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Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

CU 01: DED-ARC

Session 5.7 – Design for DED

Prepared by: David Wimpenny

FOR SAM PILOT ATTENDEES AND TRAINERS ONLY

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Contents

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Design for DED

- We tend to think about DfAM (design for AM) in terms of enhancing part performance or weight reduction
- DED does bring potential performance benefits over conventional methods but the need (usually) to machine the part to gain an acceptable accuracy and surface finish certainly introduces constraints and the DED process too
- However this implies that AM applies no constraints to the design ….this is not true for PBF-LB and is certainly not the case for DED !

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Potential performance benefits using DED

Mutimaterial deposition

WAAM – Latest results – mixed material systems Steel/bronze (CuSi3%) parts

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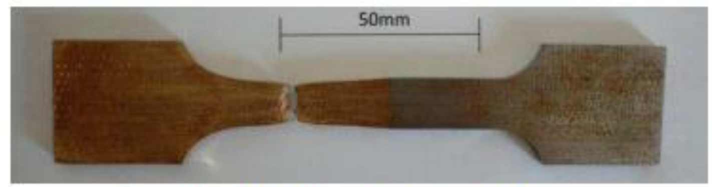
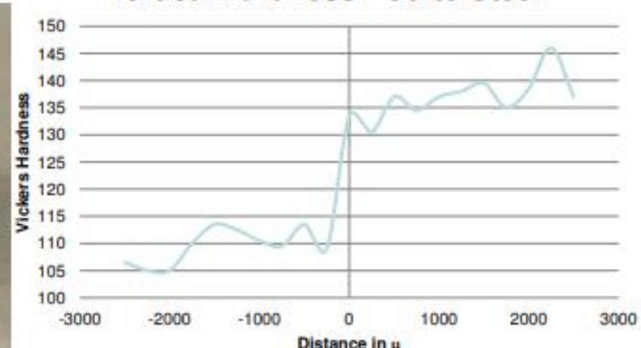


Yield 140 MPa, UTS 300 MPa, elongation 12%, failure in bronze

Vertical hardness - Cu to Steel



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Potential performance benefits using DED

30-40% more weight efficient structure – only possible by ALM manufacture

Design for DED-arc

- Necessary to consider build orientation, build sequence and design constraints of the WAAM process.
- Also needs to consider the complete manufacturing process chain – DED, post machining and inspection… from the outset.
- If post-machining is required, for example in structural applications where stress raising features are of concern or for mating faces, then machining constraints must also be considered.

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Design for Wire + Arc Additive Manufacture: Design Rules and Build Orientation Selection

Helen Lockett*, Jialuo Ding[+], Stewart Williams[+], Filomeno Martina[+]

School of Engineering and Innovation, STEM Faculty, The Open University, Walton Hall, Milton Keynes.

[+]*School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield, Bedford. UK*

*Corresponding Author. Address: Venables Building, School of Engineering and Innovation, STEM Faculty, The Open University, Walton Hall, Milton Keynes. MK7 6AA. UK. Email: helen.lockett@open.ac.uk, phone: 01908 653040

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Design for DED guidelines

DfAM Design Guideline (Gibson, Rosen, and Stucker 2010)	Description (Gibson, Rosen, and Stucker 2010)	Application to DfWAAM
Complex Geometry	"AM enables the use of complex geometry in achieving design goals without incurring time or cost penalties compared with simple geometry"	WAAM is not suitable for the production of parts with complex geometries due to relatively large minimum feature size (typically 2 mm)
Customised Geometry	"AM enables customised geometry and parts by direct production from 3D data"	WAAM enables customised geometry and parts by direct production from 3D data
Integrated Assemblies	"With AM it is often possible to consolidate parts, integrating features into more complex parts and avoiding assembly issues"	With WAAM it is often possible to consolidate parts by integrating features and avoiding assembly issues
AM Unique Capabilities	"AM allows designers to ignore all constraints imposed by conventional manufacturing processes (although AM-specific constraints might be imposed)"	WAAM offers unique capabilities in hybrid manufacturing, functionally graded materials and producing parts with integrated functionality. Conventional machining constraints must be considered if the part is to be post-machined

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Design for WAAM (Cranfield University)

WAAM Design Capabilities	
Minimising Cost, Environmental Impact and Lead Time	WAAM reduces the cost and environmental impact of manufacturing by substantially reducing the amount of waste material during manufacture compared to machining from billets or forgings. WAAM can also reduce manufacturing lead time compared to forging and machining.
Hybrid Manufacturing	WAAM can be integrated with conventional manufacturing processes to open up new design opportunities and further reduce manufacturing cost. By using WAAM to deposit features onto pre-formed parts produced by machining, forging or sheet metal, it is possible to produce hybrid parts with lower cost and manufacturing time. The substrate is commonly designed to be incorporated into the final part to minimise the amount of deposition and minimise cost.
Material Properties Optimisation	WAAM parts can be produced using mixed or functionally graded materials to tailor the material properties of the part. This is achieved by using multiple wires of different materials; the chemical composition can be tailored locally by controlling the wire feed speeds.
Functional Optimisation	Parts can be manufactured with internal features and passageways or embedded systems including fibre optics and fluidic tubing to incorporate functional behaviour into the component.
Shape Optimisation	WAAM can produce parts with shape optimised forms, benefitting from the ability to deposit overhanging features without support structures either by using multi-axis deposition or by depositing in positions other than downwards. However, care must be taken to ensure access for post machining if required.

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Part Dimensions

- Depending on the cell configuration (open or fully enclosed – usually constrained by shielding requirement for material
- Some materials – steel, aluminium can be successfully deposited from wire feedstock using relatively rudimentary shielding

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- Titanium requires more sophisticated shielding ..including enclosers
- Min wall thickness for deposition (3-5mm) – can be machined down to achieve thinner walls

Show some examples

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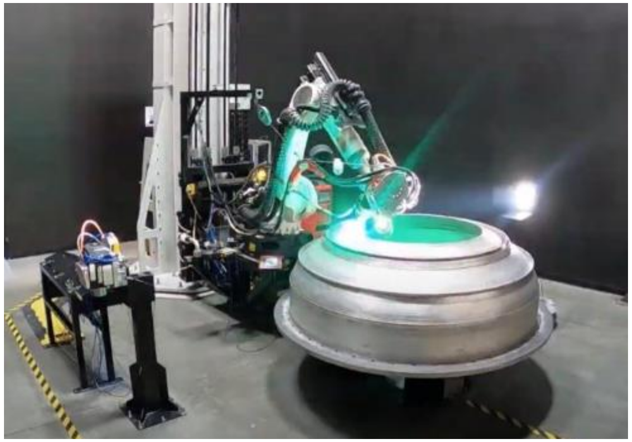
Finishing considerations

- Not all surfaces need to be machined – indeed Relativity space have been supplying launcher parts to Space unfinished and unstress relieved
- It may be possible to treat the surfaces of the parts using shot blasting, shot peening and vibratory polishing methods (although these are usually not suitable for large parts)
- Need to consider cutting tool access (possible to generate enclosed or difficult to access features with DED-arc)

https://singularityhub.com/2021/03/28/watch-a-robot-3d-printing-the-rocket-for-relativity-spaces-first-orbital-launch/



