Final Publishable Summary **February 2017**

ORPASV project

1. Executive summary

The SAGE2 Demonstration Project aims at designing, manufacturing and testing a Counter-Rotating Open Rotor (CROR) Demonstrator. It involves most of the best European Engine and Engine Modules and Subsystems Manufacturers The CROR engine architecture is a challenge for the Pitch Actuation System and especially the performance requirements associated to high flow levels to actuate the blades pitch.

Zodiac Hydraulics was selected to design, to manufacture and test servovalves needed by Pitch Actuation System architecture. This document presents the Final Publishable Summary of ORPASV project according the plan below.

2. Project context and main objectives

The Topic addressed here is an essential part of the SAGE2 Demonstration project which aims at designing, manufacturing and testing a Counter-Rotating Open-Rotor Demonstrator, forerunner of future engines for the 2020's with drastically reduced fuel consumption and emissions.

A part of the technological challenge of this architecture is the blade pitch control using electro hydraulic actuation, of which the electrohydraulic servovalves (EHSV or SV) are a key element.

The use of EHSV for electrohydraulic actuation is now state of the art in the aerospace industry, however the pitch control requirements extend beyond known applications by the high flow levels specified and the type of fluid with high viscosity and high viscosity variation with temperature.

Using state of the art EHSV would result in large envelope and weight products with oversizing aggravated by the need to provide the performance in all operating conditions.

ORPASV project have three main objectives :

- development of prototypes of demonstrator engine SV to equip Counter-Rotating Open-Rotor Demonstrator for engine testing
- development of prototype of target engine SV with optimized technologies (TRL4 targeted) based on requirements of an Open Rotor target engine specification to minimize envelope and weight of SV.
- development of a test bench necessary to test these equipment and reach the objectives of ORPASV project

3. Main S & T results/foregrounds

ORPASV project has been split in three projects :

- development of prototypes of EHSV (“demonstrator SV”)
- development of prototype of EHSV (“target engine SV”) with optimized technologies (TRL4 targeted)
- development of a dedicated test bench

Main S&T results/foreground are listed and described for each development done in the framework of the Project.

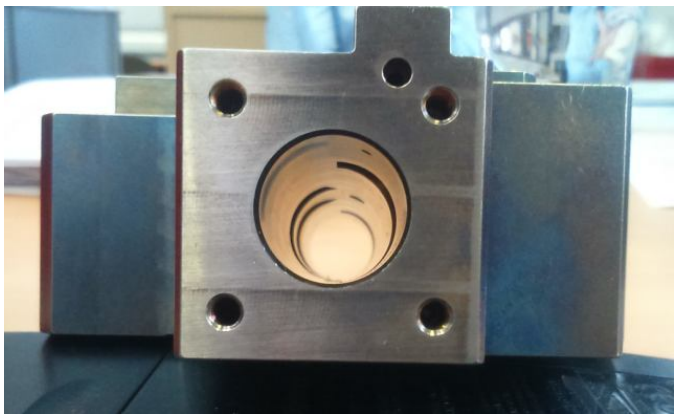
3.1 Main S & T results/foregrounds brought by the development of demonstrator engine SV

Development of demonstrator engine SV allowed to design, manufacture and validate a very large flow servovalve with unusual fluid for a new actuation application.

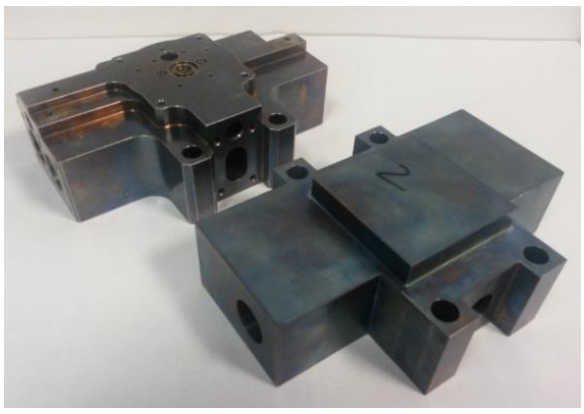
demonstrator engine servovalve

Large housing and spool

Specific constraints for the matching of functional parts of such size has been identify and solved for prototypes manufacture and delivery. It was particularly the case regarding housing of servovalve, to reach suitable cylindricity of spool line. Difficulties were linked to the size of servovalve, bigger than those usually made by Zodiac Hydraulics, because usual machining tooling were not compatible with the size of component to manufacture. An important work concerning manufacturing of housing were performed. Several types of finishing machining of housing were tested (from full automatic machine to manual machine). Some simplified housings were manufactured and finished with several types of machine and several tools. Finally, a semi-automatic process with a specific expandable honing tool allowed to manufacture housing with a suitable cylindricity of spool line.

