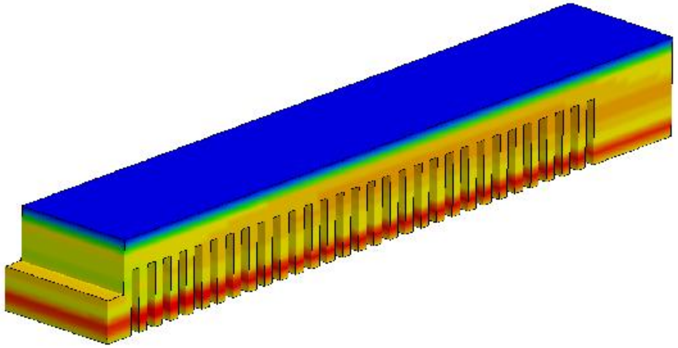
15th German LS-DYNA® Forum



Simulation strategies for additive manufacturing with LS-DYNA

C. Liebold

10/2018 – Bamberg, GER

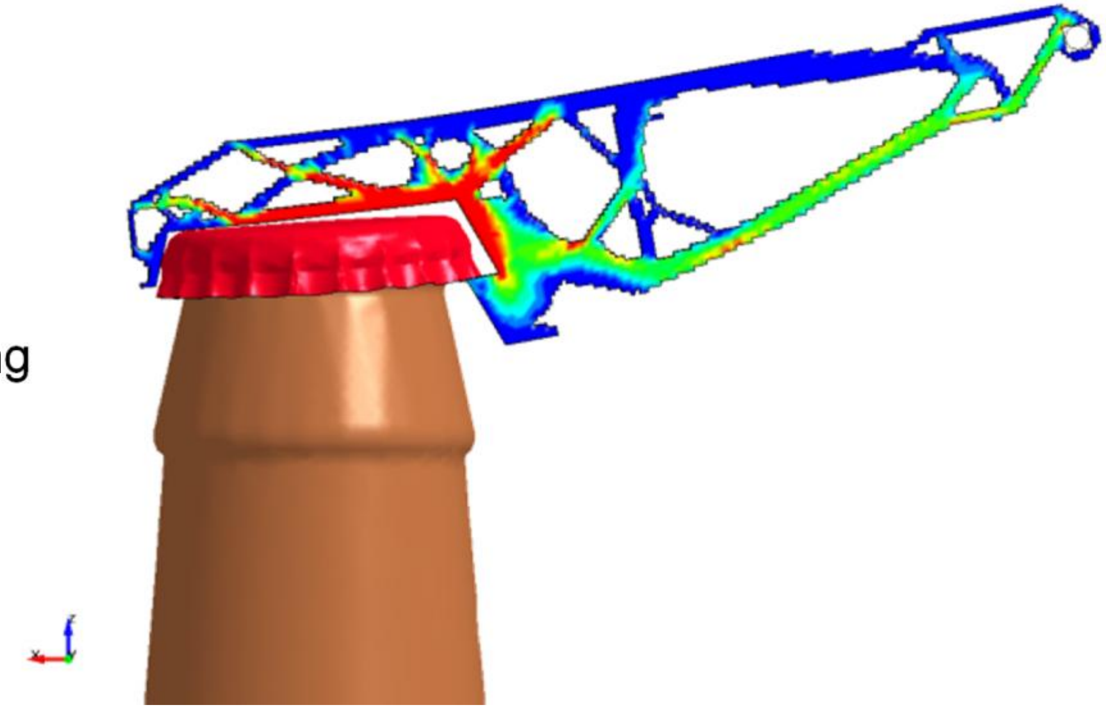
Agenda

- Motivation
- Methods available in LS-DYNA
- Modeling approaches
- Future Plans & Summary

Motivation

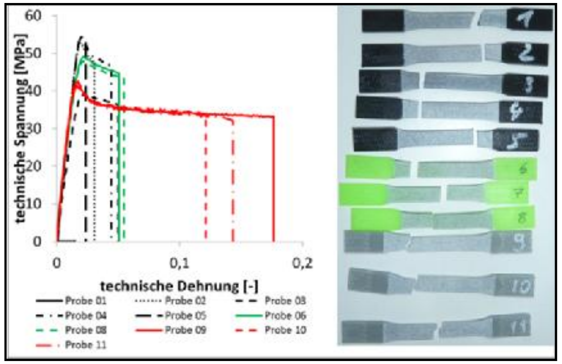
- There exist a large variety of methods:
  - Selective laser sintering (SLS)
  - Selective laser melting (SLM)
  - Fused Deposition Modeling (FDM)
  - Stereolithography (SL)
  - Laminated Object Modeling (LOM)
  - Powder Bed and Inkjet head 3D printing

