

LOX METHANE BIMETALLIC COMBUSTION CHAMBER FOR FUTURE DEVELOPMENT OF EUROPEAN SPACE LAUNCHERS

*Alessandra Loperfido**, *Alessio Gizzi**, *Viviana Ferretti**, *Daniele Liuzzi**, *Jan Van Schyndel*[†], *Justin Hardi*[†], *Jan Deeken*[†], *Graham Matheson**, *Talha Cakmak**, *Tobias Eisele*[§]

** Liquid Propulsion Department, AVIO SpA, Colleferro, Italy*

† German Aerospace Center - Institute of Space Propulsion, Lampoldshausen, Germany

** Oerlikon AM Europe GmbH, Garching bei München, Germany*

§ Oerlikon METCO, Wohlen, Switzerland

alessandra.loperfido@avio.com – alessio.gizzi@avio.com

Abstract

The focus of the EU DISCO2030 Project is to prove that two Additive Manufacturing (AM) techniques, Directed Energy Deposition (DED) and Powder Bed Fusion (PBF), are combined into a reliable manufacturing process for a subscale LOx/CH₄ rocket engine, as a result of the cooperation among AVIO, Oerlikon AM and METCO, and DLR, that are responsible for designing, manufacturing, cladding and testing, respectively. Challenges within emerging additive manufacturing technologies are addressed, while tackling potential lifetime, performance and quality increase, heat extraction and structural integrity enhancements during (pre-)fire test characterization, all by fostering reusability and time/cost efficiency in the European launcher scenario.

1. Introduction

Presented in this Paper are the ongoing works performed within the first use case in the framework of the EU DISCO2030 PROJECT - Combining DISSimilar materials into functional large-scale and light-weight COmponents and structures. The focus of the project is primarily to prove that the two Additive Manufacturing (AM) techniques of Directed Energy Deposition (DED) and Powder Bed Fusion (PBF) are successfully combined into a reliable manufacturing process for the demonstrator, namely a subscale LOx/CH₄ thrust chamber assembly (TCA), that is designed by AVIO [6].

For this purpose, the demonstrator described in Chapter 2 consists of a PBF-printed rocket engine combustion chamber, made in copper alloy, based on the design of the use-case partner AVIO following guidelines provided by Oerlikon AM, who are responsible for the production processes. This inner liner will then be covered with a Nickel alloy close-out in the shape of a topologically optimized exoskeleton on the Copper alloy substrate via powder-based DED using a DED machine located at the partner Oerlikon METCO. Details about the manufacturing process are outlined in Chapter 3.

Afterwards, the partners DLR and AVIO will perform hot fire tests to qualify the produced demonstrator and the whole process until TRL 6 level is reached [6]. During the test campaign several goals should be achieved, such as: the qualification of AVIO injector head and demonstrator combustion chamber, the development of the ignition sequence, achievement of nominal operating conditions (target chamber pressure, load points mixture ratio). In this framework, combustion stability characterization is carried out through the integration of instrumentation capable of detecting the occurrence of High Frequency coupling phenomena which may occur during operation: the so-called ‘measurement ring’ is installed between the injector head and the cylindrical combustion chamber segment and contains the majority of sensors for measurements of the combustion chamber, such as temperatures and static pressure sensors, as well as being equipped for the study of combustion instability [8]. Based on the extremely high-power density of rocket combustion chambers, they can cause fast growing pressure and velocity oscillations, as well as oscillation in heat release, which may result in damage of the engine. The actual underlying coupling mechanisms are usually divided into intrinsic and injection coupled mechanisms. Intrinsic coupling describes mechanisms caused by variation of subprocesses inside the chamber as mixing and combustion, whereas with injection coupling, pressure or mass flow

variations in the injectors interact with chamber pressure oscillations and amplify them through a modulation of the combustion dynamics [1]. The above is essential to capture the firing test campaign logic that will be carried out at the European Research and Technology Test Bench P8 for cryogenic high-pressure combustion and outlined in Chapter 4.

In the final stage of the project, the use-case partners would quantify the demonstration results according to the selected Key Performance Indicators (KPIs). This step will also encompass the identification of work-ons and further research questions to be addressed post-project to bring the technologies into higher TRL levels.

In this framework an existing broad background in rocket engine component design through in-depth study of the realization of bimetallic combustion chambers is further enhanced: additional constraints and aspects inherent to design, technologies, pre-fire test characterization, and fire test itself are tackled. Great exploitation value results from an increased knowledge of new alloys produced by additive manufacturing, which is listed among other potential new opportunities for next-generation rocket engines and launchers: heat extraction, as well as general performance and quality increase, weight reduction together with increased strength and structural integrity, and potential lifetime increase, are all crucial aspect in the Reusable Launchers scenario. These features may contribute to the expansion of the consortium partners in the space launcher market, being involved with engine scaling-up purposes in the view of developing flight components and eventually allowing heavier payloads to be carried into orbit.

2. Baseline and Specifications

Once the main objectives of the activities have been stated, the reader is introduced to the process of defining the appropriate hardware, namely a liquid LO_x/CH₄ demonstrator, consisting of a sub-scale instrumented thrust chamber assembly.

The purpose is to lay out the baseline and the specifications that are complementing the achievement of the aforementioned project goals, according to both additive manufacturing needs and target liquid propellant rocket engine performance. To highlight innovative and efficient solutions to underpin this combination and derive the major advantages, let us first give a descriptive overview of the test article and then examine in detail the design roadmap that has brought certain solutions to fruition. Finally, one may outline to what extent these tested solutions agree with certain Key Performance Indicators (KPIs), that have been specifically defined to guarantee and benchmark the innovative outcomes that may arise.

