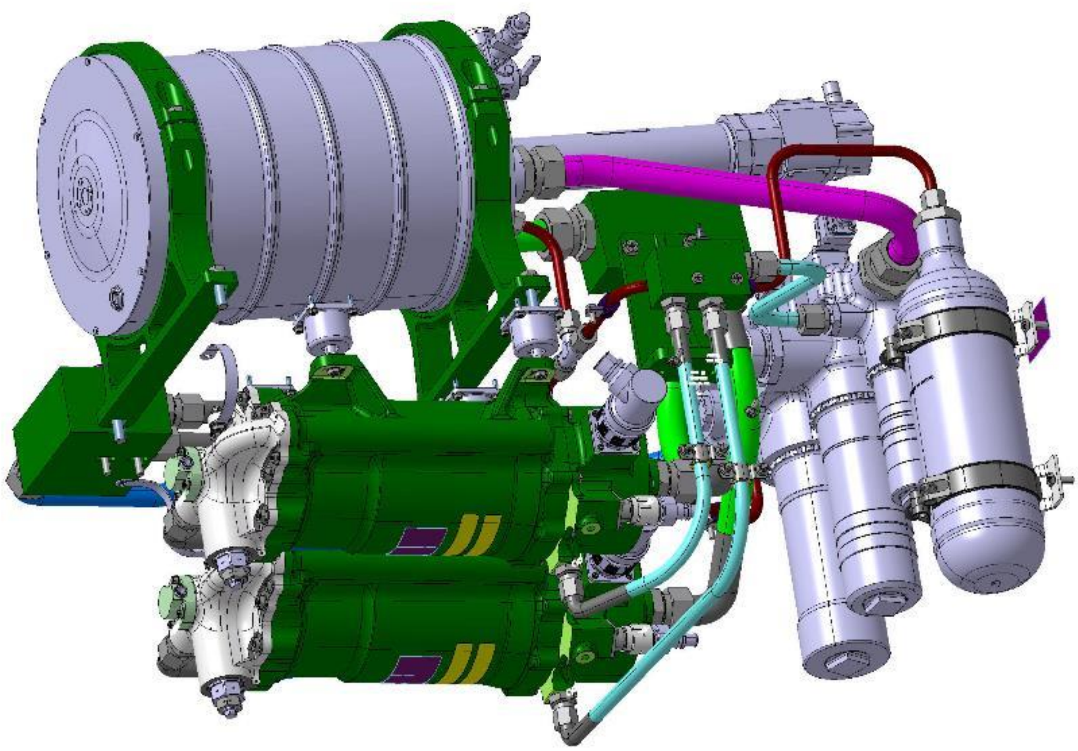

Figure 6 – High efficient power pack concept

The operating principle of the different pump types is illustrated in Figure 7. In a conventional system the pump RPM is close to constant, while the pump swash plate angle changes, increasing the displacement per revolution. In the high-efficient motorpump concept the displacement per revolution is constant, while the RPM increases to deliver higher flow rates.

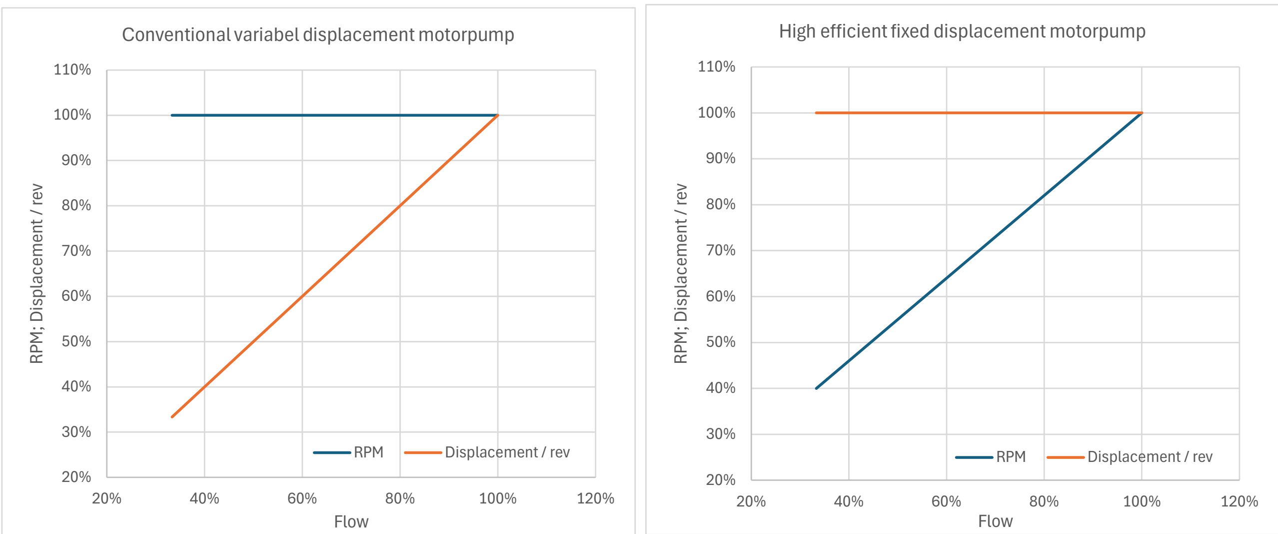

Figure 7 – Qualitative representation of conventional vs high-efficient motorpump concept

