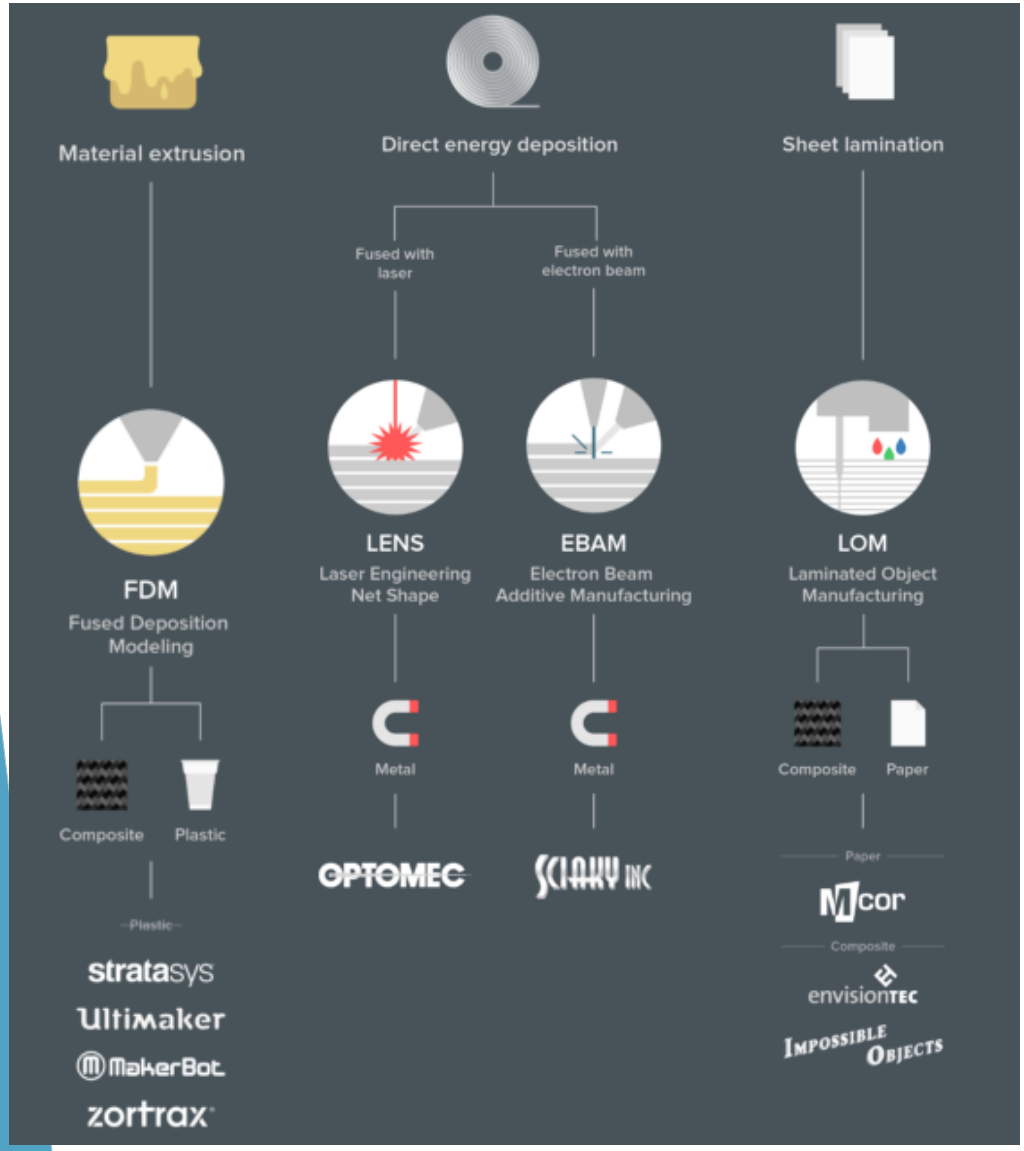
Atlas 3D

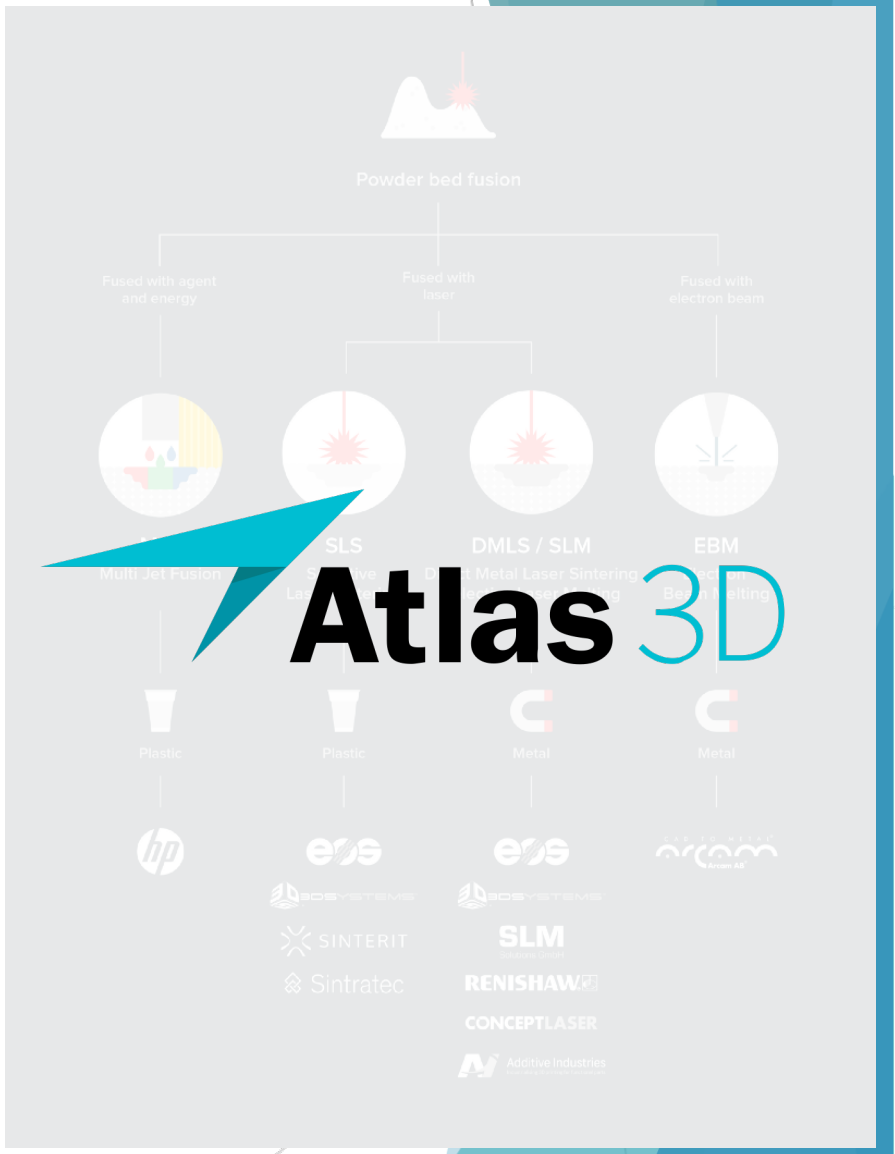
A PHYSICS-MODEL-BASED BUILD ORIENTATION OPTIMIZATION TOOL FOR METAL ADDITIVE MANUFACTURING

Hao Peng
VP of Product Development

07/23/2019

Additive Manufacturing Processes

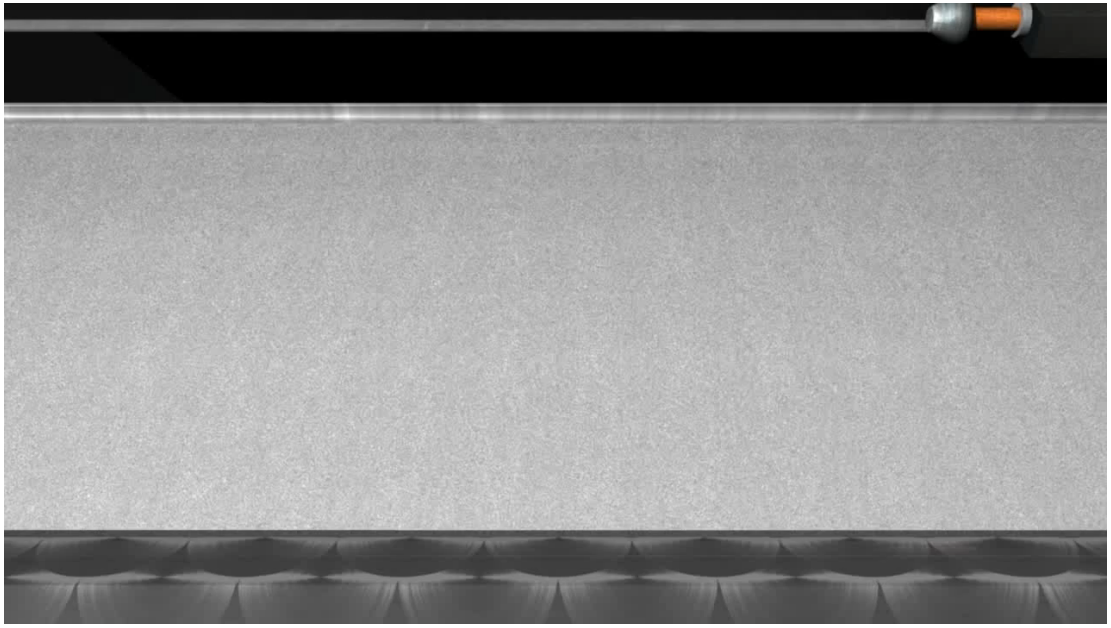




Atlas 3D

https://www.3dhubs.com/what-is-3d-printing

Powder Bed Fusion (PBF) Process



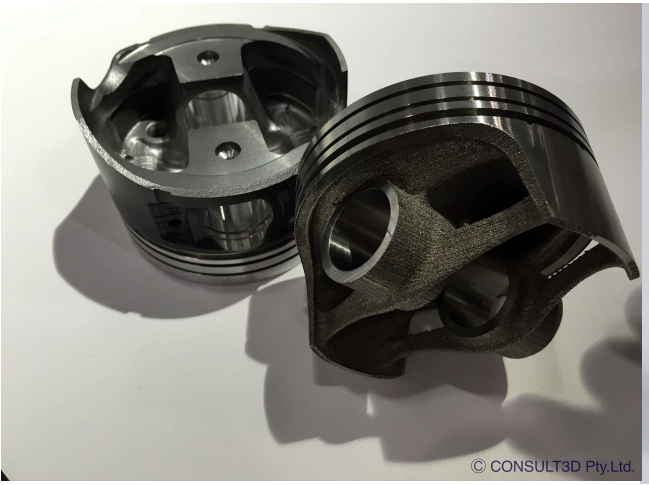
rocket motor throat
(animation from Lawrence Livermore National Labs)

ITAMCO

- Apply a new layer
- Melt the new layer
- Platform movement

Applications and Potential Markets

automotive

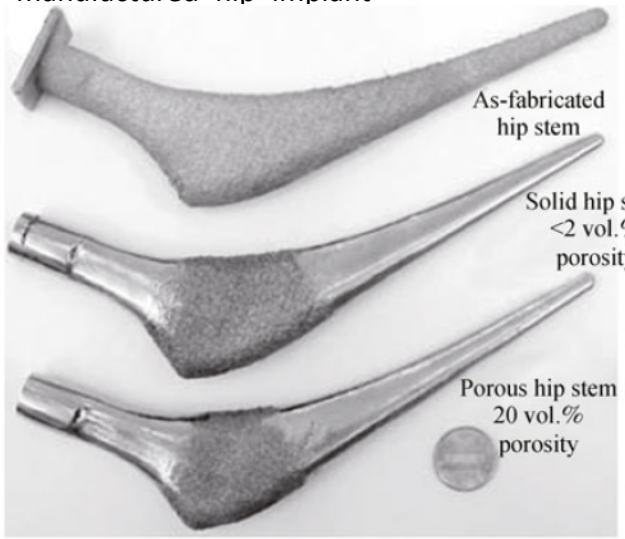


https://www.linkedin.com/company/intech-dmls

race car gear box (Guo and Leu 2013)

biomedical

http://www.eos.info/press/case_study/additive_manufactured_hip_implant

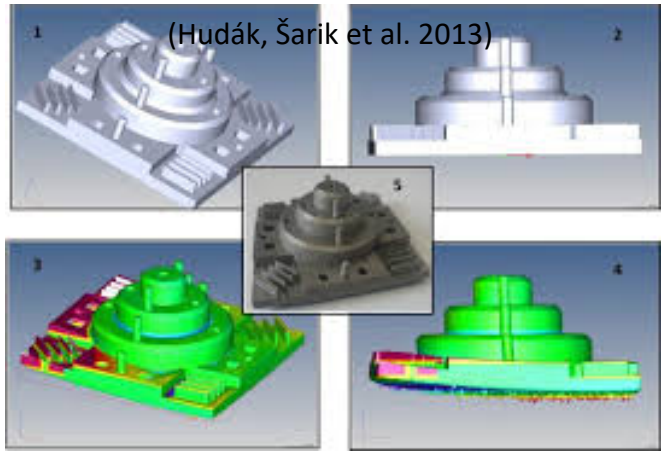


aerospace

http://www.turbocam.com/direct-metal-laser-sintering-dmls

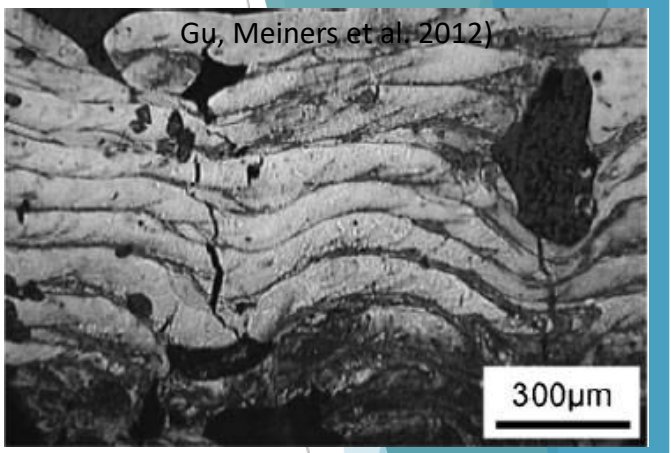
(Guo and Leu 2013)

