FLPP European Next Generation Launcher Propulsion

High Thrust Engine Demonstrator

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I. Introduction

Following the European Space Agency Council at Ministerial level held in November 2008, the Step 2 of Period 2 of the Future Launchers Preparatory Programme (FLPP) has been confirmed and funded for the next 4 years slice, in order to continue the preparation of the Next Generation Launcher (NGL), acquire new launcher technologies, contribute to safeguard European industrial capabilities and capitalize on investments already made.

This programmatic paper will present the set of system, integrated demonstrator and technology activities in Main Stage Propulsion, which deals with the baseline preparation of a development decision for a High Thrust Engine for NGL in the 2014-2015 period as well as with potential technology spin-offs for existing launcher evolutions in Main Stage Propulsion or liquid booster application.

II. History

The FLPP Main Stage Propulsion program, started in 2005 has always pursued the main goal to prepare the necessary tools and technologies that will be used to enable, design and develop first stages propulsion system. From the start, the activity in the frame of FLPP Main Stage Propulsion has been divided into two main tasks: The design and trade off of propulsion system images and integrated demonstrators on the one hand and the accompanying technologies in the different fields (turbopumps, thrust chamber,…) on the other hand. For what concerns propulsion system studies, they are conducted in close interaction with the FLPP launcher system studies, to guide the propulsion technology work, establish the engine component and sub-system requirements based on the selected reference architectures.

In the proposed approach, the development and testing of full scale, prototype engine is still considered premature and beyond reasonable budget reach. Instead, it is considered more realistic and advantageous to perform structuring test programme of an engine demonstrator called High Thrust Engine Demonstrator (HTE Demo), aiming at progressively reducing the technical and programmatic risks associated with the development of a flight engine. It will allow understanding the key problems, safeguarding and developing the competences in propulsion system integration and advanced technologies, investigating and demonstrating viable solutions and, finally, permitting industry to keep pace with competition in propulsion technology.
This demonstrator approach promoted within FLPP has several specific advantages, such as:

- Avoiding interference of development with exploitation of launchers but constituting a pool of technical options and upgrades for rapid spin-off to existing launchers.
- Concentrating use of available budget to perform high added value Research and Development tasks without spending on non strategic competences,

- Efficiently safeguarding propulsion system integration and technology competences.

By providing technical and programmatic elements in support of a future development decision jointly with the acquisition of the relevant set of competences within Industry, it secures the initial design and configuration development choices which condition most part of subsequent spending, thus limiting the risk of late modifications and problem solving which are very costly.

III. Main Stage Propulsion and High Thrust Engine Demonstrator: The global objectives

The HTE Demonstrator approach is based on the following guidelines:

- Prepare for the long term, allowing for technology spin-offs
  The main focus of FLPP remains the preparation of the longer term future, addressing system concepts (Next Generation Launcher or other advanced concepts) with an Initial Operational Capability (IOC) ca. ~2020. However, some of the technologies developed in this programme may find application in the short and medium terms, mainly on evolutions of the current ESA-developed launchers.
- Implement a system-driven approach
  Technology requirements and technology verification needs are derived from the launcher system requirements and system design choices, including overall risk mitigation and overall programme planning constraints. In turn, the technology activities allow verification of assumptions made at system level during the design loop. To this end a document called Technology Development and Verification Plan represents a pivot element between system and technology activities.
- Mature technologies through integrated demonstrators
  The programme is focusing on an integrated demonstrator approach, as the most efficient way to increase the technology readiness level and address at the same time system-level competences. For these demonstrators, a tailoring of usual development management and design rules is sought for the sake of programme effectiveness and cost efficiency. Such an approach allows also motivating and federating industry teams and capabilities around well-identified end-products, from their initial definition to their manufacturing, testing and exploitation of results.
- Include flexibility to adapt to the changing environment
  The inherent capability of liquid propulsion and of the programme organization to adapt to the possible evolution of the environment which may influence the European launcher sector, are important features of the FLPP programme.

