Coupled Thermo-Mechanical weld distortion analysis

SAND2013-4317P

Original ITER work was done 9/2010 for the ITER project

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Current Weld mod/sim capabilities and needs

- Crude residual stress analysis – Adagio/Sandia
  - Linearly cool down entire assembly
    - Apply CTE to weld, all else set CTE=0 to capture shrinkage/tension
- Moving weld 1-way coupled - Calagio/Sandia
  - *Benchmark verifications needed*
  - Uses Thermal_EP_power_weld constitutive model
  - Uses EP power law hardening with low modulus to melt with trigger-melt temp to harden
  - Option to use without trigger melt (needed in some applications)
  - Uses Surface driven heat flux
  - Uses increased thermal conductivity sized to melt metal at bottom of weld
  - Uses Temp dependent material properties (mechanical & thermal)
  - Must Specify weld diameter, speed and power
  - Cross section geometry of weld is needed for simulation

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Current Weld mod/sim capabilities and needs

- Moving weld 1-way coupled - Calagio/Sandia/KCP
  - *Benchmark verifications needed*
  - Use Thermal_EP_power_weld constitutive model
    - EP power law hardening with low modulus to melt with trigger-melt temp to harden
    - Option to use without trigger melt (needed in some applications)
  - Surface flux plus volmetric flux driven
    - weld cross section is not needed here
  - Increased thermal conductivity sized to melt metal at bottom of weld
  - Temp dependent material properties (mechanical & thermal)
  - Specify weld diameter, speed and power
  - Cross section geometry of weld needed for simulation

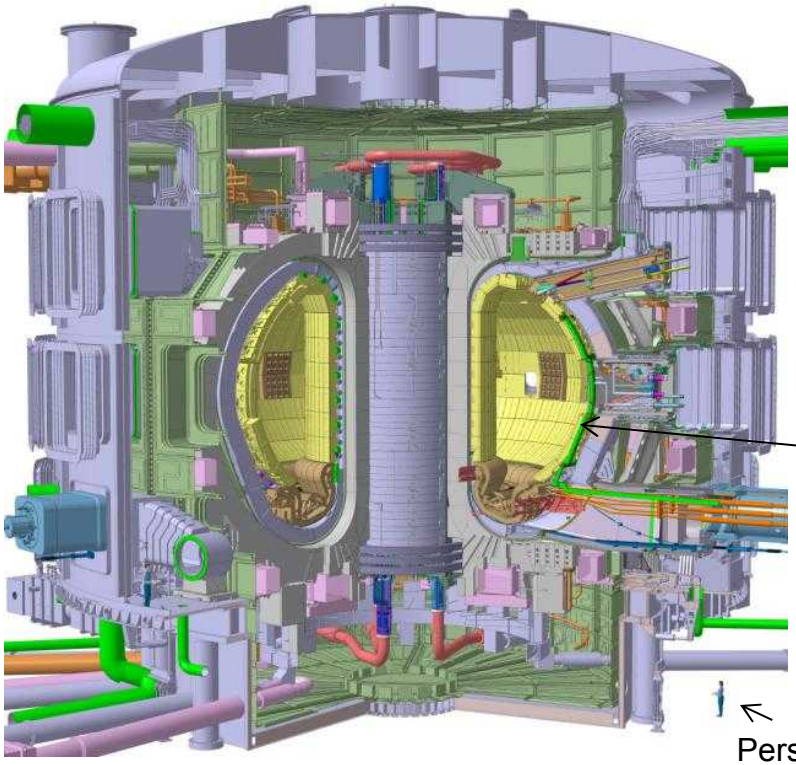
Current Weld mod/sim capabilities and needs

- Moving weld 2-way coupled - Arpeggio/Sandia
  - Same features/requirements as 2-way coupling but using analytic contact – i.e.- temperature dependent tied contact programmed to grab adjacent material at melt temperature.
    - Current capability does not retain tied contact. Needs bug fix/verification.

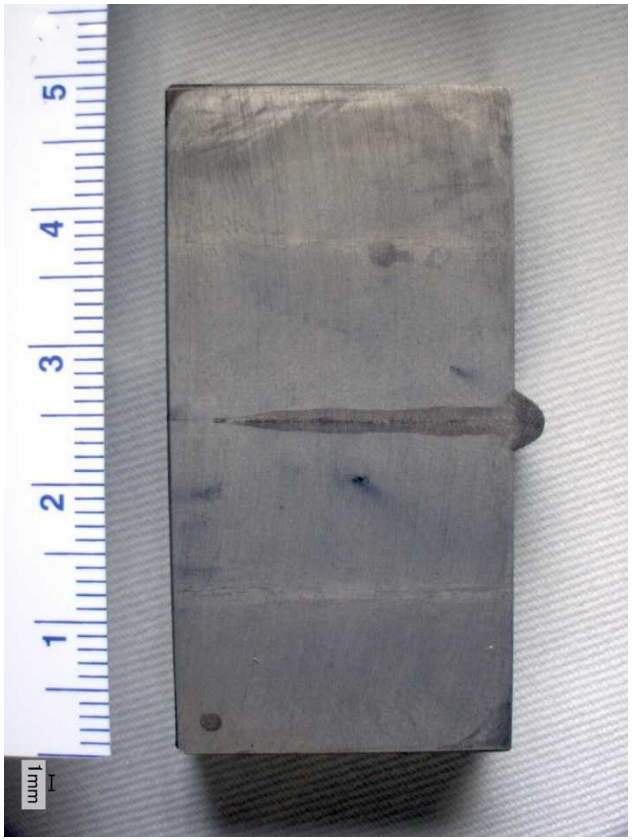
Notes for Optimization

- Considering analytical optimization for a single weld path to minimize distortion and residual stress
  - Where do we place tack welds
  - How do we support the structure
  - Where do we start and finish the weld path
- Considering multiple welds in a single structure
  - What is the weld order
  - Tack weld locations, supports, start/finish locations