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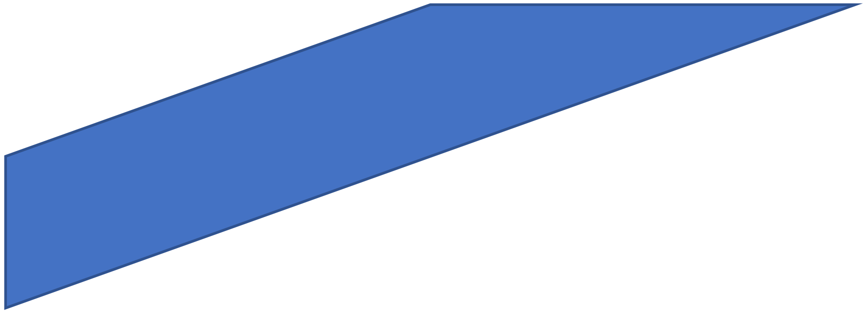
Difficult to build features

- Long thin unsupported features
- Lattice like structures
- Sharply tapering features – where it is not possible to fit the beads into the available space
- In this case it may be possible to increase the size of the feature and machine away the additional material from the finished parts
- Where it is easy to machine holes in parts after deposition then these features should be removed from the DED part model



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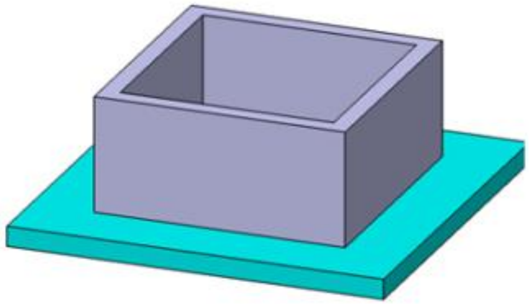
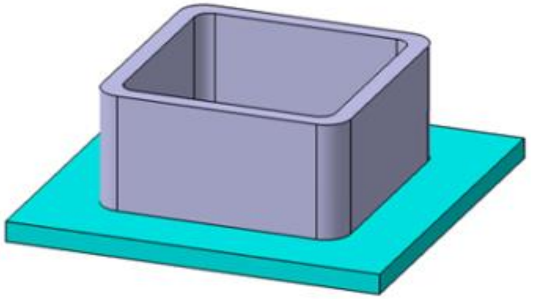
Sharp corners

- DED-arc can produce parts with sharp external corners but they are more difficult to manufacture due to additional stop-starts in deposition process.
- Good to design the part to enable <u>continuous</u> welding
- For parts that will be postmachined, internal corners must be designed with generous radii to allow for the tool radius during post machining as well as to avoid stress concentrations
- Avoid sharp features (these require finishing and may introduce stress)
- High stress points can lead to deposit separating from workpiece



Unfavourable



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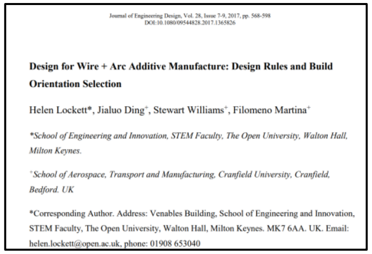

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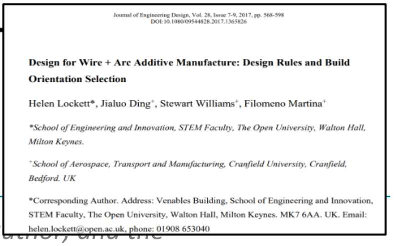
Initial Assessment Criteria for WAA Manufacture

Design Criteria	Preliminary Assessment Criteria	Comment
Minimum part mass	0.5 kg	Parts with a mass of less than 0.5kg are unlikely to be cost effective for WAAM production
Minimum bounding box dimension	20 mm	Parts with one or more bounding box dimension of less than 20mm are unlikely to be cost effective for WAAM production because they could be produced more cost effectively from plate material by machining or other methods
Maximum bounding box dimension	10 m	The maximum part size is limited by the size of the WAAM cell. Currently the largest WAAM cell available is 10m in length
Initial Buy-to-fly estimate	4	Parts with a lower buy-to-fly ratio are likely to be more cost effective to machine from billet. (Martina and Williams 2015) Minimum buy-to-fly ratio is also material dependent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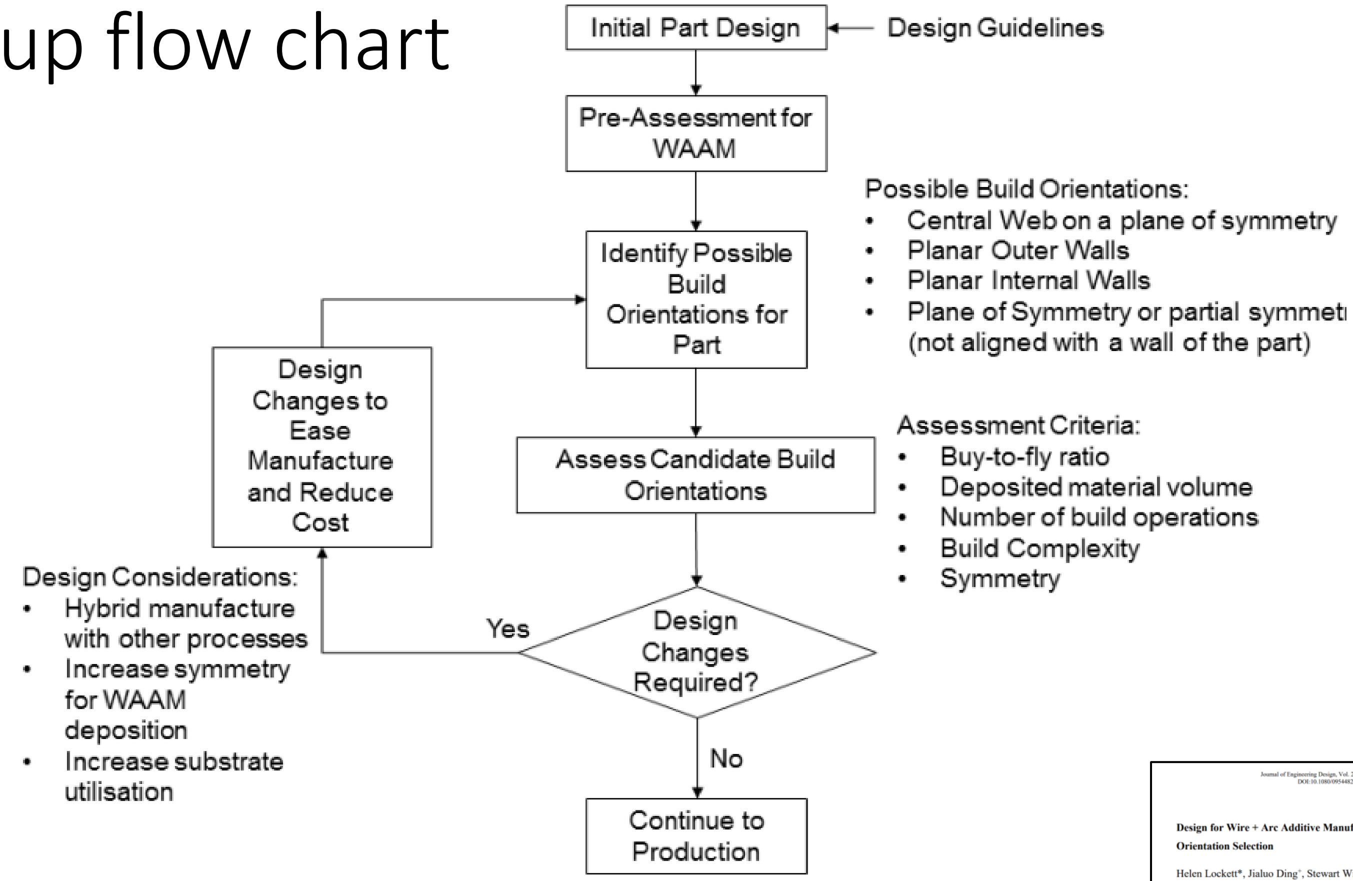
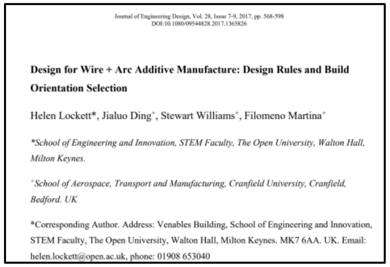
Part set-up flow chart