The configuration of the HTE Demonstrator is not yet frozen, waiting for the results of the ongoing trade off and concept review work within FLPP. Some design requirements are however considered as important and are recalled hereafter:

- Maximum integration of the enabling technologies identified for the target engines, technologies assessed in FLPP and in national programs
- Best size / cost compromise to be as much as possible representative of the challenges of a full scale (200 tons +) staged combustion engine in a limited cost environment
- Minimization of heavy bench tests adaptation needs
- Operations (manufacturing, inspection and assembly) simplification and flexibility
- Monitored mass

- Modularity of the design for rapid and flexible test configuration adaptation and test frequency optimization
- HTE Demonstrator Methane design shall be based on the reengineering of the LH2 baseline, keeping as much as possible common components (in the limits of representativeness)

IV. Interaction with Launcher system studies

Within FLPP, reference engine system studies are conducted in close interaction with the vehicle system studies, to guide the propulsion technology work, establish the engine component and sub-system requirements based on the selected reference architectures. Engine system studies will consist of screening, assessment and trade-off of engine thermodynamic cycles and propellant couples, architectures, operational parameters, expected performance and engine mass. Application to Main Stage, Booster stage and Upper Stage propulsion systems including trade-off analyses are performed.
The phasing with the vehicle system study is organized to permit the down-selection of the preferred propellant combination and propulsion system architectures with highest efficiency.

Fig. 1 Next Generation Launcher 3 / 5 / 8t GTO & 24 t LEO configuration

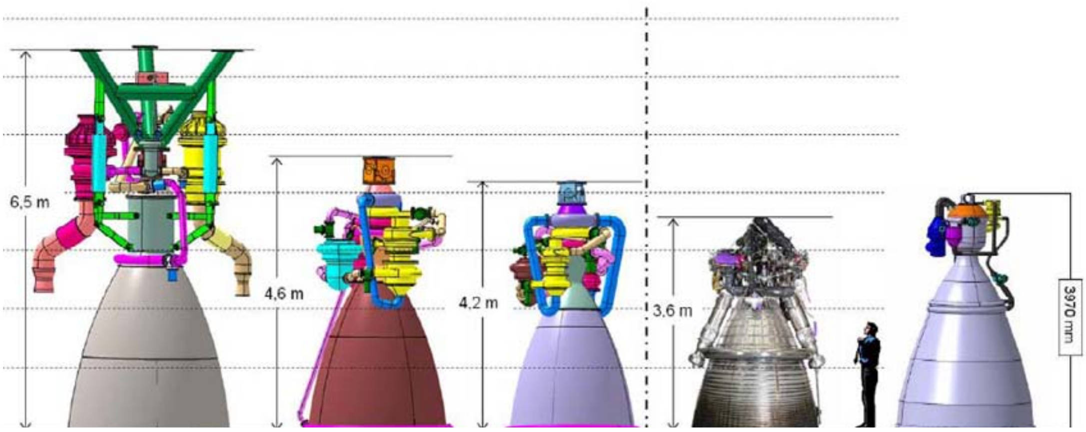


Fig. 2 Some NGL reference engine configurations

Following the engine system studies, and making use of the advances in the new engine architecture design approach, a detailed definition of the reference engine architectures, based on selected components and subsystem requirements, is underway. For the selected reference engine architectures, requirements for all the main components and subsystems will be derived.

In addition, propulsion support to the system studies is provided to ground the system work. Suitable technology developments and demonstrations are identified and carried out to assist the propulsion system work.

V. High Thrust Engine integrated Demonstrator system studies

The parallel progress of the different system studies, as well as consideration of long term evolution of existing European launchers (Ariane, Vega) have permitted to progressively focus the future demonstration work on two propellant pair candidates: liquid oxygen / hydrogen as reference propellants and liquid oxygen / methane, as well as to confirm the interest for the engine demonstration of the staged combustion thermodynamic cycle.

Activities are organized around and converge towards the integrated HTE Demonstrator, whose configuration does not prejudge the configurations retained for the launcher applications The configuration of the HTE Demonstrator is the result of Launcher System and Propulsion system analysis and tradeoffs aiming at covering within a limited budget the maximum of critical enabling technologies and competences identified in the frame of FLPP such as staged combustion, hydrogen and methane propellants. These technologies are identified as candidate for NGL application, as well as for main stage or other liquid propulsion application for existing launchers. Kerosene is considered as a valid candidate for NGL application, but considering the experience gained on a German national basis in Europe during cooperation with Russia, and the Russian experience in this field, it is not a demonstration priority in FLPP.
Being of higher performance, staged combustion system integration competences and technologies exceed other cycles requirements (Gas Generator, Expander…etc), in this respect they cover the relevant system and technological competences safeguarding issue for all the possible options. As a consequence, it was deemed reasonable to assess in FLPP in priority these promising technologies of lowest TRL in Europe, in conjunction with new propellant combination.

