



**CAESS**

Center for Advanced Engineering Software and Simulations

PTC® PartnerAdvantage

SILVER

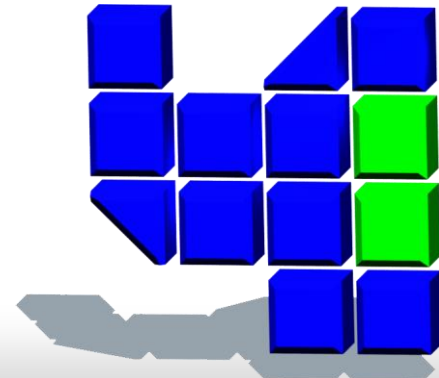


# Topology optimization of solids, shell, lattice structures by ProTOp®

Technological Innovation and Materials Seminar 2015 in Tel Aviv, Israel

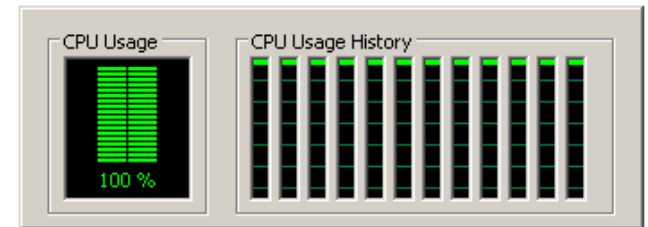
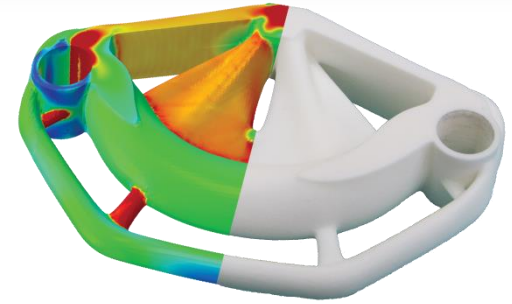
Marko Kegl  
Boštjan Harl  
Jožef Predan

[info@caess.eu](mailto:info@caess.eu)



# CAESS ProTOp®

- Cost-effective and user-friendly software to get a stiff and higher-strength structure with less material
- A standalone software package containing its own FEA solvers, only high-performance and fully parallelized code; no scripting
- Interactive optimization and target adjustments on desire
- Solid, shell and lattice structures definition and optimization
- Smooth generated structural boundaries – optimized parts are practically ready for 3D-printing and manufacturing

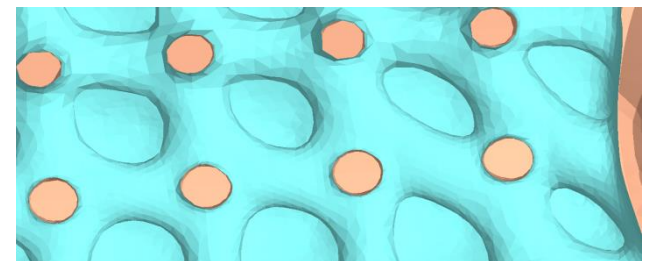


Target volume part [%]

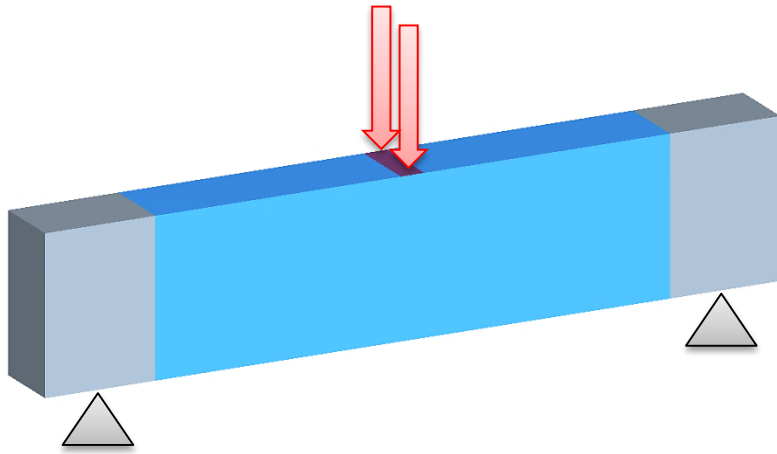
Target Mises stress

Target max displacement

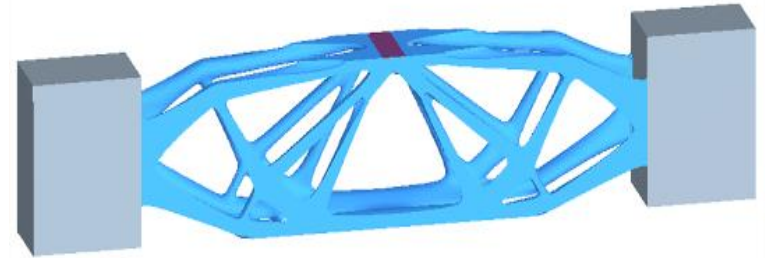
Running. Cycles: 4 VolRatio: 75.3 BStress: 3.1



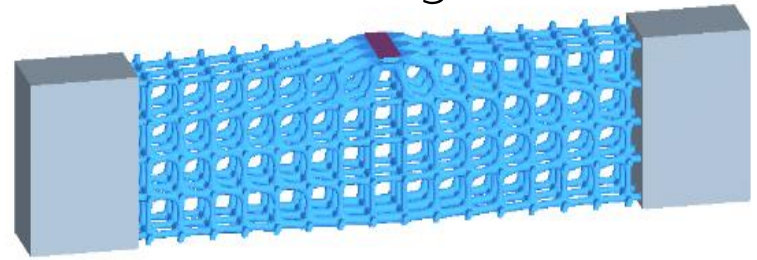
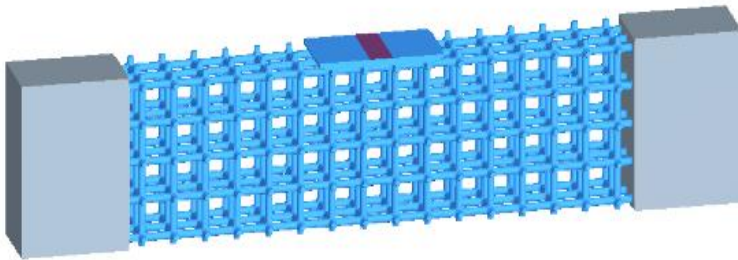
# Introduction



Optimal design from  
solid configuration



Optimal design from  
lattice configuration

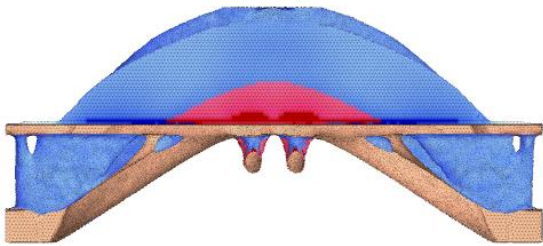


# Why to use optimization?

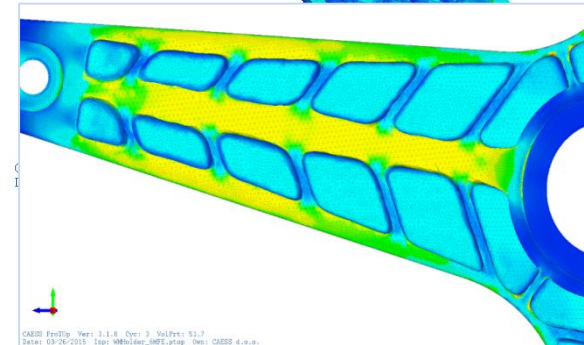
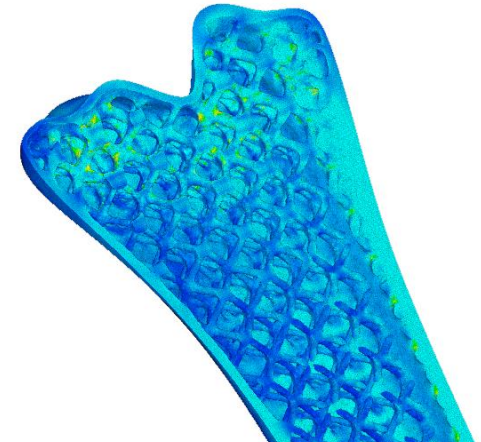
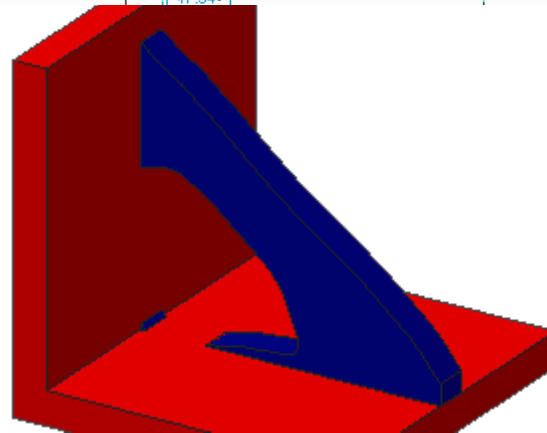
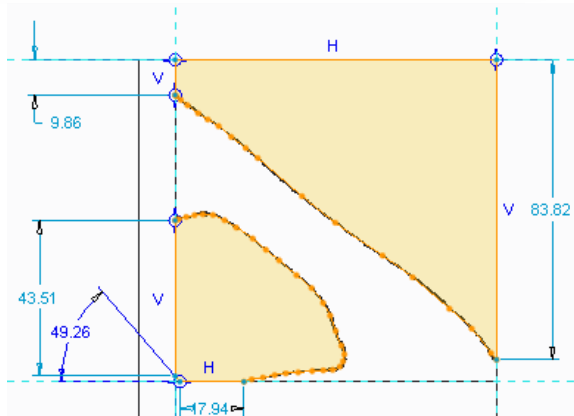
Get good design ideas

Get structures for redesign

Get the final 3D model

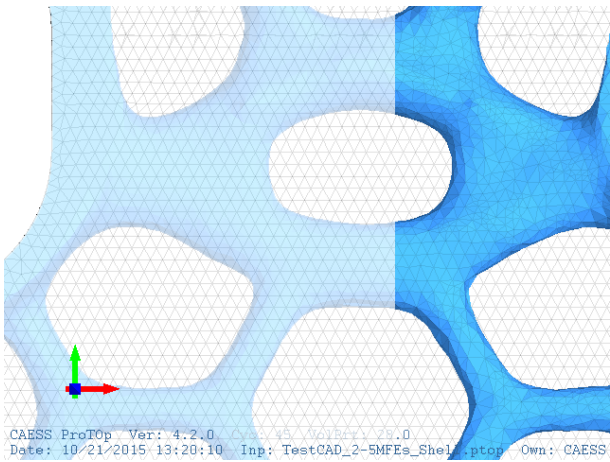


CAESS ProTop Ver: 3.1.8A Cyc: 180 VolPrt: 25.0  
Date: 04/15/2015 Inp: Bridge3.ptop Own: CAESS d.o.c



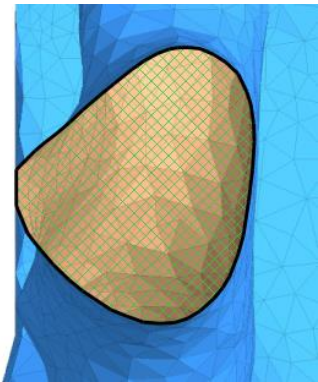
CAESS ProTop Ver: 3.1.8 Over: 3 VolPrt: 51.7  
Date: 03-26-2015 Inp: WWBolder\_S02.ptop Own: CAESS d.o.c

# Why use optimization on lattice structures



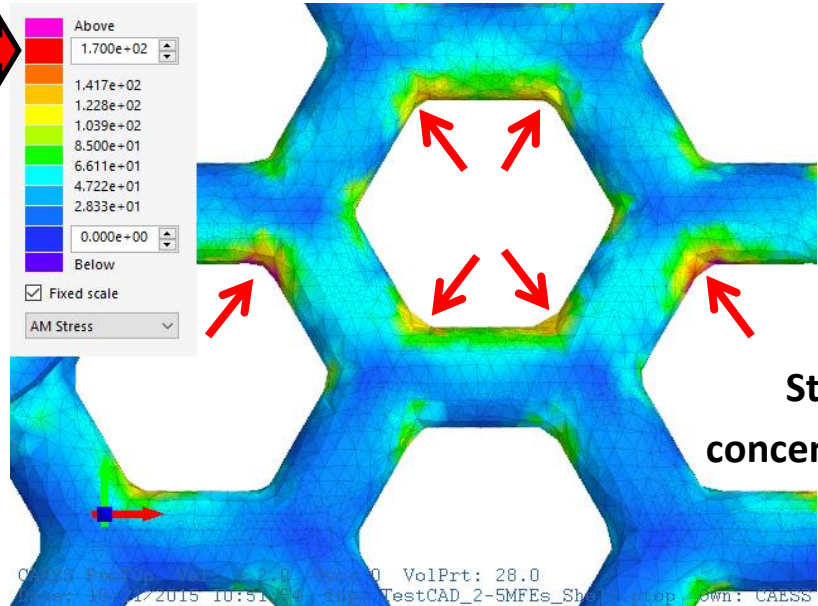
Full 3D solid optimization domain for lattice structure creation and optimization