Example - ITER Weld-finger coupled thermo-mechanical Electron beam weld distortion analysis

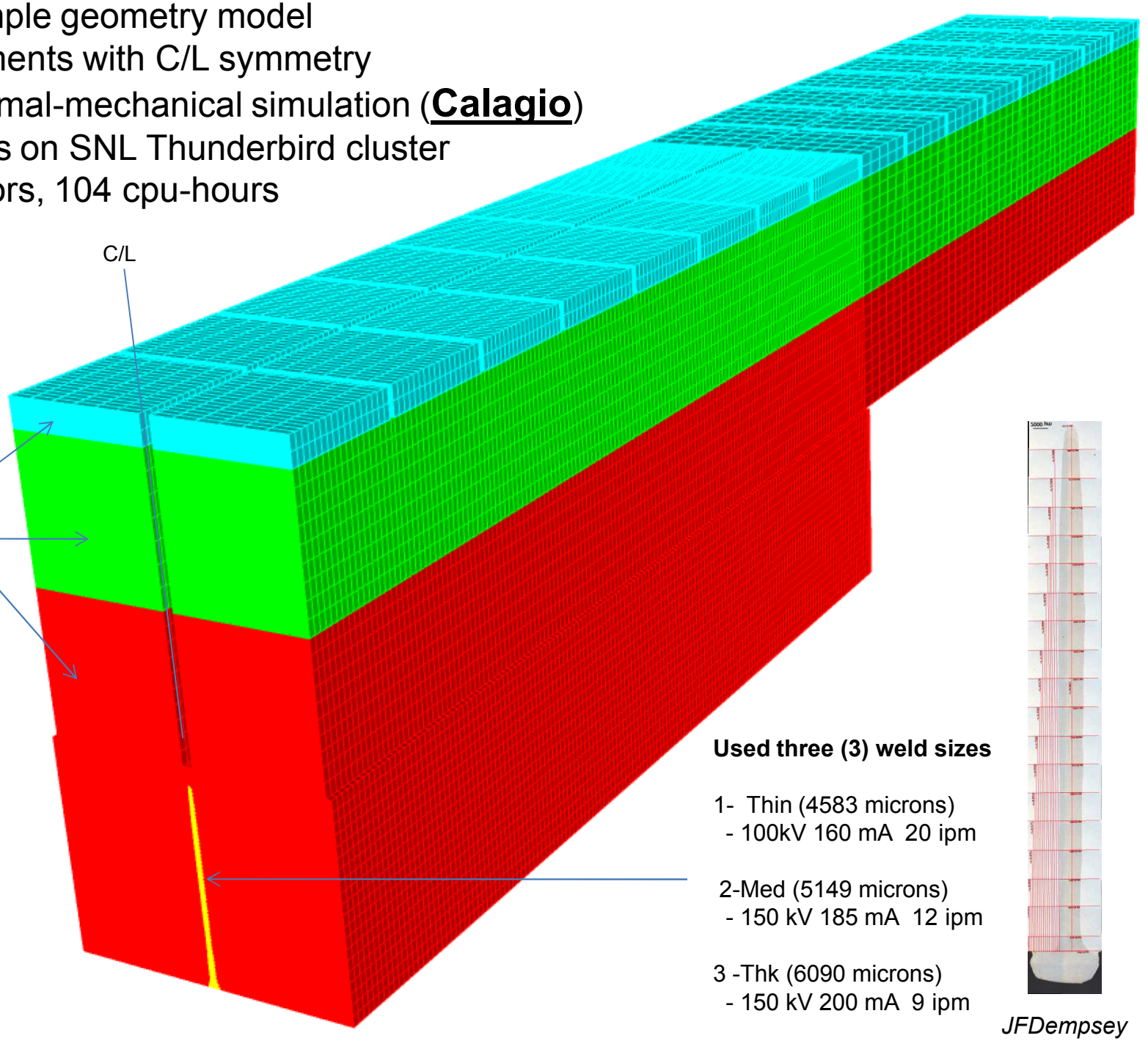


ITER fusion device - France



Example:
deep penetration laser weld

Weld finger simple geometry model
- 175,000 elements with C/L symmetry
- Coupled thermal-mechanical simulation (**Calagio**)
- Computations on SNL Thunderbird cluster
-192 processors, 104 cpu-hours



