THE STATUS ON THE DEVELOPMENT OF LM10-MIRA LOX-LNG EXPANDER CYCLE ENGINE IN THE FRAME OF LYRA PROGRAM

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Abstract
In the frame of the LYRA Program, funded by the Italian Space Agency in order to assess the possible evolutions of the Vega launch vehicle, one of the main target is the development of a new innovative LOX-LNG engine (LM10-MIRA) powering the LYRA 3rd stage. The LM10-MIRA engine has a vacuum thrust of 10 metric tons and is driven by an expander cycle using natural gas as turbine working media. The engine is developed by a joint Avio-KBKhA propulsion team in the frame of a dedicated ASI-Roscosmos inter-agencies agreement.
Critical technologies needed to develop the flight engine have been identified and a full scale demonstrator test campaign has been set-up. Demonstrator engine design have proceed through typical design reviews. Moreover, the component and subsystem tests have been performed; in particular testing on injector head, sub-scale and full-scale thrust chamber have been performed; in addition a completely new methane turbopump has been developed and it's components have been tested.
Finally the logic of development, planning and remaining milestones is presented.

1. VEGA Evolution studies

In order to increase competitiveness of VEGA launcher after completing its qualification process, some possible modifications have been identified by a dedicated study on a new architecture named Lyra LaunchVehicle.
In particular for mid-term evolutions a new launcher configuration has been defined in order to:

- Increase flexibility and versatility of the launcher;
- Increase performance in order to cope with institutional market foreseen in the period of 2020-2030;
- Take advantage of technology development coming from VEGA short-term evolution;
- Minimize the impacts on ground segment;

The possible new launcher configuration envisaged introduce a new cryogenic LOX/LCH4 Upper Stage in substitution of third (solid) and fourth (liquid-storable) stages of VEGA launcher configuration. In particular following requirements have been identified:

- DV>4000 m/s single P/L in the class 3 ton
- DV>5000 m/s dual P/L
- Height in line with actual 3° + 4° VEGA stages
- Development cost shall be minimized
- Development time below 6 years

New stage (see fig.1) layout has been set-up as well as high level engine requirements (see tab 1).

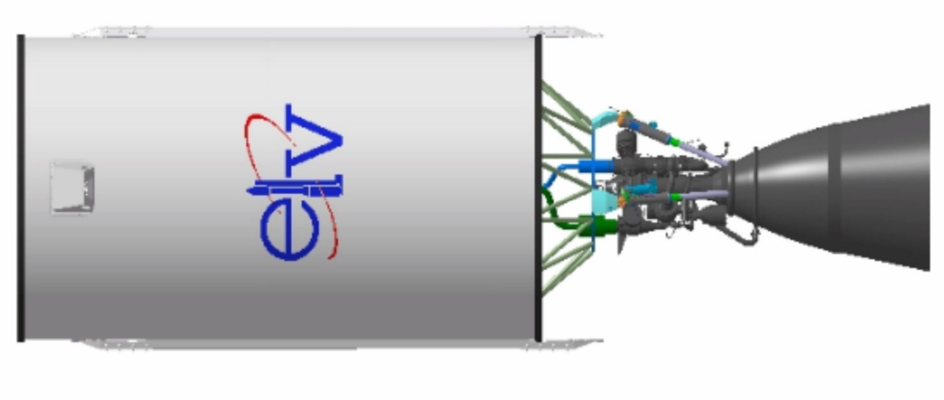

Figure 1: LYRA Third stage layout

Table 1: MIRA Flight Engine Characteristics

Propellants	LOX-LCH4
Schematic	Expander cycle
Thrust in vacuum, kN	98.1
Minimum I_{sp} in vacuum, kgf·s/kg	364
Total flow rate (kg/s)	27.6
Mixture ratio	3.4
Number of chambers	1
Thrust vector	± 6°
Max diameter, mm	1300
Max length, mm	1900
Weight, kg	< 295.5
Number of re-starts	5

2. AVIO-KBKhA Cooperation set-up

Profiting of ASI-Roscosmos inter-agencies agreement an integrated team between AVIO and KBKhA has been set-up; in accordance to development plan defined hereinafter cooperation relationship regards:

- Conceptual design of Expander Engine in flight configuration
- Design consolidation, manufacturing and testing of a full-scale demonstrator

The main challenge of the program is to profit of the experiences of both companies specialist in accordance to European and Russian standards.