The main characteristics of both solutions are as summarized in table

Item	**ESTER**	**Fixed displacement HePP**
Generation efficiency	High	High
Steering efficiency	High	Standard
Extension & retraction efficiency	High	High
Control concept	Position control (variable pressure)	Pressure control (constant pressure)
Consumers	Good for unique, non simultaneous consumers	Good for multiple, simultaneous consumers
Pump type	Fixed displacement pump type	Fixed displacement pump type
Speed	Variable, bi-directional	Variable, uni-directional
Control	Motorpump determines sense of operation. No additional control valves necessary	Additional steering servo valve & landing gear selector valves necessary

Table 1 – ESTER vs high-efficient motorpump comparison

The EHA approach results in significant efficiency improvements, since higher pressure levels are only generated when needed. The inefficiencies of servo-valves due to their high internal leakage when not commanded are also avoided. Despite the different approach for hydraulic power generation, the landing gear themselves remain unchanged. Conventional extension & retraction actuators, steering motors (rack & pinion or push-pull) and unlocking actuators can be used, increasing the flexibility of its adoption. These can additionally be locally optimized independent from the other consumers, with for instance higher pressure levels and consequently smaller actuators.

The landing gear used for demonstration was a conventional nose landing gear from the A220 aircraft, with rack & pinion type steering motor. A push pull steering motor would not result in any change in the ESTER system.

EHAs were successfully applied by Liebherr and Airbus in other applications like for instance the A400M primary flight controls.

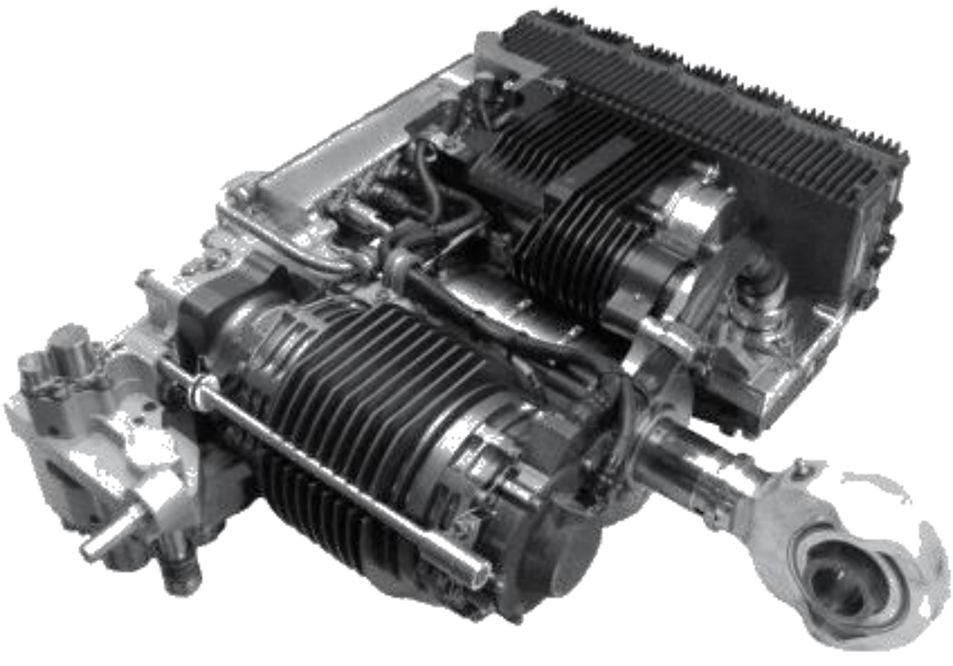

Figure 8 - Example of a Liebherr primary flight control EHA

A mere replication of the solution for the NLG is however not possible, since different functions need to be performed independent from each other. These are specifically steering and extension/retraction of the NLGs as well as opening and closing of the NLG doors. A mode selection function was therefore introduced, allowing different consumers to be controlled by the same motorpump and the same power electronics.

Another characteristic of the NLG system is the need for in field maintenance. Conventional EHAs can be treated as LRUs and replaced as a whole, since interfaces are only mechanical and electrical. In an NLG system, extension & retraction actuators, unlocking actuators and steering motors will eventually fail and on-wing replacement becomes necessary. Thus, commissioning and maintainability must be considered differently.

