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M10 CRYOGENIC LIQUID ROCKET ENGINE OF VEGA-E UPPER STAGE

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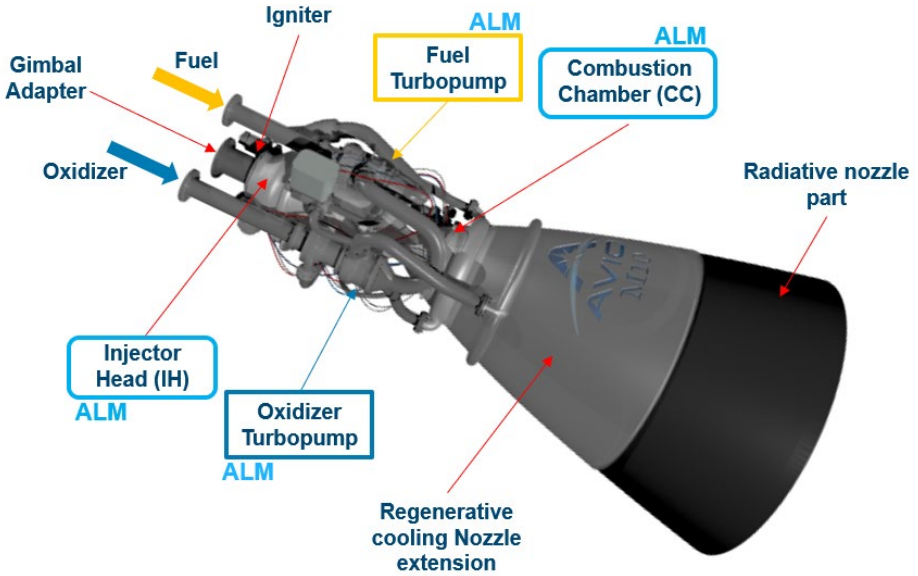
INTRODUCTION – VEGA-E UPPER STAGE

VEGA-E replaces the solid stage Z9 and the liquid stage AVUM with a Vega Upper Stage (VUS) powered by the M10 cryogenic liquid engine, a **LOx-Methane expander cycle**, **throttleable** and **re-ignitable**.

Propellants	LOx-Methane
Schematic	Expander cycle
Thrust in vacuum, kN	98.1
Minimum I_{sp} in vacuum, s	362
Mixture ratio	3.4
Number of chambers	1
Thrust vector	± 8°
Weight, kg	< 230
In-flight ignitions	6



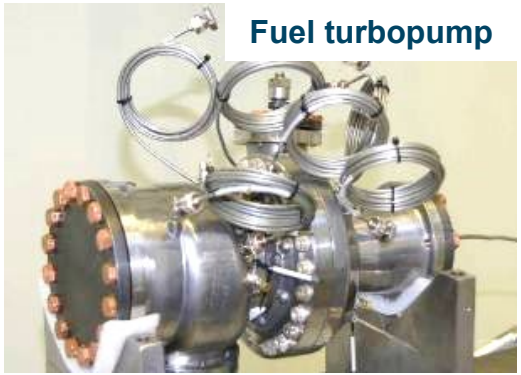
AVIO ALM BACKGROUND 1/3

The **fuel turbopump** was the first prototype that implements **Additive Layer Manufacturing (ALM)** parts and that were successfully tested at engine level in Voronesh, Russia (2014), in the frame of **project MIRA**.

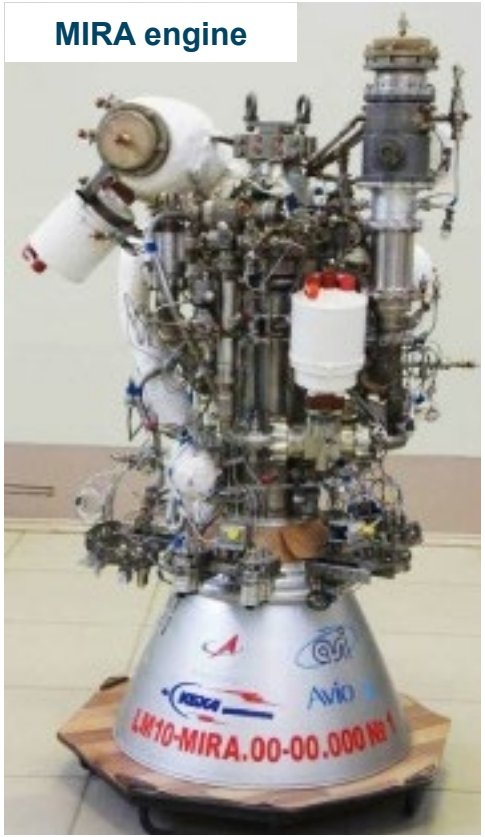
The following parts were realized by ALM

