Capitalizing on Additive Manufacturing Using Autodesk Generative Design

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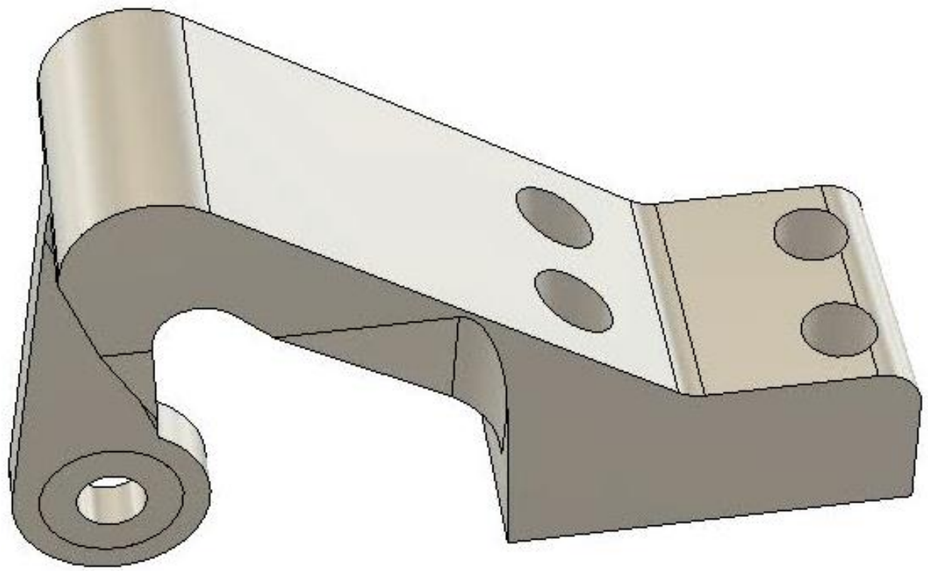
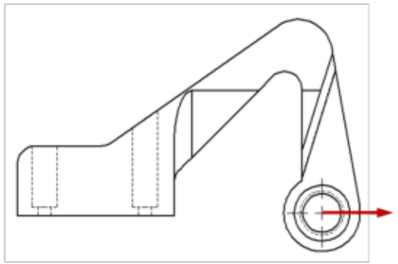
Key Learning Objectives

- Set up starting, obstacle, and preserved geometry with Fusion 360
- Use Autodesk Generative Design to re-design a structural aerospace bracket
- Use Fusion 360 with Nastran non-linear static simulation to verify additive manufactured designs
- Understand the potential of generatively designed AM parts against typical machined parts

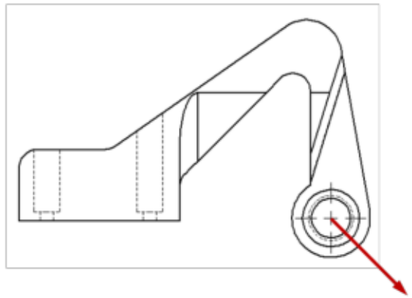
The GrabCAD Challenge

Mass optimise this bracket under these load conditions

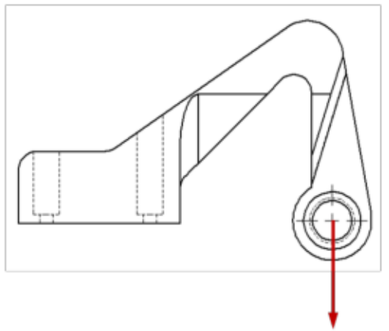




Case 1 (0°): 1250 lbf



Case 2 (45°): 1875 lbf

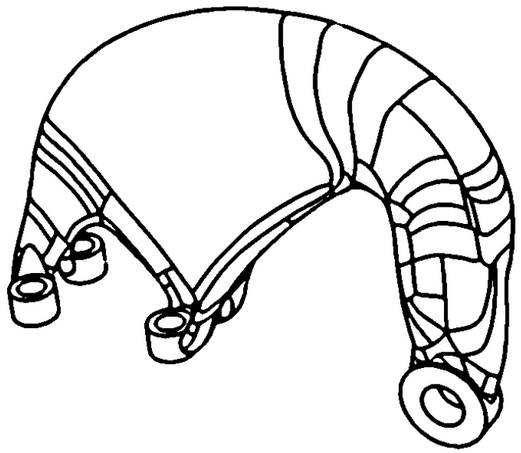


Case 3 (90°): 2500 lbf

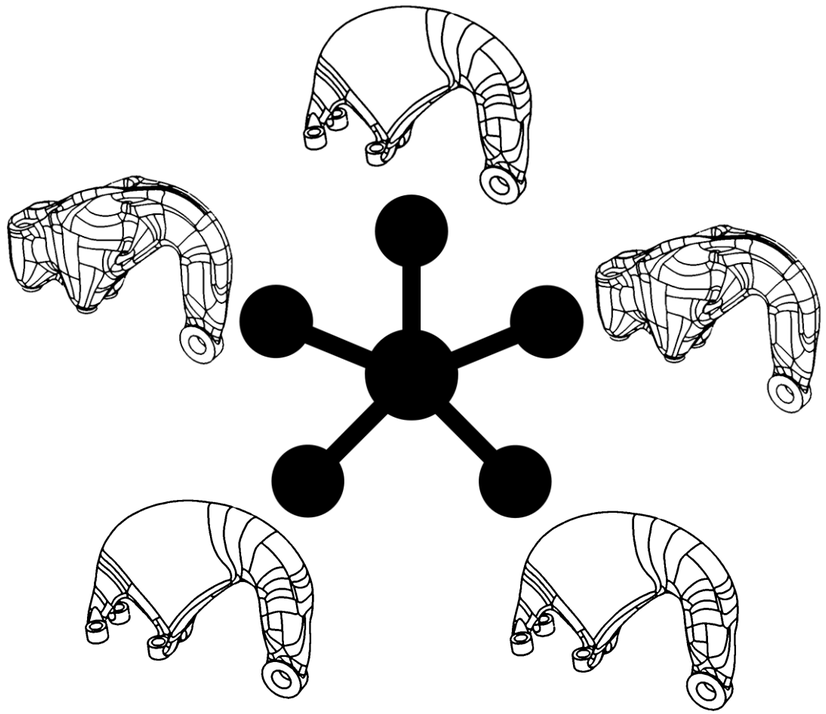
Material: 15-5PH Steel (AMS5862)
E = 29000 ksi = 200 GPa
F_y = 145 ksi = 1000 MPa

Source: https://grabcad.com/challenges/airplane-bearing-bracket-challenge

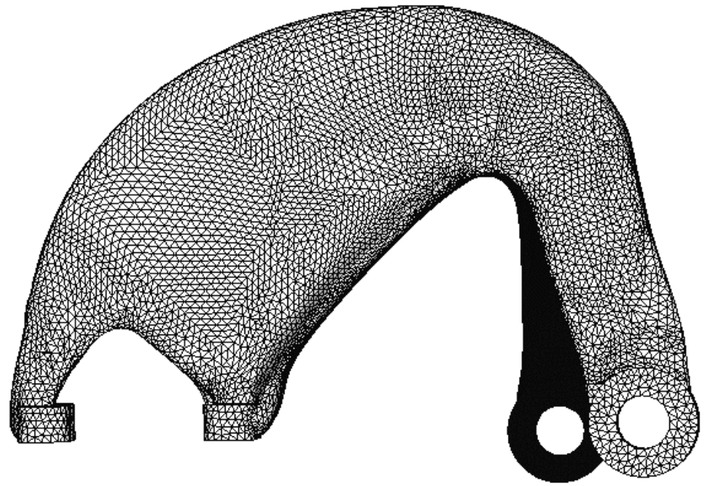
Our Challenge



Redesign with
Autodesk
Generative Design



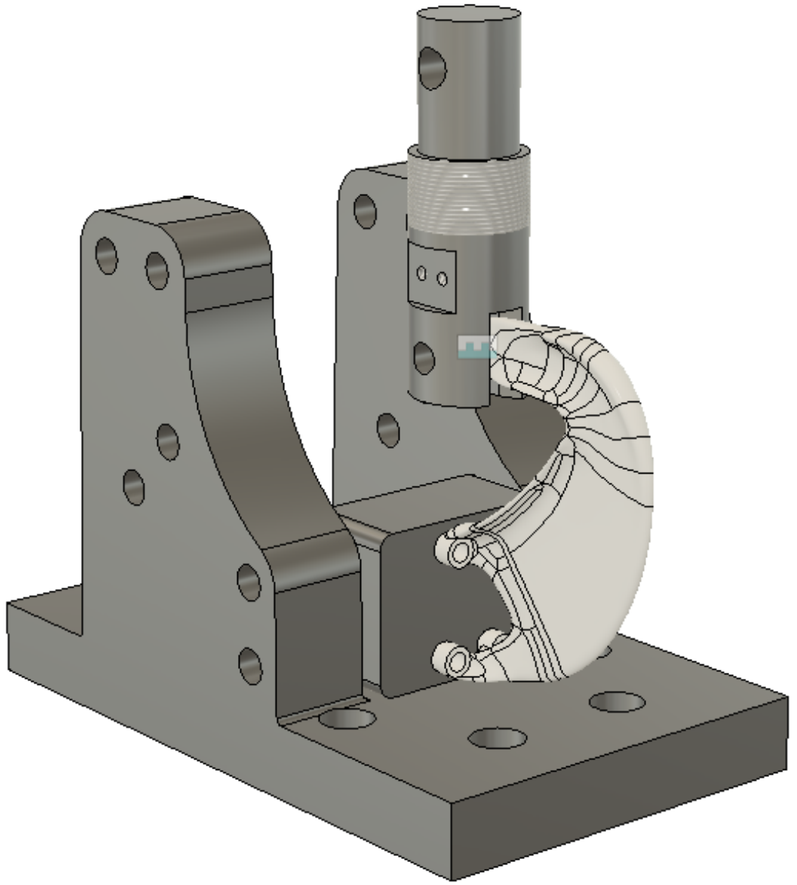
Explore the
Solution Space



Verify the Design
with Nastran /
Fusion 360

Our Challenge

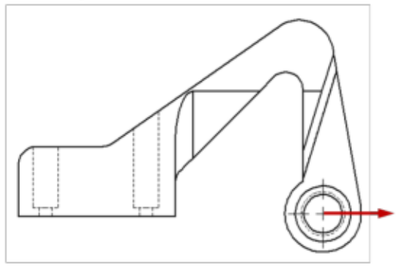
Prove Manufacture



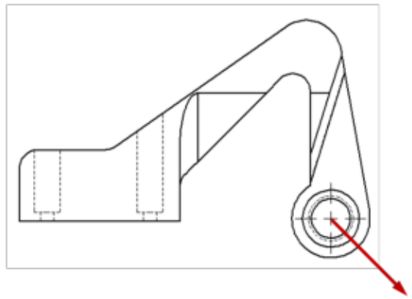
Validate by Physical Test

Adapting the Requirements

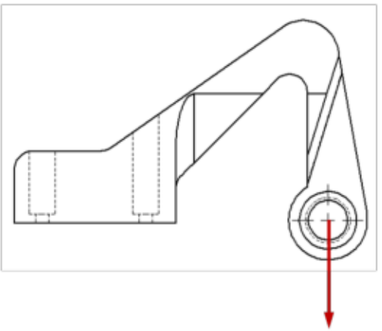
1. Material
   15-5PH Steel (F_y = 1000 MPa)→ 2014-T651 Aluminum (F_y = 447 MPa)
2. Loads
   Scale down by 447 MPa / 1000 MPa = 0.447