Because of that, the integration concept may differ from one aircraft to another. Equipment could be installed near the NLG bay, within the NLG bay or even directly mounted to the NLG.

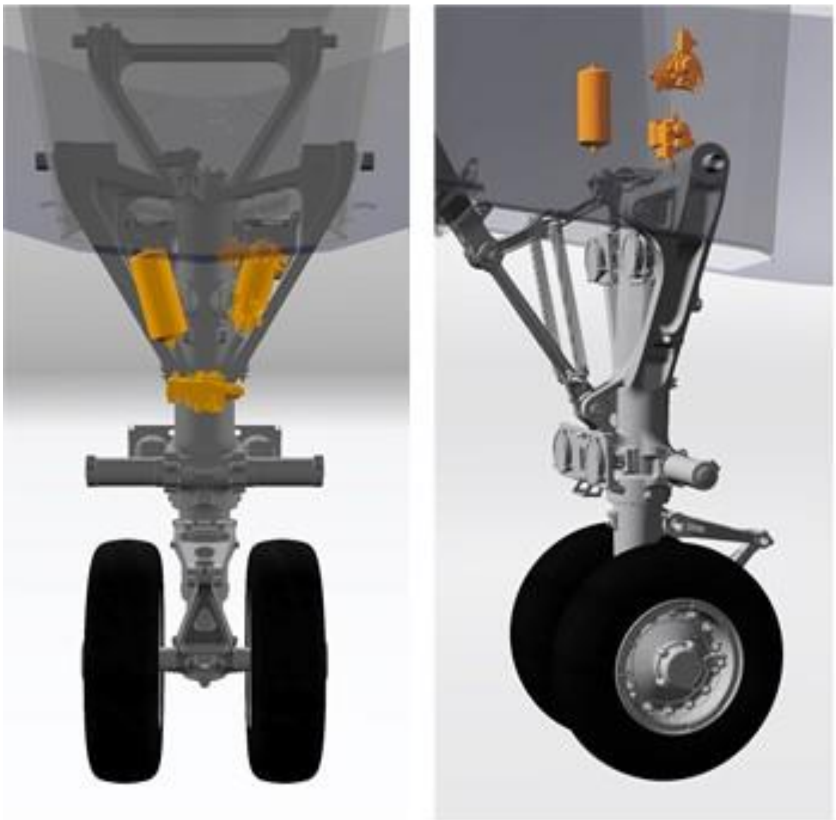

Figure 9 - Possible ESTER integration concepts

The main benefits of the ESTER system are summarized as follows:

- NLG actuation independent of central hydraulic system, representing an important step towards enabling more electric aircraft architectures.
- Removal of hydraulic lines from the aircraft center section to NLG bay allowing for benefits in aircraft weight.
- Removal of hydraulic lines to NLG allowing for benefits in particular risks assessment as for instance loss of hydraulic system due to engine uncontained rotor.
- Pre-assembly and testing at NLG allowing for quick installation supporting high production rates.
- Reduction in power consumption, heat generation and noise by adopting the EHA approach.

3. ESTER development approach

3.1 Initial trades & path to TRL 5

In the initial phase, several concepts were assessed prior to freezing the current configuration. Topics of particular interest were:

- Motorpump concept
- Hydraulic pressure levels
- Electronic architecture

The solution quickly converged to an EHA type configuration. Advantages in power management and noise were obvious. Every time steering is not commanded, the power consumption and noise levels will drop to virtually zero.

The higher efficiency due to the EHA concept will also result in a better thermal management, preventing the system from overheating despite the small fluid volume. Demanding short duration extension and retraction sequences will drive the temperatures up, whereas steering operation will allow for temperatures to recover. This would not be the case with a conventional servo-valve operated system, where temperatures would quickly reach critical values within a few minutes.

These elements combined with Liebherr’s positive experience with EHAs in flight controls applications were the drivers for the concept decision.

Some conditions were however novel for EHAs in landing gear applications.

The dynamics of the landing gear, particularly the steering system, involves high-energy events like for instance NLG shimmy. Even though these events are not part of the daily operation, they should not result in loss of the hydraulic generation or instability in the control.

The accessibility for installation also imposes a particular challenge. The ESTER system is composed of a series of elements like for instance the motorpump, motor control electronics, low-pressure reservoir, filters etc. Combining all these elements in a single power pack may result in weight and dimensions, which are difficult to manage and to install, depending on the aircraft size. Splitting the unit into various components is possible and may be a good choice depending on the installation restrictions of each aircraft.

Maintainability requirements for an NLG EHA are also different from the requirements for a flight controls EHA. On wing maintenance activities leading to opening of hydraulic lines cannot be avoided, like for instance during replacement of LG retraction actuators. Activities to put the system in a flight worthy condition after maintenance, like for instance on-wing bleeding, are therefore mandatory.

