FUTURE EUROPEAN REUSABLE PROPULSION SYSTEMS

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ABSTRACT

Two families of propulsion systems with challenging performance and cost requirements are being investigated by Snecma Moteurs to meet future european reusable launchers needs.

First family is based on a new generation of oxygen / hydrogen stage combustion engines which has potential applications both on boosters and orbiters.

Second family which has application on boosters only is based on an innovative propellant combination of oxygen with methane which has significant advantages compared to oxygen / kerosen for reusable propulsion systems.

Preliminary conceptual analysis will be presented for these two lines of rocket engines.

Objectives of predevelopment activities in order to create enhanced technical capabilities and a strong industrial basis will be also summarized.

SUMMARY

- Introduction
- Industrial approach to respond to future needs
- VEDA : a next step of european cooperation for O_2/H_2 engine
- VOLGA : a Russian European cooperation for O2/HC engine
- Roadmap for future activities
- Key design parameters
- Key technologies
- Experimental demonstration
- Conclusion

INTRODUCTION

Since the beginning of launchers history, reusability has been suggested to reduce launch costs and increase space applications.
Lessons learned from past and recent programmes in the United States (Space Shuttle, Venture Star, Space Launch Initiative) show that cost effective reusable launch systems will require a lot of efforts and a long time to overcome the technical and economical difficulties.

The road will be long to improve rocket engines endurance and life characteristics without sacrifying too much their performances in order to avoid excessive propellant masses which are detrimental to vehicle size and launch costs.

INDUSTRIAL APPROACH TO ANSWER FUTURE NEEDS

Many R.L.V. configurations have been proposed worldwide in the past years but unfortunately the market and mission needs were not well known and defined. Expectation for the space shuttle launch rate was exceeding. 50 flights per year at initiation of its operational phase !

It is interesting to note that the present situation has a lot of similarities and the needs are not better established due to uncertainties on commercial projections, governmental commitments and budget restrictions.

Cooperation is the most efficient way to share development cost and enlarge markets and future sales. It makes sense particularly if some synergies and additional expertise can be achieved in key areas like propulsion.

The European space transportation industry is currently conducting prospective investigations and trade-off studies of R.L.V. in order to identify the technological improvements that should lead to reduce the cost of hardware and operation.

It is clear that the go-ahead for development of a european R.L.V. is still a distant milestone. It is expected at the end of this decade after a long maturation and risk mitigation phase to demonstrate its technical feasibility and economical interest and will depend on the market perspectives and governements support will at that time.

SNECMA Moteurs and its european partners are deeply engaged in the preparation of the relevant technological and industrial base which are fundamental before the development of cost effective propulsion systems.

Mastering propulsion technologies cannot wait the finalization of launch system studies and the availability of propulsion requirements that will meet the vehicle needs.

The various concepts of reusable or semi reusable launchers which are presently studied in Europe have in common the use of only 2 types of engine system.

VEDA is the oxygen / hydrogen concept of reusable engine and VOLGA is the oxygen-hydrocarbon concept that fulfill these needs. Main technical features and performance data are only targets which will be updated later by the launcher authorities, but they are representative data for the technological validation and experimental demonstration which are necessary prior to development.

VEDA : A NEXT STEP OF EUROPEAN COOPERATION FOR O_2/H_2 ENGINE

A reusable cryotechnic engine with a thrust class of 2000 kN is a potential candidate both on future boosters and orbiters.

Preliminary engine trade-off studies show that the staged-combustion engine cycle offers significant advantages over gas generator cycle. Table 1 summarizes the comparison of engine cycles for an orbiter application. It shows that staged combustion cycle allows an increase of vacuum specific impulse of 20 seconds for a given geometrical envelope compared to gas generator cycle.
Differences are even higher for a booster application.
In addition a staged-combustion engine allows operation at higher mixture ratio which minimizes tank volume.

The european propulsion community has reached significant achievements on expendable cryogenic engines through the Ariane programmes. It has a good industrial basis to prepare the necessary advancements and progress for the development of a cost effective reusable staged combustion engine.

