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ILC Positron Source Target Update

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Lawrence Livermore National Laboratory
9/17/2007

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Agenda

- Review Action Items from Beijing Meeting
- UK Target Wheel Experiment
  - Rotordynamics
  - Thermal Models
  - Fatigue Modeling
- Material Behavior Issues
  - Fatigue
  - Microstructure
- Thermal Stress Simulations
- COMSOL Liquid Metal Calculations
- Radiation Damage Study with UC-Berkeley

Target Session - Action Items

- Source alternative magnet solutions for first proposed UK target prototype - Ian B to coordinate.
- LLNL to evaluate DL target prototype design for vibrational modes and compatibility with water-cooling design (flow rates, etc) - Tom P to coordinate.
- Rationalise proposed UK prototyping with available funding - Ian B to coordinate.
- Continue evaluation of alternative target materials - Chris D to coordinate.
- Seek further clarification from BINP on their 1ms OMD work - Vinod B to coordinate.
- Adopt common geometry for eddy current simulations (based on UK prototype?) - Jeff G to coordinate.
- Beam window issue remains unresolved? Wei + Alexander to discuss.

Action Items (I)

- Magnet sourced with borrowed magnet from Jim Clarke
- Prototype vibrational modes analyzed (Lisle Hagler), water-cooling not applied to prototype
- Ian and DL/Cockcroft have worked on budget and moved forward
- Alternative Target Materials –funding limited, Ian has preliminary chart

Action Items (II)

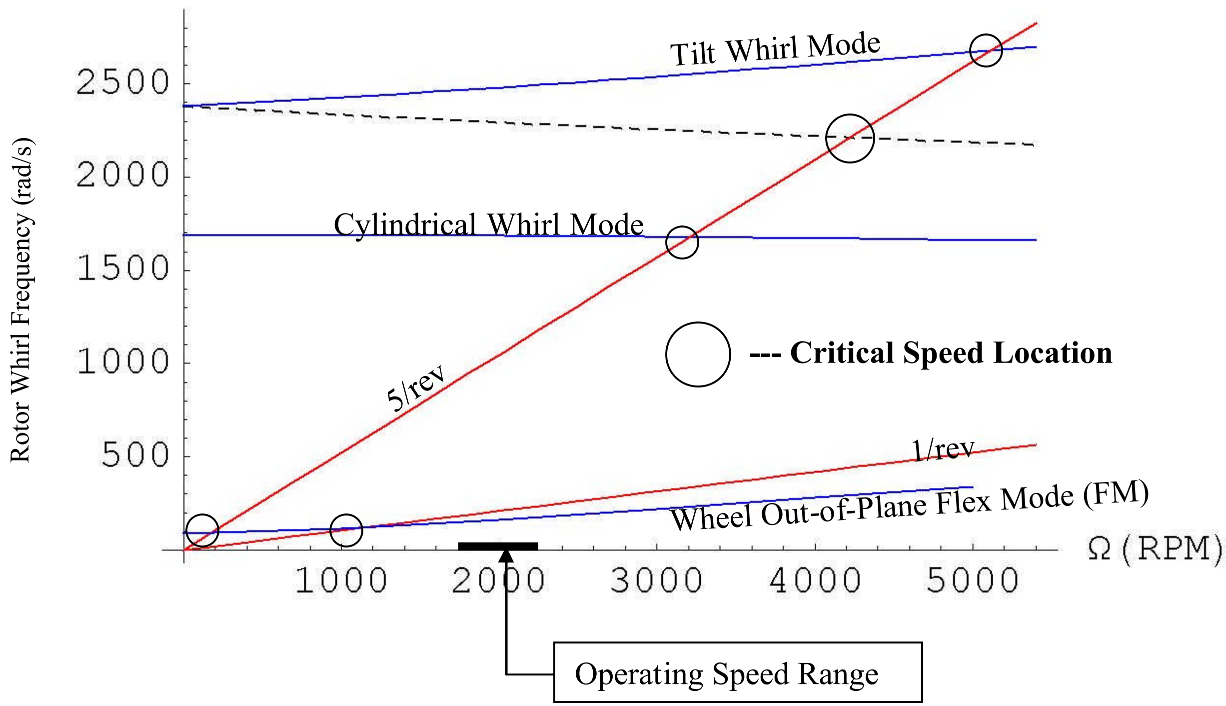
- BINP OMD???
- Geometry for eddy current simulations to be the one used for UK magnet experiments
- Beam Windows, upstream is possible, downstream might be but is unclear

Flywheel Critical Speeds
(Stainless Steel Drive Shaft)

Nominal Design Basis Bearing + Mount Stiffnesses

Support Translational Stiffness = 1,000,000 lbf/in — Support Rotational Stiffness = 10,000 lbf*in/rad