As a baseline, HTE demonstrator will be designed to operate with LOx/LH_2 propellants as well as being compatible in a de-rated operation with LOx/Methane.

The proposed approach implements progressive integration of staged combustion, LH_2 (as reference) and Methane propellants innovative technologies at subsystem, system, coupled system levels and finally on a mid-scale High Thrust Engine Staged Combustion Demonstrator (fig.3), compatible with both propellants with minimum hardware change, to reach the TRL 5-6 with best efficiency and limited programmatic risks. The risks associated to integration of innovative technologies will be carefully monitored within the generic technology activities (see paragraph VI below), to reach the appropriate TRL 5 validation at component level before introduction in the Demonstrator logic.

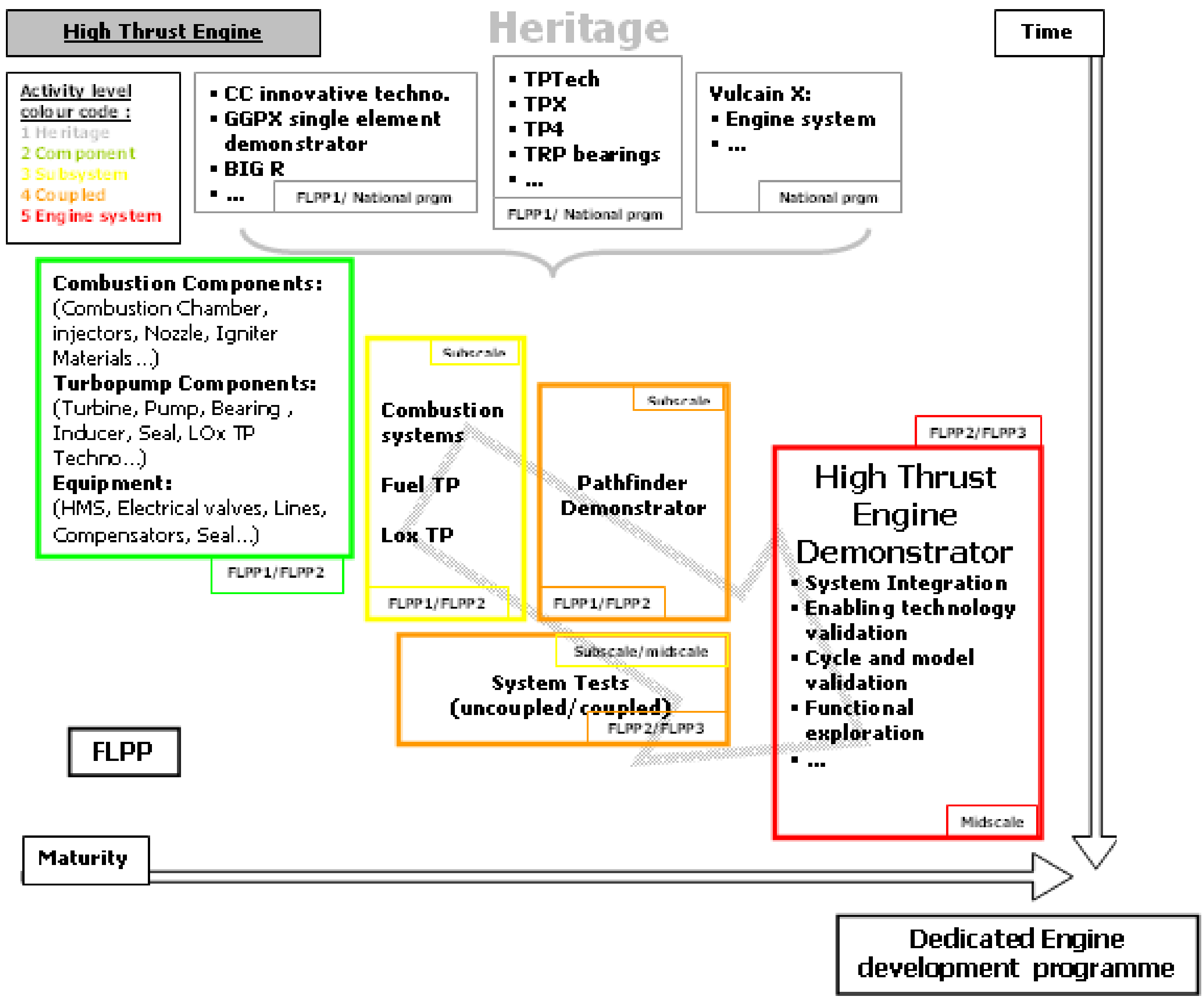


Fig. 3 Liquid Propulsion testing activities roadmap

This progressive validation and integration of Demonstrator subsystems will be achieved along two axes :

