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**FUTURE LAUNCHERS PREPARATORY PROGRAMME (FLPP) –
PREPARING FOR THE FUTURE THROUGH
TECHNOLOGY MATURATION AND INTEGRATED DEMONSTRATORS STATUS AND PERSPECTIVES**

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FUTURE LAUNCHERS PREPARATORY PROGRAMME (FLPP) – PREPARING FOR THE FUTURE THROUGH TECHNOLOGY MATURATION AND INTEGRATED DEMONSTRATORS STATUS AND PERSPECTIVES

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ABSTRACT

The ESA Future Launchers Preparatory Programme (FLPP) has the objective to achieve a significant step forward in maturation and validation of critical technologies so as to prepare for the Next Generation of Launchers (NGL) for the long term, while contributing to the technical elements needed for short term decisions.

The major lines of activity covered by the programme are:
- Launch System Concepts,
- IXV, an integrated demonstrator for re-entry
- Re-ignitable Cryogenic Upper stage related technologies, including cryogenic expander cycle engine
- Main stage propulsion, incorporating the integrated High Thrust Engine Demonstrator (HTE Demo)
- Other core technologies including Materials & Structures

The paper presents the structure of the programme showing the link between system, technologies and integrated demonstrators. An overall status of the activities is presented giving emphasis on the identification of the selected integrated demonstrators and the achievements on system concepts, technology maturation and demonstrator developments. The perspectives of the FLPP are presented showing how FLPP contributes for preparing sound decisions for future new launchers developments.

1. INTRODUCTION

The preparation of new launch systems in Europe required to better respond to the future European institutional needs and to maintain the long-term competitiveness of the European launcher sector has been a fundamental element of the European strategy for access to space since several years. It was jointly recognized in November 2000 by the EU Council and ESA Council at ministerial level in the Resolution on a European Strategy for Space, and reaffirmed by the ESA Council meetings at ministerial level in 2001, 2003, and more recently in 2005.

The **Future Launchers Preparatory Programme** (**FLPP**) was accepted by the 2001 ESA ministerial Council, to be carried out as an optional programme within the Agency framework to prepare for possible future evolutions of Ariane 5 and Vega and for the Next Generation Launcher (NGL). The 2003 ESA ministerial Council finally adopted the Period 1 of FLPP, covering the years 2004-2006, in which activities were focused on system studies and technology developments for Reusable Launch Vehicles (RLV). Step-1 of the second Period of FLPP was adopted by the ESA Council meeting at ministerial level in Berlin in 2005, with the objectives to continue the preparation for the Next Generation Launcher (already started in FLPP Period 1) for the long term, and to contribute to the preparation of short/medium term decisions, through activities on expendable launch systems.

NGL and the European launcher sector scenarios

Numerous possible scenarios of evolution for the European launcher sector in the long term (from ~2015 onward) have been analyzed in the recent past. The following scenarios of evolution have been constructed with involvement of European launcher actors and discussed in different forums during the years 2006 and 2007:

- Scenario A for which major evolutions of either Ariane 5 and/or Vega would be decided and implemented so as to start exploitation of the evolved launch systems around 2015. The preparation of the NGL would then target the end of exploitation of the evolved launchers (~2020/2025).
- Scenario B where no major evolutions of either Ariane 5 and/or Vega would be decided leading then to the exploitation of the ESA developed launchers and of Soyuz from the CSG to be continued at least until around 2020. By that time, it is expected that the qualified NGL will need to be ready to start its exploitation.
- An alternative scenario based on a Building Block Launcher development has also been considered as a back-up case to be continuously assessed.

It is important to underline that the **need for the NGL is a common factor** to both scenarios A and B, the only difference being on the foreseen initial operational capability of such a launcher, with scenario B requiring an earlier introduction into exploitation. Therefore, the preparation of the Next Generation Launcher is necessary for maintaining a guaranteed access to space for Europe in the long term, in line with requirements to be consolidated in due time.

With the objective to achieve a significant step forward in maturation and validation of critical technologies so as to prepare for the Next Generation of Launchers (NGL) for the long term, while contributing to the technical elements needed for short term decisions, the FLPP approach is based on the following guidelines:

- Preparation for the long term, allowing for technology spin-offs for shorter term,
- Implementation of a system-driven approach where the technology requirements and technology verification needs are derived from the launcher system requirements and system design choices and for which a Technology Development and Verification Plan (TDVP) is a pivot element between system and technology activities
- Maturation of technologies giving a strong focus on integrated demonstrators considered as the most efficient way to increase the technology readiness level and address at the same time system-level issues.