Campbell Diagram



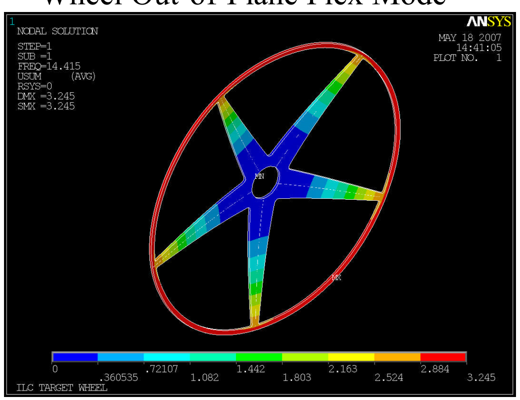
Sources of Rotor Excitation

- Lorentz Force @ 5/rev
- Unbalance @ 1/rev

Major Critical Speeds

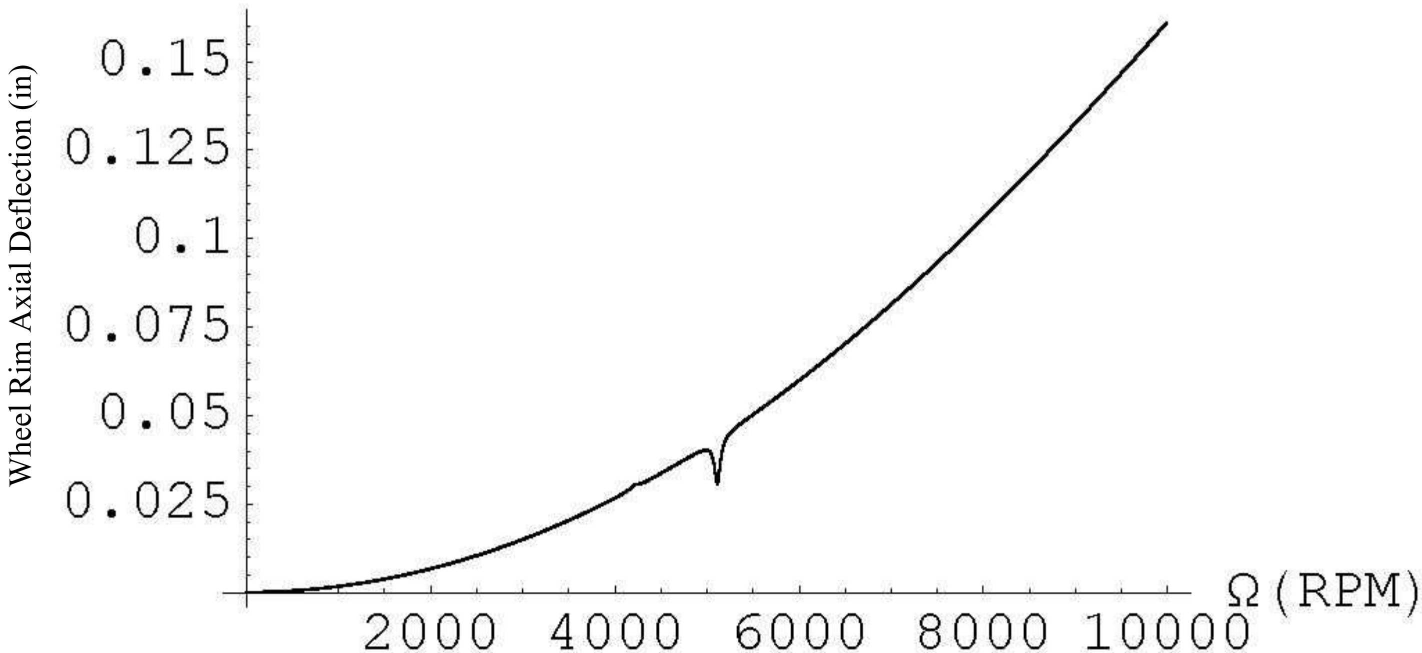
- 1st Wheel FM @ ~ 200 RPM
- 2nd Wheel FM @ ~ 1100 RPM
- Cylindrical Whirl @ ~ 3200 RPM
- Forward Tilt Whirl @ ~ 5000 RPM
- Reverse Tilt Whirl @ ~ 4200 RPM

Wheel Out-of-Plane Flex Mode



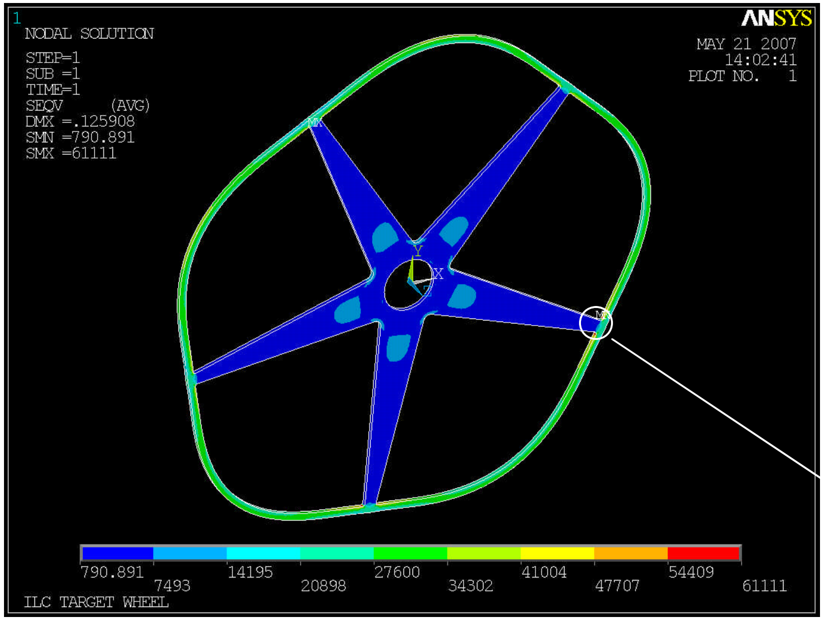
• All critical speeds sufficiently far removed from operating speed range