Case 1 (0°): 2485 N



Case 2 (45°): 3728 N



Case 3 (90°): 4971 N

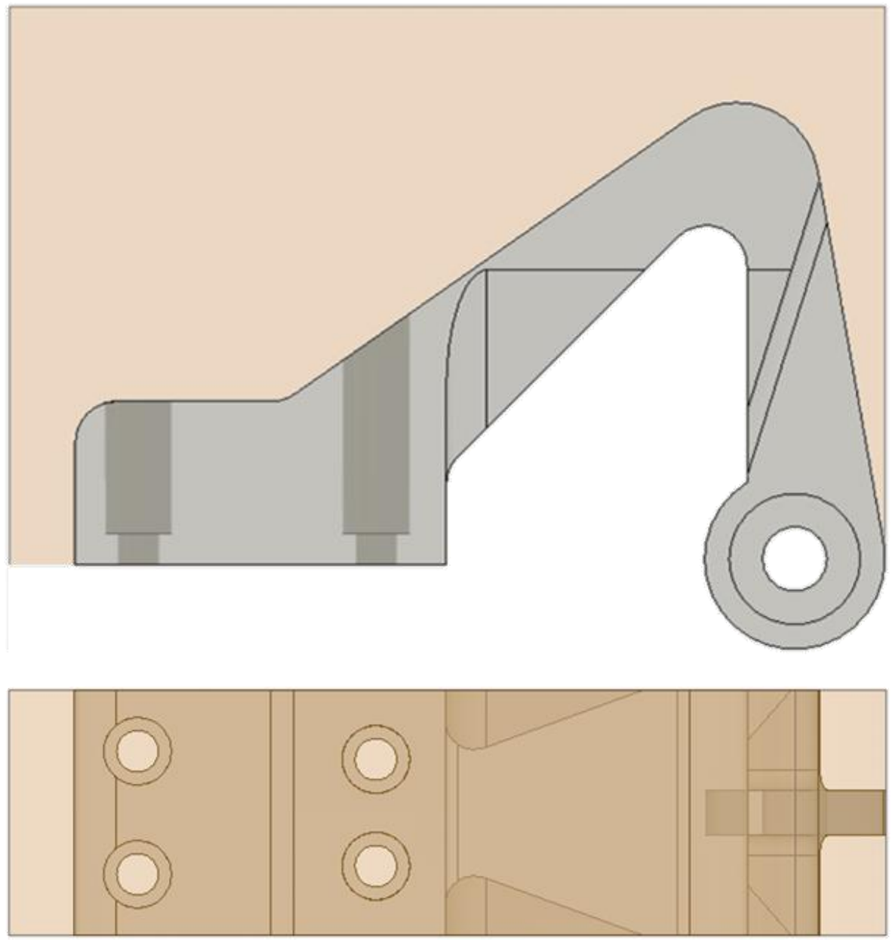
Adapting the Requirements

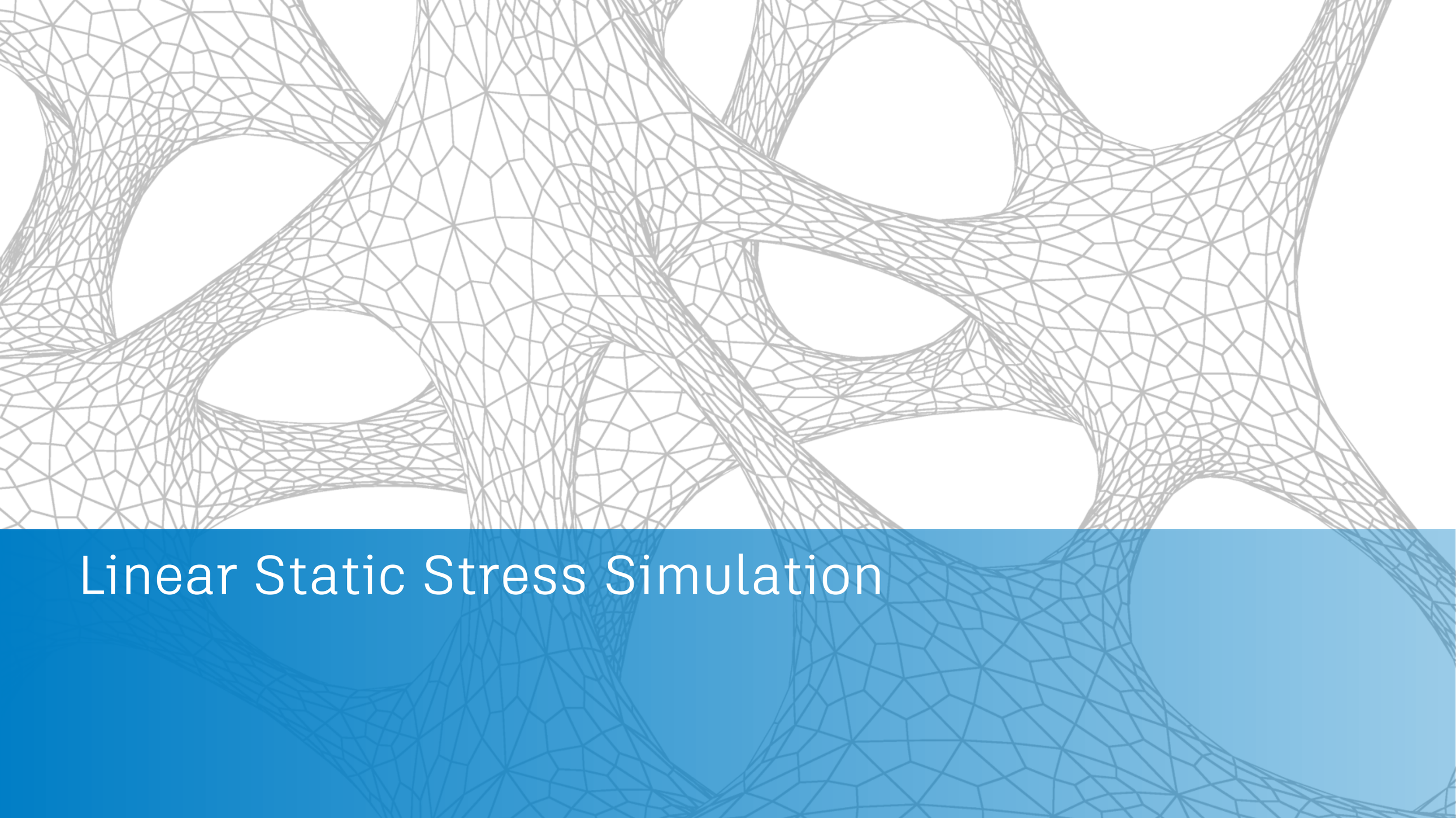
3. Space Envelope

   Increased envelope to allow for better design exploration

4. Spherical Bearing

   No spherical bearing; simple 10mm diameter hole instead

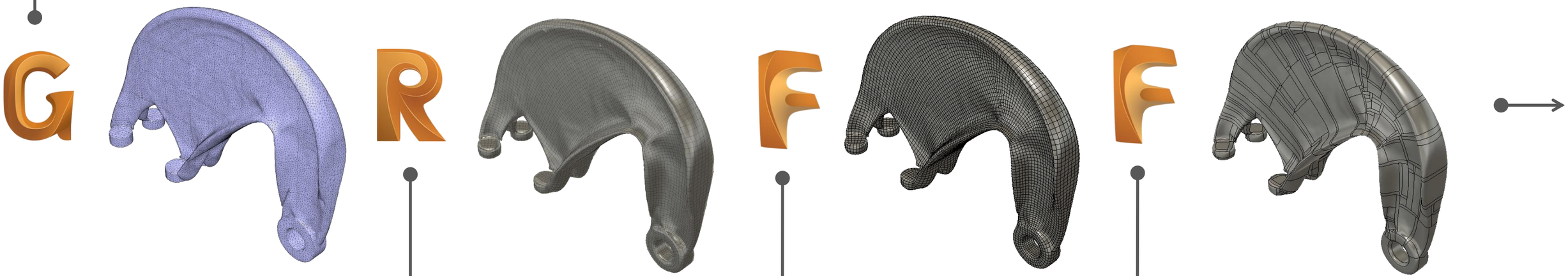




Linear Static Stress Simulation

Conversion to BREP (CAD format)

Triangle Surface Mesh
From AGD



STL

OBJ

T-Spline

BREP

Convert to Quad Mesh
Autodesk ReMake

Convert to T-Spline
Fusion 360

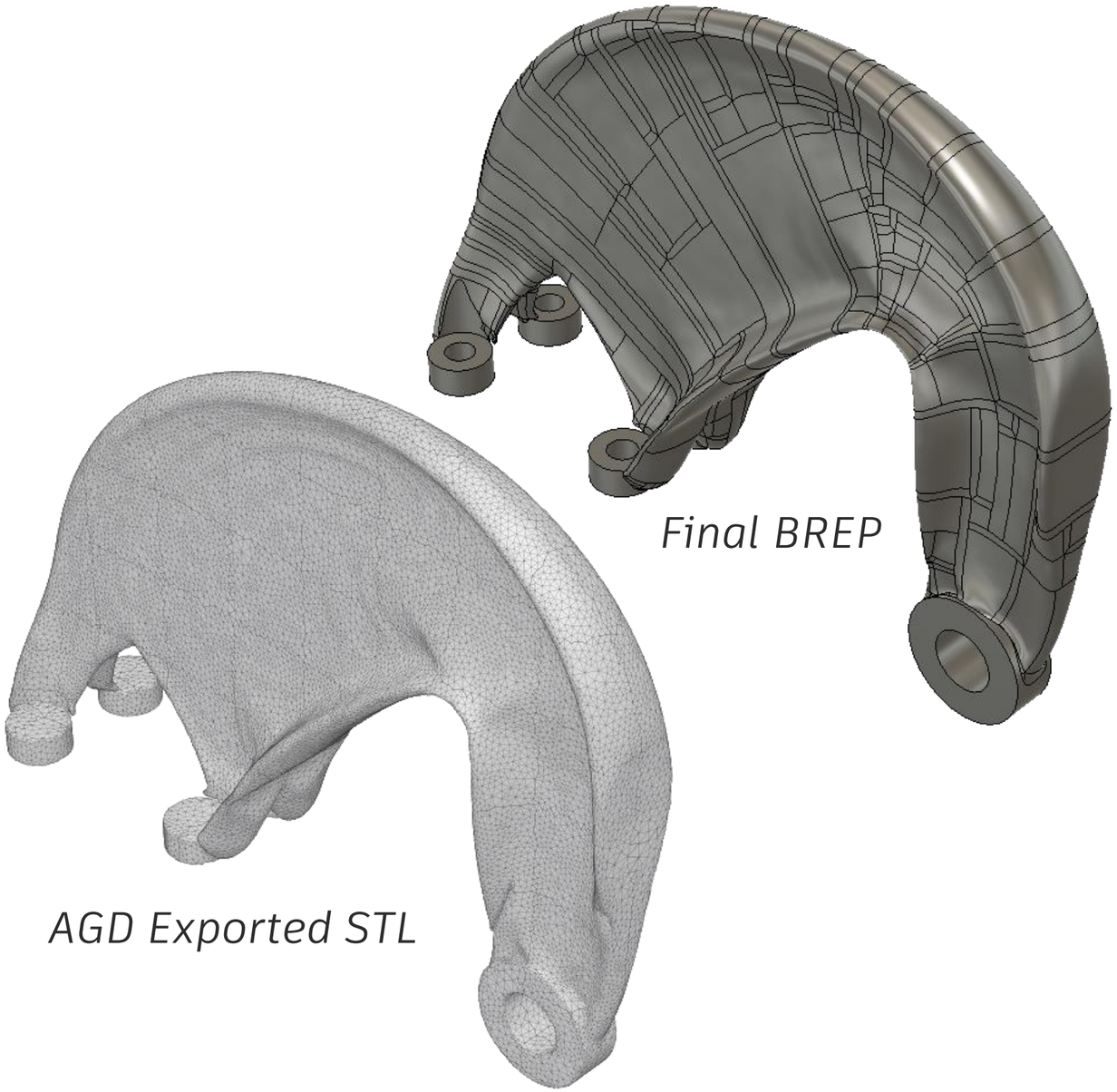
Convert to BREP
Fusion 360

Reinstate BREP Interfaces

Reinstate Interfaces
Fusion 360

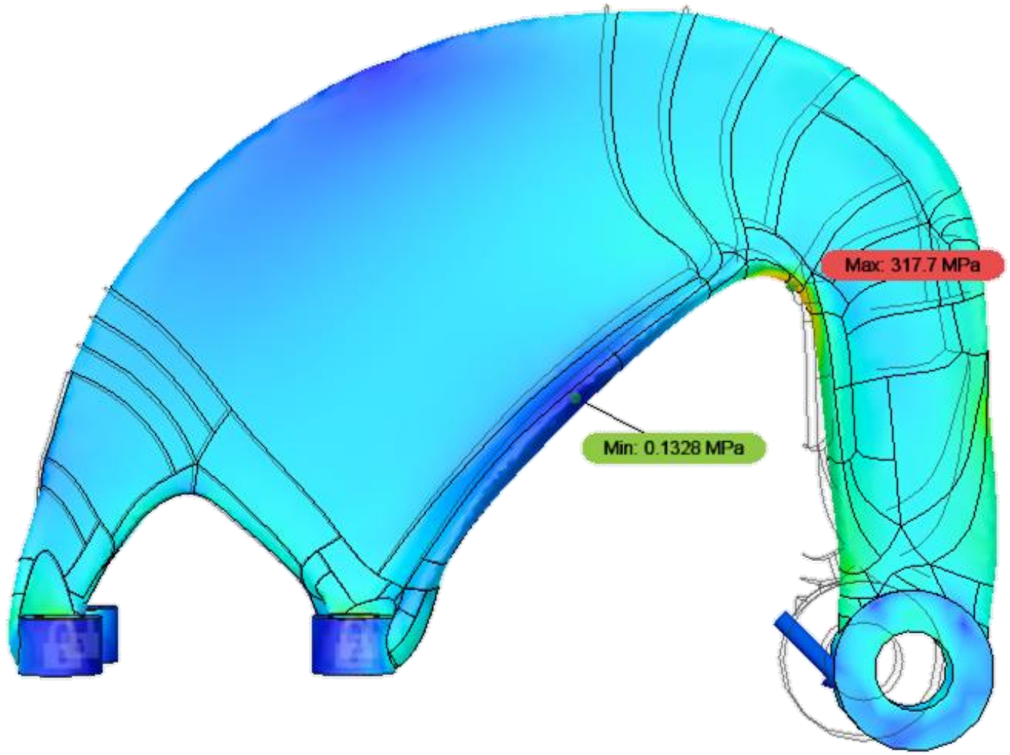
Ready for Verification Sim
Nastran / Fusion 360 Sim

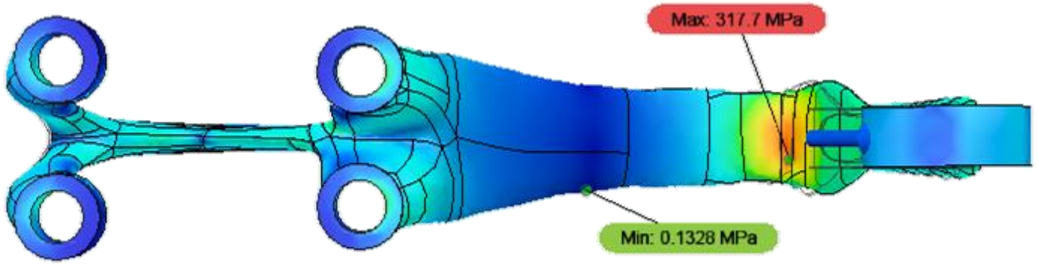
Why Verify?



