Prototype flexibility using additive manufacturing

Complex supply chains, engineering workforce labor shortages, and evolving expectations around sustainability are some of the many challenges that the satellite industry faces today. Wire-arc additive manufacturing can play a significant role in helping satellite manufacturers optimize prototype production and deliver solutions more cost effectively.

Filomeno Martina, CEO and Co-founder of WAAM3D

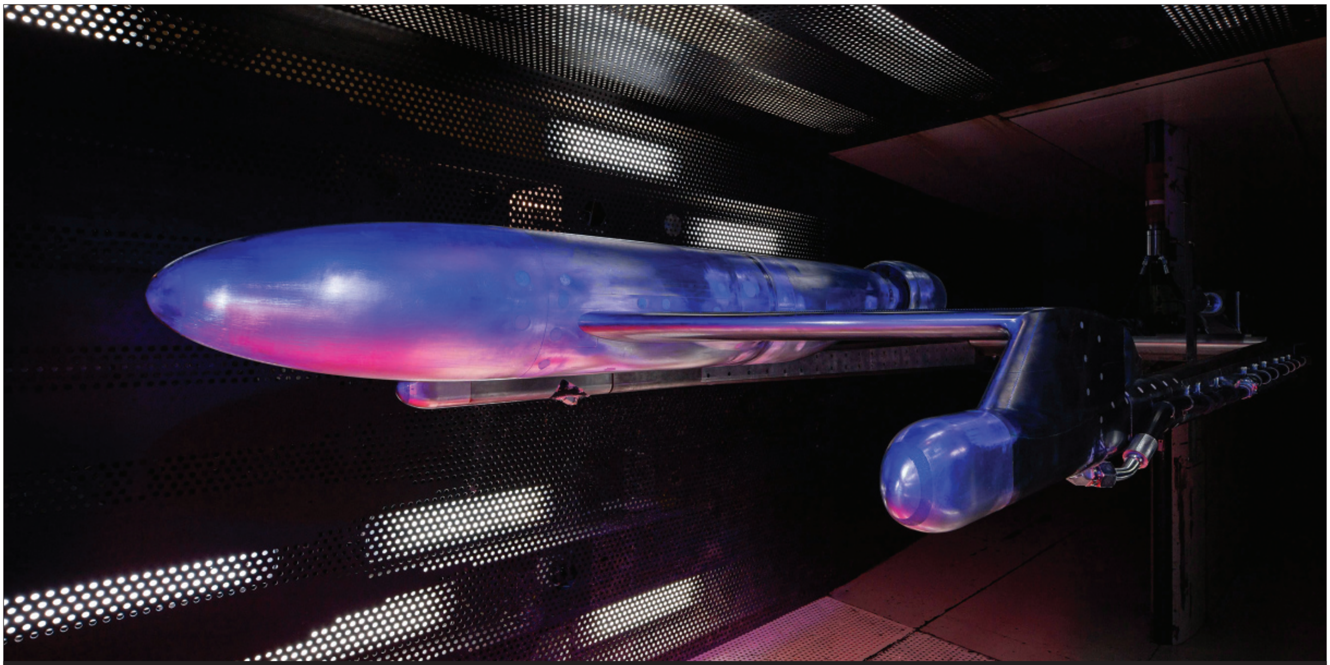
Additive manufacturing (AM) is coming of age, thanks to its multiple cost and material efficiencies. It uses significantly less material than other forms of product creation, such as subtractive processes, and can reduce the timeline from prototyping to production. It is no wonder therefore that the global 3D metal printing market grew to US$380.3 million by 2020 and is expected to expand at a staggering CAGR of 25.7 percent between 2021 and 2028[1].

Filomeno Martina, CEO and Co-founder of WAAM3D

FOUR AM PROCESSES FOR SATELLITE PROTOTYPES

When it comes to 3D metal printing, there are four AM processes that are particularly appropriate for satellite prototype applications. These are Laser Powder Bed Fusion (LPBF), Electron Beam Powder Bed Fusion (EBPBF), Wire Arc Additive Manufacturing (WAAM®) and Laser Metal Deposition (LMD).

According to a literature review of the four processes used in the aerospace industry that assessed their different technical parameters[2] (see table), WAAM is the most process efficient at approximately 70 percent (Riios et al. 2018), compared to EBPBF at 15 percent – 20 percent (D.



Aluminium wind tunnel model featuring a nose cone produced by WAAM3D for the UK's Aircraft Research Association, demonstrating that prototypes can be developed quickly and to defined tolerances using DED-Arc

Ding et al. 2015b), and LPBF and LMD at 2 percent – 5 percent (D. Ding et al. 2015b). Its build rate for Titanium is also quicker too at 0.5 – 4 Kg/h (Williams 2016b), compared to LPBF at 0.1 – 0.18 (Bhavar et al. 2014), EBPBF at 0.26 – 0.36 (Dutta & Froes 2017) and LMD at 0.1 – 1.41 (Dutta & Froes 2017). However, despite layer thickness being thicker than the other processes (1000 – 2000 im), WAAM's surface roughness compared to LPBF, EBPBF and LMD makes it more suited for medium to larger scale components that have less complex geometry. When it comes to maximum build volume, WAAM is potentially unlimited (Williams 2016b), with EBPBF limited to 200mm x 200mm x 180mm (Bhavar et al. 2014), LPBF to 500mm x 350mm x 300mm (Bhavar et al. 2014) and LMD to 900mm x 1500mm x 900mm (Frazier 2014).

