Demands of Space Industry on Rapid Technologies

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Summary

Demands of Space Industry: what is spaceflight? Are the demands on Rapid Technologies different to "earth" industries? What is different?

To answer these questions it is helpful to differentiate the space business, e.g. by application:

- Launchers (rockets)
- Satellites
- Low Gravity Research

Are the Rapid Technologies ready for use for flight hardware? Can we improve our development cycle?

The lot sizes of parts and components for space applications are very low (typically <5 pieces). Some space missions are technically very ambitious, in such cases feasibility counts more than cost! Nevertheless costs are an issue during the development chain.
Hence spaceflight should have ideal candidates for Rapid Technologies!

The paper gives a brief overview over space flight and reports some actual exemplary earth-based applications of Rapid Technologies, concluding with an outlook to future space-based applications.

Launchers

Launchers (rockets) consists -besides others- of very huge structural elements made of carbon fibre reinforced plastic, cryogenic fuel storage and related components (pumps, .lines, valves), and the engine comprising the combustion chamber and the nozzles.

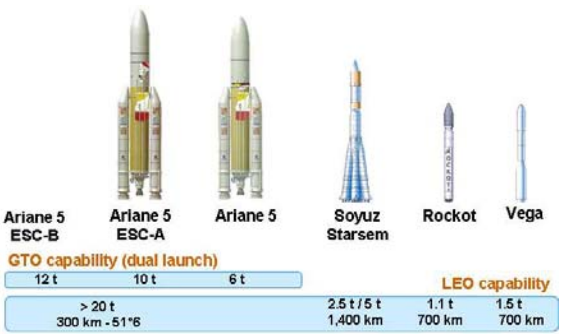

Figure 1: Europe's launcher family

The combustion chamber has to withstand very high temperatures, the inner linings are manufactured today by means of a long lasting galvanic process.
Goal is here the development of a quicker alternative manufacturing process based on powder metallurgical route. Vacuum Plasma Spraying, Fused Metal Deposition

and Selective Electron Beam Melting were considered.

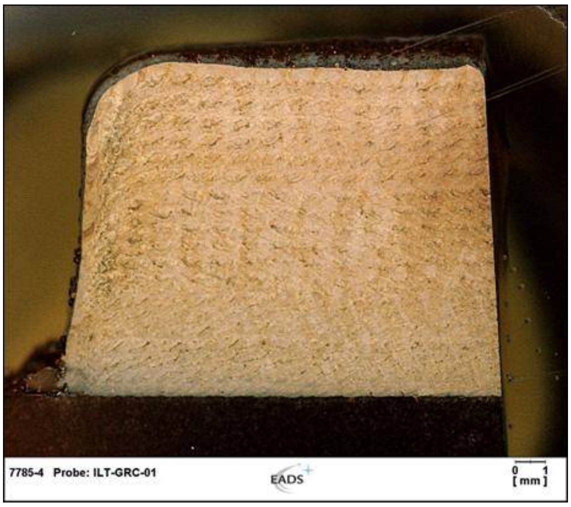

Figure 2: Combustion chamber liner material made by Fused Metal Deposition (EADS)

Focus of running activities is the material characterisation, especially the fatigue behaviour.

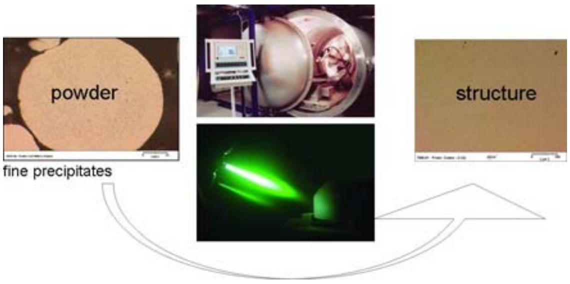

Figure 3: Vacuum Plasma Spraying for combustion chamber liners

Alternative manufacturing routes has to cope with exotic alloys, utmost reliable process, high melting temperatures and perfectly dense material. First results promise more potentialities for FDM than for EBM.