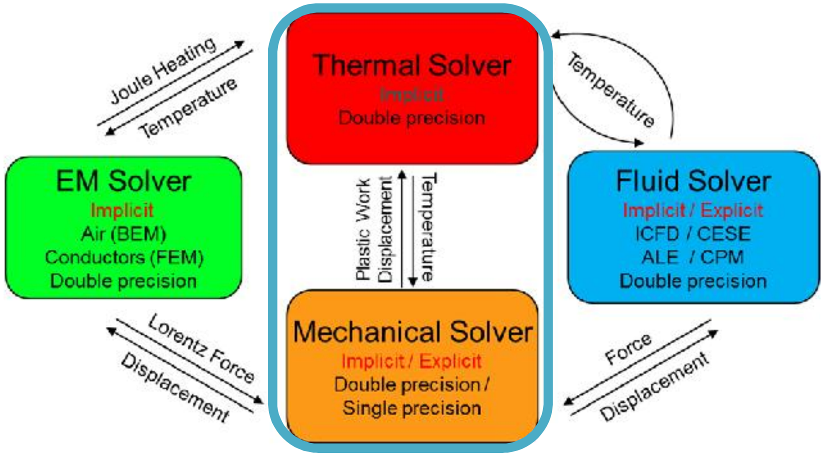
  - … and many more…



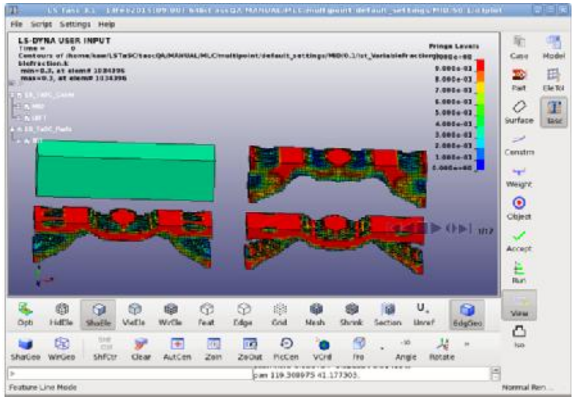
Motivation

- All these processes have something in common:
  - They are very often temperature dependent methods
  - They allow for individual and highly complex part generation
  - The production process might have an influence on the resulting components behavior





LS-TaSC: topology optimization



Methods available in LS-DYNA

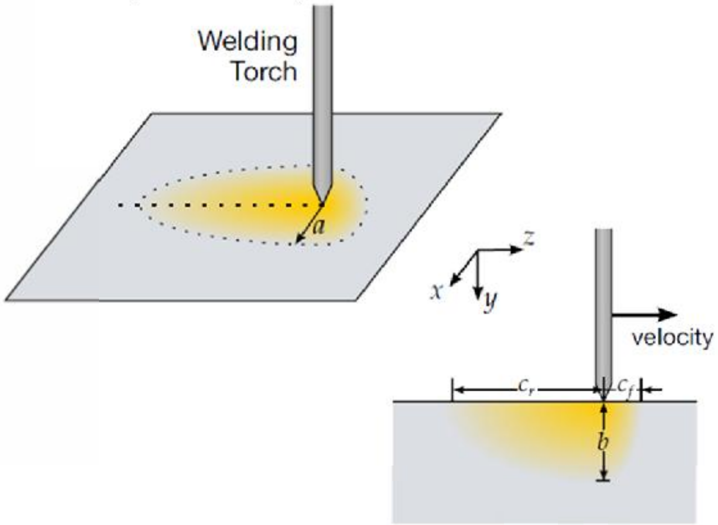
- Methods used are adopted from welding simulation:
  - Usage of *BOUNDARY_THERMAL_WELD_TRAJECTORY