Challenges: Thermal Distortion and Build Failure

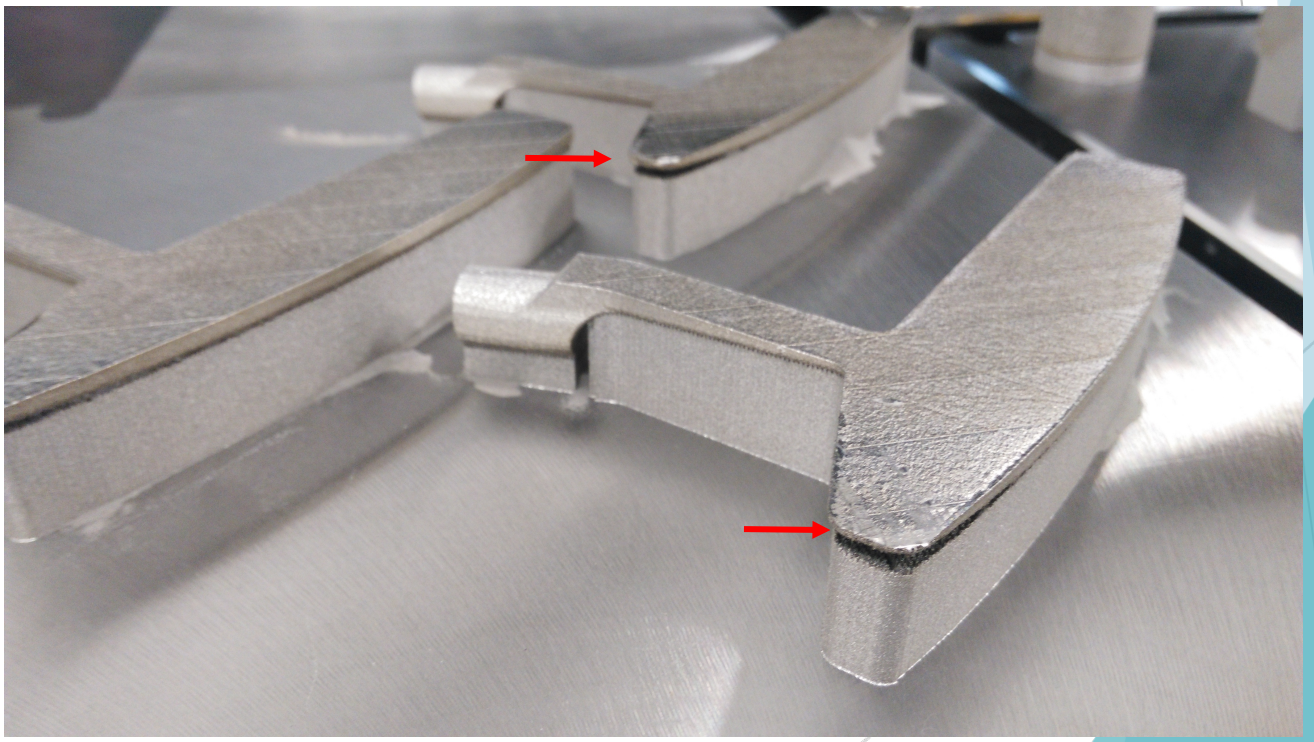


Thermal Distortion

Layer Delamination



Crack Formation



Many Tools: NONE optimize orientation with automatic support structures…

.STL File

Orient & Support (30-45 min)

Trial & Error
(Repeats 2-3x)
+/- $20,000

Simulate (4-24 hours)

Printer Planner Software (30 min)

?

Print the Part (10-60 hours)

40% Failure Rate!

The BLACK ART: Correct Orientation and Support Structures

AUTODESK INVENTOR
creo
SolidWorks
ANSYS
SIEMENS NX

Magics
QuantAM
GEONX
AUTODESK NETFABB
ANSYS
3DXpert One-Stop Solution for

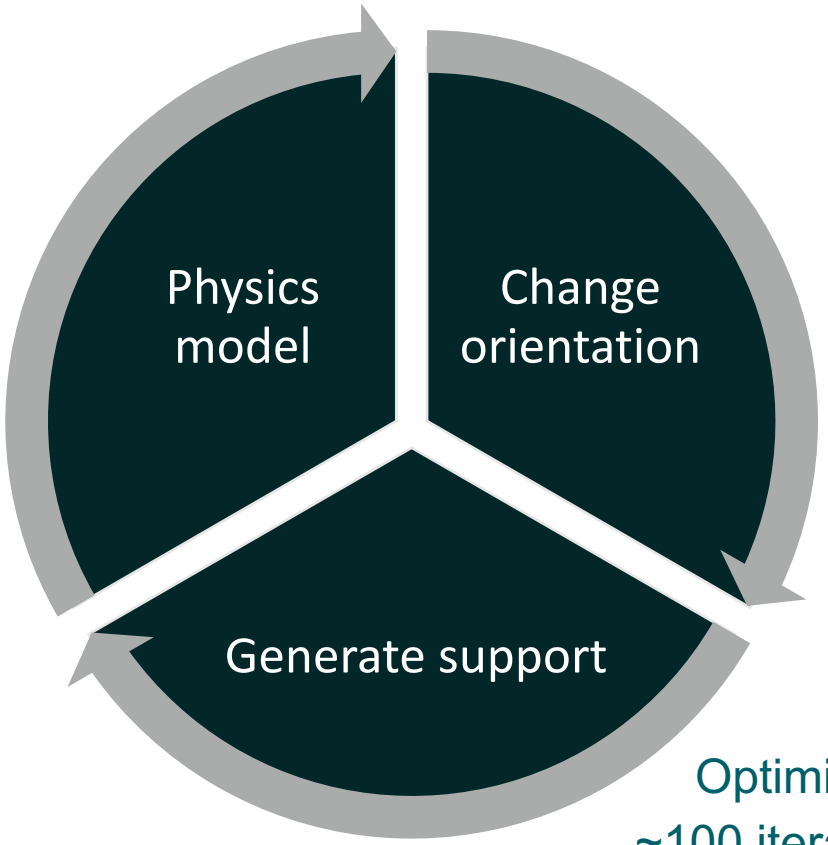
$15K+ / year

SIMULIA
simufact Simulating Manufacturing
ANSYS
3DSIM
GEONX
AUTODESK NETFABB
esi
PLM Software SIEMENS NX
3DXpert One-Stop Solution for

$50k software + $50k hardware

3DXpert One-Stop Solution for
QuantAM
eos
SLM Solutions GmbH

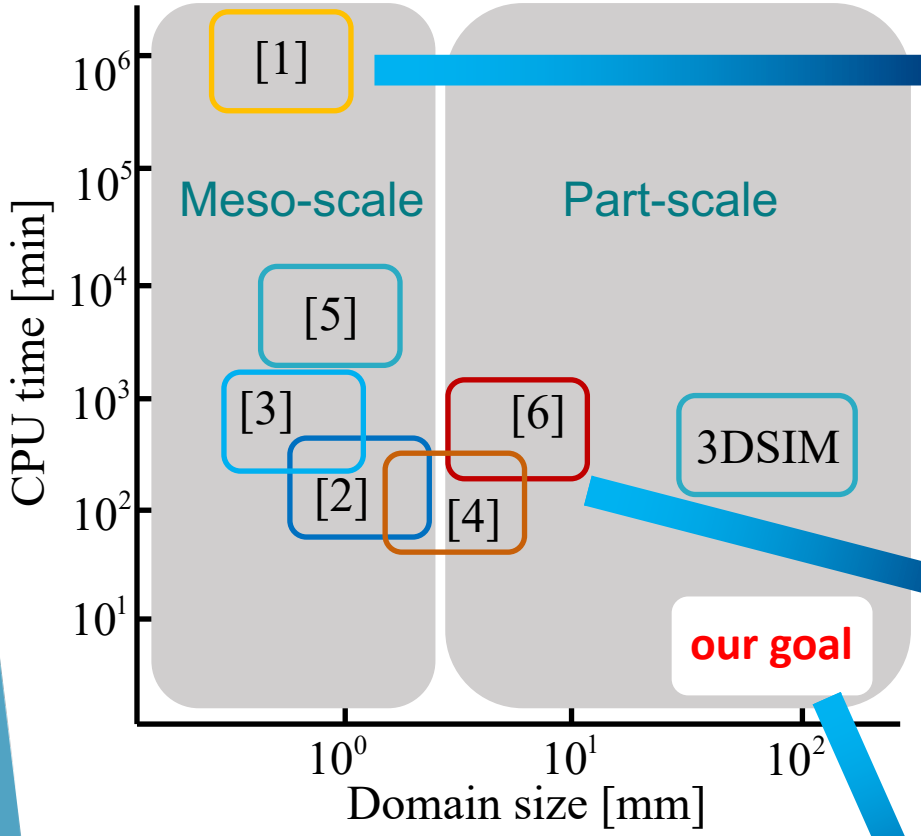
A Solution from Atlas3D



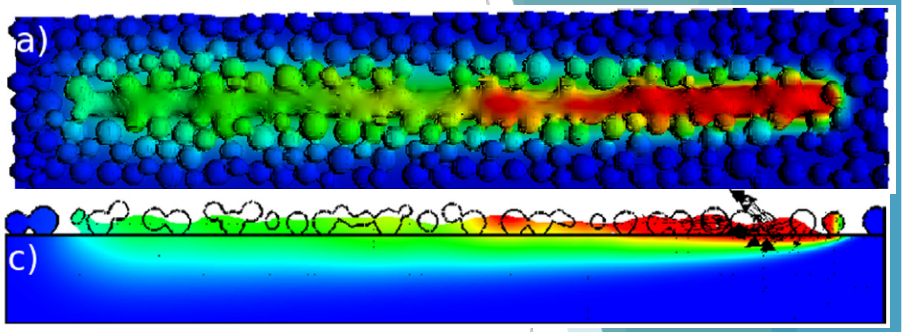
Optimization loop
~100 iterations

- Final goal: optimize part orientation and support to minimize thermal stress and distortion.
- Require fast & reliable predictive physics models!

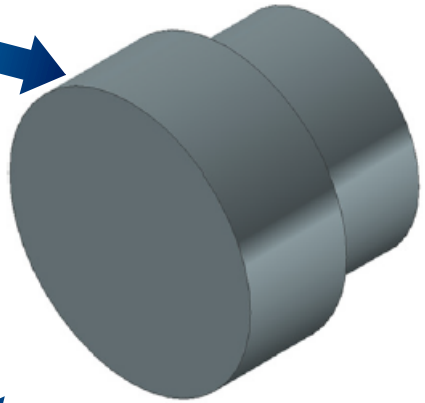
Physics Models in Literature



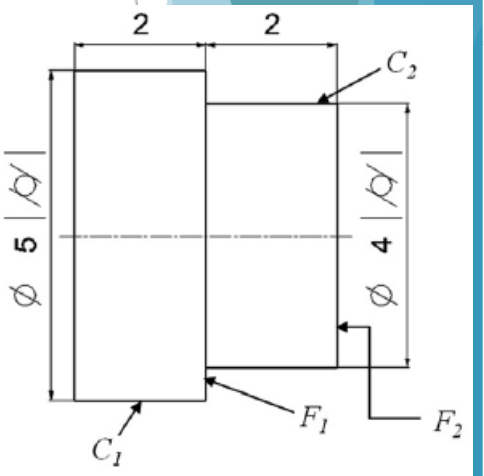
[1] Khairallah and Anderson, 2014
[2] Hussein, Hao et al. 2013
[3] Jamshidinia, Kong et al. 2013
[4] Dai and Shaw 2005
[5] Ammer, Markl et al. 2014
[6] Paul, Anand et al. 2014