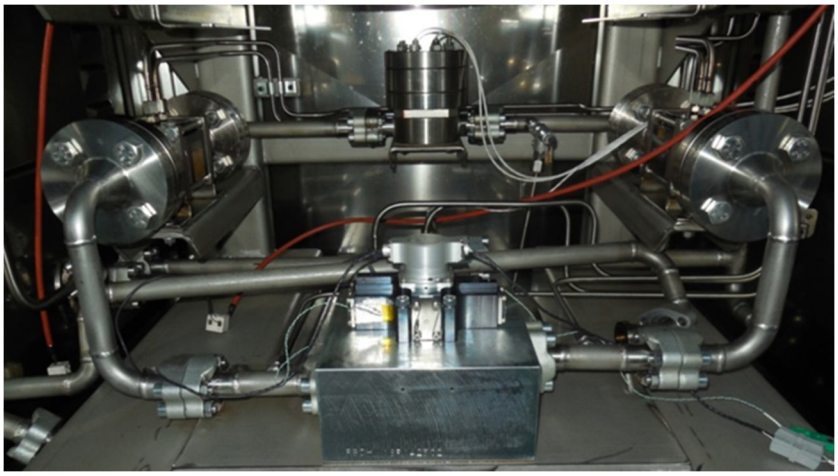


Spool line of housing



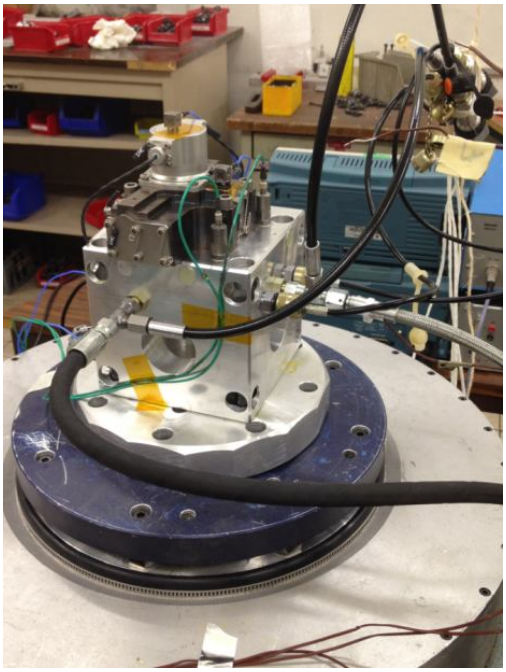
“Simplified housing” used for finishing machining tests

Development of demonstrator engine SV allowed also to understand and to address the specific constraints resulting from the properties of the fluid and the thermal transients. During development tests with delta fluid temperature between control ports of EHSV, transient thermal expansion phenomena were seen between spool and housing of EHSV. Tests performed at different high temperatures with different configurations allowed to determine the root cause of the phenomenon and to address it. The technical solution found required to adjust gap between spool and housing as well as manufacturing tolerances of spool line of housing to control internal leakage at high temperature.



Demonstrator engine EHSV inside thermal chamber of test bench before temperature test launch

Another important result of the project was the qualification of demonstrator engine SV per Topic Manager requirements. A specific qualification tests program was determined with Topic manager and was successfully passed by the equipment. This program included several qualification tests as an endurance test, a pressure cycle test, a temperature test, etc. It's also included a high level, long duration vibration testing up to 5000 Hz beyond current aerospace standards also successfully passed.



EHSV on vibrations test rig

Furthermore, two technological bricks, assessed enough mature during the first phase of development of target engine SV, were also integrated in demonstrator engine SV to increase environmental compliance :
- new coil securing device
- cadmium free brazing of first stage mobile assembly

new coil securing device

cadmium free first stage mobile assembly

In addition of environmental compliance, the new coil securing device was also identified as a solution to be able to pass the vibration tests. Before qualification tests, development tests were performed to validate that the chosen solution was compliant with high frequency range of vibration required in the technical specification.
So, successful qualification of demonstrator engine SV allowed to validate vibration robustness of a new coil securing device and cadmium free first stage mobile assembly. These results should a have an industrial application at short term for Zodiac Hydraulics.