	1	2	3	4	5	6	7	8
Card 1	PID	PTYP	NSID1	VEL1	SID2	VEL2	NCYC	RELVEL
Card 2	IFORM	LCID	Q	LCROT	LCMOV	LCLAT	DISC	
Card 3	P1	P2	P3	P4	P5	P6	P7	P8
Opt.	Tx	Ty	Tz					

    - *SET_NODE which defines the laser path
    - Velocity of the weld source
    - NCYC = Number of sub-cycling steps
    - IFORM = Geometry of energy-rate density distribution
    - LCID & Q = weld energy input rate vs. time and multiplier

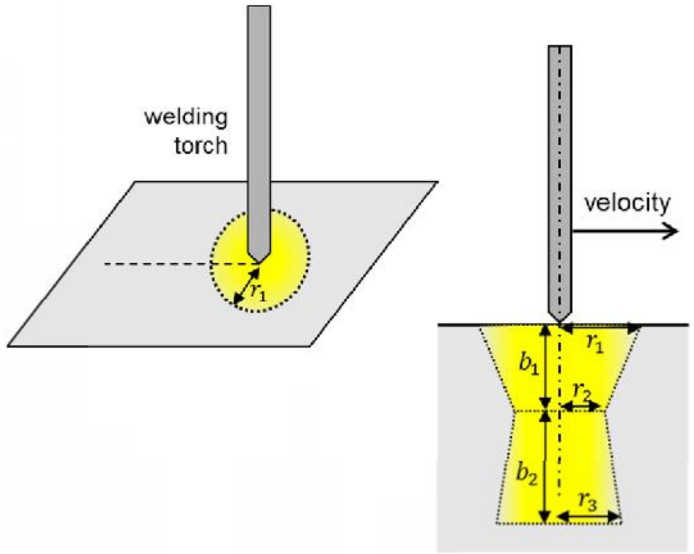
Methods available in LS-DYNA

- Methods used are adopted from welding simulation:
  - Usage of *BOUNDARY_THERMAL_WELD_TRAJECTORY
  - For IFORM=1 (Goldak)
    - P1: a
    - P2: b
    - P3: c_f
    - P4: c_r
    - P5: F_f
    - P6: F_r
    - P7: n



$$q = \frac{2n\sqrt{n}FQ}{\pi\sqrt{\pi}abc}\exp\left(\frac{-nx^2}{a^2}\right)\exp\left(\frac{-ny^2}{b^2}\right)\exp\left(\frac{-nz^2}{c^2}\right)$$

  - For IFORM=3 (double conus)
    - P1: r_1
    - P2: r_2
    - P3: r_3
    - P4: b_1
    - P5: b_2
    - P6: F_1
    - P7: F_2



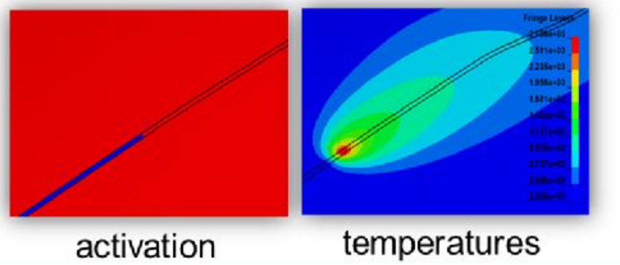
$$q = \frac{3FQ}{2\quad(R^2 + r^2 + Rr)}$$

Methods available in LS-DYNA

- Methods used are adopted from welding simulation:
  - Usage of *MAT_THERMAL_CWM (*MAT_T07)

	1	2	3	4	5	6	7	8
Card 1	TMID	TRO	TGRLC	TGRMULT	HDEAD	TDEAD		
Card 2	LCHC	LCTC	TLSTART	TLEND	TISTART	TIEND	HGHOST	TGHOST

- TISTART/-END = Material has a birth and death time
  - Allows to turn on layers
  - Until birth HDEAD/TDEAD
- TLSTART/-END = Material is activated based on temperature
  - Allows to evaluate, if melting process has been successfull
  - Until activated HGHOST/TGHOST
- All parameters are temperature dependent