Used three (3) weld sizes

1- Thin (4583 microns)
- 100kV 160 mA 20 ipm

2-Med (5149 microns)
- 150 kV 185 mA 12 ipm

3 -Thk (6090 microns)
- 150 kV 200 mA 9 ipm

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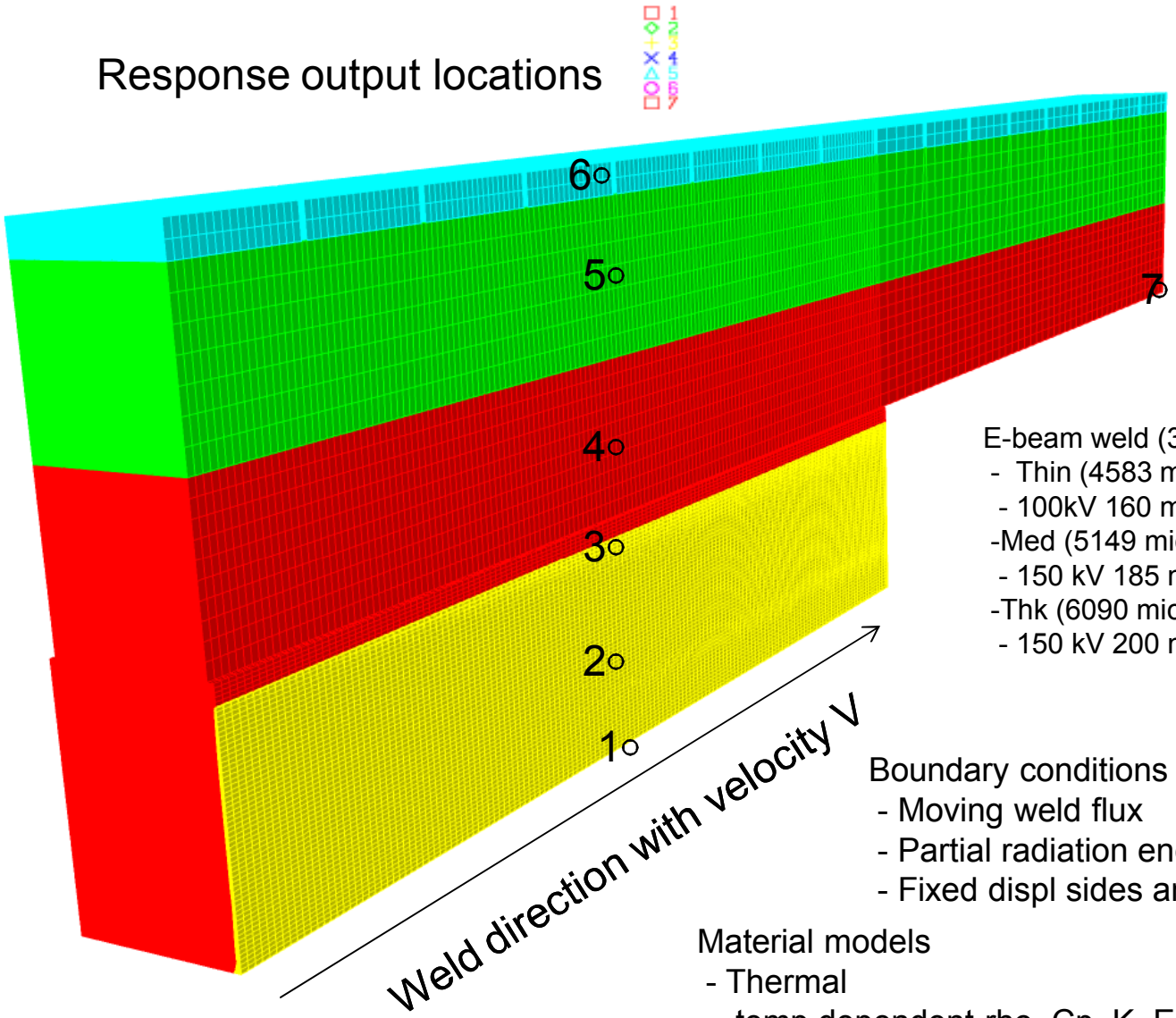
Response output locations



E-beam weld (3)
- Thin (4583 microns)
 - 100kV 160 mA 20 ipm
-Med (5149 microns)
 - 150 kV 185 mA 12 ipm
-Thk (6090 microns)
 - 150 kV 200 mA 9 ipm

Boundary conditions
- Moving weld flux
- Partial radiation encl, all sides
- Fixed displ sides and base

Material models
- Thermal
 - temp dependent rho, Cp, K, Emissivity
 - high cond. over weld length for heat penetration
- Mechanical
 - temp dependent elastic-plastic-power-law-hard

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Material constants

Material	Therm cond W/m-K	Spec heat W/Kg-k	Density Kg/m^3	Emissivity	Modulus Gpa (Msi)	Poisson	CTE ppm/C	RT – Yield Mpa (ksi)	T-Melt C (K)
316L, anealed Stainless steel	26	565	7920	0.3	194.5 (28.2)	0.264	16.6	206.8 (30)	1375 (1648)
Cu, Dispersion strengthened	40	384	8940	0.3	110 (15.9)	0.343		255 (37)	
Be, anealed	182	1717	1848	0.3	303 (43.9)	0.12	11.5	240 (34.8)	