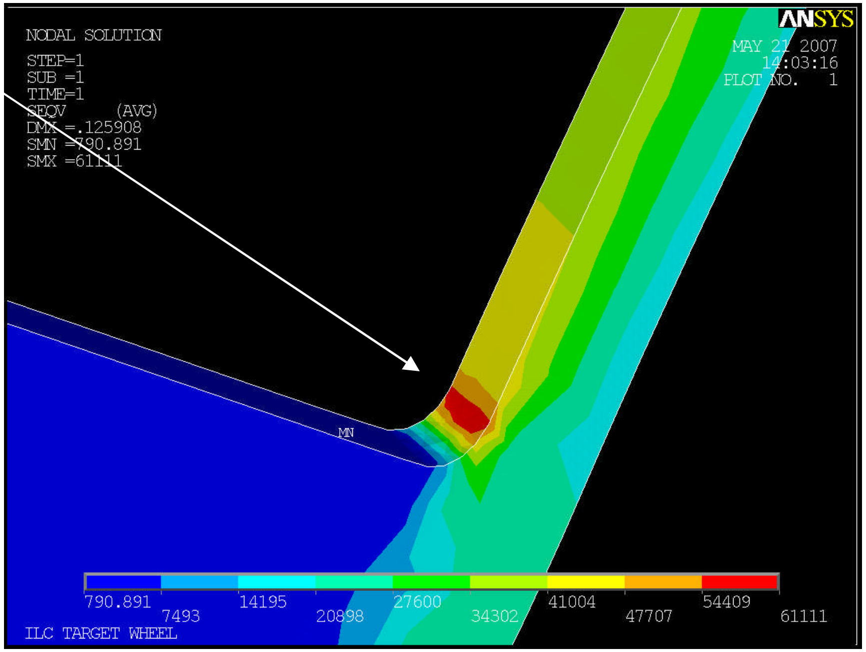
Wheel Rim Axial Deflection Due to Lorenz Forces + Unbalance



- Wheel rim deflection less than 10 mils (0.254 mm) at nominal operating speed of 2000 RPM
- This result assumes that the wheel can be balanced to within 5 mils and wheel polar axis is within 0.1º of the shaft axis

Wheel Von Mises Stress At 2000 RPM
Nominal Operating Speed
(Steady-State Inertial and Lorenz Force Loading)





- **Resultant Load on Wheel = Inertial + Lorenz Forces**
- **Maximum Von Mises Stress in Wheel = 61.1 ksi**
- **Titanium Alloy Has A Nominal Yield Strength of 120 ksi**
- **Safety-Factor = ~ 2.0**