	Unit	Vulcain 2	Gas Generator Cycle	Staged Combustion Cycle
- Engine mixture ratio	-		6	6
- Vacuum thrust	kN	1349	2000	2000
- Combustion pressure	bar	115	115	160
- Thrust Chamber Mixture ratio	-	7.18	7.33	6
- Area ratio	-	60	93	120
- Outlet surface	m2	3.57	7.73	7.73
- Outlet diameter	m	2.128	3.14	3.14
- Vacuum specific impulse	s	433	438	458

Table 1

Table 2 gives the cryogenic engine concept VEDA lay out and main technical data proposed as targets.

VEDA Reusable Cryogenic Engine

Main characteristics for sea livel ignited engine :

- Thrust range : 2000 kN according to vehicle requirements
- Mixture ratio = 6
- Specific impulse : 350 s Sea Level
  450 s Vacuum
- Weight : ≤ 3 000 kg
- Reliability ≥ 0.995, Safety ≥ 0.999, Health Monitoring
- Life time : 50 - 30 000 s to allow 25 missions with margins

Technical features :

- Staged combustion cycle
- Two turbopumps with integrated preburners
- Boost pumps
- Thrust (50-120 %) & mixture ratio (5-7) controller
- Low turnaround manpower, and minimization of propulsion cost per flight.

Table 2

VOLGA : A RUSSIAN EUROPEAN COOPERATION FOR O_2/HC ENGINE

A reusable oxygen-hydrocarbon engine with a thrust class of 4000 kN is also a potential candidate to power fly-back boosters and reusable first stage of a Two Stage To Orbit (TSTO).

Due to the large experience gained by the russian propulsion industry on all types of rocket engines but in particular in oxygen hydrocarbon propellant and staged combustion systems, it is cost effective to combine the european and russian expertise.

An industrial partnership agreement has been signed between the major european and russian propulsion companies to initiate a preparatory programme including, propellant and engine system trade-off studies, technical risk mitigation and sub-system demonstration.

Preliminary results show that the oxygen methane combustion offers significant advantages compared to oxygen-kerosen for reusable propulsion systems. They are summarized on Table 3.

Comparison of methane over kerosene

- Higher cooling capacity (2 times)
- Better ecological behaviour of components and combustion products
- Less Sensitive to carbon deposition :
  - in gas generator and turbines (soot formation)
  - in cooling channels (coking)
- Lower propellant cleanliness requirements
- Lower cost (between 2 and 3 times)
- Better combustion stability
- Lower boiling point but very close to oxygen (can be seen as an advantage for tank configuration and pressurisation)
- No coating needed on hot gas lines.

Table 3

Table 4 gives oxygen-methane engine VOLGA layout and technical data targets.

VOLGA reusable O2/CH4 engine

Main Characteristics :

- Thrust range : 4000 kN according to vehicle requirements
- Mixture ratio = 3,5
- Specific impulse : 320 s Sea Level
  360 s Vacuum
- Weight : ≤ 5 000 kg
- Reliability ≥ 0,995, Safety ≥ 0,999, Health monitoring.
- Life time : 50 - 15 000 s to allow 20 missions with margins.

Technical features :

- Staged combustion cycle with fuel rich preburner
- Single shaft turbopump
- Boost pumps
- Thrust (50-120 %) and Mixture ratio (3-4) controller
- Low turnaround Manpower, and minimization of propulsion cost per flight.