2. OBJECTIVES AND THEIR IMPLEMENTATION IN THE PROGRAMME

2.1 Objectives

The general objective of the Future Launchers Preparatory Programme (FLPP) is to prepare the technical and programmatic elements for making an informed decision on the best launch system to respond to the future institutional needs, while maintaining competitiveness on the commercial market.

While the main focus of FLPP is the preparation of the long term future, addressing system concepts (NGL or other advanced concepts) with an Initial Operational Capability (IOC) not before ~2020/2025, some of the technologies developed in this programme may find application in the short and medium term on evolutions of the current ESA-developed launchers.

The preparation of these technical and programmatic elements is mainly based on the maturation of enabling technologies which will mitigate the risk for any future launcher development.

The maturation of technologies necessitates launch system concepts studies in order to derive necessary technology requirements and technology verification needs from the launcher system requirements and system design choices. In turn, the technology activities allow verification of assumptions made at system level during the design loop.

Besides the elementary technologies maturations, integrated demonstrators are considered as a way to increase the technology readiness level addressing at the same time the necessary system-level competences. Such an approach allows also motivating and federating industry teams and capabilities around clear objectives and well-identified end-products, from their initial definition to their manufacturing, testing and exploitation of results.

2.2 Programme structure

The programme is structured in three elements, represented in figure 1:

- Study of launch System concepts
- Selection and maturation of technologies
- Definition, development and tests of integrated demonstrators

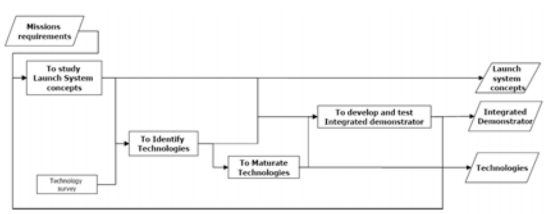

Fig. 1 Programme structure

A consistency is ensured between the three elements through a Technology Development and Verification Plan (TDVP).

- **Launch system**

The launcher system concepts studies rely on top level mission requirements covering technical (performance, functions) and programmatic (cost objectives, IOC…) aspects. In particular, technical requirements consider upper stage re-ignition and programmatic elements consider the need to reach a Technology Readiness Level (TRL) of 6 before entering in a firm development.

The launch system activities enable to identify and study launch vehicle concepts in answer to the missions' requirements. The launch vehicle concepts are gradually down-selected to a limited number of reference launch system concepts, which determine the enabling technologies and their technical requirements.
The launch system activities regularly integrate the updated maturity level of the technologies.

- **Technology**

The technology activities aim at maturating the enabling technology through on-ground test or in-flight experiment, increasing its technology readiness level in order to mitigate the risks for any future launcher development.
The commonly recognized scale through technology readiness level (TRL) as defined in [11] is considered. The objective of the technology maturation is to reach TRL 6 which is considered as adequate level to mitigate risks before entering in firm development.

Prior to the technology maturation, identification and selection of the technologies are necessary. The <u>identification</u> of the technologies relies firstly on a top down approach where a functional analysis, with the list of the necessary functions and an allocation of the functions towards a product tree enable the identification of the necessary technologies.

The identification of the technologies can not rely only on this top down approach, as the definition maturity of the launch system and stage remain low. Thus, this identification is completed by a technology survey and considers also lessons learnt from past development / exploitation as other sources for technology identification.

The <u>selection</u> of the technologies to be matured is then achieved applying selection criteria to the identified technologies. These criteria consider (i) new functions linked in particular to re-ignition for what regards the upper stage (ii) impact on launch vehicle performance, mass reduction and stage structural index improvement, (iii) robustness improvement, and (iv) launcher costs (life cycle cost) decrease.

The identification / selection of the technologies is an iterative process, performed in parallel to launch system studies. Consistency shall be ensured through the TDVP.

- **Integrated demonstrators**

While the potential links between technologies are as much as possible identified when identifying the technologies, once a technology has been selected for maturation, the maturation is relatively independent from the system and the other technologies. Once a certain technology readiness level is reached, it is worthwhile to integrate several technologies into a single platform. It is considered as the only way to experimentally address the necessary system integration link between technologies.

For each integrated demonstrator, the different phases of specification, design, manufacturing, test and post-test analysis are performed. The consideration of certain technologies in the frame of integrated demonstrator must be justified: a technology shall be considered in an integrated demonstrator only if, autonomously, the technology has reached a sufficient level of maturity and if the link between different technologies is strong.