3.2. Main S & T results/foregrounds brought by the development of target engine SV

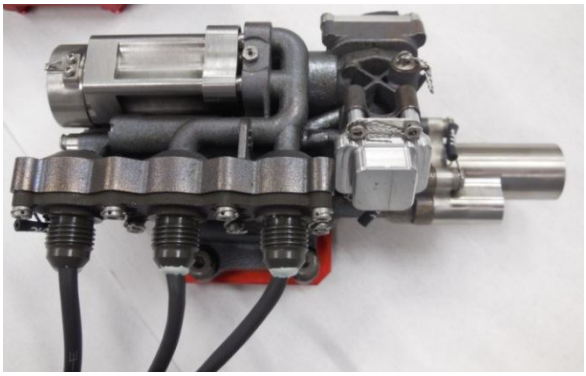
The challenge of the development of target engine SV was to identify the most suitable technological architecture to respect Open Rotor target engine specification and in the same time to minimize envelope and weight of SV. Awaited TRL4 maturity level of developed prototype was demonstrated by ORPASV project. It's an important result of the project.

Result/foreground brought by the development of target engine SV concerns technological bricks involved in the innovative architecture and their integration in a single design combining them with conventional well-tried technologies :
- a piezo-electric first stage is introduced to replace conventional electromagnetic first stage
- 2 piezo-electric actuators are used for redundancy management
- mechanical feedback is cancelled and replaced by an electronical management using an LVDT device
- jet-pipe architecture is kept but associated with piezo-electric actuation thanks to a new concept of mobile assembly
- 17-4PH stainless steel additive manufacturing used for 2nde stage housing associated with a conventional spool / housing architecture
- aluminum additive manufacturing is used for connector holders
- new material of seals

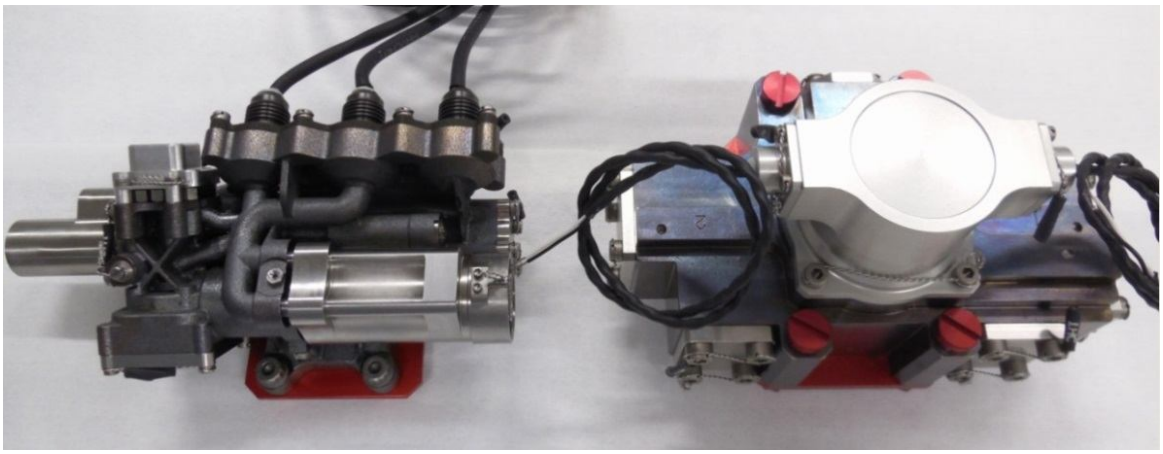
Result/foreground brought concerns also several technological bricks, not directly involved in the final target engine SV but potentially useful in case of specification evolution or necessary to improve performances of conventional design.

3.2.1. Target engine SV development :

Development of target engine SV allowed to validate the feasibility of a piezoelectric jet pipe first stage for a very large flow servovalve with improved performance with respect to current technology. Compared with a conventional architecture of demonstrator engine SV, benefits of target engine SV measured in the framework of a TRL4 validation plan are in line with expected values. These benefits are summarized in the table below. Weight saving brought by this innovative design of target engine SV is about several kilograms by Pitch Control Unit, compared with conventional EHSV, it's a great result.