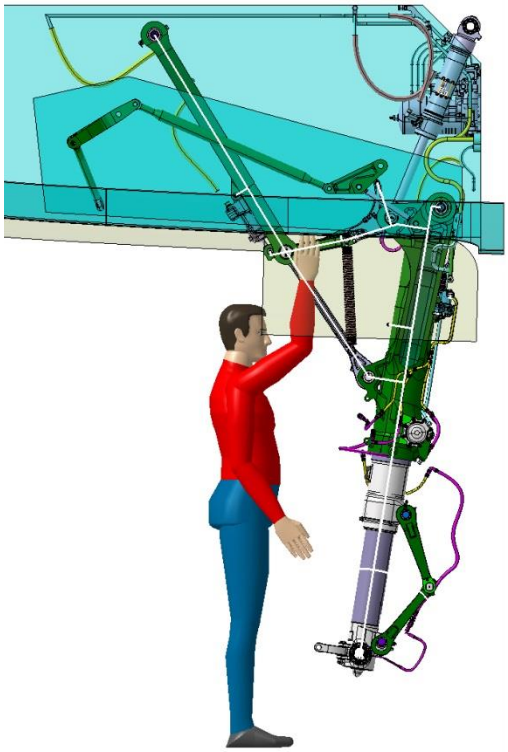

Figure 10 - Possible installation challenges in single aisle aircraft

Because of that, to achieve TRL 5 a demonstrator was built covering the following aspects of the concept:

- Representative fixed displacement motorpump
- Representative motor control electronics
- Representative control laws for steering and extension & retraction
- Representative inertias for steering and extension & retraction
- Representative loads

Installation and maintainability aspects were covered by design.

3.2 TRL5 Demonstration

For the TRL 5 demonstration a proof of concept (POC) hardware was developed and manufactured. This POC HW is shown in Figure 11, and consisted of the hardware listed below:

- Existing EHA motorpump from an aerospace application
- Existing EHA motor control electronics from an aerospace application
- Industry grade valves and other necessary components

Demonstration tests were performed in a representative demonstrator, consisting of a linear sliding mass with representative eigenfrequencies [9], as shown in Figure 12.

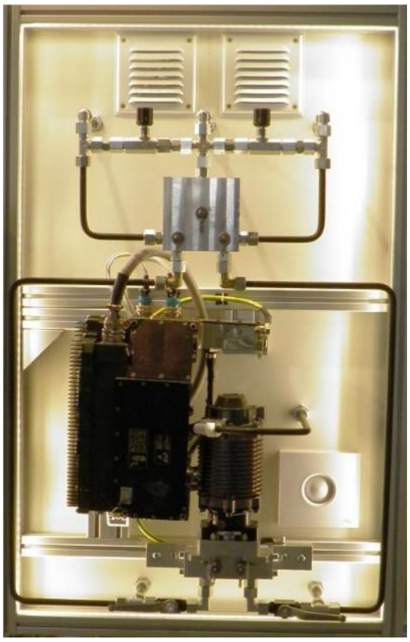

Figure 11 - ESTER POC demonstrator

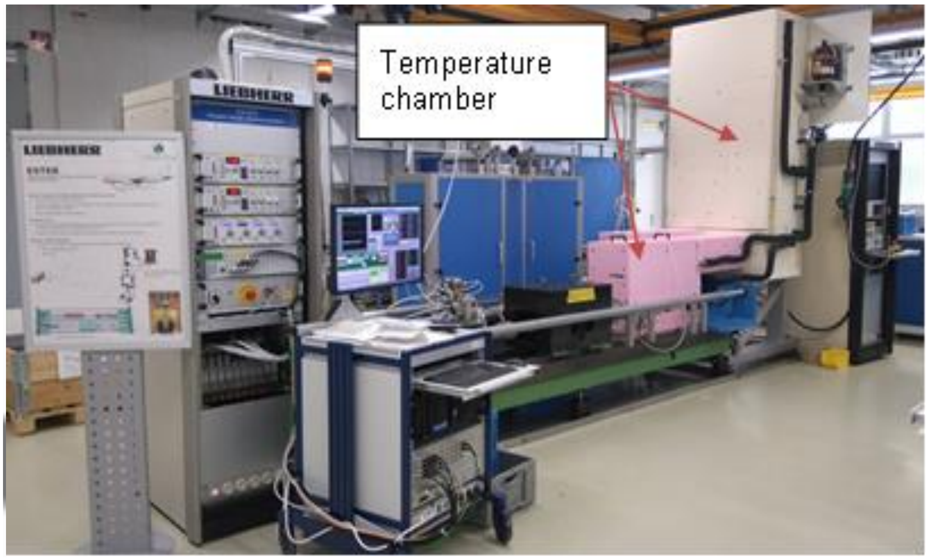

Figure 12 - ESTER POC test rig

This setup allowed the successful execution of all applicable functional and performance test points.

