DOI: 10.13009/EUCASS2017-248

Overview of FLPP Propulsion Projects

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Abstract
Innovations in propulsion technology can be challenging to implement in launcher developments. The technical risk associated with low Technology Readiness Level (TRL) propulsion technologies translates into large risk for overall development projects. To reduce this risk, as well as cost and time to market, the Future Launchers Preparatory Programme (FLPP) of ESA-Space Transportation matures propulsion technologies through the use of large-scale demonstrators. The goal is to have ready-made technical solutions, which can be transferred to new or even existing development projects with minimal cost, effort and risk.

1. Introduction

Activities on preparing the future in space transportation face the challenge of building on the following requirements:

- To deliver game-changing innovations requiring several years of maturation, in a constrained budgetary environment
- To aim at mobile objectives – launcher configurations, missions, governance, industrial set-up
- To foster the efforts and means of many parties, from the ESA Space Transportation Directorate and other departments to national R&D efforts, industrial incentives, European Commission programmes, international cooperation, etc.

In order to meet these challenges, the FLPP NEO (New Economic Opportunities) has an integrated system-driven approach, helping new and possible high-risk/high-potential technologies to cross the technology “death valley”, reaching TRL 5 or 6 as part of full-scale representative demonstrators. Generic and transverse technologies are also matured in this way. The one-to-one scale of the demonstrators ensures the consistency of the technical specifications for the integrated technologies and efficient transitions to developments and flight applications. Integrated demonstrator projects foster European cooperation and provide attractive perspectives to technologies initiated in the frame of national programmes, ESA technology programmes such as TRP and industry self-funded activities.

The benefit of preparatory demonstrators is particularly important in propulsion, where the time and investment scales are large. Engine demonstrators are designed as prototypes assembling consistent sets of technologies. They are developed up to hot-fire testing, maturing the technologies in a system-driven project frame and in a representative engine environment. Thereby the technologies reach TRL6 fully integrated in engine systems, ready to be transferred to turnkey developments and flight qualification programmes. They can also support a running development programme by testing attractive alternative technologies embedded in the demonstrators.

Relying on the system-driven studies of FLPP, the baseline requirements of the propulsion demonstrators incorporate from the start specifications to secure the future competitiveness of the selected technologies. The technology portfolios and design features of the full scale demonstrators are carefully evaluated against competitiveness criteria pertaining to cost, mass, performance and industrial aspects such as manufacturing, assembly and operations. The range of potential future mission profiles is aligned on the most recent and relevant market analyses and forecasts. For instance the advent of electric propulsion satellites and large constellations lead to the preparation of broader and more flexible mission profiles of the upper stages. In addition, overarching requirements such as those gathered in

DOI: 10.13009/EUCASS2017-248

the Clean Space Initiative of ESA are duly taken into account, with concrete and important tasks being carried out on green propellants and design for demise. Hybrid propulsion is also matured within FLPP NEO, as it offers an interesting alternative to both solid as well as liquid propulsion, especially for small and micro launchers, being easy to handle, thottleable, reignitable, safe and green. For longer term applications, the potential of LOx/hydrocarbon propulsion and reusability to bring a supplementary round of cost cutting will be evaluated more concretely.

Table 1: Advantages of Integrated Demonstrators for Propulsion Projects

Flagship Demonstrator Advantage	Comment
From TRL 3 to TRL 6	Representative testing environment provided to all subsystems and technologies
Complete systems	Coherence and representativeness for all subsystems and equipment, integration of national/European technology developments into an overall system
Competitiveness	Early incorporation of requirements securing future competitiveness
Budget and schedule gains for subsequent developments	Typically 30%-40% savings, higher with synergies over several developments Industrialisation is already performed, seamless transfer to development
Demonstration of MAIT chain	Complete project cycles from design to manufacture to testing
Safeguard/ Improvement of skills	Challenging projects enhancing industry know-how Leverage of past developments and production
Risk-benefit balance	Managed technical risk for potential high gains allowed Management, QA and standards can be tailored for demos

This paper presents the different propulsion demonstrators currently under manufacture or in test, describing their current status and future perspectives:

- 5kN storable / green engine demonstrator
- 120kN Lox/LH2 expander-cycle engine demonstrator
- Hybrid propulsion demonstrator

It concludes on a brief description of the upcoming integrated propulsion demonstrators in FLPP NEO.

2. FLPP Propulsion Demonstrators

2.1 Storable propellant engine demonstration

2.1.1 5kN storable engine demonstrator

The goal of this project was to demonstrate technologies for an engine using storable propellants in the thrust class of 3 to 8kN, to prepare versatile propulsion solutions for space transportation. Potential applications are upper and kick stages, orbital transport and exploration missions (e.g. a lunar lander) [1].

