The opportunities disclosed by Avio capabilities and Vega LV availability in the field of hypersonic vehicles technologies.

Rome, June 30th, 2014

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1st International Symposium: “Hypersonic flight: from 100,000 to 400,000 ft”
Rome, Italy, 30 June-1 July 2014
Since 2009, the drivers that support LOx-CH4 propulsion have been strengthened.
Vega Launch System at a Glance

Vega is conceived to complement the European family of launchers and to target the small payload in low Earth orbit.

Typical mission capability
1 450 kg at 700 km in circular polar orbit

Flexibility of the Vega launcher
A wide mission range

<table>
<thead>
<tr>
<th>Mass</th>
<th>Altitude</th>
<th>Azimuth</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 50 kg to 2,500 kg</td>
<td>From 300 km to 1,500 km</td>
<td>From equatorial to polar &amp; SSO orbits (5.2 deg - 102 deg)</td>
</tr>
</tbody>
</table>
Despite its relatively low lift off mass (137 ton) **Vega is the largest launch vehicle mostly based on solid propulsion** (solid stages assure as much as 95% of its DV). **Vega LV architecture is as simple as possible:** three monolithic CFRP solid propulsion stages, an upper storable liquid Vernier that contains most of the avionic equipment and the roll and attitude control system, a choice of CFRP Payload Adapter and a F2.6m Payload Fairing. Four Al alloy interstage structures complete the airframe.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height [m]</td>
<td>30.162</td>
</tr>
<tr>
<td>Maximum diameter [m]</td>
<td>3.005</td>
</tr>
<tr>
<td>Fairing diameter [m]</td>
<td>2.600</td>
</tr>
<tr>
<td>Mass at Lift-off [kg]</td>
<td>136740</td>
</tr>
<tr>
<td>Reference mission performance [kg]</td>
<td>1451</td>
</tr>
<tr>
<td>Structural Ratio</td>
<td>10.2%</td>
</tr>
</tbody>
</table>
Vega LV at a Glance

- **Avionics** is based on a single chain GNC subsystem (less than 20 parts), including an **Inertial Navigation System** and four electromechanical actuators for control of the thrust vector of each stage, a modular single chain telemetry subsystem.

- *Apart the Inertial Navigation System no sensor is functional for the flight.*

- **A Safeguard Subsystem** (fully redounded) perform the main safeguard functions.

- Well proven **pyrotechnics devices** allow for motor ignition, liquid engine and thrusters configuration, priming, and passivation, solid rocket motor neutralization, stages separation, payload fairing release and payloads separation.

- **Elastic elements** (springs or Marman clamps) generate the stages separation force, with the exception of the first to second stage where six **retro-rockets provide** the necessary $\Delta V$. 
LV is transonic 30s after lift-off, around 50s attains the maximum dynamic pressure, @3 min reaches 4Km/s, @6min passes 7.5Km/s. The mission continues up to 12000s, and allows the orbit injection of 6 independent payloads.

The upper stage may be re-ignited up to 5 times, allowing orbital plane changes for different payloads.

VEGA
REFERENCE TRAJECTORY
700 KM - PEO
VEGA VV02 Mission Profile

3 P/L were injected into 2 different orbits.

4th stage performed the direct re-entry into the Pacific Ocean
VEGA provides the best opportunities for re-entry missions.

IXV and Pride mission takes full advantage of Vega capabilities.
Next Vega Missions: drive IXV on suborbital re-entry path

PL mass = 1927 kg
Target Parameters at AVUM 1 cut-off:
- Perigee Altitude = 73,810 km
- Apogee Altitude = 420,066 km
- Inclination = 5.429 deg

Less than 20min from lift-off to P/L release

<table>
<thead>
<tr>
<th>Event</th>
<th>Trajectory up to AVUM 1 Shut.</th>
<th>Trajectory: PL release and deorbiting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event</td>
<td>Time [s] / H0</td>
<td>Phase Duration [s]</td>
</tr>
<tr>
<td>Imu Start</td>
<td>-2.0</td>
<td></td>
</tr>
<tr>
<td>Lift Off</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Pitch-Over</td>
<td>4.5</td>
<td>11.6</td>
</tr>
<tr>
<td>Gravity Turn</td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td>1st Sep.</td>
<td>114.4</td>
<td></td>
</tr>
<tr>
<td>Z23 Ign.</td>
<td>115.3</td>
<td></td>
</tr>
<tr>
<td>2nd Sep.</td>
<td>218.0</td>
<td>20.7</td>
</tr>
<tr>
<td>Z9 Ign.</td>
<td>238.7</td>
<td></td>
</tr>
<tr>
<td>Fairing release</td>
<td>244.0</td>
<td></td>
</tr>
<tr>
<td>3rd Sep.</td>
<td>379.8</td>
<td>90</td>
</tr>
<tr>
<td>AVUM 1 Ign.</td>
<td>469.8</td>
<td></td>
</tr>
<tr>
<td>AVUM 1 Shut.</td>
<td>760.1</td>
<td></td>
</tr>
</tbody>
</table>
Next Vega Missions: drive IXV on suborbital re-entry path

Vega flexibility enables both direct and indirect re-entry missions. AVUM upper stage allows any sort of orbital maneuvers and performs a reentry itself.
PRIDE: a feasible Vega mission

Vega enables missions like Pride, presenting an orbital and a distinct reentry phase.