target engine servovalve



TRL4 target engine SV vs demonstrator engine SV

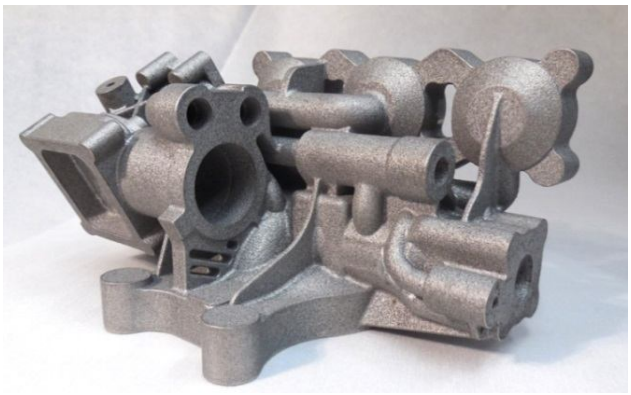
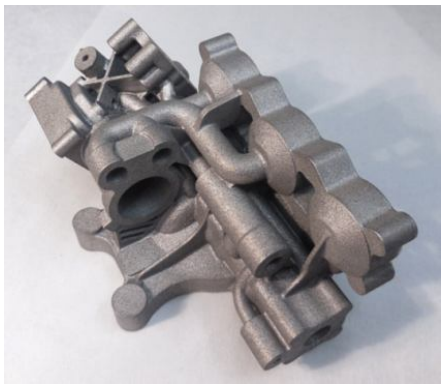
	Target engine EHSV wins (compared with Demonstrator engine EHSV)
Weight (kg)	**46%**
Internal leakage (ATP)	**61%**
Hysteresis (ATP)	**100%**
Dynamic performances control phase lag @ -90°	**100%**

Benefits of target engine SV

Regarding system aspects, works done in the project permitted also to understand of redundancy handling of a dual piezoelectric first stage, based on Topic manager specification. Several strategies were studied : active / passive and active / active.

Development of target engine SV allowed also to validate a new material of seals following several criteria : fluid compatibility, hardness, pressure range and temperature range. Zodiac Hydraulics identified a supplier offering solution working on temperature range -51°C/200°C, compatible with target engine application. Seals were tested through the acceptation tests and development tests program (TRL4) of target engine EHSV, no leakage defect was observed. Fluids compatibility was also tested with a specific test program. In conclusion, selected material for seals is compatible with fluid used for target engine. They are compliant with Topic Manager Specification of EHSV.

An important part of the project concerned additive manufacturing :development tests successfully passed by target engine SV demonstrated the feasibility of an additive manufacturing stainless steel housing for a very large flow servovalve.

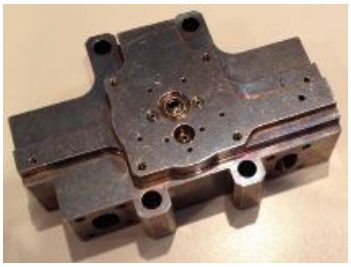



blank of housing – stainless steel additive manufacturing

Development of target engine SV allowed to a better understanding and application of the potential and constraints of the additive manufacturing :

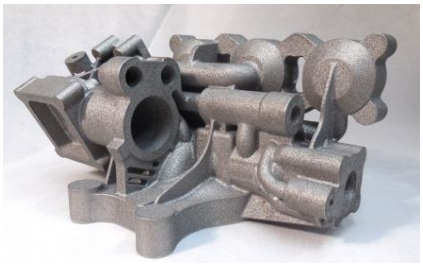
- Additive manufacturing permitted combination and reallocation of functions and parts :
  Hydraulic circuits lay-out have been optimized taking into account all the possibilities of additive manufacturing (curved channels). Skin of stainless steel has been design around functional surfaces to optimized envelop and volume of housing. Housing functionalities are greater than housing of demonstrator engine SV because it is designed to integrate components of 1st stage and also to protect internal electrical harnesses. Design and manufacture by additive manufacturing allows to reduce the number of components by integrating them into a single part : no plates were necessary for closing housing of target engine SV (except for closing spool line), no plug were used too.

- Weight reduction : additive manufacturing allowed to decrease part weight by keeping material only in functional areas. Compared with housing of demonstrator engine SV, final design housing (right picture) brings a weight saving about 50% (stainless steel material).