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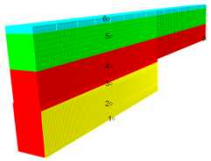
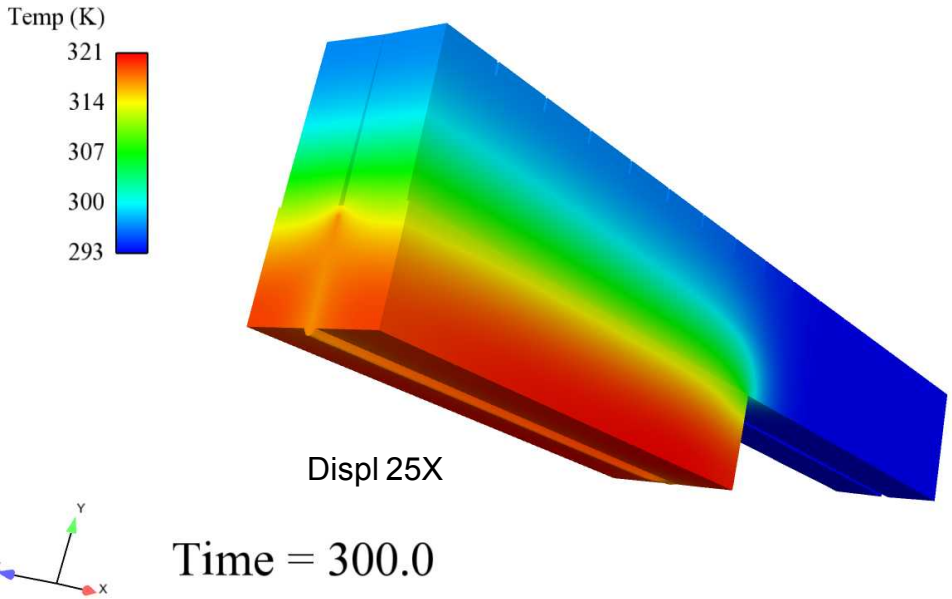
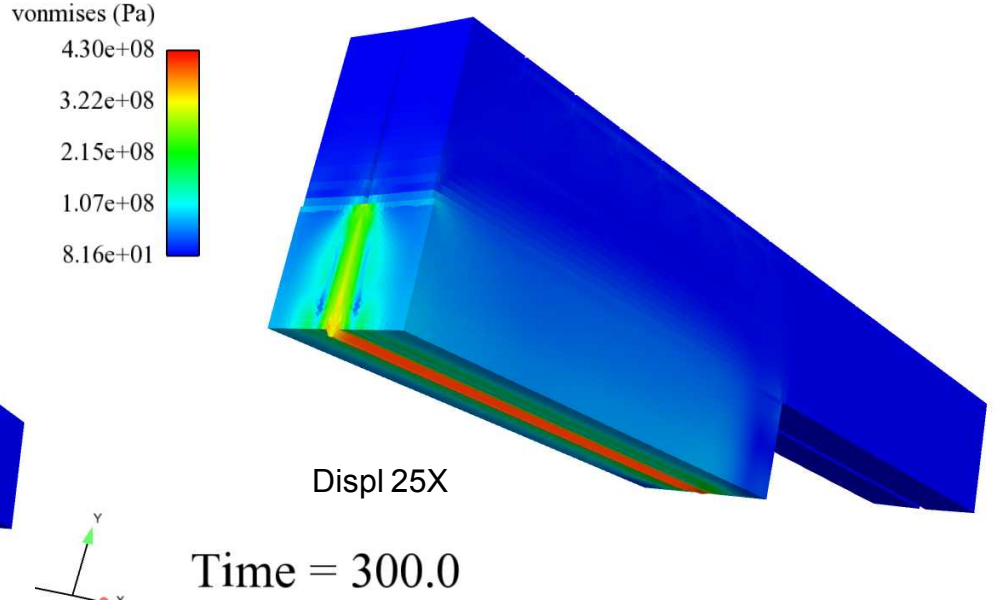
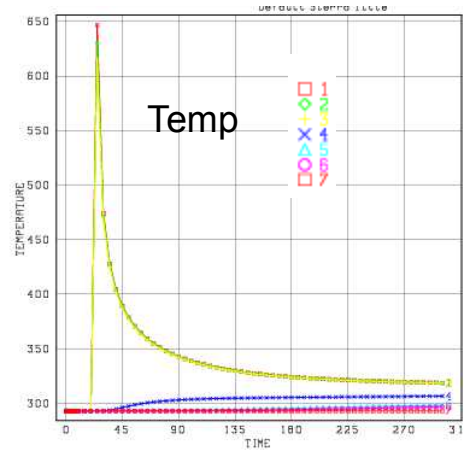
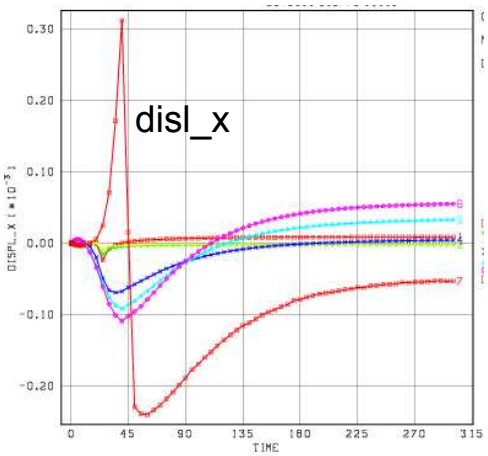
Thin Width Weld
Stress & Temperature results