Each integrated demonstrator, with federating objectives, enables to maximize the benefit of an integrated system. In flight demonstration can be a final objective for such demonstrator when needed.

This demonstrator oriented 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 evolvement of existing launchers.
- Concentrating use of available budget to perform high added value Research and Development tasks without spending on non strategic competences,
- Efficiently safeguarding system integration and technology competences.

- **Technology Development and Verification Plan (TDVP)**

The TDVP establishes the permanent link between system, demonstrators and technologies: top – down where system concepts define technical requirements for technologies and bottom – up where current status of technology performances are gathered and impacts at system level are also assessed. The TDVP highlights also how some technologies are of interest for several applications, typically the cryogenic expander cycle engine is a technology which is considered by both Next Generation Launcher and short / medium term evolution of Ariane.

A consistency is ensured between the three folds through the Technology Development and Verification Plan (TDVP) as depicted in following diagrams:

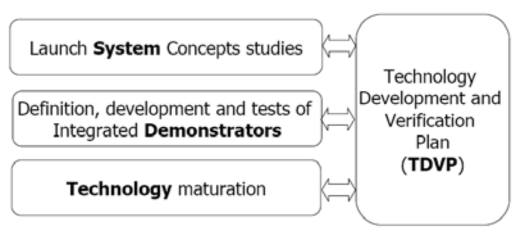

Fig. 2 Interdependency of FLPP activities

2.3 Organisation

2.3.1 Industrial organization

The FLPP programme is an ESA optional programme, where 13 Member States are participating, with a balanced subscription between the three major contributors (France, Germany and Italy).

The industrial organization, where new industrial schemes are implemented, reflects this configuration.

NGL Prime S.p.A., a joint venture of EADS SPACE (70%) and FINMECCANICA (30%), has the responsibility, with their sub-contractors, for the NGL system activities, the IXV project, the management of several technologies and is responsible for the pivot which is the overall Technology Development and Verification Plan.

The Joint Propulsion Team (JPT), a consortium of EADS-Astrium ST GmbH, AVIO SpA and SNECMA, is responsible, with their sub-contractors, of main stage propulsion technologies and related High Thrust Engine integrated demonstrator.

Snecma, and their sub-contractors, has the responsibility of the Expander Demonstration project.

Over-all, more than 60 companies, institutes or universities are involved in the activities. The programme takes benefit from this large industrial organization, where sub-contractors can be involved early in system studies for trade-offs and actors currently not involved in ESA-developed launchers can bring their know-how for the preparation of the future.

2.3.2. Technical support of National Agencies

The programme is managed by a team in the Launcher directorate in ESA-HQ. Besides the natural support of the Quality and Technical Directorate (TEC), National Agencies (ASI, CNES, DLR) provide technical support to the Agency, making best use of existing technical experience towards the agencies.

3. ACHIEVEMENTS AND PERSPECTIVES

3.1 System studies

In the framework of the preparation of the next generation of launchers to be developed in Europe, system, stage design and programmatic analyses are performed for two types of launcher scenarios:

- A new expendable mid-term launch system relying on elements or "Building Blocks" from Ariane and Vega to be operational by 2015,
- A new long-term launch system called the Next Generation Launcher (NGL) to be operational by 2020/2025.

The design reference missions include a 5 metric tons performance requirement into a Geostationary Transfer Orbit (GTO), to meet the European institutional needs, with the increased capability to 8 metric tons into GTO by the addition of solid boosters, to meet the commercial market needs. The performance requirements are defined for the standard GTO mission yet the actual mission envelope of the system concepts is much wider as it stretches from LEO over MEO and GEO up to escape missions. Accordingly, these requirements necessitate a re-ignition capability of the Upper Stage.

The system concept investigations for NGL and "building-block" launcher cover a number of options concerning propulsion (thrust level, engine characteristics), propellant choice (hydrogen, methane or solid propellants), launcher architecture (with or without strap-on boosters, bi or three stages architecture) with a special focus on upper stage structural efficiency. The NGL concepts are also further declined towards a longer term view considering a reusable or semi-reusable launcher. The current status of the industrial activities for expendable launch vehicles is reported in [9].

The figure 3 shows a reference configuration for an Expendable NGL, where addition of strap-on boost allows to cover the performance mission range 3t, 5t and 8t into GTO. This reference configuration is in its current definition based on:

- a cryogenic first stage of 156 tons propellant loading powered by a Staged Combustion (SC) engine delivering a thrust of 2500 kN in sea-level conditions at 150 bar chamber pressure. The stage architecture features a tank tandem with common bulkhead. The engine architecture is based on a two stage hydrogen turbo pump and a parallel cooling circuit.