Conventional manufacturing housing (demonstrator engine SV)

Additive manufacturing housing (works at technological brick level)



Additive manufacturing housing (target engine SV)

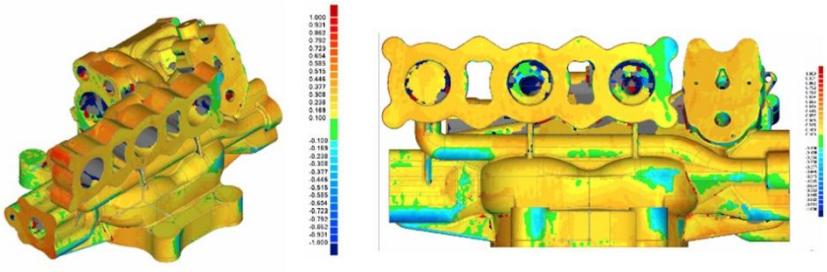

blank of connector holder – aluminum additive manufacturing

- Conditions of edification with impact on blank design and definition of conventional machining finish : the project allowed to define and to apply specific design rules to benefit of advantages of additive manufacturing. Simultaneous engineering is necessary to design a manufacturable product. Even if additive manufacturing permit lots of flexibility of shapes all is not possible, edification process has to be taken into account. After edification task, works allowed to acquire experience for all necessary following tasks : removal of residual powder, stress relieving treatment, separation of part to edification plate, removal edification supports, tribofinish process, internal finishing of channels. Goal of these tasks are to obtain a blank of

housing to be finished with conventional machining. Comparison between 3D model of the part and a 3D scan was successfully used to insure geometrical conformity of the part before conventional machining finish.

Housing with edification support

Housing after conventional finishing process



Comparison : 3D model and 3D scan

- Thermal and surface treatment behavior with respect to conventional alloys : works performed during the project allow to define and to test thermal and surface treatments to obtain the same characteristics of a conventional alloys aiming to use conventional machining. Impact of conventional surface treatment as nitriding has also been assessed : no major deviation has been detected.

  Finally, the project permitted to have a better understanding of 17-4PH alloy produced by additive manufacturing. A metallurgical study was performed to understand the behavior of 17-4 PH atomized and edified under nitrogen, obtained by Selective Laser Melting. After specific heat treatment, mechanical characteristics are at least similar than "traditional" 17-4 PH alloys. A specific heat treatment has been assessed to limit internal residual stresses and avoids degradations of alloys.

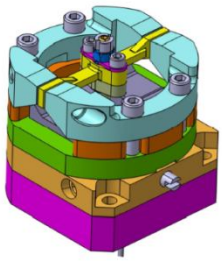
3.2.2. Main S & T results/foregrounds of other technological bricks developments:

Several other technological bricks, not directly involved in the final target engine SV but potentially useful in case of specification evolution or necessary to improve performances of conventional design were studied during the project. This paragraph present result/foreground of these works :

3.2.2.1 - 1st stage with magnetic air gaps perpendicular to magnetic axis :

This concept of 1st stage was study in parallel of 1st stage with piezo-electric actuators. Compared to a conventional electromagnetic 1st stage, benefits of this concept are :
- weight saving of 1st stage
- decrease the null shift effect (due to thermal expansion or stress relaxation)
- decrease the sensitivity to the vibration stress of several components

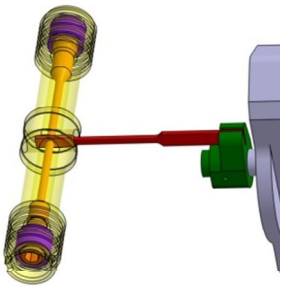
Works done in the framework of the project allowed to confirm its potential by theoretical analysis in terms of benefits. The development of this concept was stopped during the project because 1st stage with piezo-electric actuators was preferred.



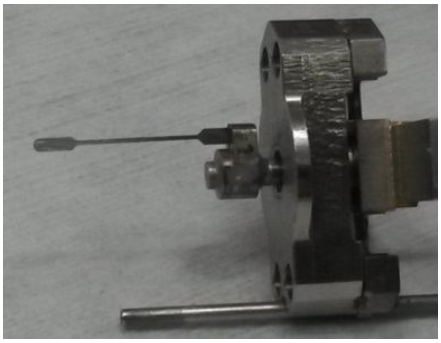
CAD view of concept

3.2.2.2 - Internal assembly design improvement - Feedback / spool joint without clearance:

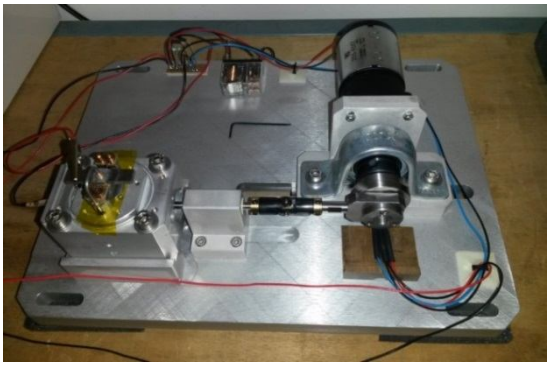
Conventional servovalve includes a mechanical feedback device between 1st and 2nd stage made by a ball, fixed on a wire, in a groove of the spool. The concept studied consists to replace this conventional mechanical feed-back by a fixed link between a blade and the spool, in order to increase reliability and improve life equipment.



