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FLPP ETID: Enabling Technologies for Future European Upper Stage Engines

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Abstract
Within ESA-Launchers, the Future Launchers Preparatory Programme (FLPP) the Expander Technology Integrated Demonstrator (ETID) project requirements focus on the full-scale demonstration of cost-effective, low-weight expander liquid rocket engine technologies that may be transferred into a future flight application. The overall goal is to reach TRL 5-6 for the chosen technologies with a planned hot fire test campaign under relevant operating conditions at P3.2, in Lampoldshausen, Germany. The start of the test campaign is planned in Q1/2018 lasting until Q3/2018.

1. Introduction

This paper is meant to give a project overview of the FLPP ETID programme with respect to the overall development logic and project status. The different products which are investigated inside the programme will be introduced. Focus is laid on the enabling technologies which have been selected for maturation through hot-fire tests at P3.2.

2. Project Overview

2.1 Industrial Setup

The industrial setup of FLPP ETID project is presented in Figure 1. The prime contractor is Airbus Safran Launchers GmbH located in Ottobrunn. The scope of work of ASL encompasses the engine system level activities, the TCA related work packages and the design and manufacturing of electrical driven engine valves. GKN Aerospace AB, Sweden, is providing the nozzle extension. Safran Aero Boosters, Belgium, is developing electrical driven engine valves that will be employed in one of the test configurations. Two different innovative ignition systems are investigated by the Carinthian Tech Research (CTR), Austria, and Aerospace Propulsion Products BV (APP), The Netherlands, respectively. The company MOOG in Ireland performs design and manufacturing of the engine piping demonstrators in Aluminium. The Czech Technical University (CTU) has been developing statistical approaches to be used for life computation and health monitoring concepts for rocket engines. The hot fire test campaign will be performed at P3.2 test bench of Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Lampoldshausen.

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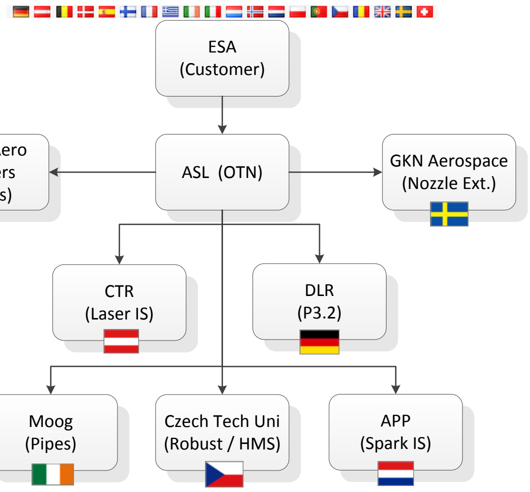

Figure 1: Industrial Setup

2.2 Schedule

As shown in Fig. 2, Phase 1 of the ETID project was kicked off in July 2013 covering the development of the demonstrator up to its Preliminary Design Keypoint (PDKP) and the subsystems e.g. nozzle extension (NE), thrust chamber assembly (TCA), regulation valve (RGV) up to the respective Manufacturing Readiness Keypoints (MRKP). In order to expedite the overall project schedule the design loops on demonstrator level and subsystem level were performed in a concurrent way.

With the PDKP of the demonstrator the last main milestone of Phase 1 has been performed in December 2015. Phase 2 that covers the manufacturing and the hot fire test-campaign until December 2018 has been contracted in March 2016. To allow for a smooth transition an ATP has been granted by the final customer ESA.

