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PROMETHEUS®: Precursor of new low-cost rocket engine family

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Abstract
PROMETHEUS® is the Precursor of a new liquid rocket Engine family designed for low-cost, flexibility and reusability. This Project, undertaken through cooperation between CNES and Ariane Group, entered in the ESA Future Launcher Preparatory Programme after the ESA Ministerial Conference in December 2016, with Germany, Italy, Belgium, Sweden and Switzerland joining France in the support of this Programme.
The aim of PROMETHEUS® programme is to design, produce, and test an advanced cost-effective 100-tons class LOX/LCH4 reusable Engine. This Engine targets flexibility in operation through variable thrust, multiple ignitions, compatibility to main and upper stage operation, and minimized ground operations before and after flight.
To reach those ambitious objectives, a design-to-cost approach is mandatory, as well as innovative technologies and advanced industrial capabilities; among the major levers, there are the extensive recourse to Additive Manufacturing for the production of engine components, the introduction of a full electric command system and the on-board Rocket Engine Computer (REEC) for Engine management and monitoring. In addition, Prometheus programme promotes the application of Agile and Frugal methodologies to get maximum profit in product innovation and value creation in operation. This paper presents the global status of Prometheus advancements and gives a specific insight regarding the last and upcoming milestones: 2021 first engine delivery, 2022 engines tests realization on Themis 1G and engine test campaign preparation for 2023 at P5 in DLR Lampoldhausen.

1. Introduction

Within the European launchers' fleet, Ariane 5 and Vega are handing over to Ariane 6 and Vega-C the leading objective of an European autonomy of access to Space as well as a reduction of the overall cost of their exploitation. However, it is crucial to invest additional efforts so as to prepare the future of European launchers and thus increase the competitiveness of the industry.

ESA Future Launchers Preparatory Programme (FLPP) implements both launchers systems' architecture studies and technology activities. These pave the way for options that target a substantial decrease of the launch cost (by a factor of 2 compared to Ariane 6). In this frame, a full liquid propulsion system was investigated.

In Europe, liquid propulsion is fully mastered since more than 40 years and benefits from a network of laboratories, industries, SMEs with world-class competences in all required fields (design, modelling, manufacturing, testing and operation of liquid rocket engines & stages). However, the commonly used propellant couple are either storable ones,

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either LOX/Hydrogen, since both power European Launchers since Ariane 1 (HM7, Viking, Vulcain, AESTUS for instance).

2. PROMETHEUS® Programme creation and goals

The aim of PROMETHEUS® programme is to design, produce, and test an advanced cost-effective 100-tons class LOX/LCH4 reusable Engine. This Engine targets flexibility in operation through variable thrust, multiple ignitions, compatibility to main and upper stage operation, and minimized ground operations before and after flight.

A first step towards this new generation of engines is the development of a demonstrator. This item's goal is to bring both technologies and LOX-Methane propulsion at the right level of maturity in order to move towards more concrete applications.

This is why the PROMETHEUS® (Precursor Reusable Oxygen METHane cost Effective propUlsion System) demonstrator program was launched under the momentum created by ArianeGroup and the French Space Agency CNES (Centrale National d'Etudes Spatiales) [1] and, thanks to the decision taken in December 2016 Council at Ministerial Level in Lucerne, transferred inside the ESA/FLPP-Neo programme in 2017. This allowed European Partners to join the project as sub-contractors while ArianeGroup remains prime contractor.