This mission might also demonstrate in-orbit servicing concept.
Integrating Vega and re-entry vehicle control systems will increase the mission range.
Avio recently studied and presented to CIRA the integration of a re-entry vehicle Flight Test Bench to Vega E. The proposal is twofold:

- Scale-up the vehicle envelope by designing an airframe able to fly w/o Vega Fairing. To possibly integrate aerodynamic control of FTB AT Vega GNC during ascent phase. This allows to test more efficient aerodynamic configurations than IXV (i.e. winged body), yet preserving the correct leading edge bluntness to survive reentry.
- Accommodate a cluster of Theseus LOx-Methane Re-ignitable thrusters. The cluster assures both the main propulsive function at full throttle and fractional (i.e. 1/2, 1/4, 1/8) and the Attitude Control Function.

The cluster, arranged in aerospike shape (i.e. adapted at different altitudes) would deliver it propulsive and attitude function both in orbit and along the atmospheric re-entry path.
Theseus LOx-CH4 thruster is a 200N class high specific impulse bipropellant thruster under development in Avio. It is able to operate in both steady state and pulsed mode, thanks to the specific design of injector head and ignition system.

It will initiate test campaign on July 2014 in Avio Fast-2 static firing test bench.

Parameter | Value
---|---
Specific Impuls, [s] | 309
Thrust, [N] | 204
total mass flow, [g/s] | 67.3
Mixture ratio, [-] | 2.8
Oxydizer | Oxygen
Fuel | Methane
MEOP, [bar] | 16
Envelope (LxWxH), [mm] | 272x262x226
Dry Mass, [kg] | 10
Ignition System | Electrical Spark Plug
The re-entry vehicle will boost after the AVUM phase in order to reach the required orbit. From such orbit a second boost will allow de-orbiting and insertion in atmosphere. Two boosts during the atmospheric flight will allow a longer flight, and larger mission flexibility.

The Flight Test Bench will be also invaluable for characterizing in altitude advanced hypersonic propulsion systems, starting from its own a aerospike engine.
Combining the USV- FTB AT and VEGA E it is possible to:

- increase the USV total mass to 3000 Kg with a 700-800 Kg of propellants for orbital change and re-enter maneuvers. In this way it is possible to widen the mission spectrum and allows possibility to carry (inside the vehicle) small high altitude experiments

- Install the VEGA avionics inside the Payload adapter. In this way it will be possible to recover the VEGA Avionics lowering the Launch cost. A possible use of VEGA avionics to pilot USV can be also evaluated avoiding in this way a duplication (recurrent cost
Avio is currently discussing with Reaction Engine Ltd an involvement in the Synergistic Airbreathing Rocket cycle.
SABRE cycle intent is to overcome the issues of supersonic combustion stability by recover subsonic conditions of air captured by the intake by cooling the fluid more than simply compressing the flow. The idea, originated in the 50ties, has faced several implementation issues, cause of the failure of several programs (i.e. LACE, RB545 ...). Central to the Sabre thermodynamic concept is a Joule Brighton closed cycle (working fluid is He).

SABRE is an hybrid engine: once passed Mach 5, it reverts, by closing the dynamic intake, to a “classical” LOx-LH2 fuel rich staged combustion cycle.
At hypersonic conditions, air compressed by the dynamic intake is regeneratively pre-cooled by liquid He, then it is compressed in a turbo compressor and finally it is injected (for the most part) into a rocket combustion chamber.

He circulation cools intake air and drives, through a turbine expansion, the air turbo compressor, heats liquid hydrogen and drives LH2 pump high pressure stage.
Avio partnership with REL

Although application of SABRE to re-usable orbiters or spaceplanes is not obvious, the pre-cooling cycle concept is gaining maturity and increasing TRL. Critical to this purpose is the design and demonstration of the air/LHE heat exchanger, whose efficiency is the driver for the engine feasibility.

In the past Avio was involved with REL in phases of LAPCAT studies. Avio is currently discussing with REL for a partnership to design and develop the turbomachinery (few of them not trivial) for a SABRE demonstrator.
Avio is currently proposing a roadmap for application of simple RAMJET propulsion to several dual use cases.
INTRODUCTION

• AVIO has a self-financed activities in the field of hypersonic vehicles and ramjet propulsion. AVIO has already proposed, in cooperation with CIRA, a roadmap relevant to the carry-on of propulsion system studies and component technology acquisition applied to hypersonic flight vehicles.

• The above mentioned roadmap is aimed to extend the national access-to-space capabilities (today already achieved with the VEGA Launch Vehicle), and to exploit the wide dual-use opportunities offered by a single development activity.

• **Reference missions UAV-1**: a unmanned atmospheric cruise vehicle whose lift-off and acceleration to cruise conditions is assured by a Solid Rocket Booster, while range is achieved by a ramjet. The vehicle is thought to carry 1 ton of dual P/L: i.e. hypersonic testing hardware or ammunitions.

• **Access to Space UAV-3**: this is a reusable carrier for airborne launcher vehicles to provide fast orbit deployment of small P/L. The carrier is conceived to lift-off and accelerate by a standard turbojet (i.e. at the end of its operational life), reach hypersonic conditions and altitude by a ramjet engine, deploy the launch vehicle and close the mission by landing.