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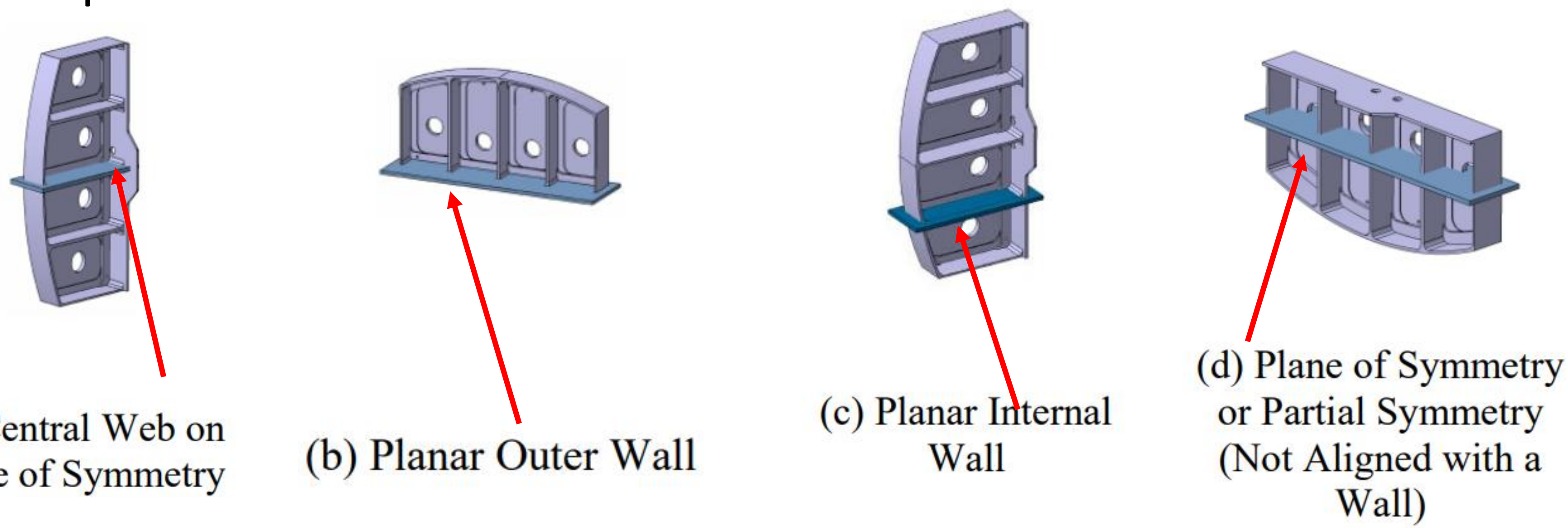
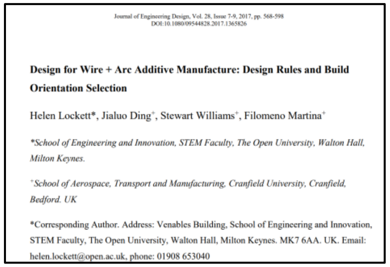
Build plate location

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(a) Stress matching
(b) Stress matching if two parts are built back-to-back
(c) Stress reduction on not stress matching
(d) Stress matching but build plate would not form substantial part of final part

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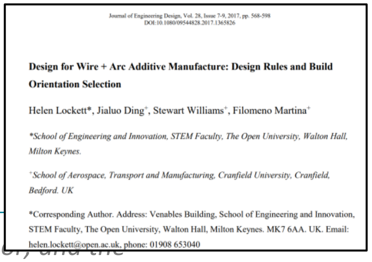
Assessment of Build Strategy

Each build plate location can be assessed based on;

- **Each substrate waste** - ratio of substrate waste material mass (Msf) to initial billet mass for the machined part ($Mi\ M$)
- **Deposited material** - ratio of the deposited material mass ($Mi\ AM$) to the final part mass(Mf)
- **Number of deposition operations** - reciprocal of number of WAAM build operations (N) required to build the part*

*assumed part is mounted on part-rotator so that deposition direction can be changed between operations to build features in different orientations. Each change of position is considered to be a build operation. Double sided build operations where the part is rotated between each layer are considered as two build operations

- Level of deposition difficulty
- Ability for stress matching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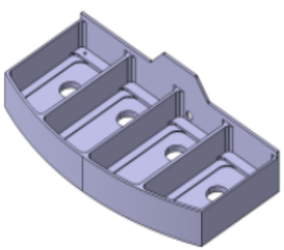
Example

Part	Bounding box mass (kg)	Machining Buy-to-fly estimate	Bounding Box X (mm)	Bounding Box Y (mm)	Bounding Box Z (mm)	Part Mass (kg)	Suitable for WAAM ?
WAAM Criteria		>4	>20mm	>20mm	>20mm	>0.5kg	
	63.95	6.6	610	305	127	9.64kg	YES

Okay it is worth progressing

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Build orientation

- Position of build plate will largely dictate the build orientation
- For the particular example used there are 5 possible build plate positions
- Build plate assumed to be rectangular and to extend by 25mm in all directions from the base of the part, and the substrate is assumed to be 10 mm thick in all cases.
- The details of the build options and the build orientation assessment results are shown in the next slide

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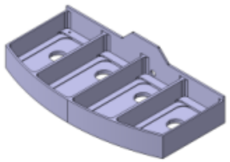
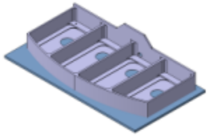
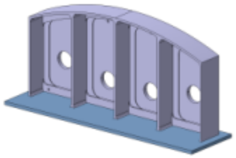
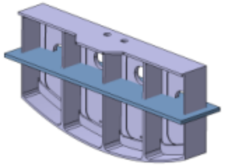
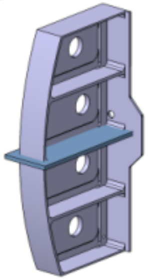
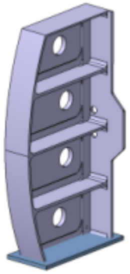
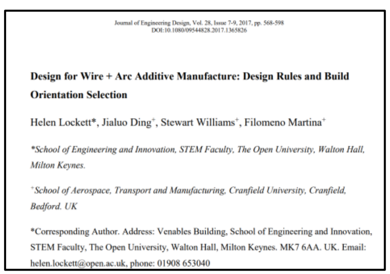
	Build Option 1	Build Option 2	Build Option 3	Build Option 4	Build Option 5
					