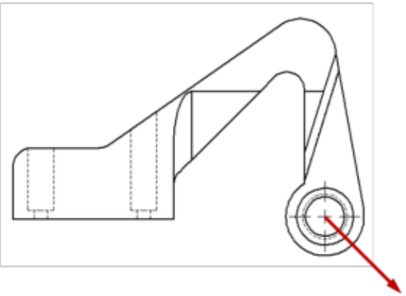
- Differences in interfaces & subtle differences in geometry
- Allowance for different kinds of simulation
  - Non-linear
  - Buckling
  - Thermal

Linear Verification: Case 2





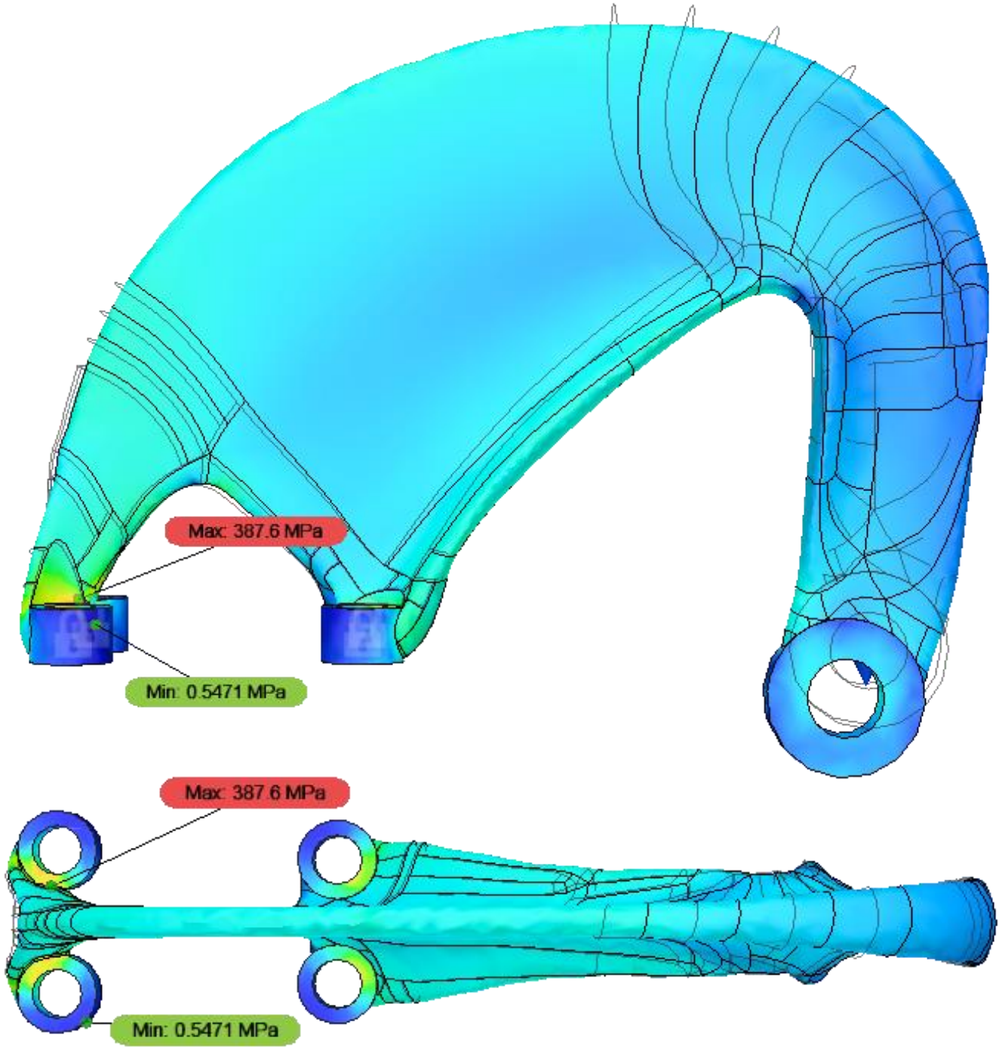
Local zone with SF≤1



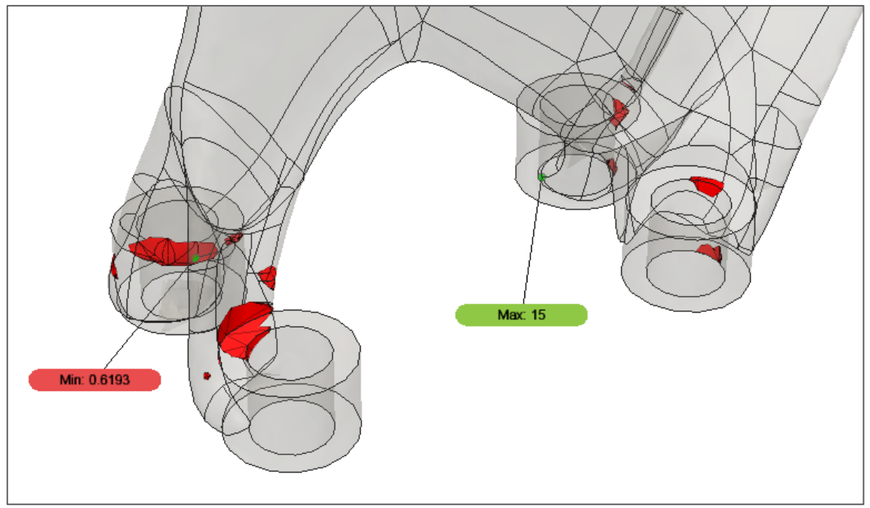
Case 2 (45°): 3728 N

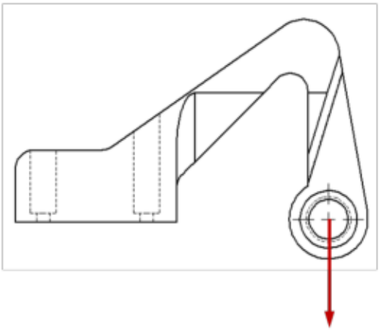
- Verification against nominal yield strength (240MPa)
- Localized region of yield

Linear Verification: Case 3



Local zones with SF≤1





Case 3 (90°): 4971 N

- Sharp edges & local constraints cause stress rise
- Some material was removed to allow access to the fasteners

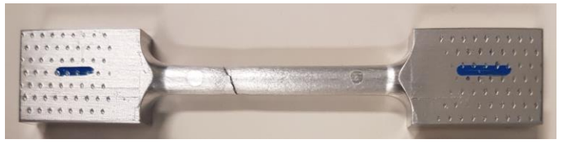
Tips for Linear Static Verification

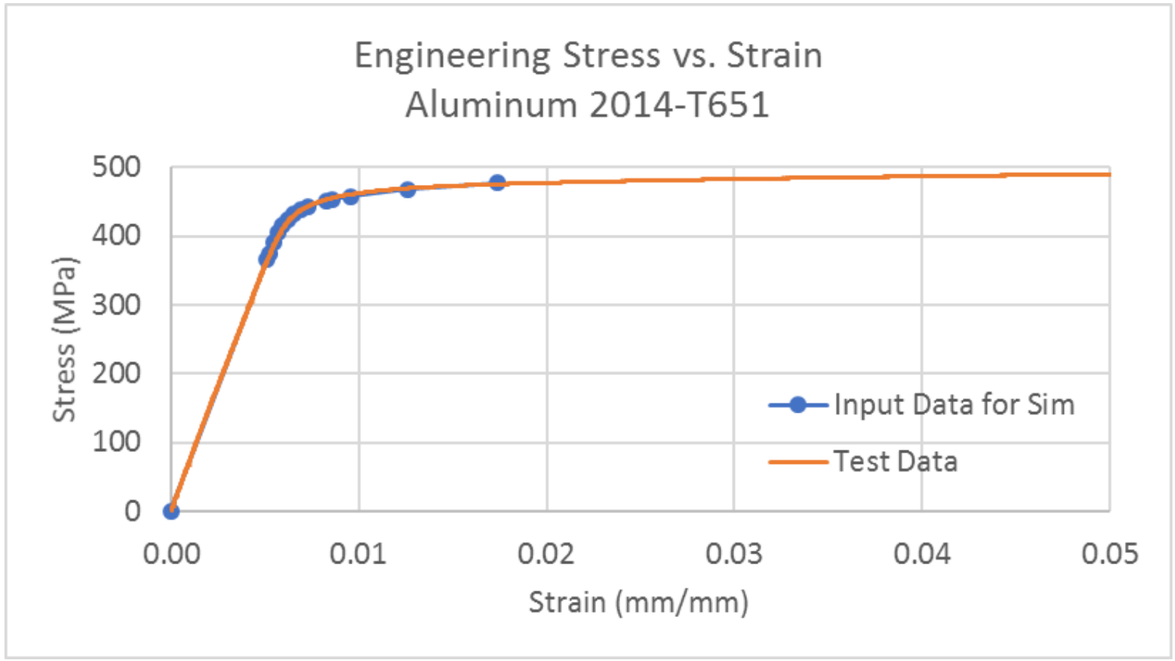
- Remember linear static removes any stress redistribution from non-proportional stress-strain behaviour
- For in-service parts:
  - Consider increasing the size of the attaching interfaces
  - For *zero* yield, consider using a higher safety factor in AGD
  - **Ensure that material properties accurately represent the as-built material**

Non-linear Static Stress Simulation

Materials

Subtractive

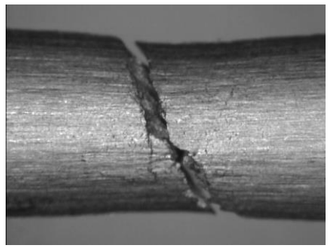




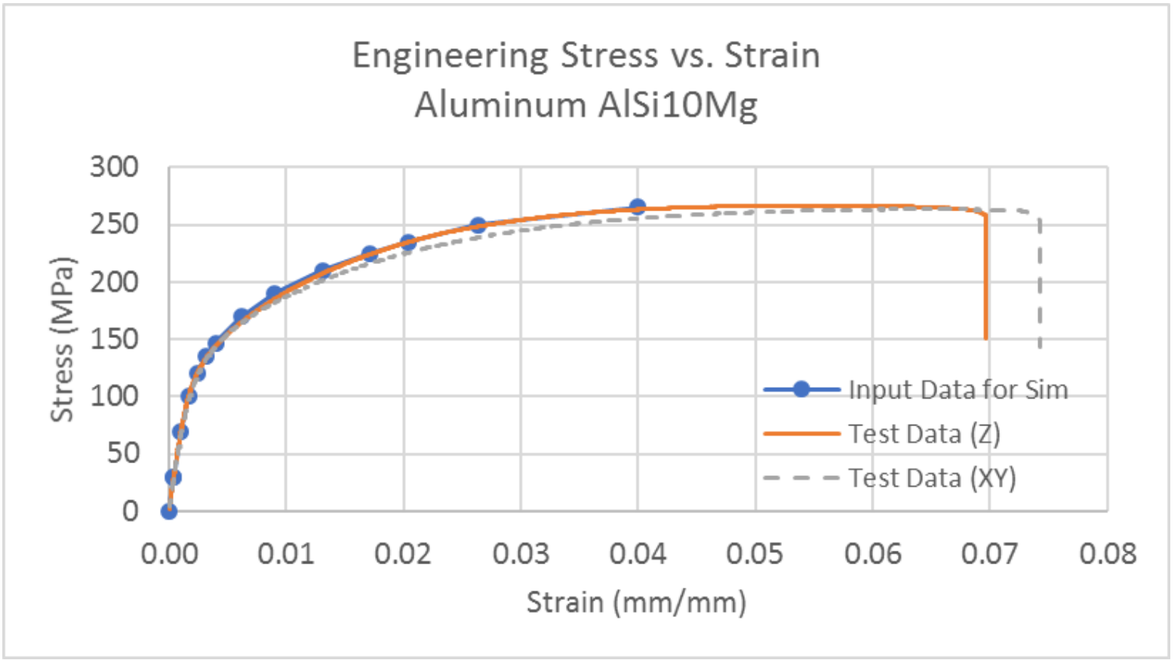
E = 72000 MPa

$f_{0.2}$ = 451 MPa

f_u = 477 MPa



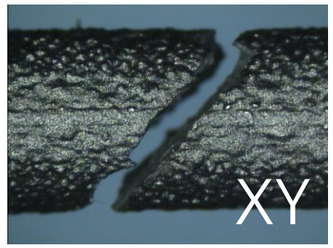
Additive

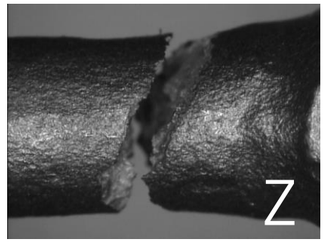


E = 75000 MPa

$f_{0.2}$ = 147 MPa

f_u = 265 MPa





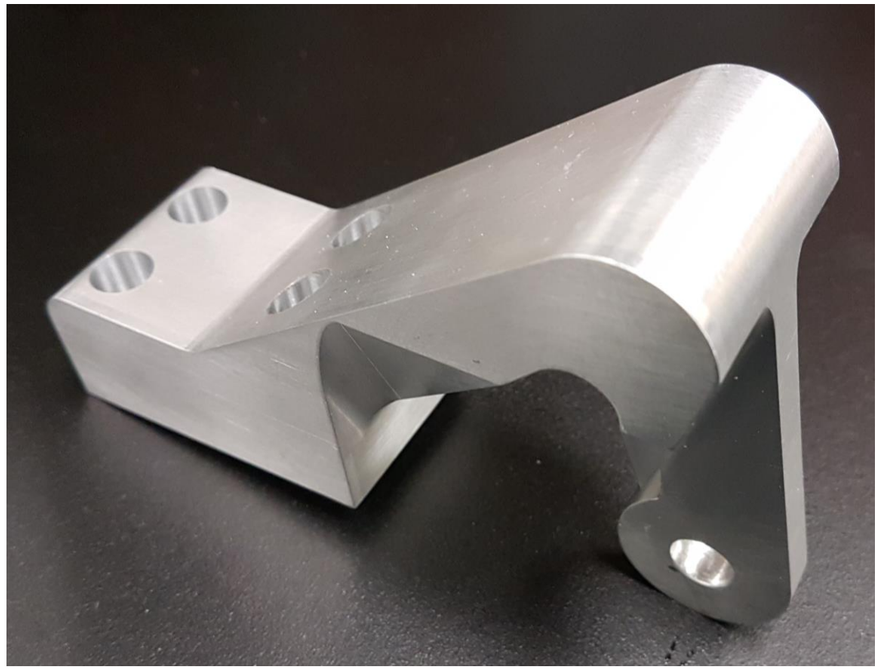
Material Properties Caution!