- an under-fairing architecture for the Cryogenic Upper Stage features, with 26t propellant loading, based on a 180 kN expander cycle engine.

Fig. 3 NGL HH SC configurations

This configuration, as well as some other configurations under study, highlighted, among others, following common drivers:

- The need for an efficient Upper Stage, where the direct GEO mission and re-ignition are considered as main drivers.
- The need for a High Thrust Engine for the lower composite, enabling configurations with mono engine main stage.

These NGL configurations are interesting because of their capability to cover the entire required mission spectrum based on a single baseline launch vehicle while providing the necessary flexibility w.r.t. performances and missions via a varying number of similar strap-on boosters combined with the re-ignition capability of the upper stage.

In order to provide heavy LEO capabilities beyond those of the concepts indicated above this “family” approach can be extended even further by a Common Core Booster configuration utilizing large liquid rocket boosters derived from the core stage of the baseline launch vehicle. Investigation for longer term will also cover Common Core Booster with re-usable boosters.

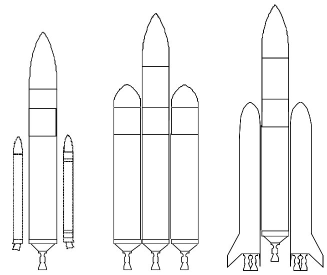

Fig. 4 family extension with CCB & re-usable booster

While the industrial activities are still running, several critical technologies have been identified, listed in the FLPP TDVP, and are, or will be, assessed in the frame of FLPP. These technology invariants, common to most of the potential launcher configurations, are converging around several demonstration lines:

- The Intermediate eXperimental Vehicle (IXV), being a vehicle integrating several key re-entry technologies at system level able to perform in-flight demonstration of system and technologies necessary for multiple space applications ranging from future launchers to human transportation.
- The Cryogenic Upper Stage Technologies demonstrator(s), aiming at maturating technologies, through ground tests and in-flight experiments and the expander demonstration project, improving the technological readiness level of the VINCI engine (re-ignitable cryogenic expander cycle engine) through test and system activities.
- The High Thrust Engine (HTE) Integrated Demonstrator, targeting the progressive integration of staged combustion, LH2 and LCH4 innovative technologies at subsystem level.
- The Solid propulsion demonstrator, including the design, manufacturing and testing of a Demonstrator flexible platform, enabling to address the pressure oscillation phenomenon, and allowing to perform easily hot firing tests with different propellant types and loading, as well as different configurations.

3.2 IXV – integrated demonstrator for re-entry

The atmospheric re-entry domain is a cornerstone of a wide range of applications that encompass the sample return, the planetary exploration, the development of space planes and crew transportation.

The IXV (Intermediate eXperimental Vehicle) project is conceived as a platform that takes advantage of the past investments on technology development (e.g. TRP / GSTP / HERMES / MSTP / FESTIP / X38 / FLPP-1 / and National programmes) and combines them to make another significant step forward w.r.t. to the ARD achievements.

In particular, the TPS activities performed in the frame of FLPP enable IXV to consolidate the TRL assessment of these different technologies and finalize the choice for the vehicle design.

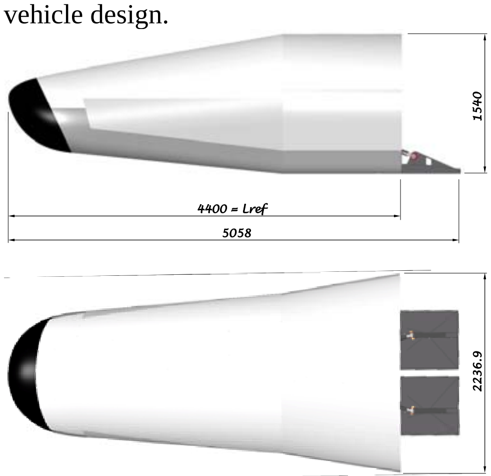

Fig. 5 IXV configuration

The IXV is designed in front of a set of high level requirements and objectives that have been iteratively discussed and jointly defined by the Agency and Industry.

The technical and programmatic constraints that define the project are:

- Perform experiments covering a well defined set of disciplined (Thermal Protection Systems & Hot Structures, / Aerodynamics & aerothermodynamics / Guidance, Navigation & Control / Vehicle Model Identification) and concentrate the experimentation in the hypersonic and high supersonic domains.
- Perform the re-entry using aerodynamic surfaces control
- Perform landing and recovery at sea and perform post flight inspection / expertise of the recovered vehicle.