CAD view feedback insered in spool



view of prototype



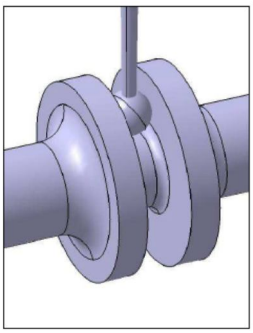
Endurance test of feed-back blade

More than 15 million of endurance cycles were performed on samples of blade and tests program performed on servovalves integrating this technology were successfully passed. Works done during the project allowed to demonstrate feasibility of the concept and demonstrate awaited advantages.

3.2.2.3 - Internal assembly design improvement - heterogenic welding / assembled spool :

As the previous topic, the main goal of works here is to increase reliability and improve life equipment but by keeping the conventional link : ball fixed on a wire moving in a groove of the spool. Works focused on reduction of wear effect of couple ball/spool.

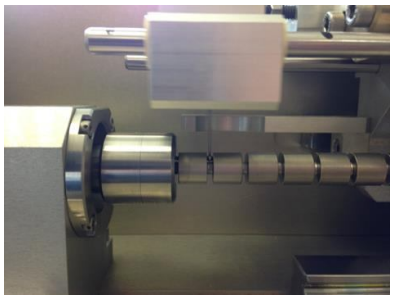
Main result/foreground of the project concern the selection of tribologic couple (ball / spool) and solution to join new material ball on wire.



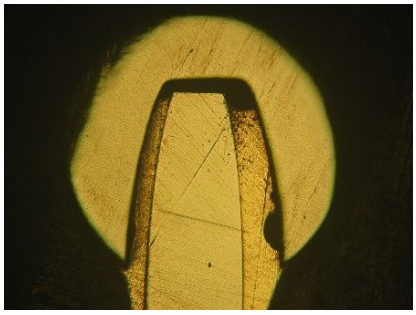
Ball in the groove of spool

wear effect seen on ball on EHSV

Regarding tribologic couple result, works allowed to demonstrate that the replacement of steel ball by tungsten carbide ball allows to reduce total wear by approximately 67% without any modification of spool. A specific solution to link tungsten carbide ball on stainless steel wire has been identified and promising test results on prototype have been performed. Further industrialization works are necessary to apply this technology in production at a short term.



Tribologic test bench dedicated do reproduce contact ball / spool in accelerated conditions

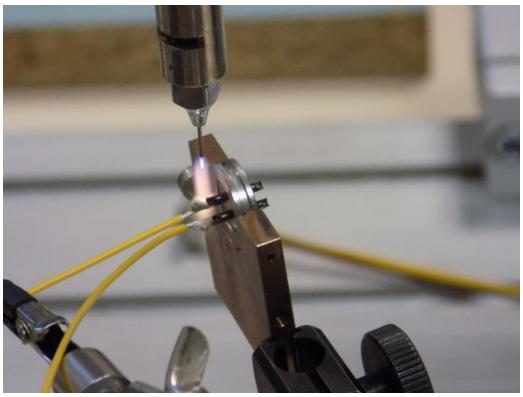


Tungsten carbide ball on stainless steel wire Conventional brazing process

Works done during the project allowed also to identify and to test an optimized tribologic couple (tungsten carbide ball / ceramic spool) reducing total wear by approximately by 90% (compare to classical solution). Works to introducing a ceramic insert in a spool have been performed but this long term solution which permits to decrease wear by approximately 90% needs more research and development.

3.2.2.4 - Lead free electrical soldering for environmental compliance :

Works performed during the project allowed to identify and to test product / process solution to replace conventional soldering material used for electrical soldering of wire by a new one environmentally friendly.
A specific Ag solder paste was identified and a specific high accuracy soldering tool was successfully tested : metallographic cuts of pins of bulkhead shown a conform soldered assembly.