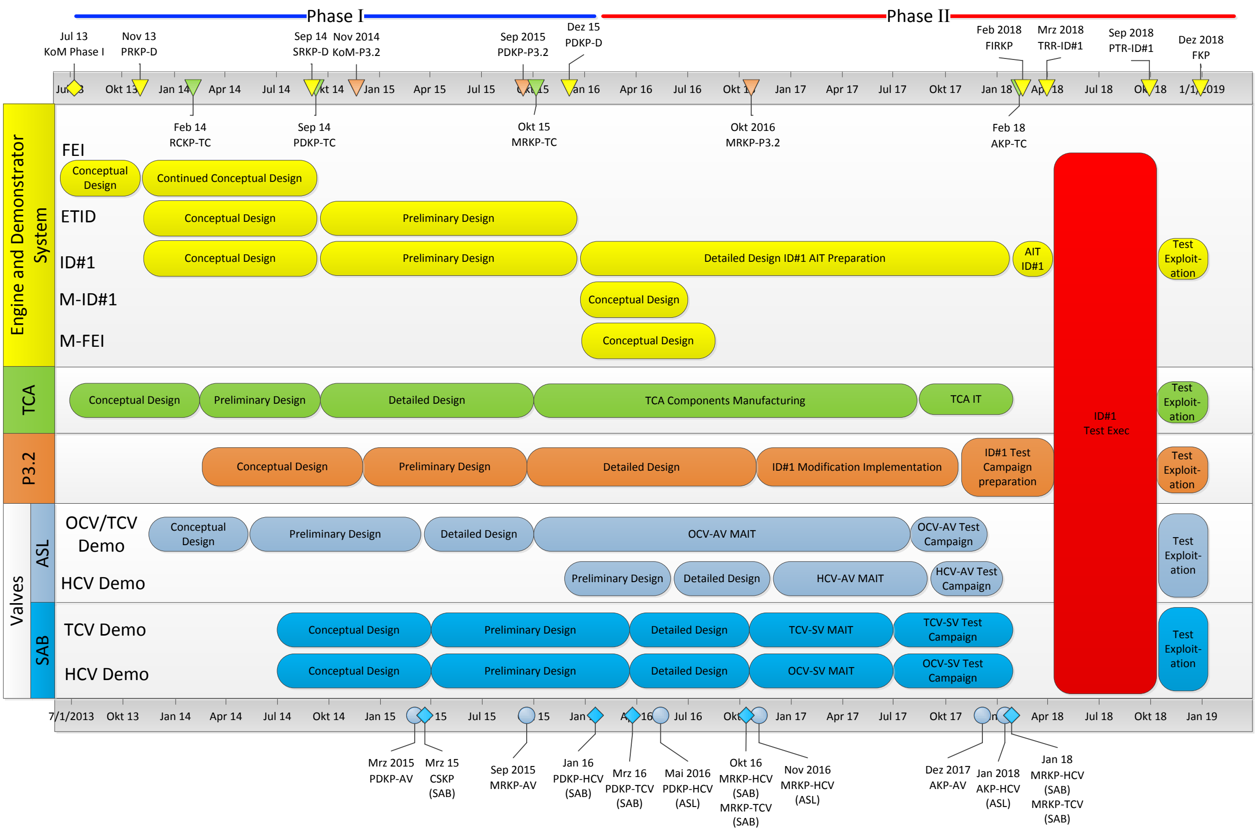

Figure 2: FLPP3 ETID project schedule

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2.3 Development Logic

A key element of the development logic is the concept of an integrated demonstrator. The term "integration" is meant here in a two-fold way. On one hand the development activities are embedded in overall scenario of a flight application product, within the ETID project the so called flight engine image (FEI). On the other hand the hardware that is to be manufactured will be hot-fire tested in an integrated configuration demonstrating also the interaction among the subsystems during operation.
Starting from the mission requirements for FEI provided by ESA ASL has performed a trade-off study with respect to the architectural and functional design of the expander cycle upper stage engine, see [3]. Table 1 presents the main design driving requirements of FEI.

Table 1: FEI requirements

	Unit	**Value**
Thrust	kN	115
Mixture ratio	-	5.5
Specific Impulse	s	> 457
Thrust to Weight ratio	-	> 45
Engine height	m	< 2.5
Life (cumulated)	s	1400
Life (cycles)	-	5

Fig. 3 provides the result of this trade-off i.e. the chosen functional architecture. The FEI is based on a fully integrated cryogenic expander cycle engine architecture that is operated with liquid hydrogen (LH2) and liquid oxygen (LOx).
The fuel mass flow for the regenerative circuit (RC) is provided by the pump-side of the hydrogen turbopump (HTP). While passing through the RC, the fuel is heated up to gaseous conditions before entering the turbines which are arranged in serial, i.e., the turbine of the HTP is passed first followed by the turbine of the OTP.
The operating point, the thrust level and the mixture ratio, of the fully integrated cryogenic expander cycle engine architecture is managed by two bypass lines; the thrust is managed by the thrust control valve (TCV) bypassing both HTP and the OTP turbines and the mixture ratio is managed by the regulation valve (RGV) bypassing the OTP turbine.
Due to the low tank pressure the pressure level of the oxygen massflow is increased by a hydraulic driven boost pump (OBP) before entering the pump side of the oxygen turbopump (OTP).
The hydrogen chamber valve (HCV) and oxygen chamber valve (OCV) serve to shut off the mass flows entering the main combustion chamber. During chill-down operation the hydrogen purge valve (HPV) and oxygen purge valve (OPV) are opened up.
The engine start-up is ensured using the expander effect of the hydrogen to spin up the turbines (without the help of an auxiliary power source) before the ignition of the combustion chamber.