To sum up, the following objectives are outlined in this Chapter: the test article baseline and specification, iteratively improvements of the use-case designs, definition of the use-case Key Performance indicators (KPIs) to be achieved during the demonstration phase

2.1 Test Article description

A general description of the Use Case 1 Thrust Chamber Assembly and its main components is provided in this Chapter, complemented with the macro-features and specifications of each item presented.

2.1.1 Thrust Chamber Assembly

The thrust chamber is the key subassembly of a rocket engine: here the liquid propellants are metered, injected, atomized, vaporized, mixed, and burned to form hot reaction gas products, which in turn are accelerated and ejected at high velocity [2].

As far as the Use Case 1 Thrust Chamber Assembly is concerned, from Figure 1 one may observe the presence of several elements composing respectively the Injector Head (IH) and the Combustion Chamber (CC) assemblies. On the one hand, the Injector Head (IH) Assy features: a modular design consisting of Liquid Oxygen (LO_x) dome and Gaseous Methane (GCH₄) dome, the Igniter and the Measuring Ring (provided by DLR), equipped with advance sensor technology. On the other hand, the Combustion Chamber (CC) Assy consists of: an actively cooled Bi-metallic Combustion Chamber, a Convergent-Divergent Nozzle, and it is equipped with two manifolds, placed on the inlet and outlet of the cooling jacket.

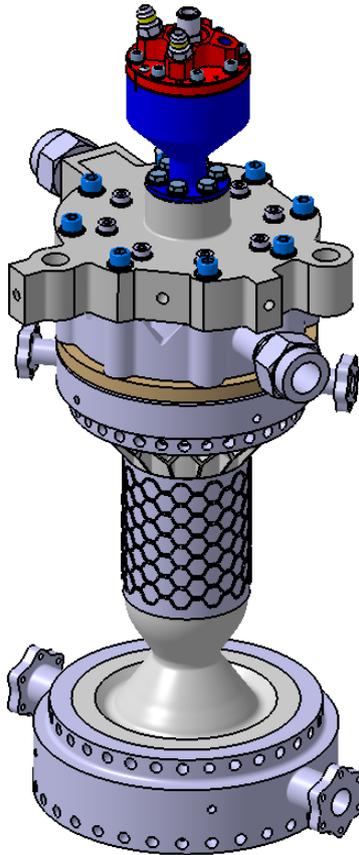


Figure 1: DISCO2030 Use-Case 1 TCA

It is worth remarking that this demonstrator is a sub-scale thrust chamber assembly, and therefore its design must be representative of a corresponding full-scale engine using proper scalability criteria [3], with the focus on capturing the physics of the full-scale phenomena. Testing such demonstrator in the P8 Test Bench facility at the German Aerospace Center (DLR) aims at investigating main phenomena involved in the fluid dynamics, structure, acoustics, etc. that would arise in a scaled-up component, thus increasing the TRL of the innovative manufacturing process.

2.1.2 Bimetallic Combustion Chamber

The Combustion Chamber is the key component responsible for guaranteeing a complete propellants combustion and driving the expanding hot gases into the convergent-divergent nozzle where the thermal energy is converted into kinetic energy. In this case, it is actively cooled through LNG collected by the manifolds and injected into the cooling channels to chill down the combustion chamber wall profile: a cylindrical part and a nozzle, the latter consisting of a convergent part, a throat section and a divergent part.

Combustion chambers, according to their functional behaviour, are subjected to both high pressure and thermal loads during firing operation, and therefore feature: a liner with cooling ribs to precisely extract heat from the chamber wall; a close-out, to add stiffness to the liner.

While traditionally obtained by die casting and brazing technological processes, or either ALM printed using a single material that must withstand both the pressure and thermal load, in the framework of the DISCO project, the challenge consists of combining two manufacturing technologies and materials in a way that appears to be both cost and time effective, as well as weight and performance efficient, as shown in Figure 2: Powder Bed Fusion (PBF) printing of a copper alloy liner, to achieve an efficient cooling of the chamber wall profile; Laser powder-based Directed Energy Deposition (DED) application of a nickel alloy close-out, in the shape of an exoskeleton, to be deposited on the copper substrate to act as a topologically optimized stiffener.

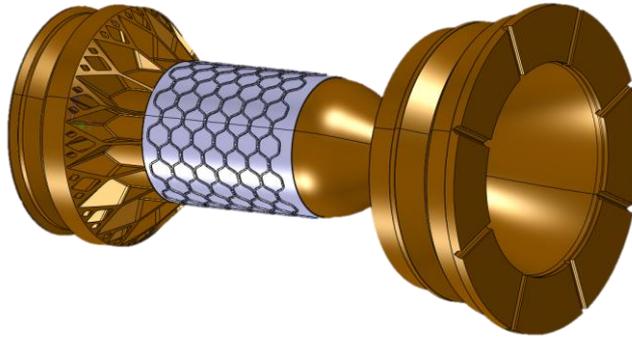


Figure 2: DISCO2030 Use-Case 1 DED configuration

The main features and performance parameters concerning the DISCO2030 DEMO Bi-metallic Combustion Chamber are summarized in the table below:

Table 1: DISCO2030 DEMO CC

	Value
Chamber Pressure	$\approx 50\div 100$ bar
Mixture Ratio	$= 3.6$
Chamber Temperature	≈ 3500 K
Thrust	≈ 20 kN
Liner, cooling channels and part of the close-out	Copper Alloy
Exoskeleton	Nickel Alloy

Design iterations outlined in the following paragraph aimed at reflecting these parameters and the final design

2.1.3 Injector Head and Igniter

The Injector Head Assy, shown in Figure 3, consists of LOx dome, GCH4 dome, Igniter and Measuring Ring, and it is responsible for collecting and injecting propellants into the combustion chamber, while ensuring their correct mixing, as well as stability of flames and acceptable combustion efficiency, overall. A key role in this purpose played by the injector element, which must introduce and meter the flow of liquid propellants to the combustion chamber, cause the liquids to be broken up into small droplets (a process called atomization) and distribute and mix the propellants so that a correctly proportioned mixture of fuel and oxidizer will result, with uniform propellant mass flow and composition over the chamber cross section. As it has been previously mentioned, injector geometry and functional behaviour in terms of hole pattern, hole distribution, and pressure drop may have a strong influence on combustion stability [2].