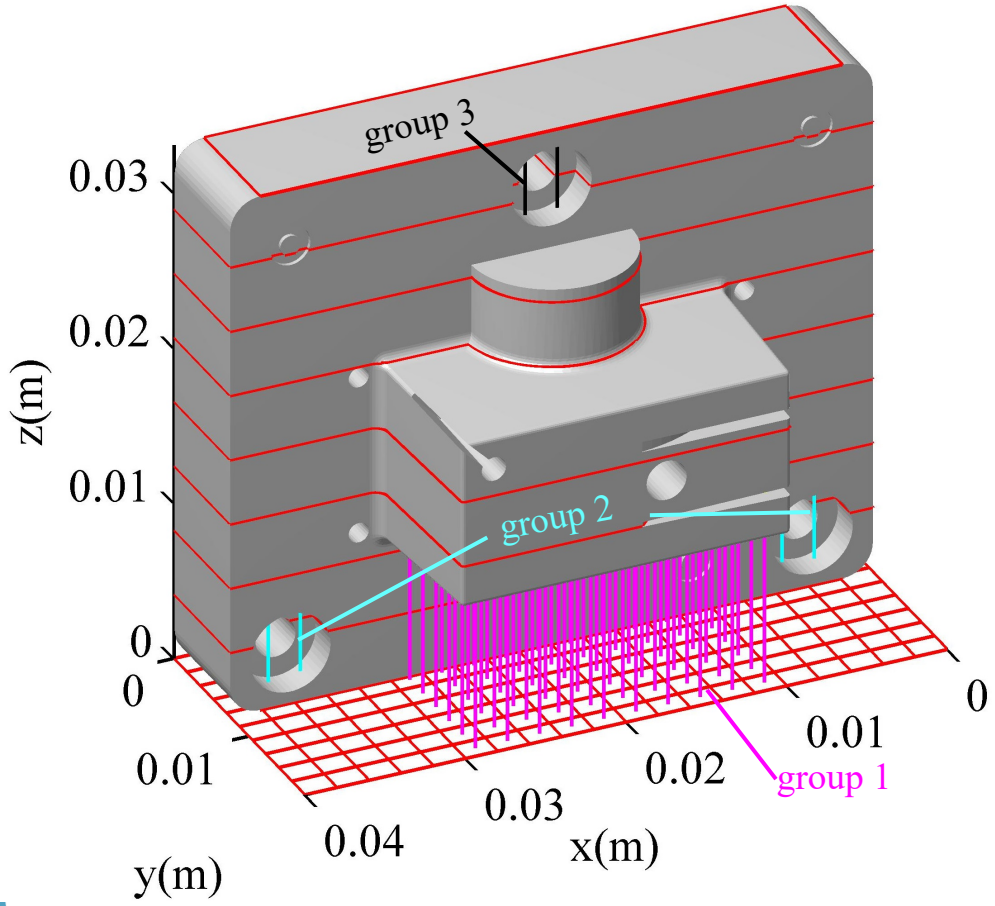
Domain: 1000 x 300 x 50 μm
Time: ~1,000,000 CPU min

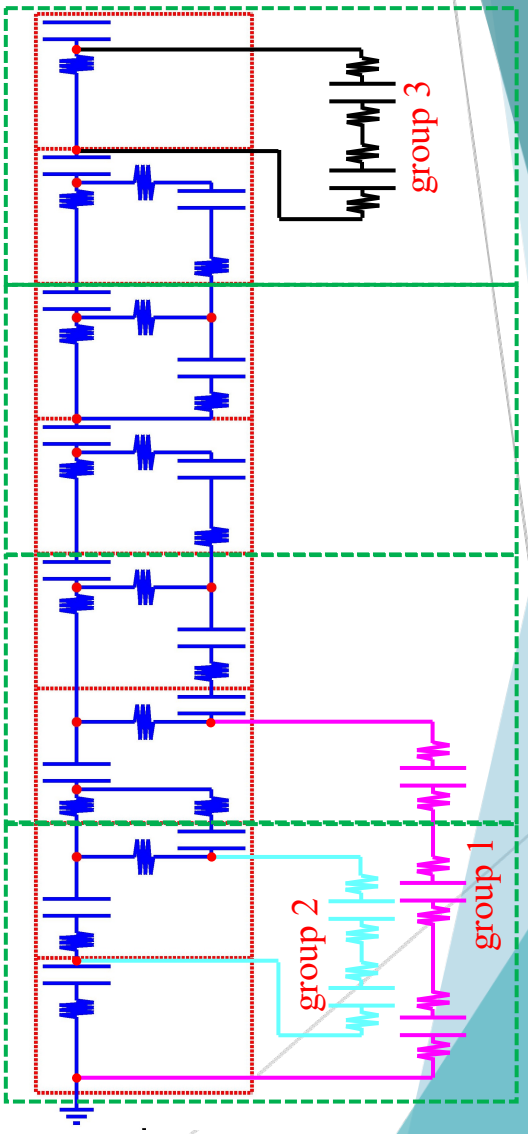


Non-FEM approach

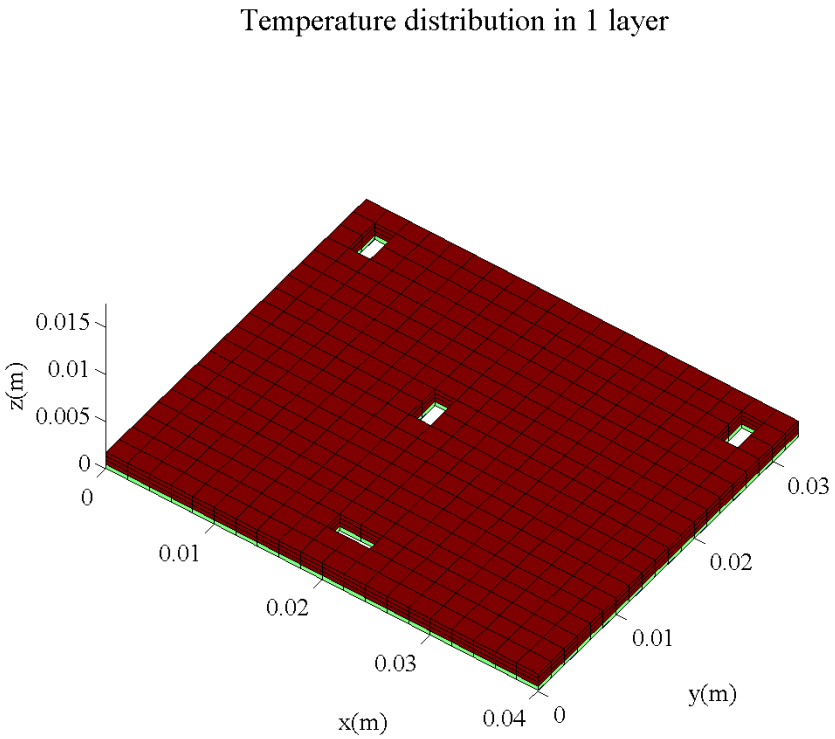


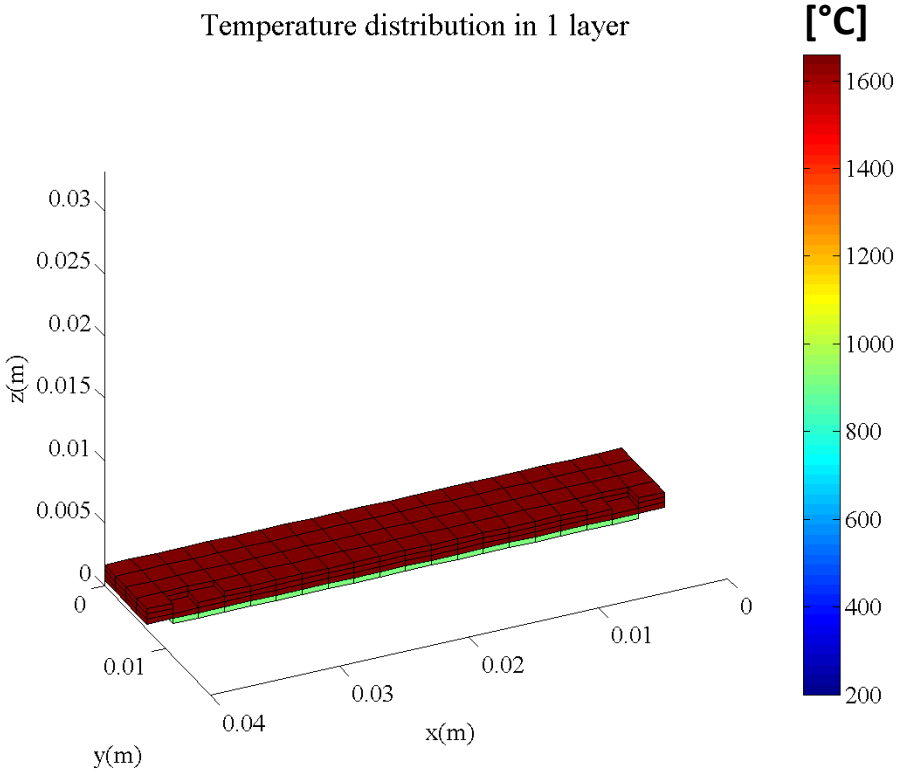
Thermal circuit network (TCN)





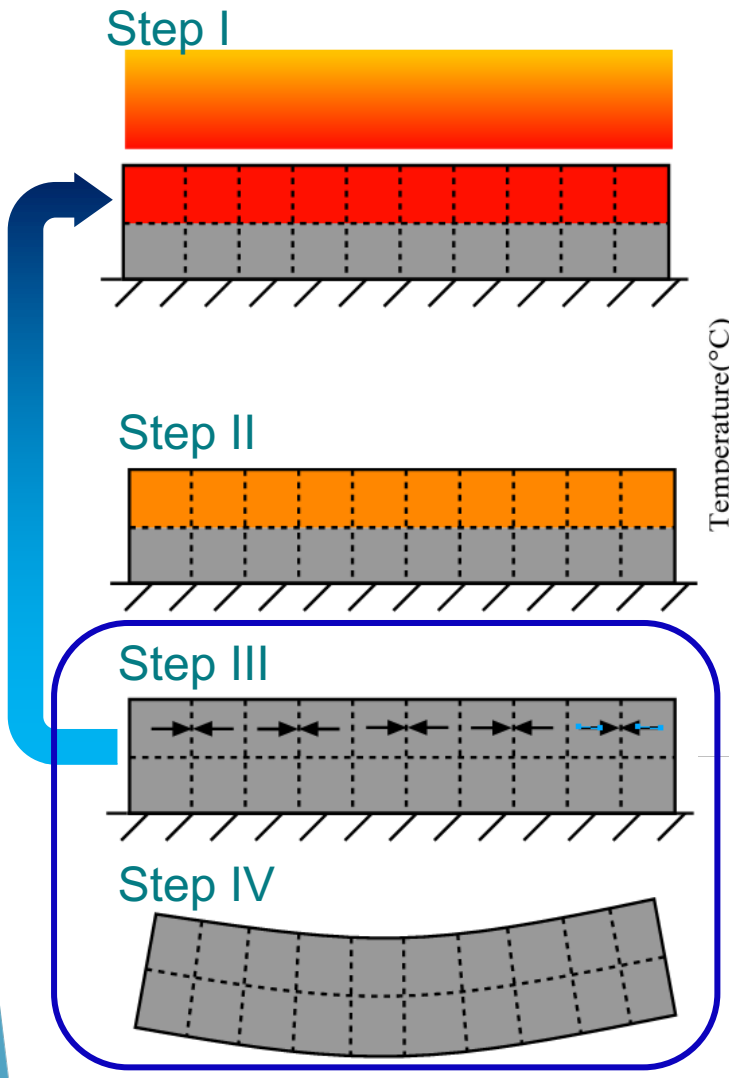
TCN: an example



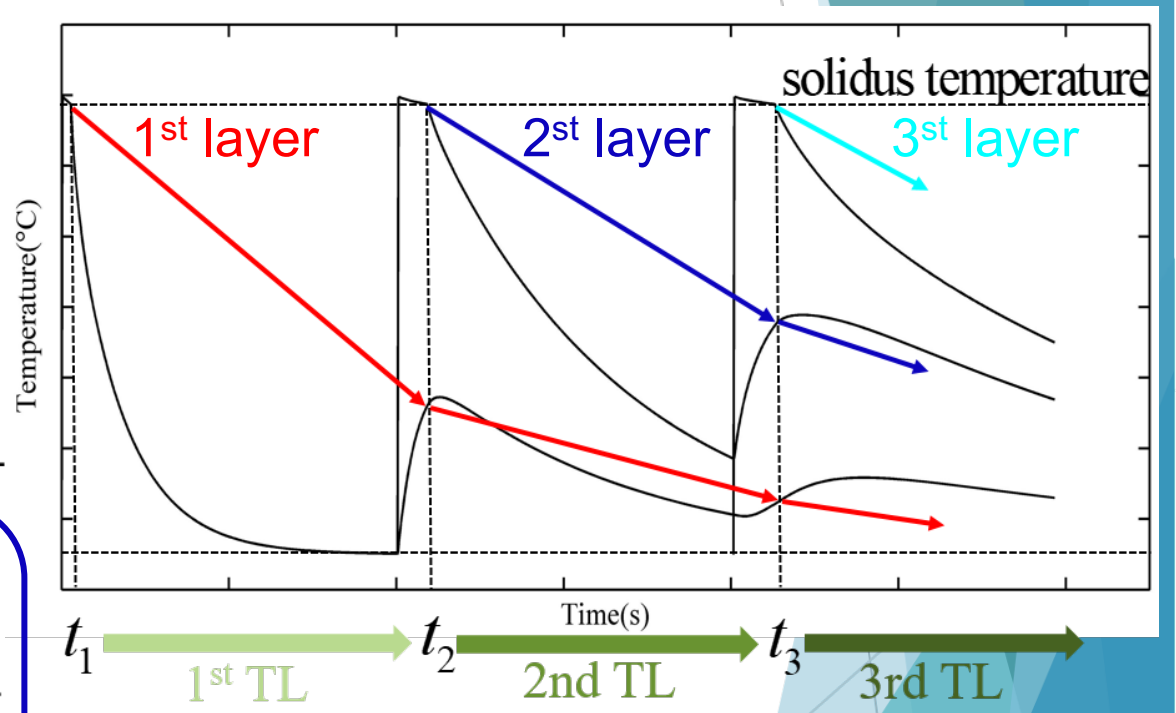


Model	Horizontal part	Vertical part	Relative error
FEM	14 h 10 min	41 h 15 min	<15%
TCN	2 min	18 min 43 sec	<15%