A-A section

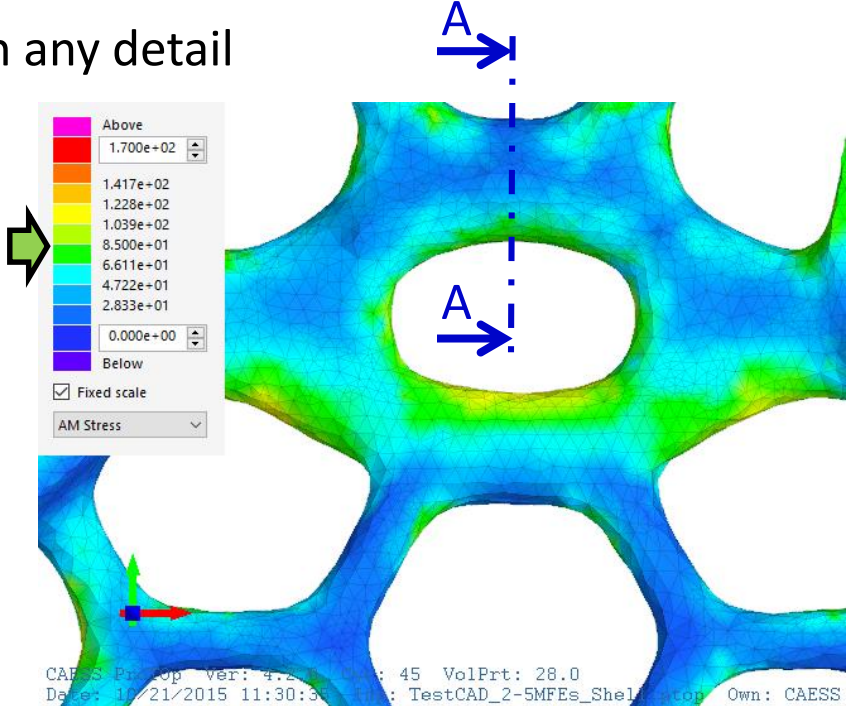


Full shaping freedom

## Full 3D shell/lattice structures optimization in any detail



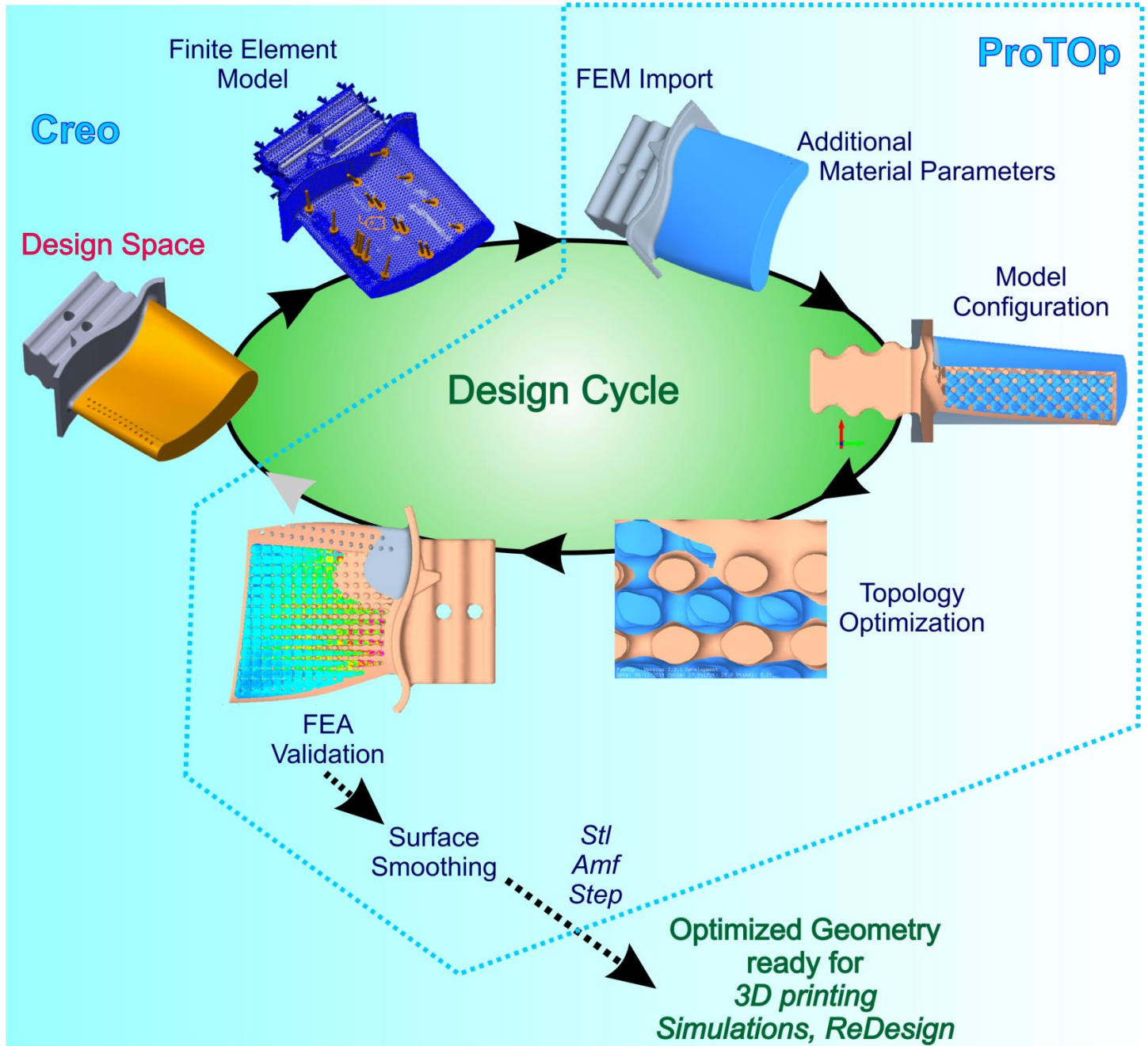
Stress concentrations



Created initial lattice structure

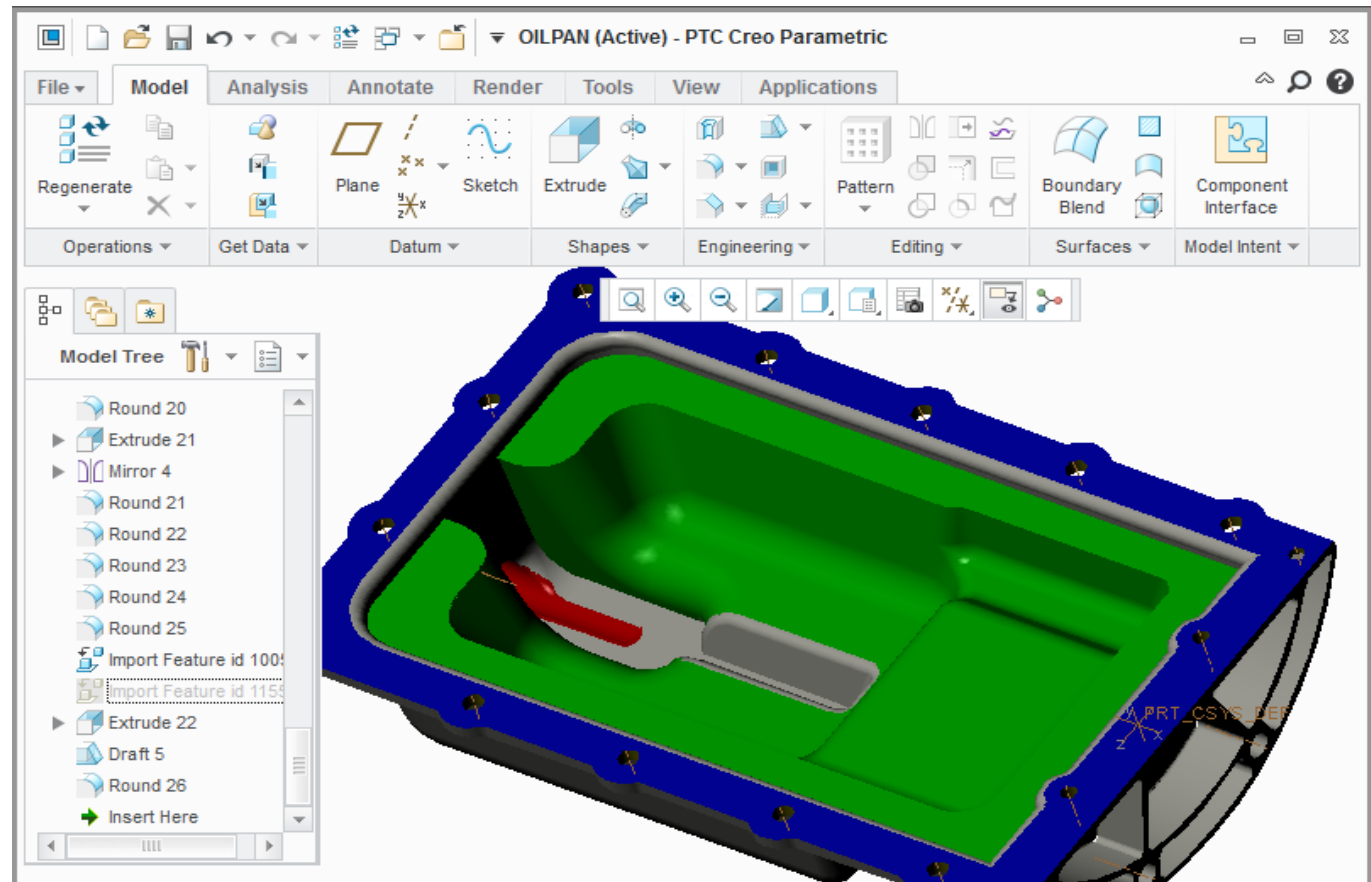
Optimized structure

# Design Workflow



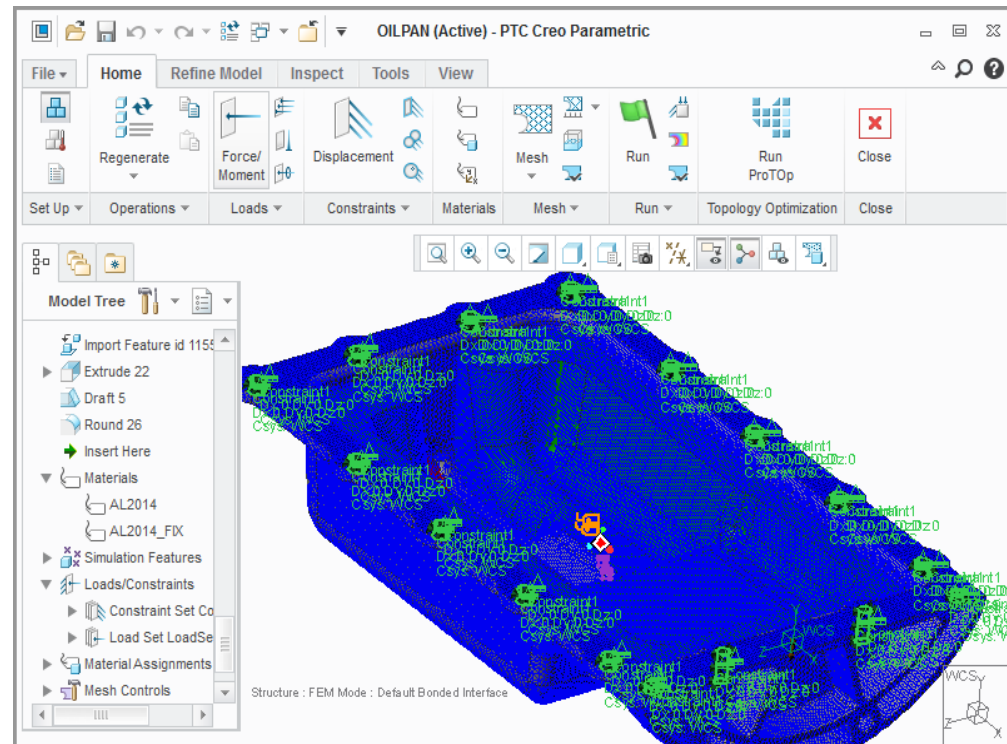
# Creating CAD Model (by PTC Creo)

- Model should include all details (interfaces, functional requirements, adding's for mechanical treatments), to get the right stiffness and possibility of direct manufacturing after optimization



# Creating FE (finite element) Model (also by PTC Creo)

- Creating volume regions
- Material definition ( *\_FIX*, *\_FIXC*, *\_CAD* )
- BCs and Loads and their sets
- Mesh control
- Create Load cases
- Run ProTOp or Export FNF



# Run ProTOp or Import FE model

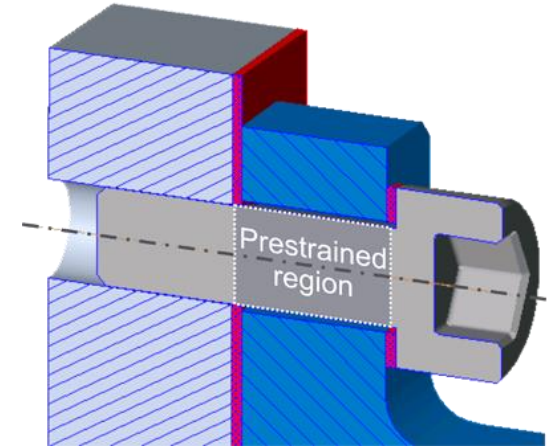
## Model tab

The screenshot shows the 'Model' tab in the software interface. It includes a toolbar with 'Source ...', 'Import', and 'Prepare' buttons. Below the toolbar is a 'Load cases' section with a dropdown menu and the text 'TestCAD\_2-5MFEs'. A table lists four load cases with columns for 'Include', 'AnaTyp', 'Active', 'ImpFac', 'FileName', and 'Notes'.