Buy to Fly WAAM	1.2	1.2	1.2	1.1	1.1
Substrate Mass (kg)	6.3	3.2	2.5	1.2	1.0
Deposited Material Mass (kg)	5.2	8.5	9.4	9.2	9.3
Waste Material from Substrate (kg)	1.9	2.0	2.2	1.0	0.7
Number of Build Operations	1	2	2	2	2
No. of Double Sided Build Operations	0	0	1	1	0
Total Build Operations	1	2	3	3	2
Mass Above Substrate (kg)	9.6	9.6	4.4	4.8	9.6
Mass Below Substrate (kg)	0.0	0.0	5.4	4.8	0.0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SAM SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

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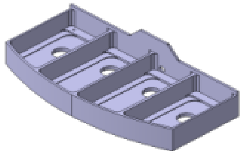
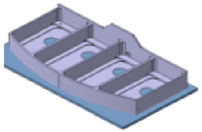
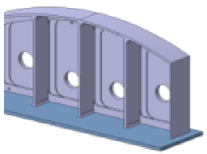
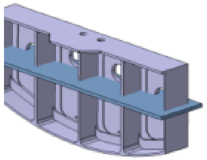
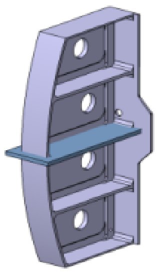
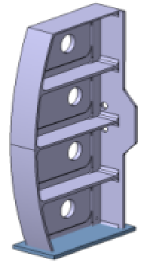
In simple terms the best single sided set-up in 1 and the best double sided set up ins 4

		Build Option 1		Build Option 2		Build Option 3		Build Option 4		Build Option 5	
											
Criteria	Weighting (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Substrate Waste	20	0.97	19.42	0.97	19.38	0.96	19.30	0.98	19.69	0.99	19.79
Deposited Material Factor	20	0.5	9.3	0.1	2.5	0.0	0.5	0.0	1.0	0.0	0.7
Number of Build Operations	20	1.0	20.0	0.5	10.0	0.3	6.7	0.3	6.7	0.5	10.0
Build Complexity	20	0.8	16.0	0.5	10.0	0.2	4.0	0.2	4.0	0.5	10.0
Symmetry	20	0.0	0.0	0.0	0.0	0.9	17.8	1.0	20.0	0.0	0.0
Total	100		65		42		48		51		40

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Practical Example of part set-up

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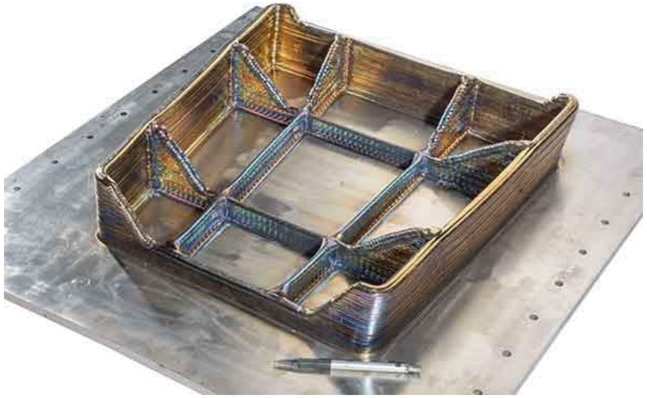
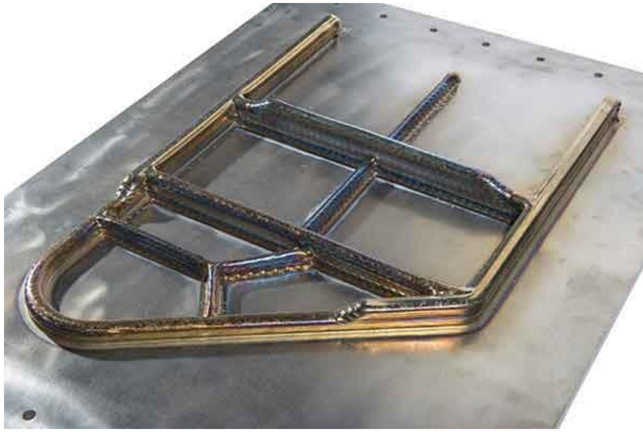
DED-Arc case studies

- 24 kg outboard landing gear rib – Bombardier (
- 0.6 x 0.6 m titanium frame – BAE Systems
- 0.7 m titanium wing flap support - Fokker



Courtesy of WAAM3D/-
Cranfield University



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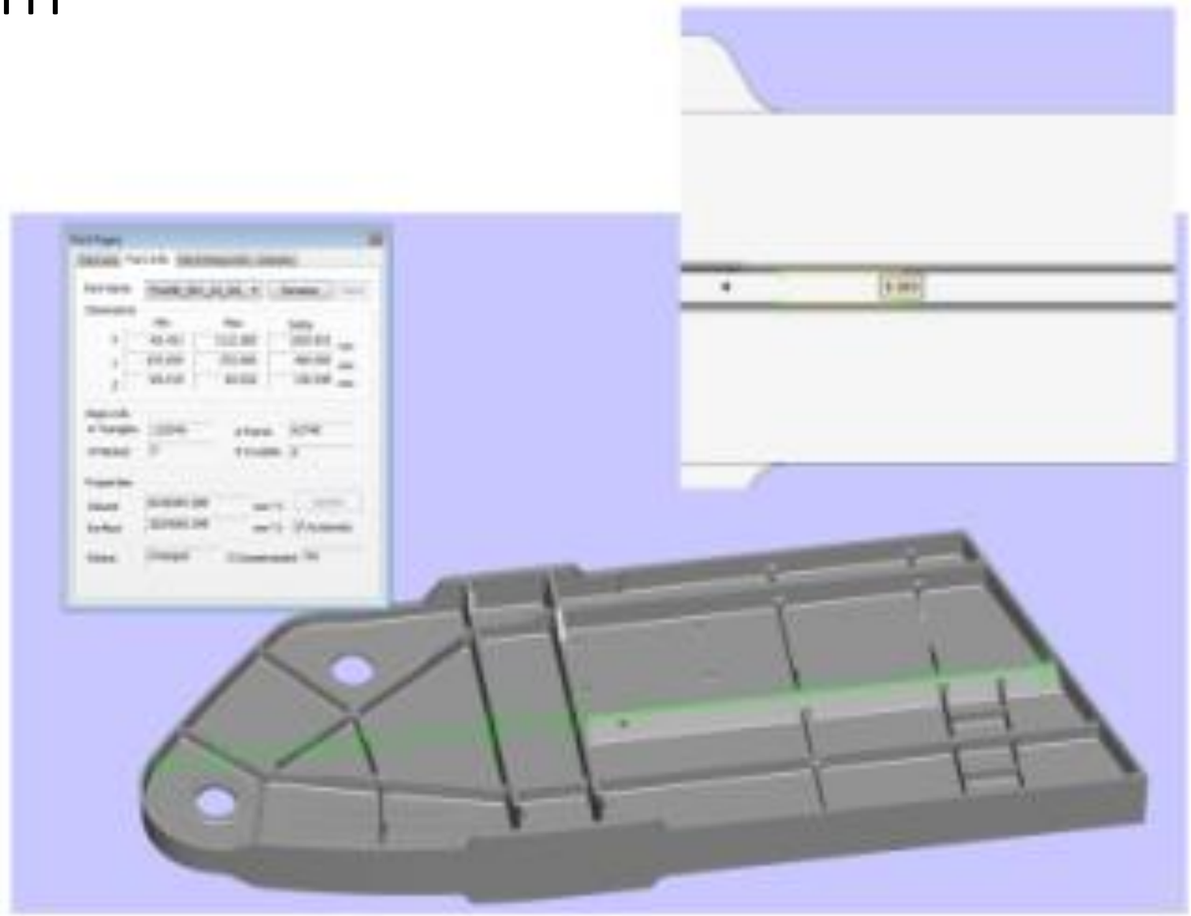
AFT Beam



