NSRP RA Project
Development of a Fast Analysis Solver for Welding Sequence Optimization of Ship Structures

Joint Panel Meeting

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Project Team

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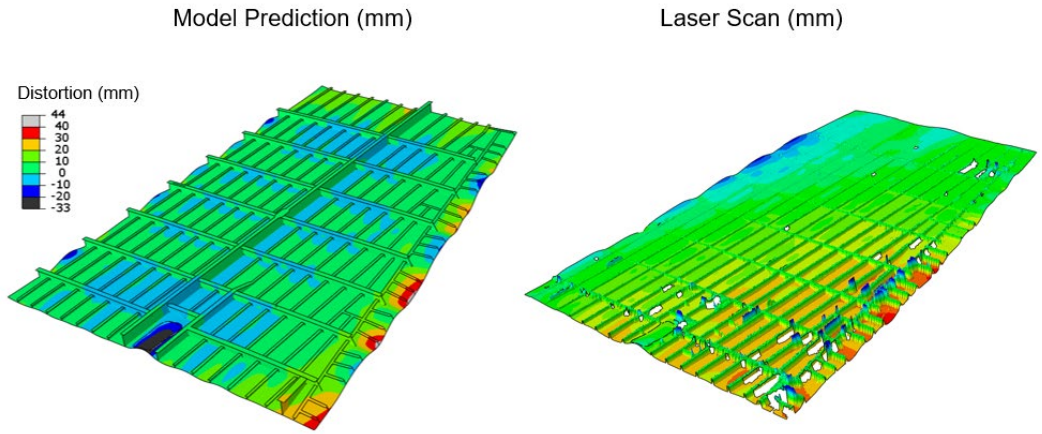
Problem Statement

- Materials are exposed to significant thermal and mechanical stresses during welding that affect dimensional accuracy, production schedules, labor hours (fitting, welding, rework, etc.) and structural performance
  - Many variables influence the stresses and resulting impacts
- Structural analyses that simulate the thermal and mechanical stresses are time-consuming
  - Simulations to optimize welding sequences and minimize impacts are cost prohibitive
  - Production uses other metrics for weld sequencing



Project Goals and Desired Outcome

- **Goals**
  - Adapt the DR-Weld transient elastic-plastic finite element analysis (FEA) solver developed by Oak Ridge National Laboratory (ORNL) for the automotive and nuclear industries to support shipbuilding applications
  - Apply the FEA solver to simulate fabrication of production panels, unit assemblies, and alignment critical foundations to examine its feasibility, effectiveness and accuracy
- **Desired outcome**: A transient elastic-plastic FEA solver for welding simulation that will be feasible in a shipbuilding environment, provide accelerated analysis speeds and is integrated with a user-friendly interface

Technical Gaps

- DR-Weld can only run eight-node solid element. Six-node solid elements are needed to add in DR-Weld to simulate a complex ship structure.
- DR-Weld does not include shell elements which are mainly used in the design of ship structures.
- DR-Weld does not have a user-friendly graphical user interface.
- DR-Weld does not have a thermal solver to predict temperature. DR-Weld has only a mechanical solver to predict stress and distortion by input the temperature data.

Technical Approach to Develop a Fast Solver for Shipbuilding Application

Phase I. Develop a Fast Solver for Panel Structures

- Develop a shell-element based fast solver
- Develop a preliminary version of graphical user interface (GUI)
- Simulate the weld process of a production panel

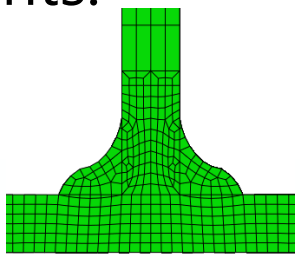
Phase II. Extend the Solver to Complex Structures

- Develop software requirements for complex structures
- Improve the software for welding sequence optimization of complex structures
- Optimize welding sequences in complex structures