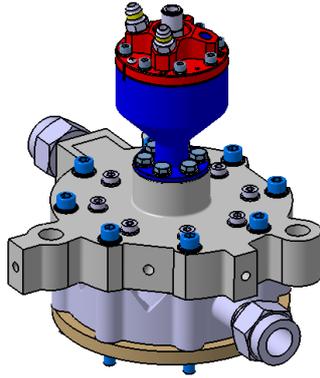


Figure 3: DISCO2030 Use-Case 1 IH Assy

The main aspects concerning the DISCO2030 DEMO Injector Head are summarized in the table below:

Table 2: DISCO2030 DEMO IH

	Value
Number of injectors	N = 6
Type of injectors	Shear coaxial
Post	Liquid Oxygen
Sleeve	Gaseous Methane

Design iterations outlined in the following paragraph aimed at reflecting these parameters and the final design.

2.2 Design Iterations

The design hereby presented is the result of a journey that builds on a broad existing background in the design of TCAs such as to be produced with additive manufacturing processes. In the framework of the DISCO2030 project, these know how has been coupled with the new design challenges that have arisen in combining the two technologies of PBF and DED, respectively with copper-based Alloys and Nickel-based Alloys. An overview of the whole design process is given by the following roadmap:

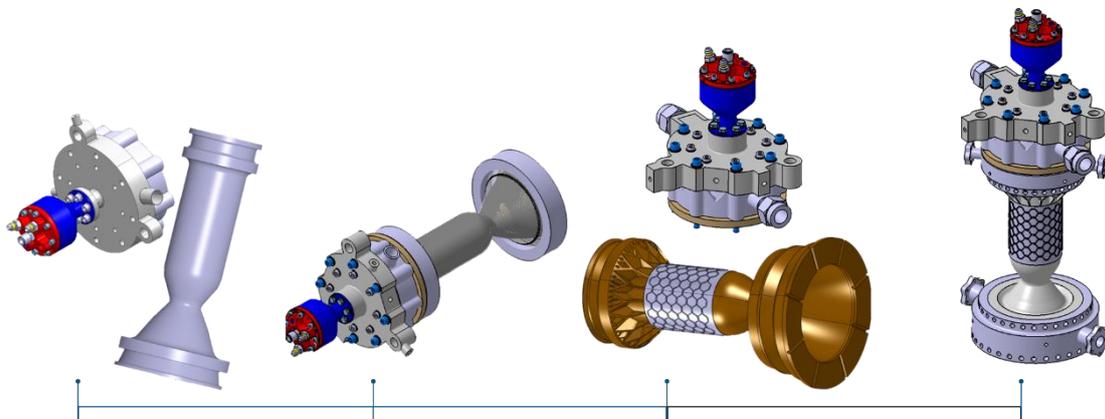


Figure 4: DISCO2030 Use-Case 1 Design Roadmap

2.2.1 Combustion Chamber

The preliminary version of the demonstrator is based on previous expertise developed by AVIO in designing thrust chambers for liquid propellant rocket engines.

The choice of the relevant design parameters such as length of the combustion chamber, length of the nozzle, throat/outlet ratio of nozzle areas, cooling channels geometries is finalized to satisfy the performance requirements and the targeted Load Points. Operative conditions or Load Points (LPs) have been defined according DLR's test bench requirements in the view of investigating a wide field of operation: chamber pressure values are ranging from 50 to 100 bar, together with propellants injected according to a proper mixture ratio, slightly below the stoichiometric value so as not to reach critical temperatures but ideal to ensure excellent performance. Moreover, the preliminary geometry has intended to achieve an adequate thrust level, which is translated in terms of operating pressure in the chamber, as well as sufficient combustion efficiency, and consequently, since the temperatures involved in combustion processes are extremely high, an active cooling system is needed. The range of operations is preliminary for component throttability, which could yet be verified at the subscale demonstrator level.

Therefore, keeping in mind those consideration made in the early design phase, the chamber profile has been chosen and a mock-up version is visible on the left side of Figure 5. The component features the following functional behavior: the internal surface (liner) of the combustion chamber, which is subjected to the high temperature of the flame, is cooled by a system of channels (cooling jacket) longitudinally developed within the chamber wall thickness. The liquid fuel flows through the cooling channels, protecting the liner from melting by extracting heat from the material. The access to the cooling channels is guaranteed by a couple of manifolds, directly integrated in the chamber geometry, respectively on the cylinder and the nozzle side. Both are visible in Figure 6.

The following step referred to a general optimization of the thrust chamber in order to derive the PBF-configuration. Surface roughness can have a large effect on the heat transfer film coefficients and thus on the heat flux inside the combustion chamber. However, surface roughness on the liquid coolant side of the wall will enhance turbulence and the absorption of heat by the coolant and reduce wall temperatures [2].

Finally, investigation on internal features of the cooling jacket and tree-shaped support structures led to a perfectly printable design without any overhang surface, shown in the right side of the Figure 5.