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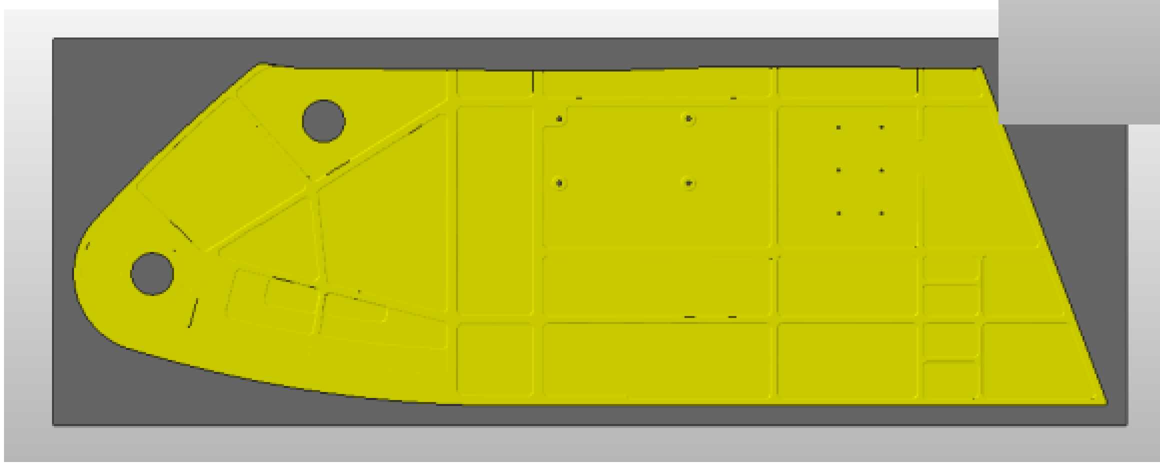
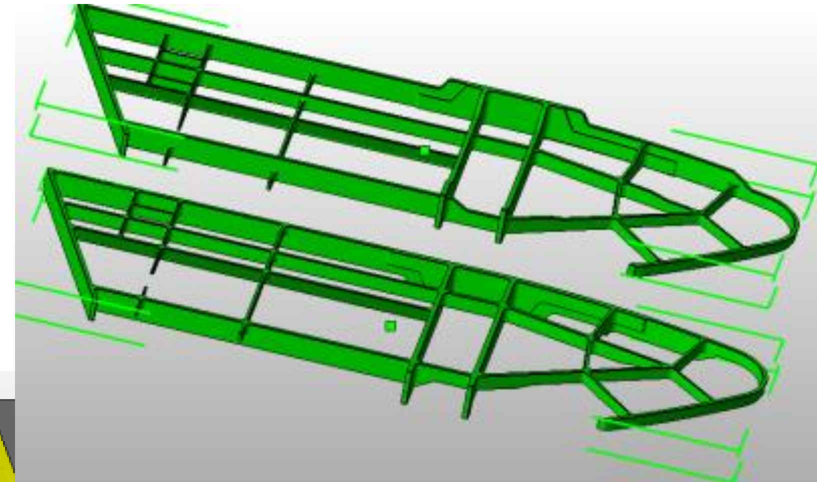
Remove ribs





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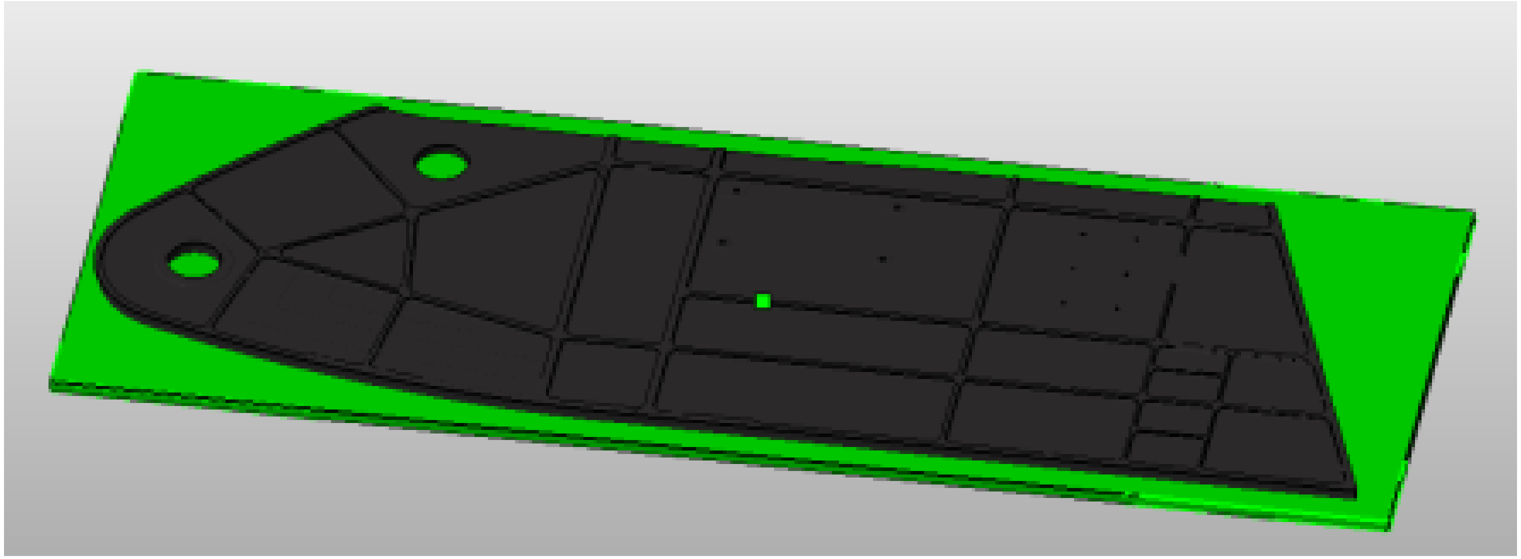
Select suitable build plate