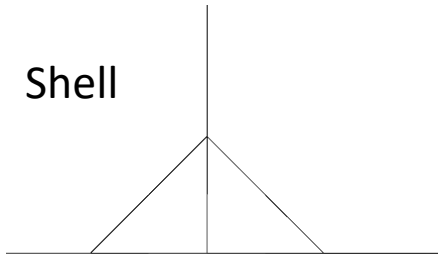
Shell Welds for Welding Simulation

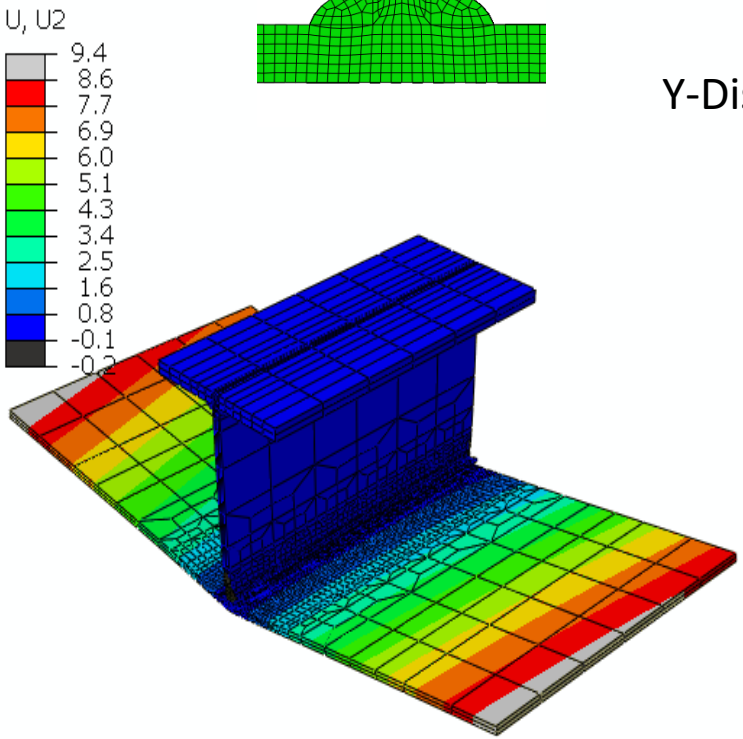
- Shell elements for welding simulation have been widely used since 2000.
- Similar distortion can be predicted with both solid elements and shell elements.

Solid

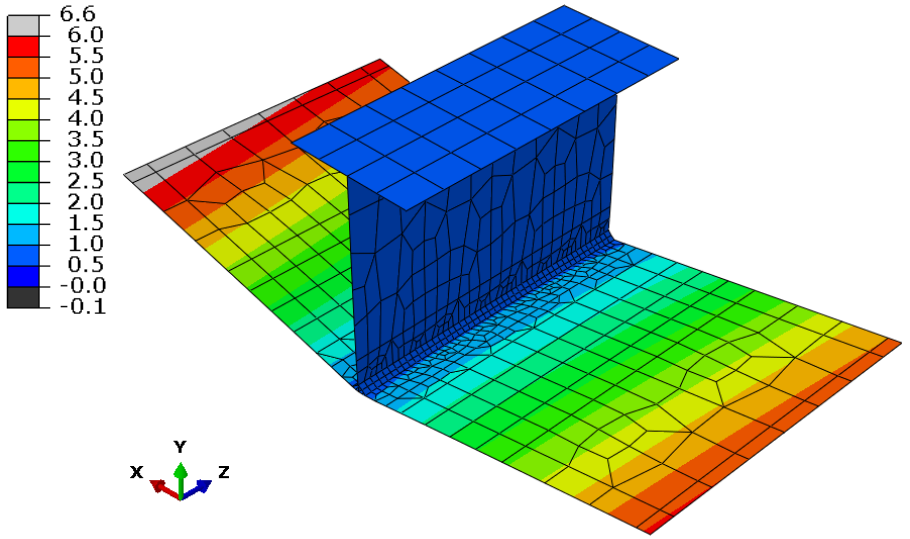


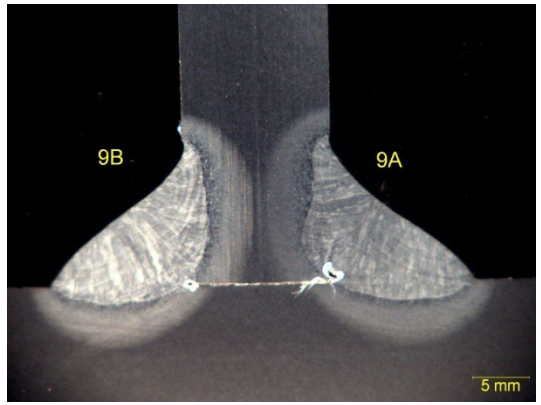
Shell





Y-Distortion (mm)

