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

Rome, June 30th, 2014

Avio

Paolo Bellomi
Avio S.p.A
Head of Product Development & New Projects

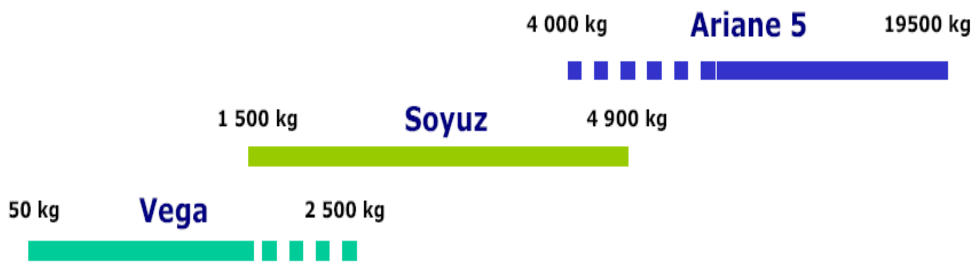
1st International Symposium: "Hypersonic flight: from 100.000 to 400.000 ft"
Rome, Italy, 30 June-1 July 2014

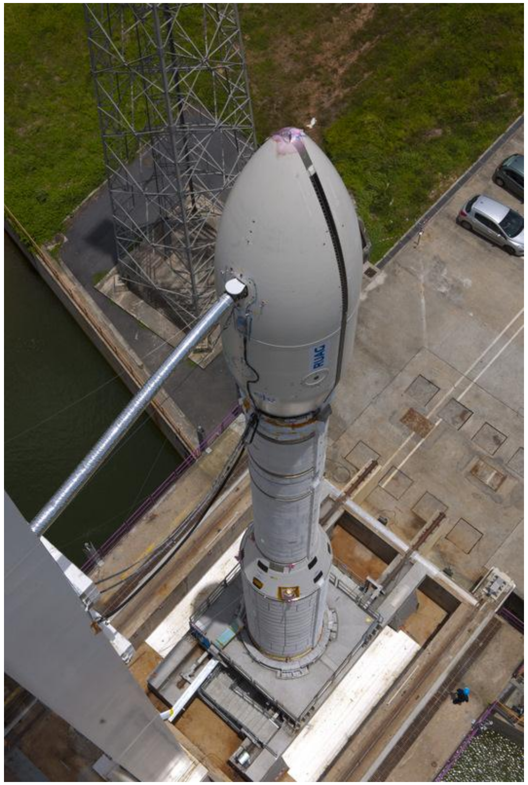
Vega at a glance

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

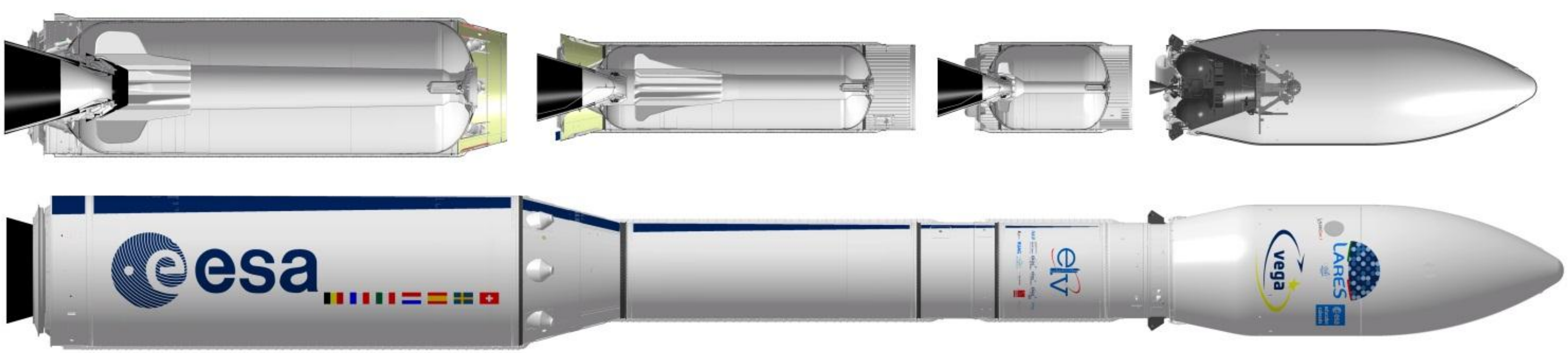
Mass	Altitude	Azimuth
From 50 kg to 2,500 kg	From 300 km to 1,500 km	From equatorial to polar & SSO orbits (5.2 deg - 102 deg)

Vega LV at a Glance

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.

Height [m]	30.162
Maximum diameter [m]	3.005
Fairing diameter [m]	2.600
Mass at Lift-off [kg]	136740
Reference mission performance [kg]	1451
Structural Ratio	10.2%