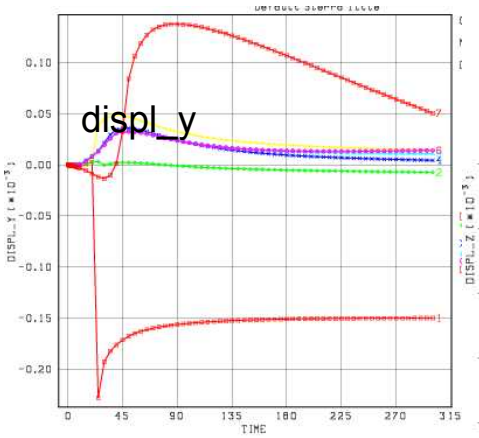


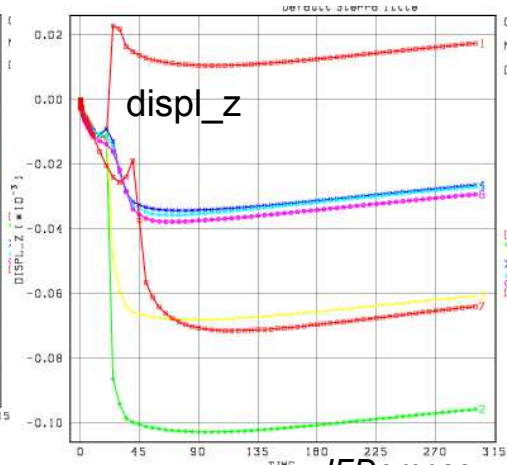












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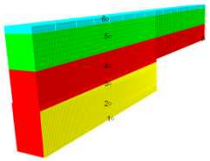
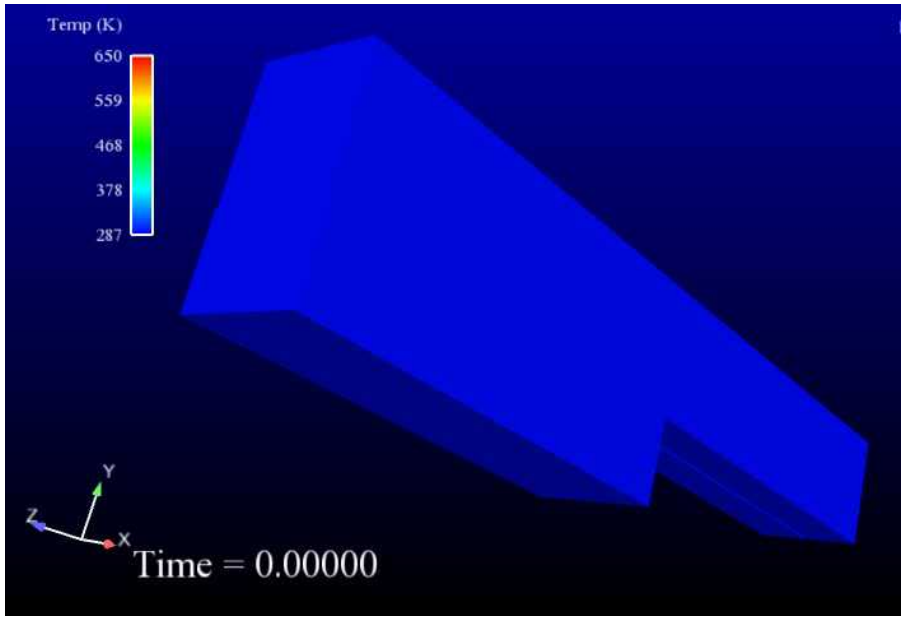
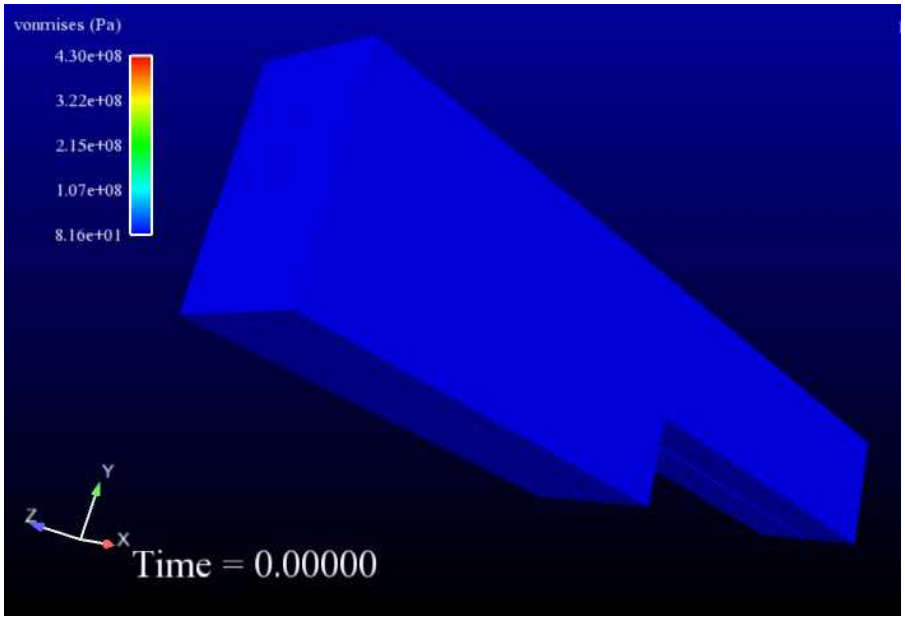
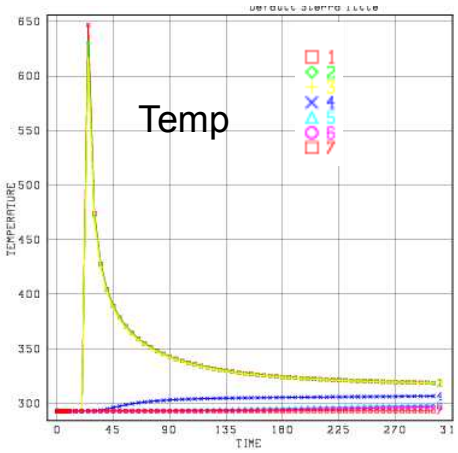
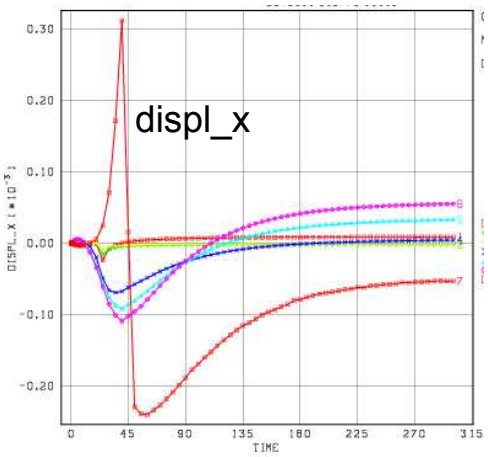
Thin Width Weld
Stress & Temperature results

