Additive Manufacturing in the Production of Rocket Propulsion System Components

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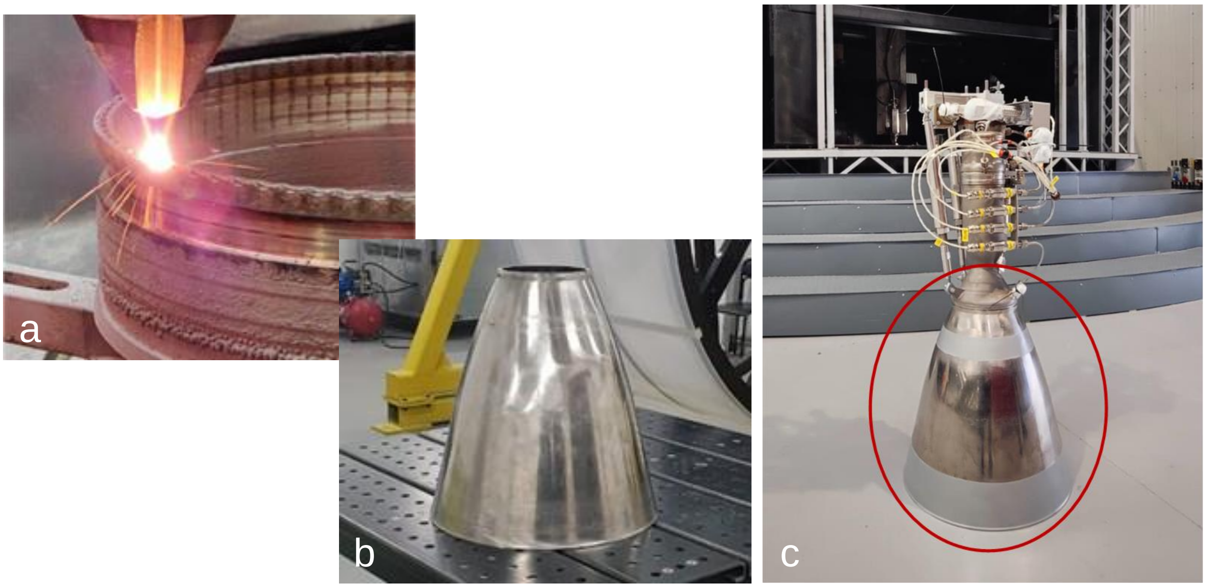
Highlights of Presentation

- Launch vehicle program of SKYRORA Ltd
- SKYPRINT 1 and SKYPRINT 2: In-house developed hybrid 3D printers utilizing laser-based powder-fed Directed Energy Deposition (DED)
- Integration of additive manufacturing in production of rocket propulsion systems and characteristics of processed components
- Perspectives of multi-materials processing using DED in production of rocket propulsion system components

Graphical Abstract



Directed Energy Deposition 3D printing of a rocket engine component (a). Nozzle extension of a rocket engine after 3D printing and machining (b). 3.5 kN LEO rocket engine of the 3rd stage of the SKYRORA XL launcher (c).

Textural Abstract

SKYRORA Ltd, a UK-based aerospace company, is developing a suite of launch vehicles aimed at providing flexible and sustainable access to space. The flagship orbital rocket, the Skyrora XL, is a three-stage launch vehicle designed to deliver payloads of up to 315 kilograms into Sun-synchronous orbit. Complementing this are suborbital vehicles such as the Skylark L, which serve as testbeds for technology validation and mission rehearsal.

SKYRORA has developed advanced hybrid 3D printing systems SKYPRINT 1 and SKYPRINT 2, to enhance its manufacturing capabilities for rocket components. SKYPRINT 2, unveiled in December 2021, is recognized as the largest hybrid 3D printer in Europe. It combines laser-based powder-fed Directed Energy Deposition (DED) with CNC milling in a single platform, allowing for the production of large-format metal parts up to 2.3 meters in length. This integrated approach enables a reduction of production times by up to 80%, decrease costs, and maintain high precision in component fabrication. The use of DED technology allows for near-net-shape manufacturing, minimizing material waste and enabling the recycling of residual powders, aligning with the company's sustainability objectives.

Hybrid additive manufacturing is central to production of rocket propulsion systems. The company employs 3D printing techniques to fabricate complex engine components, such as combustion chambers and nozzles, using high-performance materials like Inconel and titanium-based alloys. The mechanical properties of additively manufactured materials, after appropriate heat treatment, are comparable to those of conventionally produced components, which are typically fabricated through time-consuming and waste-intensive machining from cast and deformed alloys. The porosity of materials processed using DED with SKYPRINT 1 and SKYPRINT 2 usually does not exceed 0.5 %.

Although nickel-based superalloys exhibit superior high-temperature performance, exclusive use of these materials for engine components is not efficient due to their high density—approximately twice that of titanium alloys. A more optimal approach for manufacturing lightweight launchers is to strategically combine materials based on the thermal loads in different structural regions. However, directly joining nickel-based and titanium alloys using laser-based additive manufacturing techniques such as DED is not feasible, as this results in the formation of brittle intermetallic phases (IMPs). To address this, thin intermediate layers of compatible metals are proposed to prevent the formation of brittle compounds at the material interfaces.

Within the framework of the “MADE-3D” project, funded by the European Union's Horizon Europe 2022 program (grant agreement No. 101091911), the chemical composition of these interlayer materials is optimized using computer-aided design to enhance their performance at temperatures below 450 °C. This multi-material approach, which combines Inconel 718 with a Ti-based alloy, allows for a component weight reduction of approximately 35%.