Table 4

ROADMAP FOR FUTURE ACTIVITIES

Logic of activities is given in Table 5.
Three main phases are identified :
- 2002 - 2005 Technology & Subsystem Demonstrations
- 2005 - 2008 Engine Demonstration Pre development
- 2008 - 2015 Engine Development

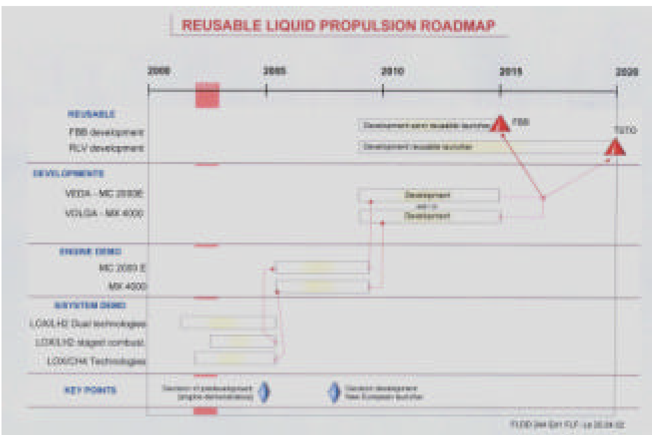

Table 5

KEY DESIGN PARAMETERS

Design activities must be cost driven. It is therefore fundamental to understand what affects reusable launch system cost, in order to examine the influence of propulsion.

Operations including controls, maintenance, propellants, etc, are the major part of reusable launch system cost. Other part is the cost of amortization of hardware which must be replaced after their operational life (a given number of flights) and cost of insurance which is proportional to the total vehicle cost.

Total cost of a reusable vehicle is depending on main propulsion system performances (specific impulse, thrust, thrust to weight ratio, mixture ratio precision …), which govern the propellant mass and consequently the size, and gross lift off weight.

It is important to optimise the propulsion characteristics which minimise total vehicle cost (Fig. 6).

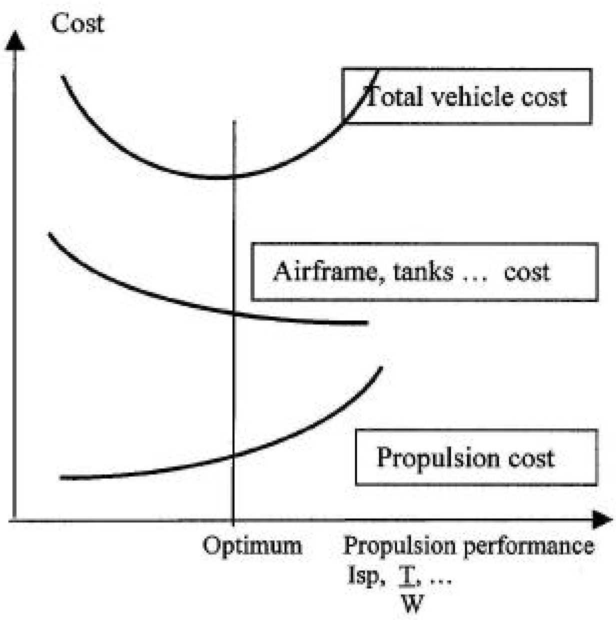

Fig. 6

Low but also too high performances are detrimental to total vehicle cost. A robust design with moderate performances and sufficient margins is the optimum.

The optimisation process must include several iterations at engine level and also at vehicle system level in order to meet launch cost objectives.
Number of reuse is an important factor. It has an influence on life and limits design data of critical components such as bearings, cooling channels of thrust chamber, etc.

One important issue is to check that operating range of critical parameters is compatible with life requirements.
Past Vulcain experience (Fig. 7) shows that most frequent damages are cracks and fissurations and are often the results of severe temperature gradients and it is important to control evolution of critical parameters during transients. Other frequent problems are due to vibrations.

Lessons learned from Vulcain 2

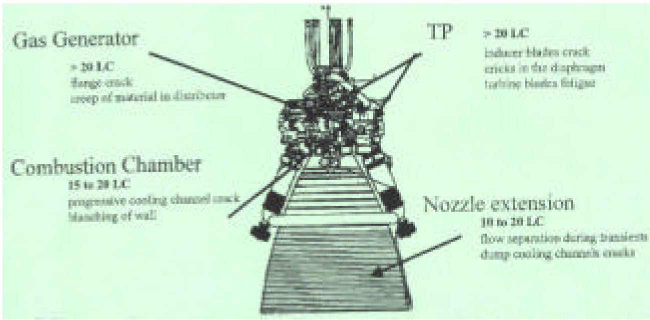

Fig. 7

Conceptual analysis and design activities needs a long maturation in order to evaluate carefully all options and make sure that potential failures are eliminated.