- Tested properties will deviate from reference ‘data sheet’ properties
  - **Especially in case of Additive Materials**
- Be aware of differences due to:
  - Printing orientation (AM materials)
  - Grain direction (wrought materials)
  - Heat treatments
- Use conservative properties when performing verification simulations (i.e. use a reasonable safety factor) OR…
- Get sufficient material data via test (e.g., dog bone specimens)

Build and Test

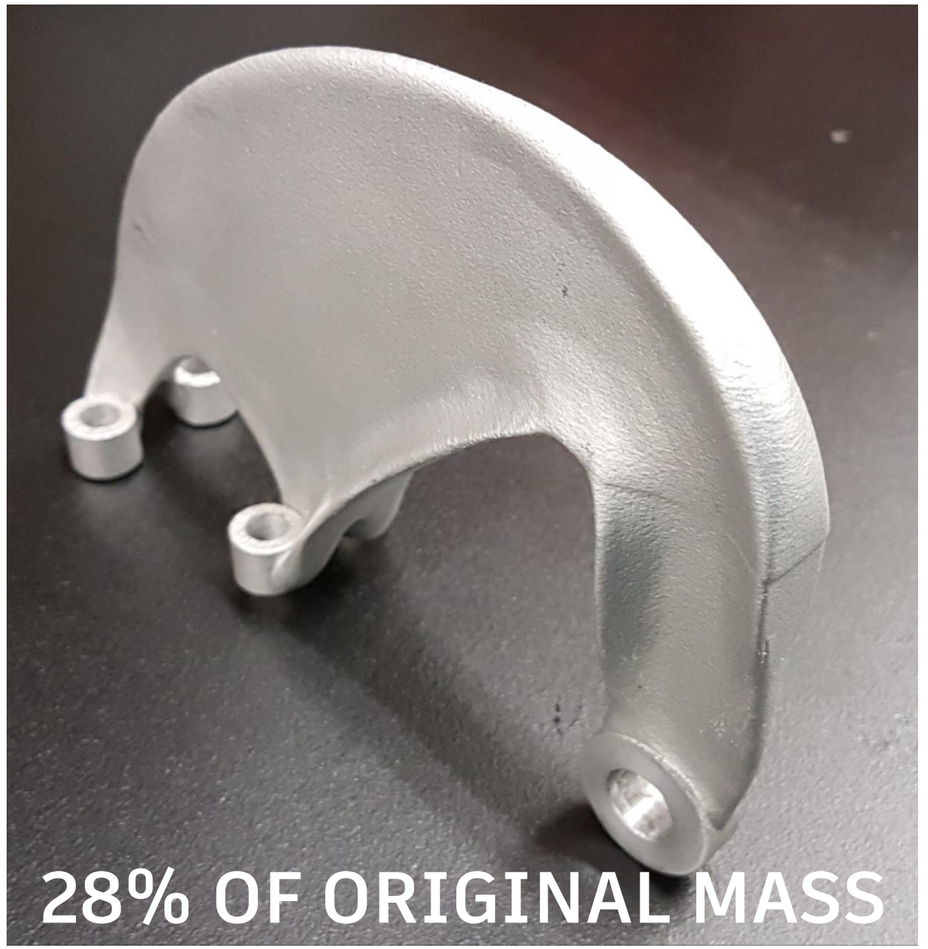
MAKE!

Traditional Design
Machined (Subtractive Manufacturing)



302.8 grams

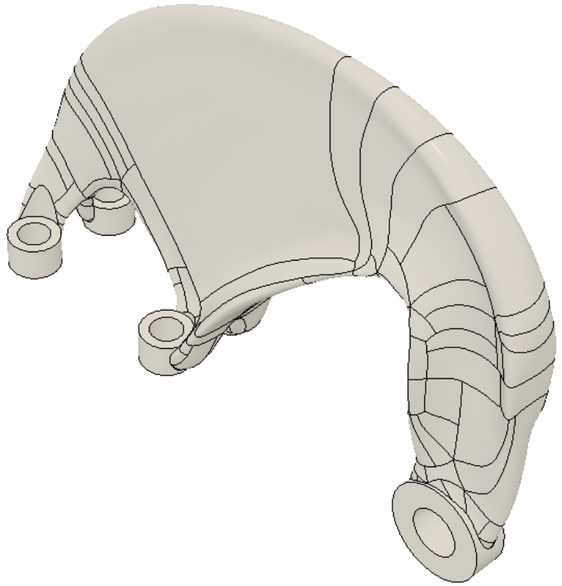
Generative Design
Additive Manufacturing

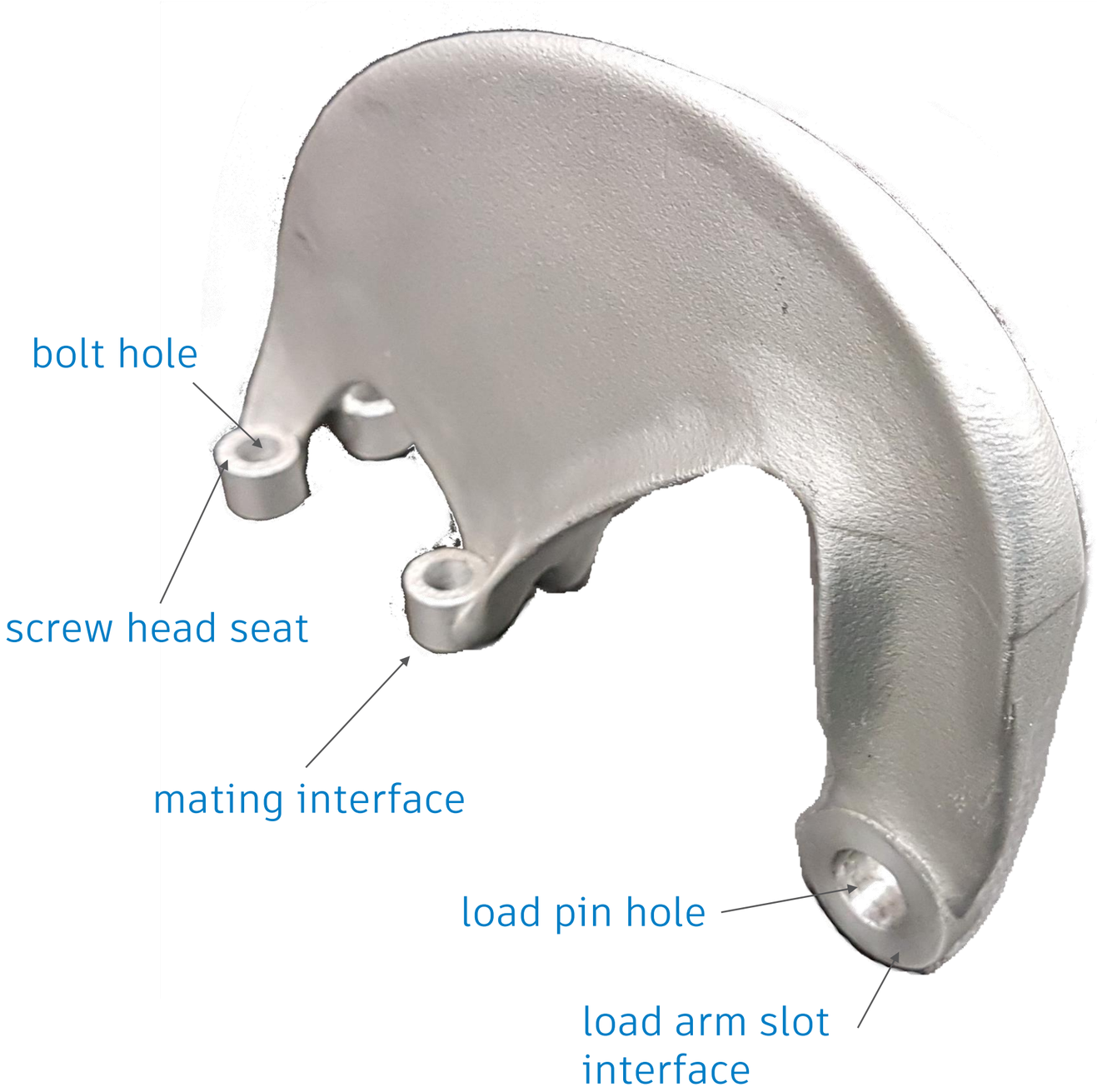


83.7 grams

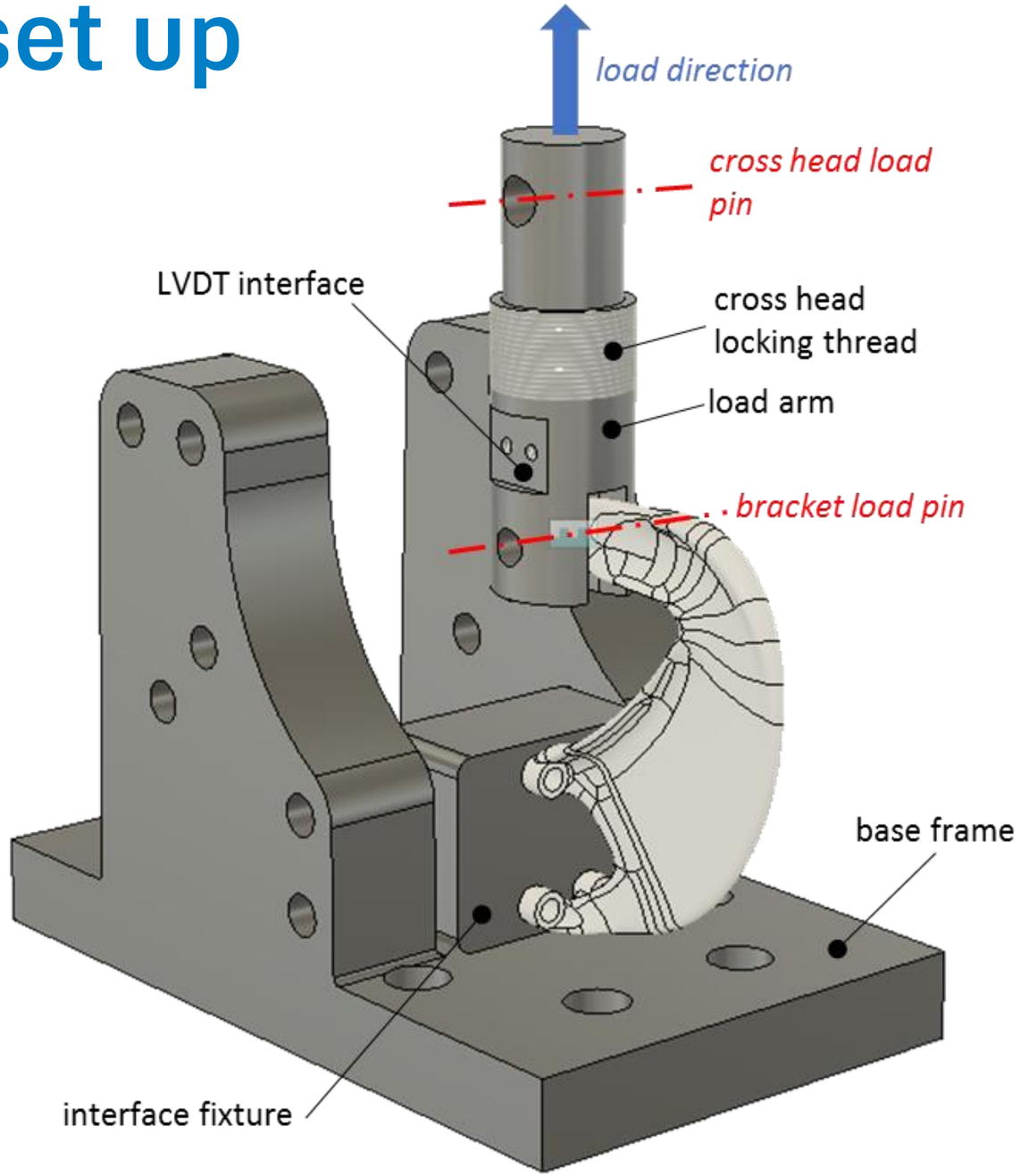
Finishing AM Parts

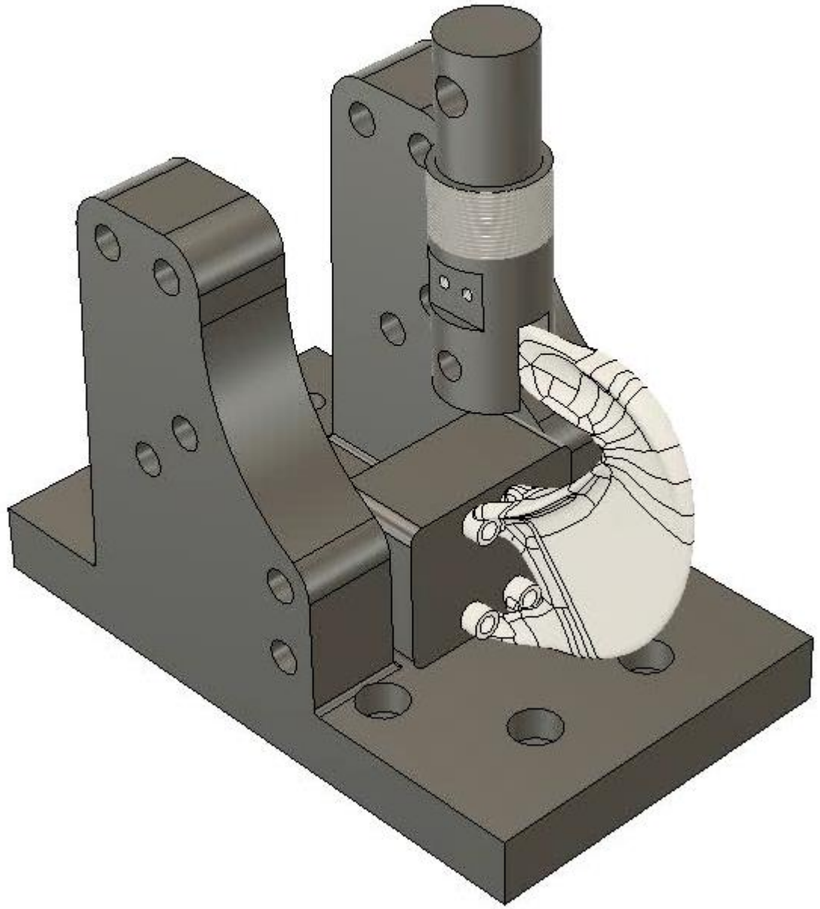
- Need machining on all important interfaces
- Anything where a higher tolerance dimension is required