- *Combustion axis* which will integrate progressively the Main Combustion Chamber, the Preburner, the igniters, the Nozzle completed by a radiative skirt, Valves and Health Monitoring and Control system

- *Turbomachinery axis* which will progressively integrate the Preburner prototype, fuel turbopumps, the Oxygen turbopump, and possibly Health Monitoring and Control System

It shall be noticed that existing launcher propulsion passenger objectives will be considered in the demonstration and integrated in the overall logic. This activity will take most benefit of the integration of technologies compatible with FLPP objectives developed in national frame, if it can justify sufficient maturity around TRL 5/6 for risk monitoring.

More specifically, the High Thrust Engine Demonstrator System activities started in July 2007 have reached an important milestone in April 2009 with the performance of a HTE Demonstrator scale Key Point which confirms the choice of a mid-scale approach.

The main Demo characteristics which are foreseen to be frozen in the near future (within July 2010) are the Demo architecture, technological content and mechanical layout approach with the following associated reviews for the LOX/LH2 HTE Demonstrator: Preliminary Requirement Review in November 2009, System Requirement Review 2Q 2010, and Preliminary Design Review 3Q 2011.

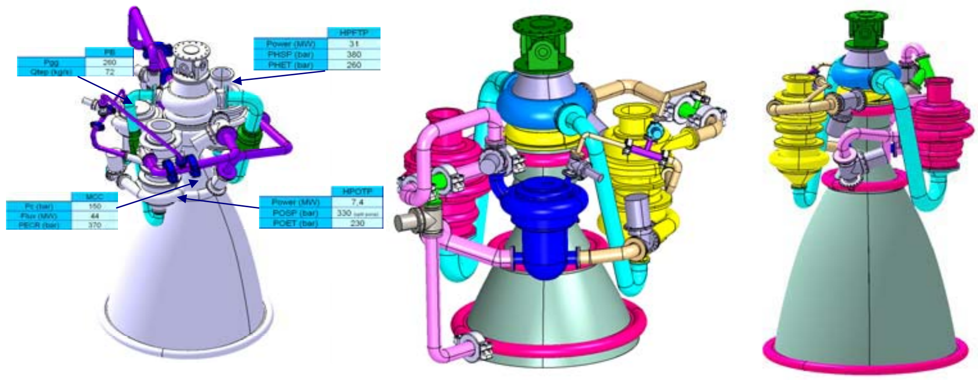


Fig. 4 Examples of functional characteristics and mechanical layouts of alternatives under study

Subsystem conceptual design studies were performed for example for the Thrust Chamber Assembly by EADS Astrium in order to support the HTE Demonstrator system study.

A unique iterative methodology was applied to layout key characteristics for the Main Combustion Chamber such as chamber contraction, chamber volume, and injection element loading with an appropriate element pattern and spacing as shown in the figure 6 below. The conceptual design served as input for the detailed design work of the injector head and chamber cooling circuit in order to estimate the thermo-hydraulic characteristics of the components.

The conceptual design work for the nozzle extension focused on the definition of an appropriate main chamber to nozzle interface area ratio, the pre-optimization of the envisaged Rao-contour given the nozzle expansion ratio of 43 for the LOX/H2 staged combustion solution, respectively 39 for the LOX/Methane one, and the estimation of the thermo-hydraulic characteristics versus coolant flow routing.