The IXV is planned to be launched end 2012 on the Vega launcher.

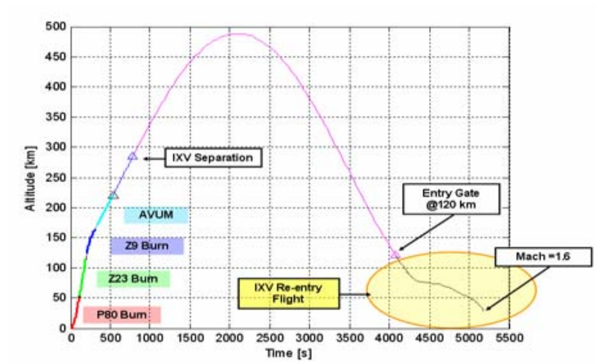

Fig. 6 IXV reference trajectory-height profile

As indicated in the name the IXV is designed to be an intermediate element in the development chain that leads to final development of the operational vehicles, without being the prototype of a specific configuration, but allowing the maturation of the core disciplines that are needed for multiple space uses. This approach where an affordable and significant step forward is performed through such an integrated demonstrator with clear objectives is a common characteristic of the demonstrators considered in FLPP.

The B1 phase activities have been concluded with the successful completion of the ESA System Requirements Review (SRR) which involved a large number of experts from ESA and national organizations (i.e. Arianespace, ASI/CIRA, CNES and DLR).

The activities are well progressing toward the PDR in all technical and programmatic areas concerned. The detailed mission and system definition is ongoing, including extensive aerodynamics and aerothermodynamics characterizations covering the complete flight domain from hypersonic to supersonic and transonic through wind tunnel testing and computational fluid dynamics.

Fig. 7: IXV mockup for wind tunnel test

The kick-off of the PDR is foreseen in November 2008, in line with the overall planning foreseeing a flight by end 2012 ([7]).

In parallel to the IXV project baseline, the Agency is analyzing the possibility to introduce additional specific features providing further answers to the newly evolving manned exploration technological needs. The additional features under evaluation (e.g. high performance ablative thermal protection systems) aim at maintaining the a.m. baseline project schedule while reducing the baseline project cost at completion, and also advancing effectively the European know-how in atmospheric re-entry from LEO for manned and robotic applications, and efficiently by using the available and unique European IXV technology platform already entering phase-C/D activities.

3.3 Cryogenic Upper Stages

The need to mature critical and enabling technologies for future re-ignitable cryogenic upper stages is a common need driven by the system studies for all configurations under investigation. In this context mid term ”Building Block” launcher configurations, long term next generation launcher configurations as well as evolutions of Ariane and Vega are taken into consideration, leading to different Upper Stage configurations.

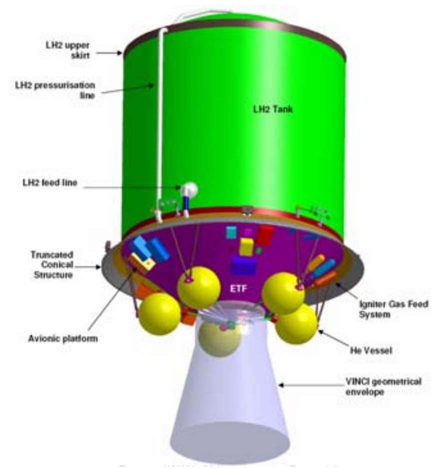

Fig. 8 Upper Stage configuration for NGL HH SC

The maturation of selected key enabling technologies for future re-ignitable cryogenic upper stages up to an appropriate technology readiness level is targeted.

3.3.1 Upper-stage cryogenic expander cycle engine - Expander Demo

One of the enabling technologies covered in the frame of FLPP, is the expander cycle engine, which is based on the VINCI engine that was initially developed as a 180 kN re-ignitable upper stage cryogenic engine in the frame of the Ariane 5 programme.

Vinci is a cryogenic expander cycle engine. This concept appears to be the most promising option w.r.t. the combined objectives of higher reliability, higher performance, multiple ignition capability and low recurring cost.