Satellites

Satellites are used for

- Earth Observation
- Telecommunication
- Navigation
- Astronomical Science and Physics

A satellite consists of the so-called "bus" and the payload. The payloads are quite different: cameras and spectrometers for different wavelength ranges, Laser Doppler sensors, magnetometers, radar altimeters, Synthetic Aperture Radars (SAR) and many others.

In the following a few examples for attempts of replacing the conventional process by Rapid Prototyping are given:

Rapid Technologies for Microwave Components

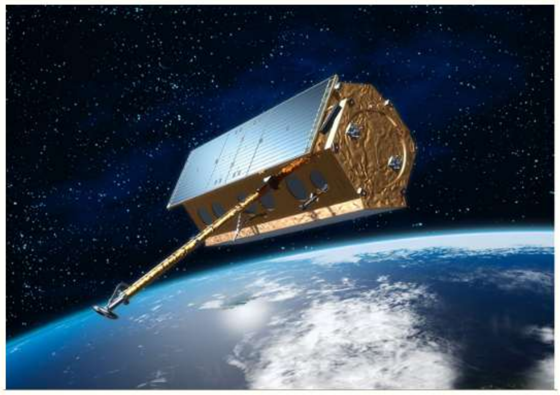

Figure 4: TerraSAR-X: German radar satellite (Astrium)

Figure 4 shows the TerraSAR-X radar satellite. The flat panel antenna consists of hundreds so called subarrays which are shown in Figure 5.

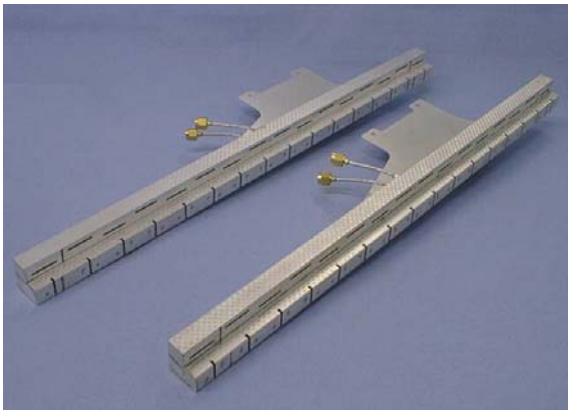

Figure 5: Slotted Waveguide Subarray for SAR Antenna (Astrium)

Parts of that subarray, made by Stereo-lithografy show Figure 6 and 7.

Figure 6: Plated and raw Waveguides made by Stereolithografy (Astrium)

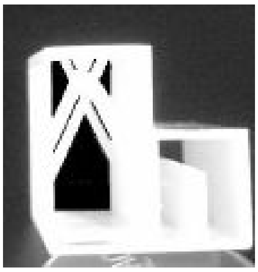

Figure 7: Cross sectional view of Waveguide made by Stereolithografy (Astrium)

To ensure sharp radar pictures the wave-guides have to be very geometrically precise and thermo-elastic stable over a huge temperature range.
Currently the results let some room for improvements: The geometric accuracy should be better than 0.1mm, and the thermal expansion of the materials to be used should be less than 10ppm.

Feed Horns (Figure 8) can benefit from Rapid Manufacturing as well, problematic is still the strength degradation over temperature (Figure 9).

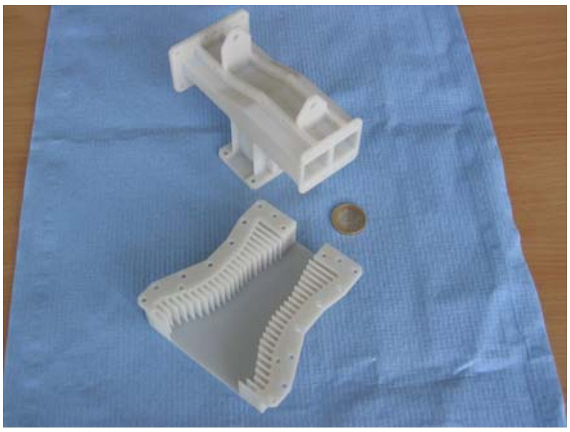

Figure 8: Feed Horns before CuNi plating (Astrium)

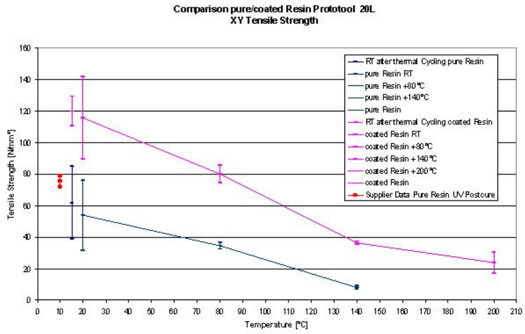

Figure 9: Tensile strength vs. temperature (Astrium)

Materials and process must ensure low shrinkage, low thermal expansion and acceptable mechanical strength.