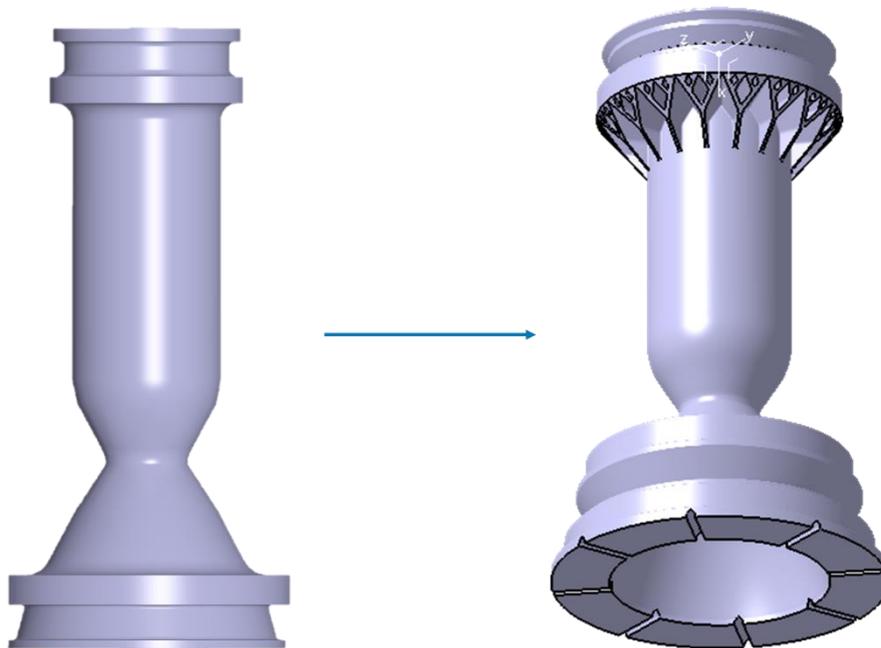


Figure 5: DISCO2030 PBF-configuration

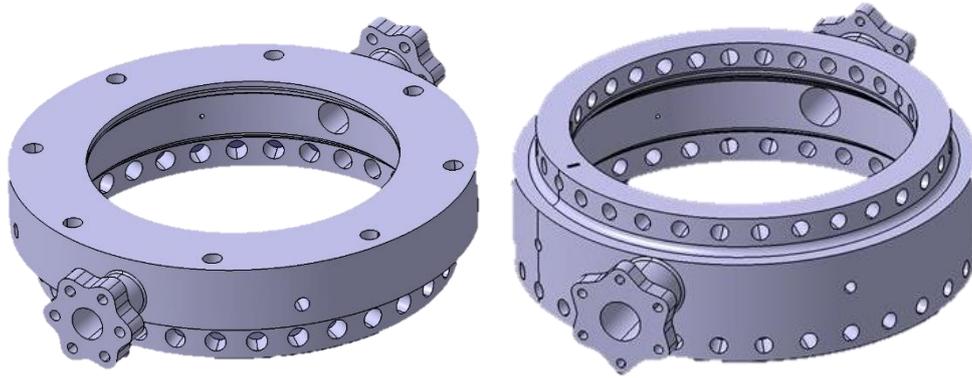


Figure 6: DISCO2030 Use-Case 1 CC Manifolds

Finally, DED-configuration has been derived mostly from Finite Element Method studies to analyse the preliminary geometry through thermo-structural and pressure simulations, aiming at investigating the effect of different close-out material distribution. A trade-off has been carried out among performance (heat and pressure loads), thicknesses (in terms of deposition needs and weight optimization), percentage of Nickel alloy coverage and stiffeners positioning, etc.

It is worth remarking that conventional heat transfer theory usually refers to the Bartz correlation, according to which the throat section is one of the most critical sections of the thrust chamber assembly in terms of heat loads absorbed by the cooled copper liner, because of its curvature. Moreover, the temperature drop across the inner wall and the maximum temperature are reduced if the wall is thin and is made of material of high thermal conductivity [2]. The wall thickness is determined from strength considerations and thermal stresses, leading to a close-out thickness defined to not interfere with the thermal expansion of the material, so not covered by nickel alloy reinforcements.

In contrast, on the cylinder side, considerations made on pressure and thermal loads led to the need of nickel alloy close out and the definition of the two materials' thicknesses: a thin layer of copper substrate on the close out is necessary to prepare the base for nickel alloy deposition of the topologically optimized exoskeleton. The result is shown in Figure 2.

2.2.2 Injector Head

As far as the injector head is concerned, the main criteria driving its design are mainly based on performance, manufacturability, mixing efficiency, thermal loads, and design complexity.

At first, two types of injectors have been considered: shear coaxial and swirl coaxial; considering the chosen propellant combination, these coaxial elements both rely on mixing achieved by the interaction of the shear stresses of a central post fed by slower liquid oxygen and an external annular sleeve with accelerated gaseous methane. Swirl coaxial injectors might offer an interesting alternative to the classical shear injectors. In swirl coaxial injectors, a tangential momentum is applied to one (or both) of the propellants. could offer increased atomization and combustion efficiency by not only relying on the shear forces generated by the propellants' velocity difference for propellant breakup, like their shear counterparts, but also on the centrifugal forces [2] [4] [5].