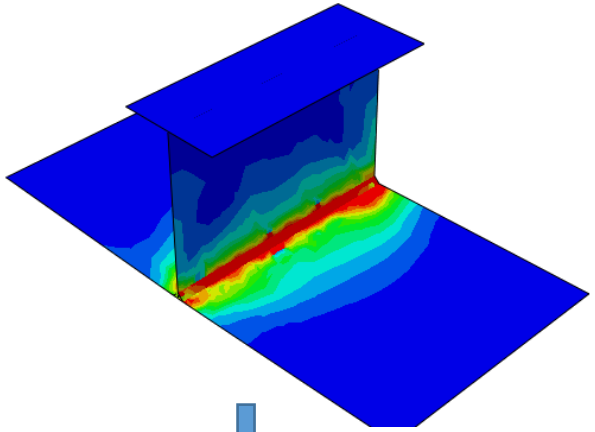




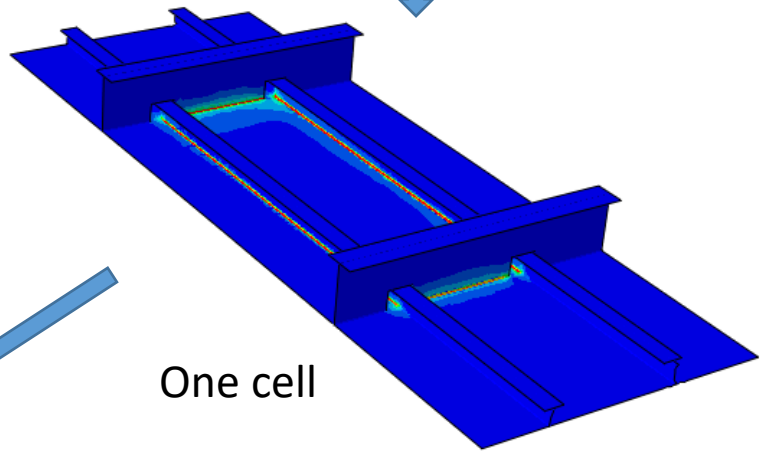
Fillet Weld Cross Section

A Step-by-Step Approach

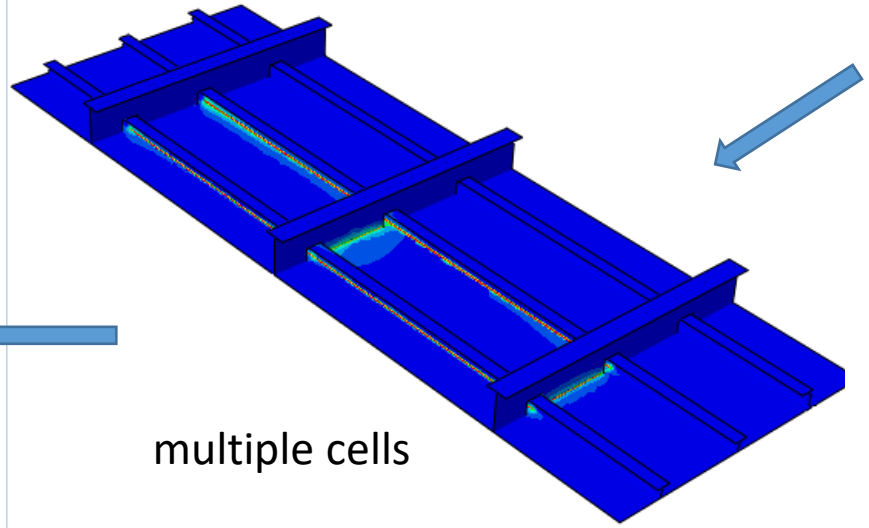
- DR-Weld will be developed and tested in four steps to achieve Phase-1 objectives
  - Step 1: Single Tee model
  - Step 2: One-cell model
  - Step 3: Multi-cell model
  - Step 4: Full production model