Several critical technologies for such an engine were identified to be developed and demonstrated. These include cooling with NTO, film cooling, innovative injector design and acoustic absorbers, as well as lightweight propellant valves and nozzle extensions. All those technologies were not available for this thrust level within ESA member states. In addition to studies, several sub-projects for component design and testing were carried out, for example injector element studies and flow checks or experiments to determine the thermodynamic properties of NTO as a cooling medium in more detail than available.

To characterise the performance of the demonstrator design and the used technologies, two test campaigns, one using a regeneratively cooled combustion chamber (REG-1E; thermal investigations, steady state) and the other one using a capacitively cooled one (CAP-1; bomb tests, chamber length variation), were performed on the P2 test bench of DLR Lampoldshausen, operated by Airbus DS. Those campaigns showed a stable behaviour and good performance of the developed engine in transients and steady state over a wide envelope of load points.

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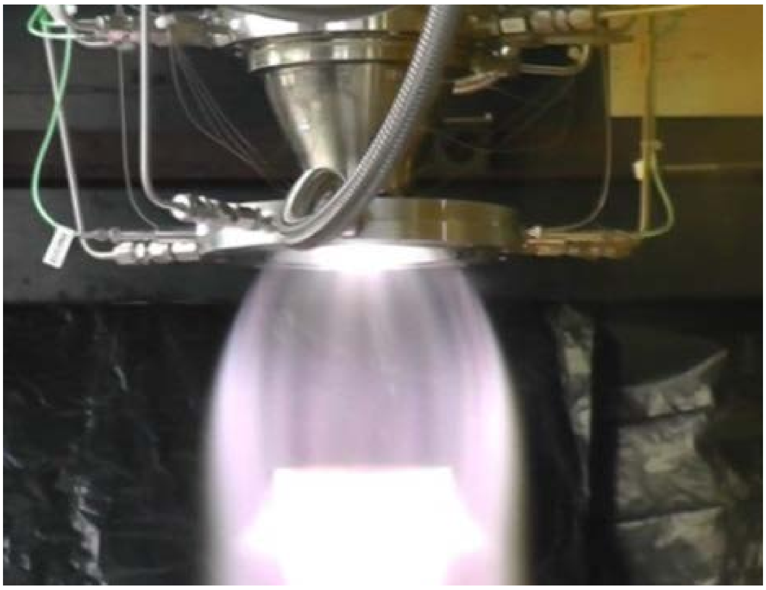

Figure 1: Hot-fire test of the storable demonstrator in regenerative configuration *(Ariane Group GmbH, DLR Lampoldshausen)*

Complementing the combustion chamber activities, technology development for engine components was included in the project to provide a complete high performance, low cost and low risk engine solution for future development projects. This included valve developments up to PDR status (one electrical, one pneumatic) and the development of technologies for a light, low-cost metal nozzle for the engine. These activities together with Franke of Switzerland achieved the production of two different seamless nozzle concepts, one with the flange welded to the nozzle, the other with the flange formed from the same metal sheet the nozzle was made of. Several units were made of each concept to demonstrate the stability of the manufacturing process.

Figure 2: Nozzle demonstrator with welded flange (*Franke Industrie AG, Ariane Group GmbH*)

The results, developed technologies and design of the original 5kN demonstrator are now the basis for several projects on advanced storable propulsion.

2.1.2 Additive manufacturing

Additive manufacturing (AM) will play an important role in manufacturing cost efficient, high performance engines in the future. Amongst a broad portfolio of activities on the topic, concerning the whole launcher, FLPP currently has

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an integrated project on maximising the benefits of AM for liquid propulsion components. Coordinated with cryogenic propulsion activities (see 2.2), the storable propulsion activities in this project aim at demonstrating an AM optimised design of combustion chambers and injectors in manufacturing, component tests and hot firing. The project will explore novel approaches for aspects such as propellant routing enabled by the new manufacturing method, while investigating the best strategies on how to overcome some of the challenges of this technology. The design of the AM optimised combustion chamber will incorporate a novel dual propellant regenerative cooling scheme not manufacturable with classical methods. This will enable a high performance, low-cost, low-weight engine. For the development of storable injector technologies, several different injector heads, employing different injection methods like impingement or coaxial, will be designed, produced and flow checked, to choose the best suited design. Limiting/eliminating the machining effort after printing, as well as the long term possibility to print chamber and injector in one piece, will also be investigated. The demonstrator, comprising combustion chamber and injector head, shall be hot-fire-tested at the P8 test bench of DLR Lampoldshausen. The results of this test campaign will verify the suitability on the production method for small scale combustion chambers and injectors, as well as help optimise the computer models (e.g. heat transfer) and design methods concerning additive manufacturing.

2.1.3 Green propellants

With the emergence of stronger regulations on toxic propellants and the need to simplify operations to reduce cost, green propellants will in many fields replace toxic storable propellants such as the combination MMH/NTO. Anticipating this trend, FLPP NEO is preparing to develop the needed technologies for a flexible application of green propellants in the propulsion of launchers and spacecraft.