Low Gravity Research

Low- or micro-gravity is used for research for physics, chemistry, biotechnology, materials science, human physiology and medicine.
Rapid Technologies are widely used for breadboarding of functional models.

One example -representative for lots of applications- is given here for medical research.
Microgravity promises several advantages for cultivation of spinal cord cells which are used for the fight against cancer. In space, e.g. on the International Space Station ISS an automated process operation by a robot and dedicated automated mechanisms is mandatory. Figure 10 shows a bio-reactor cassette made completely by Rapid Prototyping.

The demands for such applications are similar to other applications but some parts have to be sterilisable, that means to withstand high temperatures (>130°C), high pressure and steam.

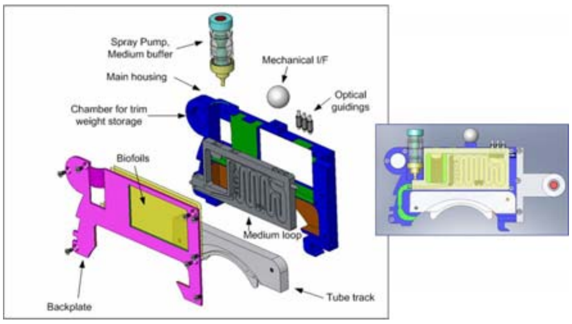

Figure 10: Bio-reactor cassette for cell cultivation, made completely by Rapid Prototyping (Astrium)

Rapid Manufacturing with Titanium

In order to investigate the Rapid Manufacturing potentiality for parts made of Titanium Astrium initiated a research project in co-operation with the Technical University of Dresden and EADS Innovation Works.

A reference part (Figure 11) was designed and ordered from several suppliers.

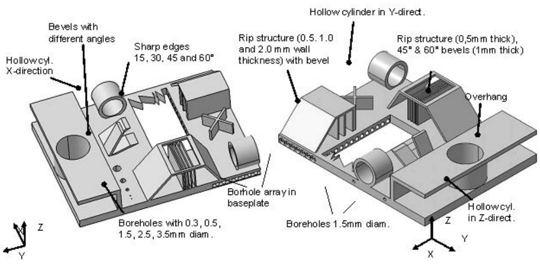

Figure 11: Reference part for Evaluation of Rapid Manufacturing of Titanium (TUD, Astrium)

In parallel samples for mechanical testing with different orientation angles were manufactured.

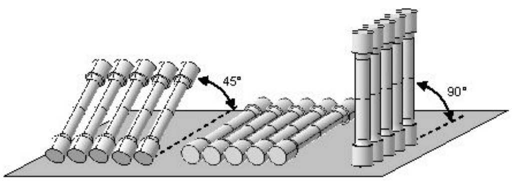

Figure 12: Titanium samples for Tensile Strength Testing (TUD, Astrium)

In total 12 different processes were assessed, 3 routes were used for hardware manufacturing and tests.

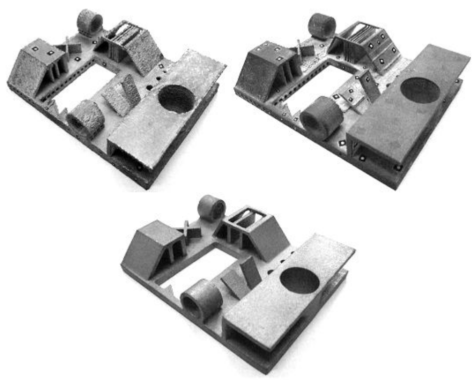

Figure 13: Manufactured reference parts: Top left: EBM, top right: SLM, bottom: conventional Precision Casting (Astrium)