	Include	AnaTyp	Active	ImpFac	FileName	Notes
▶	<input checked="" type="checkbox"/>	Static	<input checked="" type="checkbox"/>	0.7956	ModelCase0001.femm	LC_0001_TESTCAD_2-7AMFES
	<input checked="" type="checkbox"/>	EigFrq	<input type="checkbox"/>	0	ModelCase0002.femm	LC_0002_EIGENFREQUENCY
	<input checked="" type="checkbox"/>	Static	<input checked="" type="checkbox"/>	0.1022	ModelCase0003.femm	LC_0003_LC2
	<input checked="" type="checkbox"/>	Static	<input checked="" type="checkbox"/>	0.1022	ModelCase0004.femm	LC_0004_LC3

This close-up shows the 'Import' button dropdown menu. The menu is open, showing two options: 'Import source' and 'Copy data from ...'. The 'Copy data from ...' option is highlighted in blue.

# Model preparation, Materials



Model Optimization Settings

Source ... Import ▾ Prepare ▾

Materials ...

Material regions ...

Technological constraints ...

Configuration ...

Load cases ▾	Include	AnaTyp	Active	I
▶	<input checked="" type="checkbox"/>	Static ▾	<input checked="" type="checkbox"/>	1
	<input checked="" type="checkbox"/>	EigFrq ▾	<input type="checkbox"/>	0

Materials Tool

Material properties ? Help

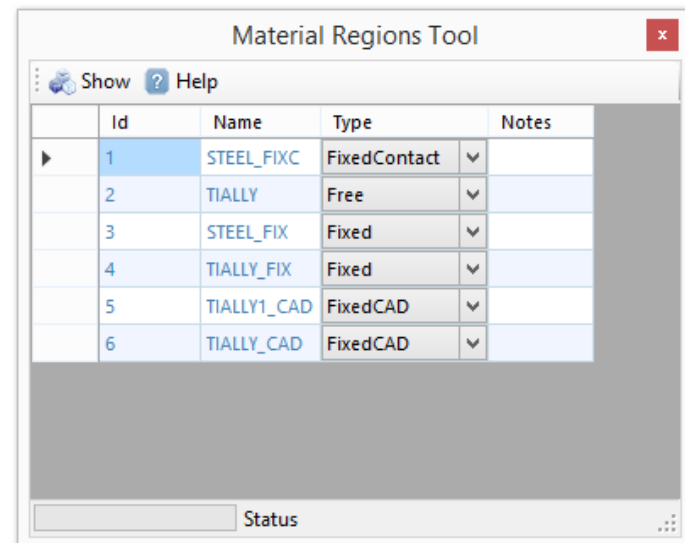
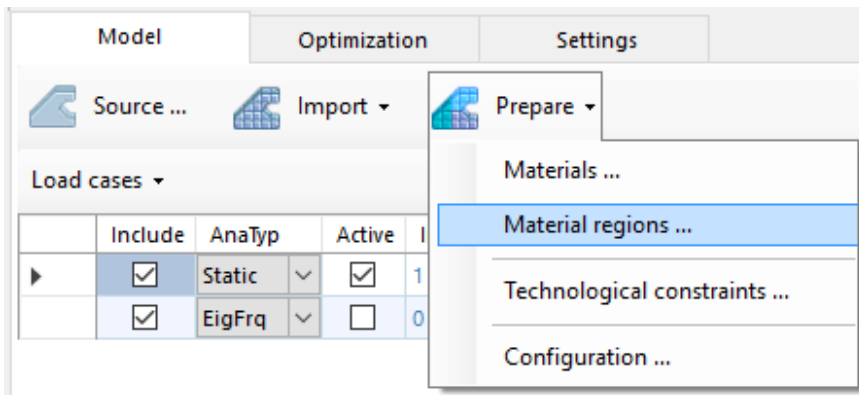
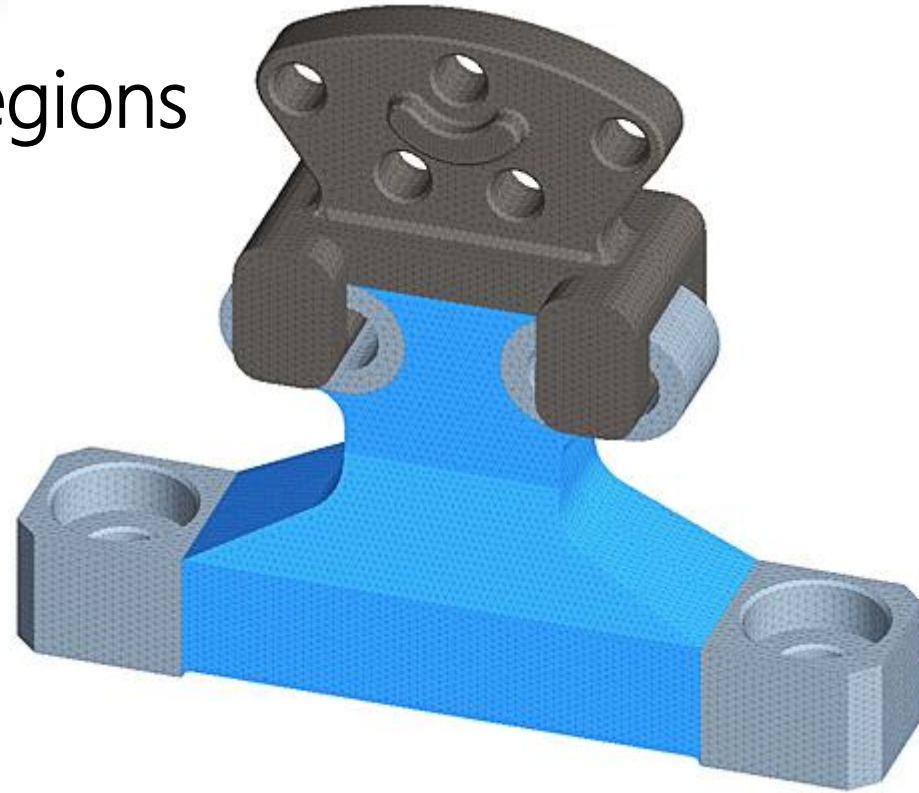
	Id	Name	ElaM	PoissR	MasDen	YStress	YHarden	ThExp
	1	TIALLY_FIX	117211	0.33	4.45323E-09	0	0.001	1.026E-05
	2	TIALLY1_CAD	117211	0.33	4.45323E-09	0	0.001	1.026E-05
	3	TIALLY_VL	117211	0.33	4.45323E-09	450	0.001	1.026E-05
✎	4	TIALLY_VR	117211	0.33	4.45323E-09	450	0.001	1.026E-05

Material fields

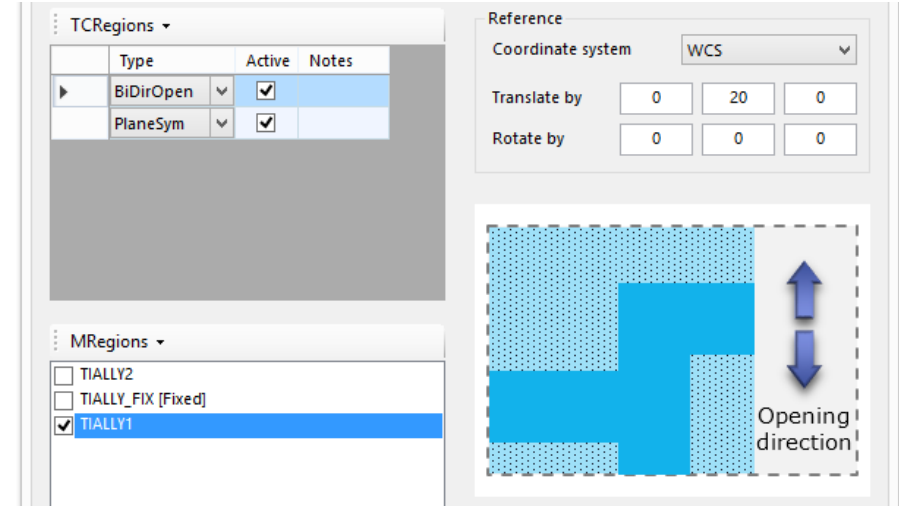
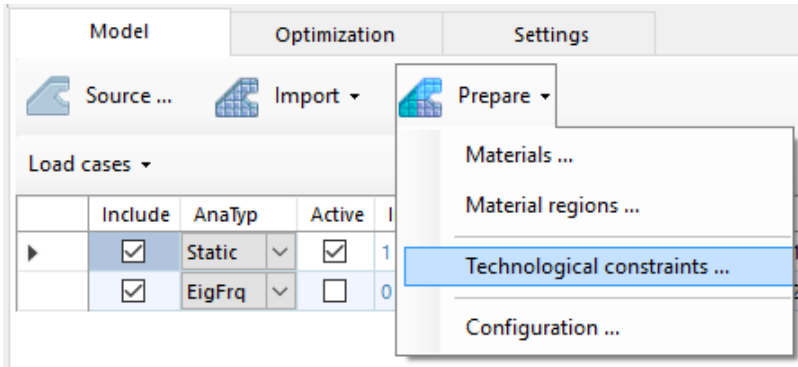
	Id	Name	PreStrain
	1	TIALLY_FIX	-0.0015
	2	TIALLY1_CAD	0
	3	TIALLY_VL	0.0005
▶	4	TIALLY_VR	0.0005

# Model preparation, **Materials regions**

- ❑ **Light blue** – optimization region (modified by the optimizer)
- ❑ Light gray – fixed region (not modified by the optimizer)
- ❑ **Gray** – fixed region; excluded from FEA (e.g., if needed for 3D print, no BCs and Loads on CAD regions)

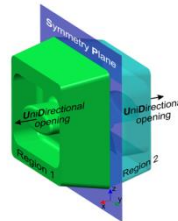
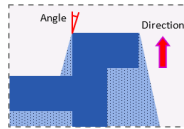


# Model preparation, Technological constraints ...

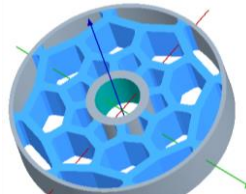


Adding technological constraints:

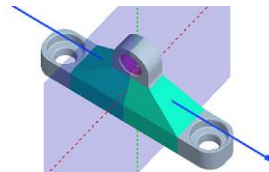
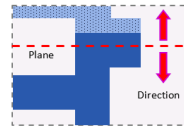
- UniDirOpen



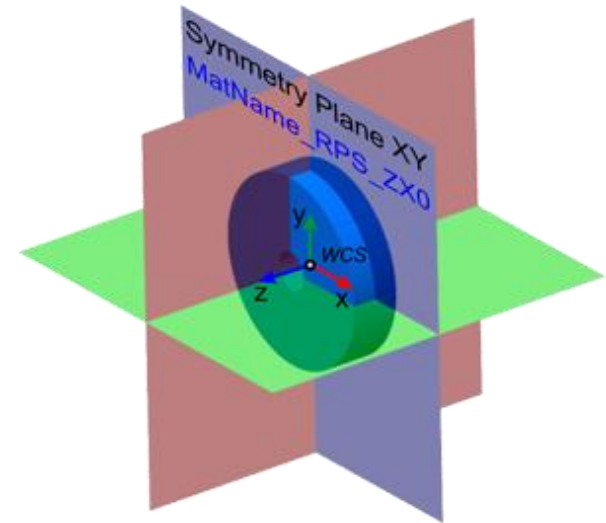
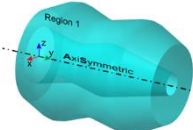
- BiDirOpen



- PlaneSym



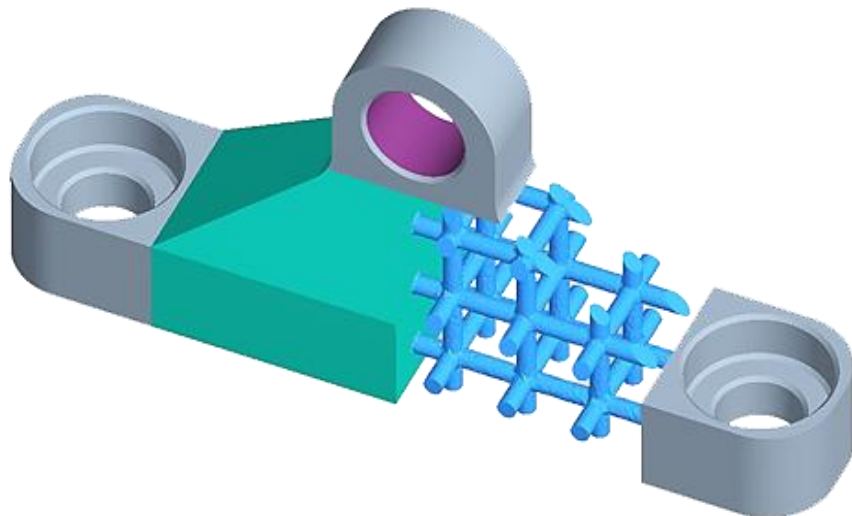
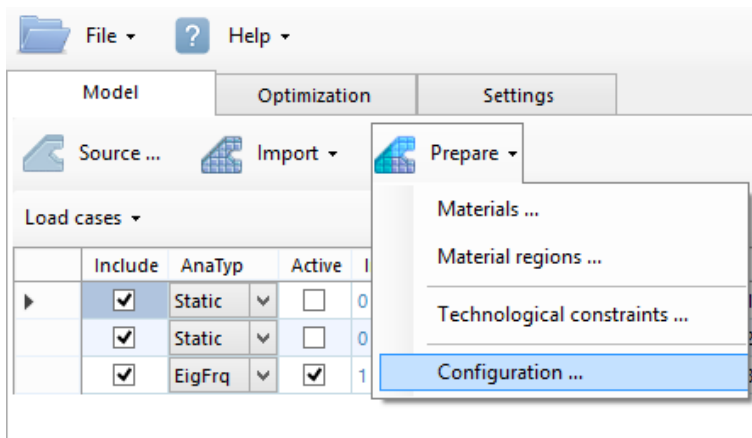
- AxiSym



# Model preparation, Configuration ...

Configuring the model:

- Solid configuration,
- Shell / lattice configuration.