When deciding on which AM process to pursue for a prototype, the following needs to be considered:

- What is the minimum required feature size in the component? Due to layer height and melt pool width dynamics, the starting point for the prototype development process selection must be the minimum required feature size of the component.

First WAAM full-scale prototype of a titanium pressure vessel to be used in future manned missions for space exploration ●●●

- What surface finish will the end component require? The natural shape of the weld pool during the build process leads to a scalloped outside surface. The size of these scallops will depend on the bead height laid down. The surface of the metal prototype - and future components created - might need finishing if specific smooth or polished surfaces are required.

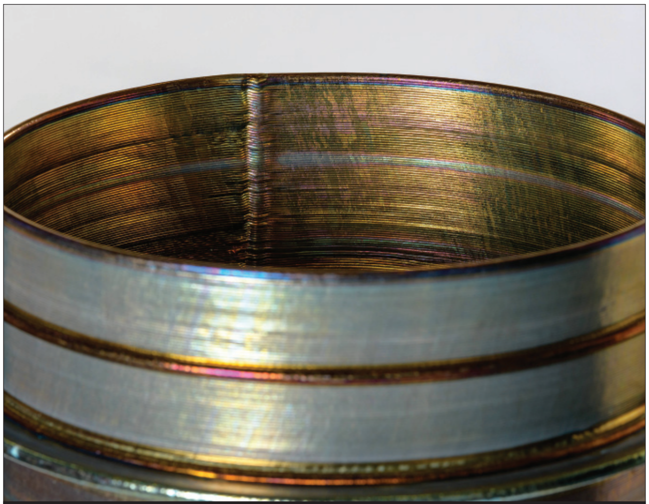
All AM processes follow the same procedure for creating a prototype. There is the translation of a 3D model—usually a 3D computer aided design (CAD) file—into a series of layers. These digital CAD designs can be easily altered between prototypes and the dissemination of the final design to other parties is straightforward. Following this, the bead dimensions of the deposited material, the slicing routines and the AM process capability are critical in determining how complex the finished prototype can be. Also, only a few AM processes offer the potential to produce fully dense metal components (Murr et al. 2013; Uriondo et al. 2015; Sun et al. 2013) with similar mechanical properties as traditional methods; thus, being suitable for aerospace applications (Joshi & Sheikh 2015; Uriondo et al. 2015)[3].

WAAM FOR LARGER PROTOTYPES

There is inevitably a trade-off in AM processes between surface finish and component size. For complex designs with thin walls LPBF is ideal, as it relies finer particles and laser spot sizes. For the production of medium to large scale components, such as cruciform, stiffened panels, wing ribs and flanges, impellers, tanks, etc. WAAM is ideal. This is because it avoids the expensive waste associated with machining materials such as titanium and can create less complex structures in a range of materials (from titanium, aluminium, refractory metals, steel, bronze and copper to Invar, nickel superalloys and magnesium).

WAAM PROTOTYPE – A TITANIUM PRESSURE VESSEL FOR SPACE EXPLORATION

A team comprising of Thales Alenia Space, WAAM3D,



First WAAM full-scale prototype of a titanium pressure vessel to be used in future manned missions for space exploration ●●●

Cranfield University and Glenalmond Technologies has successfully produced a first full-scale prototype of a titanium pressure vessel to be used in future manned missions for space exploration. The vessel is approximately 1 metre in height and 8.5 kg in mass. Made of the titanium alloy Ti-6Al-4V, it has been deposited using the WAAM process.

Due to the fact it is possible to go straight from digital drawings to final structures using WAAM, two individual pieces have been integrated into a single part, lead times have been reduced and the component has used 30 times less raw material than if it was created via traditional processes. By using the WAAM process, more than 200 kg of Ti-6Al-4V has been saved for each item.

Thanks to WAAM, prototype development can now be done in a matter of weeks. With so many pressures on satellite engineering at this current time, it's no wonder that WAAM is proving so popular with satellite manufacturers.