Quasi-static thermo-mechanical (QTM)

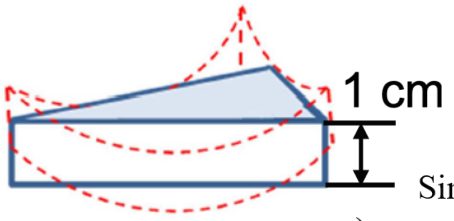


Quasi-static

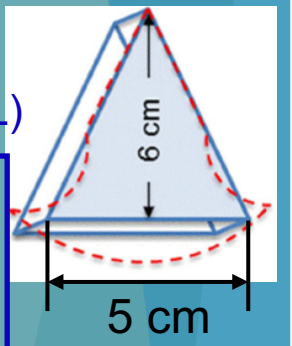


TL: thermal loading

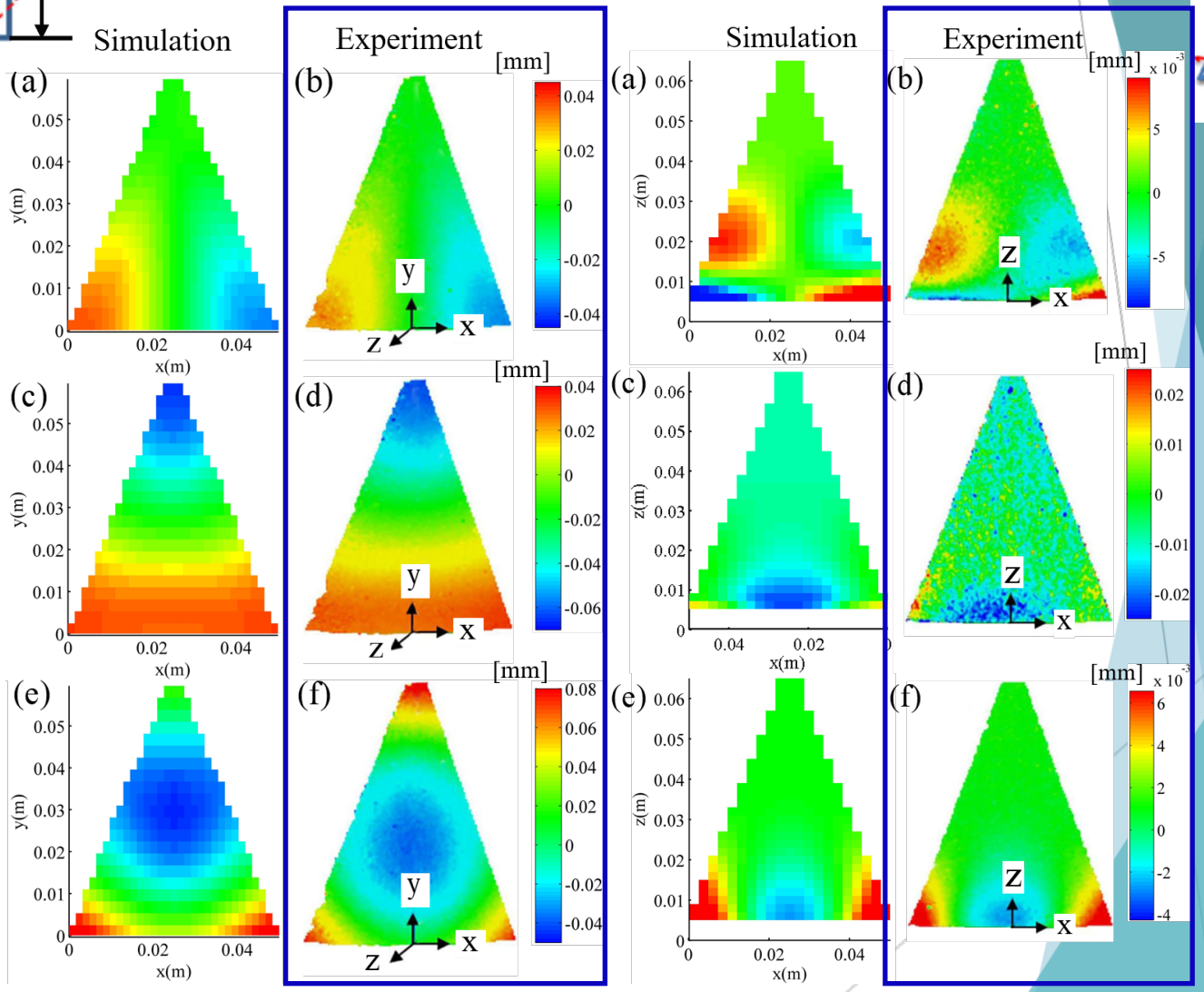
Thermal distortion: simulation vs. experiment



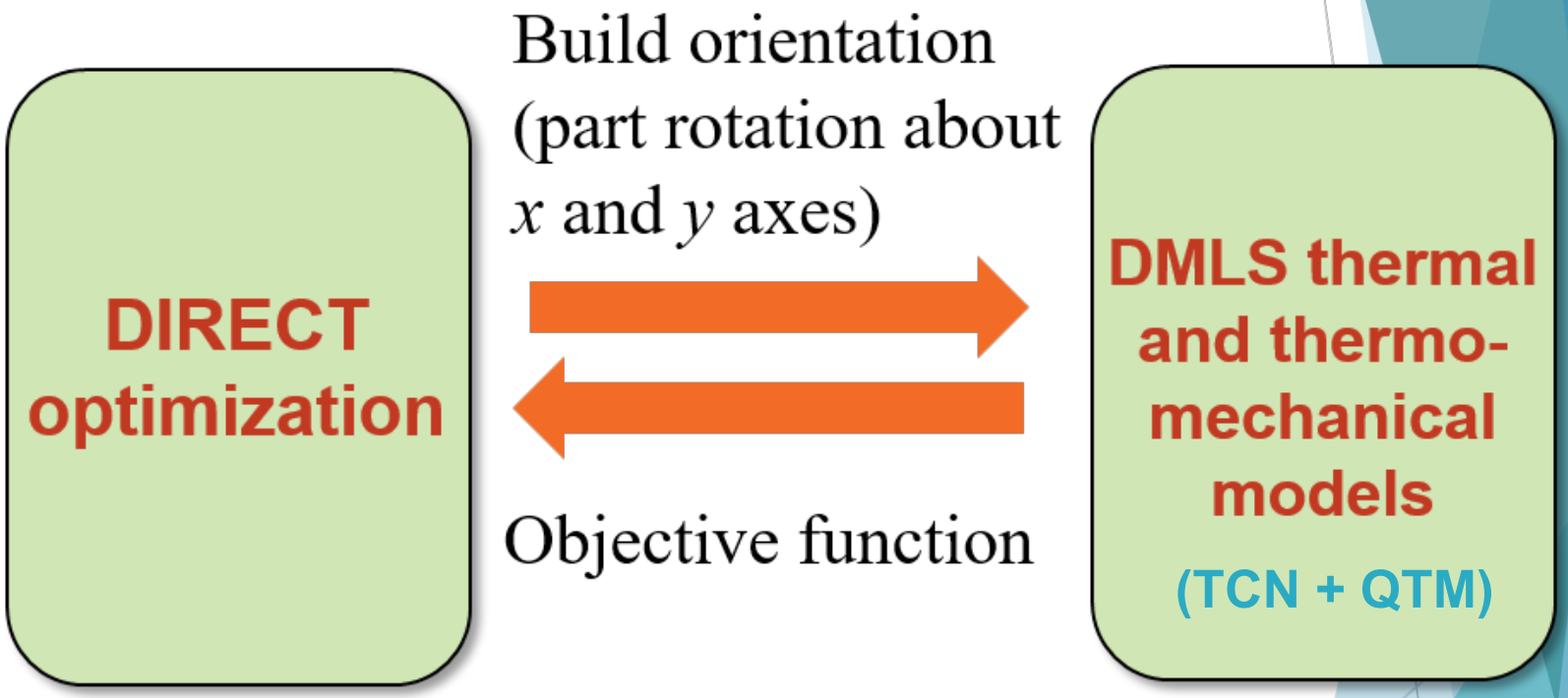
Digital image correlation (courtesy of Wu and et al. at LLNL)



316L stainless steel

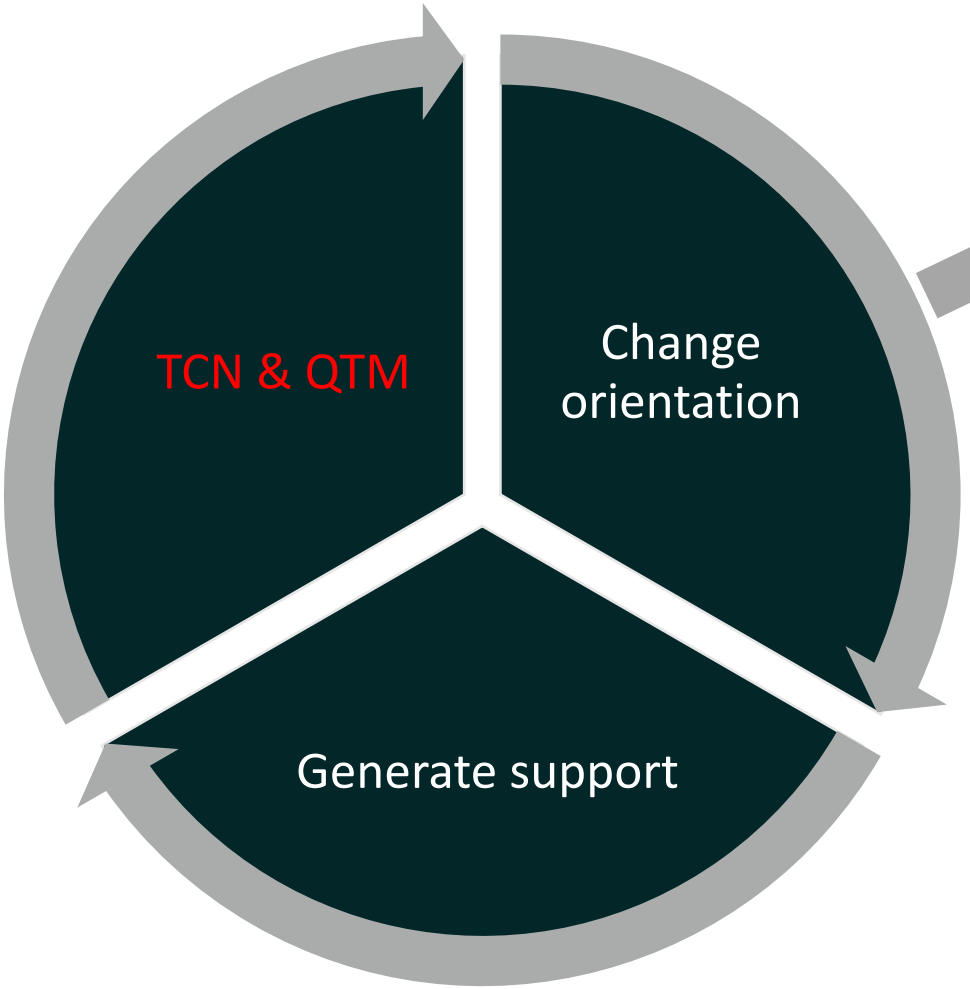


Optimization Algorithm



- DIRECT: pattern search / non-gradient method (Finkel 2003 DIRECT Optimization Algorithm User Guide)
- Assumption: rotation about z has no influence on thermal distortion