Current practices include concurrent engineering methods with a pluri-disciplinary team in order to better meet customer needs.
Simulation thanks to advanced numerical software such as CATIA which allows to study interface and integration between subsystems at an early step is a very efficient method (Fig. 8).

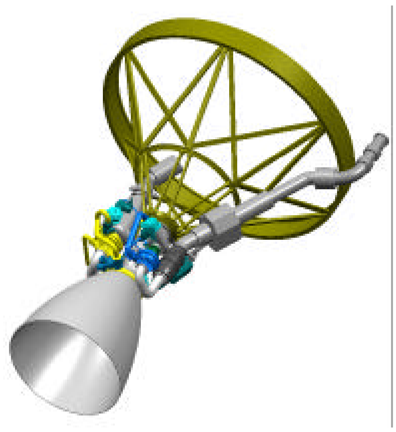

Fig. 8

KEY TECHNOLOGIES

New technologies are necessary are to have a robust design in order to increase reliability, reduce hardware costs and increase life.

Most of these technologies are "dual" for oxygen / hydrogen & oxygen / hydrocarbon propulsion systems, in particular :

Staged combustion : pre-burner + chamber
Aerodynamics (subsonic) of turbines
Low cost thrust chamber body with low ΔP regenerative circuit
Technologies for nozzles
Technologies for equipment
High ΔP unshrouded impellers
Blisk turbine
Powder metallurgy for impellers, turbines
Casted casing.

Some are on the contrary specific to the propellant combination speciality :

Hydrodynamic bearings and high speed roll bearings
Injectors pattern.

The following improvements are foreseen :

⇨ Turbopump
- Boost pumps and high suction performance inducers (reliability, smooth transients, tank weight and cost minimization)
- Hydrodynamic film bearings (life duration)
- High performance open impellers and turbines (weight, cost)

⇨ Valves
- Separation of flow control and shut-off function (reliability)
- Electrical actuators (smooth transients)

⇨ Chambers / preburners
- High flow rate injectors (reliability, cost)
- Thermal Barrier Coating
- Optimized coolant channel
- Transpiration cooling …

⇨ Nozzle extension
- Flow Separation Control Device or extendible nozzle on the plume (improved performance, weight, cost)

⇨ Engine
- Health monitoring and regulation
- Instrumentation

⇨ Propulsion Systems
- Connect / Disconnect technologies
- Electronic pressure regulator

EXPERIMENTAL DEMONSTRATION

Conceptual and design activities must be backed by an experimental programme in order to mature the technologies and to compare the figures of merit of the various design options.

Several representative experimental demonstrations are foreseen aiming at proving the technical and cost objectives and placing major emphasis on reusability (life and maintainability).

Demonstration is foreseen at first at critical component level (such as bearing, seals, injectors …) then at subsystem (turbopump, preburner, combustion chamber, …) and at engine system.

Examples of technology and subsystem demonstrations are illustrated on Fig. 9.
First operations will concern :
- Rotordynamics with fluid bearings (TP Tech)
- Staged combustion including preburner and thrust chamber models
- Deployable nozzle and flow separation device.

Main Technological Demonstrators 2000 - 2005

Fig. 9

CONCLUSION

Advances in propulsion are necessary to overcome the technical and economical challenges of future R.L.V.

Snecma Moteurs with its european and russian partners have initiated design and technological activities on two reusable propulsion systems :

- VEDA concept engine for oxygen / hydrogen vehicles.
- VOLGA concept engine for oxygen / hydrocarbon vehicles.

in order to meet all customers needs.

Predevelopment activities are foreseen within the Future Launcher Preparatory Programme of Europe (FLPP) and in cooperation with Russia.

Main goals of this programme is to mitigate the risks of the development phase whose decision is expected before the end of the present decade.