The high level requirements of the cost-effective engine precursor aim at covering most of the needs (maturation of the LOx-Methane propulsion, light mass, thrust level, reusability features …) of an operational engine for a next generation launcher. The main challenges assigned to this project were:

- Breakthrough in terms of production cost;
- Breakthrough in terms of manufacturing processes and cycle (broad use of additive manufacturing, low cost subsystem technologies, participation of suppliers from non-space mass production industrial sectors, fast and robust assembly procedures);
- Challenging schedule, relying upon a combined agile and lean management scheme, including technological and organisational aspects, riskier development steps, short design cycle; in-flight demonstration on THEMIS (reusable stage demonstrator);
- Pragmatic design-to-reusability approach, engine's health diagnosis in real time to justify reuse without retrofit, large range throttleability, electric command, while maintaining the objective of a cost-effective engine;
- Excellent thrust/weight ratio, and full use of the performance potential of the LOx/methane propellants;
- Robust engine design, guaranteeing high reliability level including reuse;
- Versatile engine, in terms of application (single engine vs multi-engine propulsion bay, lower and upper stage), use in flight (re-ignition, thrust throttling …), ground maintenance (single use vs reusability).

A full-scale demonstration in the thrust class of 1000kN is then proposed to address these objectives.

3. PROMETHEUS® demonstrator description

3.1 Engine Architecture

PROMETHEUS® engine is a gas-generator engine as for Vulcain or HM7B. This fully mastered cycle depicted in Fig. 1 is adequate to meet the requirements in terms of cost, performance and reusability.

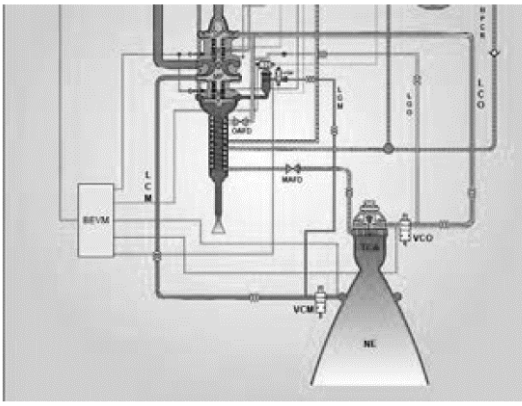

Figure 1: PROMETHEUS® engine cycle

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This engine cycle is composed of:
- A regenerative cooled thrust combustion chamber;
- A gas generator;
- 2 chamber valves (VCO and VCM);
- 2 gas generator valves (VGO & VGM);
- A mono-shaft turbopump.

The demonstrator reference point is 1000kN in vacuum conditions but the demonstrator intends to have an interval of operating thrust from 300kN at sea level up to 1000kN at sea level. This range of thrust is required for the reusability and versatility while reaching the low-thrust point is a technical challenge. To do so, a control of the engine is mandatory with electrical valves (chamber valves as well as gas-generator valves) that is an improvement with respect to Ariane 5 Vulcain 2 in-flight operating point control strategy. The control and thus throttability is performed with the REEC (Rocket Engine Electric Controller). Finally, contrary to Vulcain 2.1 engine, the engine architecture is based on a deported powerpack which embodies the gas generator and the turbopump.
Furthermore, in order to ease the assembly and maintenance, a specific and simplified frame was created to ensure the Plug&Play stage/engine interface. Finally, as design to cost is a key factor for this engine, MRO (Maintenance and Repair Operations) & RAMS (Reliability, Availability, Maintainability and Safetys) are taken into account through the identification of failure mode & maintenance plan definition.

3.2 Engine Control

European cryogenic operational engines have either one or two operating points. The introduction of an engine control required by the reusability aspect is a breakthrough for the next generation of engines.
To achieve this goal, the main pillars are the valves (and their actuators), the REEC and the Engine control applicative software. In this field, the REEC acts as the "brain" of the engine since it acquires the measurements, controls the valves actuators and runs the software.
The three elements altogether grant the control of the engine in closed loop. The profits of this feature are especially the reduction of the engine sub-systems domain, the rejections of disturbances (external and internal) and the possibility to suppress the tuning of the engine.

3.3 Health Monitoring System (HMS)

To foster the reuse of the engine, the development of health and usage monitoring system is mandatory. This system can be used in flight also after the flight. These two constituents are called Real Time HMS and Differed Time HMS. The overall logic for HMS is depicted in Figure 2.