Base Plate 1200x450x10mm

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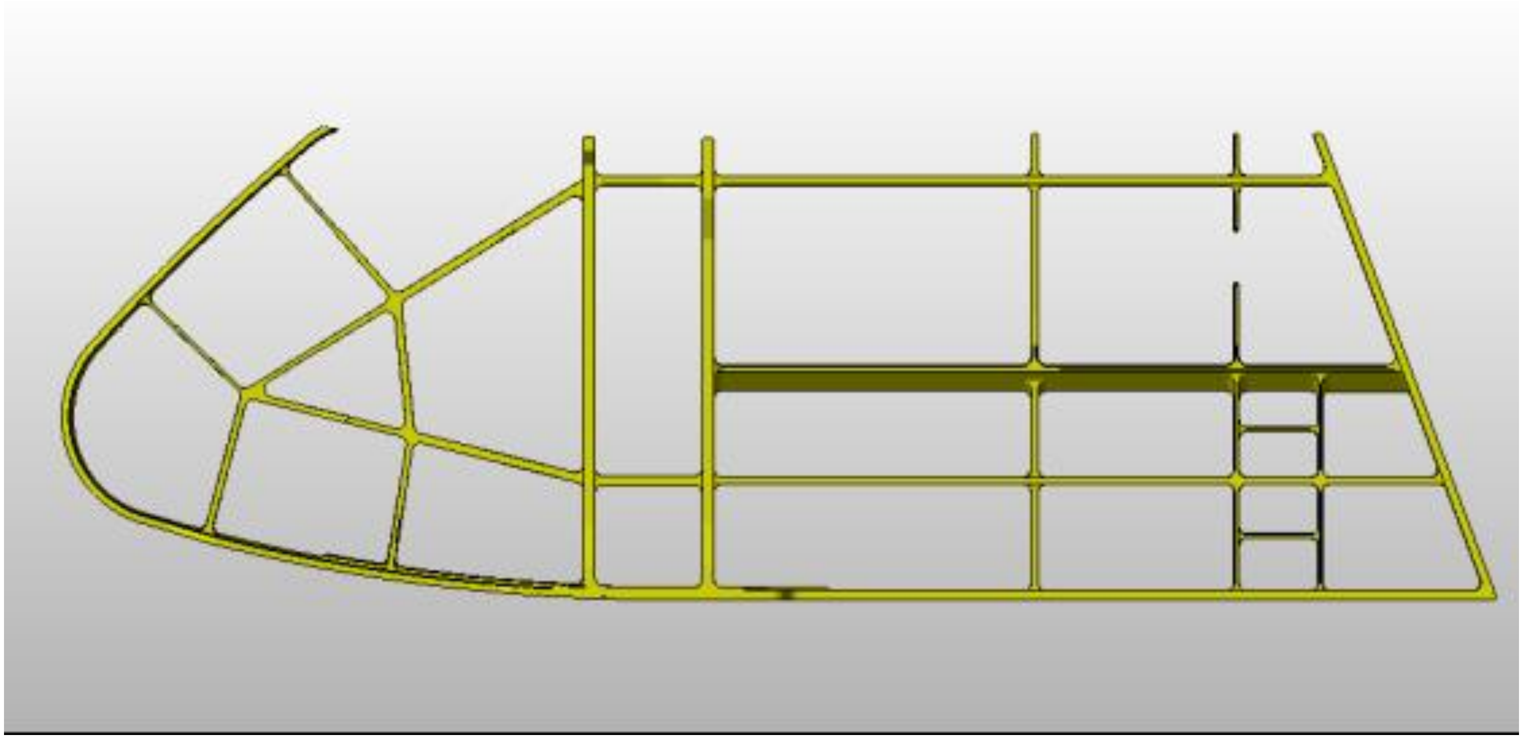
Plan deposition of ribs



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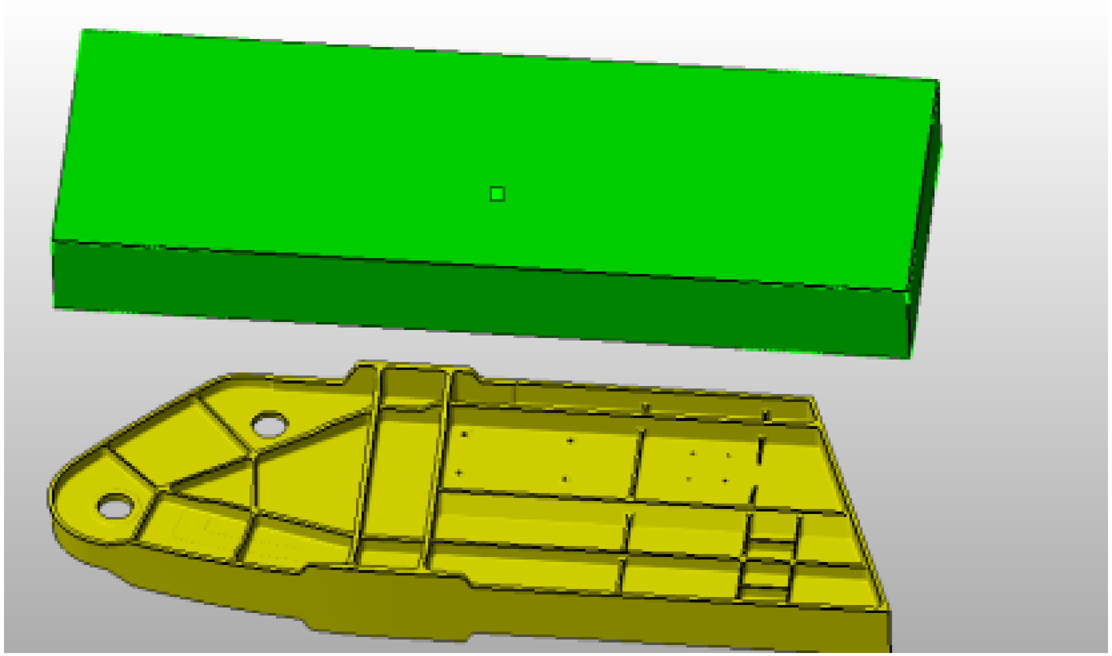
Compare with machined from Billet



Billet 1200x450x124mm

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AFT BEAM
Machining from billet Vs DED-arc + final machining

Machining from billet	
Final part weight	~30kg
Billet weight	300kg
Buy-to-fly (BTF)	10:1
Waste	270kg

~90% of original billet is machined away

DED-arc + machining	
Wire to form ribs	33kg
Build plate	27kg
Total raw material	57kg
overall BTF ~2:1	2:1
Waste	~30kg

Wire to form ribs: based on ~3:1 BTF

Assuming the parts are good first time !!!!!