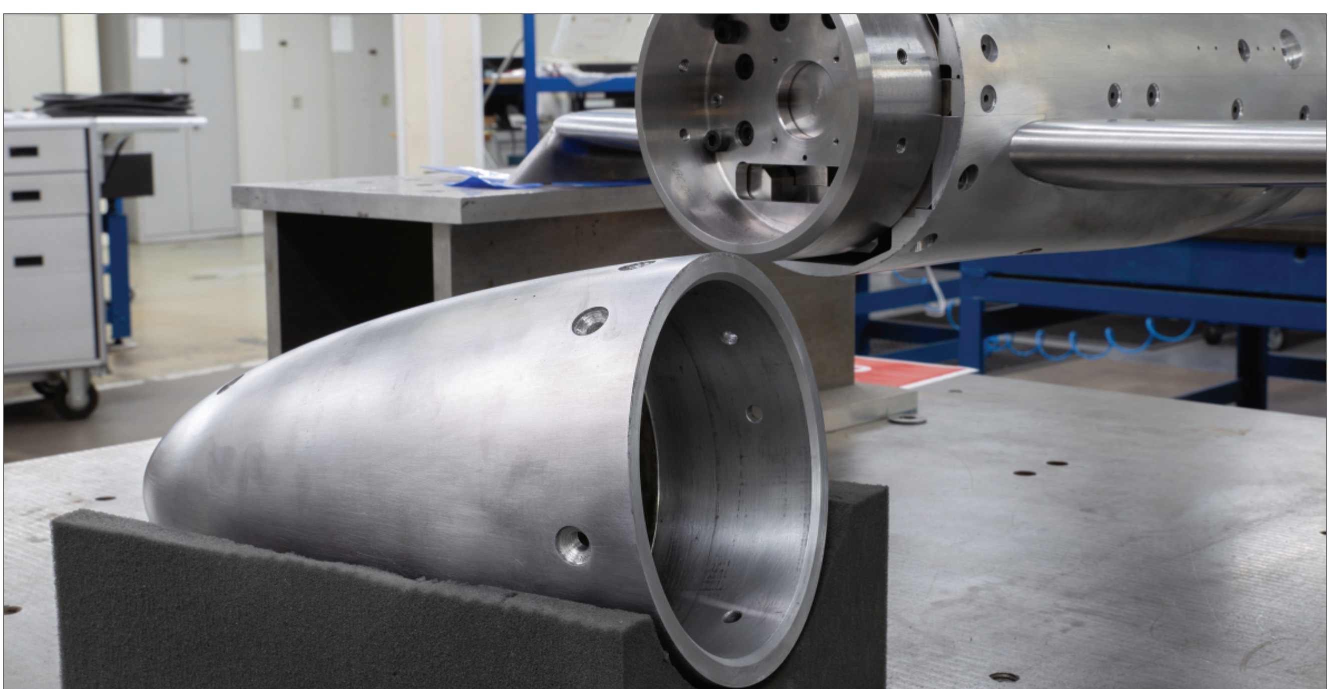
Parameter	LPBF	EBPBF	LMD	WAAM
Energy (W)	100 - 1000 (Bhavar et al. 2014)	~ 3500 (Baumers et al. 2016)	~500 - 3000 (Cao & Gu 2015)	2000-4000 (D. Ding et al. 2015b)
Overall Process Efficiency[2]	2% – 5% (D. Ding et al. 2015b)	15% – 20% (D. Ding et al. 2015b)	2 – 5% (D. Ding et al. 2015b)	~ 70% (Ríos et al. 2018)
Dimensional Accuracy (mm)	± 0.04 (Gu 2015)	± 0.05 (D. Ding et al. 2015a)	± 0.13 (D. Ding et al. 2015b)	± 0.2 (D. Ding et al. 2015b)
Build Rates (for Ti6Al4V) (Kg/h)	0.1 – 0.18 (Bhavar et al. 2014)	0.26 – 0.36 (Dutta & Froes 2017)	0.1 – 1.41 (Dutta & Froes 2017)	0.5 – 4 (Williams 2016b)
Maximum Build volume (mm x mm x mm)	500 x 350 x 300 (Bhavar et al. 2014)	200 x 200 x 180 (Bhavar et al. 2014)	900 x 1500 x 900 (Frazier 2014)	Potentially unlimited (Williams 2016b)
Layer Thickness (μm)	20 – 100 (Gu 2015; Ruban et al. 2014)	~ 100 (Murr et al. 2012)	500 – 1000 (Dutta & Froes 2017)	1000 – 2000 (S. W. Williams et al. 2016)
Surface Roughness (μm)	4 – 11 (Vayre et al. 2012; Gu 2015)	25 – 35 (Vayre et al. 2012)	20 – 50 (Gu 2015; Dutta & Froes 2017)	500 (S. W. Williams et al. 2016)
Minimum feature Size (μm)	40 – 200 (Bhavar et al. 2014)	100 (Bhavar et al. 2014)	150 – 200 (Mahamood et al. 2013)	2000 (Williams 2016)

Comparison of four AM processes ●●●

[i] 3D Printing Metal Market Size, Share & Trends Analysis Report By Product (Titanium, Nickel), By Form (Filament, Powder), By Application (Aerospace & Defense, Medical & Dental), By Region, And Segment Forecasts, 2021 – 2028, Grand View Research, October 2021

[ii] ibid

[iii] A comparison framework to support the selection of the best additive manufacturing process for specific aerospace applications. Alberto Garcia-Colomo, Dudley Wood, Filomeno Martina and Stewart W. Williams, International Journal of Rapid Manufacturing, 2020.



Aluminium nose cone manufactured by WAAM3D and Aircraft Research Association Ltd (ARA) using Wire Arc Additive Manufacturing process ●●●