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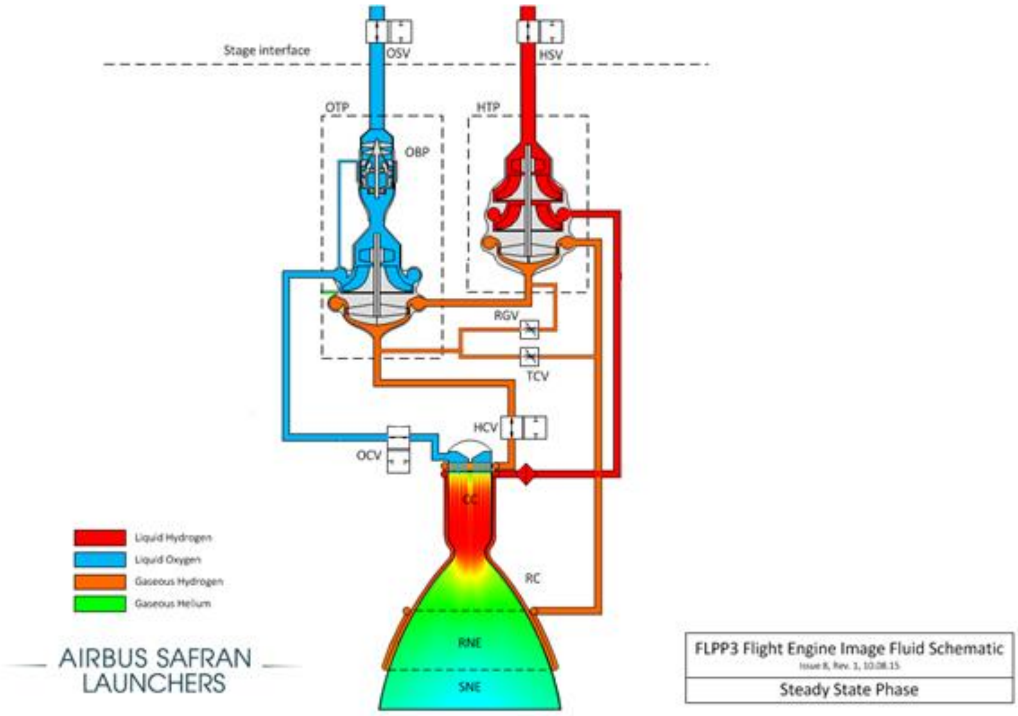

Figure 3: Functional cycle layout for FEI

Figure 4: FEI Design (PDKP-D status)

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In Fig. 4 the PDKP-D status of the 3D representation of FEI is shown. The mechanical layout is characterized by a powerpack configuration with 180 degrees between hydrogen and the oxygen turbopumps. The powerpack is located at the side of the thrust chamber. The HTP and OTP are supported by attachments to the thrust chamber. The actuators for gimballing are attached to the rigid interface ring between combustion chamber (CC) and nozzle extension (NE) reducing the forces acting on the throat region. The noticeable big bend radii of the engine lines are linked to the chosen line material (i.e. aluminium).
Following the integrated demonstrator approach the requirements for the subsystem level were derived from the functional and mechanical layout of FEI.
A full functional specification tree for the following subsystems has been elaborated:

- Thrust chamber assembly (TCA)
- Hydrogen turbopump (HTP)
- Oxygen turbopump (OTP)
- Engine control system (ECS)
- Integration components (IC)
- Valves (HCV, OCV, TCV, RGV, OPV, HPV)

These subsystem specifications also include the specific requirements and constraints arising out of the demonstration character of the ETID project. An example for such a specific requirement is the maximum diameter limitation derived from the existing test bench setup at P3.2.