The following aspects were successfully covered during the demonstration

- Functional test & performance under load
- Functional test & performance (special cases)
- Frequency response
- Towing
- Functional test & performance at steering table

Simulations have shown a good correlation with test results.

The ESTER solution demonstrated a performance, which is equal or better than a reference conventional system. The pressure source is closer to the actuator, minimizing the pressure drops in therefore delivering better performance.

3.3 TRL6 Demonstration

After completion of the TRL 5 demonstration phase, additional activities were deemed necessary to allow achievement of TRL 6. These included specific, more detailed tests at component level, in particular for the steering function.

The TRL 5 demonstrator had some components implemented as industry grade hardware. The valve block necessary to house anti-cavitation, pressure relief and flow control valves was newly designed and manufactured for the ESTER TRL 6 demonstrator.

Figure 13 - ESTER TRL 6 valve block

The demonstrator was also arranged in an assembly plate, as shown in Figure 14. This had the sole purpose of facilitating installation in a later phase in the aircraft test rig, and in a demonstrator for ground testing purposes.

The same off-the-shelf hardware for the motorpump and the motor control electronics from the TRL 5 demonstrator were re-used.

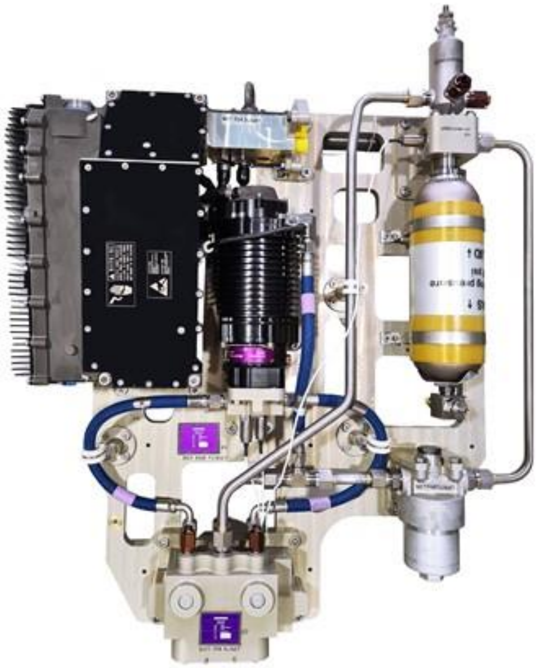

Figure 14 - ESTER TRL 6 demonstrator

The ESTER TRL 6 demonstrator was integrated into the test rig of an existing nose landing gear to perform additional steering performance tests.