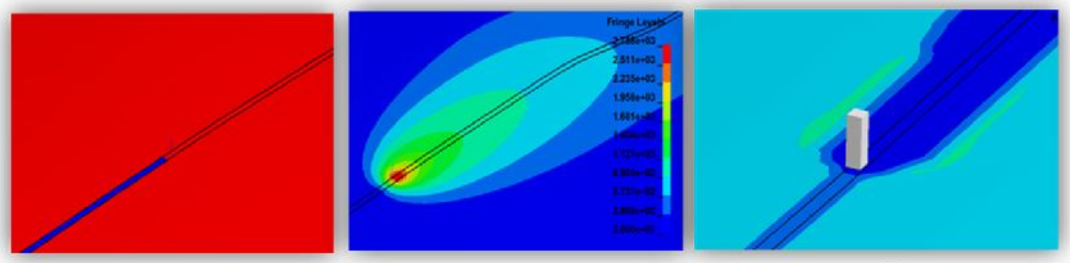


Methods available in LS-DYNA

- Methods used are adopted from welding simulation:
  - Usage of *MAT_CWM (*MAT_270)

	1	2	3	4	5	6	7	8
Card 1	MID	RO	LCEM	LCPR	LCSY	LCHR	LCAT	BETA
Card 2	TASTART	TAEND	TLSTART	TLEND	EGHOST	PGHOST	AGHOST	
Opt.	T2PHASE	T1PHASE						

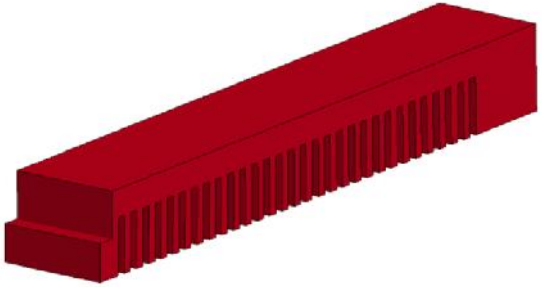
  - TASTART/-END = temperature range for annealing process
  - TLSTART/-END = temperature range for material activation
  - Until activation:
    - Low stiffness
    - Negligible thermal expansion
  - Card 1 contains activated properties

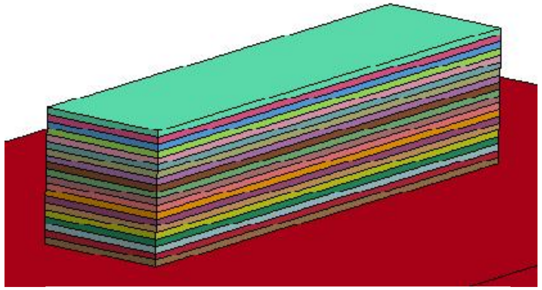


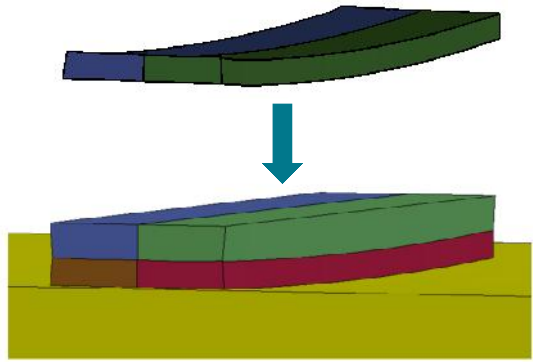
activation temperatures annealing

Modeling Approaches

- Different modeling approaches are conceivable:
  - „smeared approach“
    - Only one part
    - Coincident nodes
  - „semi-detailed approach“
    - One part for each layer
    - Contacts have to be defined between the layers
    - Thermal contact can be activated depending on time
  - „Detailed approach“
    - layer- or even element wise activation (remeshing)
    - Volume consistency?