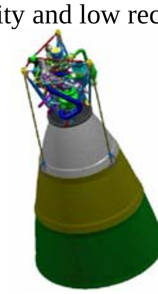

Fig. 9: Vinci engine and full NE

An optimal use of existing Vinci hardware has been made within the frame of the ESA FLPP to perform engine tests in order to collect as many as possible significant experimental data

thereby achieving major steps in engine maturity demonstration.
In complement to engine testing, system modeling and design activities have been carried out to render a future development more efficient while limiting the technical risks.

Since the first test performed in 2005, the Vinci Expander Engine has cumulated 4670s of test on two engines M1 and M2 refurbished into M1B/C and M2R, on 4 test campaigns, where 30 hot firing tests were performed, most of them demonstrating the re-ignition capability. More than 90% of the engine hot firing time has been achieved within ESA-FLPP with a last test M2R-04B performed on the 4th of June 2008.

Fig. 10: Engine in P4.1 vacuum test cell.

After the different engine test campaigns and engineering activities, the major achievements include the following (see [3] for a complete description of the achievements):

- a reference system configuration with mastered steady state and transient behaviour as well as re-start capability has been obtained,
- the reference operating point in terms of thrust and mixture ratio initially targeted in 2002 within the Ariane 5 programme has been successfully tested.
- a lot of progress has been made regarding characterisation of subsystems in engine environment. The influence of their design characteristics on the overall system performance has been quantified.
- all the functional, thermal and mechanical system models have been greatly enhanced and will be a key asset for a more efficient engine test strategy and for a good mastering of ground/flight differences for a future development.
- a wide range of experimental data has been collected and will be a very strong basis to improve system modelling and justification as well as design methodologies at subsystem level.
- the lessons learned in terms of operation of the engine and of the test facility will be accounted for to limit the risk and improve the efficiency of a future expander cycle engine development.

Some activities such as dynamic tests still remain to be carried out within the demonstration programme but all the key technical results already obtained demonstrate that the engine is well mastered and could enter development with limited risks. This engine is part of the reference proposed for Ariane 5 post ECA as well as for FLPP system concepts ([9]).

3.3.2 Other Cryogenic Upper Stage technologies

Besides the engine needed for the Cryogenic re-ignitable Upper Stage, other stage technologies need to be addressed in order to mitigate development risks for such a stage. Related activities are performed in the frame of FLPP (described in detail in [8]), they are split into 3 phases:

- In a first phase, key technologies are identified and selected and technology development and verification plans (TDVPs) for enabling technologies are established by industrial technology suppliers.

- In a second phase selected technologies will be maturated to a level appropriate for the development start of new cryogenic upper stage.
  Integration of different technologies on a single demonstrator will be considered, mainly for structural / thermal technologies.
- In addition, it is intended to identify the possible need for in-flight demonstration.

The activities related to the first phase were kicked-off in early 2008, and two loops of technology selection were already being performed.
The major selection criteria used in evaluating the different technologies were:
- the interest for re-ignitibility (restart of the engine, and coasting phases)
- the applicability towards the launcher targets (short/medium term evolution of Ariane 5 and longer term NGL)
- the interest in terms of launcher performance.

Several technologies were selected for which Technical Specifications were issued as a base line for the elaboration of the TDVP by the sub-contractors. The selected technologies cover in particular:
- several thermal insulation technologies (versatile thermal insulation, jettisonable thermal foam panel, Inner wetted Insulation)
- common bulkhead, and other structural technologies and associated materials (e.g. Al-Li and CFRP tanks)
- Pre-chill down of the engine enabling optimization of the use of propellants for chill-down
- Technologies linked to the management of the propellants in micro-gravity (Propellant Management Device, Gas Port Phase Separators)
- The use of Super Critical Helium to limit the mass of necessary He for pressurisation

Based on the TDVP under elaboration, the maturation of the technologies shall start early 2009.

3.4 Main stage propulsion - HTE Demonstrator

The need for a Main Stage High Thrust Engine is identified as a common driver for several NGL configurations. The related activities carried out in the frame of FLPP deal with the preparation of development decision for a High Thrust Engine for NGL enabling potential technology spin-offs for existing launcher evolutions in Main Stage Propulsion or liquid booster application, bringing also key elements for the preparation of further term Main Stage Propulsion for RLVs.

For what concerns NGL, NGLHHSC launcher reference is based on a Staged Combustion (SC) engine delivering a thrust of 2500 kN in sea-level conditions at 150 bar chamber pressure, with a two stage hydrogen turbo pump and a parallel cooling circuit. This constitutes the interface between system concept studies and HTE activities.