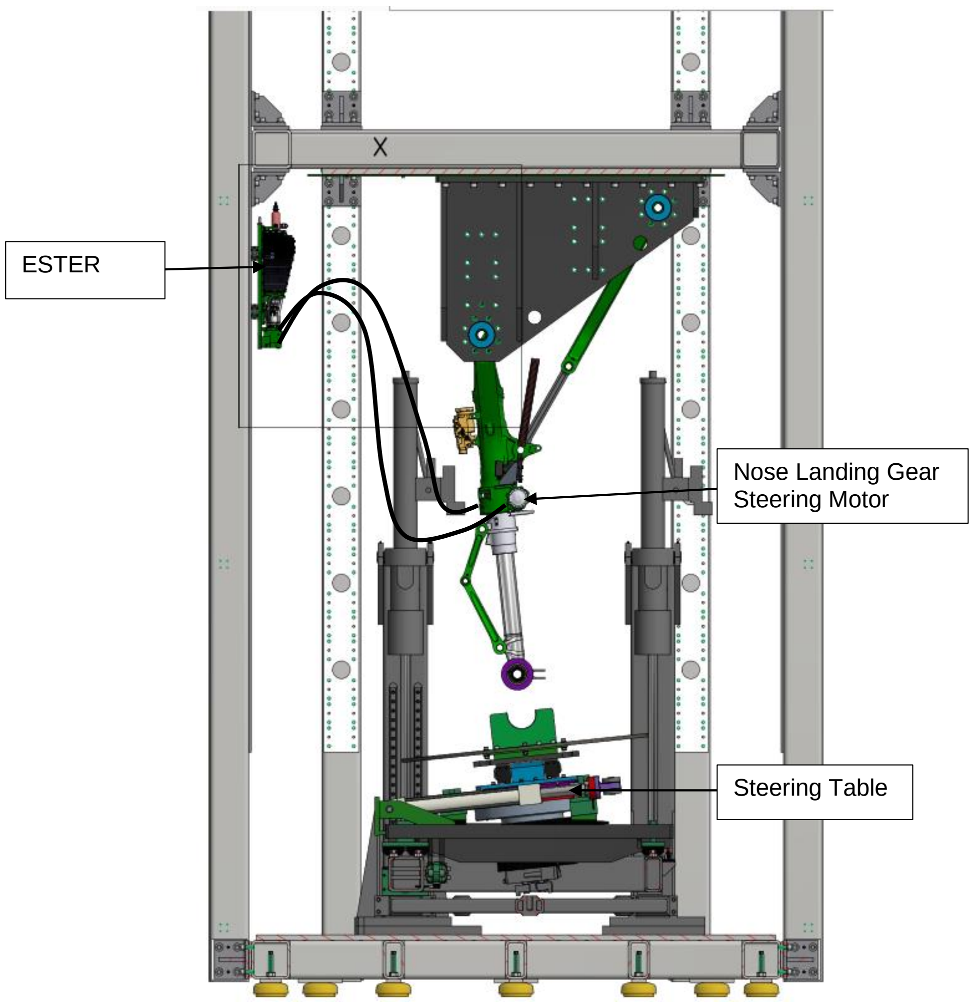

Figure 15 - ESTER TRL 6 test rig

Figure 16 qualitatively shows the performance of the ESTER system under load and medium steering rates. Figure 17 shows the same information for small steering rates.

Note that the steering position closely follows the steering command. One of the main ESTER characteristics, the electro-hydrostatic approach with higher pressure levels only in loaded conditions, is also clear from the performance plots.