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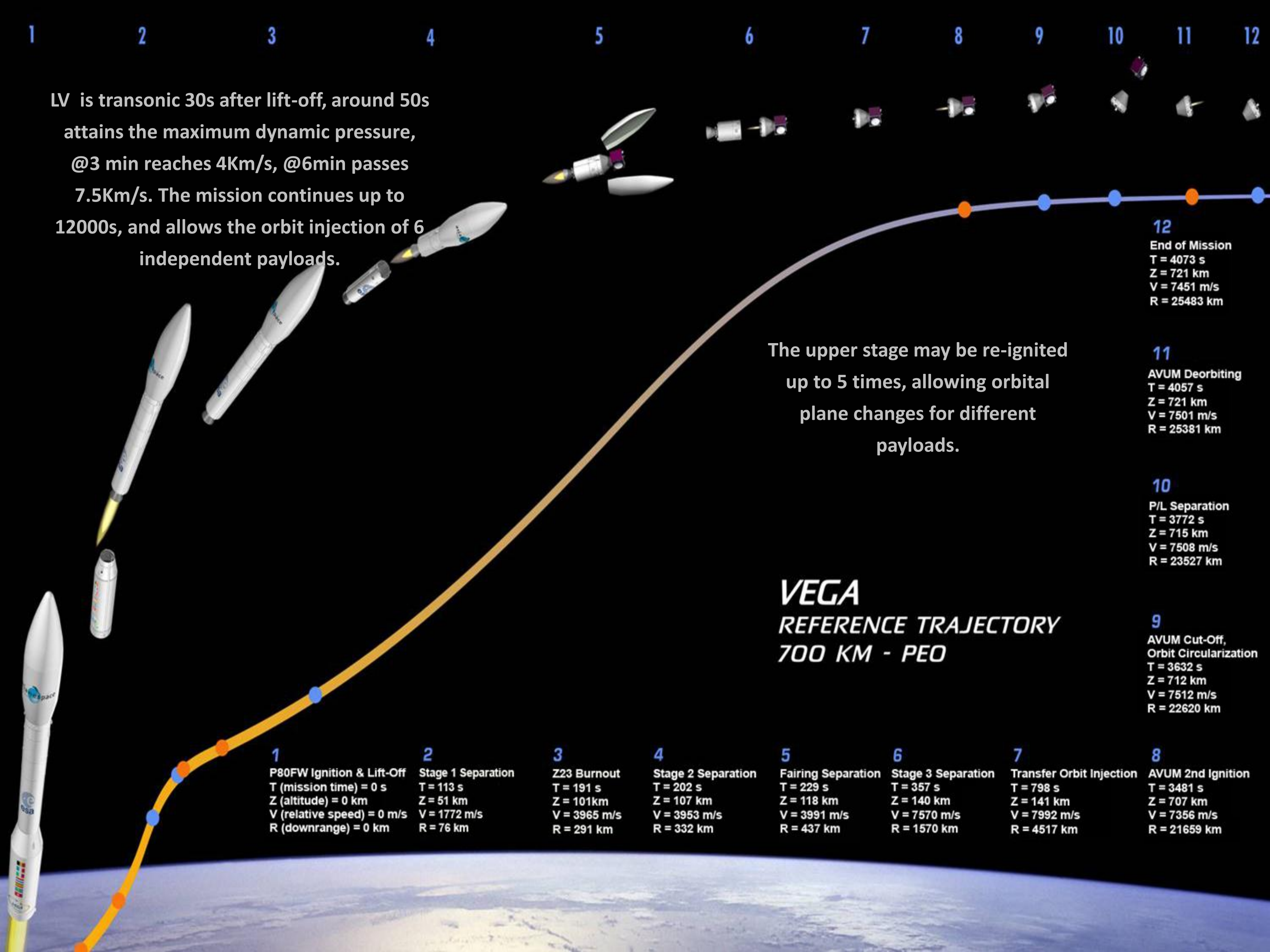
Vega LV at a Glance

- **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 ΔV.