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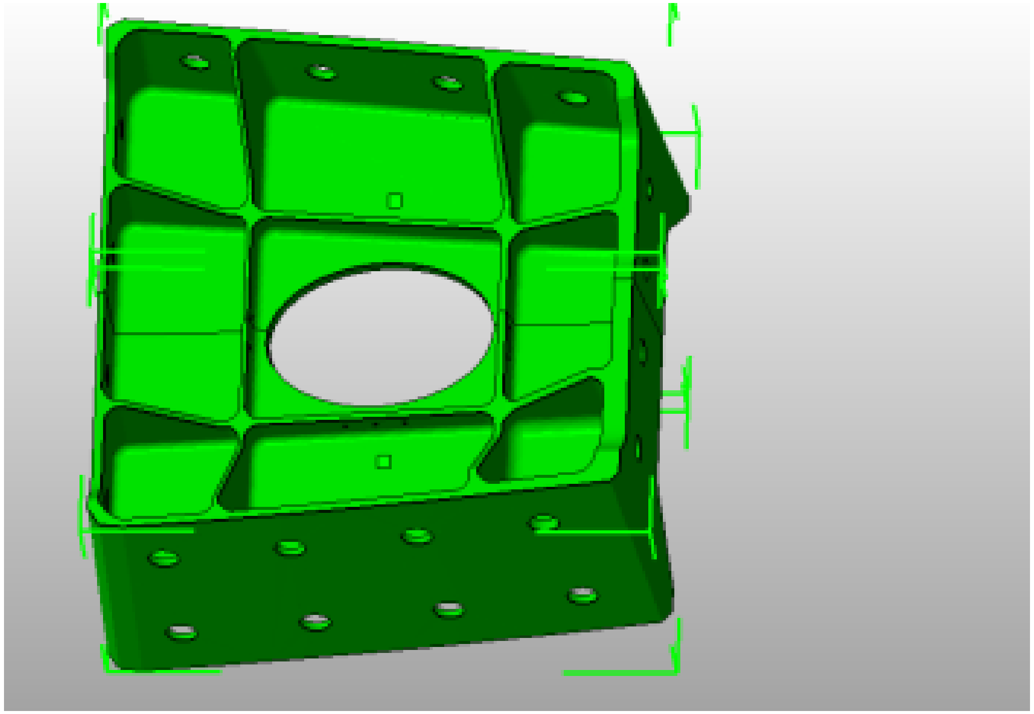

MLG

ACcelerated CLAdding and Integrated Machining
Collaborative project
TSB: ADMA – Inspiring new design freedom through Additive Manufacturing

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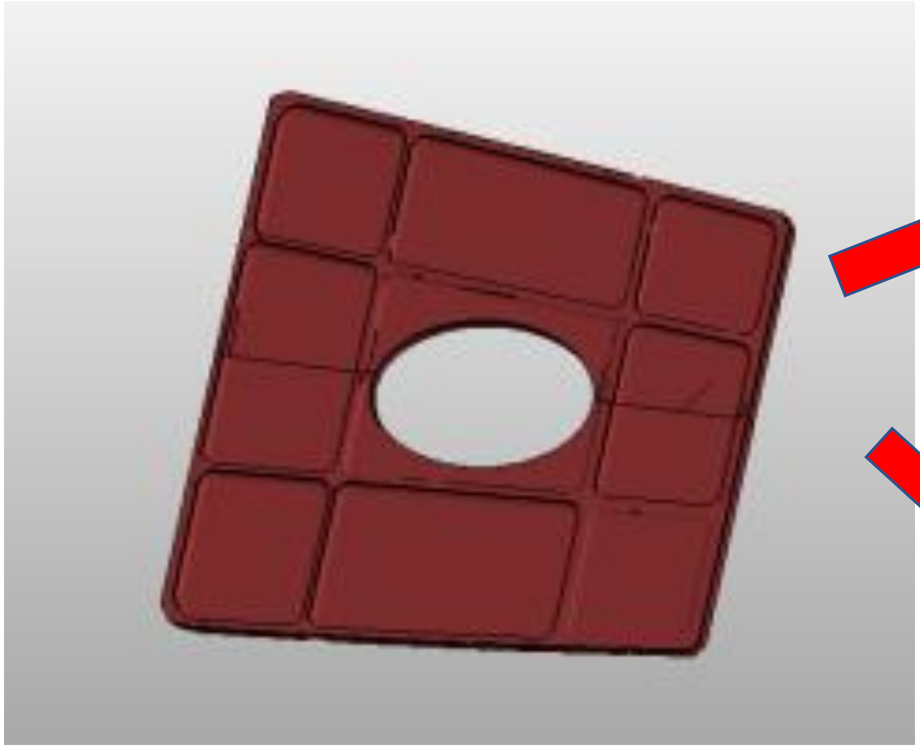
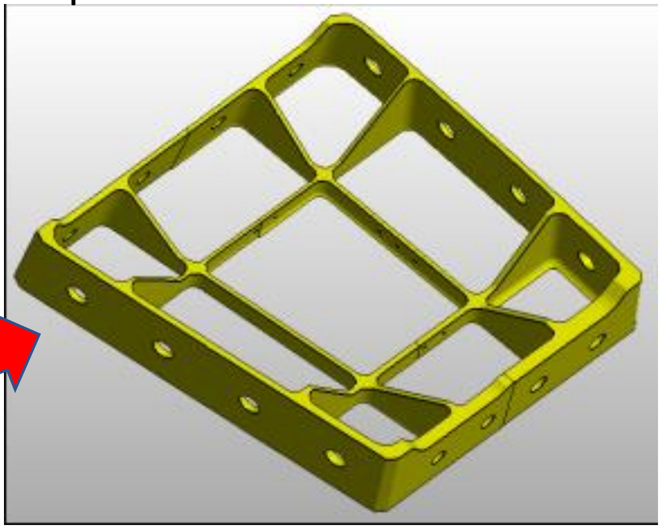
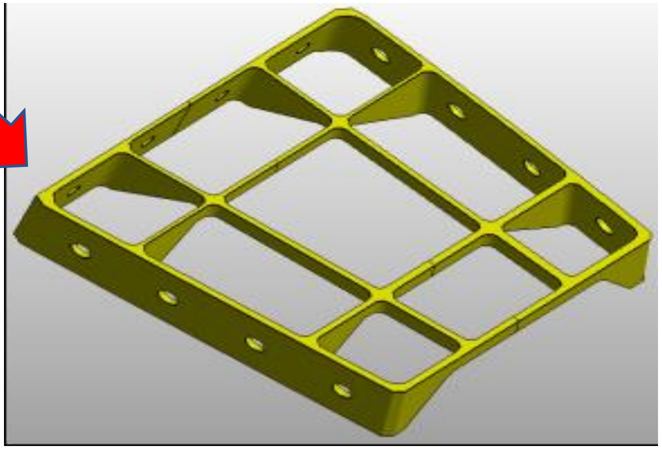
Remove ribs