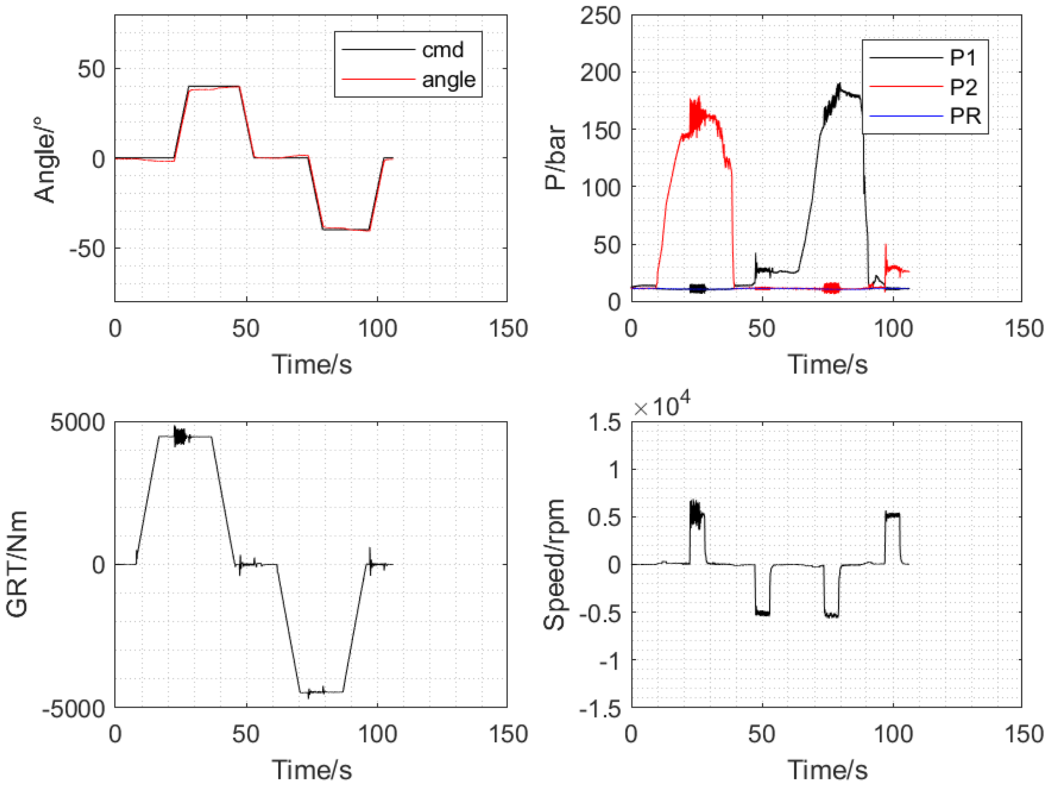

Figure 16 – ESTER performance under load – medium steering rate

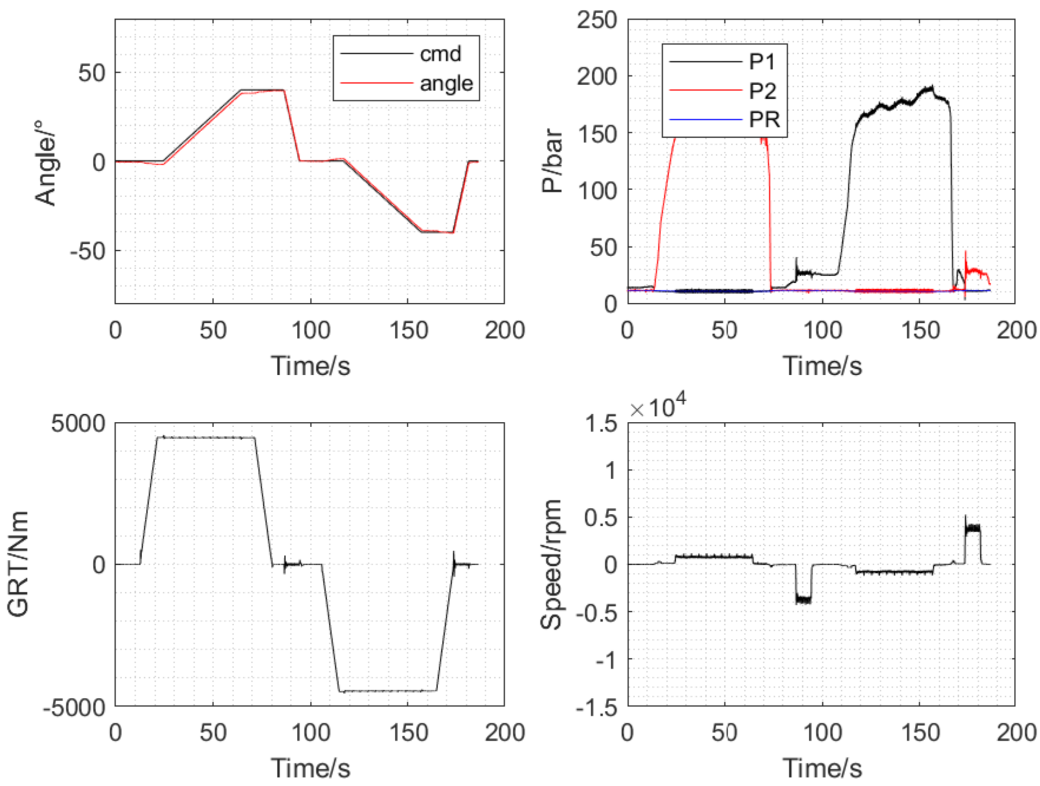

Figure 17 – ESTER performance under load – small steering rate

Figure 18 qualitatively shows the performance of the ESTER system in unloaded condition and medium steering rates. Figure 19 shows the same information for high steering rates. Note that in unloaded condition, pressure doesn't build up despite the high RPMs. This is the main reason for the low power consumption of this solution when compared to a conventional system.