The planned activities comprise a broad screening of promising propellant combinations and technologies, followed by component tests and later full scale tests. These activities will build upon the versatile 5kN storable engine demonstrator concept and corresponding technologies. Nevertheless, the application in other thrust classes will also be taken into account in defining the objectives and technology maturation plan.

The screening will concentrate on storable propellants, but might also take into account soft cryogenic combinations, especially for upper stage applications, as the operation time is usually limited to a few hours. Promising combinations shall be tested in sub-scale tests to evaluate their properties and performance. In addition, those tests will be used to develop and refine injector technologies. Here, the experience developed in the additive manufacturing activities (see 2.1.2.) can help implement fast development loops by applying rapid prototyping using AM production. Once the field of promising propellant combinations has been narrowed down to one or two, a full scale demonstrator shall be developed, manufactured and tested. This will then provide an established basis for a range of potential developments and applications, abolishing the dependence on toxic propellants.

2.1.4 Future technologies for storable propulsion

Apart from the mentioned technology development projects, FLPP is monitoring and assessing a variety of technologies with potential benefits in the realm of storable propulsion. This includes both existing technologies with spin in potential as well as emerging technologies. If deemed promising, those technologies will be included in integrated FLPP demonstration projects. One promising technology for future application are electrically driven propellant pumps (e-pumps). They provide the benefits of classical propellant pumps, such as low propellant tank pressures and thus weight, limited need of pressurisation gas and the potential for high combustion pressures, while providing a set of advantages. The use of batteries and electric motors instead of a gas generator and turbines to drive the pumps may reduce manufacturing and handling effort and increase safety. In addition, this technology leads to increased flexibility, both in vehicle design (e.g. placement of batteries) as well as in mission design (e.g. complex thrust profiles; restarts) and especially lends itself to long engine burn times at lower thrusts as encountered for example in upper stages and exploration missions. FLPP plans to implement technology maturation activities, to develop a modular e-pump solution, optimised for European propulsion developments.

2.2 The Expander Technology Integrated Demonstrator (ETID)

The Expander-cycle Technology Integrated Demonstrator (ETID) prepares competitive evolutions of upper stage propulsion by assembling technologies that pave the way for the next generation of cryogenic upper stage engines in Europe. The mission requirements document (MRD) for this engine was centred on key competiveness factors such as low cost, low mass and high performance through high-level specifications, however few technologies were imposed – the technology push was to come from industry responding to the MRD. Through its inherent versatility

DOI: 10.13009/EUCASS2017-248

the demonstrator was to optimise potential applications and also therefore synergies between applications. Considering “test as you fly”, the representativeness of the demonstrator was ensured by first defining a flight engine – Flight Engine Image (FEI), and then applying testing constraints to arrive at an engine demonstrator design – Expander Technology Integrated Demonstrator (ETID). The current phase is dedicated to the design, manufacture and test of a thrust chamber technology demonstrator – ID#1. The prime for this project is Ariane Group, with several sub-contractors for subsystem activities [2].

2.2.1 Design of a Flight Engine Image (FEI)

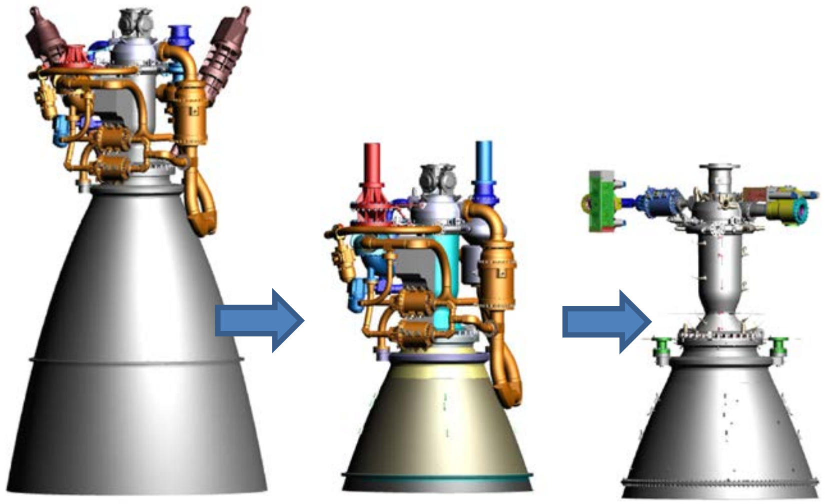
The first step of the project was to design a target flight engine, responding to the mission requirements. This “image” engine is used as a reference frame to identify the technologies to be matured, and to define the most effective demonstrator. The architectural trade-offs, computer simulations and modelling performed when designing the FEI as well as the outcome of the technology choices made in order to meet the challenging MRD requirements have resulted in a flight engine with the characteristics detailed in Table 2.