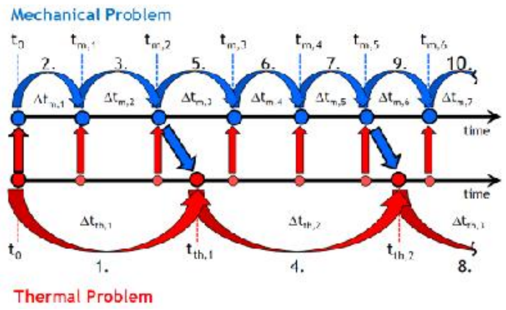






Modeling Approaches

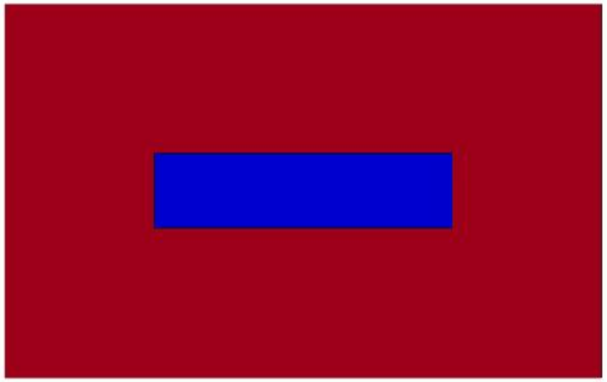
- All approaches allow for path consideration:
  - Element-wise activation - small thermal timestep size ncyc = 1
  - Patch-wise activation - medium thermal timestep size ncyc = ↗
  - Layer-wise activation - large thermal timestep size ncyc = ↑
- Simulation can be done in two steps:
  - 1) Run thermal analysis only
  - 2) Run mechanical analysis using *LOAD_THERMAL_D3PLOT



- Direct coupling between thermal and mechanical analysis is possible
- Thermal analysis is implicit, mechanical can be implicit or explicit

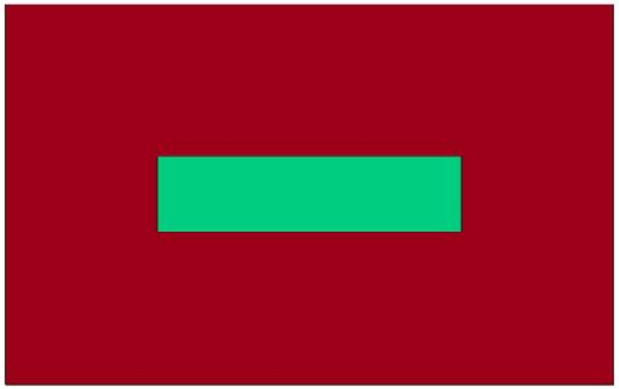
Modeling Approaches

- Thermal only analysis (20 Layers)
  - dt_max = 1.0
  - Printing time for each layer: ~ 0.04 s, cooling time/layer = 10 s, final cooling = 100 s