**Configuration Tool**

Show ? Help

⋮ CNTools ⌵

	Type	Active	IniTPFac	Notes
	Shell	<input type="checkbox"/>	0.22	ShellOnl
	Shell	<input type="checkbox"/>	0	Shell
	Solid	<input type="checkbox"/>	0.001	Solid
	Lattice	<input type="checkbox"/>	0	
▶	Lattice	<input checked="" type="checkbox"/>	-0.27	Lattice
	Lattice	<input checked="" type="checkbox"/>	-0.27	Lattice

⋮ MRegions ⌵

- TIALLY\_FIX [Fixed]
- TIALLY1\_CAD [FixedCAD]
- TIALLY\_VL
- TIALLY\_VR

**Rounding**

Thickness Min: 10    Max: 20

Range: 2    Sharpen: 0.0

**Current volume part:** 0.0 %  
**Min/Max volume parts:** 0.0 % 0.0 %

DomainVol = 2.460E+05    AveElemSize = 1.15E+00

---

Shell    Lattice

Coordinate system: WCS

Translate by: 0    0    0

Rotate by: 5    0    0

Cell CS type: Cartesian

RangeMin: 0    0    -12

RangeMax: 0    0    12

Diagram showing a lattice cell structure with dimensions A, B, C, and d.

Cell type: 106    Cell rotate: 0

Lines subdivide: 1

Cell size ABC: 20    20    26

Cell translate: 0    -5    0

Thickness Min: 3.734    Max: 11

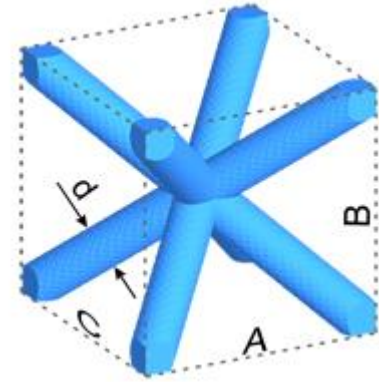
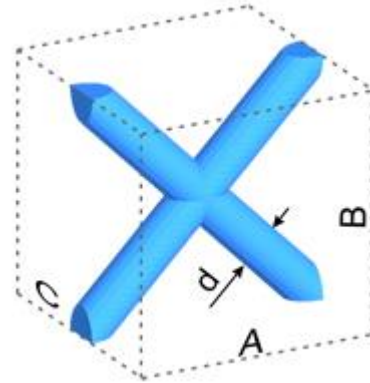
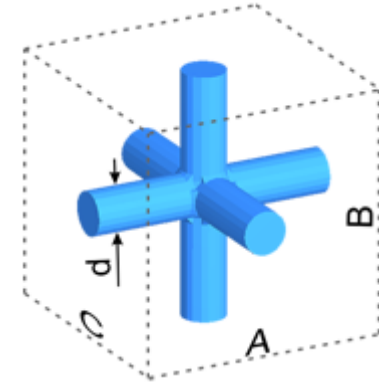
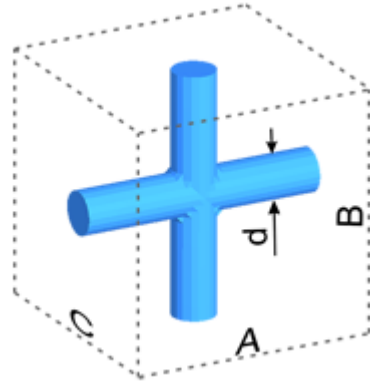
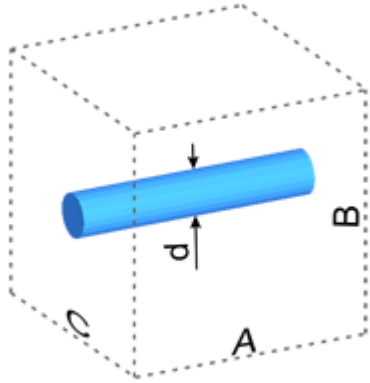
# Model preparation, Configuration ...

Cells

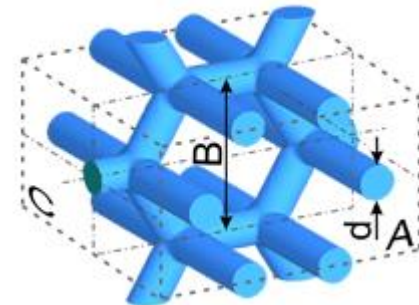
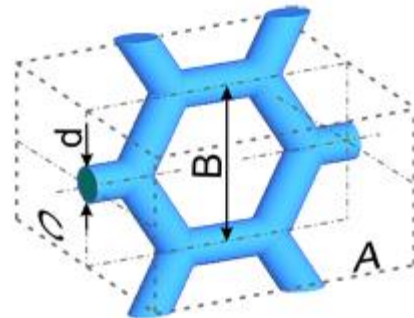
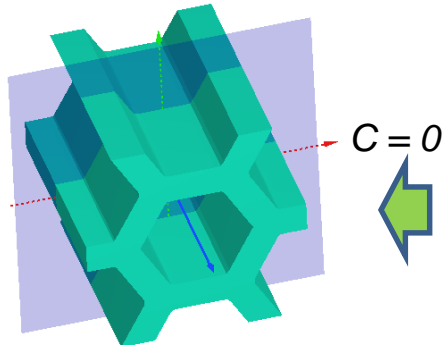
1D

2D

3D

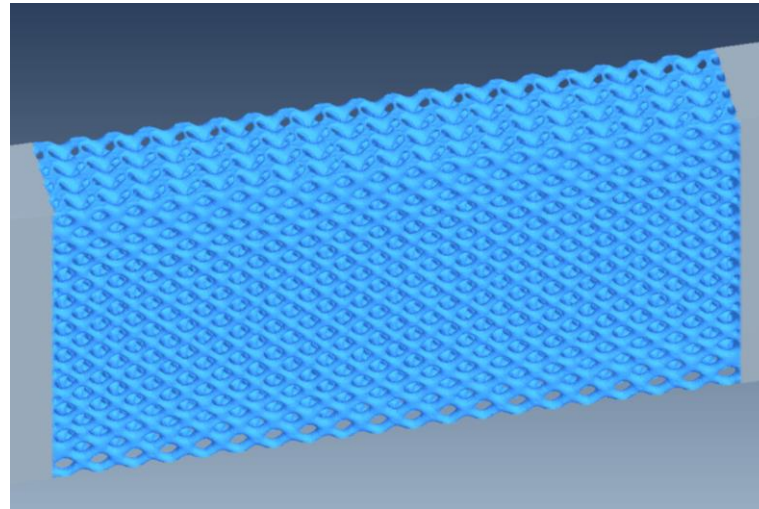


Wall from lattice

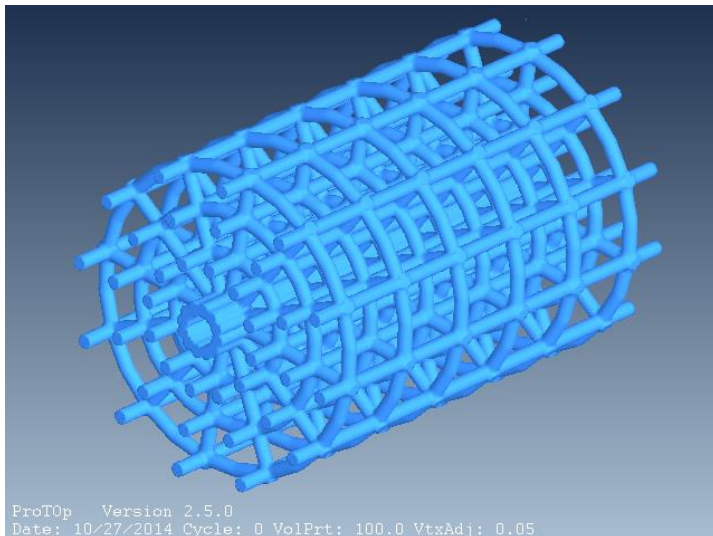


# Model preparation, Configuration ...

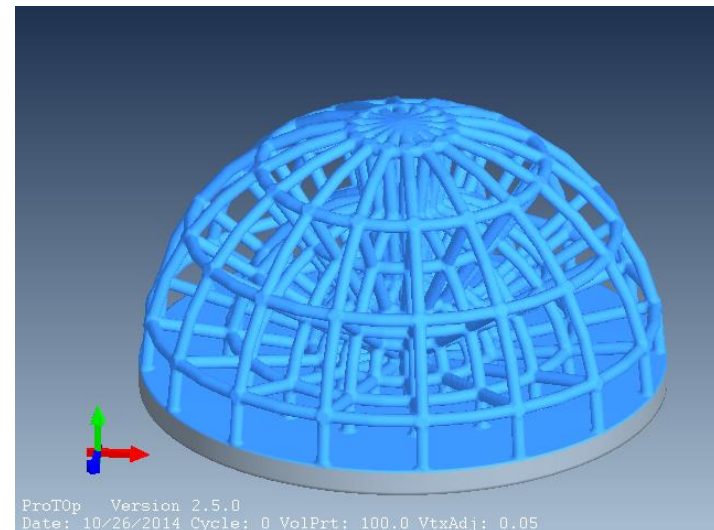
## Coordinate systems



Cartesian CS



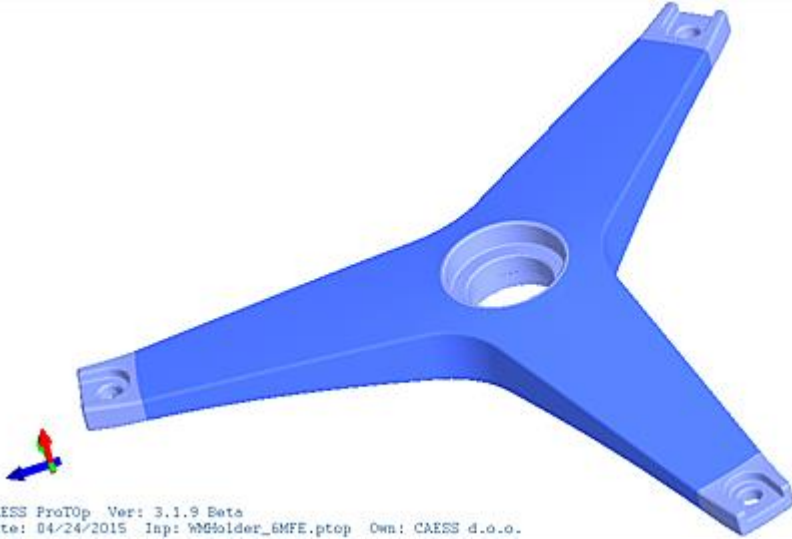
Cylindrical CS



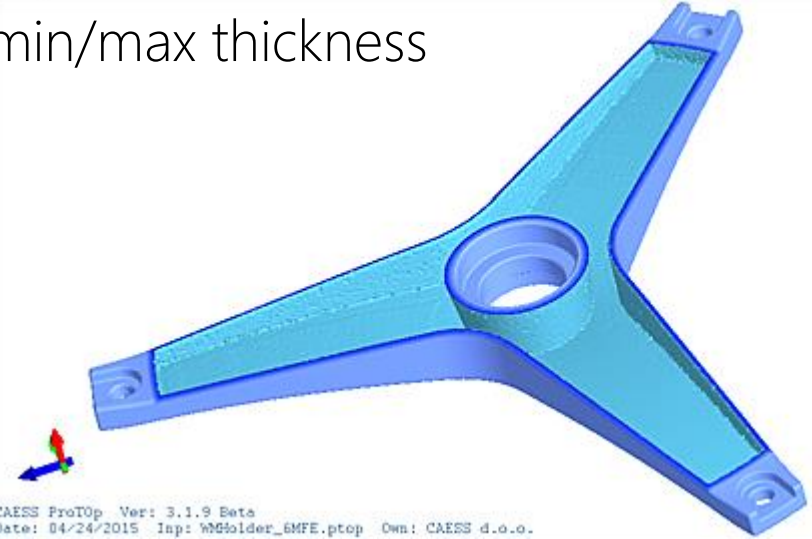
Spherical CS

# Model preparation, Configuration ...

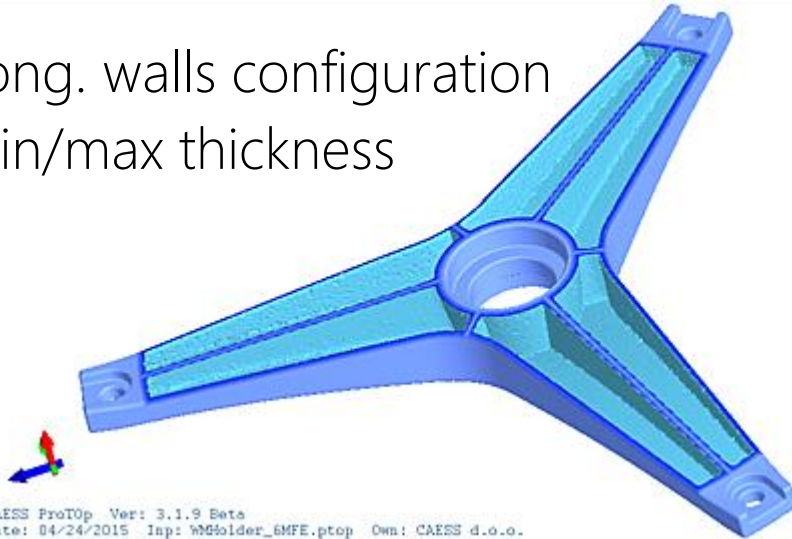
Initial model (solid from Creo)