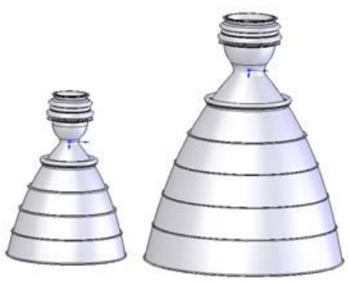


Fig.5 TCA layouts

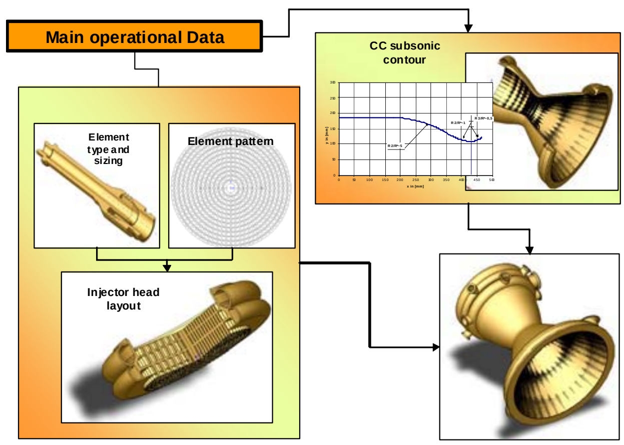
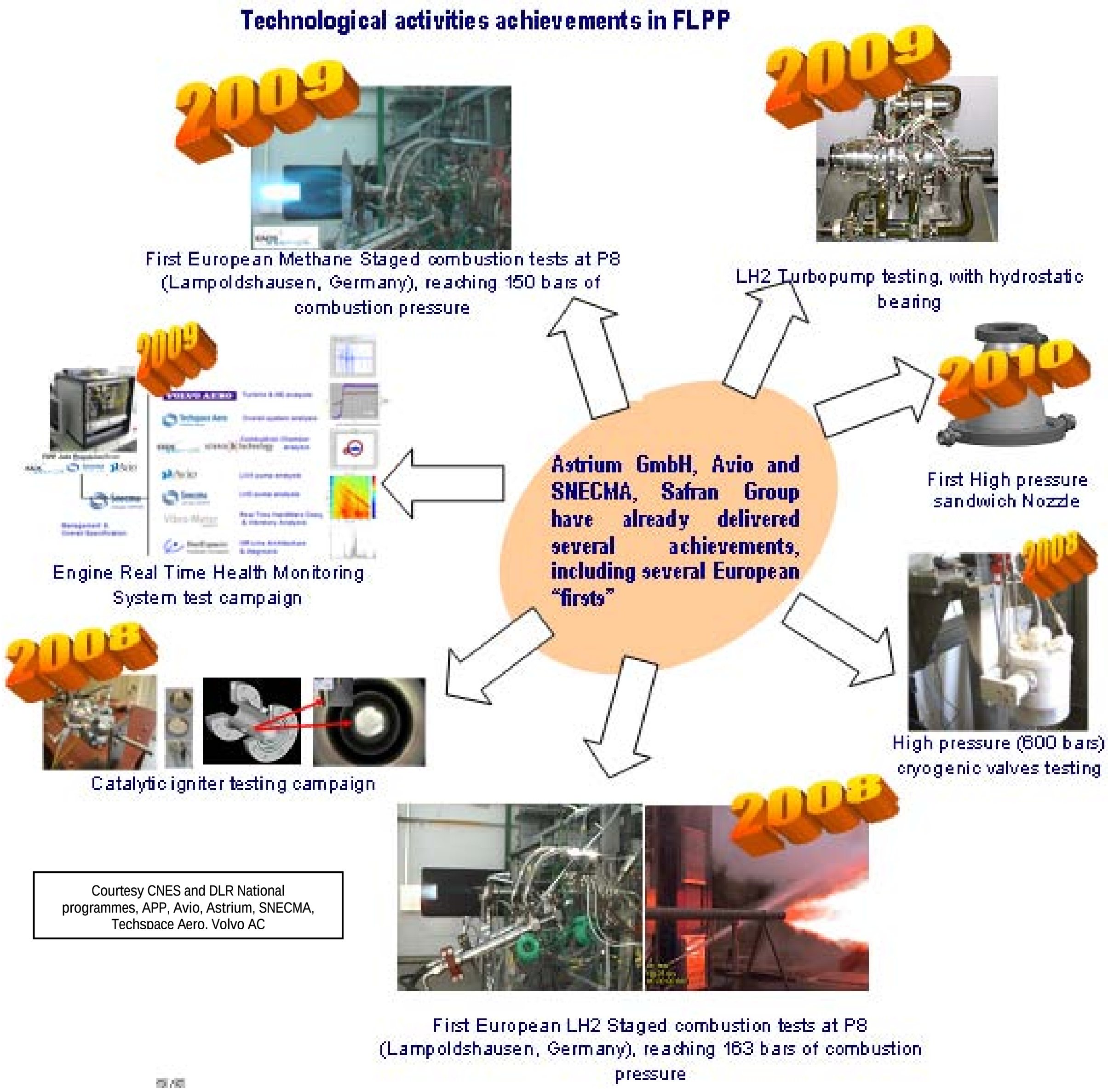