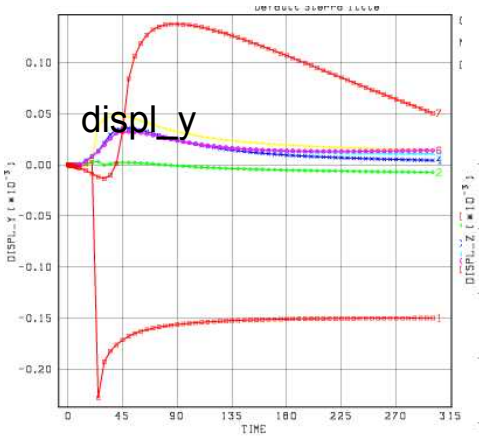


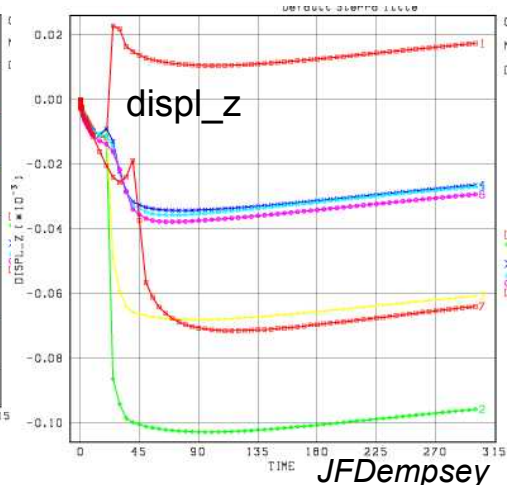












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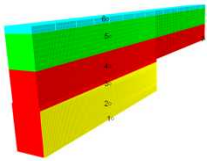
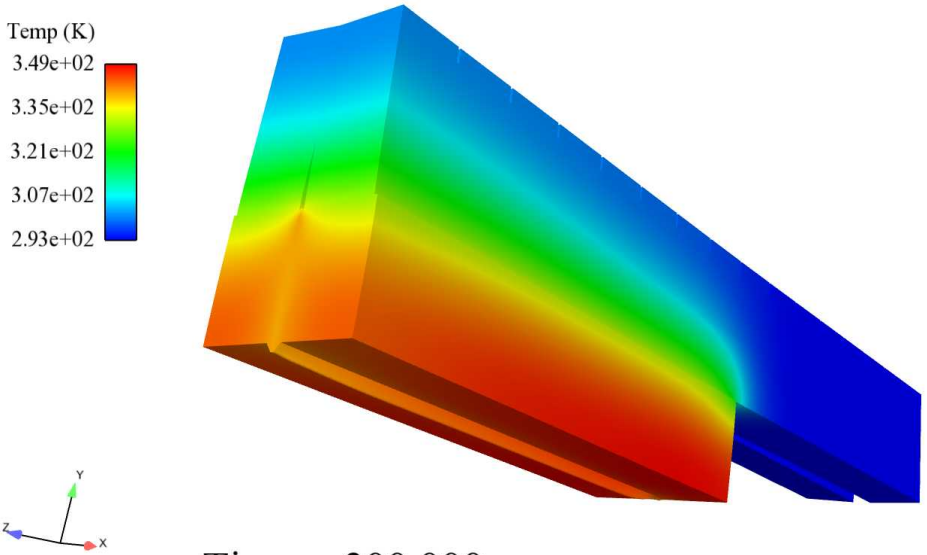
Medium Width Weld
Stress & Temperature results





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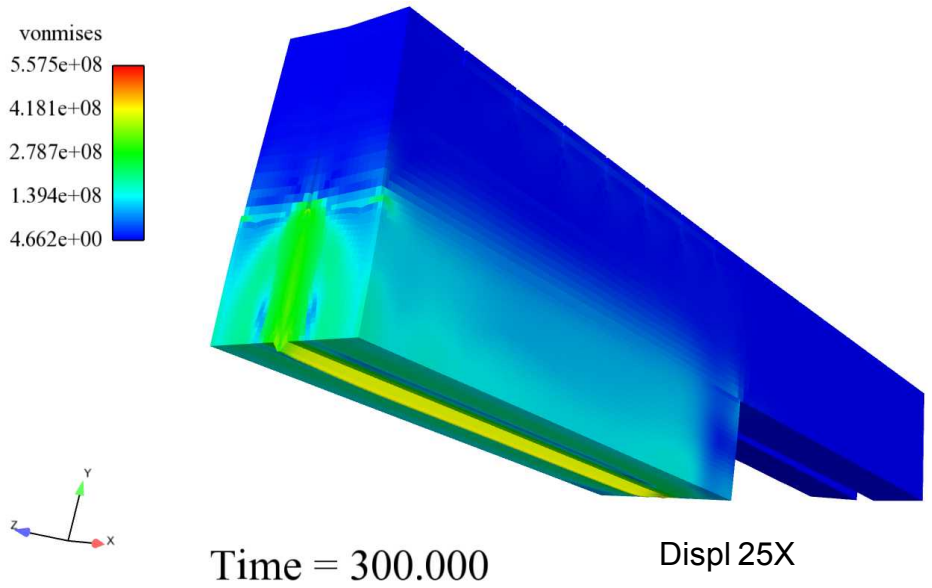
Displ 25X



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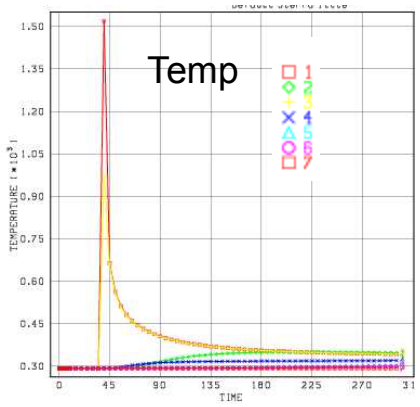