Being the AVIO SpA heritage coincident with the shear coaxial oxidizer-centered configuration, the outcome configurations are outlined as follows: even though the swirl coaxial injectors may be more performant from the point of view of mixing efficiency, they may increase the level of design and manufacturing complexity, which would be not necessary in the framework of the DISCO2030 project, whose focus is the operation of a bi-metallic combustion chamber DEMO; on the other hand, the shear coaxial configuration is enhancer of good enough performances and less design complexity. Therefore, the baseline injector type choice is the oxidizer-centered shear coaxial element, that could be arranged on one or two rows, thus being a total of 6 or 18 injectors, as shown below:

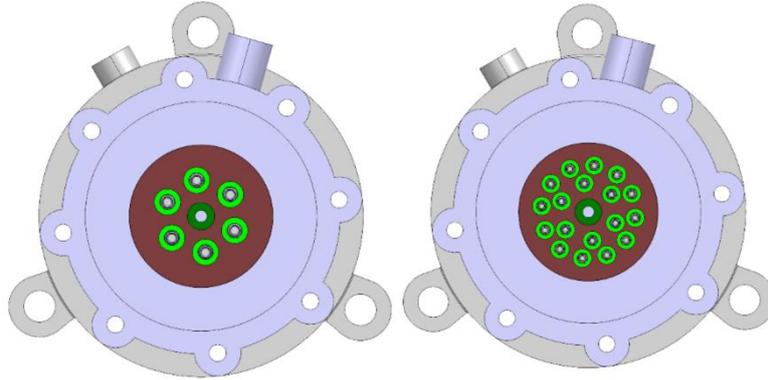


Figure 7: DISCO2030 Use-Case 1 IH Firing Plates

In order to define the final pattern of injectors, the following points should be addressed in the trade-off: a higher density of injectors allows a more uniform flow rate into the chamber, which is reflected in the flame front; at the same time, the individual elements are much smaller and this could lead to limitations from an additive manufacturing perspective, as well as problems with nut integration; on the other hand, having fewer injectors allows more freedom of layout, facilitating the allocation of a firing plate cooling method with transpiration methane flow rate. The second option is selected as baseline design choice.

In addition, the modular design of this subscale injector plate, consisting of two domes with a flanged connection, allows for design flexibility. Therefore, the part made of PBF, namely the methane dome with injectors of complex geometry, has undergone topological optimisation to meet manufacturing requirements and lighten the solid part: residual stress phenomena occurring during the printing process have been limited. This optimization process is outlined in the following figure:

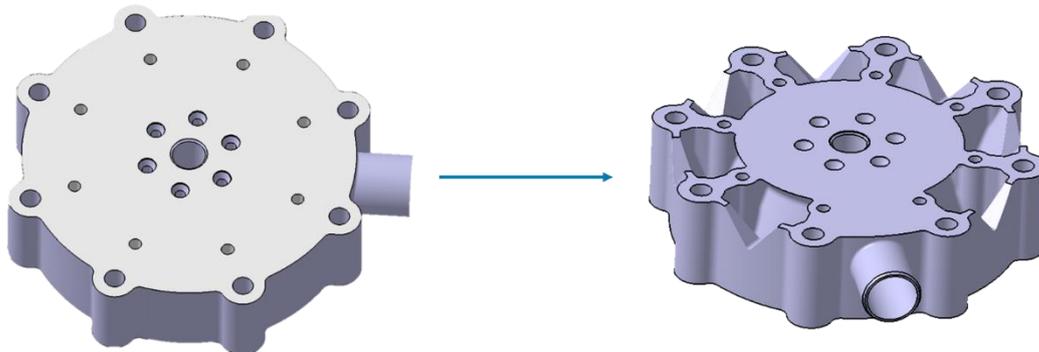


Figure 8: DISCO2030 Use-Case 1 IH Dome CH4 PBF-configuration

Liquid Oxygen dome, manufactured by traditional technology, is shown below:

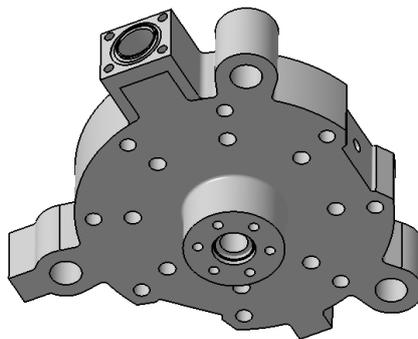


Figure 9: DISCO2030 Use-Case 1 IH Dome LOx machined configuration

2.2.3 CFD simulations

To evaluate the influence of multiple different combustion chamber design aspects, the development process was aided by CFD simulations. In order to increase the amount of investigated aspects, the investigations were split into 2D and 3D simulations. All simulations were performed using the DLR TAU Code [11] applying a 2-layer $k - \epsilon$ turbulence model [12]. The 2D simulations were performed using a finite rate chemistry model [13] to increase the accuracy regarding the wall heat flux predictions, whereas the 3D simulations were done using a flamelet [14] combustion approach to keep the numerical effort within reasonable bounds. For the wall heat treatment, a simplified one-dimensional heat transfer assumption, consisting of variable coolant media temperature and one-dimensional heat conductivity coefficient was used. The two variable parameters allow for a much-simplified modeling of different cooling channel designs and coolant media properties such as mass flow, temperature, pressure or type of coolant. In an external coupling, the conduction coefficient is modeled to include the influence of commonly shaped cooling channels using a fin heat transfer approach combined with Dittus–Boelter [15] or a Dipprey and Sabersky [16] approach for determining the heat transfer to the coolant media, whereas the coolant media heating and properties are modeled using CoolProp.

In the context of the EU DISCO Project multiple 2D simulations were performed to assess the influence of a wide range of design parameters on the combustion chamber wall heat fluxes. Some of the aspects investigated included the influence of different chamber pressures due to a variation of the injector mass flow, different cooling channel designs, different cooling channel modelling approaches, different cooling channel mass flows, varying coolant media properties, and the influence two different nozzle throat contours and diameters. For the 2D simulations multiple assumptions and simplifications needed to be made. The major simplification is the neglect of the injection system. Instead, the inflow was modeled to directly consist of hot combusted exhaust gases with the given composition based on the injection ROF. Hence the Temperature at the beginning of the chamber is already very high (see Fig. 10), as no mixing processes are considered, and subsequently all results in the first half of the combustion chamber need to be omitted for any further evaluation.