Table 2: FEI Engine Characteristics

Flight Engine Image (FEI)	
Engine cycle	Closed expander
Mixture ratio	5.0 – 6.0
Combustion pressure	56 bar
Vacuum specific impulse	> 457 sec
Vacuum thrust	115 kN
Nozzle area ratio	130.4
Pump inlet pressures	O_2: 2 bar H_2: 3 bar

2.2.2 Demonstrator architecture

A generic demonstrator architecture (“ETID”) was derived from the flight engine image design by applying the constraints of the P3.2 test bench. The main impact was a reduction in the nozzle length in order to fit the demonstrator into the vacuum box that serves to produce a low-pressure environment during the hot-fire testing start-ups. Although the nozzle length had to be shortened it was decided to maintain both a sandwich and a radiative part of the nozzle in ETID such that the junction between these two elements could be tested in a representative environment. A first physical demonstrator was then derived from ETID by focussing on the thrust chamber assembly, with some additional technologies. This demonstrator, ID#1, will test a full-scale expander cycle thrust chamber and nozzle in representative conditions at the P3.2 test bench. Figure 3 below shows this evolution from a flight engine design to a global engine demonstrator design to the first thrust chamber demonstrator, including some engine valves.



FEI **ETID** **ID#1**

Figure 3: Flight Engine Image, Expander Technology Integrated Demonstrator and Integrated Demonstrator #1 (*Ariane Group GmbH*)

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The thrust chamber for ID#1 had its Manufacturing Readiness Review less than two years after the start of the project, with long lead time items anticipated by more than six months. The manufacturing of the hardware for the ID#1 tests is currently on-going, as presented in chapter 2.2.4 below. Leading up to the successful manufacturing readiness reviews of the components, a number of technology tests, described below, took place in order to improve the TRL of the technologies proposed for ID#1.

2.2.3 Technology development testing

Successful sub-scale test campaigns at the P8 test bench in Lampoldshausen, Germany took place for both laser and direct spark igniters. A sub-scale additive-layer manufactured (ALM) injector head, coming from a DLR national R&D programme, was also successfully demonstrated during this test campaign. Continuing on from the sub-scale tests a further test campaign took place at the P8 with a full-scale injector head built to the ID#1 proposed design and with both laser and spark igniters in the same test campaign, igniting from a radial position. The laser and direct spark igniter were shown to operate in both ignition and re-ignition propellant conditions. Margin tests on the laser igniter were also able to prove the robustness of this technology with respect to power reduction and laser head misalignment. These new igniter technologies, with promising mass and performance, reliably enabling multiple ignitions, have the potential to be applied to other combustion elements, such as the gas generator of Vulcain 2 or the Vinci engine. Further work in this sense is now on-going with the laser igniter supplier.

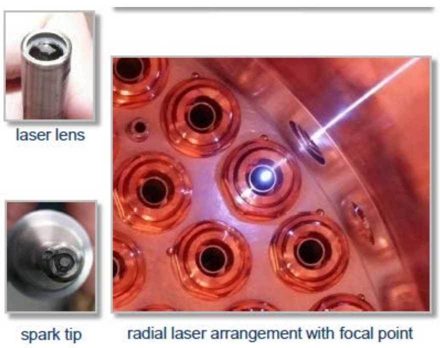

Figure 4: Igniter technologies tested on the P8 test bench (*CTR, APP, Ariane Group GmbH*)

Safran Aero Boosters, who are providing two electrically driven valves along with valve control units designed and produced by TAS-B, as passengers for the ID#1 tests, have also performed a number of technology tests on such elements such as GH_2-immersed bearings and rotative obturators, confirming the hypotheses taken during the design of the valves.

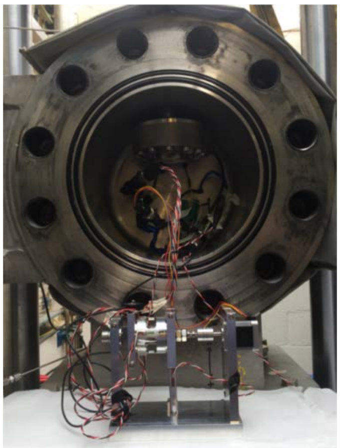

Figure 5: GH_2 immersed ball bearings test set-up (*Safran Aero Boosters*)

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2.2.4 ID#1 manufacture

Following the manufacturing readiness reviews for the demonstrator components the production of the ID#1 demonstrator is now fully underway. To ensure the availability of sub-systems for the complete test campaign, several examples of each sub-system hardware are produced. To maximise the technological return of the demonstrator testing, the multiple hardware of the sub-systems often have the same global design but have differences in the technologies applied. This results in up to five different test configurations on the test bench, such that the impact of each technology can be independently assessed – e.g. with or without grooves on the combustion chamber, AM vs. machined injector head. Table 3 below lists the different technologies that are part of the various test hardware under manufacture.