Figure 5: FLPP3 ETID products

Fig. 5 presents this logic of requirements derivation based on the different products investigated within the ETID project. The basis and the leading product for requirements, trade-offs, technology and design choices is the FEI that is shown on the left side of Fig. 5.
The ETID product shown in the middle is taking into account all specific requirements linked to the demonstration itself e.g. the P3.2 diameter constraint. One can identify that apart from the nozzle extension no difference persists between the FEI and ETID subsystems. This fact is the core of the development logic of the project. ETID is in fact a demonstrator configuration testable at P3.2 which is combining all FEI subsystems.
In the budget and industrial frame of Phase 1 and Phase 2 of the project the ETID product (see middle of Fig. 5) with all subsystems cannot be realized. Compared to ETID, a reduced scope is contracted. Manufacturing of this reduced configuration, named ID#1, is currently ongoing and will be hot-fire tested starting in Q1 2018. Fig. 5 shows ID#1 on the right hand side. It consists of the following subsystems:

- TCA
    - Cardan spacer by ASL
    - Injector head by ASL
    - Combustion chamber by ASL
    - Nozzle extension by GKN
    - Laser ignition system by CTR
    - Direct spark ignition system by APP
- OCV by ASL
- TCV by ASL or SAB
- HCV by ASL or SAB

The technological content that is matured up to TRL5-6 in the frame of FLPP ETID by hot fire demonstration is allocated to these different subsystems.

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3. Selected Technologies

Based on the logic and requirement elaboration described above several key technologies were identified that are required to reach the stringent cost and weight targets for FEI. Lessons learnt gained in the VINCI development fostered the choices made.

3.1 Thrust Chamber Assembly Technologies

For the thrust chamber assembly the main difference compared to the VINCI expander cycle layout is the allocation of the heat pick-up functionality to the CC and the NE. The sandwich nozzle, developed by GKN, provides a portion of the overall required heat-pick up to the hydrogen to close the full-expander engine cycle. This architectural change on TCA level leads to weight reduction potential. A reduction of the cylindrical length of the CC and a lower interface area ratio for the interface position between CC and NE is achieved capitalizing the lower area specific weight of the NE structure. This TCA architecture contributes to the targeted engine Thrust-to-weight ratio of >45.
Fig. 6 presents the demonstrator TCA design with the cost-efficient injector head and combustion chamber, the metallic sandwich nozzle and the equipment (i.e. igniters, sensors, connector bracket) mounted.

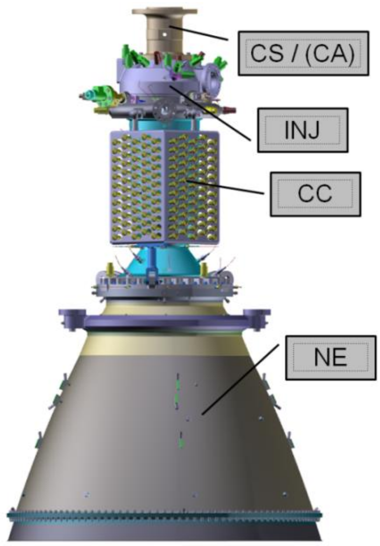

Figure 6: FLPP3 ETID TCA

To achieve the cost and weight target values for the TCA the following specific technologies and design choices were identified for the TCA. A detailed description and elaboration on all these technologies will not be given in publications. However, the following table shall give an overview of the number and variety of the investigated technologies in the frame of ETID project.

Table 2: Summary Table of Investigated and Matured Technology (TRL5-6 reached in Q3/12018)

Injector head - Variant 1
Cost efficient stainless steel injector with minimum weld seams
Integral milled baseplate incl. LOx-posts
No axial igniter access port

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Injector head - Variant 2
Additively manufactured ("3D-printed") single piece injector
Significantly reduced cost compared to Variant 1
Significantly reduced lead time compared to Variant 1
Combustion chamber liner and jacket
High strength electro-plated Nickel-Cobalt jacket
Low cost copper alloy liner
Hot gas wall design with increased heat-pick up
Nozzle Extension
Stainless steel sandwich design
Contributing to TCA heat pick-up
Radiatively cooled skirt
Ignition systems
Re-ignitable
Radial access via combustion chamber
Designed as line replaceable unit ("LRU") with operational advantage

The manufacturing and integration phase for the TCA parts is ongoing at ASL and its partners at the moment.