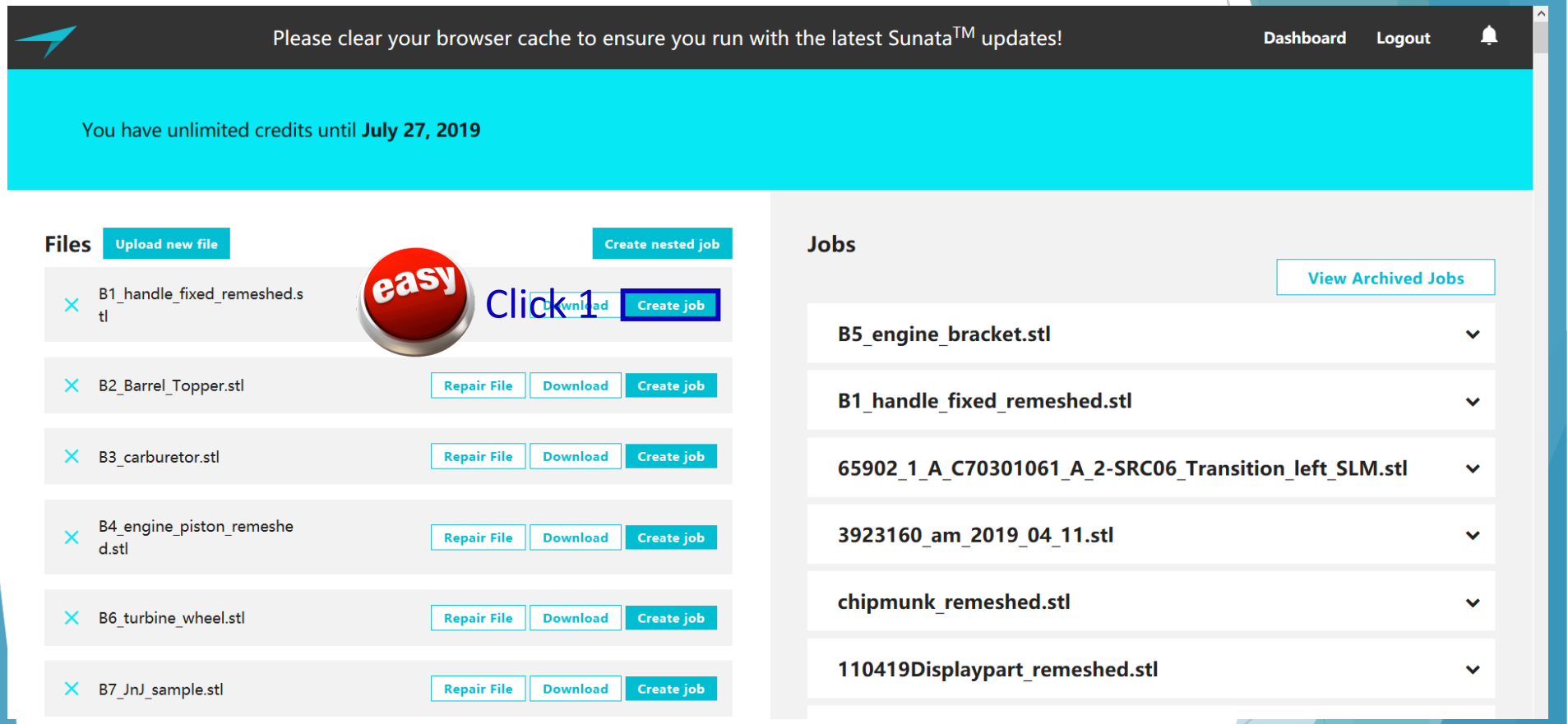
A Short Summary:



DIRECT Optimization

.stl file: new STL file at optimal build orientation
.cli file: slicing file of optimal support structures

User Interface (3 clicks)



User Interface (3 clicks)

CREATE JOB FOR

B1_handle_fixed_remeshed.stl:

CHOOSE MATERIALS:	CHOOSE PRINTER:
Ti64 ⌄	EOSM290 ⌄

Advanced Options

☐ Remesh your file for better resolution (Original geometry will be preserved)

☐ Create an additional job result that includes design modifications that compensate for thermal distortion (remeshing is required)

☐ Use this job's specifications for the next job

Prepare file for print run:

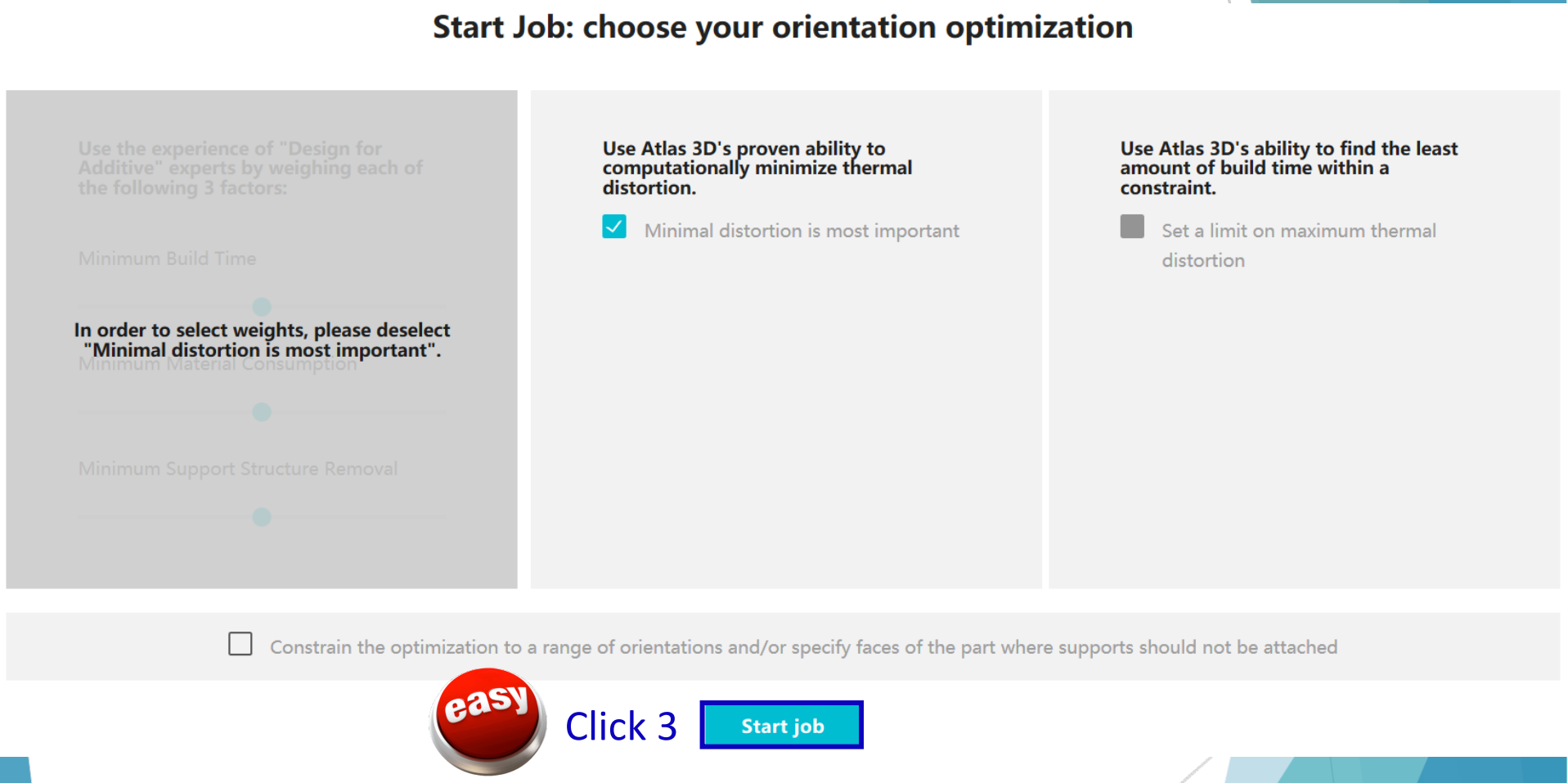
You can choose to orient your part manually. Sunata™ will automatically add support structures where you need them.
Caution - we do not guarantee a successful build when using this option.

Click 2

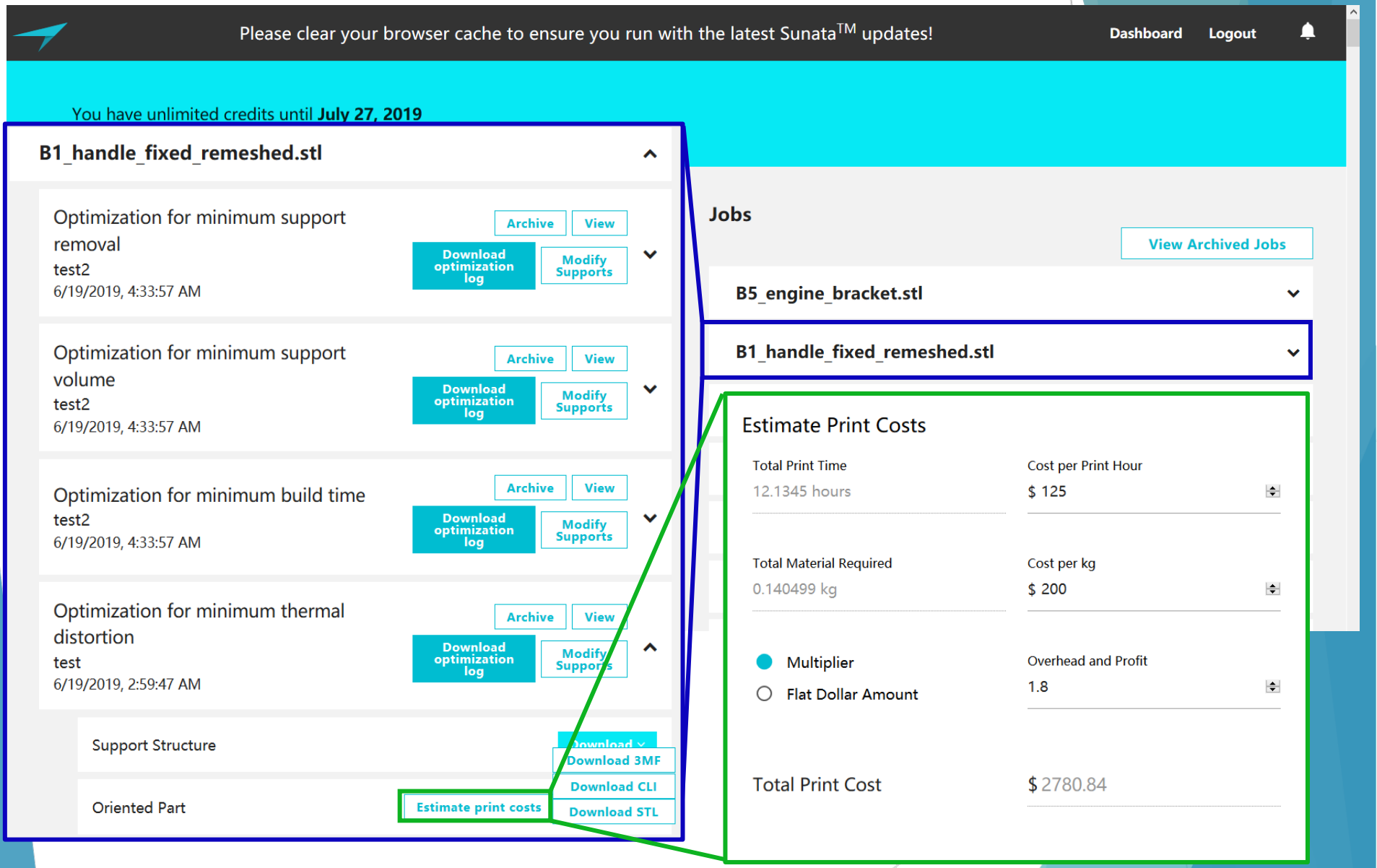
Use Sunata Intelligence

Orient Manually

User Interface (3 clicks)



Job Results


Please clear your browser cache to ensure you run with the latest Sunata™ updates!
Dashboard
Logout
You have unlimited credits until July 27, 2019
B1_handle_fixed_remeshed.stl
Optimization for minimum support removal
test2
6/19/2019, 4:33:57 AM
Archive
View
Download optimization log
Modify Supports
Optimization for minimum support volume
test2
6/19/2019, 4:33:57 AM
Archive
View
Download optimization log
Modify Supports
Optimization for minimum build time
test2
6/19/2019, 4:33:57 AM
Archive
View
Download optimization log
Modify Supports
Optimization for minimum thermal distortion
test
6/19/2019, 2:59:47 AM
Archive
View
Download optimization log
Modify Supports
Support Structure
Download
Download 3MF
Download CLI
Oriented Part
Estimate print costs
Download STL
Jobs
View Archived Jobs
B5_engine_bracket.stl
B1_handle_fixed_remeshed.stl
Estimate Print Costs
Total Print Time
12.1345 hours
Cost per Print Hour
$ 125
Total Material Required
0.140499 kg
Cost per kg
$ 200
Multiplier
Flat Dollar Amount
Overhead and Profit
1.8
Total Print Cost
$ 2780.84

Job Results

B1_handle_fixed_remeshed.stl

Optimization for minimum support removal
test2
6/19/2019, 4:33:57 AM

Archive | View | Download optimization log | Modify Supports

Support Structure — Download

Oriented Part — Estimate print costs | Download

Optimization for minimum support volume
test2
6/19/2019, 4:33:57 AM

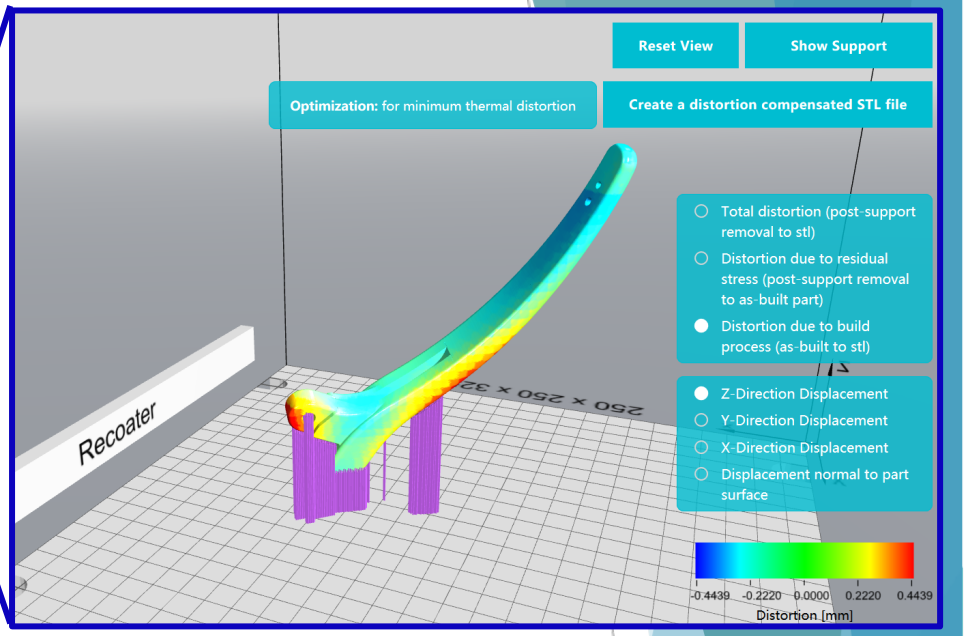
Archive | View | Download optimization log | Modify Supports