Table 3: ID#1 sub-systems and technologies

Sub-system	Technologies	Comment
Combustion chamber	• Cost-efficient Cu-HCP liner • High-strength NiCo jacket • Milled cooling channels • Internal grooves	*Ariane Group GmbH* See Figure 6
Injector head	• Selective Laser Melting (SLM) / Additive Manufacture (AM)	*Ariane Group GmbH* See Figure 7
Igniter system [3], [4]	• Direct spark • Laser igniter	*Carinthian Tech Research (CTR)* *Aerospace Propulsion Products (APP)* Radial access
Nozzle [5]	• Hydraulically balanced coolant flow • Laser Metal Deposition (LMD) • Carpenter 21-6-9 sandwich nozzle • Haynes 230 radiative skirt	*GKN Aerospace* See Figure 8
Valves [6]	• Electrically operated • AM parts, GH_2 immersed bearings • Family design for full engine valve set • Fault-tolerant controller	*Ariane Group GmbH* *Safran Aero Boosters & Thales Alenia Space Belgium* See Figure 9
HMS / ECS	• Rapid Prototyping Platform	*Ariane Group GmbH* Provides additional data channels for ID#1 tests

In addition to the manufacture of the test hardware, manufacturing verifications have prepared for and accompany the production process of these components and technologies. Several verification programmes have been undertaken on a number of processes, such as:

- NiCo electro- plating
- AM baseplate verification parts
- AM process verification (powder procurement, process surveillance and inspections)
- Weld developments and verifications including NDI and repair processes
- Forming, milling, laser-welding of sandwich walls
- Laser metal deposition (LMD)

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Figure 6: ID#1 Combustion chamber, with NiCo jacket (*ARIANE GROUP GmbH*)

Figure 7: ID#1 Injector head (*ARIANE GROUP GmbH*)

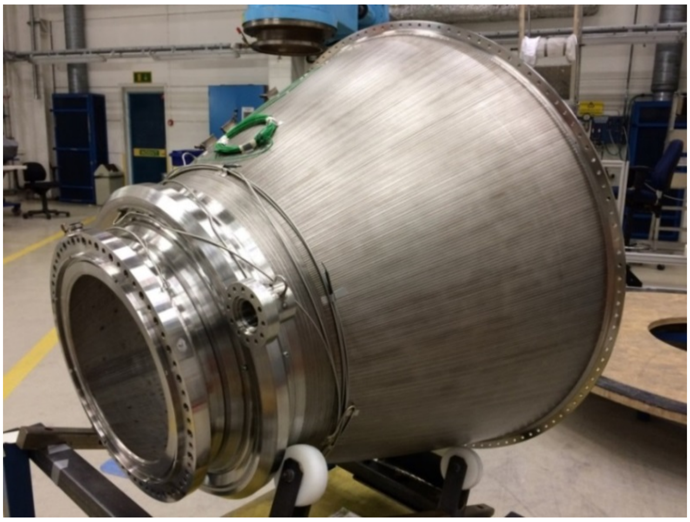

Figure 8: ID#1 Regenerative nozzle (*GKN Aerospace*)

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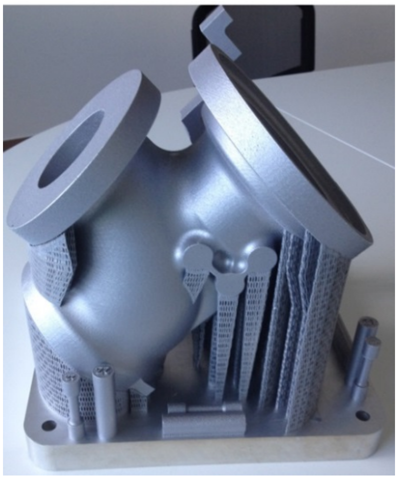

Figure 9: Hydrogen Chamber Valve AM casing, with its build supports (*Safran Aero Boosters*)

2.2.5 ID#1 – test bench preparation

ID#1 hot-fire tests are planned for 2017/2018 on the P3.2 test bench in DLR Lampoldshausen, Germany. This test bench offers high pressure propellant feeding capabilities enabling the firing of thrust chambers without turbopumps. The demonstrator will be mounted inside a vacuum chamber, with a supersonic diffuser at the nozzle end, such that the vacuum conditions for an upper stage engine can be simulated during the firing of the thrust chamber. At the P3.2, the project will also to make progress in the accurate measurement of thrust and high accuracy in other measurements, such as propellant mass flow. The ID#1 will be heavily instrumented, providing the maximum amount of experimental data with which to qualify technologies and analysis tools, the P3.2 must therefore design and implement a highly performant measurement system.