Fig. 6 Unique iterative Main Combustion Chamber Conceptual Design Methodology

VI. Highlights on parallel Main Stage Propulsion technology maturation

Early technology activity start, before completion of system studies, was possible because of the generic aspect of many critical technologies, common to most of the possible engine configurations. The continuity of the relevance of the technological activities is insured by their generic character and by the anticipation of the interest of staged combustion together with the necessity to expand the limits of European know-how in the field.



The first set of EADS Astrium's Thrust Chamber Assembly (TCA) technology maturation activities by means of hot fire tests were started in 2006 and centered on the staged combustion injection element technology as well as the combustion chamber heat flux characterization for both propellant combinations LOX/H2 and LOX/Methane.

In order to maximize the test exploitation and minimize the hardware manufacturing cost, an injector head design was chosen with modularity for fast exchange of injection element design features and for positioning of a large number of sensors to allow for a detailed thermal mapping. A further contribution to cost optimization was achieved by designing the hot gas injection elements for dual propellant use capability for both LOX/GH2 and LOX/GCH4. The figure below depicts the subscale injector head with the main components such as the fuel dome, the injection module, the oxidizer manifold, and the igniter ring.

Two test campaigns were performed with this design in cooperation with SNECMA, Safran Group featuring LOX/H2 in the first and LOX/Methane in the second campaign. In total, 26 successful hot fire tests with an accumulated hot fire time of more than 850s were achieved.

Both campaigns were marked with European firsts in terms of achieved combustion chamber pressure levels of 163bar and 150 bar in the LOX/H2 and LOX/Methane campaign, respectively. Further details on the performed test campaigns can be found in [R1] and [R2].

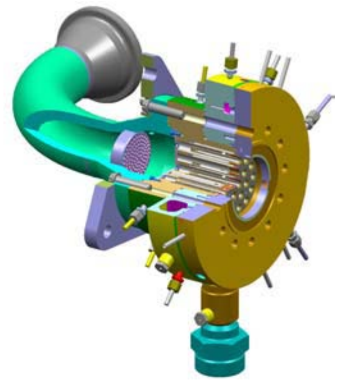


Fig. 7 Sub-scale Staged Combustion Injector

The upcoming hot fire TCA technology maturation activity linked to the sandwich manufacturing technology based Staged Combustion Engine Nozzle Extension (SCENE) will be performed in cooperation with Volvo Aero. This campaign is scheduled for the 1st quarter of 2010.

The next steps include the design and manufacturing of an enlarged subscale hot gas generating device and injector head featuring already HTE Demonstrator relevant design solutions. The activities will start in 2009 but will be mainly executed in 2010.

The final step of the TCA technology maturation logic before integrating the various subsystems and components into the HTE Demonstrator envisages coupled Preburner / TCA hot fire tests on the P3.2. These tests are scheduled around 2013 and will subject the final TCA-assembly to representative ignition, start-up and shut-down operation.

The FLPP Main Stage Propulsion technology maturation activities are supported by the German national programme TEKAN 2010 co-funded by DLR and Astrium GmbH as well as the Bayerische Forschungsstiftung. In these projects, new manufacturing technologies for combustion chambers are evaluated and tested; the injector technology will be extended to cover typical preburner mixture ratios enabling TCA tests later within FLPP that are more representative in regard to key subsystem design features. It is foreseen to stepwise transfer these technologies into the FLPP starting in the 3rd quarter of 2010 supporting already the design and test activities for the HTE Demonstrator.