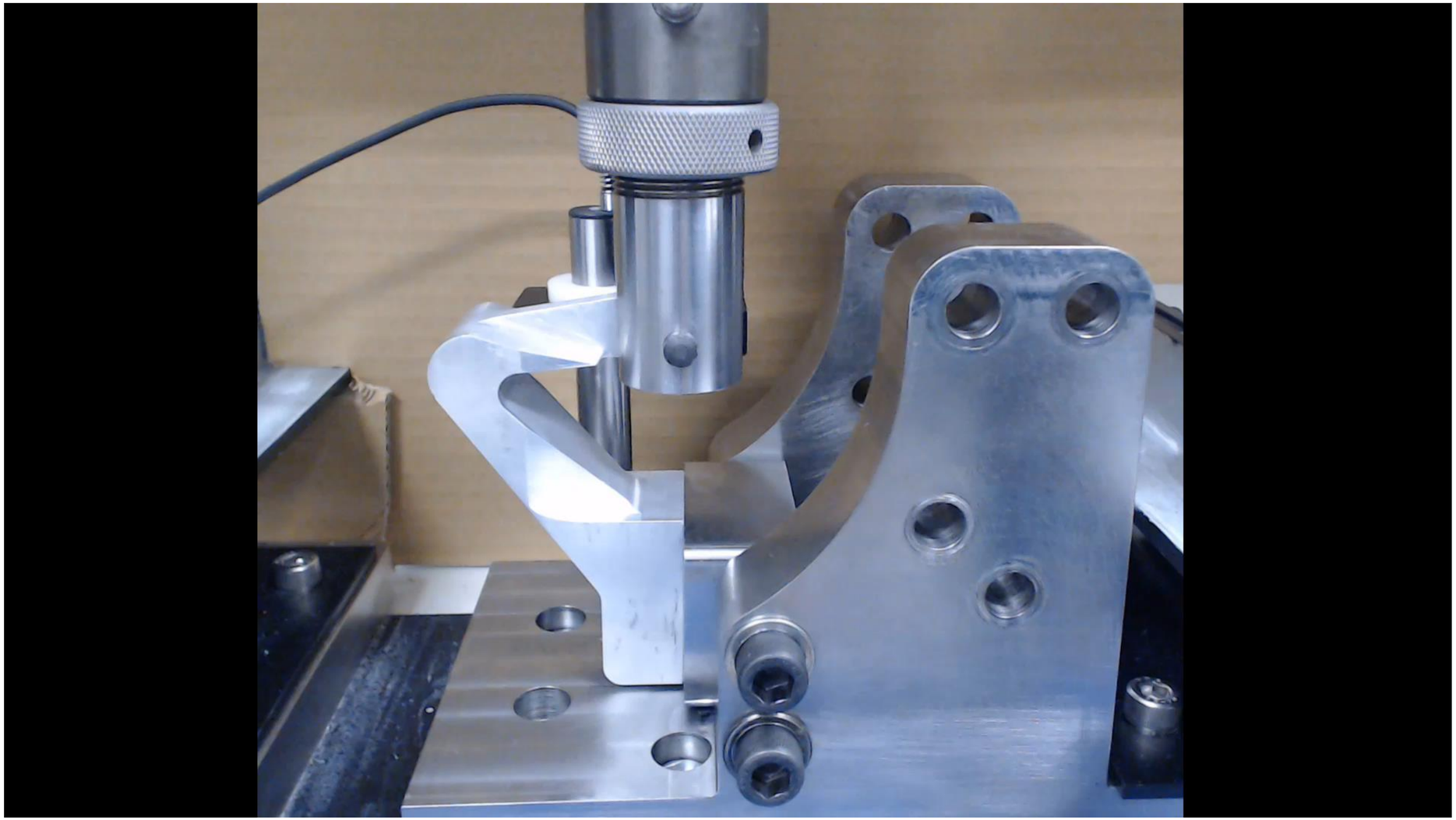


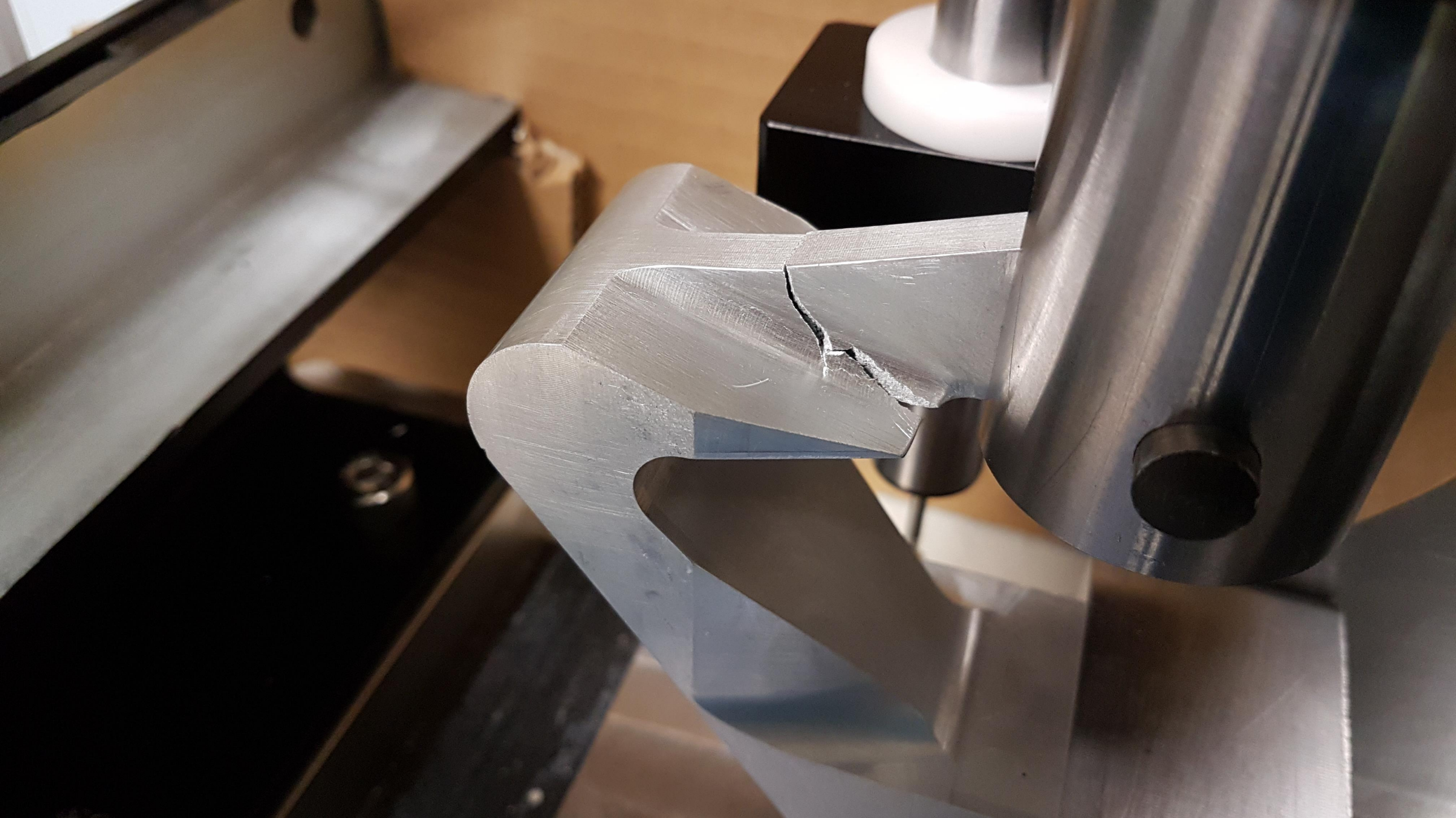
Test set up


load direction
cross head load pin
LVDT interface
cross head locking thread
load arm
bracket load pin
base frame
interface fixture

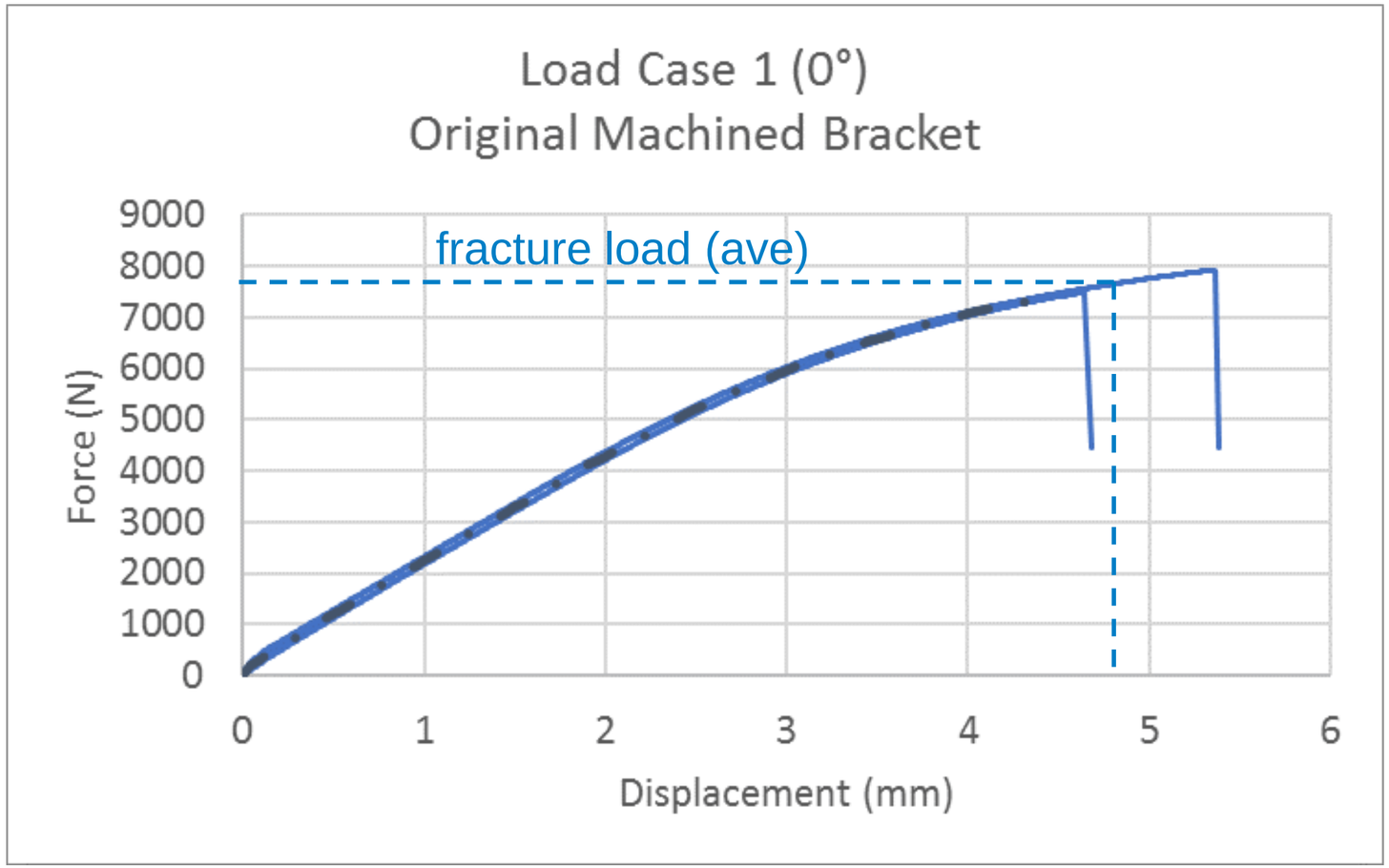


Video: Original Machined Bracket Load Case 1 Test to Failure





Original Machined: Force-displacement



- **Poor elongation to failure (~4.8mm)**
- Load at fracture ~7700 N
- Material ultimate strength