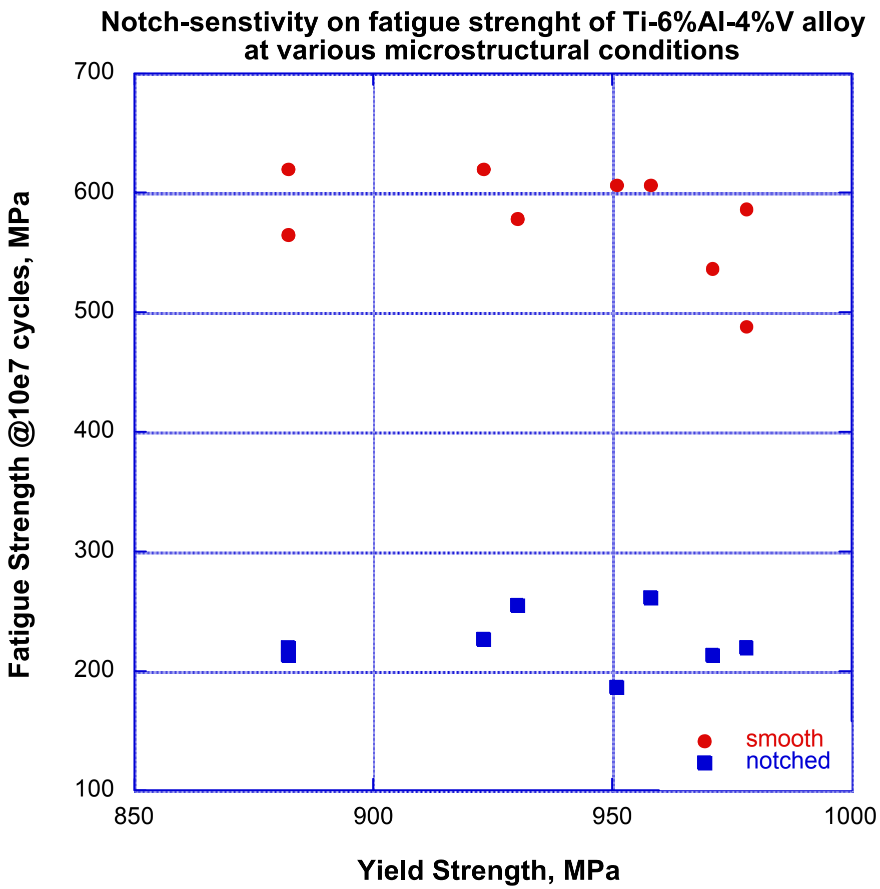
Rotordynamic Conclusions

- All the critical speeds are adequately removed from the ILC wheel operating speed range of 1800 RPM to 2200 RPM for the latest ILC system design using the plumber-block roller bearings
- Bearing dynamic loads are well below capacity
- High stiffness of roller bearing necessary to keep major critical speeds away from wheel operating speed range
- Lorenz force and inertial loading will not cause the wheel to rub the magnet in the operating speed range
- There will be no yielding or rupture of the wheel in operating speed range

Fatigue Calculations

- Fatigue failure is failure due to the action of repeated stress loading
- This can occur at load levels below the yield strength of the material
- Failure begins with a small crack at a discontinuity in the material, which then propagates and leads to a sudden fracture
- Failure can occur without warning

Fatigue Strength of Ti6Al4V



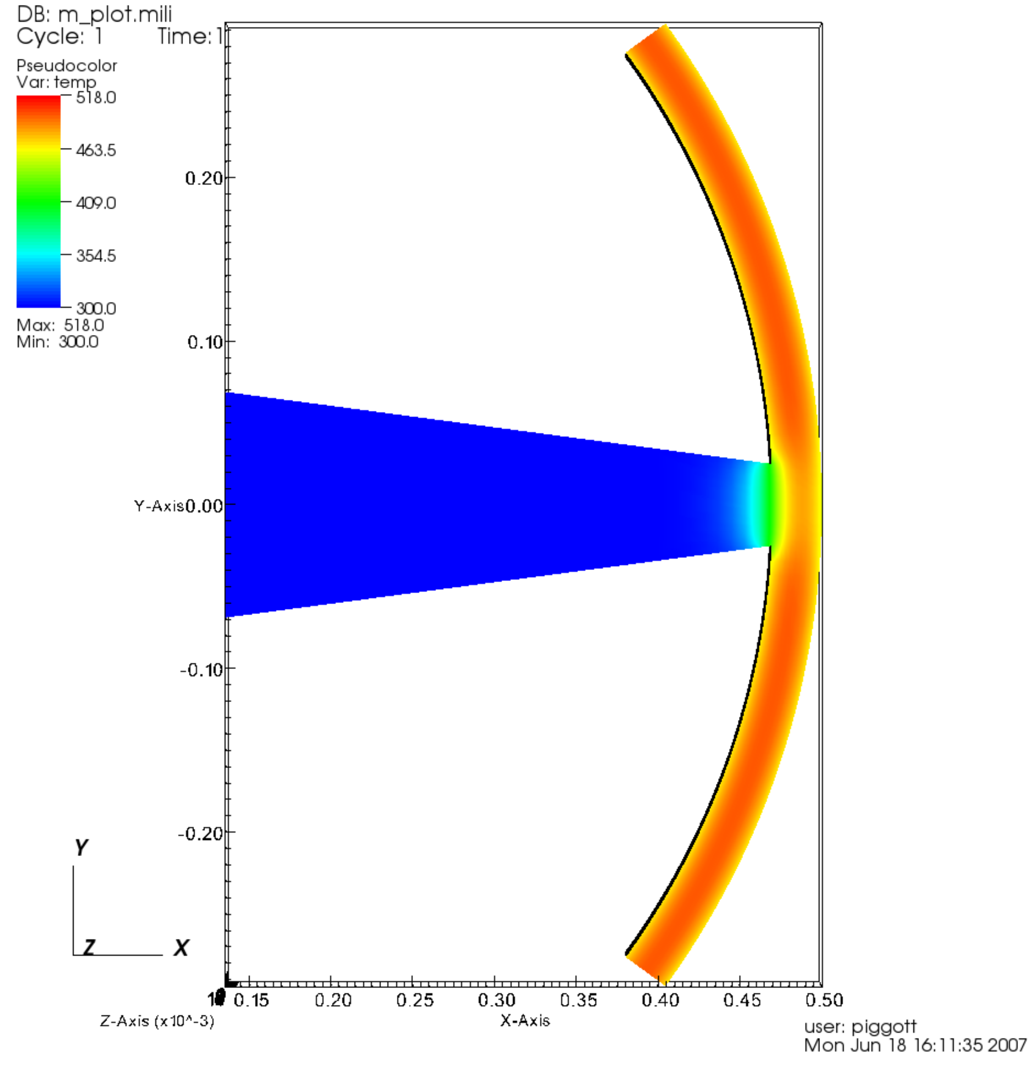
Sparks:1984

Fatigue Calculations for Prototype Wheel

- High Cycle Fatigue- Loading due to spokes being influenced by magnetic field
- Low Cycle Fatigue- Loading due to spin-up/spin down of target wheel to operating conditions
- High cycle fatigue has a margin of safety of about 2
- Low cycle fatigue has a margin of safety of about 1, with further calculations showing a fatigue life of about $6*10^6$ cycles