- Centrifugal pump impeller, with Ti and IN718 both with working range 80000-100000 [rpm]
- Pump manifold, proof tested at 250 [bar]
- Turbine manifold, proof tested at 250 [bar]

Fuel turbopump



MIRA engine

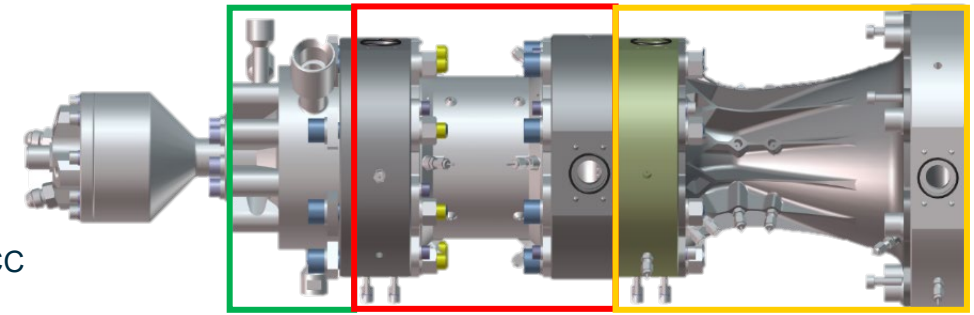


AVIO ALM BACKGROUND 2/3

After the successful MIRA firing test demonstration, AVIO started several self found activities focused to the development of the sub-systems of a 2-tons thrust **sub-scale combustion chamber** (CC) to be realized by ALM technology with **Inconel 718**.

AVIO R&D program:

- **CRIO4**, sub-scale injector head
- **CRIO5**, cylindrical part of the sub-scale CC
- **CRIO9**, nozzle part of the sub-scale CC
- **CRIO6**, unconventional cylindrical part of sub-scale CC



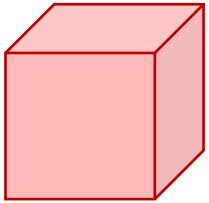
CRIO6 Cooling jacket with **reticular structure** for increased thermal transfer during combustion phase

Ongoing activity
Firing test coming soon

ALM testing of different reticular geometries

AVIO ALM BACKGROUND 3/3

Mid-size commercial PBF Printer



250 x 250 x 280 mm³

Single injector geometry cold flow study

CRIO4

As-built

CRIO5

As-built

Finished

Complex shapes ALM growing studies

CRIO9

As-built

Finished

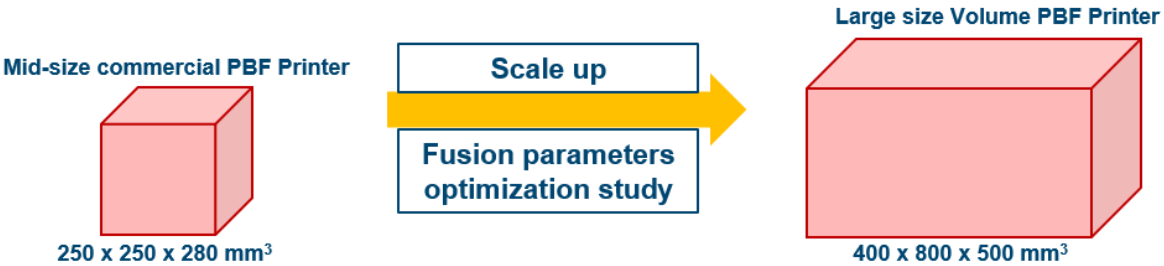
VEGA-E DEVELOPMENT PROGRAM

The achieved results by the research programs opened the way for the development of **VEGA-E upper stage engine** by exploiting ALM technology. The need to realize a **Single Material Single Part (SMSP) [Patent No. 20170122258]** sub-scale combustion chamber required the use of a large size printing machine.