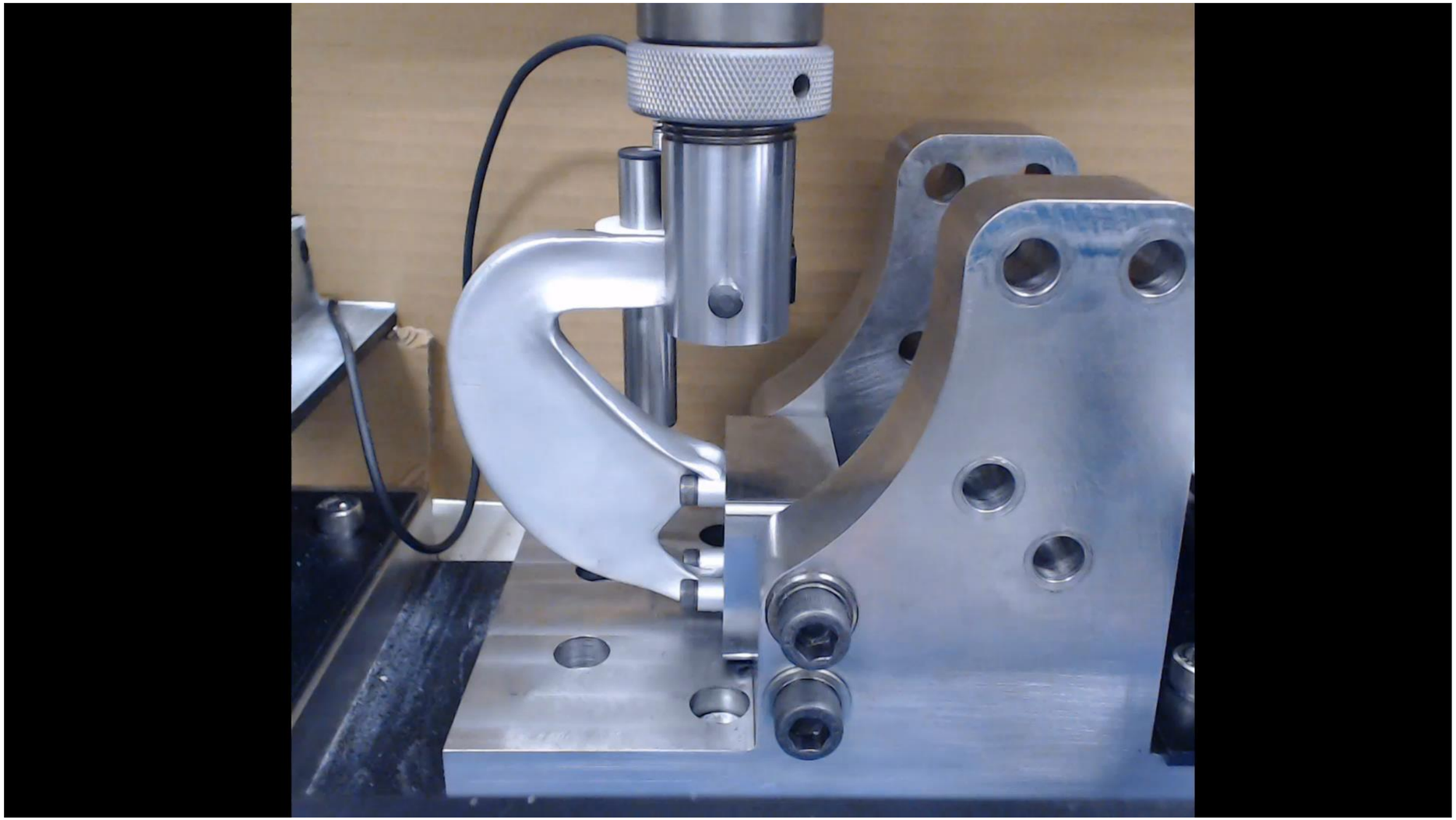
  F_u = 451 MPa
- **Normalized load at fracture ~8537 N**

  (normalized to F_u = 500 MPa)

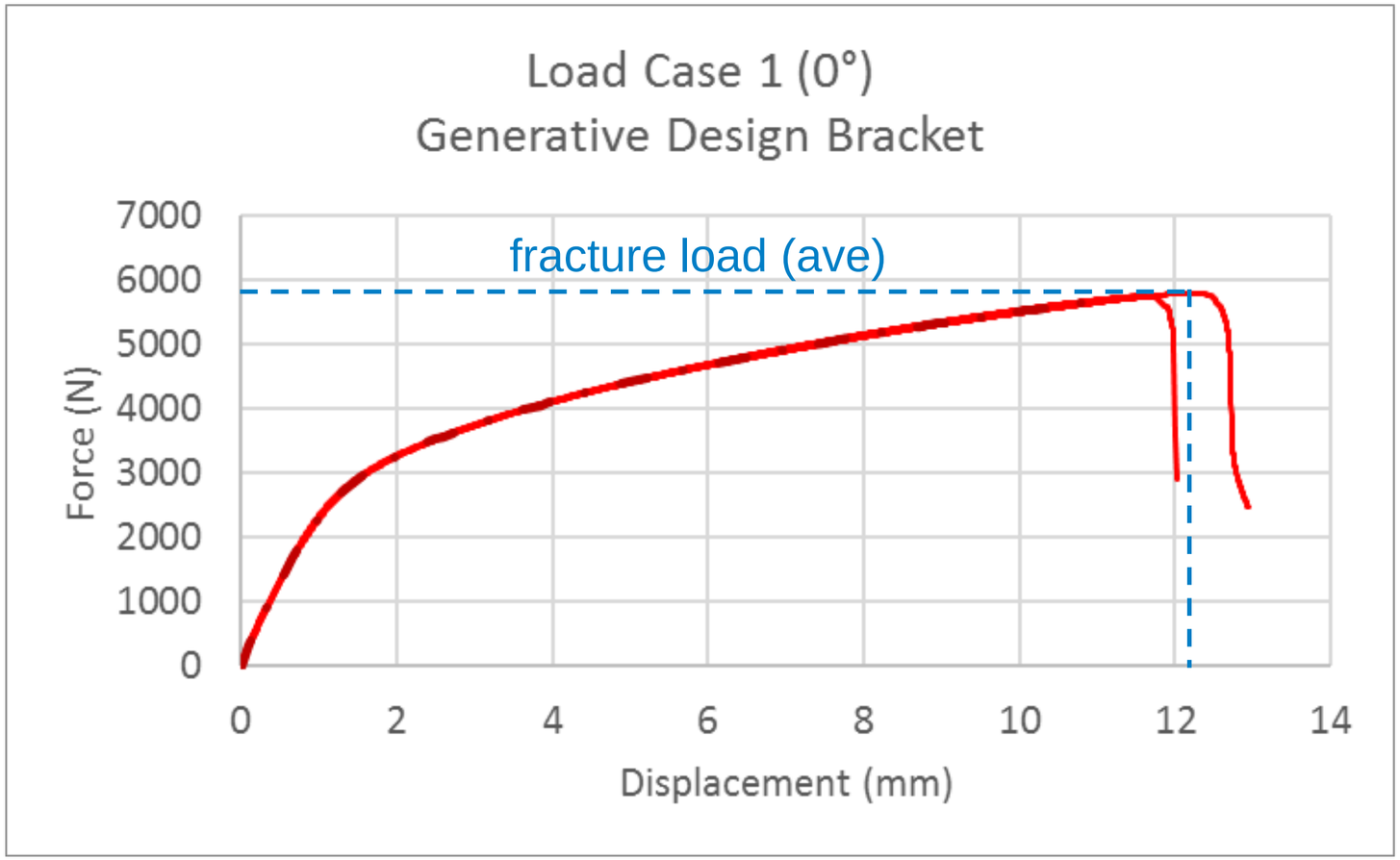
  I.e., 7700 N x 500 MPa / 471 MPa

  =8537 N

Video: Generative Design Bracket Load Case 1 Test to Failure



Generative Design: Force-displacement



- **Good elongation to failure (~12.2 mm)**
- Load at fracture ~5600 N
- Material ultimate strength

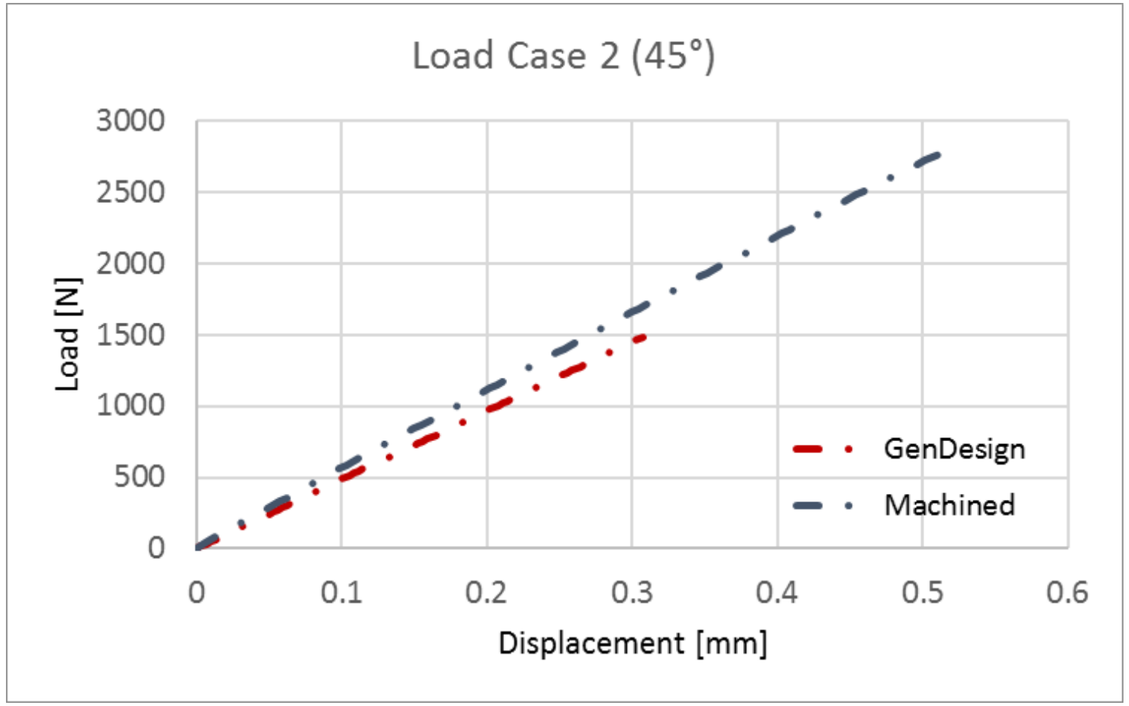
  F_u = 265 MPa
- **Normalized load at fracture ~10566 N**

  (normalized to F_u = 500 MPa)

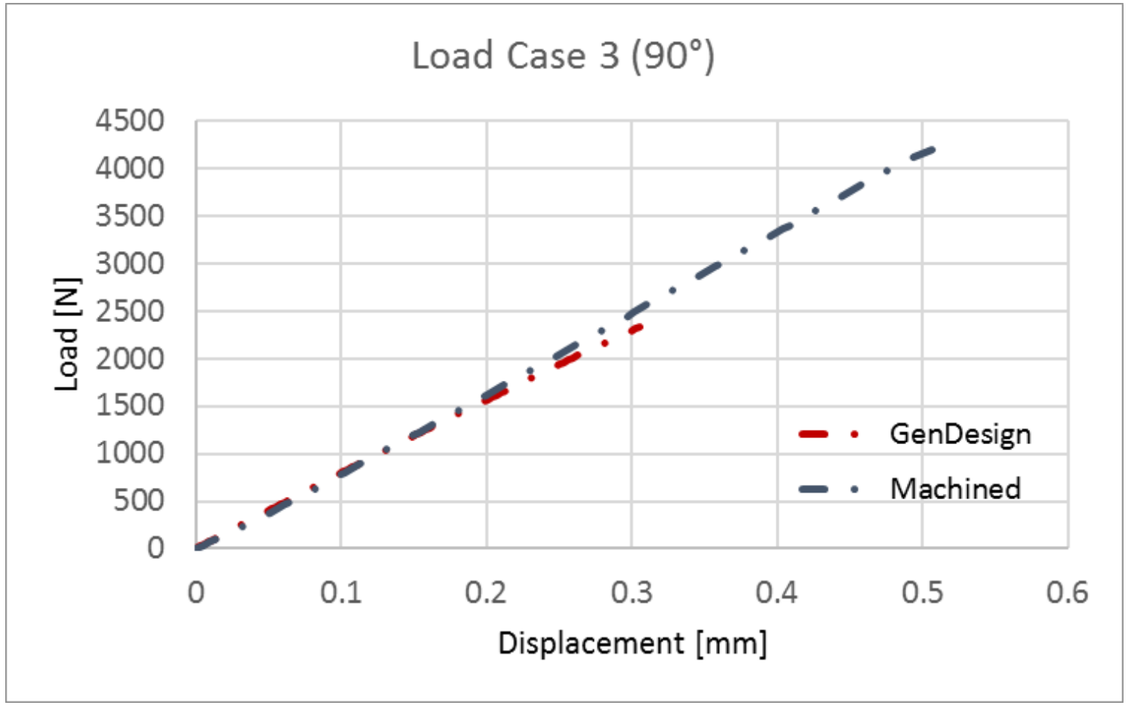
  I.e., 5600 N x 500 MPa / 265 MPa =10566 N