Optimization for minimum build time
test2
6/19/2019, 4:33:57 AM

Archive | View | Download optimization log | Modify Supports

Optimization for minimum thermal distortion
test
6/19/2019, 2:59:47 AM

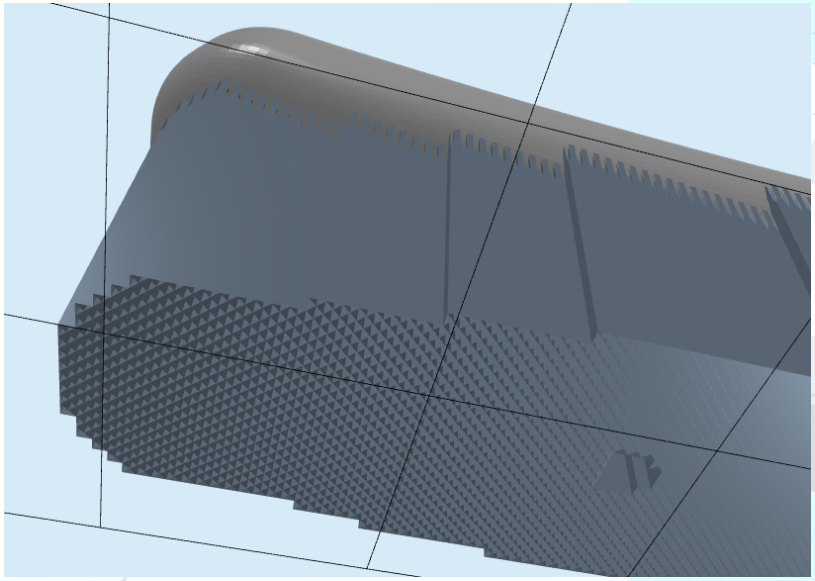
Archive | View | Download optimization log | Modify Supports



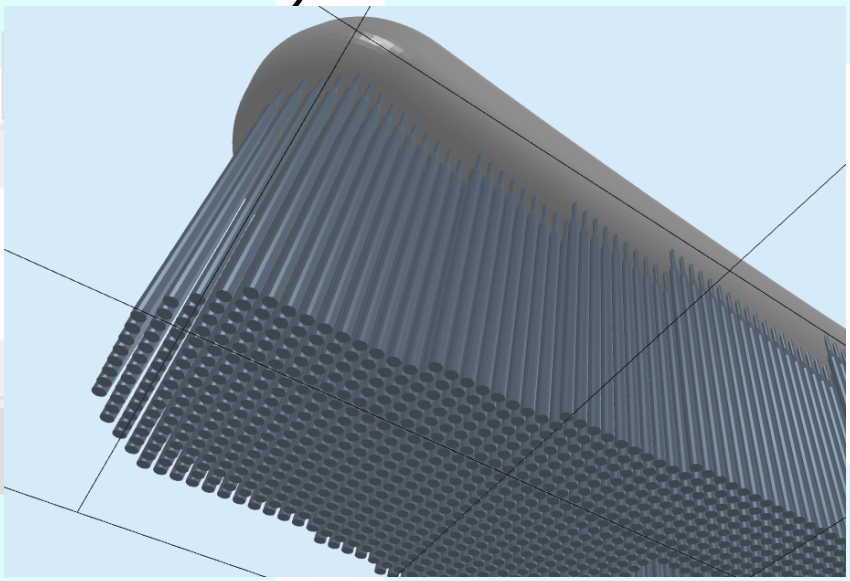

```
============  Job setup information:  ============
Printer:                              EOSM290
Material:                             Ti64
Powder layer thickness:               40 um
File name:                            B1_handle_fixed_remeshed.stl
Unit of STL file:                     mm
Scaling of STL file:                  1
STL dimensions before rotation:       162.144 x 16.7411 x 59.735 mm
Input orientation:                    0.0    0.0    0.0
Element size:                         2.0 mm
Z-offset:                             5.0 mm
Compensation flag:                    0
Support flag:                         1
Support size:                         0.5 mm
Critical angle for support:           40.0 degree
Build plate temperature:              80.0 degreeC
Laser speed:                          500.0 mm/s
Laser diameter:                       100.0 um
Laser power:                          400.0 W

============  Job output information:  ============
    Attempt   Run time     Orientation              Objective Function Result
P 0:      1     0.72 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 2:      1     0.72 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 7:      1     0.72 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 5:      1     0.72 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 3:      1     0.72 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 6:      1     0.73 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 4:      1     0.73 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 1:      1     0.73 min     -89.9 -131.4     0.0     Max z disp.:   0.51 mm; Max y disp.:  -0.43 mm; Max x disp.:  -0.28 mm; Max normal disp.:  -0.30 mm
P 3:      2     0.66 min     -89.9  -11.4     0.0     Max z disp.:   0.58 mm; Max y disp.:   0.75 mm; Max x disp.:  -0.81 mm; Max normal disp.:   0.57 mm
P 1:      2     0.71 min      30.1 -131.4     0.0     Max z disp.:   0.30 mm; Max y disp.:   0.27 mm; Max x disp.:  -0.39 mm; Max normal disp.:  -0.44 mm
P 0:      2     1.15 min    -209.9 -131.4     0.0     Max z disp.:   0.64 mm; Max y disp.:   0.27 mm; Max x disp.:  -0.52 mm; Max normal disp.:  -0.33 mm
P 2:      2     1.22 min     -89.9 -251.4     0.0     Max z disp.:   0.31 mm; Max y disp.:  -0.54 mm; Max x disp.:  -0.32 mm; Max normal disp.:  -0.57 mm
P 5:      2     0.52 min     -89.9  -91.4     0.0     Max z disp.:   0.32 mm; Max y disp.:  -0.43 mm; Max x disp.:   0.16 mm; Max normal disp.:  -0.32 mm
P 4:      2     0.54 min     -89.9 -171.4     0.0     Max z disp.:   0.62 mm; Max y disp.:   0.74 mm; Max x disp.:   0.92 mm; Max normal disp.:   0.53 mm
P 3:      3     1.05 min     -49.9 -131.4     0.0     Max z disp.:   0.33 mm; Max y disp.:  -0.34 mm; Max x disp.:  -0.37 mm; Max normal disp.:  -0.44 mm
P 0:      3     1.22 min    -209.9 -251.4     0.0     Max z disp.:   0.31 mm; Max y disp.:  -0.33 mm; Max x disp.:   0.38 mm; Max normal disp.:  -0.42 mm
P 2:      3     1.27 min    -129.9 -131.4     0.0     Max z disp.:   0.72 mm; Max y disp.:  -0.41 mm; Max x disp.:  -0.51 mm; Max normal disp.:  -0.28 mm
P 1:      3     1.62 min    -209.9  -11.4     0.0     Max z disp.:   1.36 mm; Max y disp.:  -0.56 mm; Max x disp.:  -1.06 mm; Max normal disp.:  -0.75 mm
P 2:      4     0.53 min    -129.9 -171.4     0.0     Max z disp.:   0.95 mm; Max y disp.:  -0.48 mm; Max x disp.:  -1.04 mm; Max normal disp.:  -1.28 mm
P 1:      4     0.56 min      30.1  -11.4     0.0     Max z disp.:   0.68 mm; Max y disp.:  -0.32 mm; Max x disp.:   0.93 mm; Max normal disp.:  -0.87 mm
P 3:      4     0.57 min    -129.9  -91.4     0.0     Max z disp.:   0.35 mm; Max y disp.:  -0.36 mm; Max x disp.:  -0.32 mm; Max normal disp.:  -0.32 mm
P 0:      4     0.93 min      30.1 -251.4     0.0     Max z disp.:   0.42 mm; Max y disp.:   0.38 mm; Max x disp.:  -0.55 mm; Max normal disp.:  -0.71 mm
P 3:      5     0.57 min    -209.9  -91.4     0.0     Max z disp.:   0.33 mm; Max y disp.:   0.26 mm; Max x disp.:  -0.39 mm; Max normal disp.:  -0.32 mm
P 2:      5     0.58 min    -209.9 -171.4     0.0     Max z disp.:   0.86 mm; Max y disp.:  -0.29 mm; Max x disp.:  -0.93 mm; Max normal disp.:  -0.81 mm
P 7:      2     0.69 min    -129.9 -118.0     0.0     Max z disp.:   0.38 mm; Max y disp.:  -0.35 mm; Max x disp.:  -0.35 mm; Max normal disp.:  -0.23 mm
```