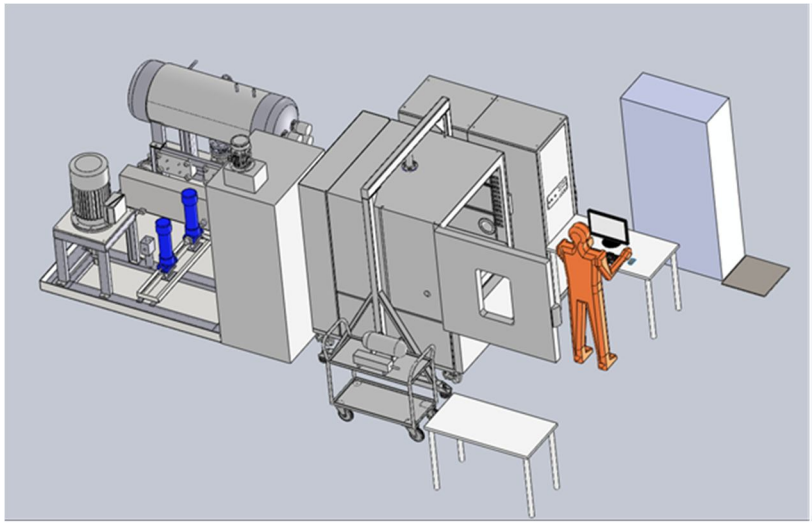
high accuracy soldering tool

This results are good for environmental compliance but further works would be necessary to introduce this technology in production.

3.3 Main S & T results/foregrounds brought by the development of test bench

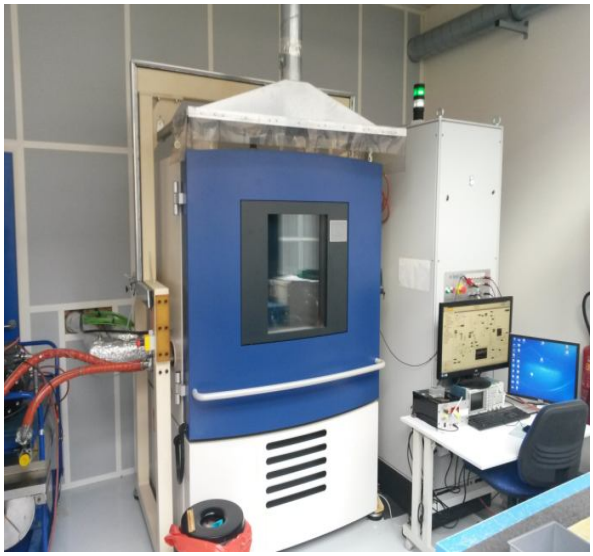
Test bench development was required to adjust and test demonstrator engine SV and target engine SV.
Test bench specification was deduced from servovalve specification at the beginning of the project. Test bench requirements were frozen at the right time with Topic manager in order to declare it entry in service when needed.

Main requirements of the test bench are :
- Test oil : fluid MIL-PRF-23699 type II
- Flow 100 l/mn
- Pressure 150 bar
- Temperature (performance) + 10°C to + 150 °C
- Cold start - 55 °C (cold start sequence)
- Delta temperature between use ports
- Dynamic characterization using a shift actuator



Test bench planned (work area and hydraulic generation) - CAD view

Achievement of objectives of development for demonstrator engine SV and target engine SV demonstrated ability to specify, integrate and use a large, complex test bench with unusual fluid and temperature conditions.



View of test bench (work area)

4. Potential impact and the main dissemination activities and the exploitation of results

4.1 Potential impact

Works done in the framework of ORPASV project will contribute to the feasibility of Open Rotor project allowing reduction of kerosene consumption and pollution, first by supplying the equipment needed for the demonstration of the Pitch Control System, and second by defining future generation servovalves able to fulfill this blade positioning function with improved performances, mass and robustness.

Demonstrator engine servovalves designed, manufactured and delivered by Zodiac Hydraulics should allow the Topic manager to conduct needed tests at system level and realize tests of demonstrator engine of Open Rotor. Demonstrator engine servovalves have been qualified according Topic manager specification. Several technical challenges were met successfully: specified high flow levels, type of fluid used with high viscosity and high viscosity variation with temperature and high level, long duration vibration testing beyond current aerospace standards.

Progresses made in validation of new concepts (1st stage of servovalve with piezo-electric actuator and additive manufacturing technologies) and all works done during the development of target engine servovalves allow to improve performances of target engine servovalve (weight saving, low internal leakage and dynamic performances).

Generally, ORPASV project allowed to improve technologies of hydraulic equipments, by increasing know-how in the fields of in design, manufacture and tests. Especially more environmentally friendly solutions have been investigated and validated.