In contrast to other engines the injector head design is based on a cost efficient forged stainless steel raw part. The injector head body is milled on high speed machines leading to short overall machining times. The internal injector head layout design is simplified significantly. As no axial igniter port is required in the ETID design only two electron beam weld seams are sufficient for the INJ assembly reducing the production cost substantially.
To lower the manufacturing cost and lead time even further compared to this milled injector head additive manufacturing is applied. One variant of the injector head that will be hot-fire tested is a single-piece injector manufactured by additive layer manufacturing.
As the choice of the raw material is one of the biggest drivers, a cost-efficient copper alloy has been selected in order to reach the demanding RC targets. The design challenge is here to achieve the required hot fire life time with the given derated material characteristics.
In addition to the raw material of the liner also the composition of the jacket material has been changed compared to VINCI and Vulcain II. A plated layer consisting of Nickel and Cobalt leads to higher strength, faster overall process and better weldability answering to lower mass and cost objectives.
With negligible additional cost circumferential grooves in the hot gas wall are manufactured increasing the heat pick up in the cylindrical part of the CC. After the demonstration of the performance of this feature an additional reduction in chamber length is envisaged.
The architectural reasons for the metallic nozzle extension have already been provided above. For details about the sandwich nozzle design and the hydraulic balance please refer to [2].
Regarding the ignition system and the igniter port to the combustion chamber a new design approach is followed. Due to exchangeability and maintainability reasons the igniter is located radially at the combustion chamber at a dedicated igniter ring. This leads to a high gain in operability of the upper stage engine. Two igniter concepts are examined in the frame of FLPP ETID. An igniter based on laser technology and a so called direct spark ignition system. Both systems that allow for in-flight re-ignitions feature a very low mass. The ignition system provided by

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different partner companies will be demonstrated in the hot-fire test campaign in Q1 2018. The key requirements here are the reliability for ignition and the featured life under relevant operating conditions.
For detailed information concerning the laser ignition system please refer to [1].

3.2 Valves

The requirement for the FEI engine layout is that all engine valves are electrically actuated with the upper stage electrical supply voltage of 55V. In the frame of FLPP3 ETID project, ASL designs and manufactures demonstrators for the chamber valves (HCV and OCV) and the regulation valves (TCV and RGV). The valve development logic foresees that the technologies that are required for the 4 different valve types will be demonstrated with two specific demonstrator valves:

- An OCV/TCV/RGV demonstrator valve with an inner diameter of 40mm.
- An HCV demonstrator valve with an inner diameter of 80mm

For the particular design of the ASL valves for ETID, the following companies' structure was set up for the development of the valves:

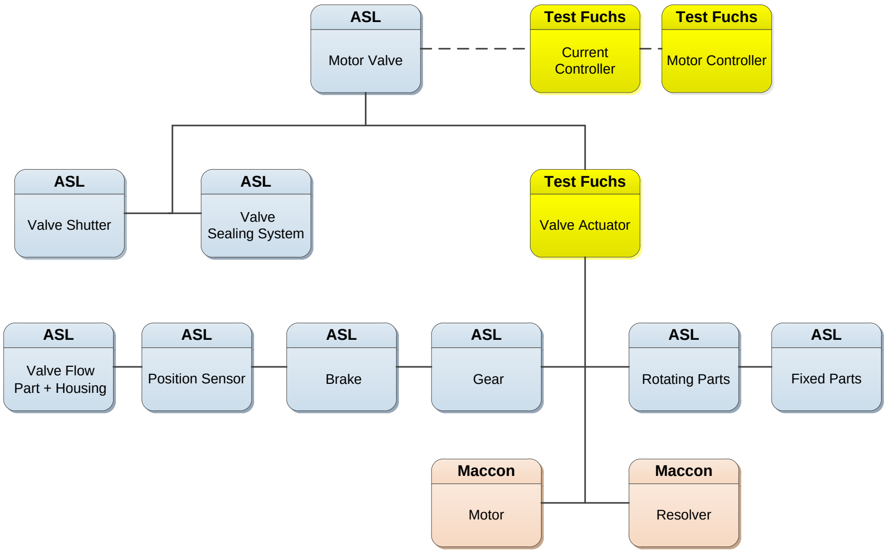

Figure 7: Company structure for the development, manufacturing, integration and test of the ETID valves

3.2.1. Demonstrator Valve OCV/TCV/RGV

The sketch below shows the final design of the OCV/TCV/RGV coaxial demonstrator valve mounted on the tooling specifically designed for the cold test campaign to be performed at ASL premises. This valve demonstrator features a co-axial design with the electro-actuator located in the outer part of the internal volume of the valve.