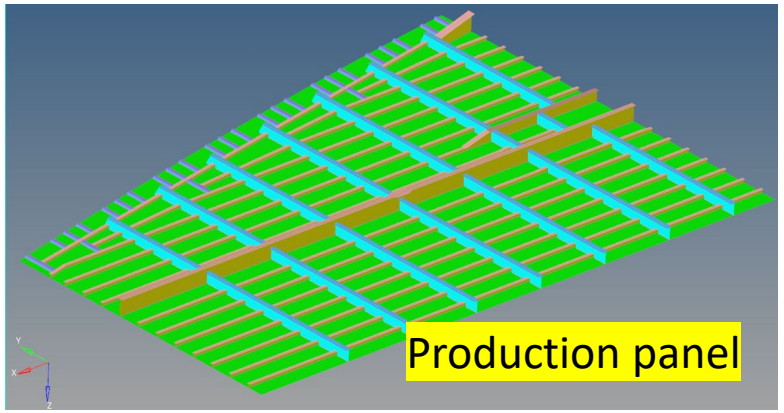
One Tee



One cell

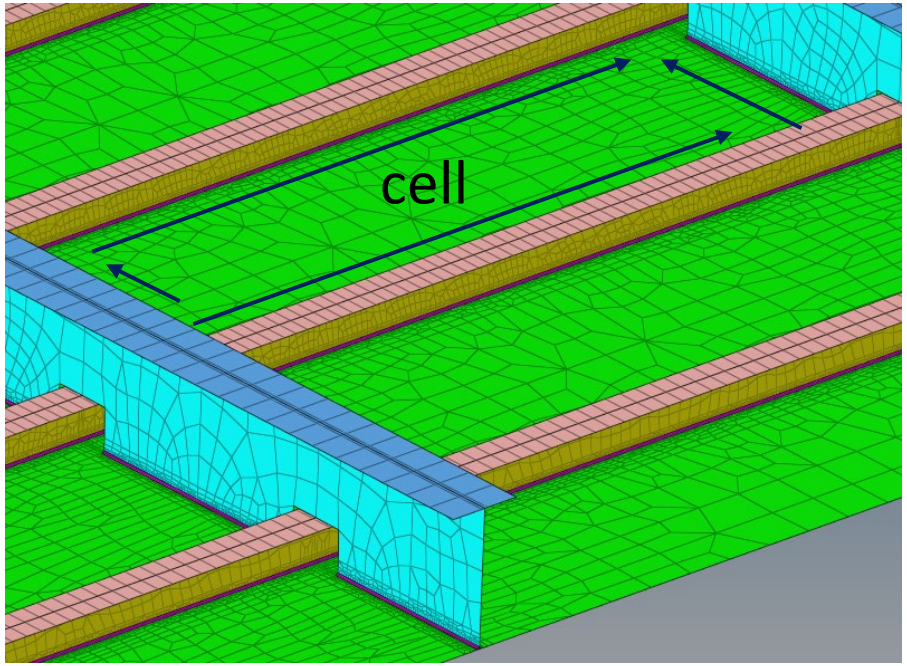


multiple cells



Welding the Selected Production Panel

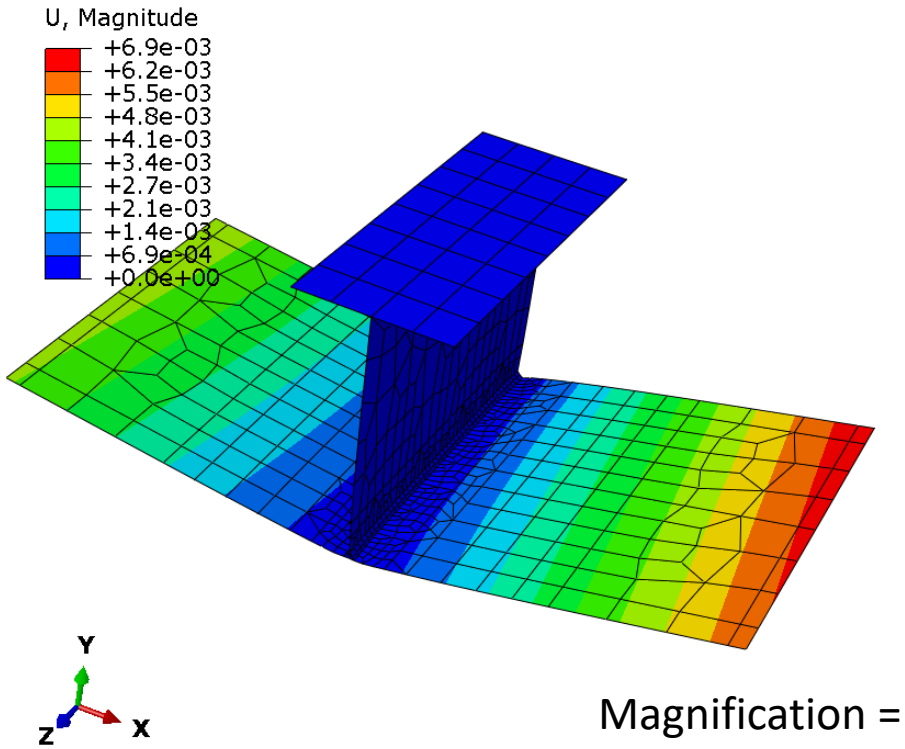
- A typical production panel includes about 120 welding cells.
- Four robots are used to weld the panel simultaneously.
- Robots move from one weld cell to another so the cooling time between cells is negligible.
- The residual temperature from previous weld cells will affect the temperature of the following cells, which may contribute to the effect of weld sequence on distortion.