Heating Calculation for Prototype Wheel

- Worst case scenario
- Uniform heating in outer rim
- Thermal expansion in shaft appears unlikely
- Temperature in K



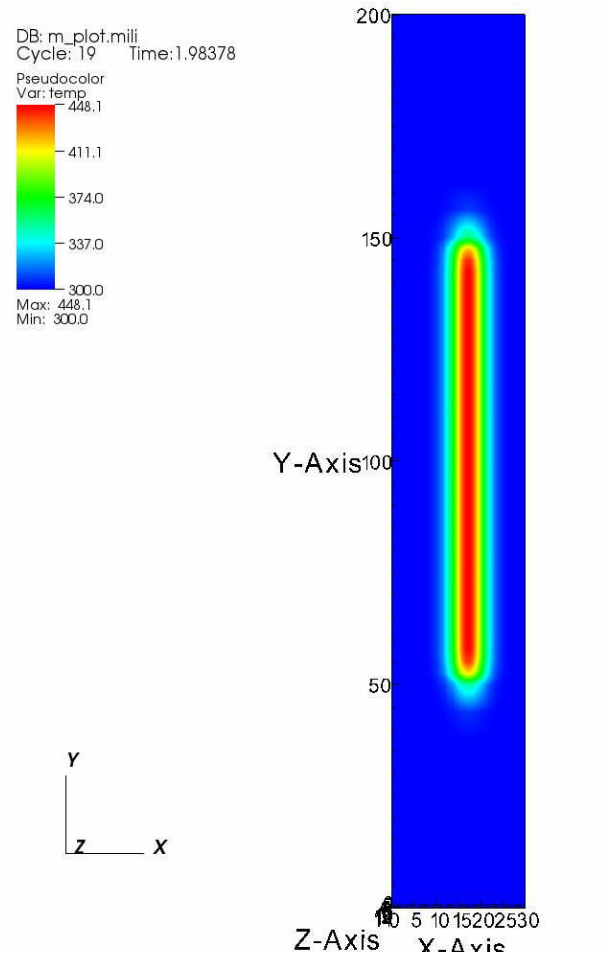
Thermal Stress Simulations

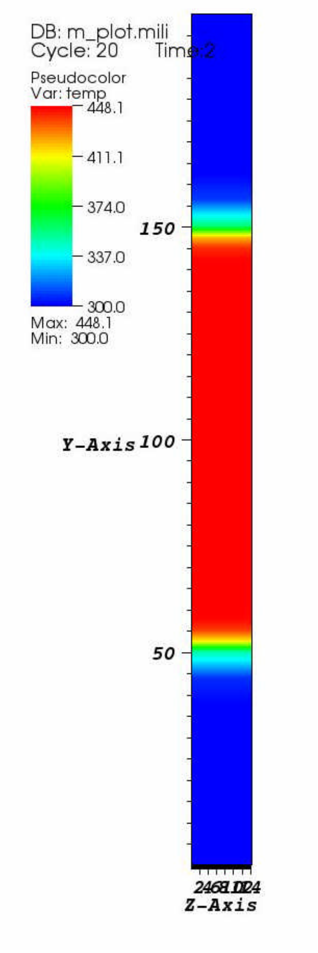
- Series of calculations using a thermal code sequentially coupled with an explicit or implicit structural code
- Working on slice models to work out mesh and other analysis requirements
- Values used to determine loading based on J. Sheppard’s quarter-wave transformer specifications
- Improved heat generation model used

$$\dot{q}(x,y,z) = \frac{Q}{2\pi\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right), r^2 = \left(\frac{x - x_o}{x_{fl}}\right)^2 + \left(\frac{y - y_o}{y_{fl}}\right)^2 + \left(\frac{z - z_o}{z_{fl}}\right)^2$$

- Uniform distribution through material assumed- will be refined as work progresses