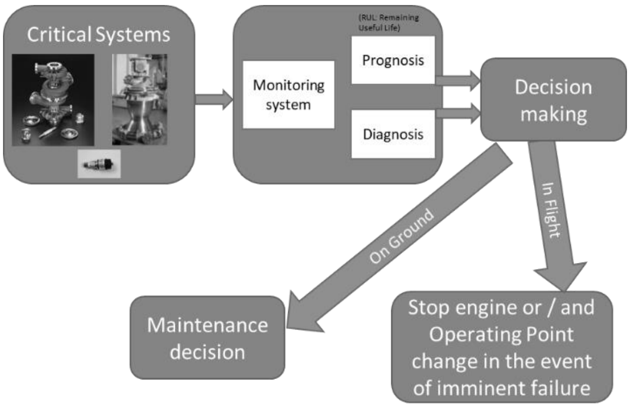

Figure 2: HMS Logic

3.4 Additive manufacturing processes

Additive manufacturing is now widely used because of the maturation acquired in the last decade. In Europe, the use of this technology applied to liquid propulsion reaction engine has boomed in the same time interval [2] with parts on

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Vinci, Vulcain 2.1. This technology offers new possibilities in terms of design and optimization of mass. This is entangled in the design to cost approach as well as the agility that are at stake in the PROMETHEUS® Programme. Therefore, additive layer manufacturing was extensively used for the engine, with production of large casing, pump impellers, turbines (Figure 3). New processes are also developed such as cold gas spray for the production of the combustion chamber [3].

Figure 3 : Turbine parts (courtesy of GKN)

4. Technical status

4.1 Engine demonstrator

Some insights of the development of the engine and its subsystems were given in reference [4] & [5].
It was shown that on the subsystems major achievements were fulfilled:

- The gas generator and its valves were successfully tested in P8 together with a closed loop control;
- For the Thrust chamber, maturation and development activities were on-going within the ESA FLPP NEO CORE technological maturation Programme frame. For example, Cold Gas Spraying (CGS), for which a successful demonstration has been already achieved last year on ETID scale, has been selected because making possible production of large components under short production cycle.

End 2021, the first engine demonstrator was assembled, as shown in Figure 4, and delivered in the historical Viking production building in Vernon where more than 1000 Viking engines were delivered for ensuring Ariane 1 to Ariane 4 flights.

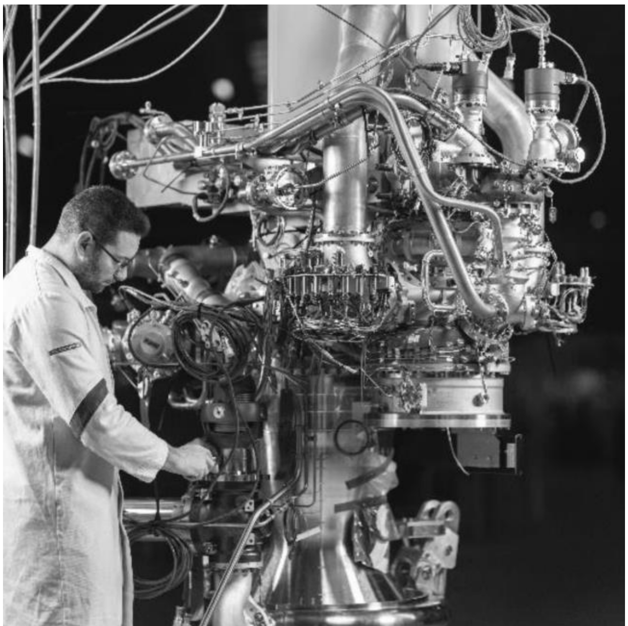

Figure 4 : First PROMETHEUS® engine delivered

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The assembly was then pursued in Vernon on Themis 1G thrust frame in the beginning of 2022, as shown in Figure 5.