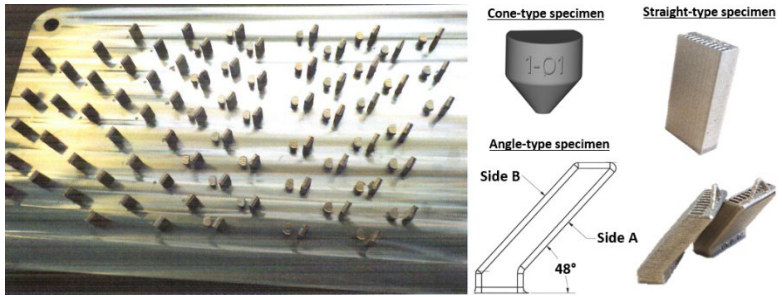
VEGA-E program:

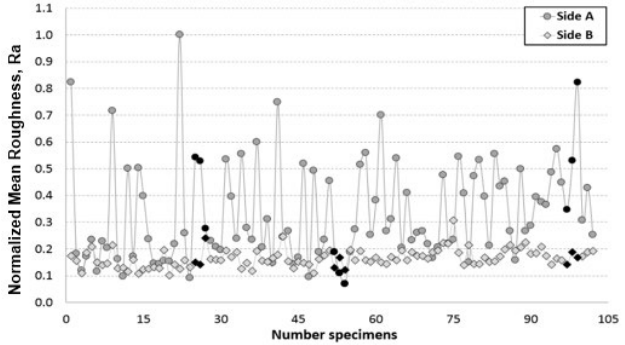
- build-up of **SMSP** sub-scale CC
- build-up of injector head
- sub-scale firing test campaign

- build-up of **SMSP** full-scale CC
- build-up of full-scale injector head
- full-scale firing test campaign



Fusion parameters optimization focused on **density maximization** (absence of porosity) and **roughness minimization**.





VEGA-E PROGRAM – SUB-SCALE ALM COMBUSTION CHAMBER

After few SMSP manufacturing demonstrators, the CC **VUS4** was finally realized and successfully fire tested at AVIO Facility.

In perspective of full-scale CC development, a two segments SMSP CC, called **VUS6**, was printed and welded to test the welding reliability during the hot firing conditions.

VUS4

Firing test

A total amount of 100 firing tests, more than 3000 [s] accumulated firing time between CRIO and VEGA-E programs

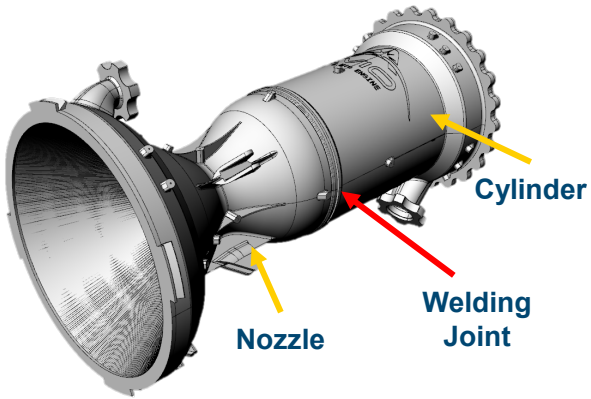
VUS6

Welding

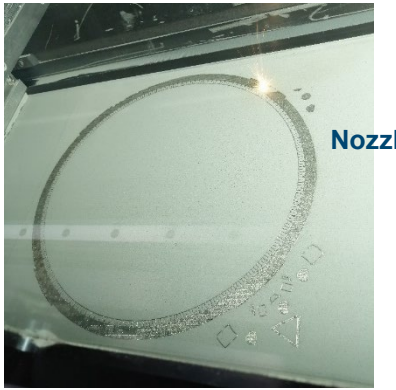
Firing test

VEGA-E PROGRAM - FULL-SCALE COMBUSTION CHAMBER 1/2

Combustion chamber realized by **Additive Layer Manufacturing (ALM)** with Inconel 718 based on **Single Material Single Part (SMSP)** patent.