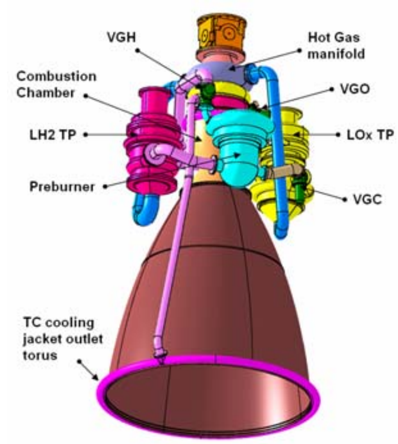

Fig. 11 High Thrust Engine

Based on these system requirements, the HTE activities converge towards an integrated Demonstrator, the configuration of which is not the configuration of the future launcher applications, but enables to address, on an adequate scale, the critical technologies in order to consolidate the choice of the future launcher application. This configuration is the result of propulsion system analyses and tradeoffs aiming at covering within an affordable budget the maximum of critical enabling technologies and competences identified in the frame of FLPP such as staged combustion, hydrogen and methane propellants.

The trade-off on the demonstrator configuration is in progress. This trade-off will also build on activities at component level which have been initiated.

Significant results are already available in the integration of critical technologies. For what concerns the LOx/LH2 propellants, a subscale demonstrator was manufactured and tested in 2007 / 2008. Pre-burner / Main Combustion Chamber coupled tests were performed on the DLR P8 test bench.

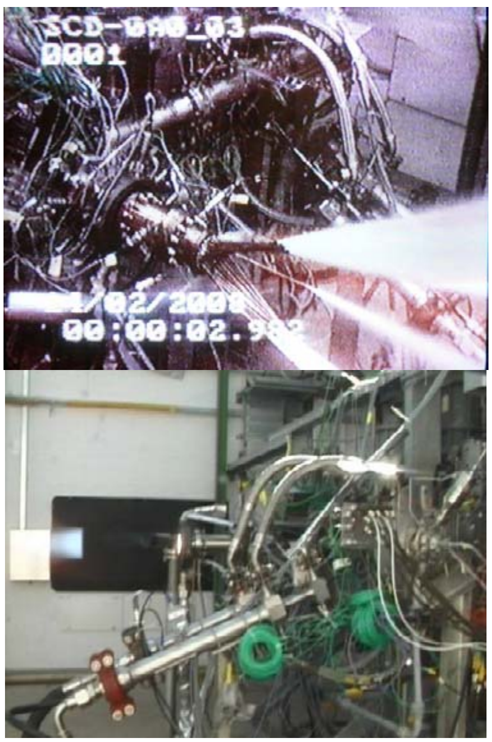

Fig. 11 LOx/LH2 Pre-burner / MCC combined test

During the test campaign, where P8 test bench was operated on new operating points, more than 450s hot testing time was accumulated with 19 ignitions. The subscale demonstrator, with a thrust up to 50 kN, enabled to reach Main Combustion Chamber pressure up to 163 bars, and Pre-burner pressure up to 220 bars. Three different main chamber injectors were characterised in a wide operating domain.

The detailed exploitation of all the data acquired is in progress; it will bring important knowledge and will enable to improve modeling of coupled configurations pre-burner / main combustion chamber, being a first important step on the staged combustion path finder.

The activities will continue with progressive integration of staged combustion, LH2 and LCH4 innovative technologies (LOx/LCH4 Pre-burner / Main Combustion Chamber (MCC) will be performed before end 2008) at subsystem, system, coupled system levels and finally on a mid-scale High Thrust Engine Staged Combustion Demonstrator of representative size, using both propellants with minimum hardware change, to reach the TRL 6 with best efficiency and limited programmatic risks.

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 sandwich Nozzle possibly completed by a radiative skirt, Valves and Health Monitoring and Control system
- Turbomachinery axis which will progressively integrate the Preburner prototype or an equivalent tooling, fuel turbopumps, the Oxygen turbopump, and possibly Health Monitoring and Control System

<u>3.5 Technologies</u>

Besides technologies related to cryogenic re-ignitable upper stage (including its engine) and the High Thrust Engine for the main stage, several other technologies shall be addressed to prepare for the future launchers. Similarly, the objective of the technology maturation is to bring technical and programmatic elements to secure decision for new launcher development, enabling also spin-off on short term evolution of ESA-developed launchers.

By nature, this pillar for the preparation of the future deals with diversity, current and past activities focused on:

- Materials and structures for lightweight cryogenic stages
- Thermal Protection System (TPS), and Hot Structures, which bring valuable elements for TRL assessment necessary in the frame of IXV
- Densified propellant which could bring, for the long term, a way to improve launcher performance while keeping similar launcher size.