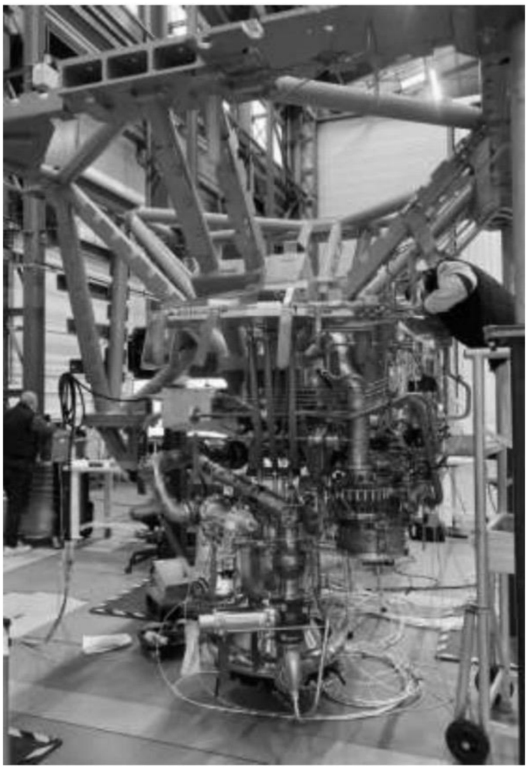

Figure 5 : First PROMETHEUS® engine assembled on THEMIS thrust frame

4.2 Test bench preparation

P5 test bench (shown in Figures 6 and 7) in Lampoldshausen need to be adapted in order to accommodate the engine PROMETHEUS® but also to be able to supply methane through a dedicated tank (with pressurization).

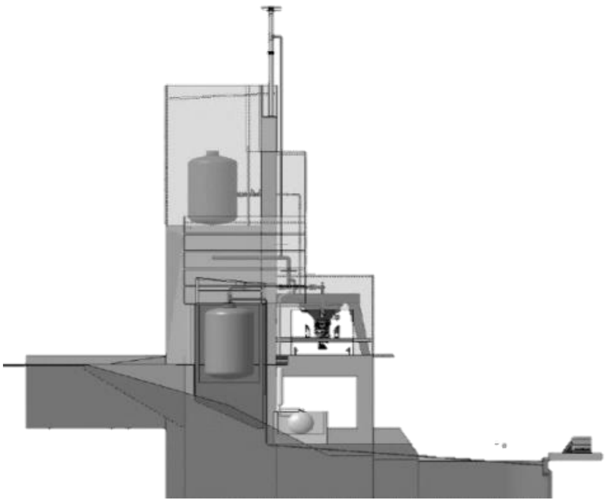

Figure 6 : P5 illustration (DLR Courtesy)

These adaptations are accompanied with:

- Measurement Control and Command System (MCC) extensions, to ensure compatibility with engine REEC.
- Development of mechanical elements such as the Thrust measurement system (TMS) and feedline adapters supplied by Magna Steyr, in order to cope with new engine interfaces.

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During the second half of 2021, the methane tank has been installed and civil works were completed yearly 2022. Fluid supplies (both cryo and gaseous ones), flarestack, cabling, and MCC extensions manufacturing are under finalization, and are foreseen to be finished during summer 2023. R1/R2 acceptance should start then from July 2023 and end of 2023.