24% higher than original

Original Machined vs. Generative Design: Cases 2 & 3



Slight reduction in linear stiffness ~10%

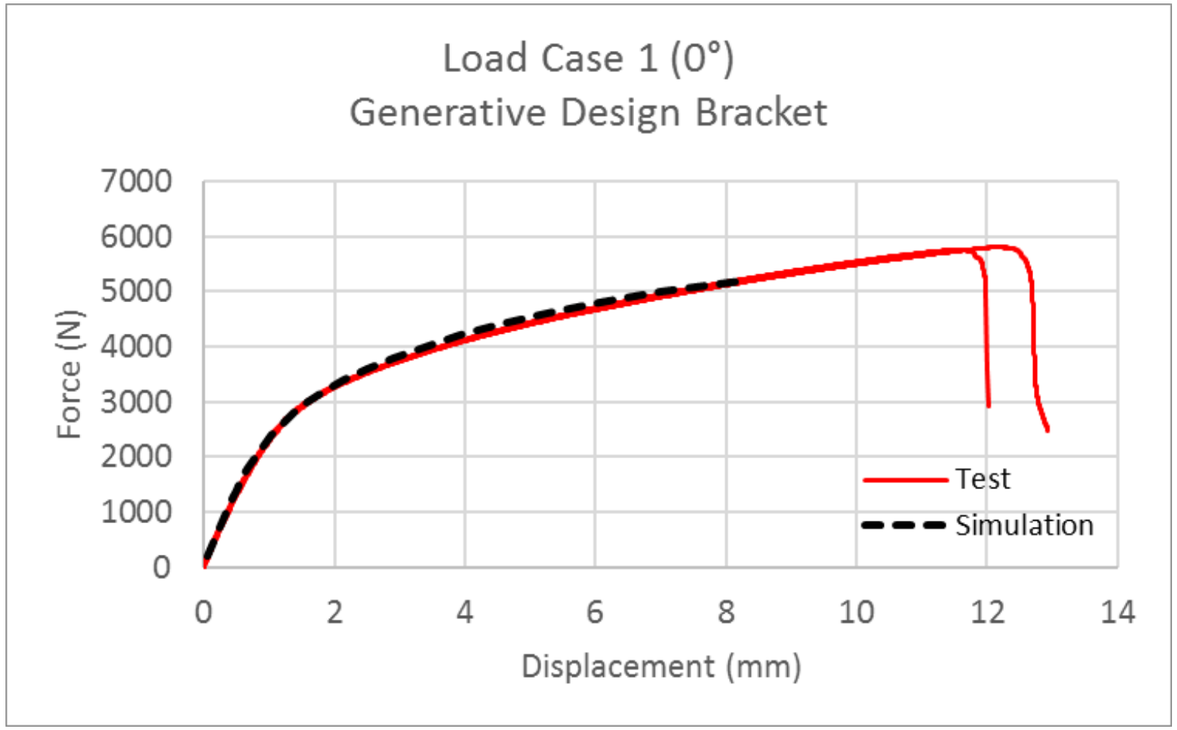


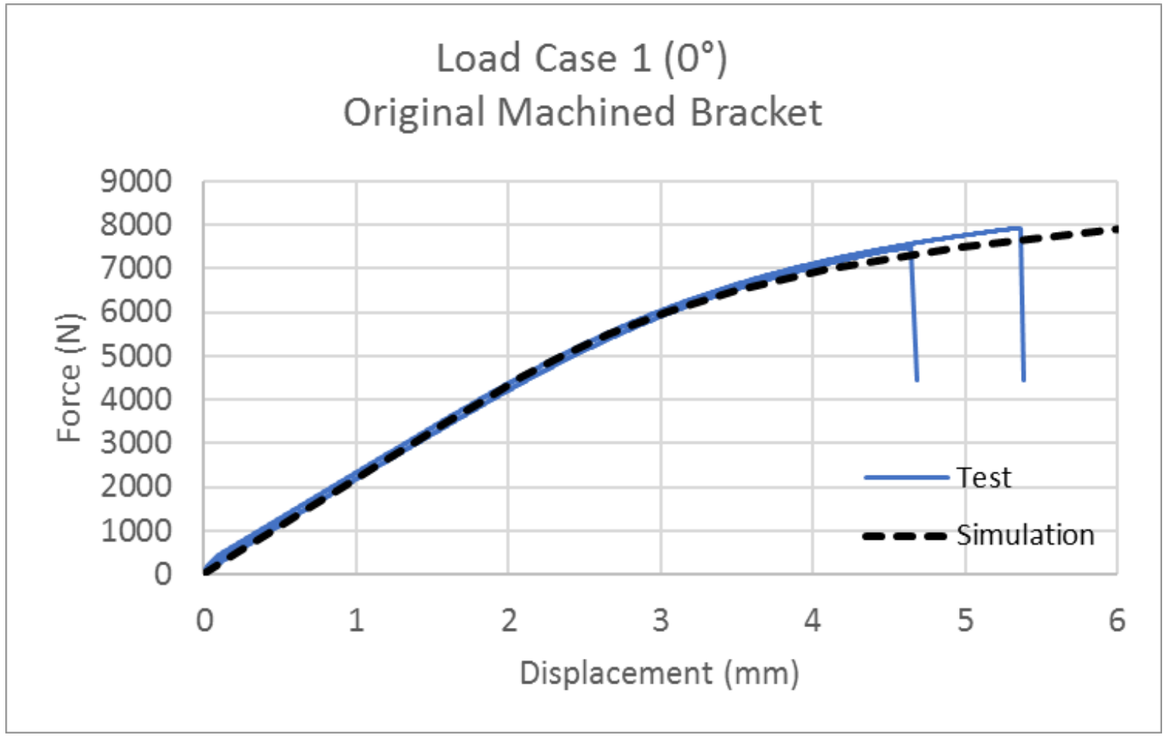
Equal linear stiffness

Correlation of Test Results

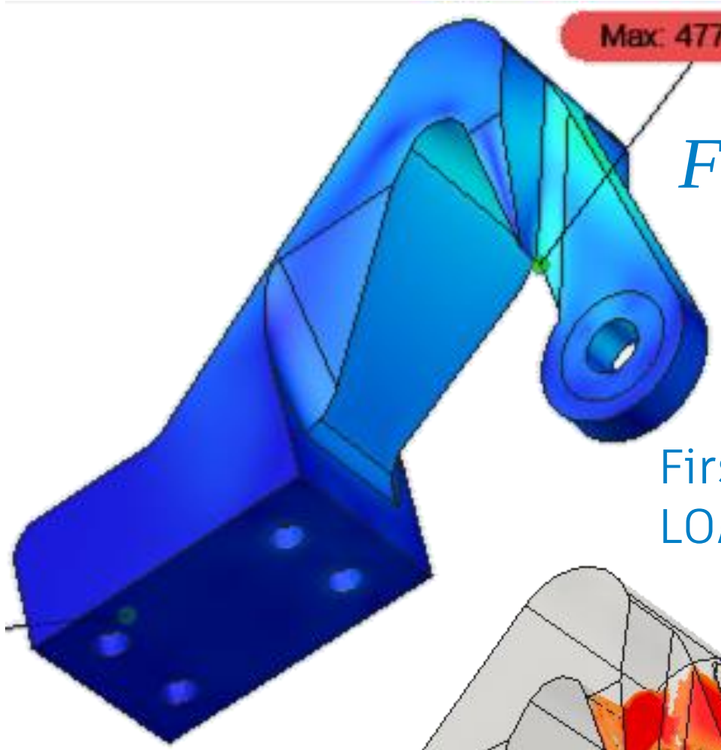
Correlation of Sim

- Force-displacement measures at load pin location
- Non-linear Static Stress solution does not predict fracture



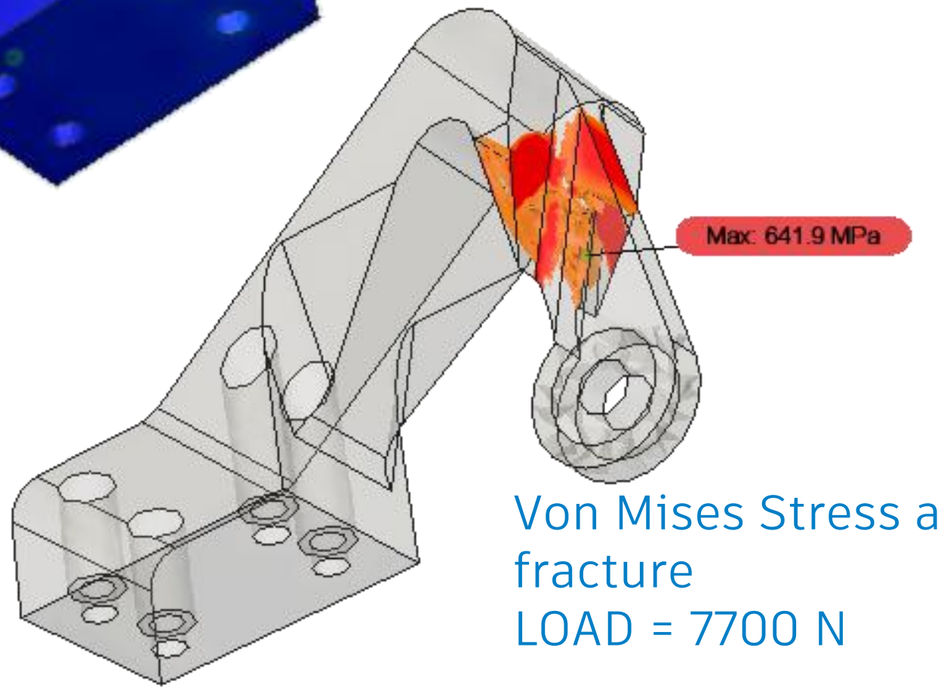


Failure Location: Original Bracket



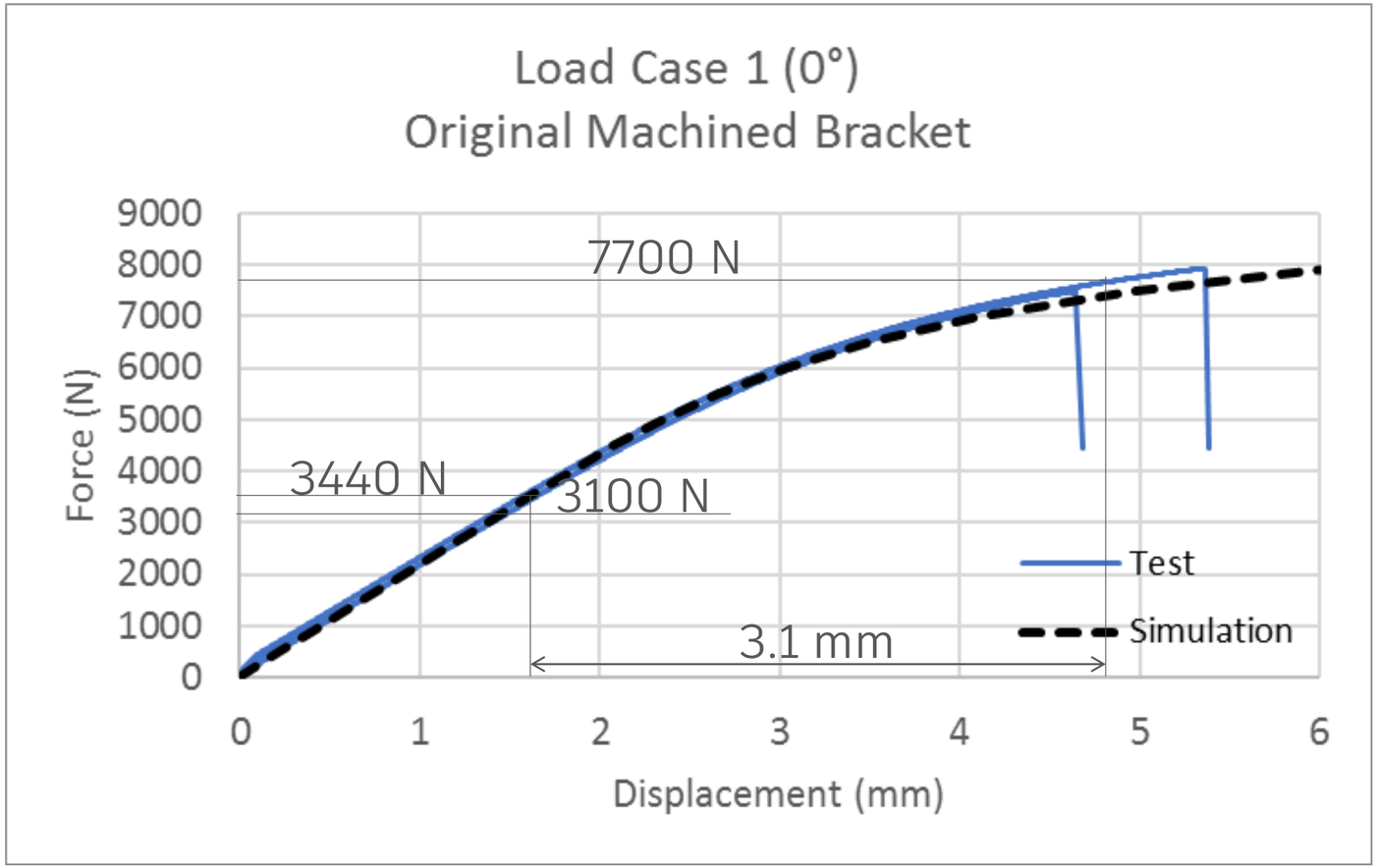
F_u = 477 MPa

First exceedance of F_u
LOAD = 3440 N



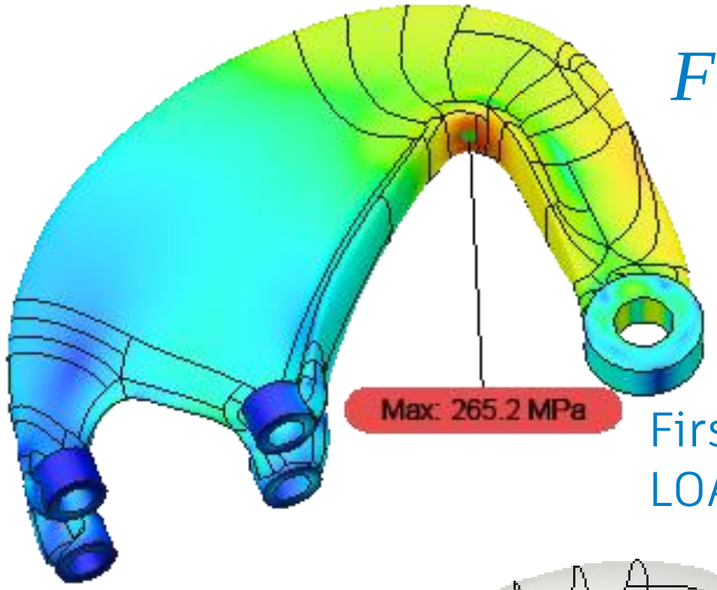
Von Mises Stress at final fracture
LOAD = 7700 N