Top ribs



Bottom ribs



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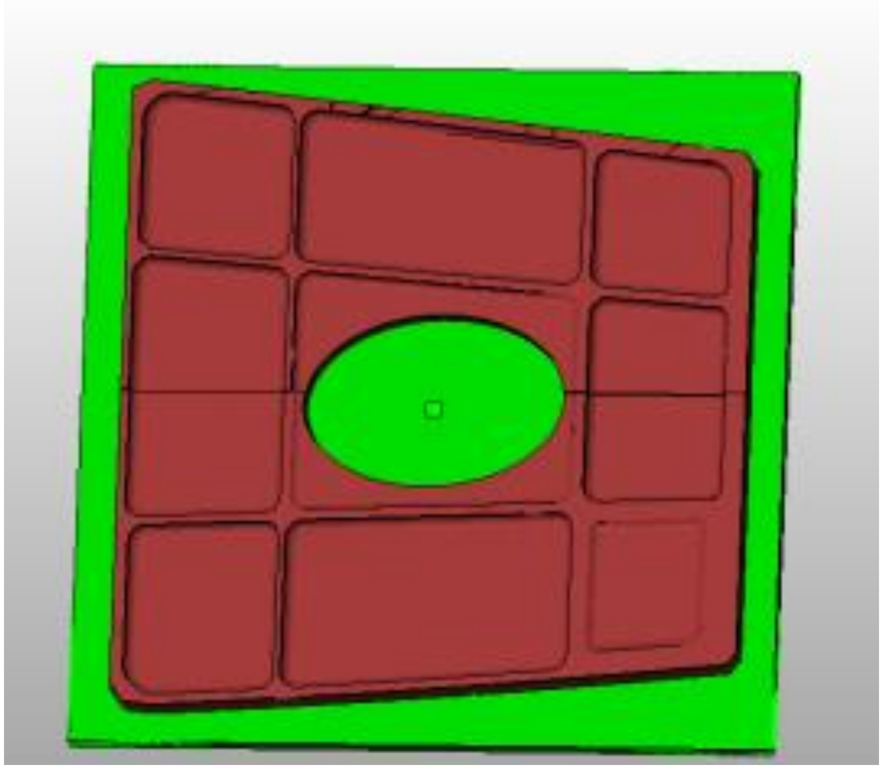
Select suitable sized build plate



Base plate 500x500x10mm

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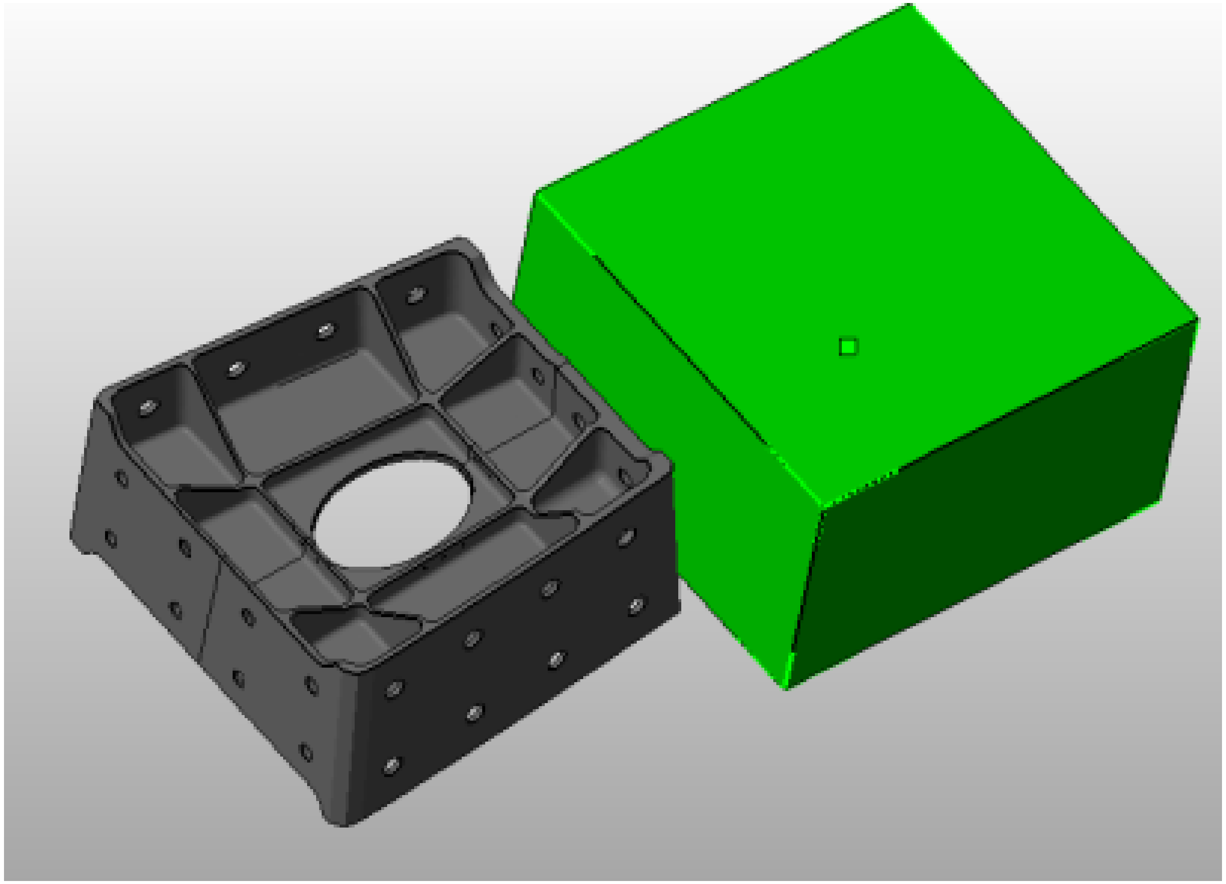
Billet required to machine part

Billet 500x500x300mm



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AFT BEAM
Machining from billet Vs DED-arc + final machining

Machining from billet		
Final part weight	~24kg	
Billet weight	300kg	
Buy-to-fly (BTF)	12.5:1	
Waste	276kg	~92% of original billet is machined away

DED-arc + machining		
Wire to form ribs	45kg	based on ~3:1 BTF
Build plate	11kg	
Total raw material	56KG	
overall BTF ~2:1	2.3:1	
Waste	~32kg	

Assuming the parts are good first time !!!!!

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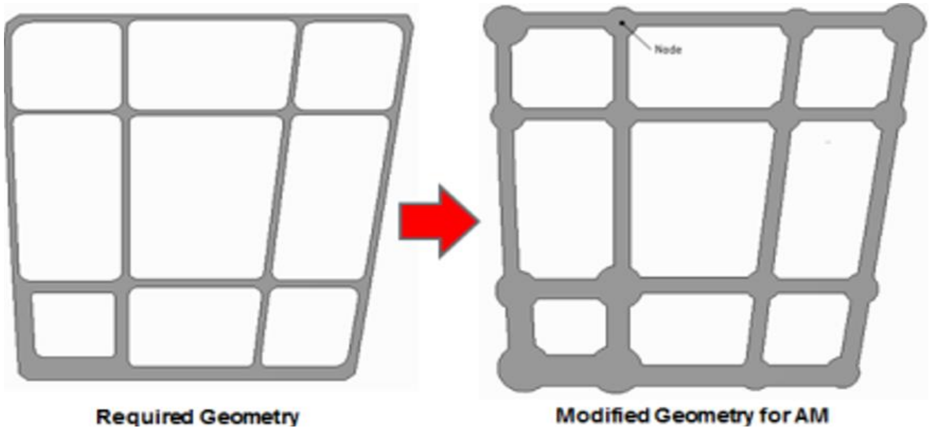
Planning how to deposit material

Decided to use a "node & web" strategy

- Simplifies/standardises programming and parameters
- Helps to manage thermal input and stress accumulation
- Add material to finished geometry



<u>Approach</u>

- Deposit one layer of every circular node
- Draw one layer of the web between each node
- Rotate part and repeat for other side of part
- Repeat process layer-by-layer until the part is finished
- After about 30mm of rib height it is distortion is not a problem but better to continue rotating to manage thermal input

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Bead width

Minimum bead size possible is 2-3 mm

Maximum bead size possible using oscillation is 30mm

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www.skills4am.eu

Thank you & Questions ?

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Thank you

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