Some other technologies such as avionics, opto-pyrotechnics, aerodynamics methods are also considered.

Only TPS and densified propellants are further detailed in this paper, ref. [10] gives a complete view of the technology activities performed in the frame of FLPP.

▪ TPS and Hot Structures

The reusable / semi-reusable NGL system concepts studies and IXV development have spurred technology activities related to TPS and this activity was carried out in order to validate dedicated critical ceramic and metallic TPS architectures.

A variety of TPS concepts are being developed and verified. Recent activities were addressing CMC TPS array tested in a PWT to evaluate a complete TPS subsystem with CMC shingles assembly, seals, insulation and fastening system.

Testing of behavior of sensor instrumented shingle, inter panel gaps arrangement and sealing systems, thermal insulation and the fastening system to the vehicle substructure as well, discontinuities, damaged shingles and evaluation of repair methods for impact damages or damages that could occur during manufacturing and integration steps was performed under plasma flow. Thermochemical and oxidation behaviour, as well as CFD plasma predictive model of TPS surface catalytic effect on aerodynamic heating and additional testing on instrumentation panel local features were assessed in the clean plasma flow of the induction-heated plasmatron facility.

Fig. 12: CMC TPS in Scirocco PWT facility

Additional mechanical testing like TPS IXV simulated combined heat loads and dynamic pressure loads, inner-outer pressure difference variation and venting issue, internal heat transfer and behaviour of the TPS assembly under the various shock levels featured during a typical mission are under preparation.

Similarly, a test programme was performed on a metallic TPS array.

▪ Densified propellant

In order to assess the feasibility and advantage of slush hydrogen propellant into the Next Generation Launcher concepts a manufacturing pilot plan is being designed and will be manufactured.

Fig. 13: Preliminary production unit design.

The advantages as seen already in the ’70s are due to the higher density and heat capacity which can be achieved adding a solid fraction to liquid hydrogen. However this mixture presents a number of open issues still to be solved to make it a practical potential propellant for the future of space transportation.

The activity focuses on the topics dealing with improvement of slush H2 production facility, measurement devices development, characterization of stored slush, slush transfer, long term storage issues. Parallel System studies are running to assess launch vehicle concepts based on combinations of densified propellants.

The results of these investigations will provide the elements to evaluate all the advantages and drawbacks related to the use of slush into propulsion systems.

CONCLUSION

The ESA Future Launchers Preparatory Programme (FLPP) has the objective to achieve a significant step forward in maturation of critical technologies so as to prepare for the Next Generation of Launchers (NGL) for the long term, while enabling possible spin-off for the short / medium term.

Significant results have already been achieved, where spin-offs are being considered for short / medium term evolution Ariane 5, like for the VINCI engine which was studied and tested in the FLPP Expander demonstrator frame.

FLPP system studies are identifying a target launcher reference which is a first piece for a long term view of NGL family and towards which technologies are being selected and maturated. Integrated demonstrators with well identified federating objectives are now being identified, and some of them enter in specification / design phase. Continuation of the programme with the completion of the demonstrators, including the in-flight demonstration for some of them, will bring technical and programmatic elements for necessary decisions on the Next Generation Launcher.

ACRONYMS

Al-Li	Aluminum Lithium alloy
ARD	Atmospheric Re-entry Demonstrator
BB	Building Block (Launcher)
CFD	Computational Fluid Dynamics
CFRP	Carbon Fiber Reinforced Plastic
CH4	Methane
CMC	Ceramic Matrix Composite
CSG	Centre Spatial Guyanais
ESA	European Space Agency
FLPP	Future Launchers Preparatory Programme
GEO	Geostationary Orbit
GTO	Geostationary Transfer Orbit
HH	launcher configuration with LOX/LH2 Lower and upper stages
HTE	High Thrust Engine
HTE Demo.	High Thrust Engine Demonstrator
IXV	Intermediate eXperimental Vehicle
JPT	Joint Propulsion Team
IOC	Initial Operational Capability
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
MEO	Medium Earth Orbit
MCC	Main Combustion Chamber
NE	Nozzle Extension
NGL	Next Generation Launcher
PDR	Preliminary Design Review
PWT	Plasma Wind Tunnel
RLV	Reusable Launch Vehicle
SC	Staged Combustion
TDVP	Technology Development and Verification Plan
TPS	Thermal Protection System
TRL	Technology Readiness Level

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