1
2
3
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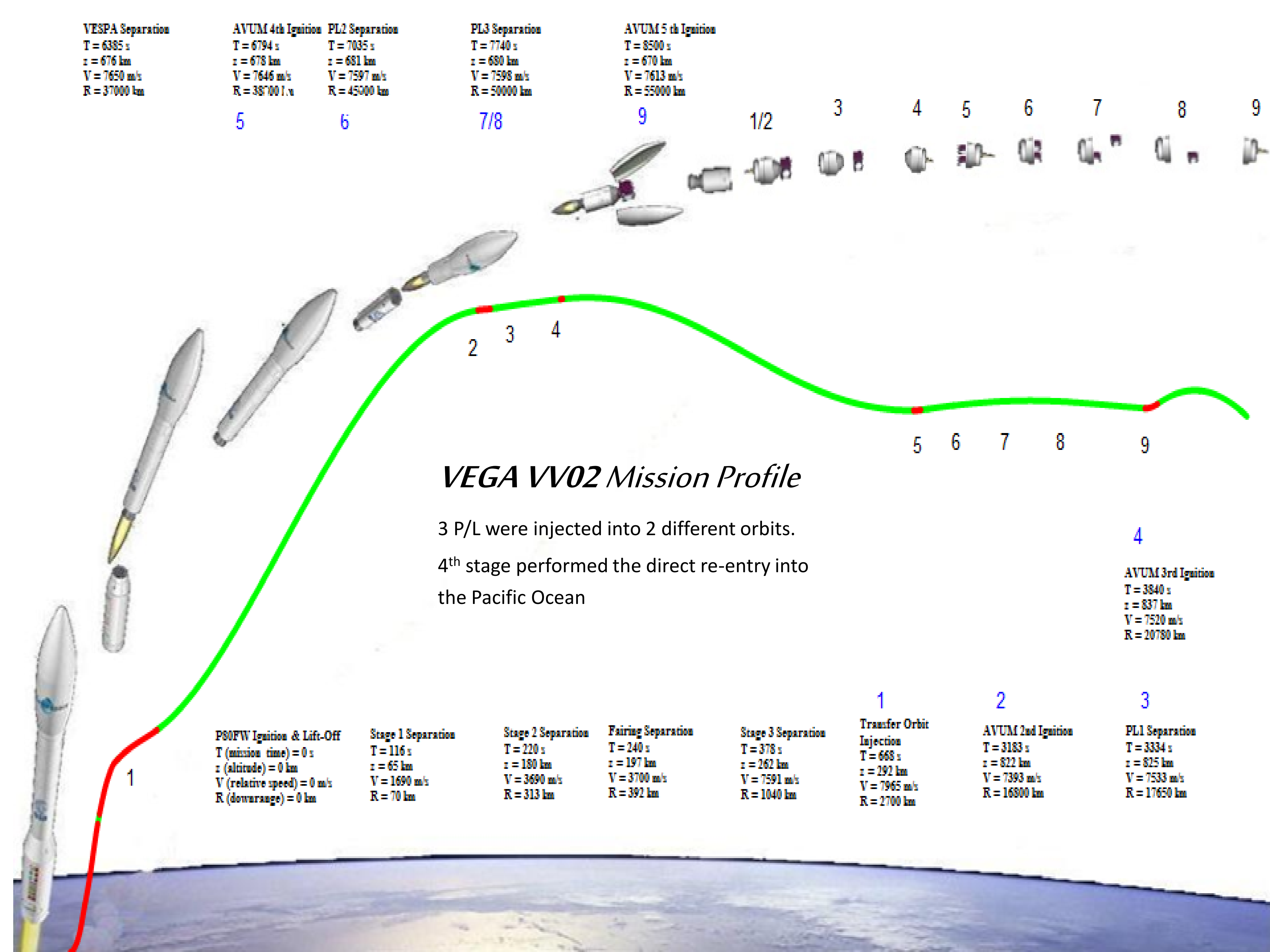
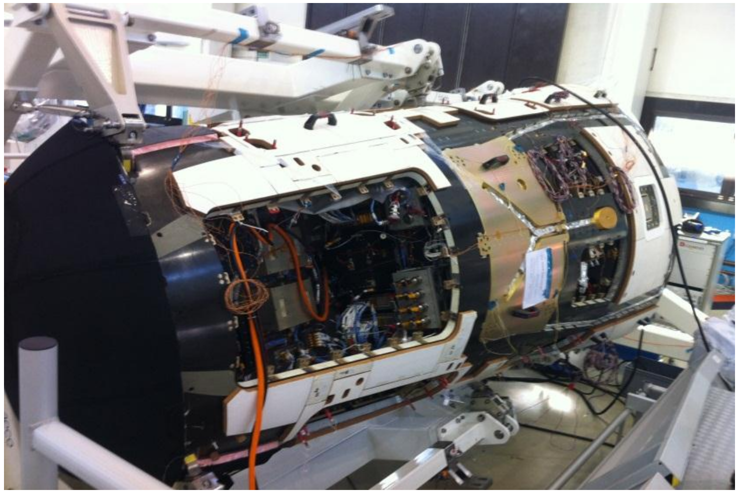
10
11
12
LV is transonic 30s after lift-off, around 50s attains the maximum dynamic pressure, @3 min reaches 4Km/s, @6min passes 7.5Km/s. The mission continues up to 12000s, and allows the orbit injection of 6 independent payloads.
The upper stage may be re-ignited up to 5 times, allowing orbital plane changes for different payloads.
VEGA
REFERENCE TRAJECTORY
700 KM - PEO
1
P80FW Ignition & Lift-Off
T (mission time) = 0 s
Z (altitude) = 0 km
V (relative speed) = 0 m/s
R (downrange) = 0 km
2
Stage 1 Separation
T = 113 s
Z = 51 km
V = 1772 m/s
R = 76 km
3
Z23 Burnout
T = 191 s
Z = 101km
V = 3965 m/s
R = 291 km
4
Stage 2 Separation
T = 202 s
Z = 107 km
V = 3953 m/s
R = 332 km
5
Fairing Separation
T = 229 s
Z = 118 km
V = 3991 m/s
R = 437 km
6
Stage 3 Separation
T = 357 s
Z = 140 km
V = 7570 m/s
R = 1570 km
7
Transfer Orbit Injection
T = 798 s
Z = 141 km
V = 7992 m/s
R = 4517 km
8
AVUM 2nd Ignition
T = 3481 s
Z = 707 km
V = 7356 m/s
R = 21659 km
9
AVUM Cut-Off,
Orbit Circularization
T = 3632 s
Z = 712 km
V = 7512 m/s
R = 22620 km
10
P/L Separation
T = 3772 s
Z = 715 km
V = 7508 m/s
R = 23527 km
11
AVUM Deorbiting
T = 4057 s
Z = 721 km
V = 7501 m/s
R = 25381 km
12
End of Mission
T = 4073 s
Z = 721 km
V = 7451 m/s
R = 25483 km


VEGA VV02 Mission Profile
3 P/L were injected into 2 different orbits.
4th stage performed the direct re-entry into the Pacific Ocean
P80FW Ignition & Lift-Off
T (mission time) = 0 s
z (altitude) = 0 km
V (relative speed) = 0 m/s
R (downrange) = 0 km
1
Stage 1 Separation
T = 116 s
z = 65 km
V = 1690 m/s
R = 70 km
2
Stage 2 Separation
T = 220 s
z = 180 km
V = 3690 m/s
R = 313 km
3
Fairing Separation
T = 240 s
z = 197 km
V = 3700 m/s
R = 392 km
4
Stage 3 Separation
T = 378 s
z = 262 km
V = 7591 m/s
R = 1040 km
1
Transfer Orbit Injection
T = 668 s
z = 292 km
V = 7965 m/s
R = 2700 km
2
AVUM 2nd Ignition
T = 3183 s
z = 822 km
V = 7393 m/s
R = 16800 km
3
PL1 Separation
T = 3334 s
z = 825 km
V = 7533 m/s
R = 17650 km
4
AVUM 3rd Ignition
T = 3840 s
z = 837 km
V = 7520 m/s
R = 20780 km
5
VESPA Separation
T = 6385 s
z = 676 km
V = 7650 m/s
R = 37000 km
5
AVUM 4th Ignition
T = 6794 s
z = 678 km
V = 7646 m/s
R = 38700 km
6
PL2 Separation
T = 7035 s
z = 681 km
V = 7597 m/s
R = 45000 km
7/8
PL3 Separation
T = 7740 s
z = 680 km
V = 7598 m/s
R = 50000 km
9
AVUM 5 th Ignition
T = 8500 s
z = 670 km
V = 7613 m/s
R = 55000 km
1/2
3
4
5
6
7
8
9

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:

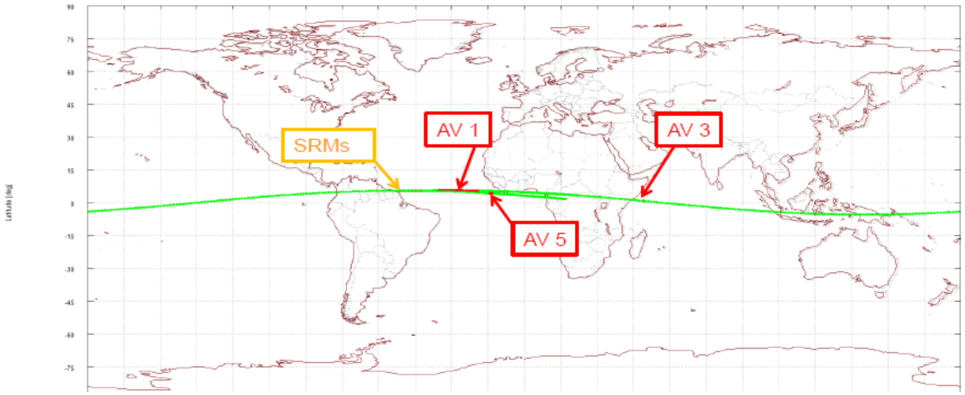
- Perigee Altitude = 73.810 km
- Apogee Altitude = 420.066 km
- Inclination = 5.429 deg

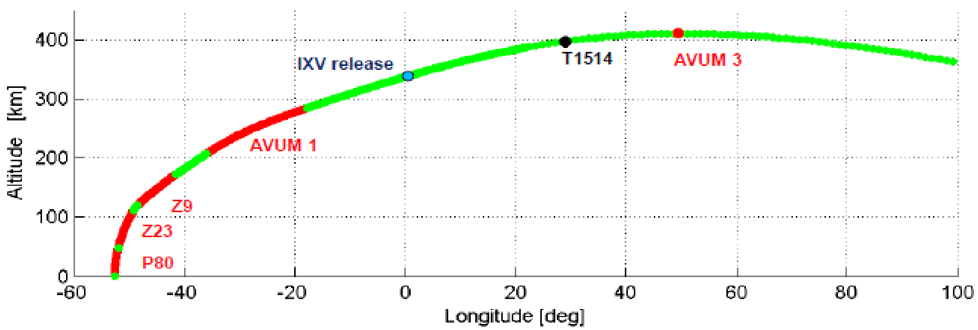
Less than **20min** from lift-off to P/L release

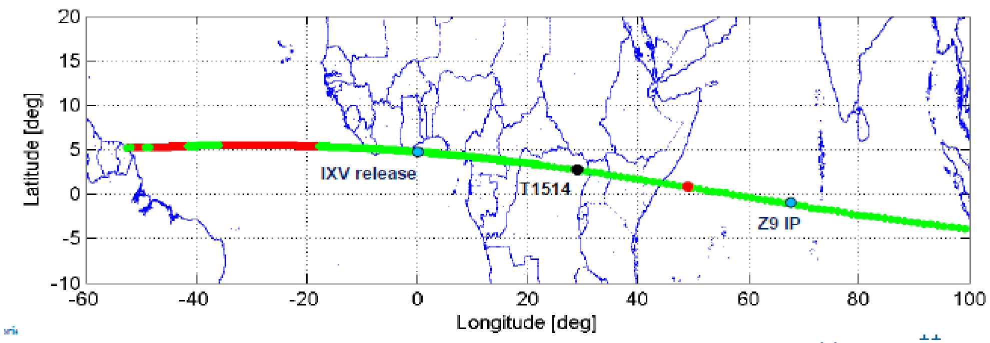
	Trajectory up to AVUM 1 Shut.	
Event	**Time [s] / H0**	**Phase Duration [s]**
Imu Start	-2.0	
Lift Off	0.3	
Pitch-Over	4.5	11.6
Gravity Turn	16.1	
1st Sep.	114.4	
Z23 Ign.	115.3	
2nd Sep.	218.0	20.7
Z9 Ign.	238.7	
Fairing release	244.0	
3rd Sep.	379.8	90
AVUM 1 Ign.	469.8	
AVUM1 Shut.	760.1	

	Trajectory: PL release and deorbiting	
Event	**Time [s] / H0**	**Phase Duration [s]**
PL release	1060.1	805
AVUM 3 Ign.	1865.1	
AVUM 3 Shut.	1877.7	4718.9
AVUM 5 Ign.	6596.6	
AVUM 5 Shut.	6642.5	

Next Vega Missions:
drive IXV on suborbital re-entry path







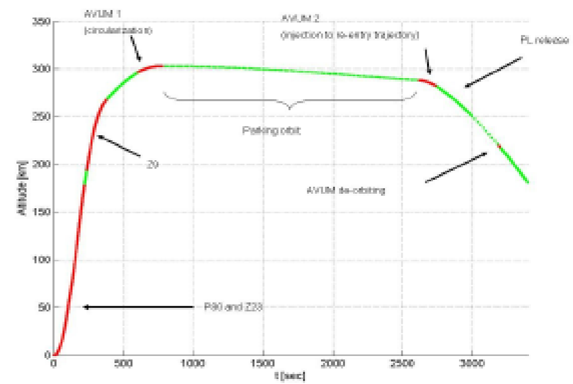
Vega flexibility enables both direct and indirect re-entry missions.