Job Results: Support Structures

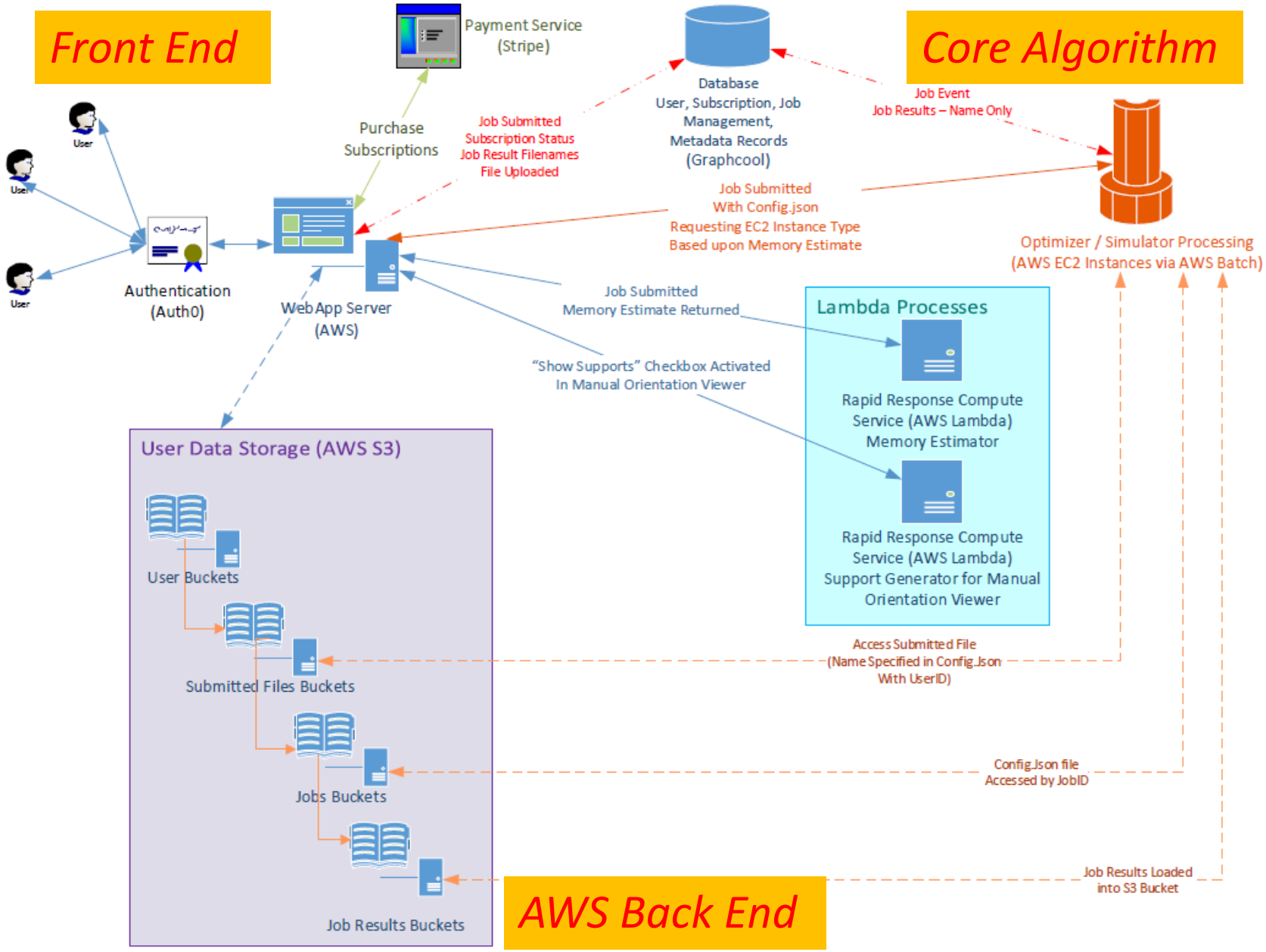
lattice



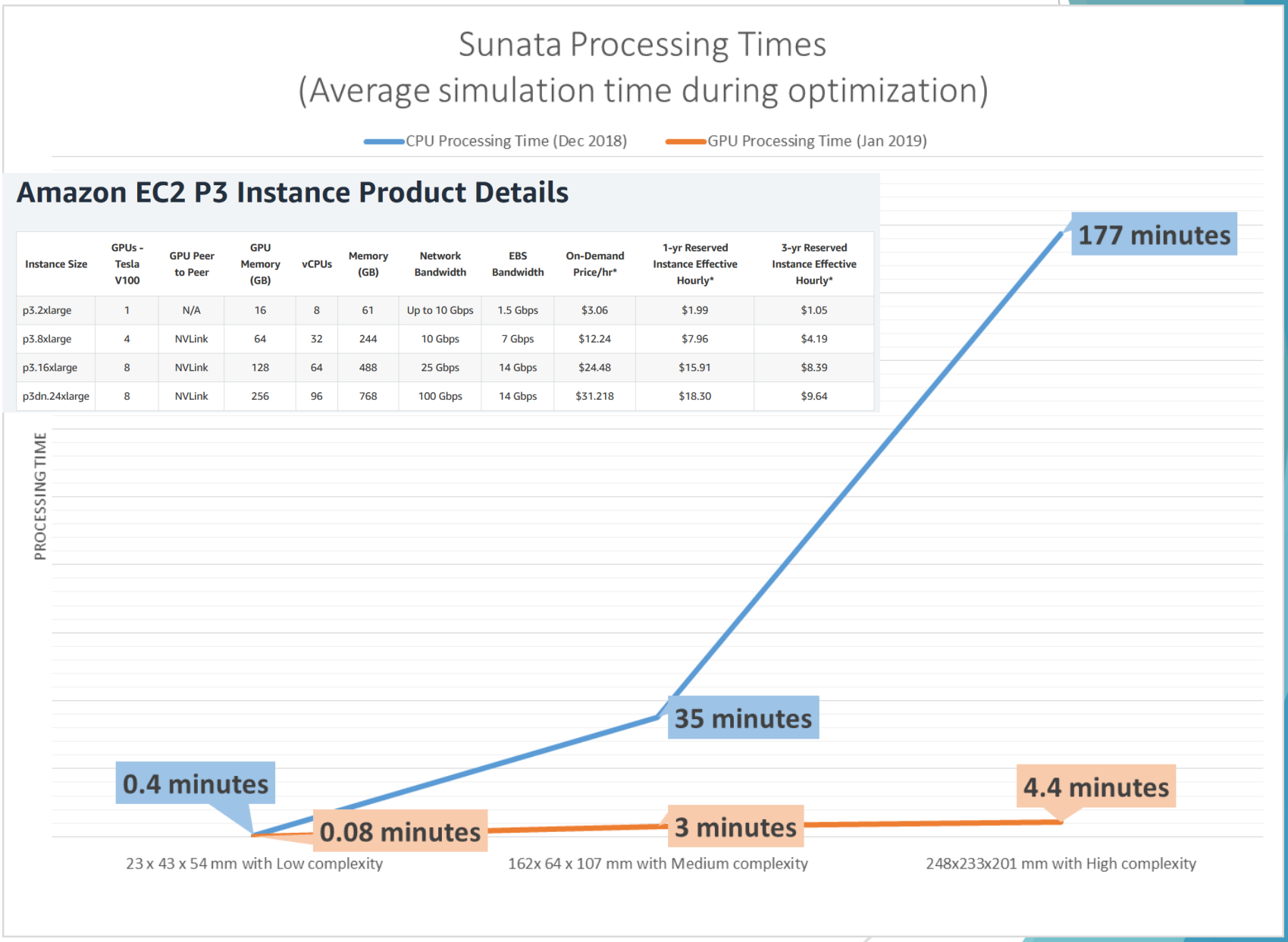
cylinder



What's happening behind the scene…



Code Acceleration: CPU (MPI) + GPU (Kokkos)

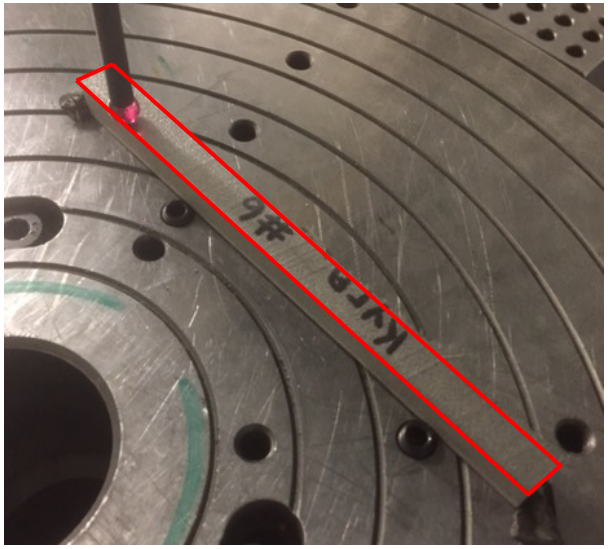


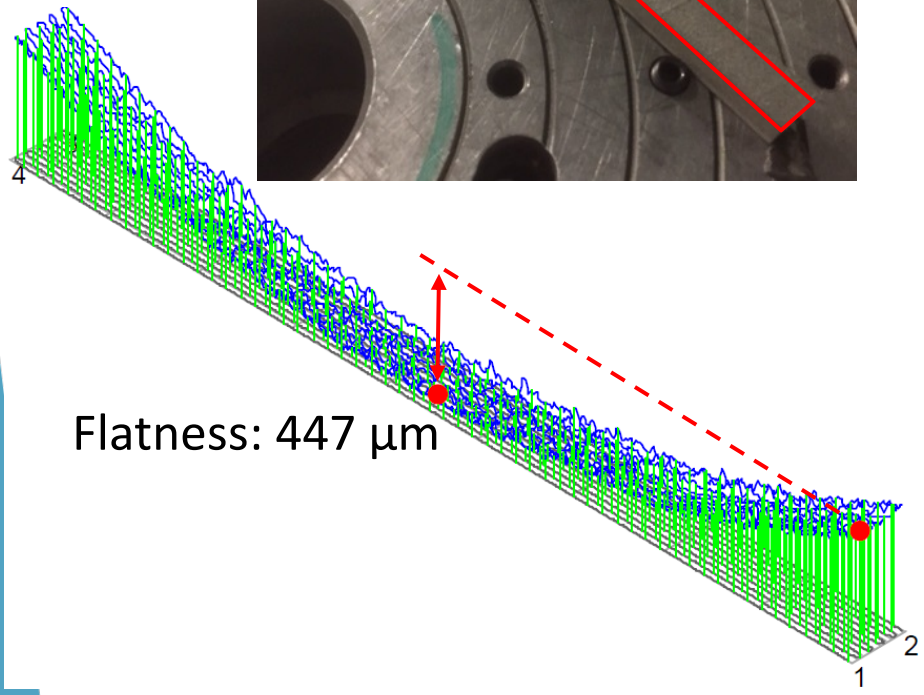
Amazon EC2 P3 Instance Product Details

Instance Size	GPUs - Tesla V100	GPU Peer to Peer	GPU Memory (GB)	vCPUs	Memory (GB)	Network Bandwidth	EBS Bandwidth	On-Demand Price/hr*	1-yr Reserved Instance Effective Hourly*	3-yr Reserved Instance Effective Hourly*
p3.2xlarge	1	N/A	16	8	61	Up to 10 Gbps	1.5 Gbps	$3.06	$1.99	$1.05
p3.8xlarge	4	NVLink	64	32	244	10 Gbps	7 Gbps	$12.24	$7.96	$4.19
p3.16xlarge	8	NVLink	128	64	488	25 Gbps	14 Gbps	$24.48	$15.91	$8.39
p3dn.24xlarge	8	NVLink	256	96	768	100 Gbps	14 Gbps	$31.218	$18.30	$9.64

Case Study: A Rectangular Bar

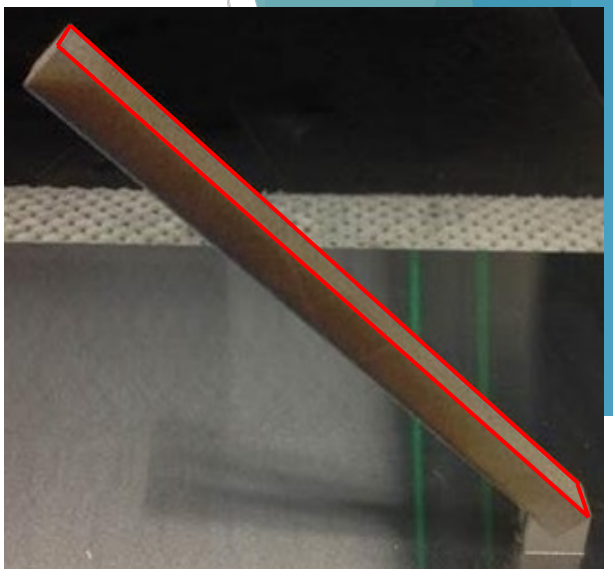
Horizontal build

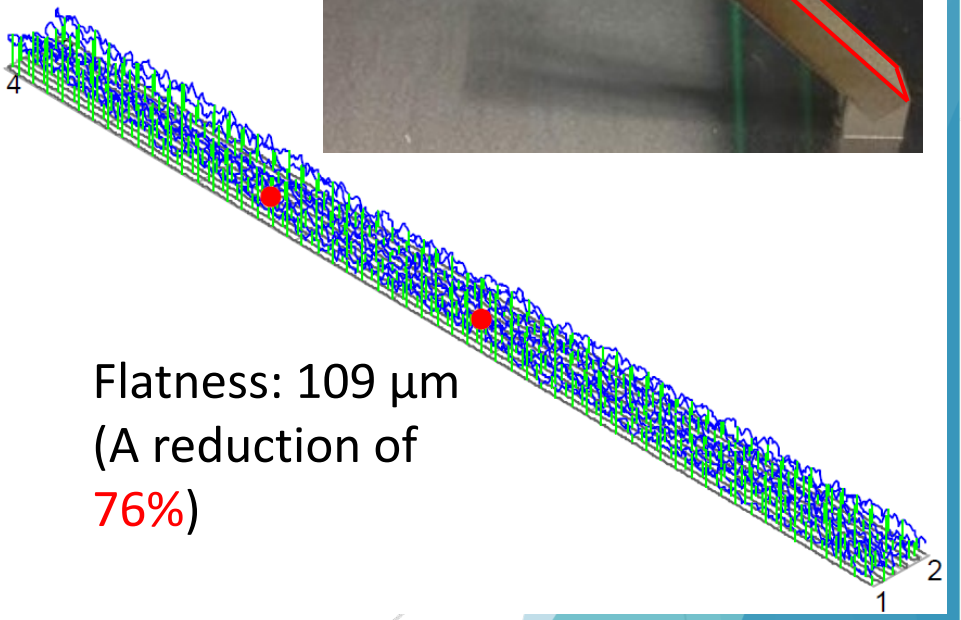




Flatness: 447 µm

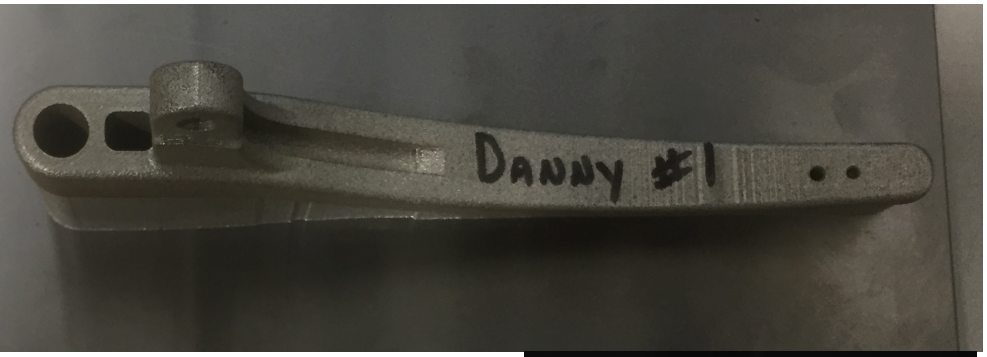
Optimal build



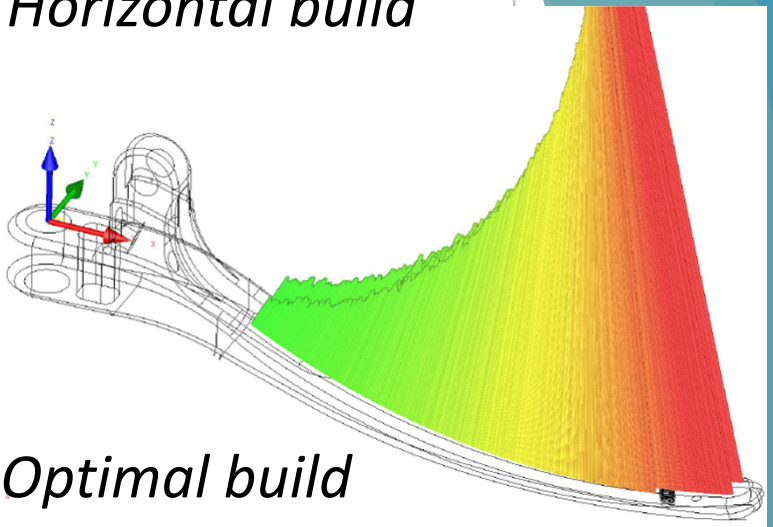


Flatness: 109 µm
(A reduction of
76%)