The comparison reveals the diverge of claim and truth:

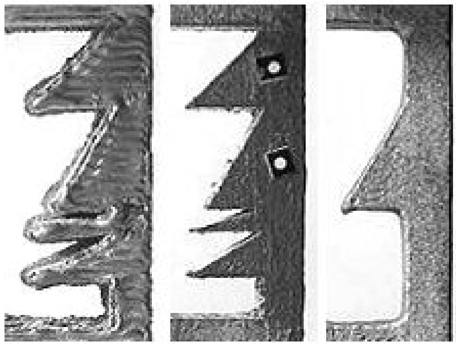

Figure 14: Edge comparison: left: EBM, mid: SLM, right: precision casting (Astrium)

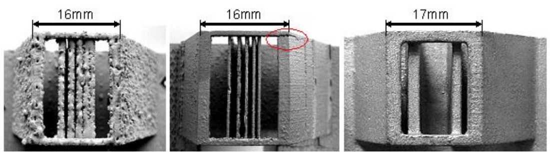

Figure 15: Comparison of ribs, left: EBM, mid: SLM, right: precision casting (Astrium)

It should be noticed that SLM is able to generate the fine rib structure, whereas the precision casting is over its limit.

Deviation	EBM [mm]	SLM [mm]	Prec. Casting [mm]
Max +	0.700	0.700	0.700
Max -	-0.700	-0.700	-0.529
Average +/-	0.318 / -0.161	0.107 / -0.072	0.142 / -0.063
Std.- Dev. (σ)	0.309	0.119	0.139

Figure 16: Geometry Deviations (Astrium)

The tensile tests of EBM samples showed very wide scatter, the evaluation of the fracture surfaces revealed unmelted powder nests:

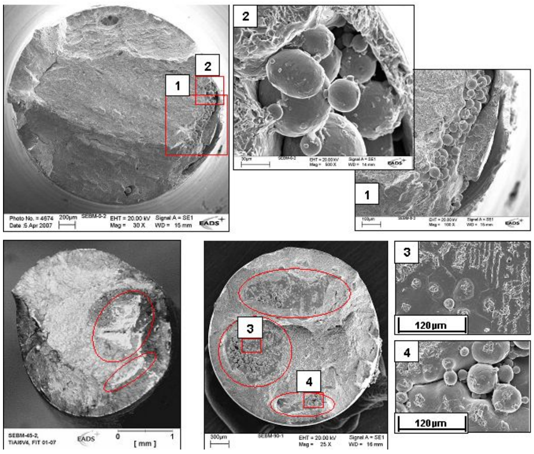

Figure 17: Fracture surfaces of EBM samples showing unmelted powder bulks (EADS, Astrium)

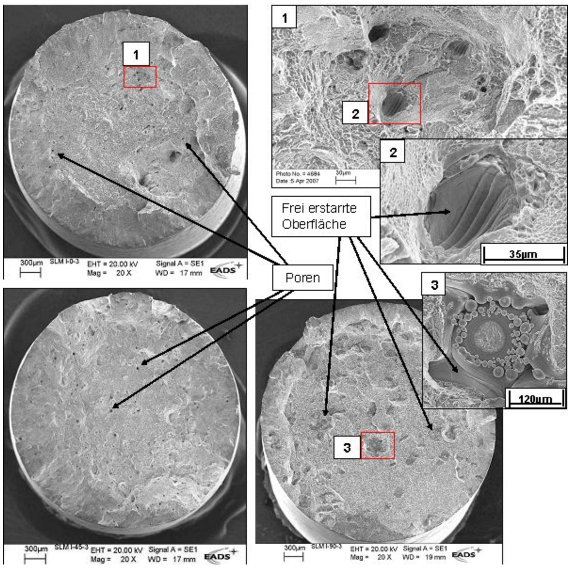

Figure 18: Fracture surfaces of SLM samples showing pores and zones of free surface solidification (EADS, Astrium)

The achieved surface roughnesses need an additional machining for load carrying parts:

Process	EBM			SLM			Precision Casting		
Orientation	**#**	**Ra**	**Rq**	**#**	**Ra**	**Rq**	**#**	**Ra**	**Rq**
X	**2**	6,6µm	8,1µm	**5**	6,6µm	8,3µm	**1**	3,4µm	4,4µm
	5	9,5µm	12,1µm				**2**	2,8µm	3,5µm
Y	**3**	18,6µm	22,2µm	**2**	6,4µm	8,0µm			
	4	10,9µm	15,0µm						
Z	**1**	32,2µm *1)	39,3µm *1)	**1**	7,0µm	8,8µm			
				4	8,3µm	10,8µm			
45° XZ-layer				**3**	11,8µm	14,7µm			

Figure 19: Achieved Surface Roughness (Astrium)

Status Summary

Rapid Technologies are indeed rapid in their own development. Tasks which were yesterday impossible to be solved by Rapid Prototyping or even Manufacturing may be considered for these routes already today or tomorrow.

The demands of spaceflight may be summarised as follows:

- reliable and reproducible process without pores and unmelted powder bulks
- lower shrinkage, especially at cross sectional steps
- absolute accuracy 1/100mm
- materials with low thermal expansion (<10ppm)
- mechanical strength comparable to basic material
- minimal surface roughness (Ra < 1µm)
- quick response time and
- reasonable prices

The status for polymers is quite satisfactory for some of the a.m. requirements. For metals like Titanium there remains room for further improvements.

Rapid Nanotechnology

Nanotechnology suffers from the headiness of the nano particles which prefer to agglomerate than being dispersed in a fluid, e.g. a resin. Currently this problem is tried to be solved by functionalisation of the nano particles which is costly and tedious.

Hence some research effort focus on a “rapid” process avoiding powder but using solids. The nano particles are knocked out individually by spark erosion or other techniques.

If this novel Rapid Technology can be fully mastered in the future the manufacturing of nano-materials will be boosted drastically.

Exploring the Universe:
Rapid Technologies on Mars?

Future space exploration missions may benefit from Rapid Technologies: All resources are mass critical because of the high effort and cost bringing them into space.
Long lasting missions to Mars and beyond rise at the horizon. Imagine that a structural part of a Mars rover fails: spare parts from earth are really no rapid alternative. How will astronauts obtain replacement spacecraft parts en route to Mars and beyond? Rapid Manufacturing technology may provide the answer.

NASA together with the Milwaukee School of Engineering started first attempts to modify Rapid Manufacturing facilities for use under reduced gravity in a KC135 aircraft.

They proposed Fused Deposition Modeling and Shape Deposition Modeling for use under reduced gravity, the results (Fig. 20) show that there is still a long way to go.

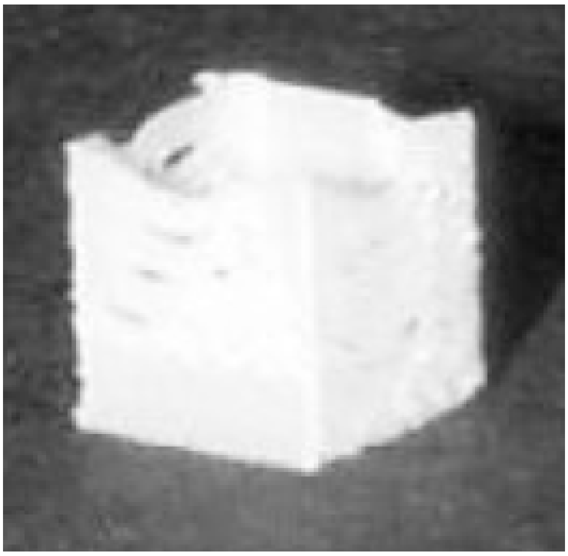

Figure 20: Fused Deposition Modeling under zero-g, first results (Crockett et al, MSE, NASA)

There was planned to continue that tests on the International Space Station but there are no results being reported.

The problem of processing under reduced or even zero gravity ask for further developments: here “earth” and “space” should get together: Astrium proposes - together with R&D entities and Rapid machine manufacturers - a joint lobbying towards the European Space Agency ESA.

Are you ready for joining a Mars based “Rapid Repair shop” ?

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