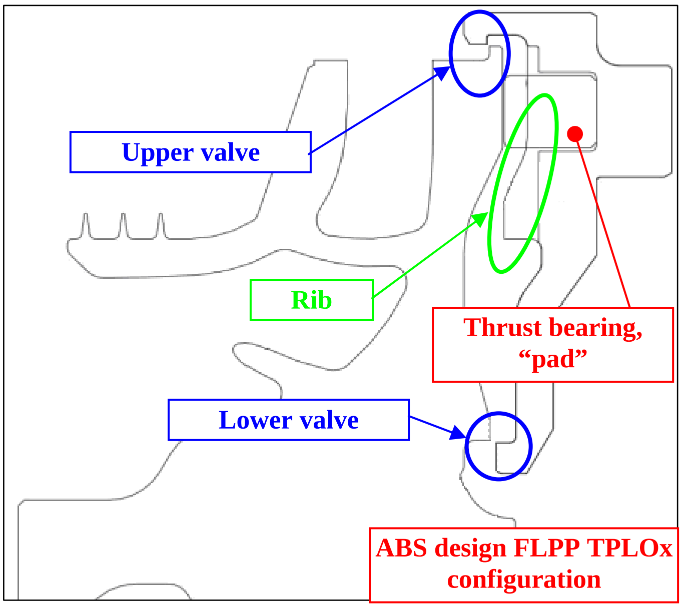
In the same Approach, LOx Turbopump Main Stage Propulsion technological maturation activities are focused on the following topics: Dynamic Seal Package (DSP), Split Pump and Axial Balancing System.

Design experience and know how heritage from Vulcain and Vinci programmes shows that DSP solution for HTE Demonstrator oxygen turbopump necessitate innovative designs, deriving from HTE Demonstrator performance requirements in terms of high pressure and temperature as well as lifting capability of seals at TPO DSP Level. Today, state of the art is not cannot meet requirements into a single design. Thus a logic to increase the TRL of an innovative DSP in view of a suitable design for the TPO of the demonstrator has been elaborated. Even the ambitious objective to reduce the Helium consumption to zero is considered, which requires a new seal concept and performance (multiple seals failure capabilities, multiple LOx/gas drains etc..).

Furthermore, the engine cycle will require the use of a split pump for LOx. It is characterized by a low specific speed; it must guarantee good hydraulic performance and stability in the full operating range; stall and instability problems may occur on the diffuser; low Ns implies a thin and high impeller that involves a greater manufacturing complexity.

Finally, an Axial Balancing System has been designed in order to avoid unacceptable axial loads to be supported by the spool bearings. The ABS uses as balance piston the back plate of the centrifugal impeller which, together with the "central housing", defines the balance cavity. The compensating thrust is controlled by two variable gap valves, located on the outer and on the inner diameter of the balance cavity.

The fluidic circuit obtained by the above mentioned valves located on the back face of the Impeller and by the labyrinth seal, located on the front-shroud of the Impeller, determines the LOx re-circulating flow rate toward the Impeller inlet. The values of the pressure acting on the Impeller back face and of the re-circulating flow rate are set by the axial position of the rotor that sizes the orifices of the two valves. The spool is free to move axially over a proper distance before the thrust bearings stop. If the rotor moves towards the pump, the upper valve axial clearance is reduced while the lower valve axial clearance is increased with consequent Impeller back-face pressure reduction. The Impeller back-face LOx flow rate is re-circulated together with the bearings LOx one to the Impeller inlet through several holes in the Impeller hub.



ABS design FLPP TPLOx configuration

During transients (start-up and shut-down of the TPO), axial loads will be supported by two sets of pads: one placed on the same back-plate and the other on the liner, interfacing with the front side of the impeller.

For what concern test benches, the joint French-German P8 test facility (Fig. 8), operated by DLR in Lampoldshausen, has been identified early in this program to provide the right capabilities for a quick step into the demonstration of key engine technologies, especially those related to combustion devices and nozzles. Already in operation since 1996 as a high pressure research and technology bench, the P8 supports propellant flow rates up to 14 kg/s for LOX, 3 kg/s for LH2, and 1.8 kg/s GH2, as well as a complementary water flow rate of 50 kg/s for cooling purpose. These supply conditions enable to reach combustion chamber pressures up to 170 bar involving a standard size of subscale hardware in the typical thrust class up to 40 kN and were therefore perfectly suited to meet the staged combustion engine requirements in the LOX/H2 domain set forth within the FLPP system studies.

For the methane propellant, the P8 had to be extended by an additional liquid storage tank with separate pressurization and feeding system. The investment in this additional methane supply system was limited taking major benefit of the extensive infrastructure already existing at the P8.