Verification of Abaqus Prediction

- Abaqus has been widely used to predict distortion induced by welding processes
- Abaqus prediction will be used to check the accuracy of DR-Weld prediction on the one-cell model and the multiple-cell model
- Abaqus prediction has been verified on the one-Tee model
  - Abaqus predicted the similar distortion shape as observed in the experiment
  - The predicted distortion magnitude was close to the experimental measurement

Distortion (m)



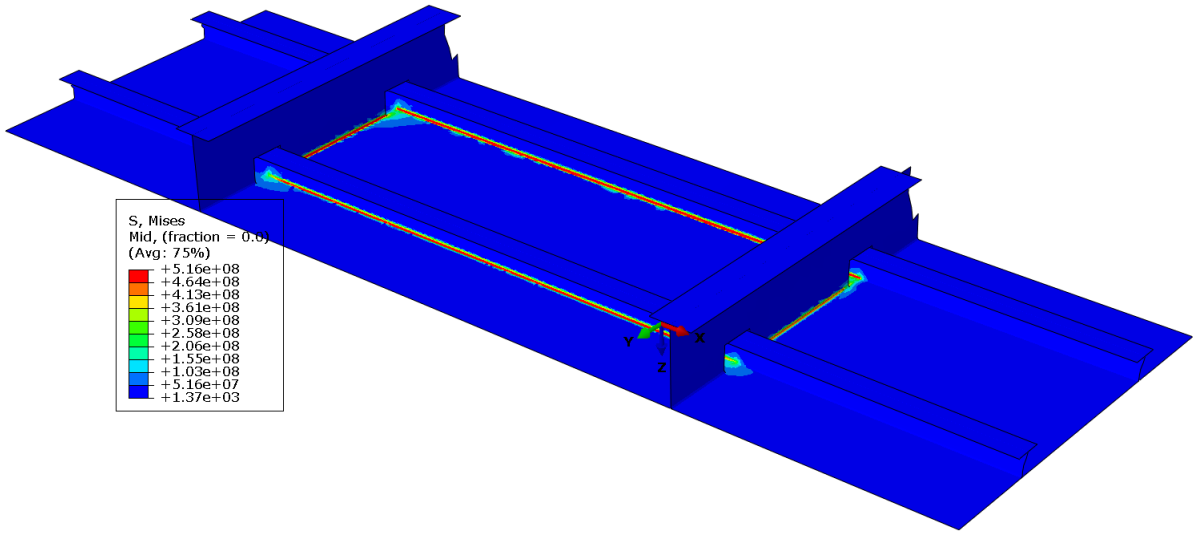
Magnification = 10

Abaqus predicted distortion