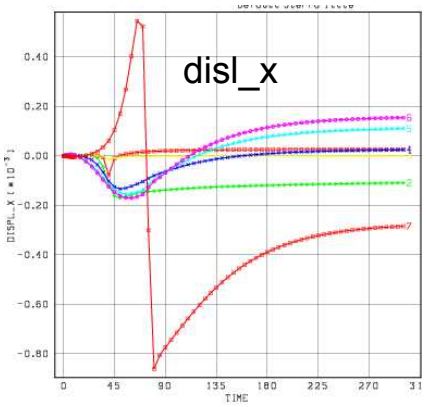

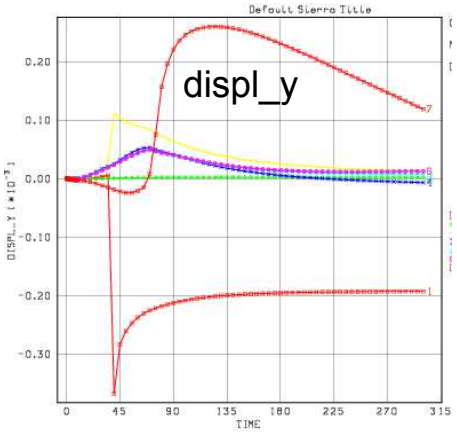

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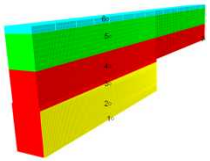