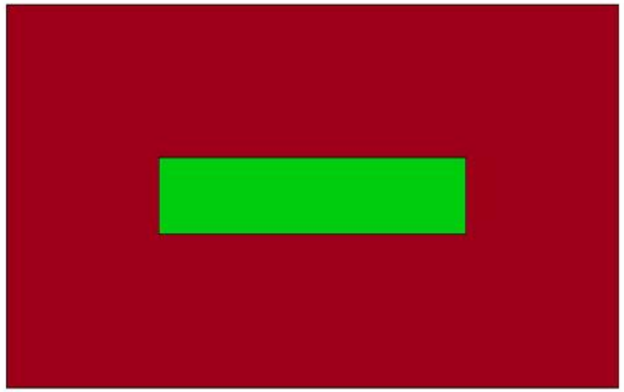
Element-wise activation

min. dt = 2.E-04
cpu time = 21min, 16 s
ncyc = 1



Patch-wise activation

min. dt = 2.E-03
cpu time = 16min, 15 s
ncyc = 11

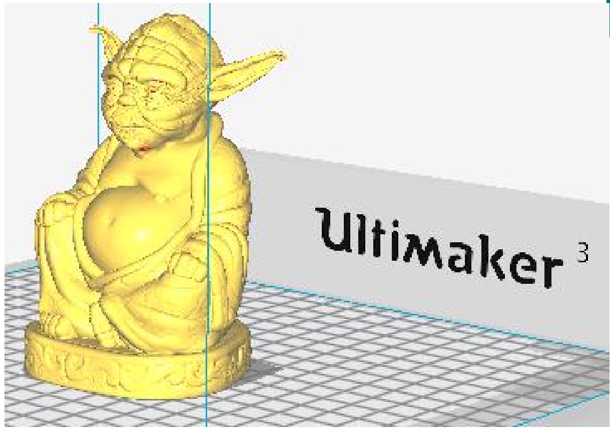


Layer-wise activation

min. dt = 2.E-02
cpu time = 7min, 26 s
ncyc = 101

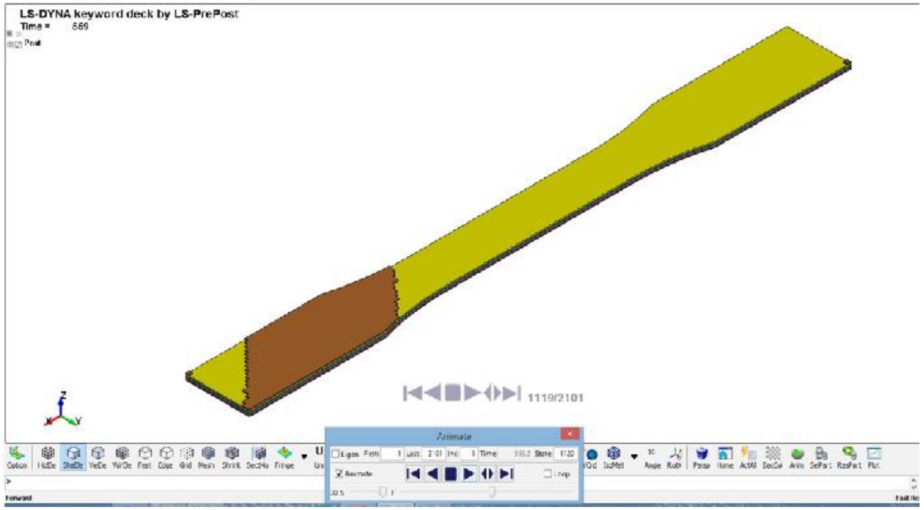
Modeling Approaches

- How do we get the path into the model?
  - Ultimaker Cura software allows for gcode-path generation based on step-data
  - envyo® allows for data interpretation, point cloud and *SET_NODE – generation
  - *BOUNDARY_THERMAL_WELD_-TRAJECTORY cards, min/max timestep curves, part and contact activation times
  - (model uses ~1.7million points, 1730 layers, more than 95.000 trajectories)

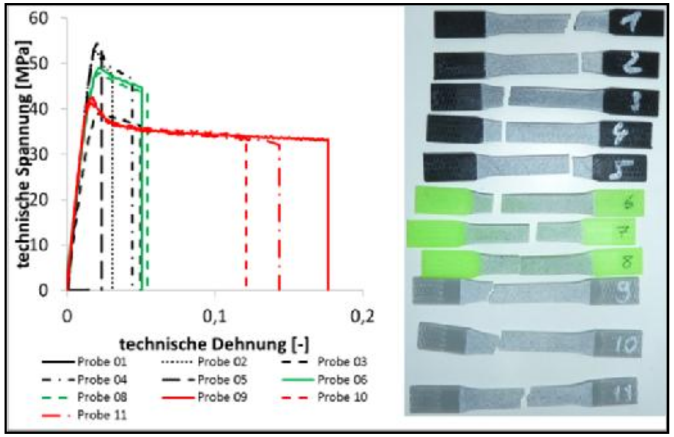


Future Plans & Summary

- Simulation of additive manufacturing processes is doable with LS-DYNA
- envyo® helps to simplify the pre-processing when it comes to path-considerations

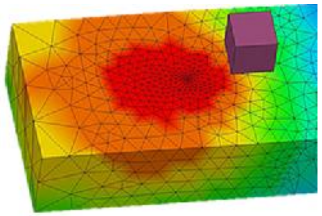


- Further investigation should be done regarding the influence of the introduced methods on the warpage of the part
- Mapping the simulation result and paths onto structural meshes

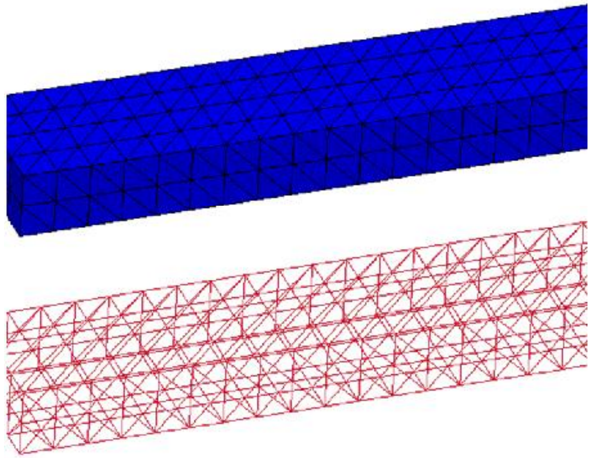


Future Plans & Summary

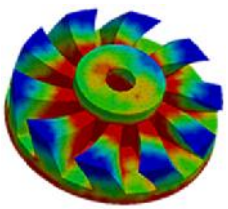
- LSTC is working on that topic
- Recent enhancements include adaptive remeshing based on the temperture gradient
- Further information:
  - www.lstc-cmmg.org/3d-printing