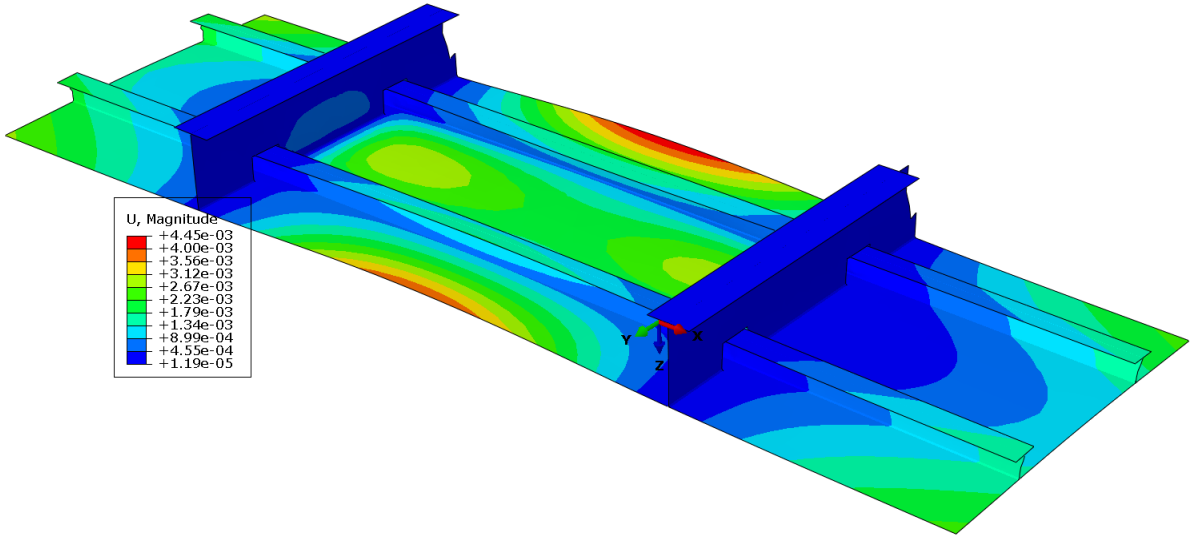
Analyze One-Cell Model

- One-cell model was analyzed with Abaqus to predict temperature and distortion.
- Abaqus temperature will be input to DR-Weld to predict distortion and compare with Abaqus results.

Predicted Von Mises Stress (Pa)



Predicted distortion (m)

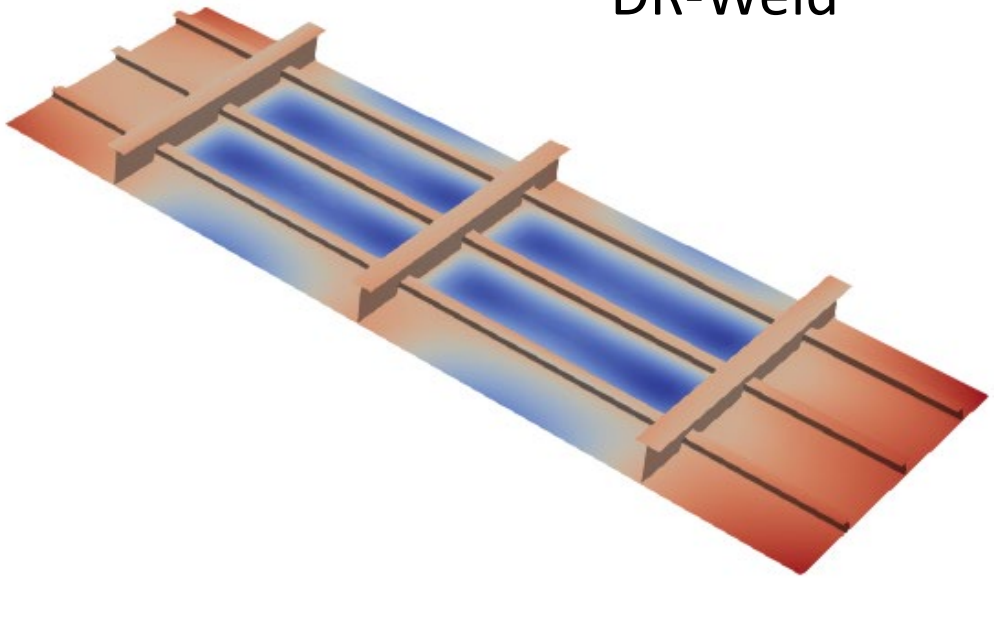


Multiple-Cell Model Comparison between DR-Weld and Abaqus

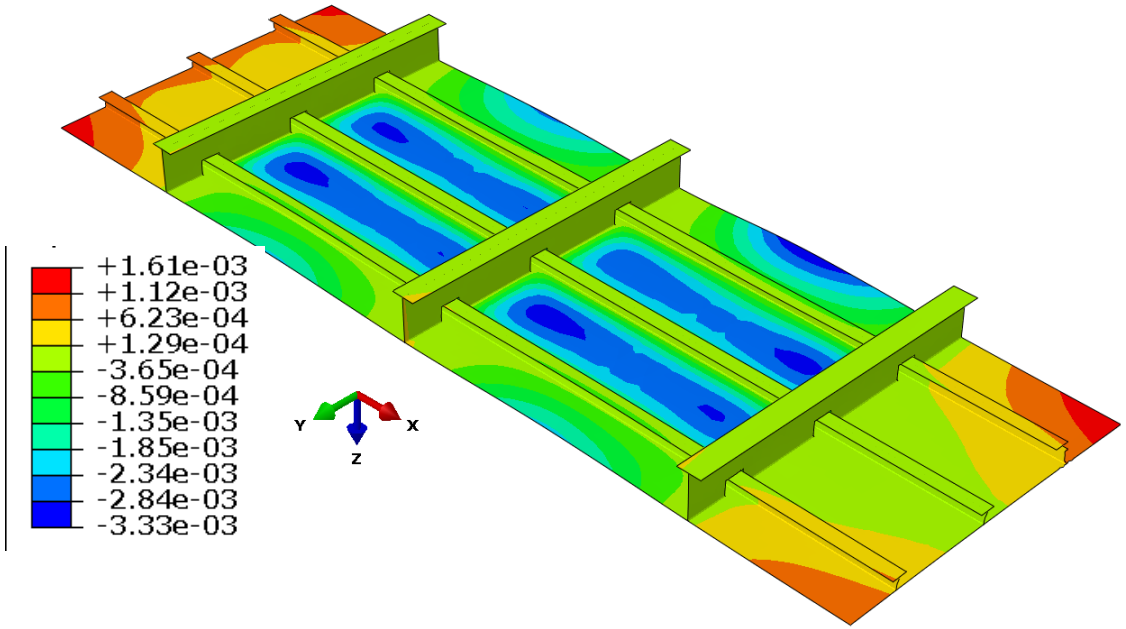
- DR-Weld predicts similar distortion trends as Abaqus.
- DR-Weld predicted distortion magnitude is slightly smaller than Abaqus.