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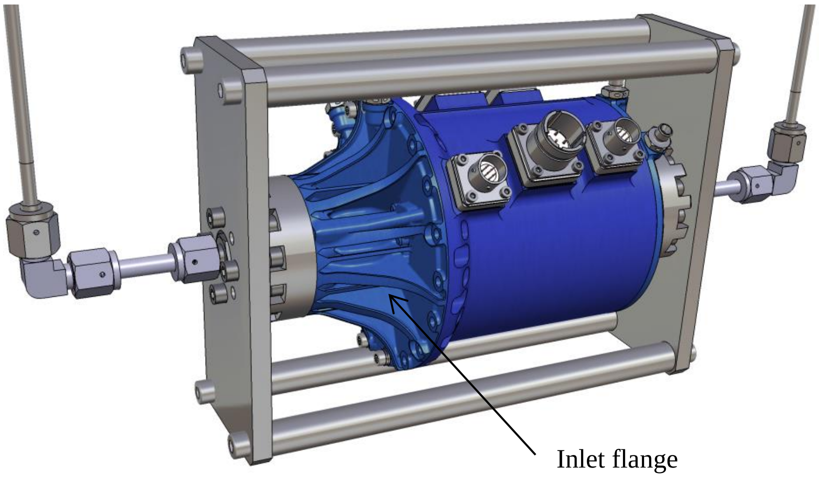

Figure 8: OCV/TCV/RGV demonstrator valve mounted for the cold test campaign (the geometry of the inlet flange is manufactured using an ALM technique)

The technological content linked to this valve is as follows:

- A brushless DC electromotor which has been developed by Company Maccon. The motor is fully redundant.
- A reluctance motor brake to reach bi-stable valve behaviour.
- A resolver for measuring angular position. The resolver acts on the reluctance principle.
- An LVDT for shutter position detection.
- A ball screw gear for the transmission of the rotatory motion of the motor to the linear motion of the shutter.
- The flow part features a movable, pressure balanced tubular shutter with a polymeric valve main seat.
- To keep the internal leakage values within requirements, a polymeric valve seat made of PEEK has been selected.
- Internally to the valve, a streaming cone (for an OCV function) or a mass flow regulation cartridge (for a TCV/RGV function) can be featured.
- The dynamic sealing systems of the valve are arranged as such that all external leakages will be collected in the sealing chambers and carried off by the collecting lines.
- The inlet flange of the valve has been manufactured using an ALM (Additive Layer Manufacturing) technique.

There are three different applications of this electric demonstrator motor valve: as OCV, TCV and RGV. The design of the motor valve was selected in a way that all three valve types are identical except for a flow part which is exchangeable with low effort due to a common interface to the valve. The OCV is a shut-off valve located in the main oxygen line of the demonstrator engine. The task of the OCV is to enable or to stop the oxygen mass flow into the thrust chamber. For this valve no regulation of the mass flow is necessary. The valve must have the ability to close the line leak tight. The TCV and RGV are regulation GH2 valves which consist of a flow part that has the ability to adjust the GH2 mass flow in order to regulate the turbine speed. A streaming cone has been designed for the OCV functionality with the purpose to allow a smooth transition of the LOx flow from the inlet to the main body of the valve. A mass flow regulation cartridge has been designed for the TCV/RGV (both valves share an identical design) which includes axial slots in such a way to match the required mass flow accuracy.

Currently, this demonstrator valve is finishing its manufacturing phase, with the cold test campaign of the flow part (without electric actuator) already being performed. This test campaign encompasses proof pressure tests, leakages test and shutter functional tests. The next steps are those to perform the qualification and the acceptance test campaigns of the complete valve prior to the delivery and ETID hot-firing testing at DLR in Lampoldshausen.