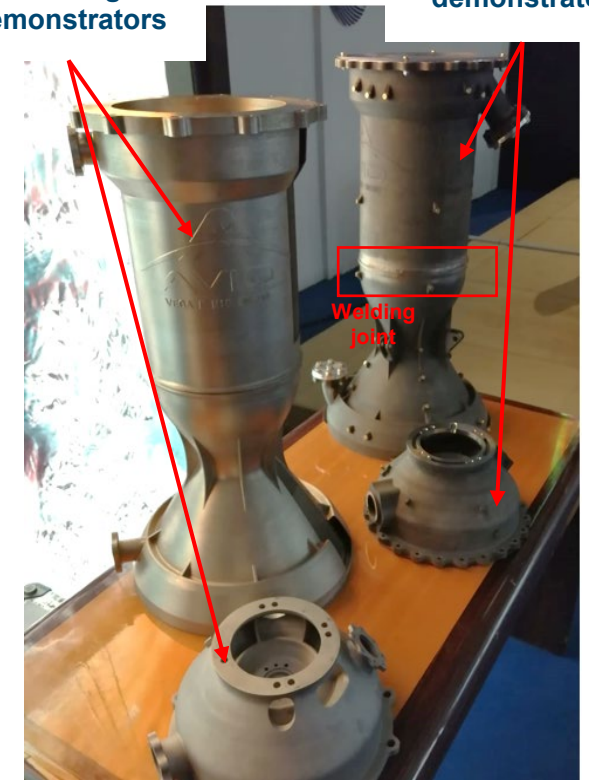
As-built cylinder segment



Nozzle segment printing

Printing demonstrators

Manufacturing demonstrator



The printed Cylinder and Nozzle segments required to be machined to realize the welding joint.

VEGA-E PROGRAM – FULL-SCALE ALM INJECTOR HEAD

ALM Injector Head made by Inconel 718 in a single part, avoiding welding joint or brazing of several parts, as typically required by traditional technology.

Composed by few parts:

- 2 single elements: main body and firing plate;
- 90 sleeves;
- No structural brazing joints in the critical joint. Thus, no leak of any propellants can occur at fuel/oxidizer interface
- No structural welding joints, that can represent a weak point of the structure itself

FIRING TEST CAMPAIGN – FETCA DEMONSTRATOR PROTOTYPE

The Fully Equipped Thrust Chamber Assy (FETCA) includes not only the combustion chamber and injector head, but also the **oxygen main valve**, the **igniter** and **oxidizer/fuel inlet pipes** coming from engine configuration.

The FETCA was imposed to the **firing demonstrator prototype** test, where the propellant (LOx/GCH4) conditions were simulated by test bench means.