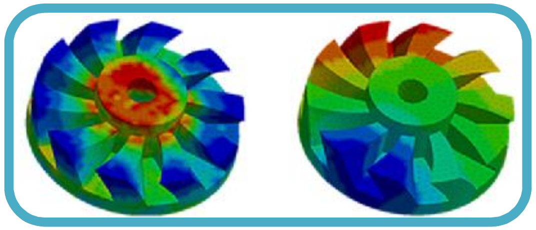
temperature



v. Mises stress

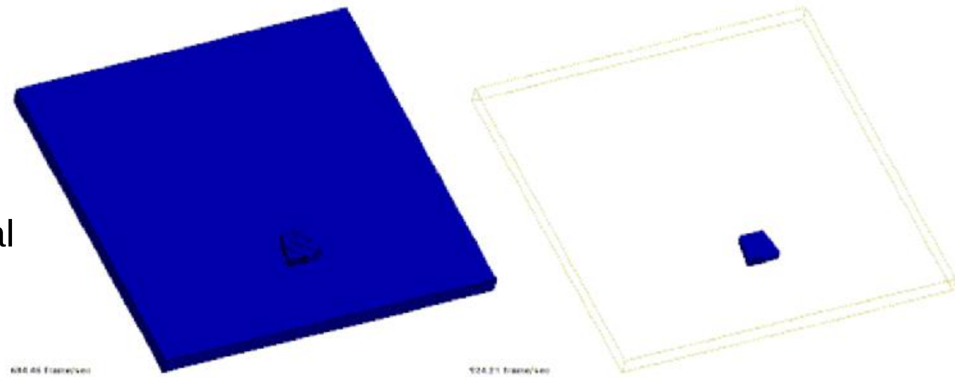


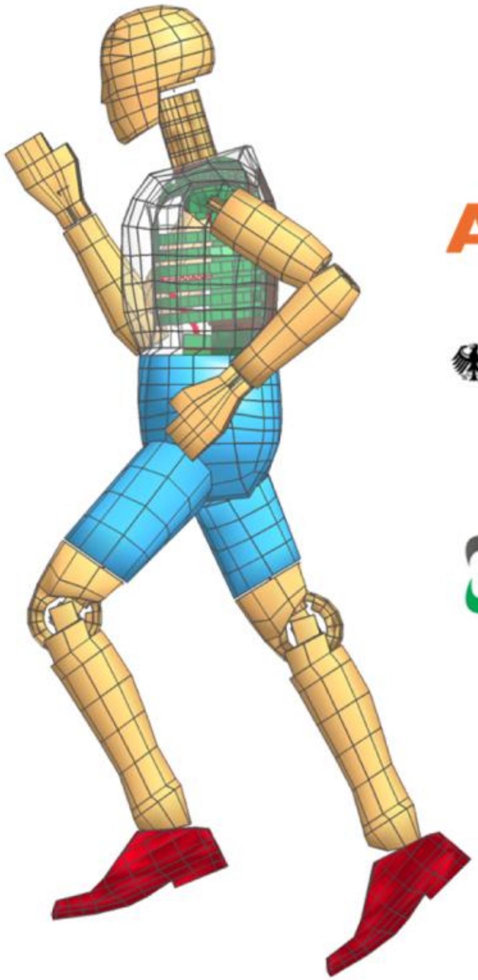
springback



v. Mises stress res. Displ.

300s printing time
0.1s time step
0.5s adapt. interval
1.5h on 8 CPUs





ARENA2036 DigitPro

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

FORSCHUNGS
CAMPUS
öffentlich-private Partnerschaft
für Innovationen

PTKA
Projektträger Karlsruhe
Karlsruher Institut für Technologie

ITEA3

VMAP

C. Liebold[1]

[1]DYNAmore GmbH
Industriestraße 2
70565 Stuttgart

cl@dynamore.de