Fig: 10: Representative temperature field comparison for two simulations comparing the AVIO nozzle contour (up) with the LUMEN nozzle contour (down).

Exemplarily for all the simulations performed, Fig.11 shows the influence of a varying coolant mass flow on the wall heat flux. One can see that while within the combustion chamber the influence of different coolant mass flows is minimal, within the nozzle throat the effect is considerably larger. With increasing coolant mass flow the heat flux also increases and consequentially the chamber wall temperature decreases.

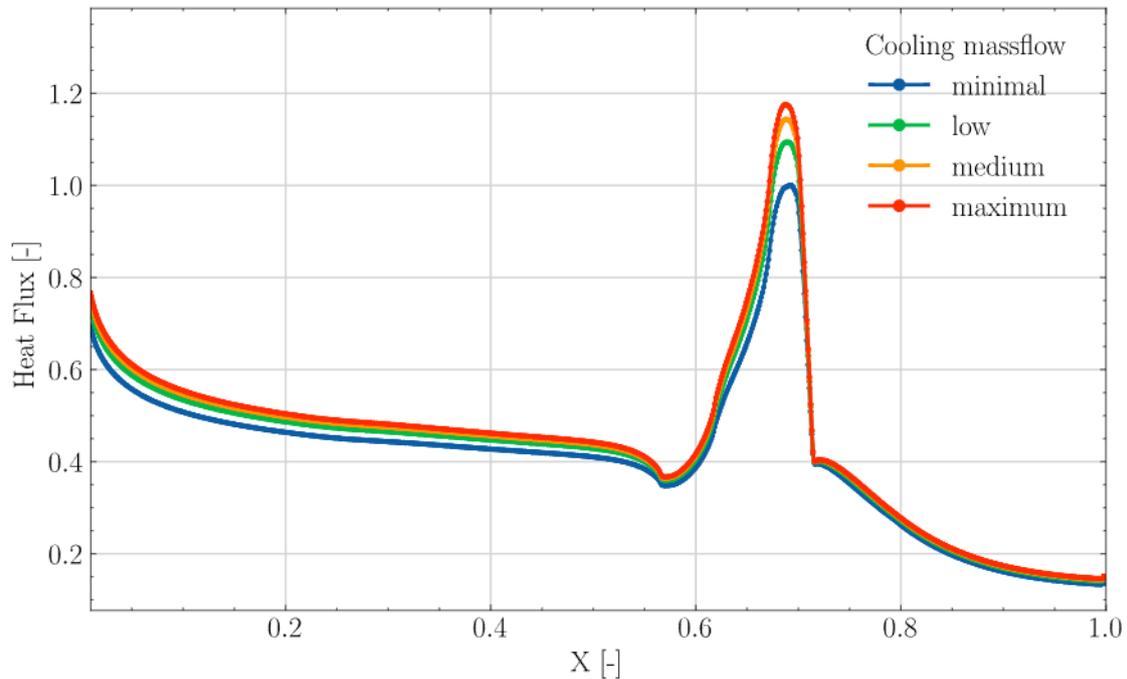


Fig. 11: Influence of the different cooling mass flows on the wall heat flux (dimensionless) at a given injector mass flow / base pressure.

In a later stage of the project a single 3D simulation of the chamber design was performed. The 3D simulations were to cover some of the aspects that were missing due to the assumptions in the simplified 2D simulations. Some of the aspects focused on were the mixing behavior at the injector, the size of the recirculation zone at the chamber wall close to the faceplate and the temperatures and heat fluxes on the faceplate. The calculation domain consists of a slice containing a single injector with symmetry boundary conditions on both sides. A sketch including boundary conditions is shown in Fig. 12.



Fig. 12: 2D Sketch of the computational domain (slice through the middle the injector) including boundary condition: CH₄ injection temperature and mass flow rate (black), external wall: slip, thermal reservoir, h_{cc} , T_{∞} (green), pressure outlet $P_{out} = 1$ bar

Fig 13. Shows the temperature field within the flow close to the faceplate for a cut going straight through the middle of the injector. The length of the recirculation zone, cold area on the top left part, has direct impact on the wall heat flux and sequentially it has implications on the cooling designs in the first parts of the combustion chamber.

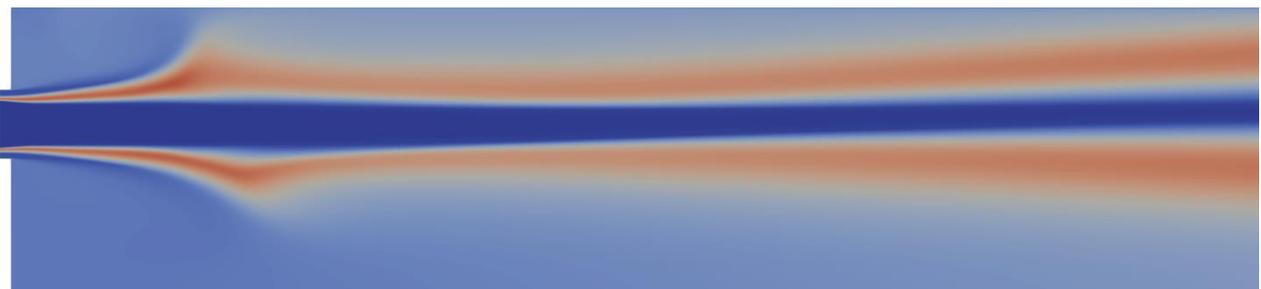


Fig. 13: Temperature Field for a cut going through the middle of the injector.