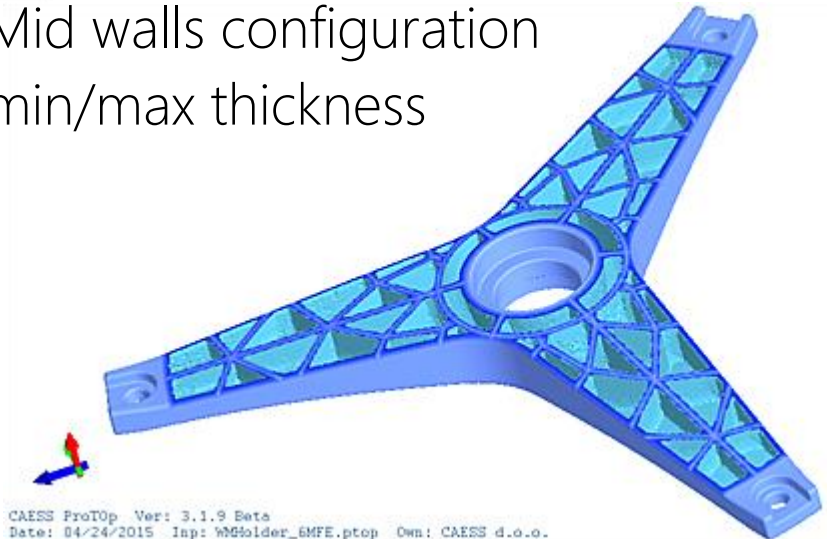
Outer shell configuration  
min/max thickness



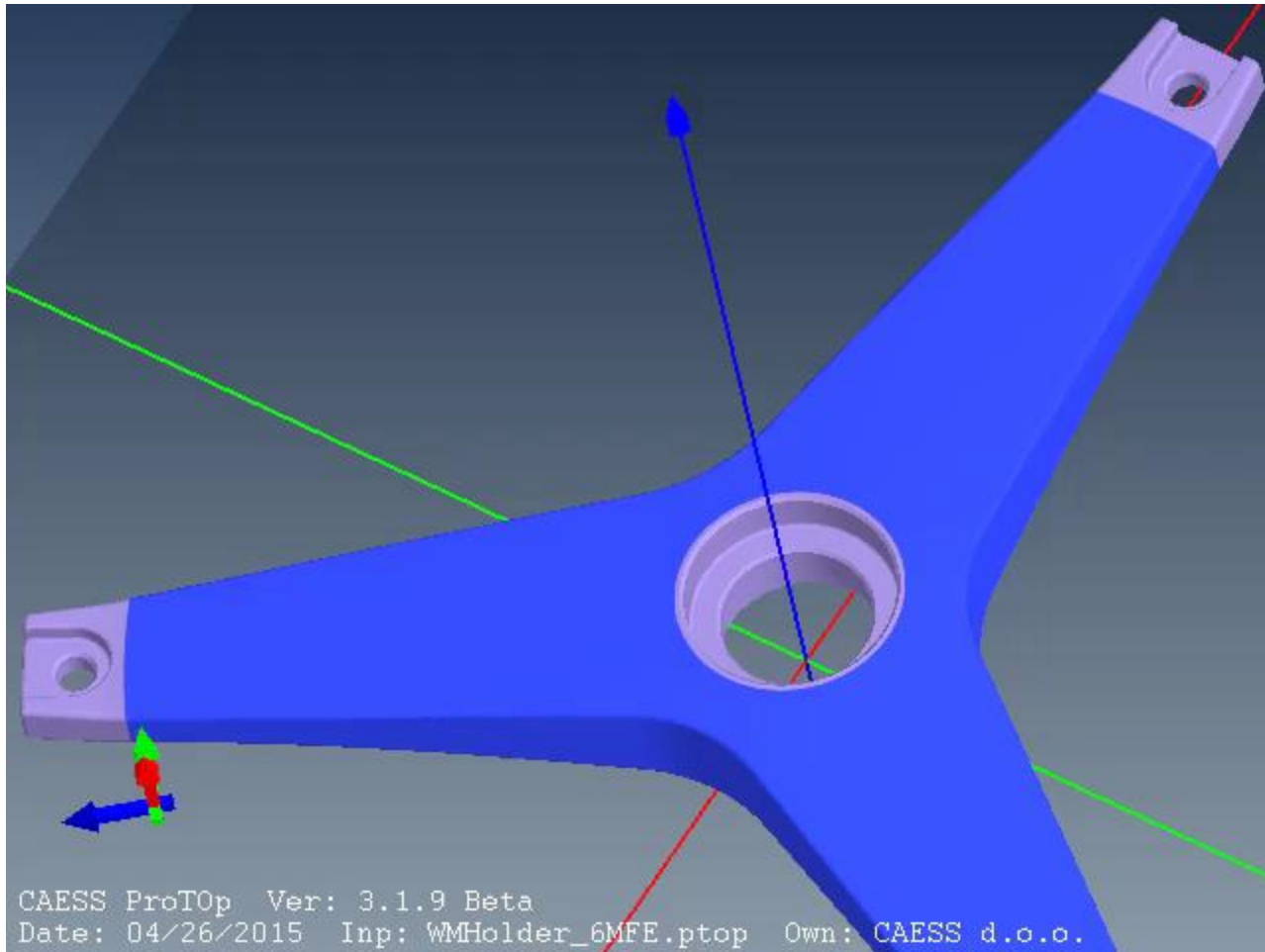
Long. walls configuration  
min/max thickness



Mid walls configuration  
min/max thickness



# Animation, Washing machine drum holder



# Run ProTOp or Import FE model

## Optimization tab

Model Optimization Settings

Start session Run cycles Pause cycles End session

Auto run after session start  Use semi-elastic-plastic model

Double-precision solver Yield stress factor 1.00

Cycles Min 10 Max 100 Yield hardening factor 1.00

Running ... Initialized VolPrt: 28.0 BStress: 6.16e+01 MaxU: 1.06e-01 IniTime: 00:00:28

Target volume part [%] 28.0

Target Mises stress 0.0

Target max displacement 0.0000

Material redistribution rate Low High

Fields and step smoothing Low High

Save ...

	LCaseld	SEner	BStress	MaxU	EigFrq	ImpFac
▶	1	343.9144	52.28614	0.1058919		0.8143
	3	267.7943	61.63913	0.08563435		0.0926
	4	266.9981	61.64093	0.08507962		0.0931

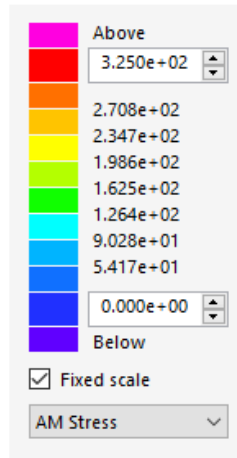
# Run ProTOp or Import FE model

## Advanced settings tab

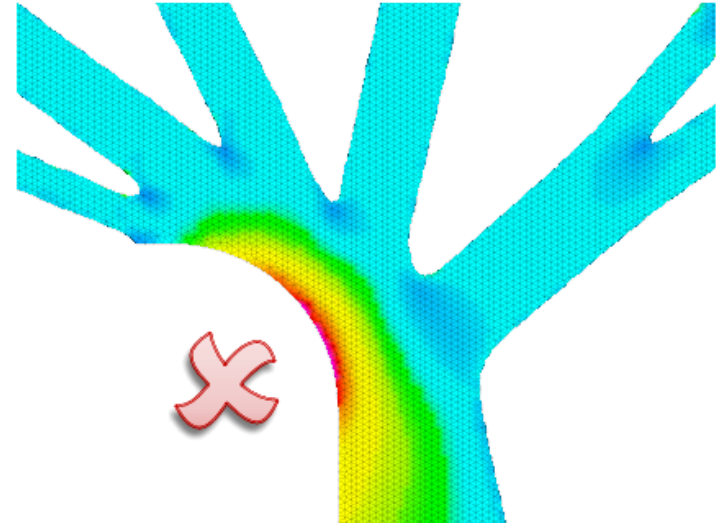
Model		Optimization		Settings	
Settings	Filter	<input type="text"/>			
	Key	Value	Notes		
	Con.FEAPProcessPriority	-1			
	Opt.ConvergenceTolerance	0.01			
	Opt.TopInfluenceDist	1.0			
	Opt.ElementActLimit	-0.05			
▶	Opt.ElementActBandWidth	2			
	Opt.NumLevelCycles	4			
	Opt.NumIniVoidCycles	0			
	Supp.SlvRSSP	5			
	Supp.SlvRSDP	0			

# ProTOp® functionalities, Semi-elastic-plastic material behavior

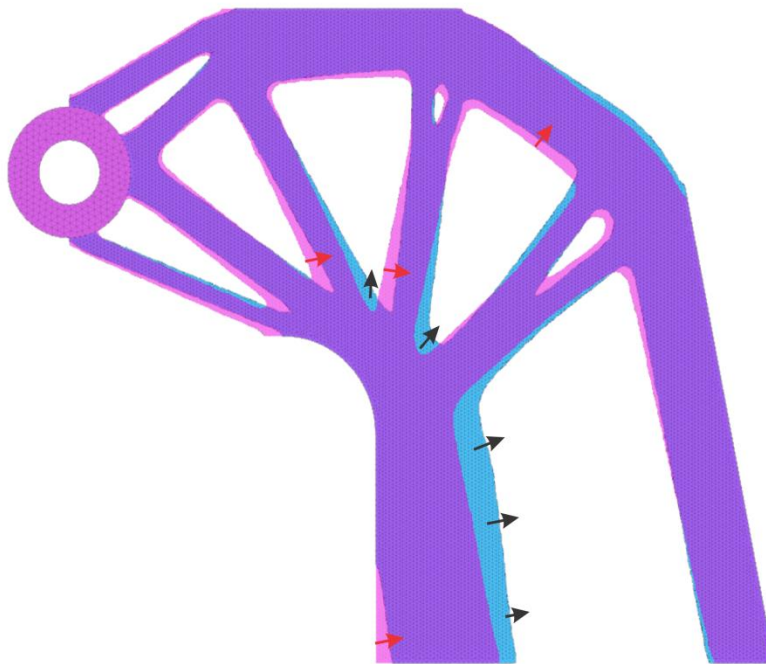
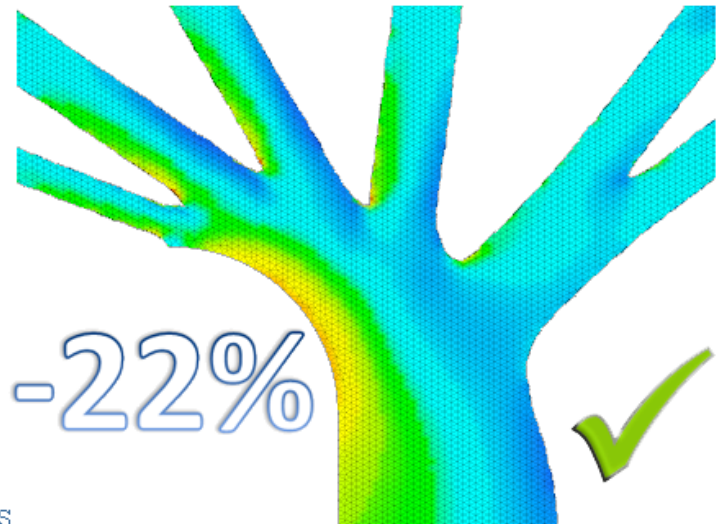
**Diminish  
stress concertation  
by elastic plastic  
material behavior**



Optimized: **Linear elastic behavior**  
Validated: **Linear elastic behavior**



Optimized: **Elastic plastic behavior**  
Validated: **Linear elastic behavior**



# ProTOp® functionalities, Tens./Comp. Stress controlling

File ? Help

Model Optimization Settings

Settings Filter **FEA.Sta.**

Key	Value	Notes
FEA.Sta.MaxSolverIterations	30	
FEA.Sta.TopCriteriaCode	0	SEner = 0; Mis
FEA.Sta.TenCompStrengthRatio	1.0	
FEA.Sta.BStressExp	4	Range: from 1

