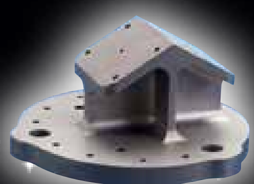
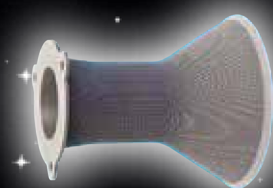
EUROPEAN SPACE AGENCY investigates Additive Manufacturing DMP parts for in-space satellite engines

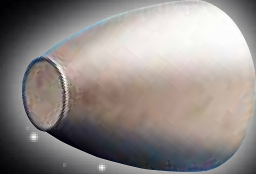
In-space satellite engine injector



Combustion chamber incl. scaffold

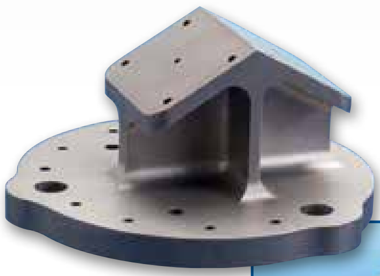


Large-scale expansion nozzle

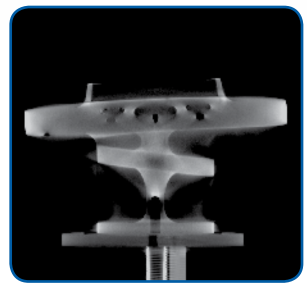


In collaboration with the European Space Agency, 3D Systems produced injectors, combustion chambers and expansion nozzles representative of a bi-propellant communication satellite engine through Direct Metal Printing (DMP) with its On Demand Parts Manufacturing Services team. These parts enable ESA to assess the potential to further improve the manufacture of current designs. In addition, ESA and 3D Systems specialists exploited DMP's design opportunities to engineer functional separated design alternatives for the aforementioned satellite engine parts; for example a monolithic combustion chamber design incorporating a thin wall pressure vessel with a supporting external structural scaffold. DMP saves weight, simplifies assembly, speeds manufacturing, and supports late-stage design adaptation. The collaboration with ESA fits in 3D Systems' strategy to offer its unique know-how in support of space and aerospace manufacturing excellence.

> *Innovative DMP manifolding optimises the propellant flow in the injector.*
>
> *Simon Hyde, European Space Agency (ESA)*



Innovative DMP manifolding allows optimised propellant flow from the valve to the combustion chamber.



Judging from x-ray images with 130 micron resolution, DMP is a practicable approach to injector manufacturing.

The current state of DMP

Communication satellites are essential for mobile internet and secured financial communication between banks, direct TV broadcasting, and earth observation for weather forecasting. One of ESA's roles is to oversee development of in-space satellite engine technologies. As part of an internally funded program ESA is investigating the current state of metal Additive Manufacturing/Direct Metal Printing, assessing its potential and maturity in light of future engine developments.

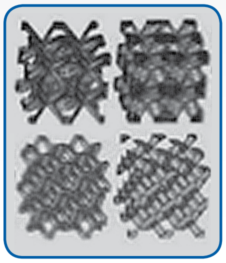
As part of the research program, ESA selected 3D Systems because of the their technology expertise and customer services offered. 3D Systems produced the current designs of three critical engine parts, as well as alternative DMP-enabled functional design variants.

The injector part of a satellite engine brings two propellants together in a controlled way, igniting spontaneously and burning continuously. The venturi-shaped combustion chamber accelerates the chemical exhaust gases to power the satellite to the right orbit. The expansion nozzle influences the motion characteristics by influencing the gas flow further downstream.

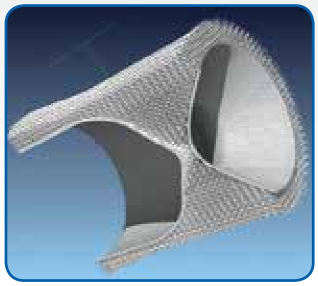
Innovative injector manifolding

"DMP offers innovative manifolding to optimize the flow from the propellant valve to the combustion chamber," says Simon Hyde. It's design freedom enables ESA to reduce the number of injector assembly parts to 1, coming from more than 5 with conventional manufacturing; eliminating many risky sealing welds required to achieve reliable hydraulic injection operation; reducing cost and risk considerably. By acquiring full control over the AM production process, 3D Systems achieves a homogeneous micro structure with a relative density of up to 99.98%, for an increasing number of metal and alloys including titanium.