The activities with DLR-Lampoldshausen on the preparation of the P3.2 test bench were officially started with the Preliminary Design Review of the P3.2 test bench modifications. The Manufacturing Readiness Review of the test bench modifications was successfully passed at the end of 2016 and these modifications are now underway at the P3.2. The logic of the modifications, between the demonstrator and the vacuum chamber in which the tests will take place and between the vacuum chamber and the test bench is to prepare the pipes using an ID#1 dummy, a simple metal structure that has the same geometry as the final demonstrator. In this way the pipes inside the vacuum chamber were manufactured and fit-checked at the pipe supplier before the vacuum chamber and the pipes were shipped to Lampoldshausen. This is shown in Figure 10 below, where the blue structure is the ID#1 dummy.

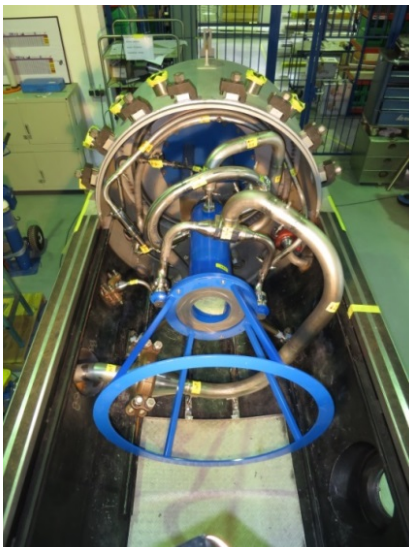

Figure 10: Fit-check of thrust chamber lines inside the vacuum chamber at the pipe supplier (*DLR Lampoldshausen, Ariane Group GmbH*)

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In Figure 11 below, the vacuum chamber can be seen mounted on the P3.2 test bench, with the ID#1 dummy inside. Assembly and modification work at the P3.2 is continuing in preparation for the arrival and mounting of the test hardware before the Test Readiness Review.

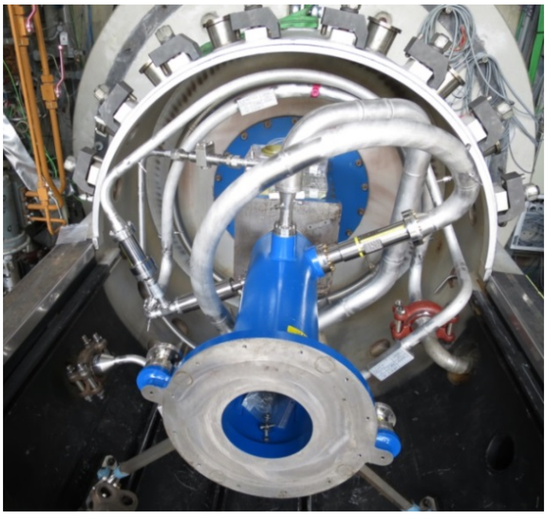

Figure 11: Vacuum chamber mounted at the P3.2 test bench with the ID#1 dummy (*DLR Lampoldshausen, Ariane Group GmbH*)

2.2.6 Prospectives and applications

Beyond the ID#1 test campaign there are a number of continuations in preparation for the ETID project.

Technology application to existing engine upgrades

Certain technologies from the project can already be investigated for direct implementation as upgrades of existing engines. These include among others:

- Laser igniter, for various combustion devices
- AM parts
- Cost-efficient combustion chamber materials, application of NiCo combustion chamber jacket

ETID next technology steps – ID#2

- Further reducing the costs, in particular with a wider scope of application of additive manufacturing
- Further reducing the mass, with the design and assembly of an aluminium regenerative nozzle in the place of the stainless steel nozzle
- Build on the results of the ID#1 to optimise further the image engine

LOx-Methane synergy

The ETID can present a real interest as a significant input for a LOx-methane expander demonstration. Such an approach would give way to real synergies of design and hardware between LOx-LH_2 and LOx-methane upper stage propulsions. It would also provide effective technological support to the upcoming Prometheus 1000 kN engine precursor.

The prospectives and technologies for the ETID project are summarised in Table 4 – see chapter 3 below.

2.3 Hybrid propulsion demonstrator

The hybrid propulsion demonstration project was started in FLPP, with the support of the Norwegian space agency (NSC). The company Nammo AS was selected as the prime contractor to set up a project to demonstrate large scale hybrid propulsion [7]. The main possible applications of this technology were identified as sounding rocket and nano-launcher propulsion. The project is structured in several stages, from small scale technology tests, through several scale-ups to flight demonstrations. Currently, the hybrid motor has been upscaled to a thrust of 30kN

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(Unitary Motor/UM), with a further scale up, as well as a flight demonstration of a single engine sounding rocket planned for the near future. With a further upscaling of the motor and clustering, thrusts of up to 450kN could be reached to propel the first stage of a nano-launcher.