3. Development Plan

Logic of the program is to define first of all requirements for the Flight Engine; on the basis of this activity, a technology demonstrator (full scale thrust compared to the flight engine) has been defined that partially re-use existing hardware in order to verify the performance defined in the system requirement specification and to identify the main critical areas for the final development of the flight engine (chill down phases, ignition transients, restarts, combustion stability, thermal loads and cooling effectiveness). During the development of the demonstrator focusing on increase competencies on critical technologies to be applied in LOX/LCH4 propulsion has been taken into account, in particular linked to Injector Head and Fuel Turbopumps areas.
In particular the steps covered by the development of the demonstrator are recalled hereinafter.

1) Experimental activities at sub-scale level

18 elements injector head has been tested on water cooled ground combustion chamber at FAST2 facility in order to verify injector design, design tools and firing plate cooling capabilities; test campaign has been successfully accomplished in 2009-2010;

2) Experimental activities at component level

a) Igniter testing

In 2008 a test campaign has been conducted in cooperation with APP, on a 204 kW gOx-gCH4 torch igniter verifying multiple start capability, ignition delay and ignition power

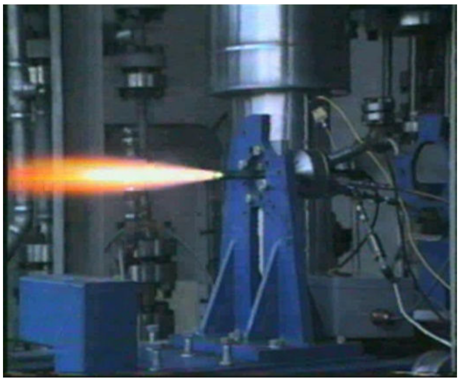

Figure 2: Torch igniter testing at AVIO

b) Cold flow Full-scale injector head

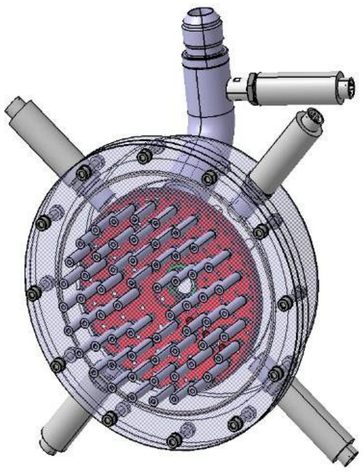

Figure 3: MIRA Perspex Injector Head

full scale perspex injector head (see Fig.5) has been manufactured in order to verify by water test the uniform distribution of LOX flowrate between the 60 injectors; in parallel technological manufacturing processes linked to brazing and welding joints have been defined and developed.

Due to the fact that no test at FTPA assembly level are foreseen, in order to reduce uncertainties during engine tests, after the freezing of the turbopump architecture, some component test has been highlighted; in particular:

c) Cold flow FTPA turbine

Air tests have been carried out in Avio Sangone experimental facility on turbine inlet manifold and stator row, without rotating parts on 2011; correct distribution of the flow coming from the manifold inlet has been successfully proven as well as manifold losses and predicted flow function vs pressure ratio.

d) Water test FTPA pump

A specific rig has been developed in order to test inducer, impeller, diffuser and volute of FTPA in water at Colleferro test facility; pump performance with different position of the ABS upper valve axial gaps has been carried out in 2012 and results are in line with expectations; in addition unsteady and steady cavitation test are been performed and pump pressure decay verified.