DMP is also suitable for establishing an injector thermal design that prevents heat from soaking back to the sensitive propellant valves seat and the spacecraft itself. The absence of tooling access constraints allows the redesign of the thermal standoff by controlling the conductivity using a metal scaffold instead. Built in a flight-capable titanium material (Ti6Al4V), the injector parts are approaching the product assurance requirements of the space sector and the design needs of the rocket motor designer.

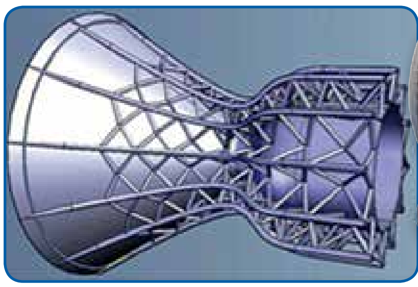


A notable DMP feature is its ability to build low-density meshes, which has become standard in DMP software.

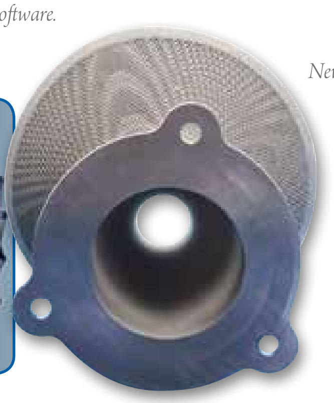


A promising design opportunity resulted in an a low-density mesh on the radiating surface supporting the thin wall of the engine combustion chamber.

Existing design



New design



Separating combustion chamber functions between operational and non-operational load cases, translates into strut-work ribs supporting the thin wall.

Separated chamber functions

The combustion chambers of compact in-space satellite engines typically consist of a convergent-divergent nozzle with an unsupported nozzle exit. The propellant reactions complete in the convergent section before the exhaust gases flow through the throat contraction into the divergent section where they are expanded supersonically. Existing chambers are designed to withstand the non-operational loads associated with the launch, with thicker walls reacting these transient loads. Once on station and operational the chambers do not need such thick walls.

Simon Hyde says that DMP allowed the chamber functions to be separated between operational and non-operational load cases. Intuitively, this translates into strut-work ribs supporting the thin combustor wall and the weld flange for the attachment of the expansion nozzle. Instead of the crude strut work, 3D Systems produced the support structure as low-density mesh. As its volumetric density is as low as 12%, DMP potentially yields major combustion chamber weight reduction or improvement of the structural safety margins.

Built in Ti6Al4V material, the true chamber material would be a refractory material alloy (e.g. based on niobium, molybdenum, tantalum, tungsten, and/or rhenium) to withstand the extreme combustion heat. Further investigation of this revolutionary combustion chamber design involves the study of the mesh's isotropy in the stress field as well as its detailed thermal impact. This mesh will increase the effective surface emissivity, so it will certainly influence the heat fluxes around the chamber.

▲ *DMP increases design flexibility compared to traditional spin forming sheet metal, so engine performance can be tuned towards customer-specific thrust profiles.*

▲ *The expansion nozzle with an exit diameter close to 50 centimeters.*

Large-scale DMP

ESA engineers also examined DMP for manufacturing an expansion nozzle with an exit diameter close to 50 centimeters. Talking about DMP production volume, 3D Systems is able to produce any part geometry that fits in a 275 x 275 x 420 millimeter box. The stress in the nozzle is comparitively low and minimizing the overhung mass is critical for increased margin on the cantilever engine design. 3D Systems produced the expansion nozzle in titanium (Ti6Al4V), which largely meets the mechanical and thermal requirements for the expansion nozzle.

According to Hyde, DMP offers distinct fabrication advantages compared to traditional spin forming of sheet material that kills all design flexibility. It allows the engine performance to be tuned towards customer-specific thrust profiles, leaving many design options open until late in the process.

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