2.3.1 Demonstrator architecture

A large series of small scale tests was used to define the design of the upscaled demonstrator, especially the propellant combination. In addition, they delivered valuable data for test design and evaluation. Finally, a propellant combination of HTPB as fuel and H_2O_2 as oxidizer was chosen for the upscaling step to 30kN. In the design, the H_2O_2 is decomposed by a catalyst and then injected into the combustion chamber walled with HTPB. Due to the high temperature and the oxygen rich atmosphere, the ignition is spontaneous, without the need for a dedicated igniter. For initial testing, the oxidiser is supplied by the test bench systems. A pressure fed supply system for a flight demonstration is currently being manufactured and tested. Later a pump driven oxidiser supply might also be added, especially for larger rocket stages.

The Unitary Motor design has been refined in several stages. First, a heavy design, called Heavy Wall Unitary Motor (HWUM), was manufactured and thoroughly tested, before going to a flight weight design, called the Flight Weight Unitary Motor (FWUM). This flight weight version features weight optimised casings, nozzle and flanges, as well as improved insulation and a slightly larger (14”) diameter to match typical sounding rocket dimensions and extend the burn time.

2.3.2 Unitary motor hot-fire test

The first test campaign of the Unitary Motor was performed in HWUM configuration from August 2014 till February 2015. During all tests the motor showed propulsion performance in line with predictions and especially good regression behaviour of the fuel grain.

Figure 12: Hybrid engine demonstrator hot fire test in heavy wall configuration (*Nammo*)

Based on the results from the HWUM test campaign, the design of the motor was optimized and the FWUM manufactured. The hot fire campaign for this configuration lasted from May 2016 till March 2017. As in the heavy wall configuration, the motor exhibited a stable behaviour and good performance, with a maximum burn time of 25s. During the campaign, the design and manufacturing processes were fine-tuned, to optimise performance and safety margins. In addition, advanced inspection (e.g. laser scanning of fuel grain) and modelling methods were developed, to help gaining output from these tests.

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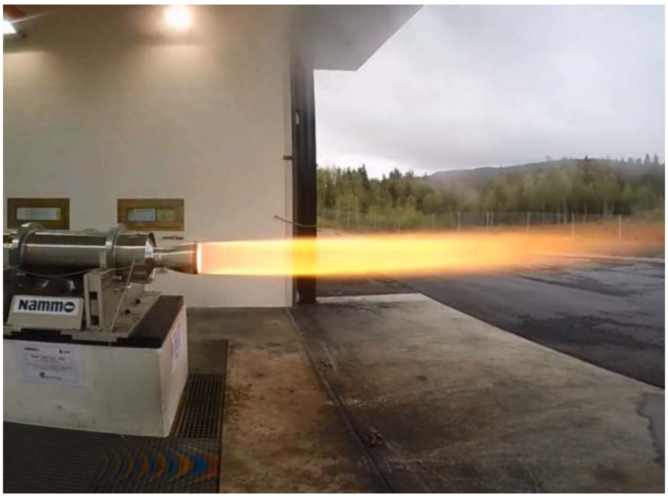

Figure 13: Hybrid engine demonstrator hot fire test in flight weight configuration (*Nammo*)

2.3.3 Flight demonstration

Based on the flight weight configuration of the Unitary Motor, a flight of a sounding rocket demonstrator, the Nucleus, from the Andøya Space Center is planned to demonstrate the function of the complete propulsion system and the other components in a flight environment. The design of this demonstrator features a propulsion system comprised of a slightly improved FWUM with a pressure fed, weight optimised oxidiser supply. The rocket will carry an adapted standard payload providing measurements, a video camera and telemetry. It will be launched on a trajectory above the North Sea with an estimated maximum altitude above 100km.

The design of the Nucleus demonstrator was started in 2016, based on the requirements for a small sounding rocket. Apart from the unitary motor, the design makes significant use of off the shelf components to reduce the recurring and non-recurring cost, while incorporating custom made parts and adaptations where necessary to achieve a high performance. Prior to the demonstration flight, there will be another ground test campaign to thoroughly test the complete Nucleus propulsion system including oxidiser tank, pressuriser tank, lines, valves and control system.

Figure 14: The design of the Nucleus sounding rocket demonstrator (*Nammo*)

2.3.4 Future activities on hybrid technologies

Future work on hybrid technologies in FLPP will be aimed at reducing production cost and weight, while increasing thrust and total impulse. To this end, there shall be efforts to develop motor components suitable for very low cost serial production, while delivering the same or better performance at lower weight. For the application in larger rocket stages, a further scale-up of the Unitary Motor is planned, leading to increased thrust and total impulse. As a method to further increase the thrust, the clustering of several motors will be investigated. To reduce the weight of the oxidiser feed system in those large rocket stages, turbo-pumps could be introduced to the design.