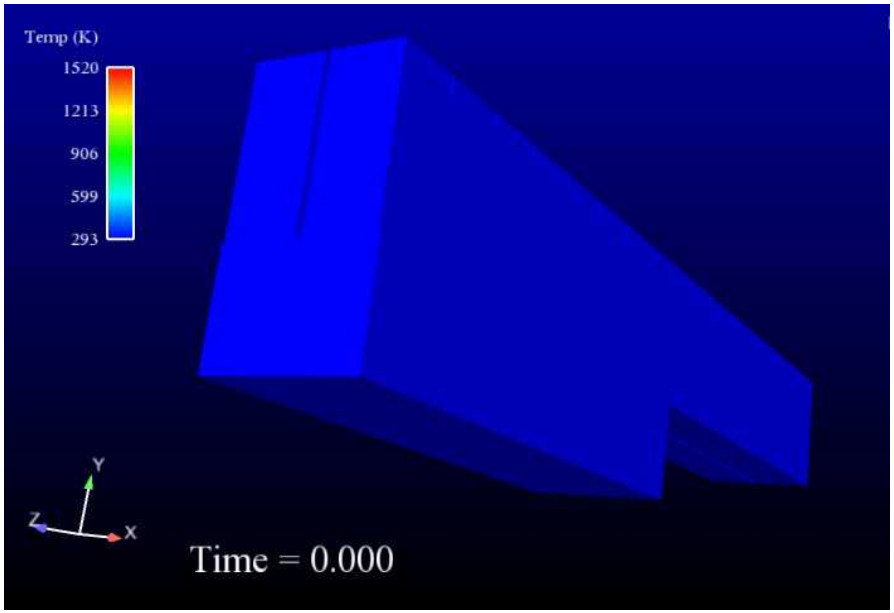

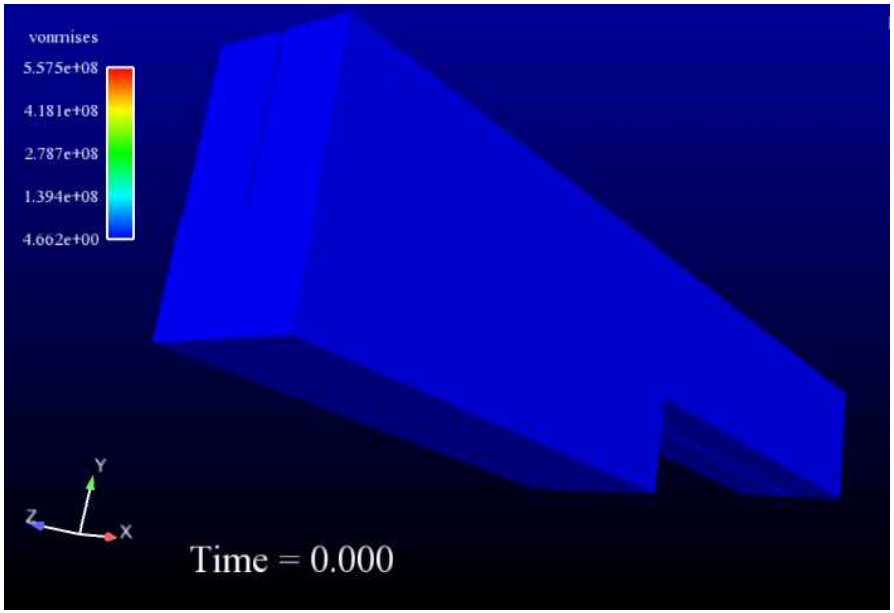

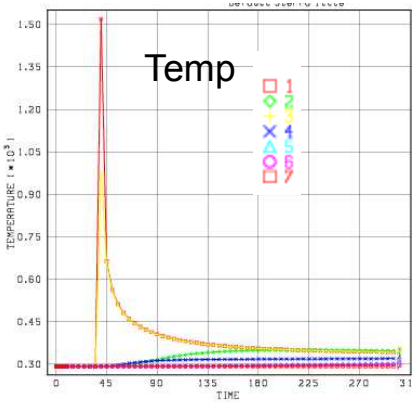

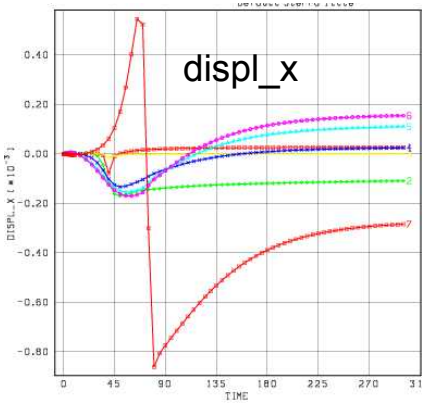

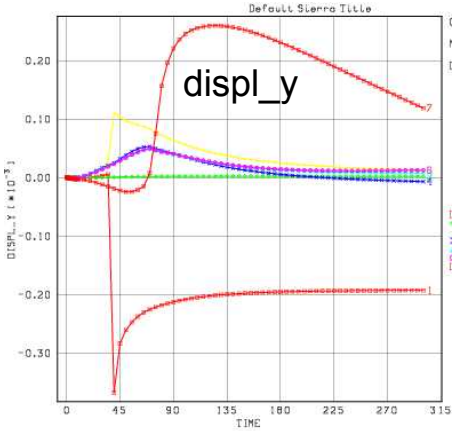

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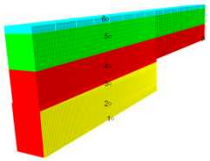
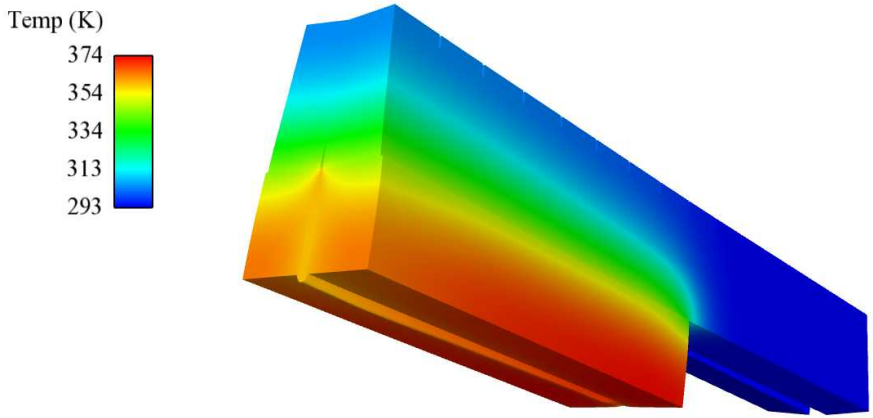
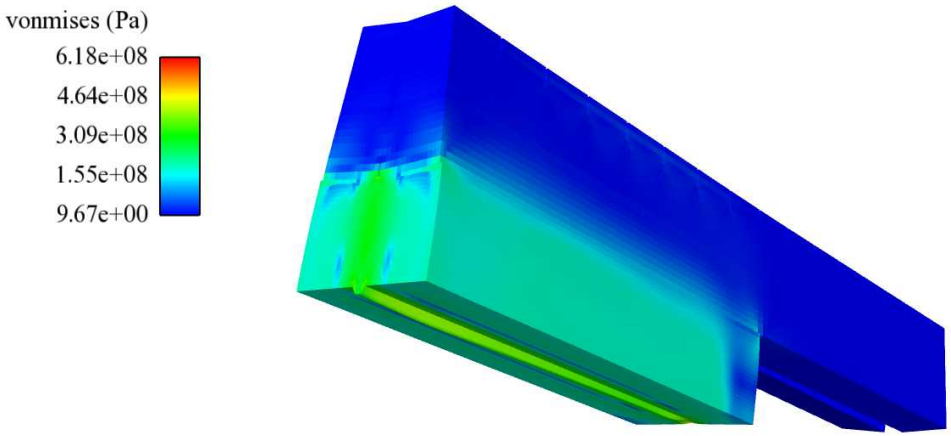
Thick Width Weld
Stress & Temperature results



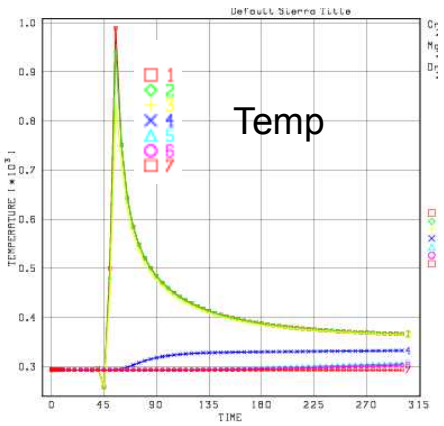


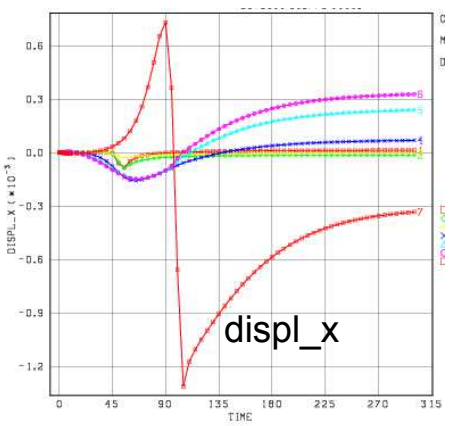


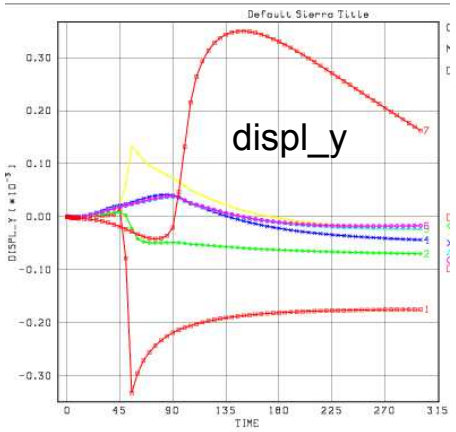
Time = 300.000

Displ 25X

Time = 300.000







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Thick Width Weld
Stress & Temperature results