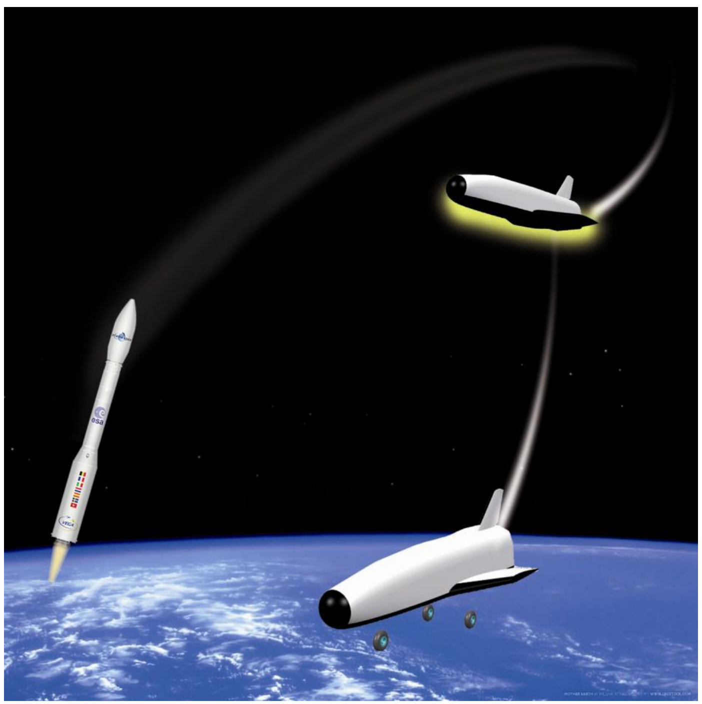
AVUM upper stage allows any sort of orbital maneuvers and performs a reentry itself.

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.





TRAJECTORY EVENTS STAGE/EVENT	TIME [s]	REL.SP. [m/s]	ALT. [km]	WEIGHT [kg]	MACH [-]	P.DYN [Pa]	(T-D)/M [m/s2]	GAM.R [°]	ALPHA [°]	DV_BALANCE DVprop [m/s]	DVgrav	DVaero	DVdis	DVinert
1 IMU Start	-2.0	0.0	0.0	138943.6	0.0	0.0	0.00	90.0	0.0	0.0	0.0	0.0	0.0	0.0
1 Motor Start	0.0	0.0	0.0	138943.6	0.0	0.0	0.00	90.0	0.0	0.0	0.0	0.0	0.0	0.0
1 Lift-off	0.3	0.0	0.0	138891.6	0.0	0.0	9.85	90.0	0.0	0.0	0.0	0.0	0.0	0.0
1 Pitch-over	4.2	28.3	0.1	135152.8	0.1	468.9	18.42	89.9	0.2	66.5	-1.1	0.0	-64.6	0.9
1 q*alpha max	11.4	103.0	0.5	127444.5	0.3	5952.1	21.18	79.8	3.6	(22390.6 Pa*°)				
1 GravityTurn	14.2	136.1	0.8	124398.0	0.4	10090.0	21.50	76.2	0.0	272.0	-16.9	-0.1	-205.4	49.7
1 Mach 1	31.6	332.1	4.7	107641.8	1.0	40599.3	17.50	61.2	0.0					
1 P.dyn. max	57.5	655.2	14.0	86041.4	2.3	56127.6	25.14	42.1	0.0					
1 (T-D)/M max	92.5	1617.7	34.4	55224.3	5.2	12012.3	38.32	27.0	0.0					
1 AT Det.	114.5	1751.2	50.1	50690.3	5.3	1665.5	0.71	21.1	0.0	2644.2	-390.5	-119.4	-405.9	1728.5
1 Separation	114.7	1750.6	50.2	50687.3	5.3	1637.8	0.69	21.1	0.0	2644.4	-391.1	-119.4	-405.9	1728.0
2 Coasting														
2 Motor Start	115.5	1747.7	50.7	42198.3	5.3	1532.5	-0.06	20.8	0.0	2644.4	-391.1	-119.4	-405.9	1725.7
2 (T-D)/M max	160.0	3017.8	78.3	25794.3	10.9	125.2	35.19	12.0	15.1					
2 AT Det.	193.5	3876.2	102.5	18325.4	13.8	2.5	1.28	11.4	10.3	4981.5	-546.1	-120.8	-437.6	3874.5
2 Separation	218.3	3838.7	119.4	18299.3	10.0	0.2	0.00	9.0	0.0	4985.4	-571.4	-120.8	-437.7	3841.3
3 Coasting														
3 Motor Start	230.6	3821.7	126.3	15531.2	8.2	0.1	0.00	7.8	1.7	4985.4	-571.4	-120.8	-437.7	3826.2
3 HS Jettison	236.0	3874.7	129.0	15217.2	8.0	0.1	13.35	7.3	9.1	5045.2	-577.3	-120.8	-437.8	3879.9
3 (T-D)/M max	335.5	6807.5	168.7	5110.3	10.5	0.0	42.93	3.5	4.2					
3 AT Det.	348.5	7210.7	174.1	4383.2	10.9	0.0	1.27	3.0	37.7	8494.1	-653.1	-120.8	-468.4	7222.4
3 Separation	373.3	7202.2	183.3	4376.6	10.5	0.0	0.03	2.9	35.9	8498.3	-664.2	-120.8	-469.3	7214.6
4 Coasting														
4 Motor Start	1485.0	7016.7	329.2	2991.1	8.2	0.0	0.00	-1.1	39.9	8498.3	-664.2	-120.8	-469.3	7040.1
4 Cut-off	1822.6	7241.3	300.0	2723.4	8.7	0.0	0.90	0.0	60.3	8787.5	-629.9	-120.8	-570.4	7262.6
4 Coasting														
4 Mtr Restart	3022.6	7251.0	292.1	2723.4	8.8	0.0	0.00	-0.1	0.0	8787.5	-629.9	-120.8	-570.4	7271.8
4 Cut-off	3154.7	7168.8	286.6	2618.6	8.7	0.0	0.93	-0.6	153.4	8908.6	-623.4	-120.8	-780.4	7189.2
4 Coasting														
4 P/L Sep.	3304.7	7185.3	273.4	2618.6	8.9	0.0	0.00	-0.8	0.1	8908.6	-623.4	-120.8	-780.4	7204.7
4 Coasting														
4 alpha max	4185.5	7363.8	131.6	918.6	14.7	0.2	0.00	-1.5	179.6					
4 Deorbiting	4264.7	7382.8	116.5	918.6	20.5	0.9	0.01	-1.5	179.6	8908.6	-623.4	-121.1	-780.4	7390.7
4 (T-D)/M max	4304.7	7283.7	108.9	886.9	23.7	2.8	2.78	-1.5	177.1					
4 Cut-off	4304.7	7283.7	108.9	886.9	23.7	2.8	2.78	-1.5	177.1	9017.0	-614.2	-121.7	-997.3	7291.0
4 Coasting														
4 Passivation	4320.7	7287.3	105.8	886.9	24.7	4.8	-0.04	-1.5	15.8	9017.0	-614.2	-122.1	-997.3	7294.46