The Nucleus demonstrator could be transferred to an operational small sounding rocket, with the remaining effort being mostly in the field of industrialisation of the manufacturing. A bigger two stage sounding rocket, using a clustered first stage with a common oxidiser feed system for all motors, is also envisaged. Later versions of those rockets could use the throttling and restart capabilities of the hybrid motors to perform more complex flight trajectories than possible with conventional solid rockets and thus provide significant additional benefit to some

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experiments. One major application of the hybrid technology of Nammo shall be within a micro/nano launcher. This vehicle would likely feature three stages, with the lower stages consisting of clustered hybrid motors.

Due to the flexibility of FLPP propulsion demonstrator projects, spin off and spin in of technologies is possible during the projects progress. For the hybrid propulsion demonstration, this could mean a spinoff of technology to smaller propulsion applications like reaction control systems or ullage motors (re-ignitability) or a spin in of oxidiser pump technology. Possible technologies and applications are investigated throughout the project and the project scope is adapted accordingly.

3. FLPP NEO upcoming propulsion demonstrators

Based on the successful running of the existing demonstrators, presented in the chapters above, and the system analysis of the needs of the European space transportation sector in the years to come, the FLPP NEO programme proposal was presented at the ESA Ministerial Conference in December 2016. A comprehensive portfolio of activities was voted to answer the competitive long-term challenges of the European space transportation sector – European industry must actively and intensively participate in the currently progressing, highly dynamic industrial transformation – the so called Industry 4.0 – opening ways for new manufacturing technologies, leveraging the continued rise in computational power and on transferring digital design to the physical world through 3-D printing whilst advances in technologies must be regularly re-evaluated to re-assess their feasibility and impact.

With the goals of enabling further cost reductions for Europe's family of launchers - specifically targeting a drastic cost reduction of liquid propulsion engines, of securing access to advanced technologies and new industrial processes and of safeguarding the economic sustainability of existing industrial partners whilst also creating new business opportunities, the following integrated propulsion demonstrators, as presented in Table 4 below, were proposed in continuation of the existing projects. Such demonstrators fit into a European launcher technology roadmap approach, streamlining European critical competences to be at the level of worldwide industrial and technological state of the art. Following the successful conclusion of the Ministerial Council, these demonstrators are now under preparation within FLPP NEO. Noticeably, a 1000 kN ultra-low cost LOx-methane engine demonstrator (Prometheus) has joined the ESA FLPP NEO programme, after its first two years under the aegis of the French Space Agency, CNES.

Table 4: Upcoming propulsion demonstrators in FLPP NEO

Predecessor(s)	Demonstrator under preparation	Comment
5 kN storable	Green propellant demonstrator	E-pumps All-in-One AM propulsion parts Mission versatility via kick-stage Space exploration
ETID – ID#1	ID#2 *Prospective*	Fully integrated engine demonstrator Further cost reduction Aluminium nozzle All-in-One AM propulsion parts Launcher performance increase
	ID-M *Prospective*	Methanised engine demonstrator Engine synergy Methane technology maturation
Hybrid demonstrator	Sounding rocket	Micro/nano-launcher
National Programmes	LOx-hydrocarbon engine demonstrator	Ultra-low cost Reusability investigation Launcher competitiveness

4. Conclusion

Being at the upstream end of the development chain, the FLPP NEO engine demonstrators are the best moment to introduce new structuring requirements with high potential impacts on future competitiveness such as dramatic cost and mass reductions. The technologies are evaluated on their ability to reduce costs, deliver versatile performance and contribute to lean industrial processes for future evolutions of launchers but also space transportation for Europe. Integrated engine demonstrators are the most time and cost-efficient way to assemble and mature the elected

DOI: 10.13009/EUCASS2017-248

technologies up to real hot-firing conditions. Designed as prototypes, these demonstrators prepare well for their transfer into shorter and cost-effective space transportation engine developments.

This paper has presented in-depth the core FLPP NEO propulsion demonstrator projects that are currently in manufacture or undergoing test. The inherent versatility of the propulsion demonstrator projects means that technologies but also potential applications can be introduced during the course of the project:

- Anticipating to the need to prepare broader and more flexible mission profiles of upper stages, the storable propellant demonstrator matures an engine design that could also be applicable for a versatile kick-stage. In the meantime technologies such as additive manufacture, but also the investigation of green propellant combinations are introduced into the demonstrator.
- In terms of cryogenic propulsion, the Expander Demonstrator ETID prepares for more performance at lower cost of the European launchers and will provide technology maturation support to the ultra-low cost, LOx-hydrocarbon engine demonstrator Prometheus that has joined FLPP NEO.
- The hybrid propulsion demonstrator has the potential to be a key building block for a micro/nano-launcher.

Whilst these demonstrators are being brought to successful completion within FLPP, continuations of these demonstrators are under preparation as well as new demonstrators, all integrating new technologies and industrial processes as well as global trends such as increased computing power and big data to answer the competitive long-term challenges of the European space transportation sector.

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