Key Results: Original Bracket



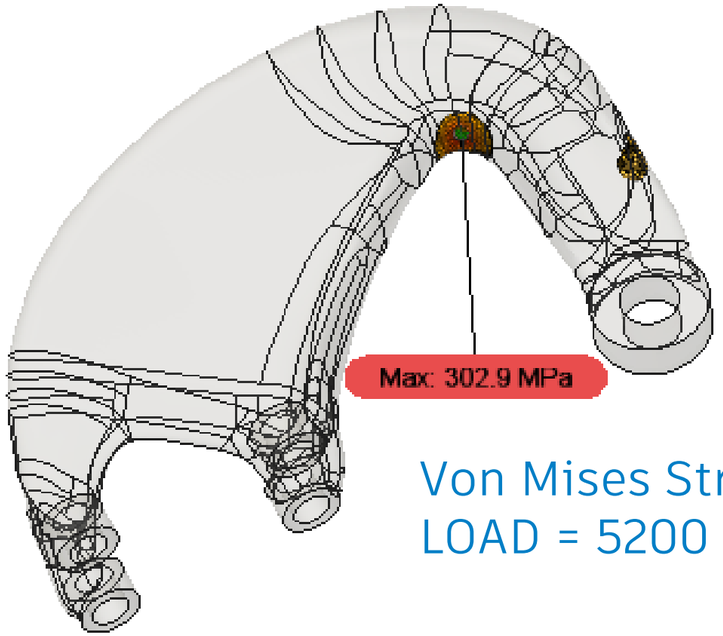
- Onset of plasticity: 3100 N
- Initiation of crack: 3440 N
- Final fracture: 7700 N
- 3.1mm from initial crack to final fracture

Failure Location: GD Bracket



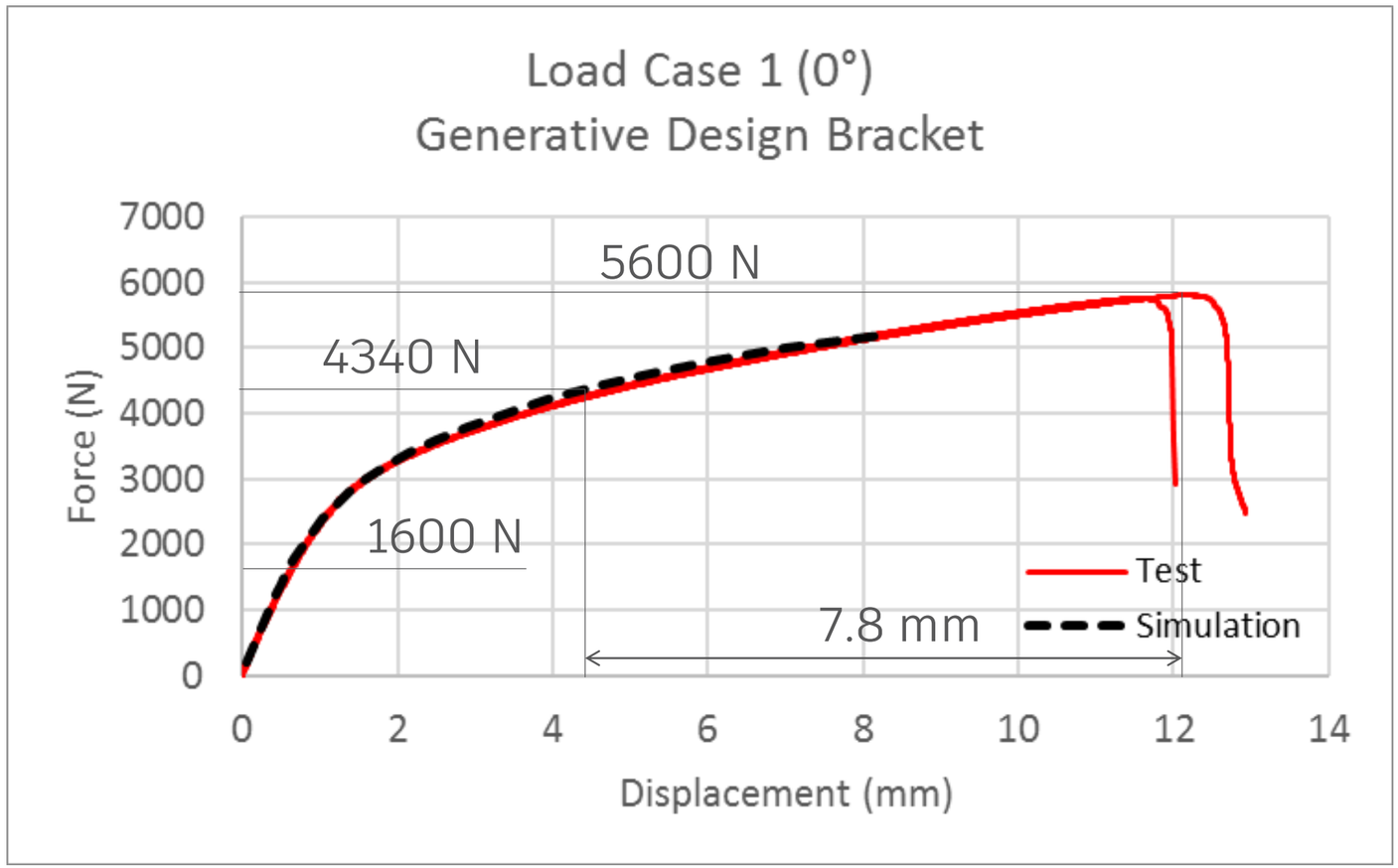
F_u = 265 MPa

First exceedance of F_u
LOAD = 4340 N



Von Mises Stress at final load
LOAD = 5200 N

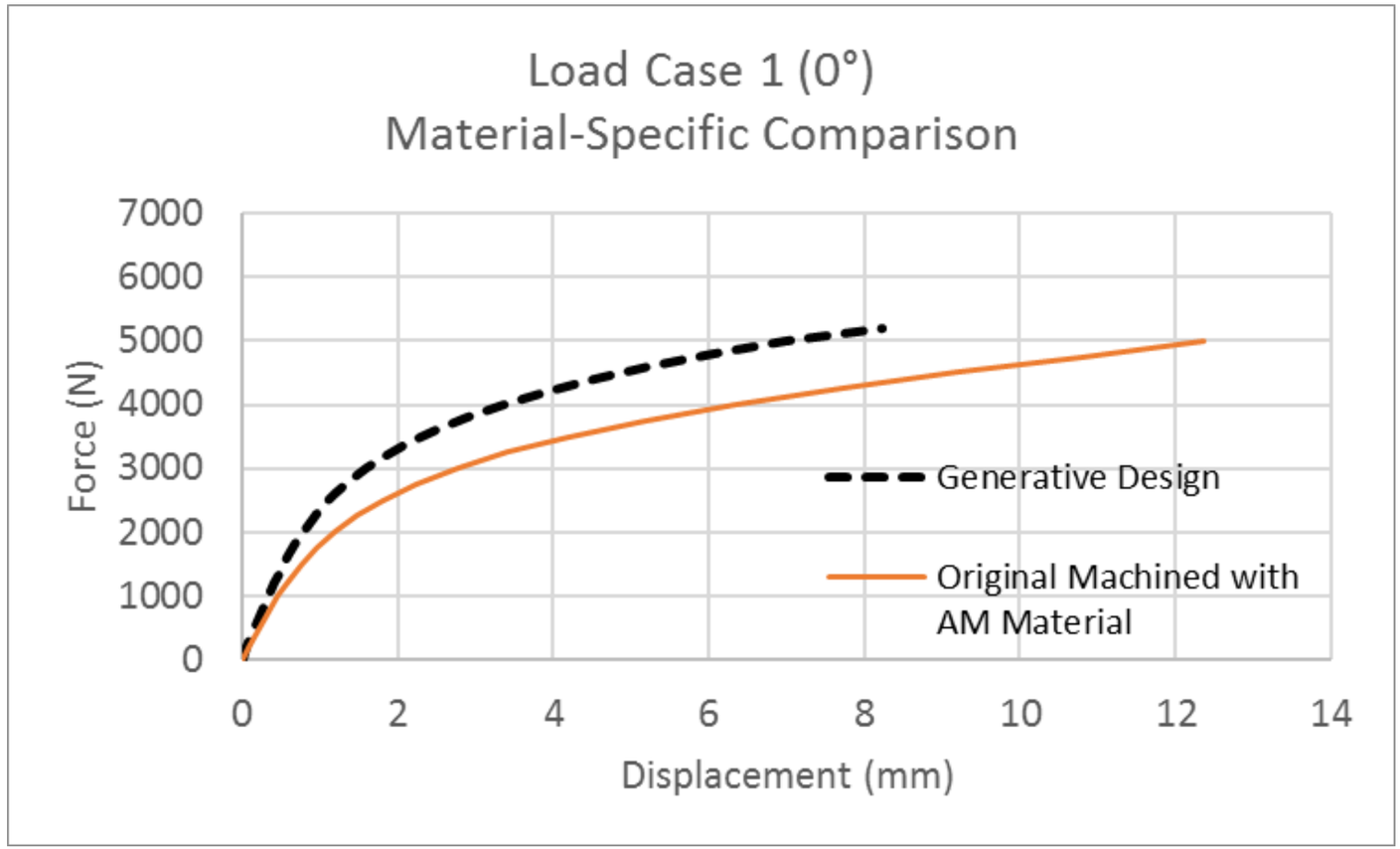
Key Results: GD Bracket

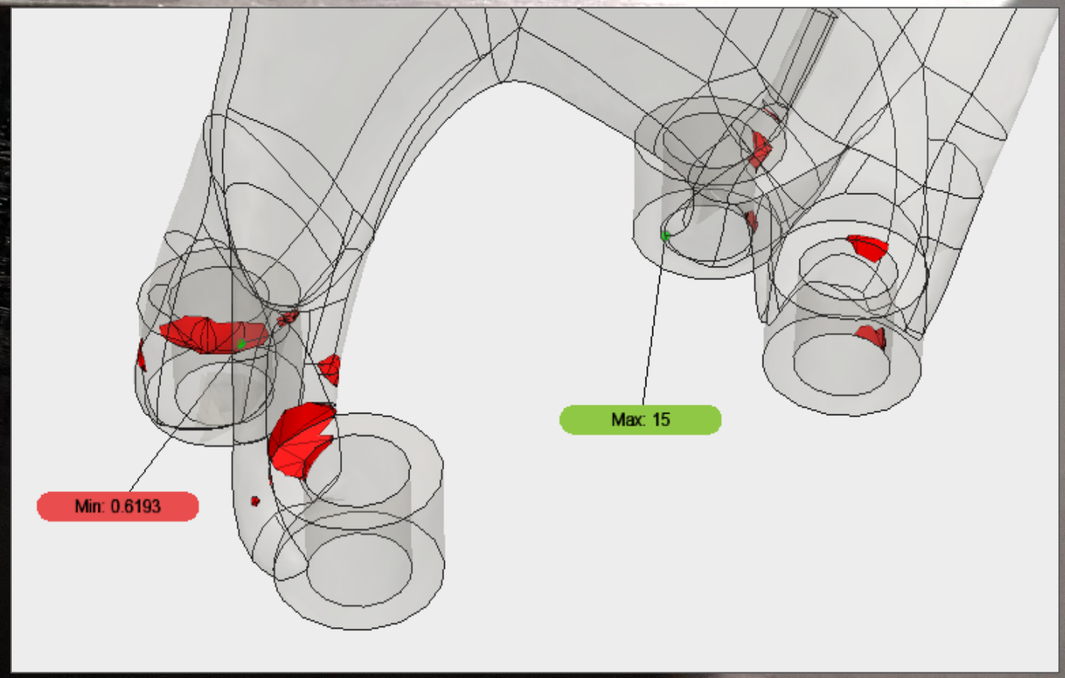


- Onset of plasticity: 1600 N *(-48%)*
- Initiation of crack: 4340 N *(+26%)*
- Final fracture: 5600 N *(-27%)*
- 7.8mm from initial crack to final fracture *(+152%)*

Take Material Out of The Equation!

- Simulate original bracket with AM material
  - Provides measure of ‘shape efficiency’
- GD bracket is superior against all metrics
- Original begins to yield at 1175N
- GD begins yield at 1600N
  - 36% improvement




Min: 0.6193
Max: 15

Conclusions

- Learned how to rapidly generate many designs with AGD
- Learned how to verify a design with Fusion 360 Sim
- Original bracket used much stronger material
- GD bracket had superior shape efficiency and ductility
  - 36% higher load for plasticity (like-for-like material)
  - 24% improvement in normalized failure load
  - 28% of original mass
- For in-service usage, AM material should be higher quality with properties closer to machined Aluminum

AUTODESK®

Make anything.