Legenda: columns report time, relative velocity, geodetic altitude, mass, Mach number, dynamic pressure, non-gravitational acceleration, flight path angle, angle of attack, the ΔV gains (propulsive) and losses (for gravity, aerodynamics, and incidence), and the total inertial ΔV

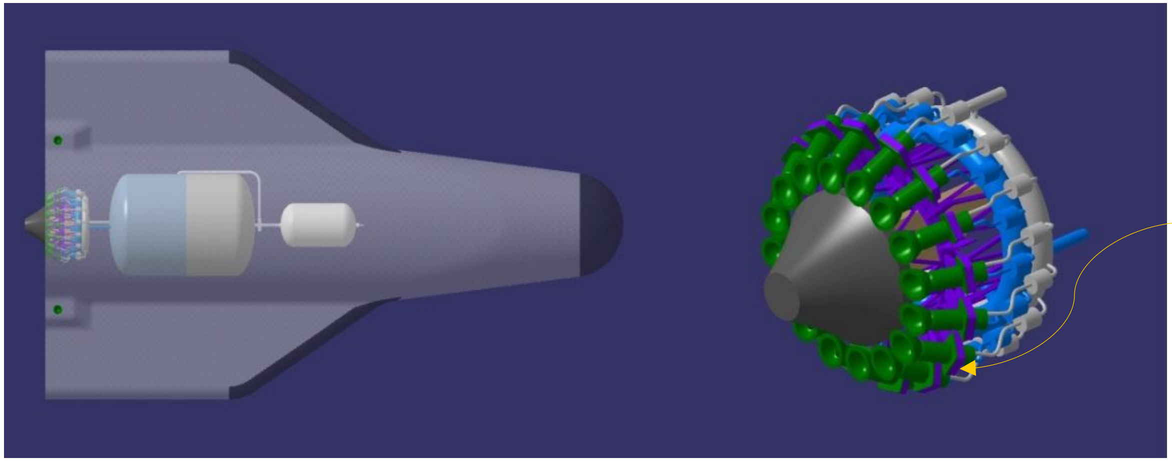
VEGA-E integration to re-entry vehicle

Integrating Vega and re-entry vehicle control systems will increase the mission range.

USV- FTB AT

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.

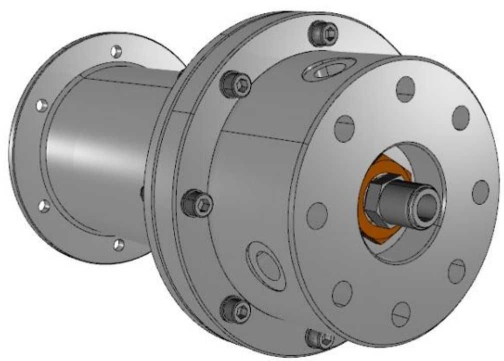


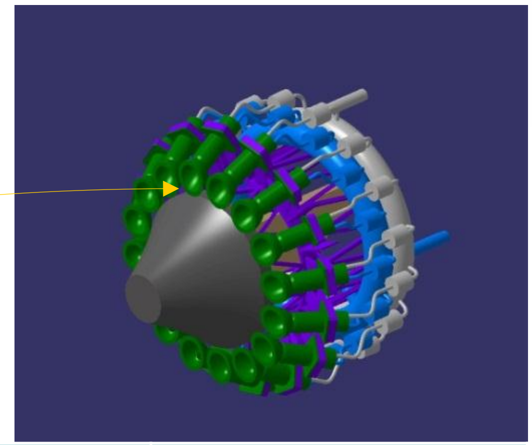
The cluster, arranged in aerospike shape (i.e. adapted at different altitudes)would deliver it propulsive and attitude function both in orbit and along the atmospheric re-entry path.

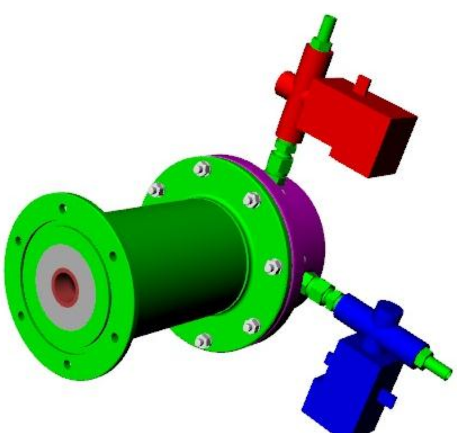
USV- FTB AT

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.