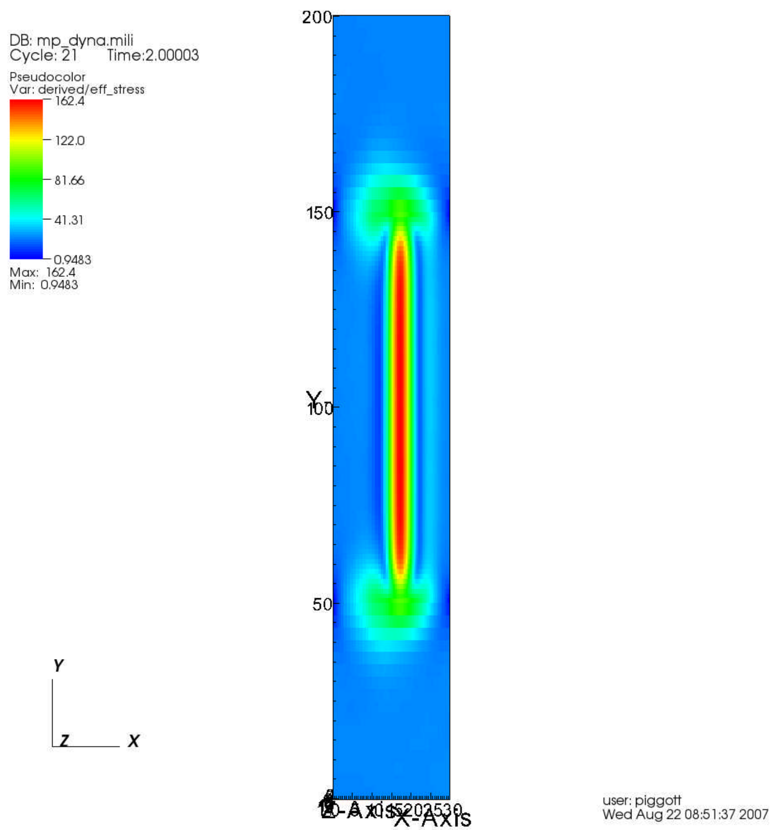
Temperature Results

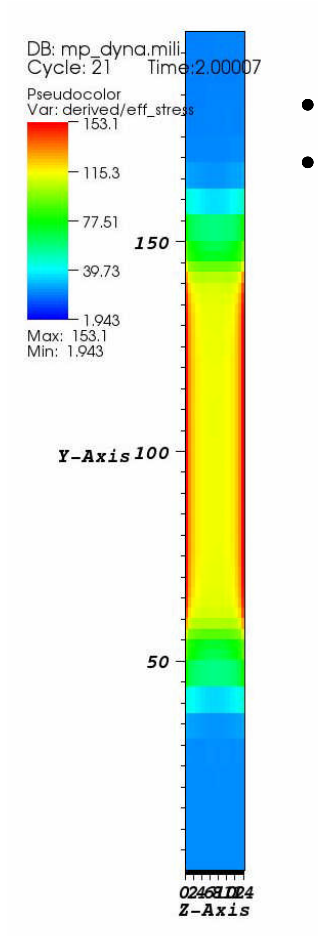




- Coarse Mesh, 22400 Elements, T_{max}=448.1 K
- Fine Mesh, 179200 Elements, Tmax=449.6 K

Thermal Stress Results

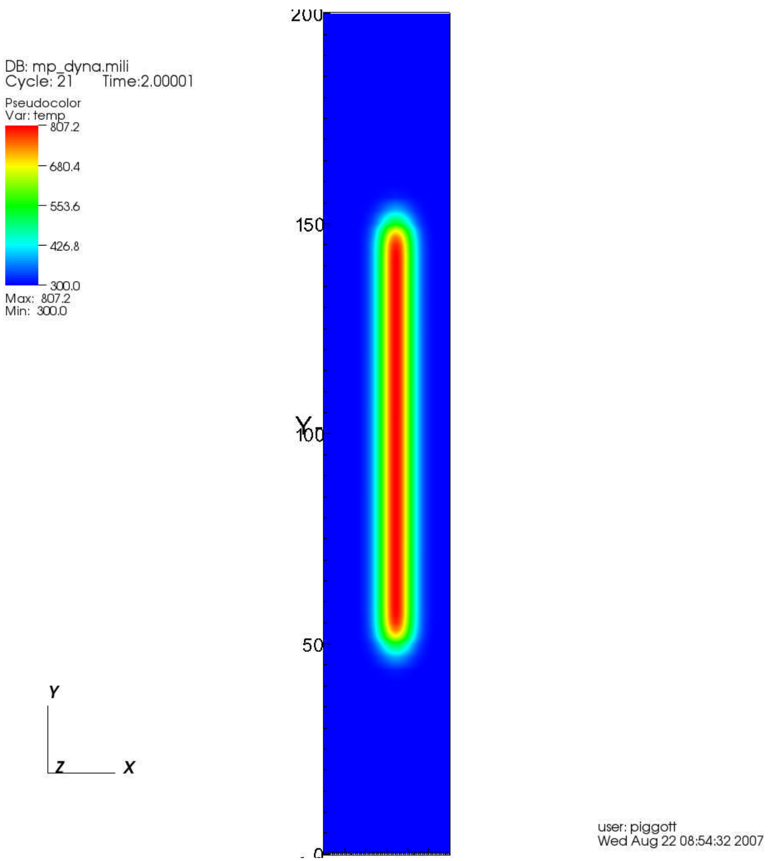




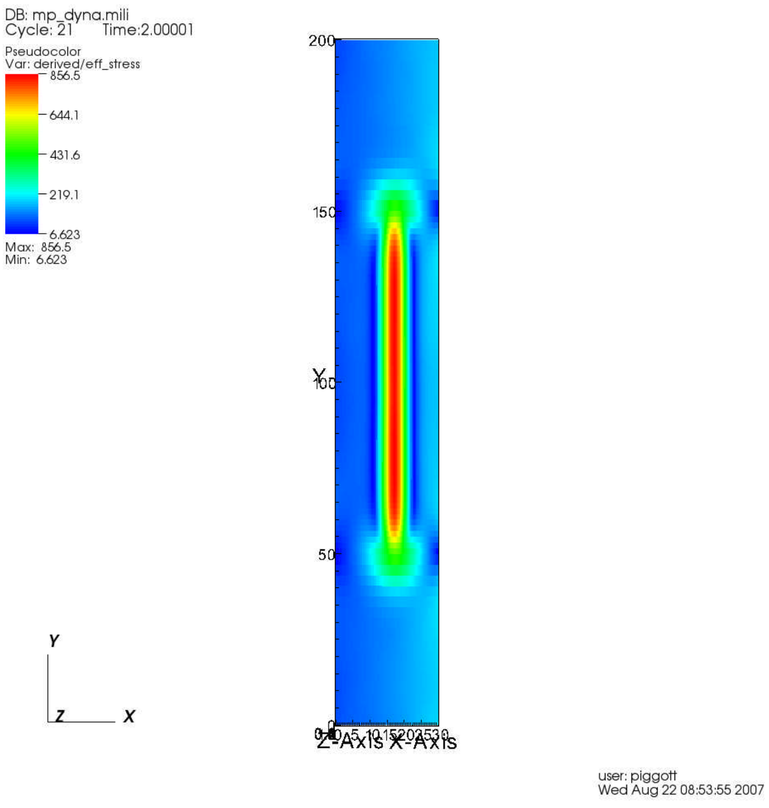
- Coarse Mesh, 153.1 MPa max
- Fine Mesh, 162.4 MPa max