2.3 Key Performance Indicators (KPIs)

The Key Performance Indicators (KPIs) that have been selected for each use-case are related in general to lifecycle, performance, and physical requirements; their respective means of verification would be crucial after or during components tests to verify and validate project's progresses. As far as the first use-case "Rocket Engines" is concerned, lifecycle requirements are referring to combustion chamber structural integrity, recyclability, and combustion instability handling; performance indicators involve mass reduction, as well as chamber pressure and coolant temperature; finally, physical requirements refer to combustion chamber bimetallic structure and printed quality. Moving deeper into the subject, one can examine in more detail the verification methods and criteria that are referred to each Indicator.

Analysis and firing test methods are used to ensure the structural integrity of the bimetallic combustion chamber: structure failure is prevented by ensuring that the limit characteristics of the materials will be respected during one or multiple firing tests (reusability). In this framework, combustion instabilities, especially High Frequency (HF) ones, are a critical phenomenon for LPRE because they may seriously damage the engine and eventually lead to its failure. In general, oscillatory operation of a rocket engine is undesirable for many reasons, for instance: severe vibrations may impair the operation of sensitive guidance components and have severe effects upon payloads and even relatively massive structural members; grossly increased heat transfer that is often sufficient to melt and destroy portions of the rocket system; other less drastic effects such as decreased performances, uncontrolled impulse, variation in thrust vector and consequences of oscillatory propellant flow rates. Those issues combined may lead to extensive damage of the thrust chamber and the injector [7]. One may realize the actual industrial concern about experimental studies on these phenomena, easily leading to extensive, full-scale testing and relatively high costs. Therefore, to prevent instability occurrence one may face the challenge of accurately predict the stability behaviour of a Liquid Rocket Engine either during an early design phase through numerical modelling, or with Injector Head preliminary characterization, especially with reference to the injection coupling mechanism as instability driving [8]. As far as the modelling state of art is concerned, one possible classification sees the numerical predictive methods for thermo-acoustic instability divided into two branches: high fidelity and low order approaches, which differ in the depth of the hypotheses considered, the level of accuracy of the results and the computational costs. Both are strongly interconnected with experiments, useful to validate modelling approaches [9].

Combustion chamber mass could be optimized by combining two metals, while achieving high chamber pressure ensures high thrust levels and high specific impulse, which are two key performance parameters for rocket engines. Moreover, an efficient cooling system can extract more heat from the chamber walls, improving overall performance. The combustion chamber channels and the body structure must ensure a good surface quality and absence of loosen particles: AM parts can in general show rough surfaces and can have loosen powder particles partially attached to the surface which can detach during operation and compromise the performances: de-powdering strategy and certain AM printing parameters are being assessed in order to address this topic, as well as careful surface inspections.

3. Manufacturing

The task of manufacturing the sub-scale combustion chamber to AVIO design specifications in the DISCO2030 project falls to the sister companies Oerlikon AM Europe GmbH and Oerlikon Metco AG of Germany and Switzerland, respectively. The copper alloy laser powder bed fusion (L-PBF) combustion chamber with integrated cooling channels and flanges is shown in Figure 14 while still on the building platform. A large format L-PBF machine capable of building the entire component height without a stop was used to minimize the risk of building interruptions. After depowdering, and heat treatment, the chamber liner then undergoes a laser powder direct energy deposition of a nickel alloy closeout before final machining and integration into the test assembly.



Figure 14: Copper alloy combustion chamber liner on L-PBF building platform during cleaning and depowdering phase

A primary challenge with applying the Ni alloy L-DED overlay is maintaining the intended geometry of the copper alloy liner. The mechanisms behind distortion can be explained by a simple principle: any welding filler material deposited by means of melting and solidification will contract during solidification. The substrate, which is at room temperature or even preheated, will not contract as much as the overlay. This results in a mismatch because the overlay will always remain shorter, creating stresses that distort the part to remove the mismatch. Consequently, the part attempts to form round shapes with the deposition being on the inner diameter, making it shorter, and the substrate on the outer diameter, making it longer. This process is illustrated graphically in Figure 15.

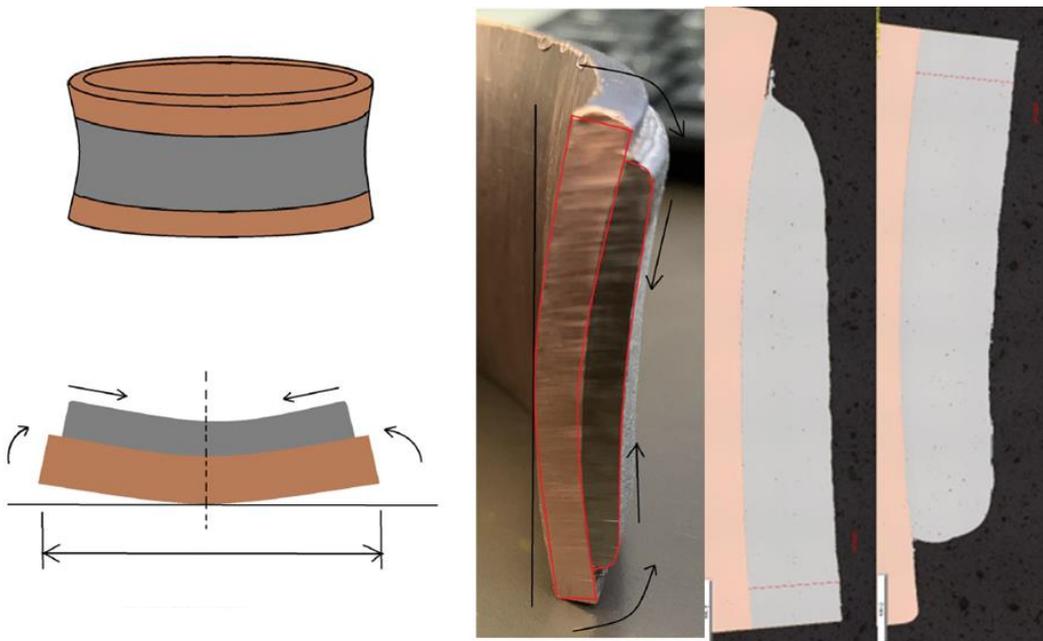


Figure 15: Distortion of a copper alloy substrate caused by heat input and coating material solidification