FETCA transportation configuration

FETCA integrated on NASA MSFC test bench in Huntsville

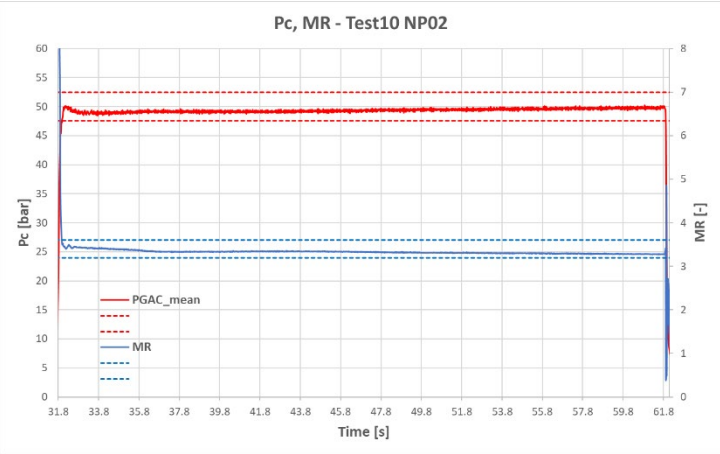
FIRING TEST CAMPAIGN – FETCA DEMONSTRATOR PROTOTYPE

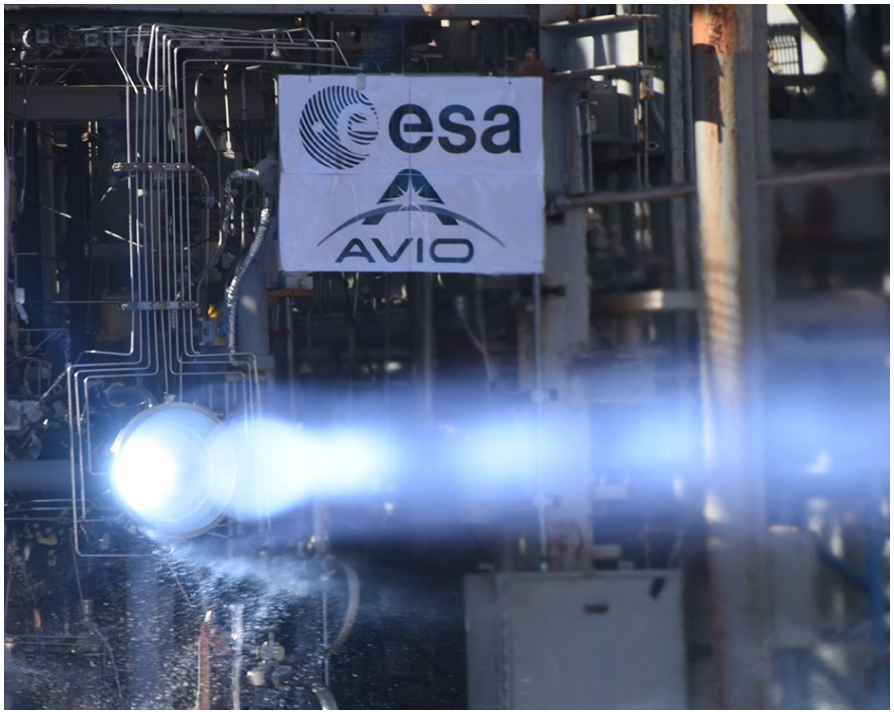
The firing test campaign scheduled 20 firing tests performed in the beginning of 2020.

The test campaign was successfully completed by accumulating about 500 s of firing time, demonstrating the capability:

- to sustain the nominal thermo-chemical loads
- to explore the different conditions of its operative box

Pressure and O/F during the firing in agreement with the prediction margins (±4%).





SPACE PROPULSION TEST FACILITY (SPTF)

Contemporary, in order to be ready for the test campaign of the 1st M10 Development Model (DM1), a new and dedicated test facility (SPTF) was realized in Sardinia.

- Operational since 2021 for test in ambient conditions.
- Additional test bench adaptation to simulate different flight conditions to be developed and implemented.

M10 ENGINE DEVELOPMENT MODEL (DM1) EXPERIMENTAL CAMPAIGN

After the successful milestone achieved by TCA firing test in NASA Marshal Space Flight Center, a new TCA item was manufactured to be integrated in the 1st M10 Engine Development Model (DM1).

The integration of DM1 was carried out in AVIO, in the same building where the VEGA upper stage is assembled prior to be shipped to Guyana base.

After engine integration in AVIO, the DM1 was shipped to SPTF in Sardinia to be installed on the test bench.

The DM1 firing test campaign has the following objectives:

- ❑ Verification of engine performance at sea level conditions
- ❑ Verification of the performance of engine components at sea level conditions
- ❑ Verification and adjustment of engine chill-down phase
- ❑ Verification and adjustment of engine ignition sequence
- ❑ Verification and adjustment of engine start-up and shut-down sequences
- ❑ Verification of chamber cooling
- ❑ Evaluation of effects of pressure and temperature variations at pump inlets
- ❑ Validation of models and tools used for the prediction of engine performance

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