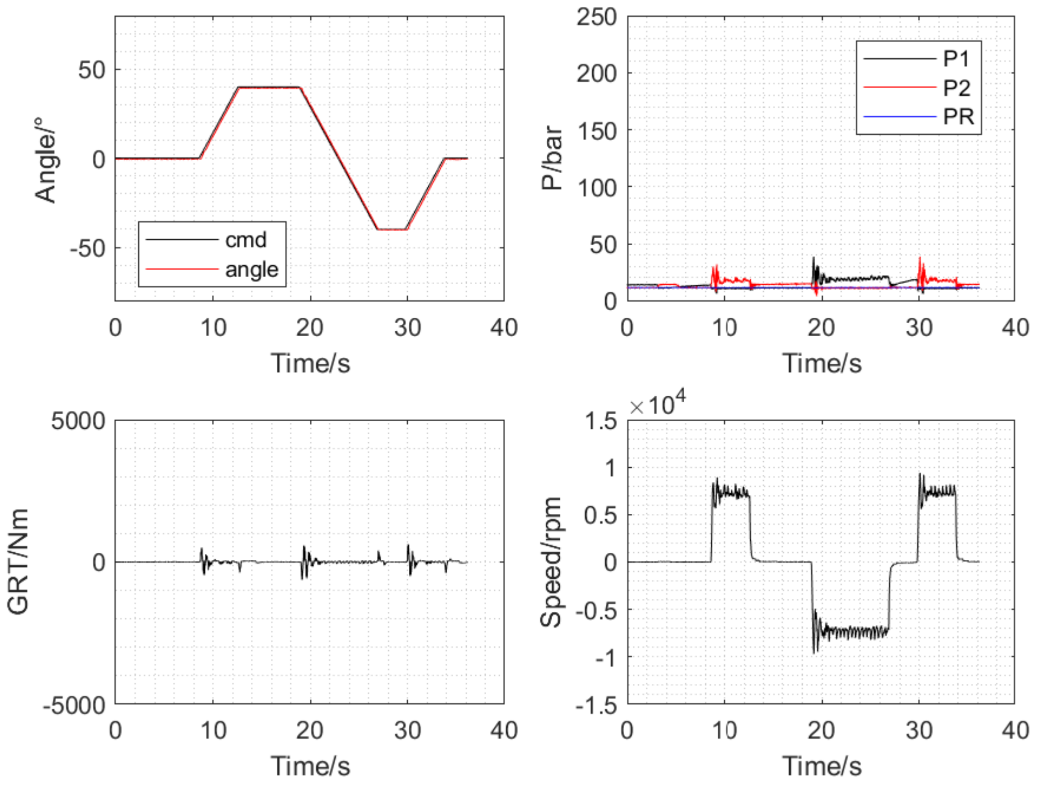

Figure 18 – ESTER unloaded performance – medium steering rate

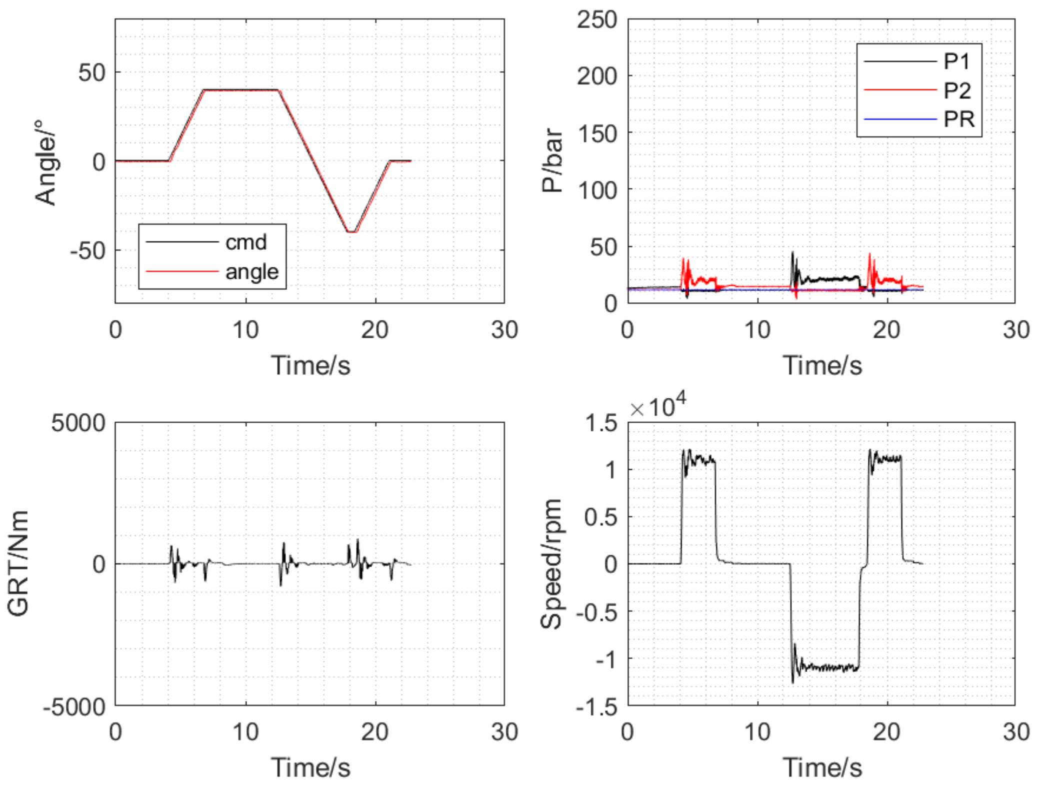

Figure 19 – ESTER unloaded performance – high steering rate

3.4 Aircraft rig demonstration and aircraft taxi testing

Integration tests of the ESTER unit in an aircraft representative test rig at Airbus facilities are currently being performed. These tests are necessary steps prior to installation of the unit in an aircraft for ground testing, planned for 2024.

The ESTER equipment was installed in a single plate, allowing for quick installation and removal of the prototype.

The following items will be covered by ground tests at aircraft level:

- Installation and commissioning
- Pilot feel
- Noise in the cockpit
- Interaction between airframe and system
- Performance of system under dynamic taxi loading

4. Conclusion

At system level, Liebherr has successfully demonstrated ESTER's capability to perform the nose landing gear functions in a single aisle aircraft, achieving TRL 6.

Tests confirmed results from simulations and the performance was equal or better than the one with a conventional system.

ESTER is a significant brick to enable more-electric aircraft architectures. It has the advantage, that it can be fitted to conventional landing gear designs with hydraulic actuation for extension & retraction and steering.

Complementary activities to reach TRL 6 at aircraft level will be performed by Airbus and are planned to be completed in 2024.

The same technology can be adopted for smaller aircraft like for instance regional jets, or larger aircraft like for instance wide bodies, regardless of the steering motor concept (rack & pinion or push-pull actuators).

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