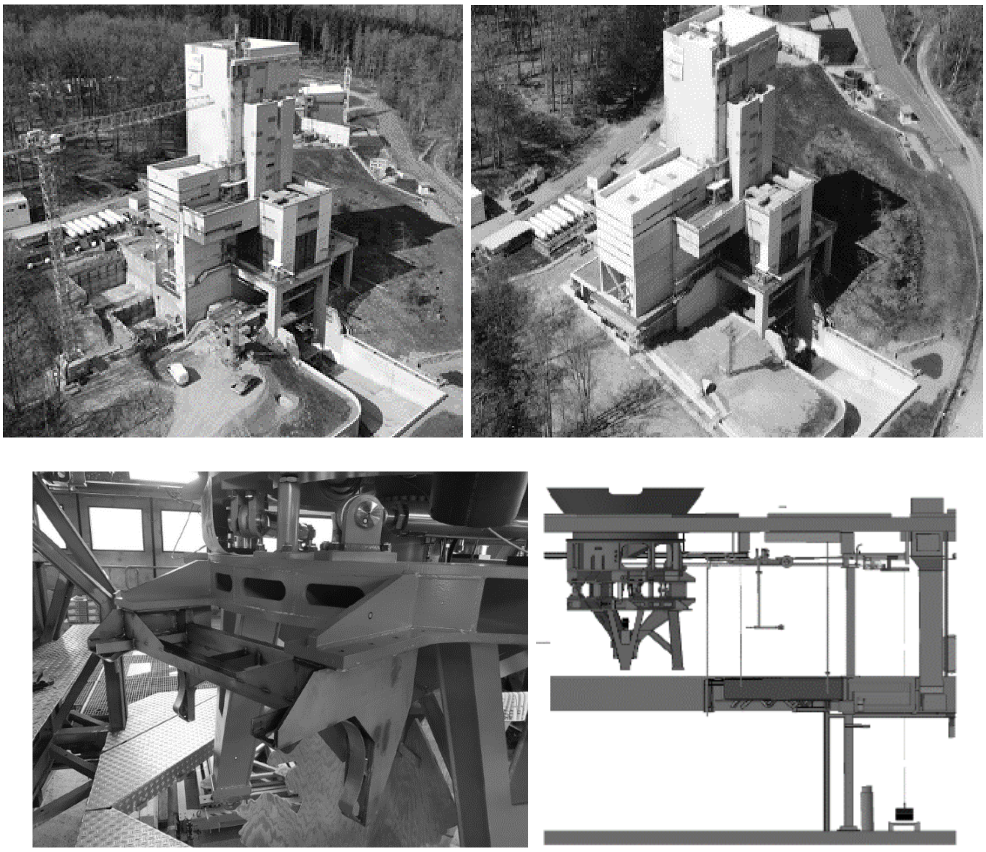

Figure 7: P5 under modification (DLR Courtesy), the aerial view of P5 during and after civil works (top) and the TMS implementation (bottom)

4.3 Engine demonstrator test campaigns

Following the France Relance recovery plan announcement [6], a specific work was performed to accelerate the engine maturation planning through the engine first test campaign while derisking PROMETHEUS® with regard to upcoming P5 engine tests as further detailed in [7]. This was made possible thanks to the opportunity represented by THEMIS stage demonstrator running in parallel to ensure the synergy. Both, engine and vehicle demonstrators were completed to be used as a test bench. For instance, a duct was built to allow hot firing test duration up to 20-40s This test assembly allows high agility for test campaign allowing to dismount the engine for refurbishing if necessary.

First filling of the tanks as well as the first chill-down of the engine in liquid nitrogen were performed in summer 2022, paving the way to the first ignition of the thrust chamber and the spin-up of the turbopump performed in September 2022. Following this test, additional ones were realised in the past months leading to cover the so-called ignition test campaign. The current target is to continue the test campaign in Vernon up to the availability of P5 bench which will bring extended capabilities for test duration. As the project follows an incremental approach, the targeted evaluation of the engine & sub-systems performance and behaviour (including engine closed loop control) will be performed opening progressively up the domain and cumulated duration.

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Figure 8: PROMETHEUS® Engine demonstrator during hot-firing tests

5. Way forward 1200kN

Following consolidation of the Launcher system architecture, it appeared that there was a need for an increase of thrust for PROMETHEUS®, from 1000kN to 1200kN at vacuum conditions. This augmentation of thrust drove the edition of new technical specifications, mostly based on the 1000kN engine's ones, apart from overall performances and interfaces specification. A design derived from the existing one was therefore reoptimized and the design and justification phase were successfully performed.
This engine development will carry on in parallel of the 1000kN one and will inherit from all return of experiences from the ongoing firing tests in a continuous optimisation loop.
Currently, the PROMETHEUS® Mark2 detailed definition is under final convergence and the manufacturing of the first parts will start this year. Thanks to the recent ESA Ministerial Conference held in Paris in November 2022, it was decided to support the engine development up to its final validation.