Above 3.500e+02

2.917e+02

2.528e+02

2.139e+02

1.750e+02

1.361e+02

9.722e+01

5.833e+01

0.000e+00

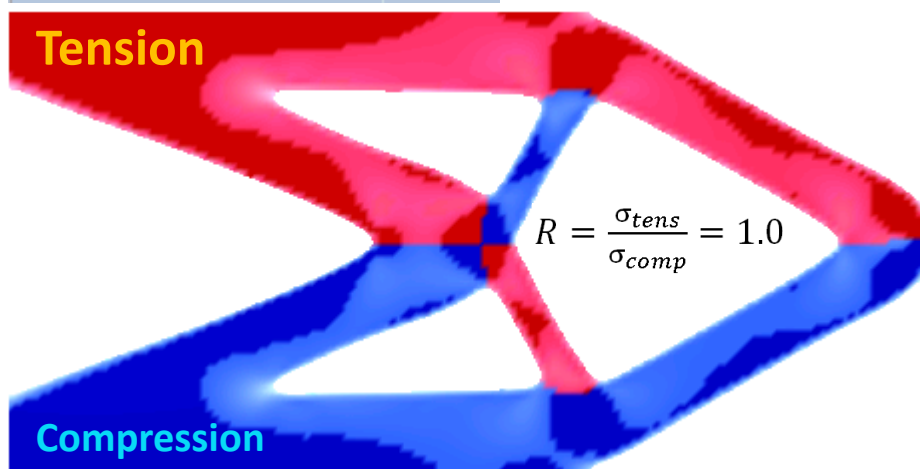
Below

Fixed scale

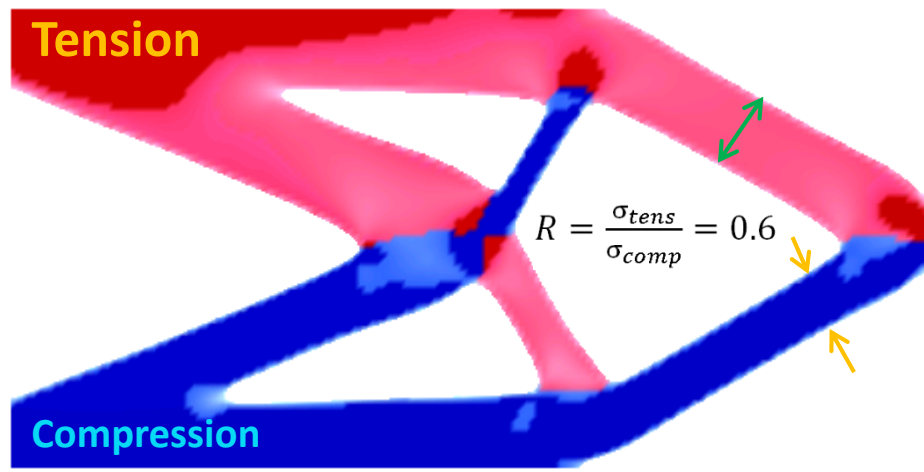
AM Stress

von Mises stress field

FEA.Sta.TenCompStrengthRatio 1.0

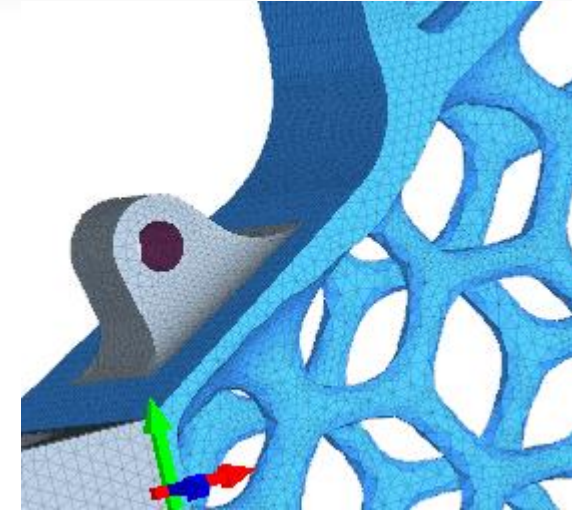
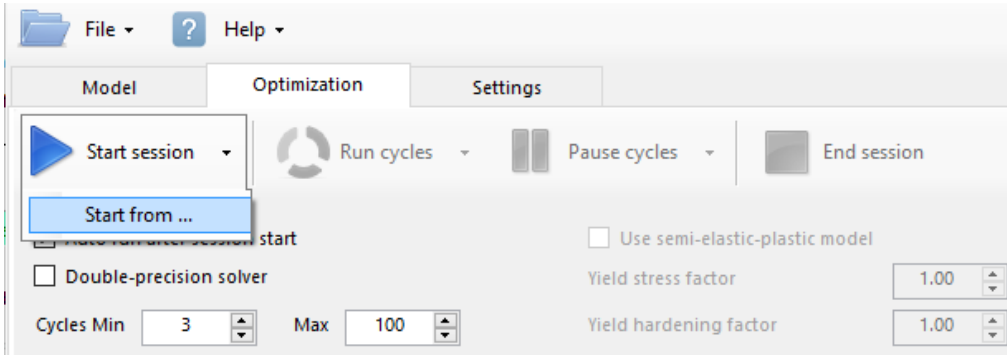


FEA.Sta.TenCompStrengthRatio 0.6

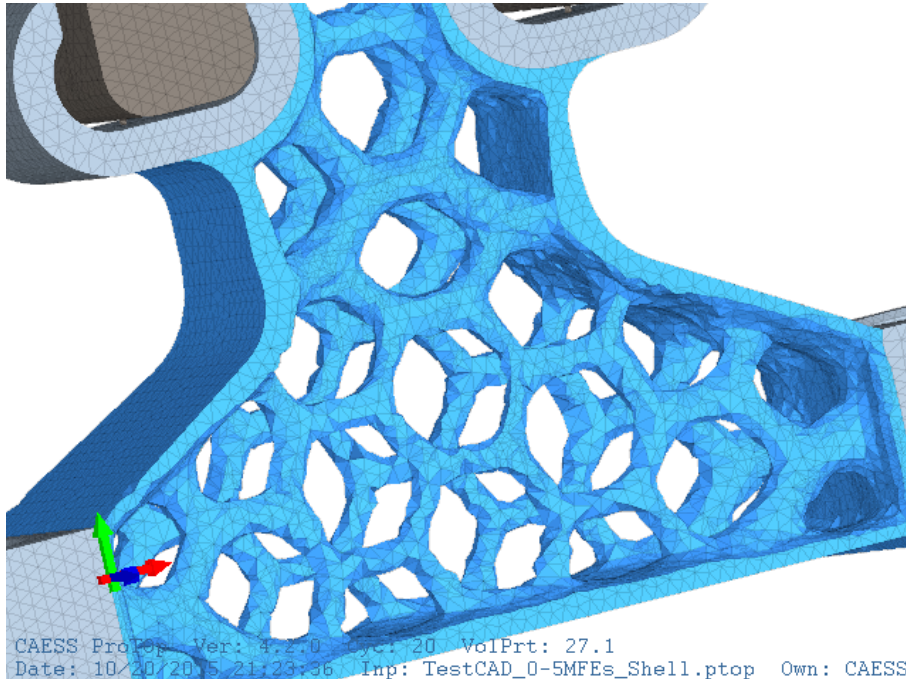


On crack initiation resistant structure

# ProTop® functionalities, *Start from...* mode

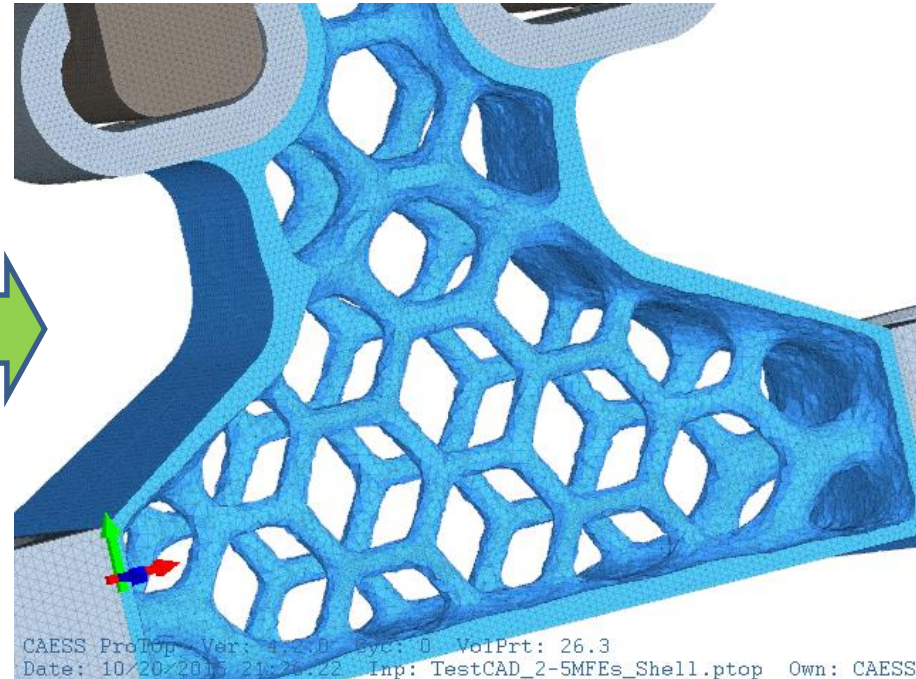


Small FE model (0.5 MFEs)



CAESS ProTop Ver: 4.2.0 Cyl: 20 VolPrt: 27.1  
Date: 10/20/2015 21:23:36 Inp: TestCAD\_0-5MFEs\_Shell.ptop Own: CAESS

Larger FE model (2.5 MFEs)



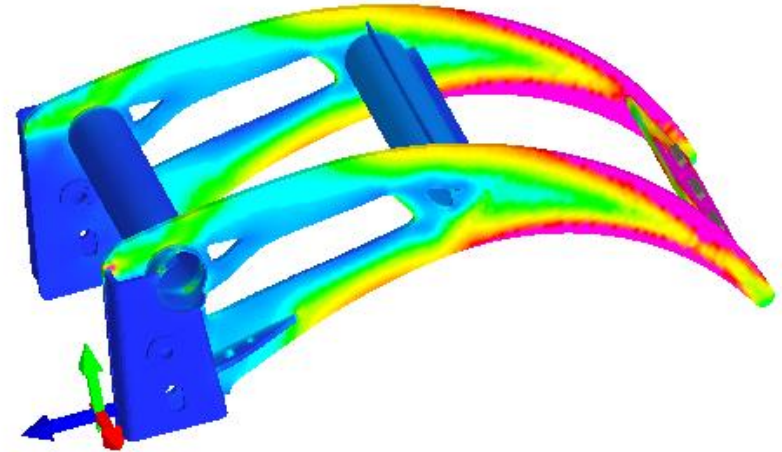
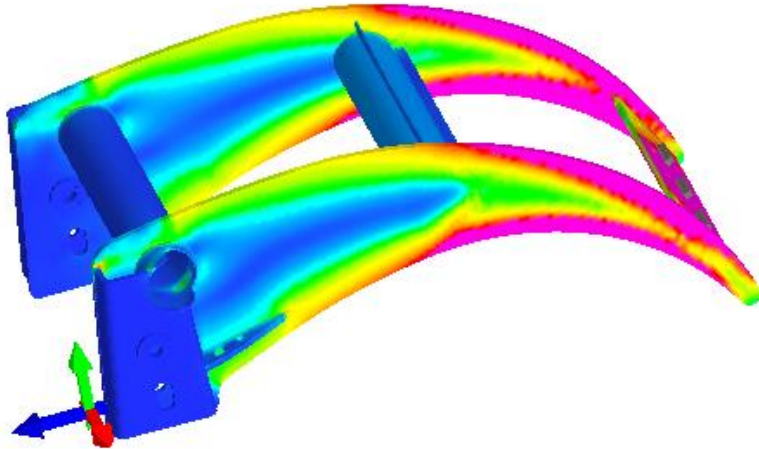
CAESS ProTop Ver: 4.2.0 Cyl: 0 VolPrt: 26.3  
Date: 10/20/2015 21:26:22 Inp: TestCAD\_2-5MFEs\_Shell.ptop Own: CAESS



# Optimization of welded structure made of thin plates

Initial model (solid from Creo)

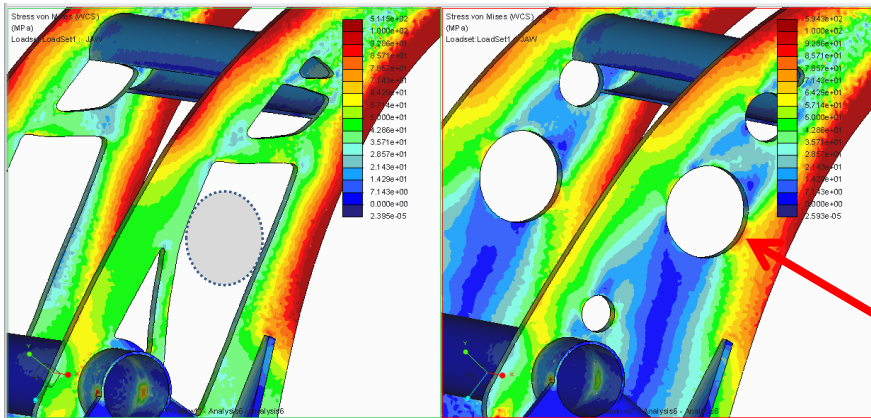
Optimized shape



CAESS ProTop Ver: 4.2.0 Cyc: 0 VolPrt: 100.0  
Date: 10/24/2015 10:42:05 Inp: Jaw.ptop Own: CAESS

CAESS ProTop Ver: 4.2.0 Cyc: 11 VolPrt: 85.8  
Date: 10/24/2015 10:46:14 Inp: Jaw.ptop Own: CAESS