Distortion (m)

DR-Weld

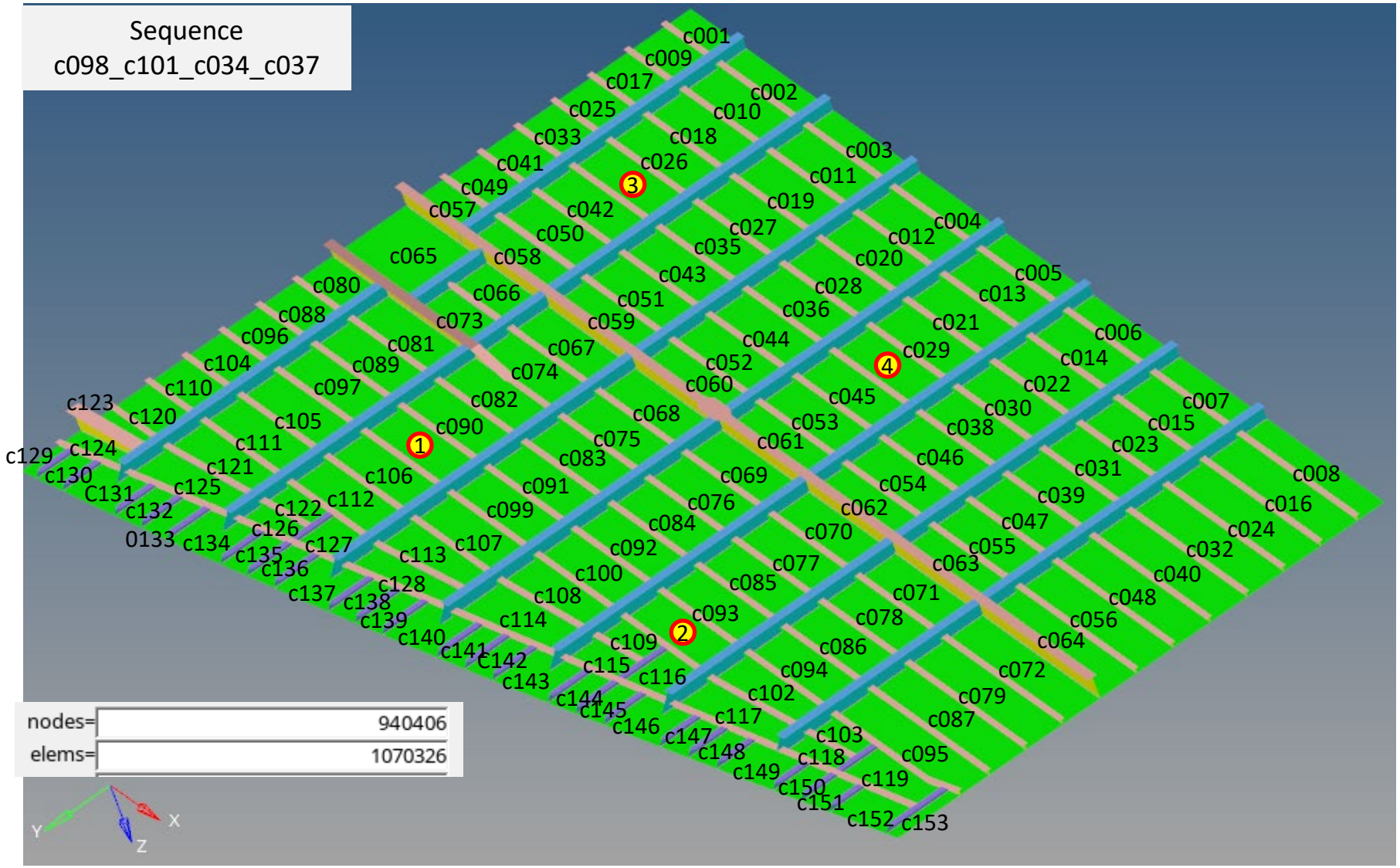