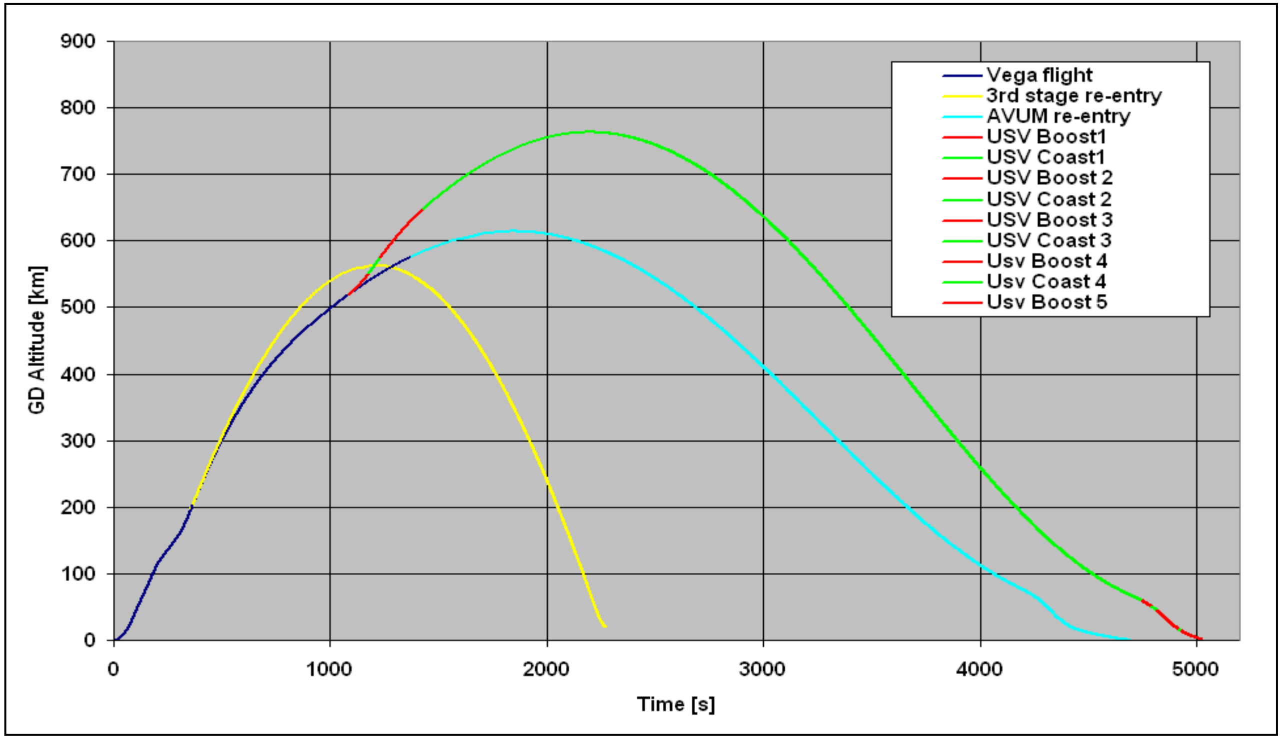


Parameter	Value
Specific Impuls, [s]	309
Thrust, [N]	204
total mass flow, [g/s]	67.3
Mixture ratio, [-]	2.8
Oxydizer	Oxygen
Fuel	Methane
MEOP, [bar]	16
Envelope (LxWxH), [mm]	272x262x226
Dry Mass, [kg]	10
Ignition System	Electrical Spark Plug

USV FTB AT

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.

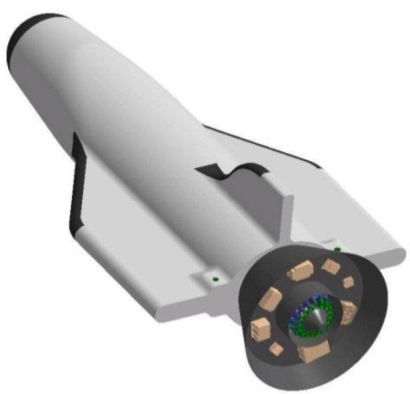


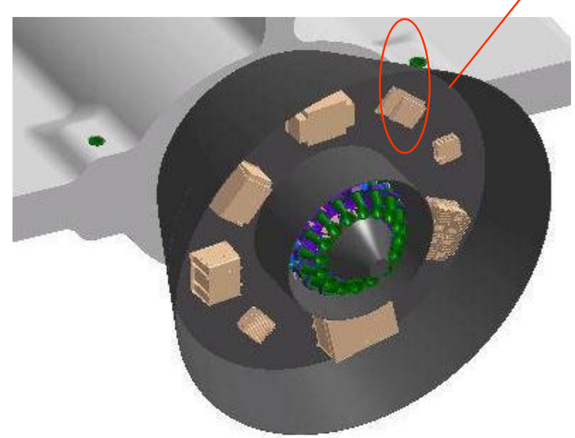
Avio

USV- FTB AT (3/3)

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. It 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



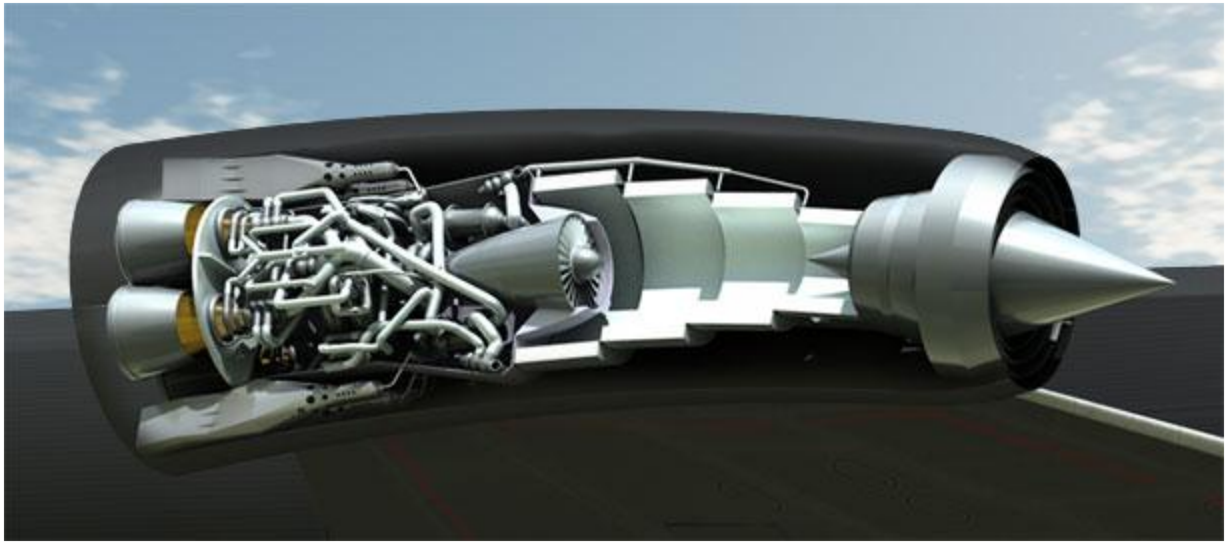


AVIO long lasting involvement in REL SABRE concept

Avio is currently discussing with Reaction Engine Ltd an involvement in the Synergistic Airbreathing Rocket cycle