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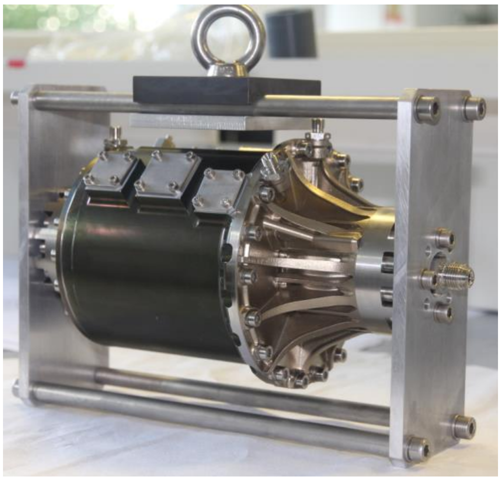

Figure 9: OCV housing (with inlet flange produced by laser beam melting) and campaign test at LN2 temperature conditions (77 K)

3.2.2 Demonstrator Valve HCV

The HCV (Hydrogen Chamber Valve) is a valve demonstrator featuring a co-axial design with the electro-actuator located in the inner part of the internal volume of the valve.

Figure 10: HCV housing (to be manufactured by ALM process)

The technological contents are the same as for the OCV/TCV/RGV demonstrator valve apart from the following differences:

- A cogwheel break is used (instead of a reluctance break) because the function of the valve is an open/close function with less number of activations than the OCV/TCV/RGV demonstrator valve.
- Bellows were accomodated inside the valve due to the fact that working pressures are lower than in the case of the OCV/TCV/RGV demonstrator valve.
- As a consequence of the good isolation function of the bellows, there is no need of a dynamic seal system.
- The ALM technique is also used here, in this case for the housing of the valve.

This demonstrator valve has successfully passed the Manufacturing Key Point Review. Currently, the ordering and manufacturing of the different parts (including the ALM housing) are in progress. This being done, the qualification

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and acceptance test campaigns at valve level will be performed in Ottobrunn. Afterwards, the valve will make part of the ETID hot-firing test campaign at DLR in Lampoldshausen during the year 2018.

4. Ignition Campaign at P8

In 2015, ignition tests with a full scale injector of the ETID setup were performed. These tests were performed as risk mitigation tests to check the robustness of the laser and direct spark ignition system for the later use with a flight-like combustion chamber setup on the test facility P3.2 in Lampoldshausen. The 2015 ignition tests were performed on the P8 test facility in Lampoldshausen.

Due to the bench's limitations in propellant mass flow rates, nominal combustion chamber load points could not be achieved during the tests. Instead, the tests aimed at to simulate the flight-like startup transient in terms of propellant mass flow profiles and temperatures. Additionally, the location of the interface valves on the setup was fully representative of the later application on the engine. A heat sink combustion chamber with supporting water cooling was used to limit the handling effort on the test bench.

With the laser igniter a total of 43 ignition attempts with were performed, resulting in 40 successful ignitions.

With the direct spark igniter a total of 29 ignition attempts with were performed, resulting in 25 successful ignitions.

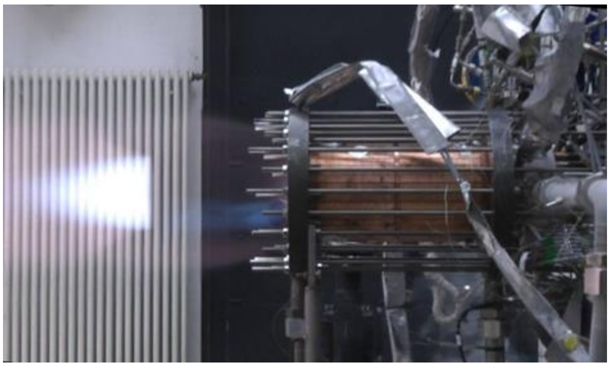

Figure 8: FLPP Fullscale Ignition (FFI) hot-fire test campaign at P8, Lampoldshausen

5. Methanization

Within Phase 2 of the FLPP ETID project the usage of methane as fuel for the FEI was investigated. The focus for the conceptual design activities and the trade-offs regarding the methane variant for the flight engine image (M-FEI) is the potential commonalties with the hydrogen variant. The imagined scenario could be the parallel application of FEI on Ariane and M-FEI on Vega. This would lead to cost saving impacts on both variants if the commonalities are exploited as much as possible. Design activities were already started at ASL and GKN to assess this methanization in the frame of the ETID project.

6. Acknowledgements

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