In parallel to this, ESA and ArianeGroup are exploring the applicability of the low-cost technologies, pushed by the Lox/methane demonstrator, to be extended to a Lox/hydrogen version of the PROMETHEUS® engine. A first PROMETHEUS®-H engine architecture has been proposed last year and specific demonstrations objectives are pushed not only in ESA frame but also thanks to European Commission initiative, Horizon Europe. Last November the ENLIGHTEN (European iNitiative for Low-cost, Innovative & Green High Thrust Engine) project was kicked-off with the overarching objective to complement the ESA PROMETHEUS® development of key technologies for rocket engines, in order to create a family of reusable, high-power engines using bio-methane or green hydrogen. Final aim for ENLIGHTEN will be to test these technologies on a Lox/hydrogen engine platform at P5 at end-2025.

6. Conclusions & Acknowledgements

The PROMETHEUS® programme paves the way for the preparation of the future of space transportation. The engine concept based on a gas generator cycle with LOX and Methane has ambitious targets, for costs, manufacturing time & performance (reusability, throttling & reignitions). To achieve these goals, disruptive approaches were carried out.
These targets are achievable in PROMETHEUS® thanks to years of technological research and demonstration, enabling today new technologies available today such as the digital revolution or the additive manufacturing.
Redesign of industrialization schemes based on extensive use of Additive Manufacturing process is indeed one of the key to achieve a target of cost-effective production.
A first engine was already installed on the THEMIS 1G test bench for its first firing test campaign and another ought to be delivered this year to be tested on P5 in Lampoldshausen and a third one to be used within THEMIS hop-test demonstration in Kiruna (Sweden) next year.

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References

[1] C. Bonhomme, A. Iannetti, N. Girard, D. Tchou-kien, N. Ravier, E.Edeline, Prometheus: European Next Generation Liquid Rocket Engine, IAC-17-C4.1.2, 68th International Astronautical Congress, Adelaide, Australia, 25-29 September 2017

[2] S. Soller, R. Behr, S. Beyer, F. Laithier, M. Lehmann, A. Preuss, R. Salapete, Design and Testing of Liquid Propellant Injectors for Additive Manufacturing, EUCASS 2017-306, 7th European Conference for aeronautics and space sciences, Milano, Italy, 2018, 3-6 July

[3] T. Fuhrmann, B. Mewes, G. Kroupa, K. Lindblad, A. Dorsa, R. Matthijssen, K. Underhill, FLPP ETID: TRL6 reached for Enabling Technologies for Future European Upper Stage Engines, EUCASS 2019-208, 8th European Conference for aeronautics and space sciences, Madrid, Spain, 2019, 1-4 July

[4] P. Simontacchi, E. Edeline, R. Blasi, S. Sagnier, N. Ravier, A. Espinosa-Ramos, J. Breteau, Prometheus: Precursor of new low-cost rocket engine family, IAC-18-C4.1.2, 69th International Astronautical Congress, Bremen, Germany, 1-5 October 2018

[5] P. Simontacchi, R. Blasi, E. Edeline, S. Sagnier, N. Ravier, A. Espinosa-Ramos, J. Breteau, Ph. Altenhoefer, PROMETHEUS: Precursor of new ***low-cost*** rocket engine family, EUCASS 2019-743, 8th European Conference for aeronautics and space sciences, Madrid, Spain, 2019, 1-4 July

[6] ArianeGroup et le CNES signent un contrat pour les essais de Prometheus, 13 January 2021, https://presse.cnes.fr/fr/arianegroup-et-le-cnes-signent-un-contrat-pour-les-essais-de-prometheus, (accessed 20.07.22)

[7] A. Rémy, E. Humbert, N. Meyers, J-L Normand, A. Espinosa, J-N Caruana, PROMETHEUS® tests on T1Bench in Vernon, EUCASS 2023-965, 10th European Conference for aeronautics and space sciences EUCASS – 9th CEAS, Lausanne, Switzerland, 2023, 9-13 July