Reaction Engine Ltd: SABRE cycle intent

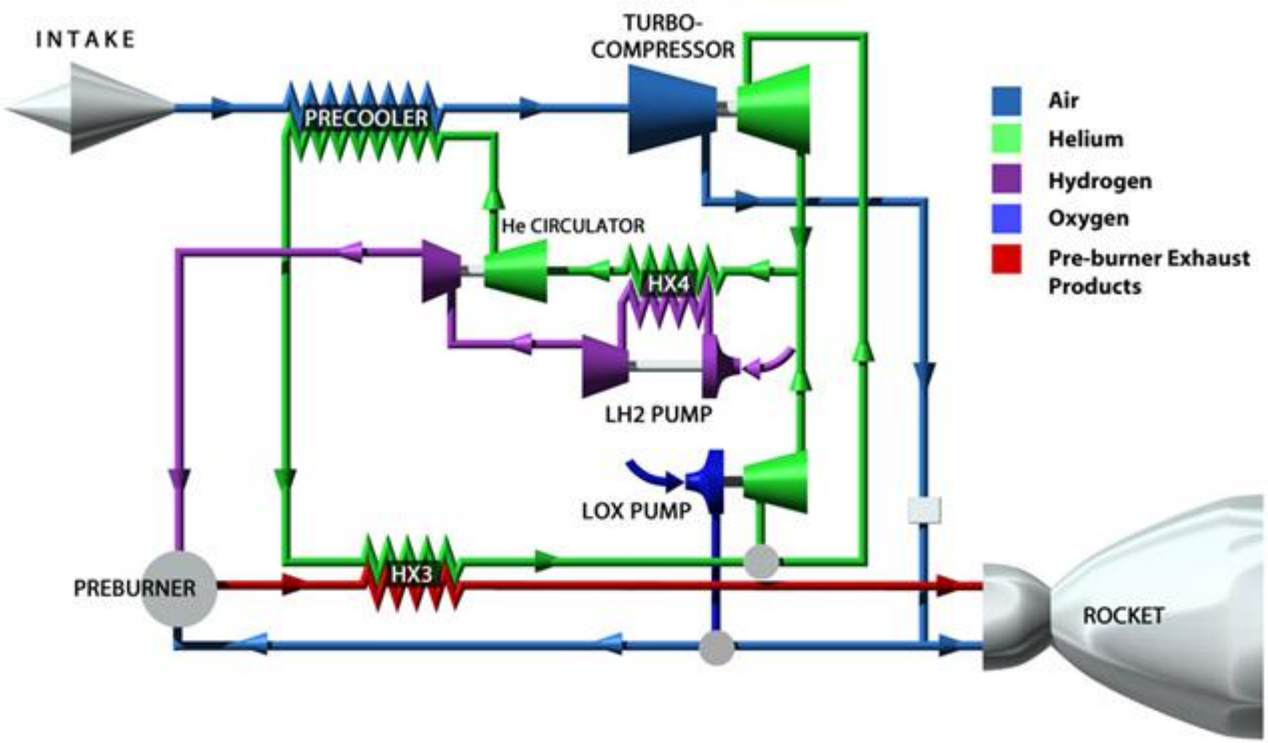
SABRE cycle intent is to overcome the issues of supersonic combustion stability by recover subsonic conditions of air captured by the intake by cooling the fluid more than simply compressing the flow. The idea, originated in the 50ties, has faced several implementation issues, cause of the failure of 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.

Reaction Engine Ltd: SABRE cycle in two words

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.



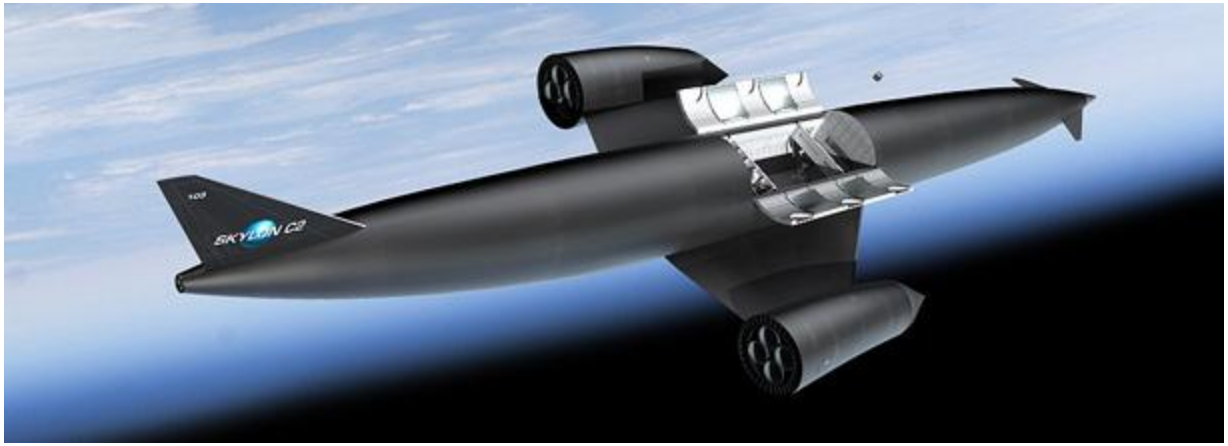
He circulation cools intake air and drives, through a turbine expansion, the air turbo compressor, heats liquid hydrogen and drives LH2 pump high pressure stage.

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 Proposed Roadmap to RAMJET

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.