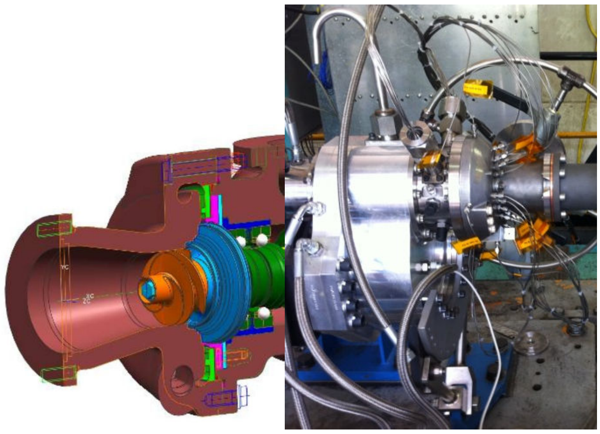

Figure 4: MIRA CH4 TP pump 3D and test rig mounted at AVIO Colleferro test bench

e) LN2 and LCH4 FTPA bearings

LN2 tests on specific rig have been performed in 2013 at AVIO Sangone facility to verify the bearings capability to withstand the radial and axial loads for the required life at the defined coolant pressure and flow rate; the test campaign gives the chance also to verify bearings cooling system arrangement performance and behavior. Following the logic of the test, a first part has been completed and a second part of the test campaign still to be performed in order to investigate the lifetime.

Figure 5: MIRA CH4 TP bearing test rig

3) Experimental activities at subsystem level

TCA firing test (Injector Head integrated with Chamber in pressure fed configuration, cooled with water) at KBKhA premises have been conducted in 2011 and 2012 in a configuration that includes the full scale injector head (same design to be mounted in the demonstrator) and the combustion chamber (same to be mounted in the demonstrator) in water cooled with water instead of liquid methane and feed with pressurized propellants. First test campaign showed results in line with expectations, stable conditions and nominal values as predictions; the second one confirm the first results and in this way injector head design has been qualified and authorized to be used for the demonstrator.

Figure 6: MIRA TCA firing test campaign

4) Manufacturing and Integration at engine level

Most of S/S of the demonstrator are re-used hardware coming from KBKhA RD-0146 engine (that has the same engine cycle of the demonstrator but it use hydrogen instead of methane).
New parts are the injector head (already manufactured), FTPA (under assembly) and some specific piping (already available) ; Integration activities of the demonstrator started in early 2013 with TCA assembly and piping definition; finalization of this activities is foreseen end 2013.

5) Demonstrator firing test campaign

Aim of the demonstrator firing test campaign is to demonstrate the feasibility of the expander cycle with LOX-CH4 (including re-start capabilities and thermal limitations, methane cooling performance);to verify the achievable performance with respect to LYRA third stage propulsion requirements; to verify functional aspects of turbopump elements on fuel side (pump, bearings, dynamic seals and turbine); validate the design methodologies for Liquid Rocket Engines.

4. Planning Status

Almost all the preparatory activities to demonstrator testing have been performed. Still to be finalized component test for the FTPA and the integration itself of the turbopump.
After that the integration activities can be finalized and the firing test campaign can start.
Test campaign will be arranged on several test days, with increasing functional and operative objectives. In particular, a number of tests and related duration shall be defined step by step during the start-up sequence by modifying in appropriate way the functioning parameter (i.e. mixture ratio, pressure temperature, flow rate), in order to tune the start-up and to achieve the steady state mode. It is to worth noted that these tests are performed in atmospheric condition.
The target of the final test campaign is to perform:

- Five engine test runs , 60s each
- Maximum chamber pressure (keeping as reference the obtained characteristic of AVIO injector head and FTPA)
- Chamber propeller ratio = 3,4. Setting tolerances shall be additionally defined.

Test shall be performed in vacuum condition for start-up.
Finally it shall be achieved at least 450 sec of the total firing time
Results of the firing test campaign shall be used to refine preliminary design and requirements given for the MIRA Flight Engine, profiting of the heritage acquired.
This important milestone shall be only the first one to prove feasibility of LOX/CH4 expander cycle to satisfy requirements given by stage designer. After that, very challenging development plan has been identified in order to freeze the engine flight configuration, to test its major subassemblies (i.e. FTPA, OTPA, TCA) , to verify the functioning at engine level and to qualify the final configuration.

5. Conclusions

The development of LM10-MIRA LOX-LNG expander cycle demonstrator engine in the frame of LYRA program has entered in its final phase. Design activities and analytical verification have been completed. Experimental activities at subsystem level of the new demonstrator engine components has been completed . Manufacturing of the

demonstration engine elements is in progress. Final assembly, acceptance test, integration to the test bench and firing test is planned to be completed within year 2013.
Successful completion of the Demonstrator engine activities will provide an input to activate a further design and development activities related to LM10-MIRA LOX-LNG Flight engine which could be a key element for VEGA launcher mid-term evolution.

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