Work done in the framework of ORPASV project is really promising for the future of Open Rotor engine.

4.2 Dissemination activities

The increase of knowledge resulting from the ORPASV project will be disseminated beyond Zodiac Hydraulics and the Topic Manager by several paths. All communications involving engine information will be coordinated with the Topic Manager.

Audience targeted by dissemination activites is mainly the aerospace community and also the industrial community specialized in manufacturing technologies and surface treatments.

This paragraph presents the list of means planned to disseminate foreground od ORPASV project.

LIST OF DISSEMINATION ACTIVITIES								
No.	Type of activities	Main Leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	Exhibitions	ZODIAC HYDRAULICS	Paris Air Show Le Bourget 2017	19/06/2017	Le Bourget - France	Industry - Civil society		Worldwide
2	Oral presentation to a scientific event	ZODIAC HYDRAULICS	Association de Traitement Thermique et de Traitement de Surface (A3TS) (type of activity to be confirmed)	06/12/2017	Colmar - France	Scientific community (higher education, Research) - Industry		TBD
3	Oral presentation to a scientific event	ZODIAC HYDRAULICS	Recent Advanced in Aerospace Actuation Systems & Components (R3ASC) (type of activity to be confirmed)	15/03/2018	Toulouse - France	Scientific community (higher education, Research) - Industry		worldwide
4	Oral presentation to a scientific event	ZODIAC HYDRAULICS	Actuators 2018 (type of activity to be confirmed)	25/06/2018	Bremen - Germany	Industry		TBD

4.3 Exploitation of results

Several innovative concepts relative to servovalve technologies have been evaluated during ORPASV project. To manage resulting intellectual property rights Zodiac Hydraulics patents were applied.

Following patents are considered as no confidential because they are published at the date of writing this report :

LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS,UTILITY MODELS, ETC.					
Type of IP Rights	Confidential	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant(s) (as on the application)
Patents	No	05/02/2016	FR3024505	DUAL MOBILE ASSEMBLY SERVOVALVE	Zodiac Hydraulics
Patents	No	03/02/2016	EP2980417	DUAL MOBILE ASSEMBLY SERVOVALVE	Zodiac Hydraulics
Patents	No	02/04/2016	US201600330552	SERVO VALVE WITH DOUBLE MOBILE ASSEMBLY	Zodiac Hydraulics
Patents	No	18/03/2016	FR3025844	SERVOVALVE A TIROIR COMPOSITE	Zodiac Hydraulics
Patents	No	02/12/2016	FR3036765	SERVOVALE WITH PILOT STAGE OF THE JET TYPE	Zodiac Hydraulics
Patents	No	30/11/2016	EP3098456	SERVOVALE WITH PILOT STAGE OF THE JET TYPE	Zodiac hydraulics
Patents	No	01/12/2016	US20160348805	ENHANCED PILOT STAGE SERVOVALVE	Zodiac Hydraulics

The table below gives the list of exploitable foreground associated to patent application.

OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND								
Type of Exploitable Foreground	Description of Exploitable Foreground	Confidential	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Patents or other IPR exploitation (licences)	Owner and Other Beneficiary(s) involved
Commercial exploitation of R&D results	New type of servovalve with improved performances - Dual mobile assembly servovalve	No	05/02/2016	New type of servovalve with improved performances	All industries using electro-hydraulic equipment (aerospace, automotive, etc.)	Only potential use, no timetable, further works needed	Patent FR3024505, EP2980417, US201600330552	Zodiac Hydraulics
Commercial exploitation of R&D results	New type of servovalve with improved performances - servovalve with composite spool	No	18/03/2016	New type of servovalve with improved performances	All industries using electro-hydraulic equipment (aerospace, automotive, etc.)	Only potential use, no timetable, further works needed	Patent FR3025844	Zodiac Hydraulics
Commercial exploitation of R&D results	New type of servovalve with improved performances - servovalve with pilot stage of the jet type	No	02/12/2016	New type of servovalve with improved performances	All industries using electro-hydraulic equipment (aerospace, automotive, etc.)	Only potential use, no timetable, further works needed	Patent FR3036765 EP3098456	Zodiac Hydraulics
Commercial exploitation of R&D results	New type of servovalve with improved performances - Enhanced pilot stage servovalve	No	01/12/2016	New type of servovalve with improved performances	All industries using electro-hydraulic equipment (aerospace, automotive, etc.)	Only potential use, no timetable, further works needed	Patent US20160348805	Zodiac Hydraulics

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