Optimal shape vs. just holes

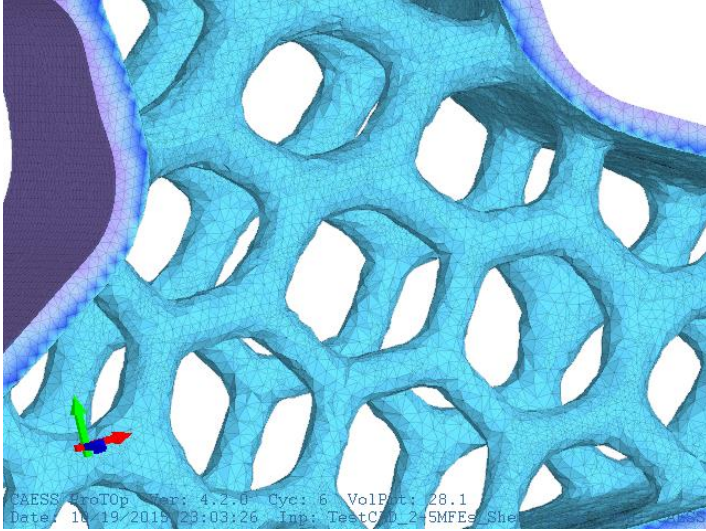


PTC Creo Simulate

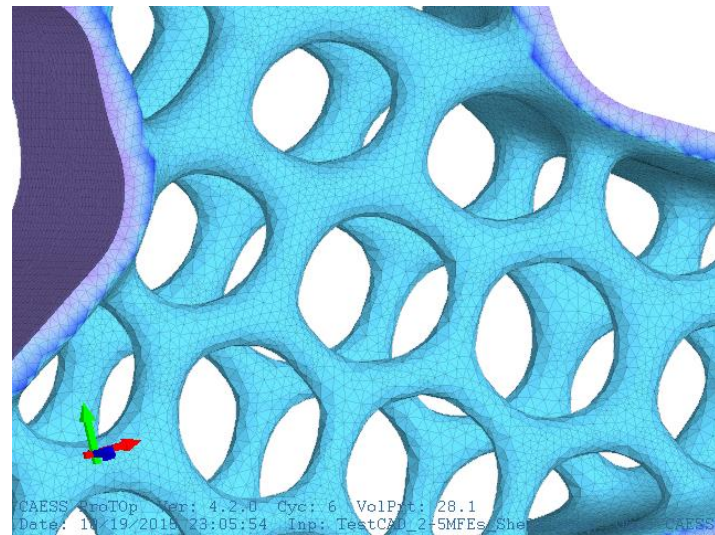
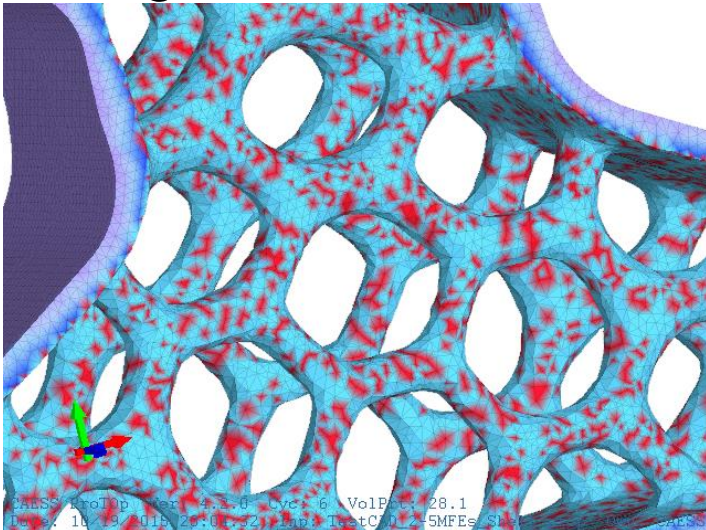
Stress concentration at hole,

# Smoothing and export

## Surface after optimization



Smoothing



Export to STL, AMF or STEP formats

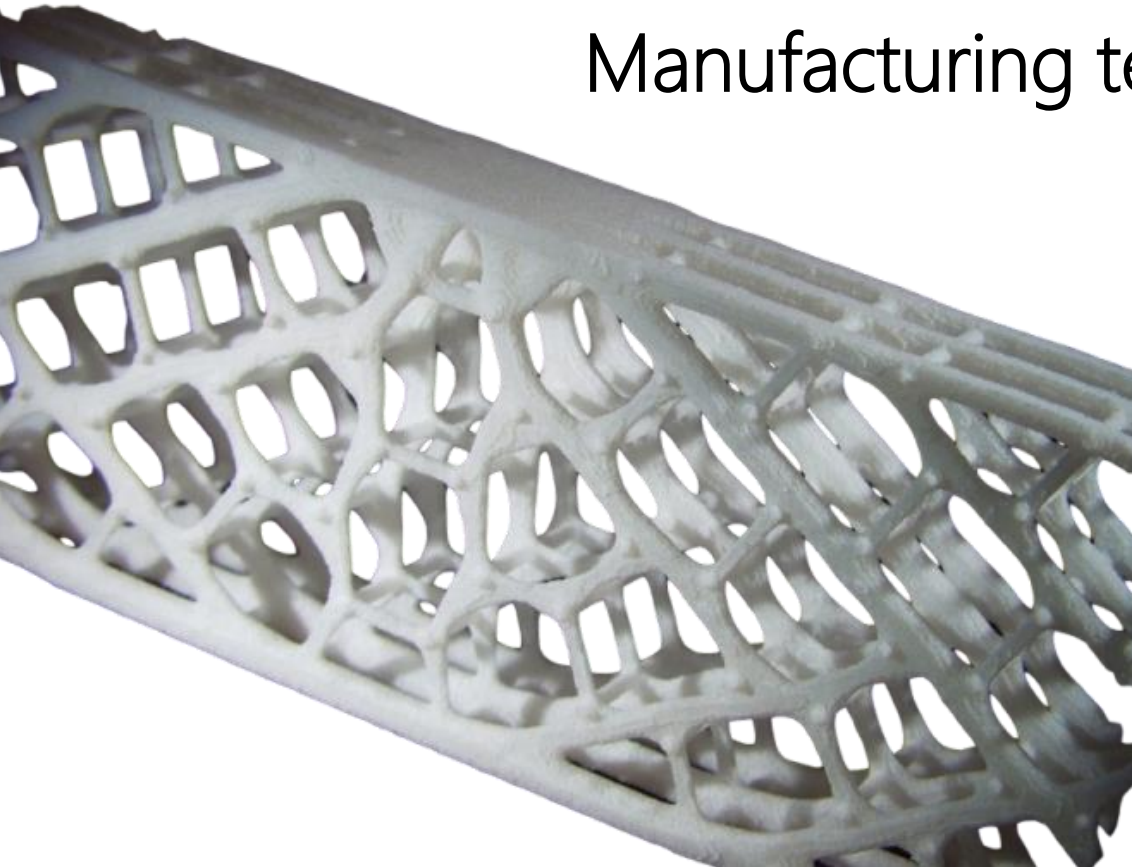
Surface tools:

- Surface mesh errors check
- Mesh simplification
- Peaks and pits removal
- Smoothing

Errors free and smoothed surface

# Additive Manufacturing

ProTOp® solution perfectly suited for new **Additive Manufacturing** technologies.



- Freedom of design
- Complex geometry
- Lattice structure
- Export to STL

# Live Demo: Brakcet

ProTop - M:\Boeing\TestCAD\_2-5MFEs\_Shell.ptop

File Help

Model Optimization Settings

Start session Run cycles Pause cycles End session

Auto run after session start  
 Double-precision solver  
 Cycles Min: 20 Max: 100

Use semi-elastic-plastic model  
 Yield stress factor: 1.00  
 Yield hardening factor: 1.00

Target volume part [%]: 28.0  
 Target Mises stress: 0.0  
 Target max displacement: 0.0000

Material redistribution rate: Low High  
 Fields and step smoothing: Low High

Save ...

LCaseld	SEner	BStress	MaxU	EigFrq	ImpFac

```

Resultant Fx: 0.000000E+00
Resultant Fy: 0.000000E+00
Resultant Fz: 0.000000E+00
Number of nodes: 445920
Number of elements TTH4: 2457261
Number of elements HXH8: 0
  
```

Status

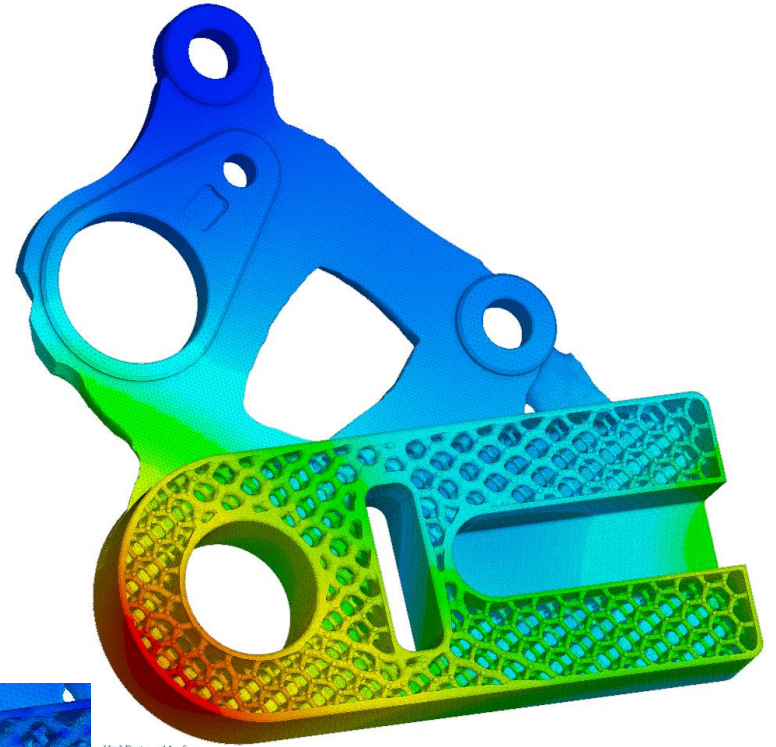
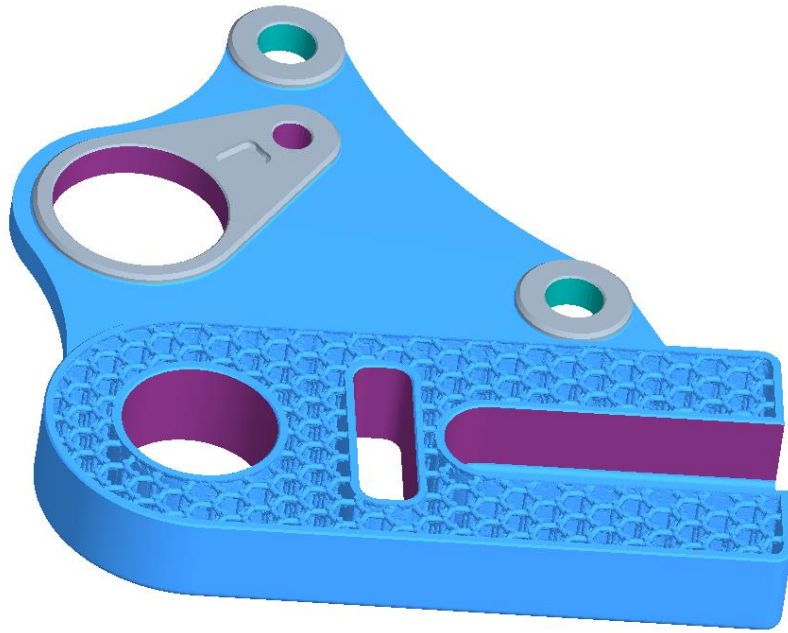
Geometry View Maximize Suspend

Above: 1.000e+02  
 8.333e+01  
 7.222e+01  
 6.111e+01  
 5.000e+01  
 3.889e+01  
 2.778e+01  
 1.667e+01  
 0.000e+00  
 Below

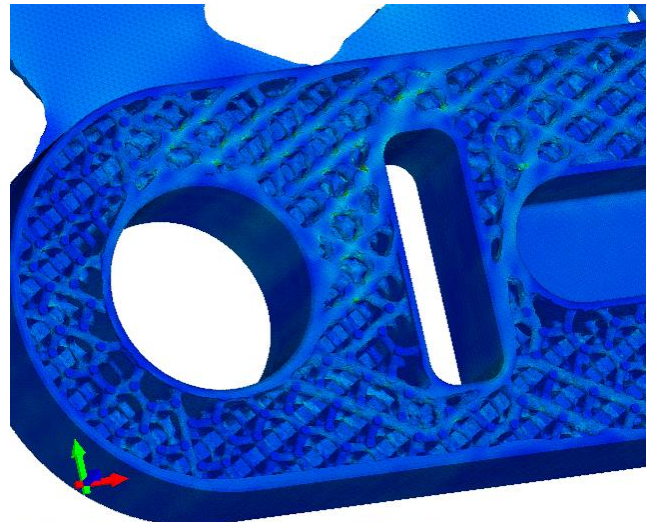
Fixed scale  
AM Stress

CAESS ProTop Ver: 4.2.0 Cyc: 6 VolPrt: 28.1  
 Date: 10/20/2015 12:55:55 Inp: TestCAD\_2-5MFEs\_Shell.ptop Own: CAESS  
 Generator: 0.36 sec Vertices: 94982 Triangles: 190172 BBox: ...