Von Mises Stress (MPa)

WRe Thermal Stress

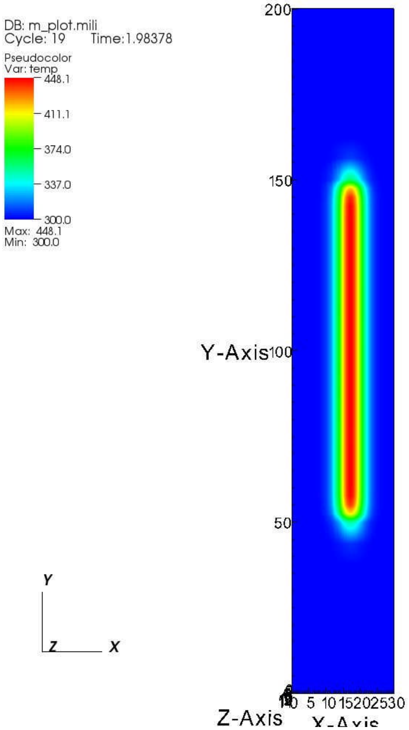


Fine, Max=807.2 K

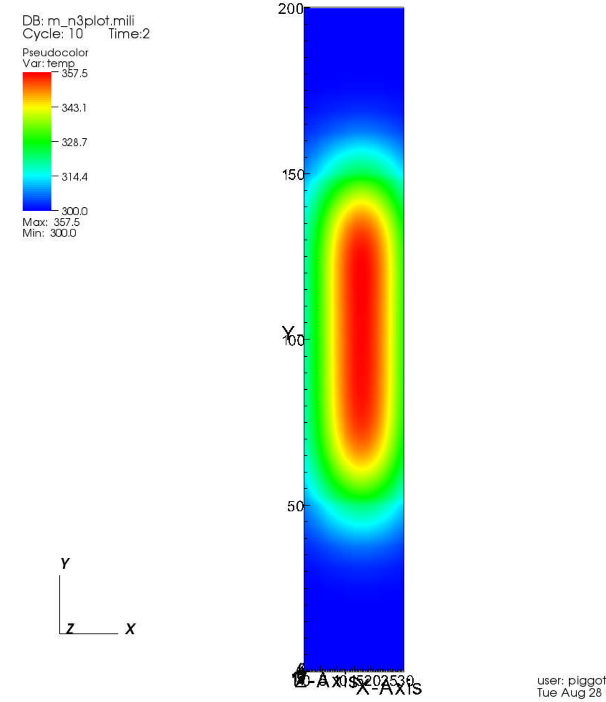


Fine, Max=856.5 MPa

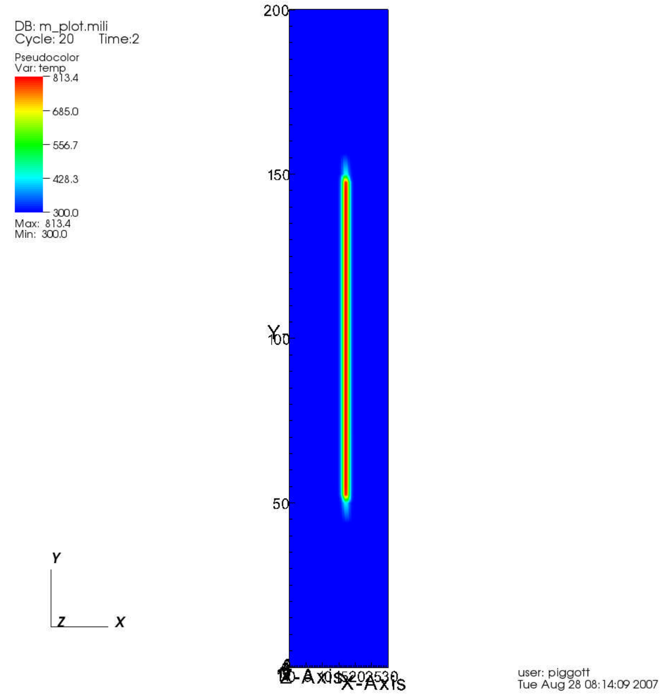
Spot Size Comparisons- Temperature



Sigma=1.7 mm
T_{max}=448.1 K

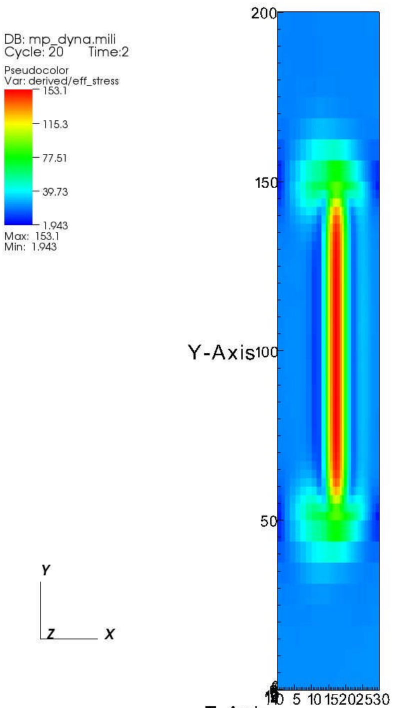


Sigma=3.4 mm
T_{max}=357.5 K

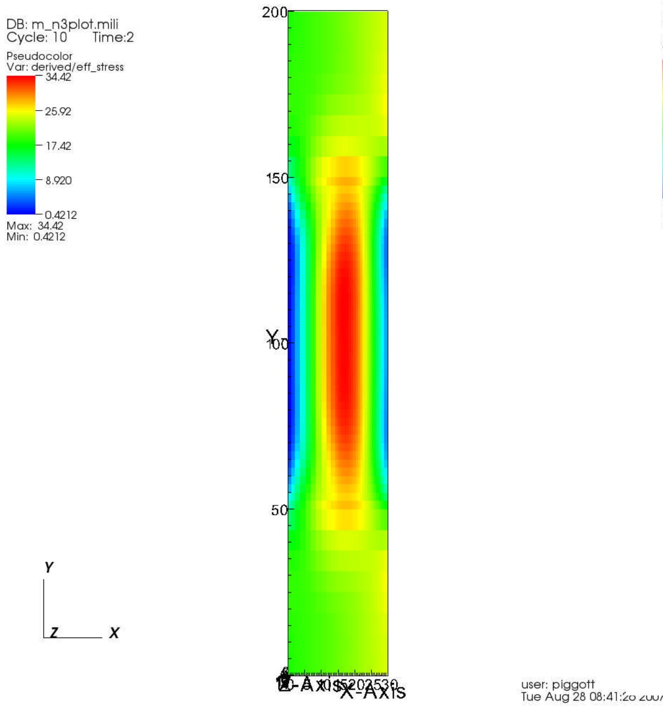


Sigma=0.85 mm
T_{max}=813.4 K

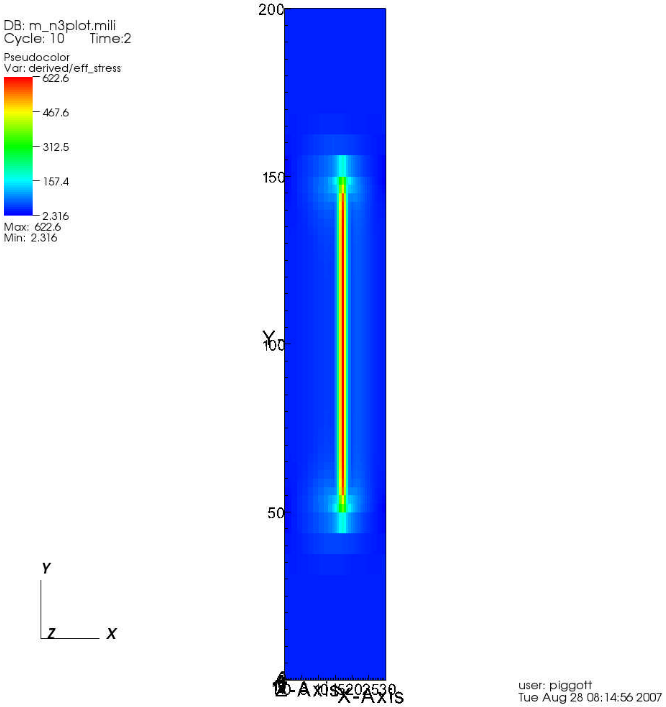
Spot Size Comparisons- von Mises Stress



Sigma=1.7 mm
σ_{max}= 153.1 MPa



Sigma=3.4 mm
σ_{max}= 34.42 MPa



Sigma=0.85 mm
σ_{max}= 622.6 MPa

Other Activities

- Model is in development using COMSOL Multiphysics to model stress effects for lithium lens and liquid metal targets
- Contract is underway with Brian Wirth at UC-Berkeley to evaluate radiation damage effects and resolve disagreement from previous studies
  - Delays due to contract transition and logistical delays

Future Work

- Continue thermal stress simulations for different loading (heat input and cooling) cases, mesh densities
- Incorporate desired thermal stress cases into larger model incorporating wheel motion
- Look into material properties, including fatigue strength and radiation damage property degradation
- Continue working with UC-Berkeley on radiation damage with assistance from A. Ushakov
- Continue working with DL on prototype wheel experiment
- Duplicate prototype wheel calculations as well as possible to provide an accuracy check
- Continue development work on liquid metal/lithium lens model