Various trials to minimize distortions were evaluated, including different clamping methods and in-situ expansion methods using flexible fixtures. The summary of these methods and resulting cross sections are shown in Figure 16. The results with flexible fixtures indicate significant progress in minimizing distortion. This advancement has allowed the process to be transferred to L-PBF printed combustion chamber geometries as shown in Figure 17, where an exoskeleton Ni-alloy structure is deposited on top of a combustion chamber convergent-divergent profile.

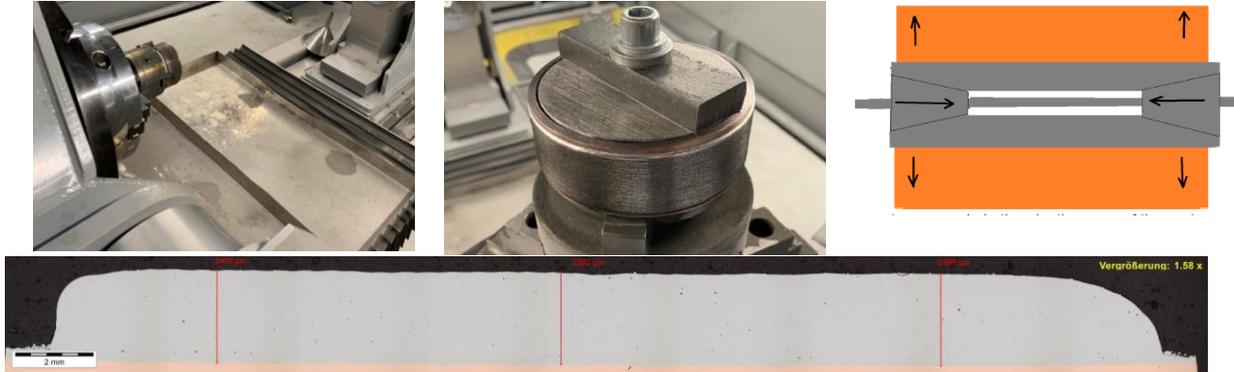


Figure 16: Internal flexible fixturing inserts used to compensate and minimize distortion the copper alloy substrates after L-DED



Figure 17: Ni-alloy exoskeleton stiffened close out deposited by L-DED on Cu-alloy combustion chamber mockup components

After application of the Ni-alloy exoskeleton stiffening structure onto the DISCO demonstrator combustion chamber liner, the component will be 3-d scanned to assess geometrical accuracy, and interfaces will be machined for integration into the final assembly.

4. Testing

The responsibility for testing the use-case demonstrator lies with the German Aerospace Center (DLR). Testing will be performed at the Institute of Space Propulsion in Lampoldshausen, using the European Research and Technology Test Facility P8 for cryogenic rocket engines, pictured in Figure 14. The P8 can provide cryogenic oxygen (LOX) as well as liquified natural gas (LNG) and compressed natural gas (CNG) at pressures, temperatures, and flow rates required for a thrust chamber demonstrator of this scale to be operated at conditions representative of an operational engine. An example of a DLR-produced demonstrator in the same thrust class and using the same propellants is the LUMEN engine. One of the hot-fire tests during qualification of the additively manufactured thrust chamber is pictured in Figure 15.



Figure 14: Aerial view of the P8 test facility at DLR Lampoldshausen (Video: <https://youtu.be/ZSAUOMs1U64>)

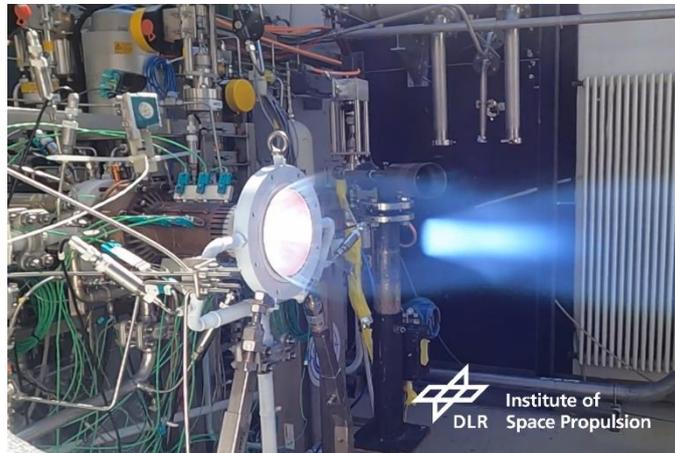


Figure 15: Test of the LPBF manufactured regeneratively cooled thrust chamber of the DLR LUMEN LOX-LNG 25-kN demonstrator engine

In the test campaign for the DISCO project, the injector head will first be tested using a robust, water-cooled combustion chamber. This approach avoids placing the demonstrator thrust chamber at risk while bringing the new injector head into operation for the first time. After establishing reliable operation of the injector, the DISCO-demonstrator will be installed and run with LNG as the coolant. The primary test objectives are to verify the design of the regenerative cooling circuit and the thermomechanical integrity of the bimetallic components.

References

References must be numbered in the text in the following style [3] and listed at the end of the paper in the following way.

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