# Simultaneously optimization of solid, shell and lattice structure



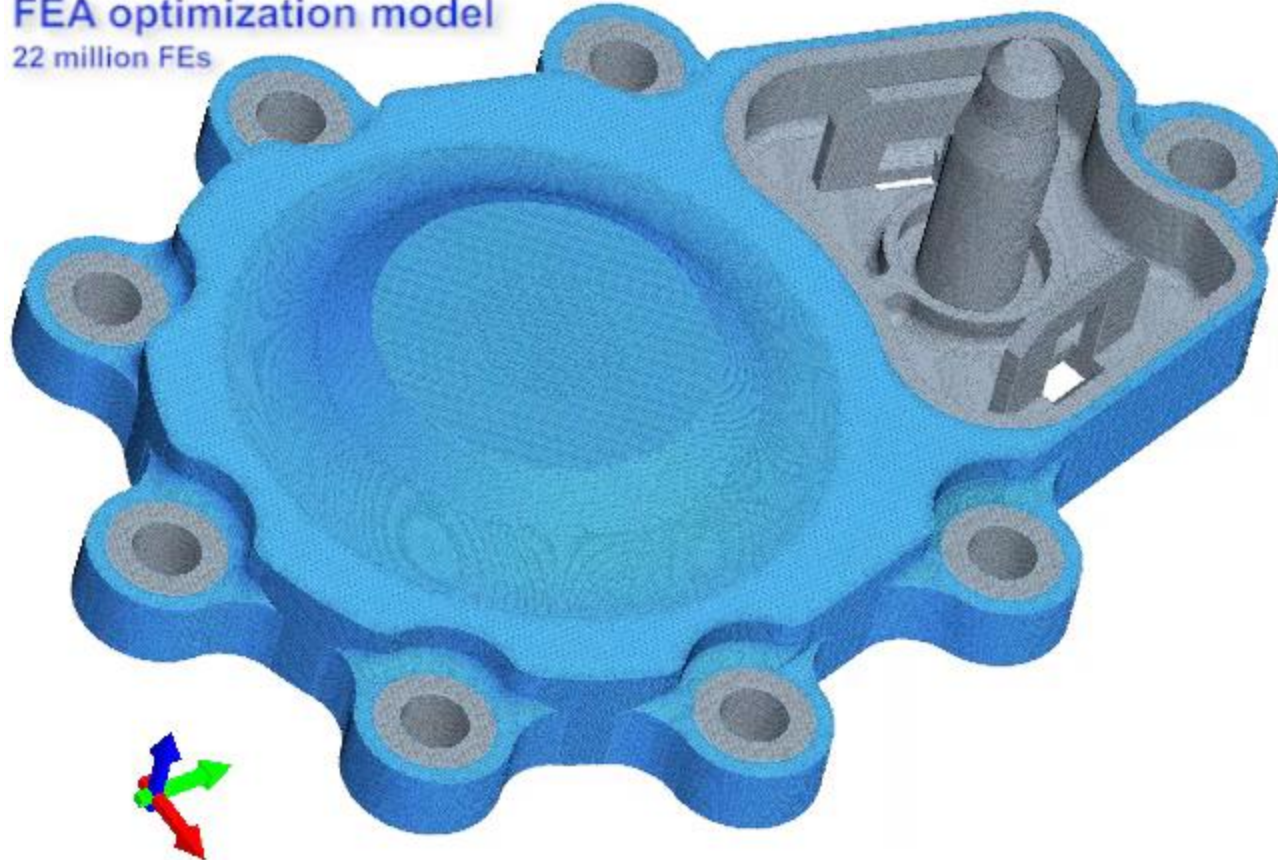
VolPrt: 41.6





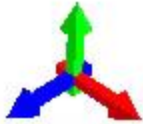
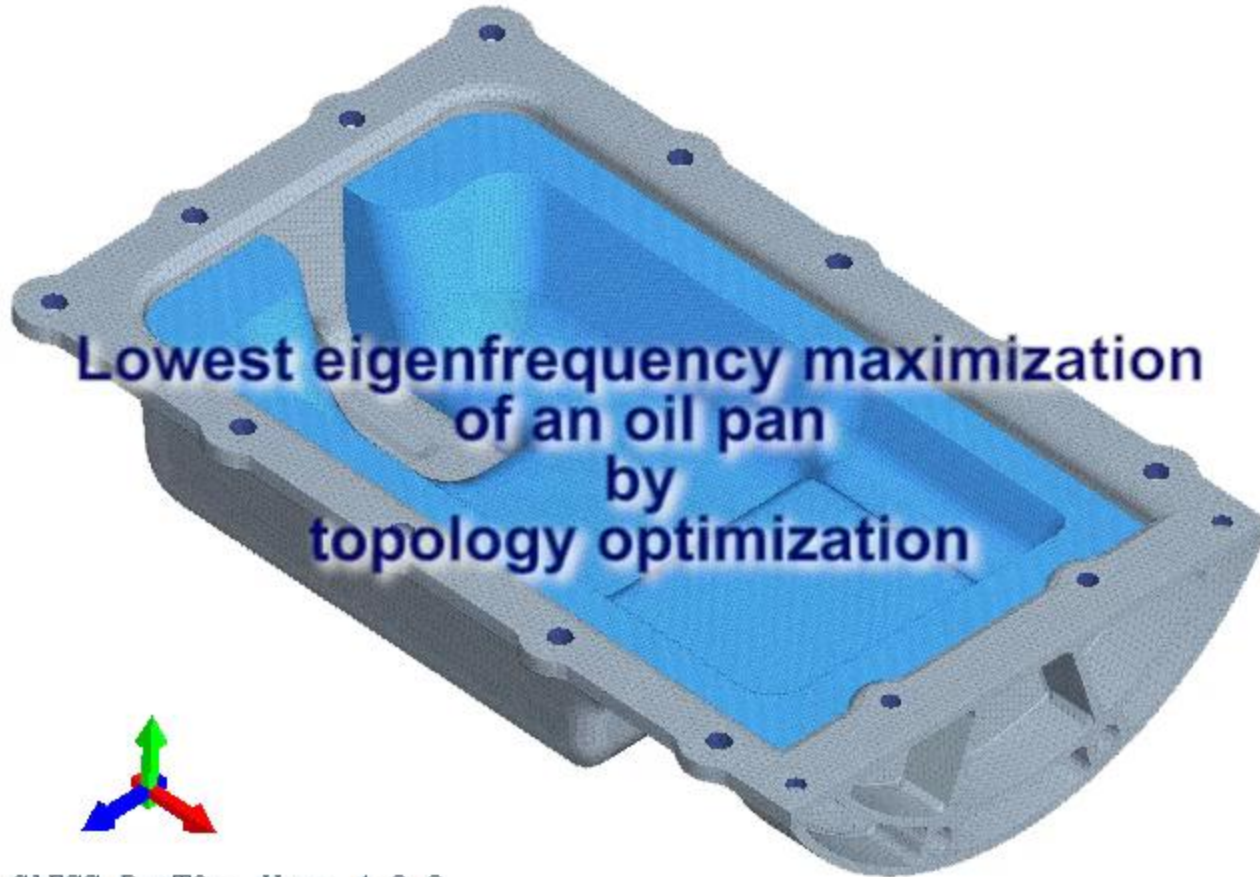
# Animation, Pressure cover

**FEA optimization model**  
22 million FEs



CAESS ProTop Ver: 3.1.9 Beta  
Date: 04/28/2015 Inp: CoverAssembly\_Large\_Lattice.ptop Own: CAESS d.o.o.

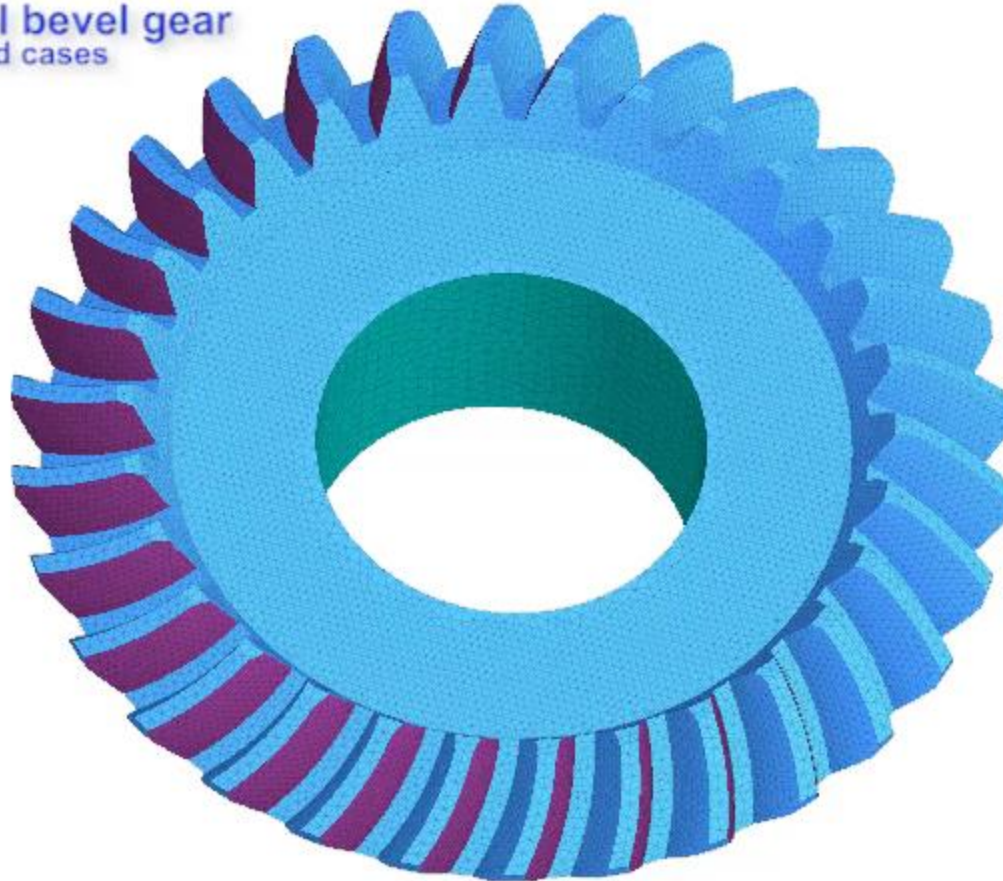
# Animation, Oil pan



CAESS ProTOp Ver: 4.0.8  
Date: 08/24/2015 Inp: OilPanM.ptop Own: CAESS d.o.o.

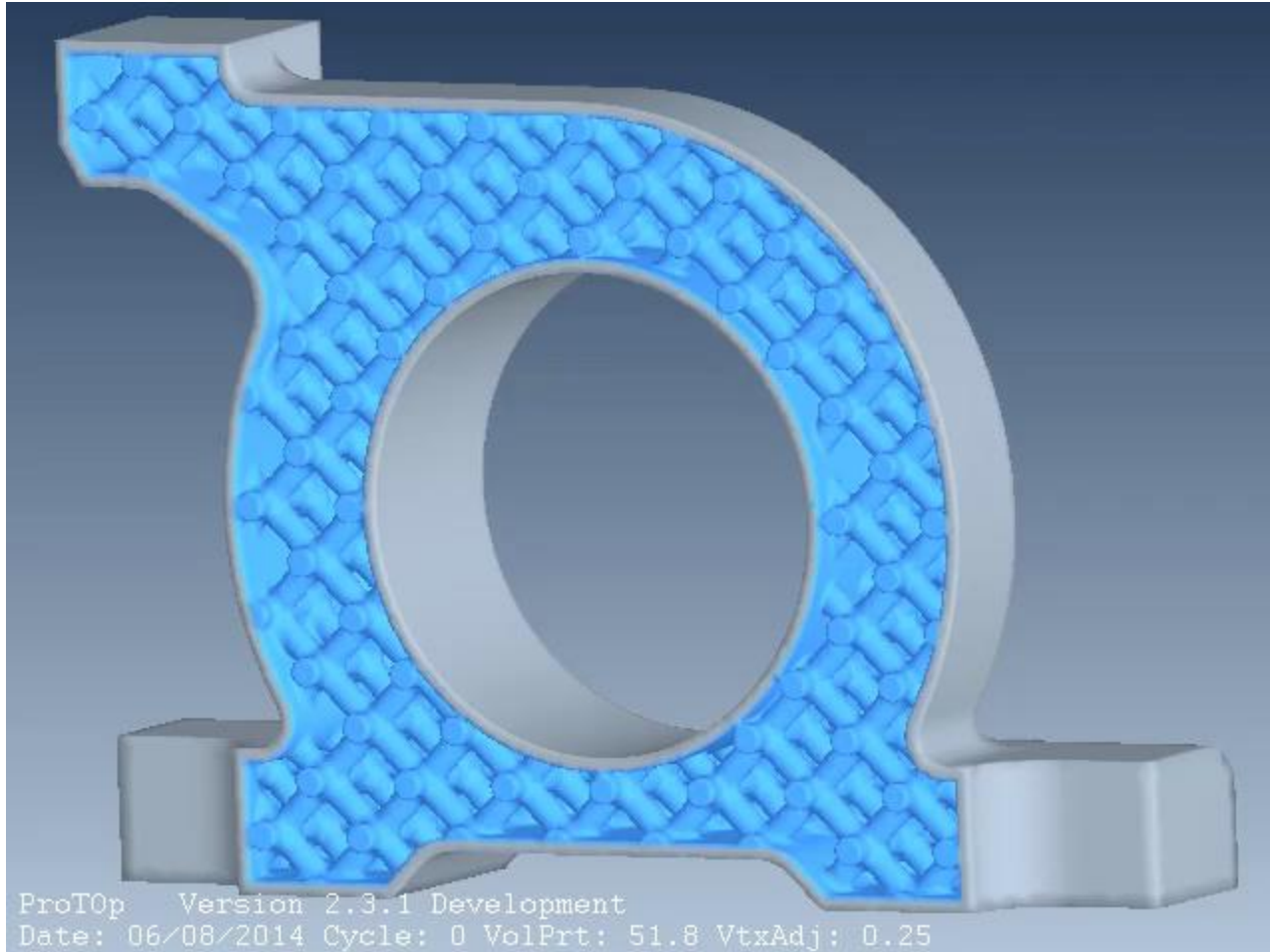
# Animation, Spiral bevel gear

Spiral bevel gear  
30 Load cases



CAESS ProTop Ver: 3.1.9 Cyc: 46 VolPrt: 58.1  
Date: 04/30/2015 Inp: SpiralBevel.ptop Own: CAESS d.o.o.

# Animation, Bearing holder





**CAESS**

Center for Advanced Engineering Software and Simulations

SILVER

PTC® PartnerAdvantage



# Thanks!

CAESS in collaboration with our partner