As mentioned before, further TCA subsystem tests at HTE Demonstrator level are planned on the P3.2 test facility in Lampoldshausen around 2013. This test position was originally erected in the course of the Vulcain engine development providing a GH2 and GN2 pressurization system up to 800 bar enabling to supply liquid hydrogen and oxygen over about 10 to 20 seconds for a TCA subsystem in the 1000 kN thrust class. The P3.2 is presently used to perform dedicated TCA tests for the Vinci expander cycle engine.

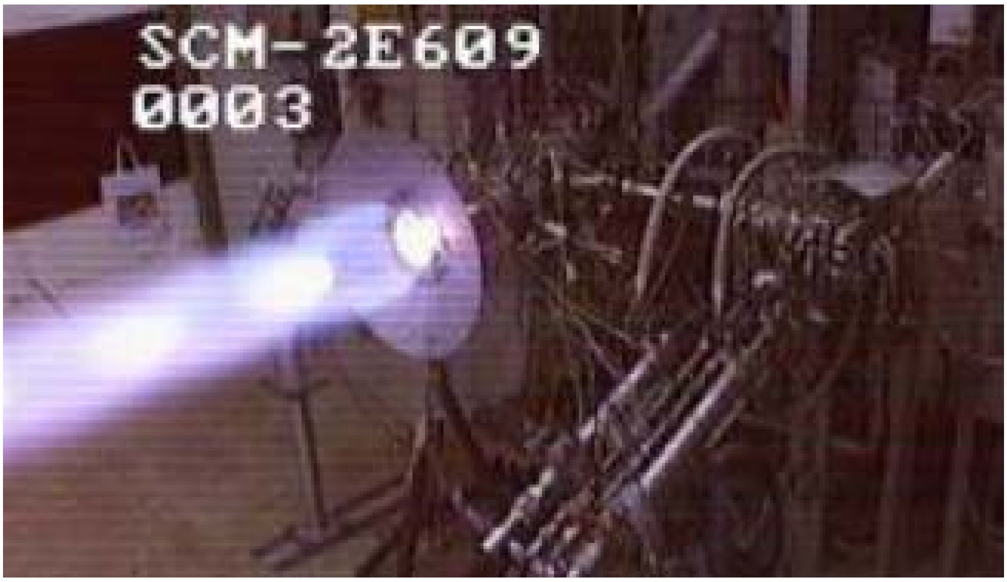


Fig. 8 P8 subscale test Bench (Germany)

Fig. 9 Fast 2 Test Bench (Italy)

Fig. 10 PF50 Test Bench (France)

Fig. 11 P3.2 Test Bench (Germany)

VII. Conclusion

FLPP High Thrust Engine Demonstrator within Main Stage Propulsion project:

- Secures the mastering of the enabling technologies to cover all the arising main stage propulsion needs foreseen in the mid or long term. Thus it answers to present and future Launcher propulsion requirements for Next Generation Launcher as well as existing family of launchers.
- Builds long term perspectives and creates new momentum for liquid propulsion in Europe. It will ensure, as a consequence, the quality, excellence and robustness of launcher propulsion Industry, key of the reliable and affordable access to space.
- Ensures staff motivation and attract new talents towards engineering disciplines in the space sector, in this sense it is the necessary complement to development programme to reach the minimum level of critical propulsion competences safeguarding with « Value for money » in terms of pure R&D spending
- Is a European project with balanced France, Germany and Italy contributions, and Industry Joint Propulsion Team
- Offers flexibility and growth potential to accommodate the inevitable evolution of the needs in Europe at the horizon 2020-25, condition to affordable and reliable propulsion, as well as safe and performing parallel launcher exploitation.

Next FLPP-3 phase to start in 2012 will cover completion of first set of sub-systems manufacturing and testing (prototype level), HTE demonstrator CDR, the Demonstrator manufacturing completion and final hardware integration, the Demonstrator testing, including test facilities adaptation and test engineering support. First integrated Demonstrator testing is foreseen in 2014.

[R1] R. Strunz, et al.: Status of LOX/GH2 Staged Combustion Activities within the Future Launcher Preparatory Programme FLPP, Space Propulsion Conference 2008

[R2] G. Le Forestier, et al.: First Firing test campaign of European staged-combustion Demonstration, 3rd EUCASS conference, Versailles, 6th-9th July, 2009