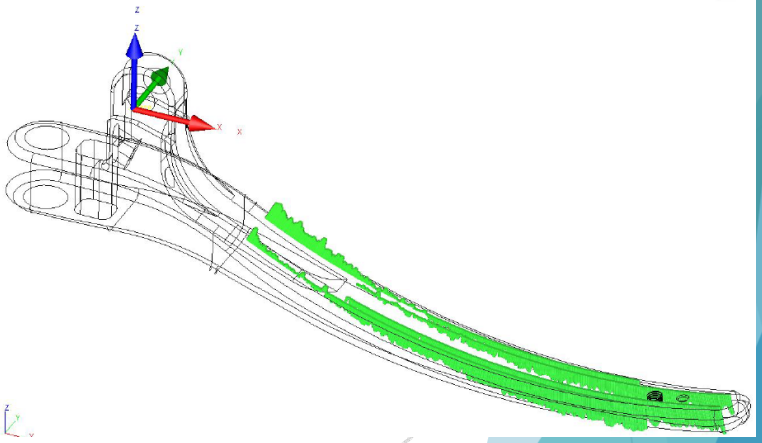
Case Study: An Orthopedic Part

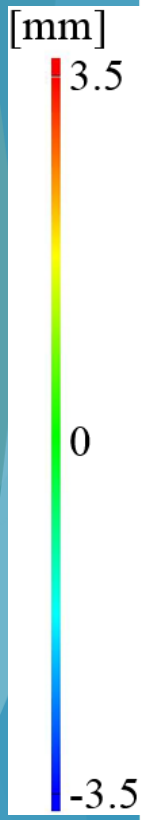


Horizontal build

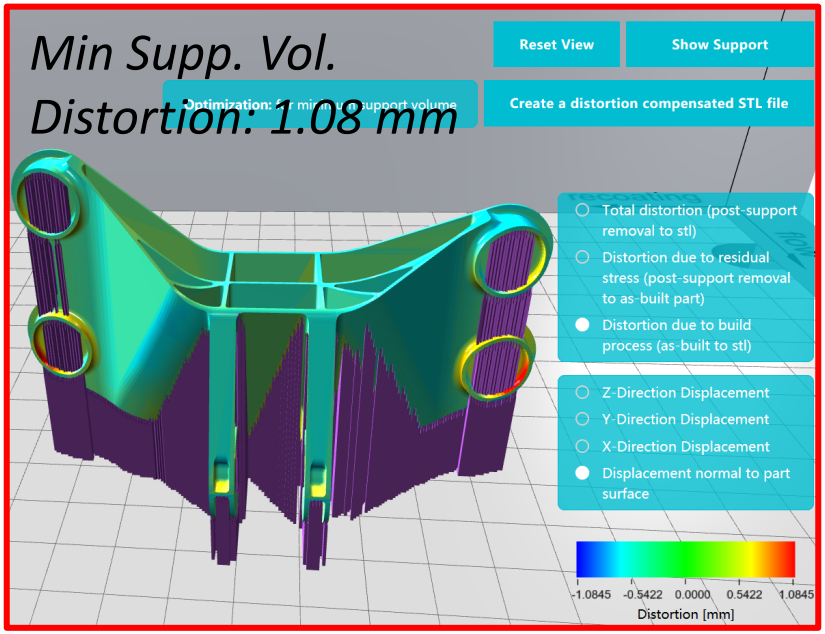


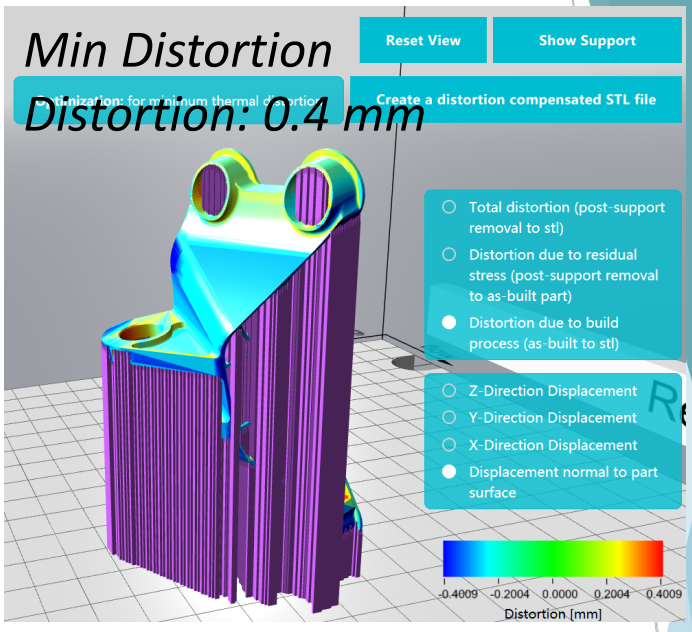
Optimal build

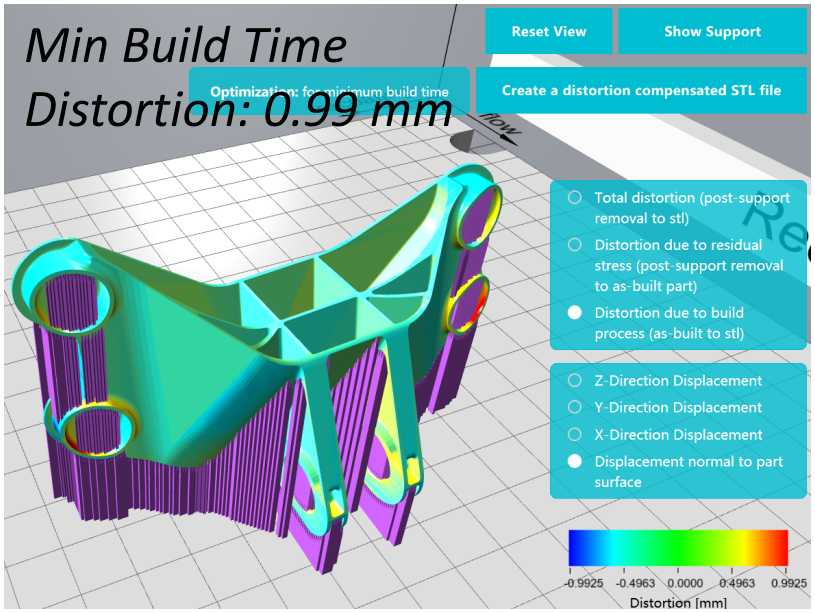


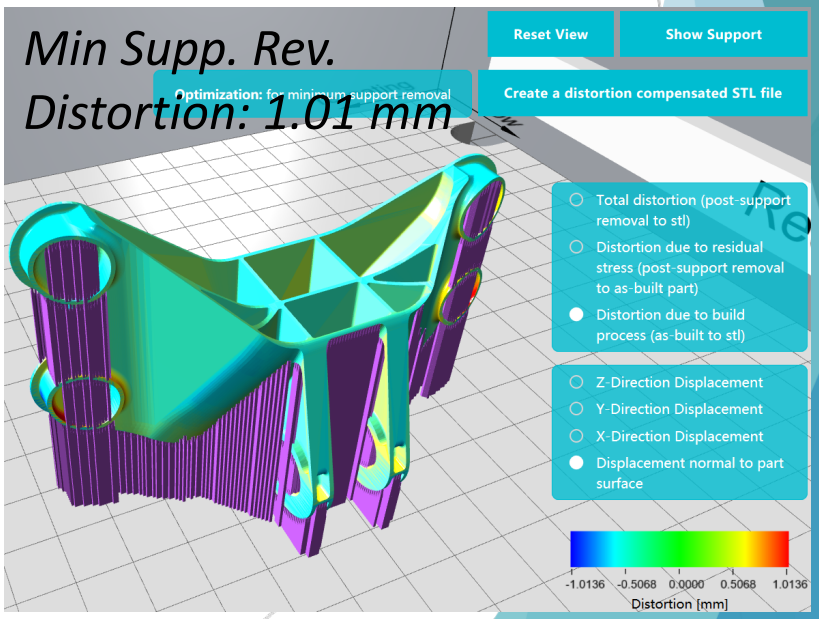


Case Study: An Engine Bracket

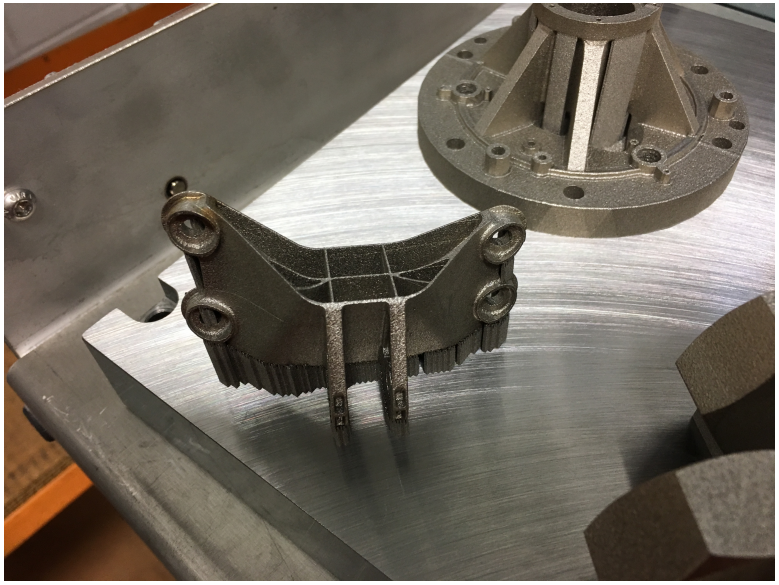


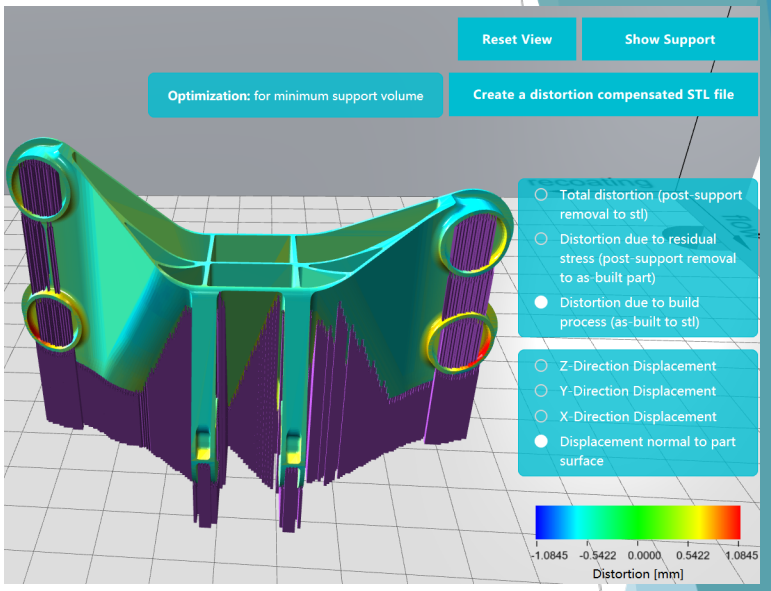




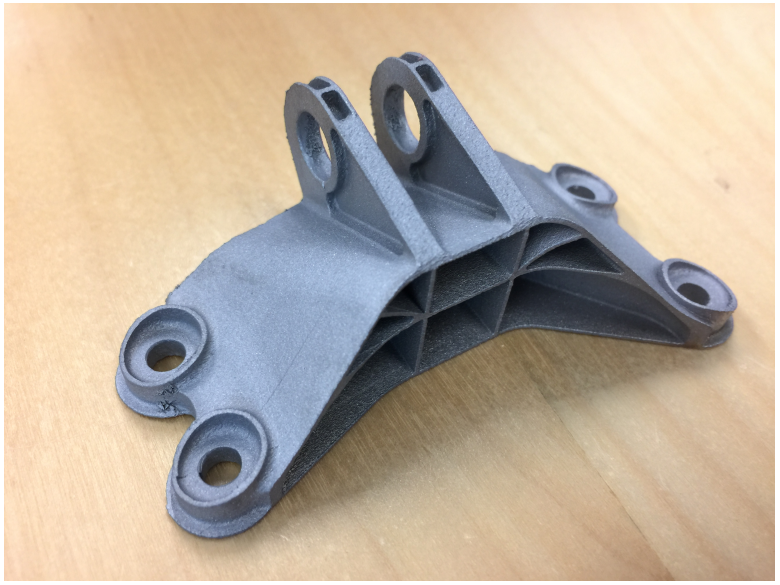


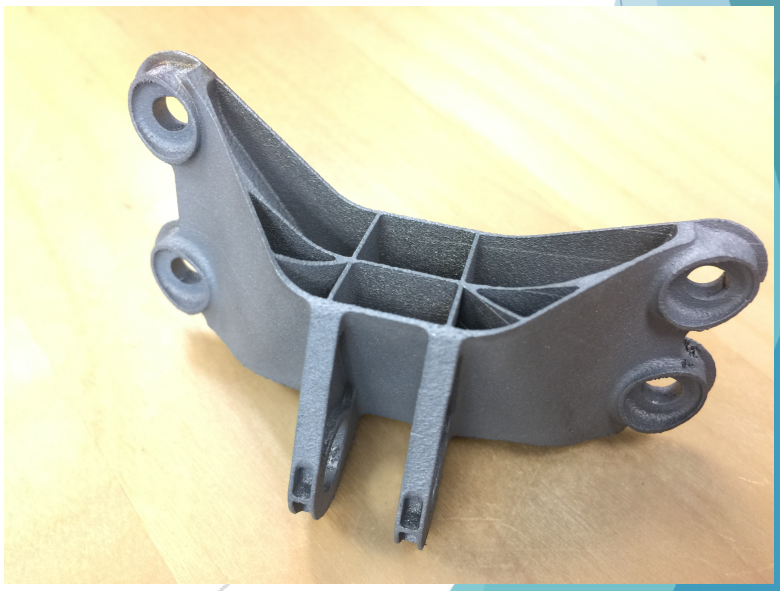
Case Study: An Engine Bracket (Min. Supp. Vol.)





After post-processing:





Successful build with right orientation…

Atlas3D Free Trial: https://atlas3d.xyz

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thank you!