Abaqus



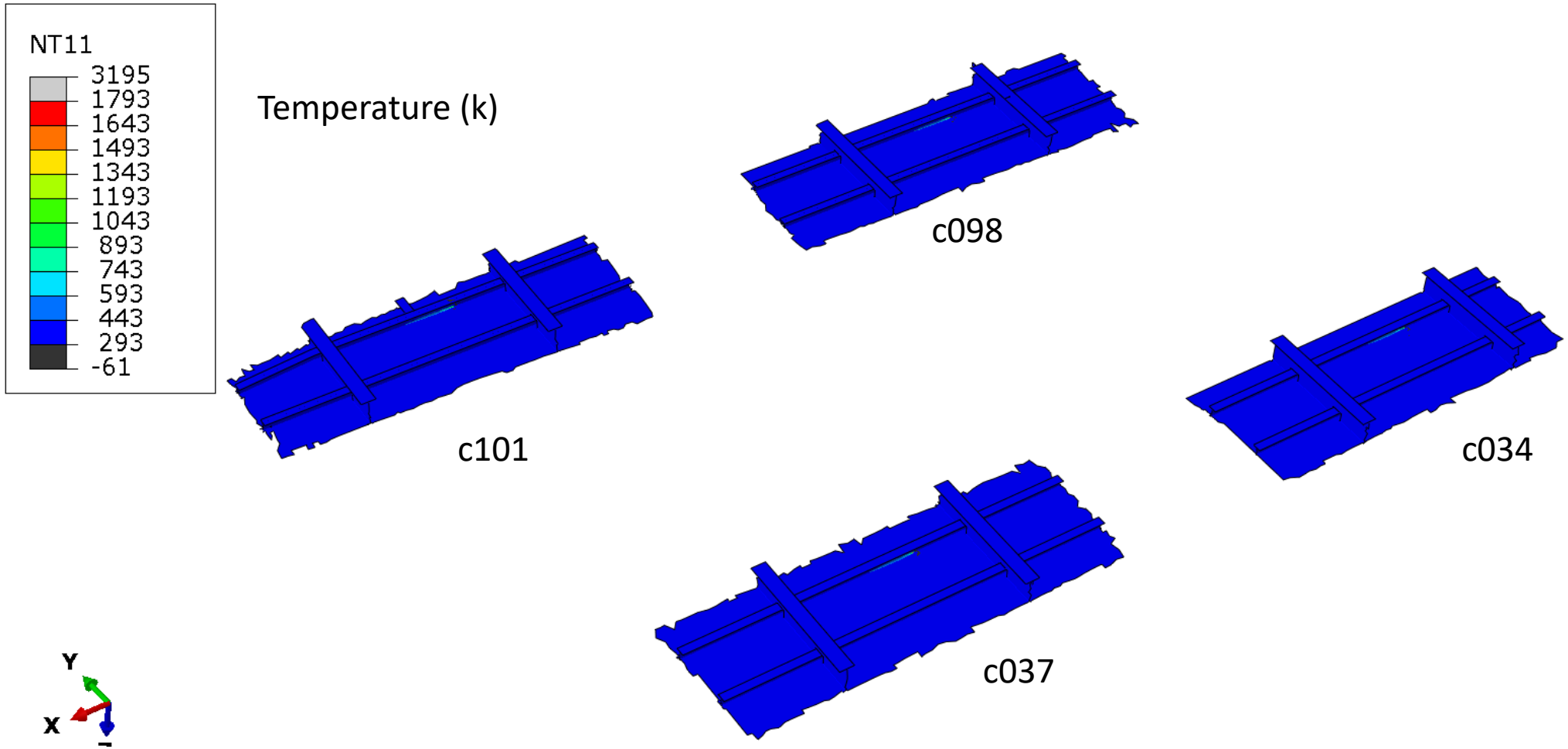
Analyze a Panel Structure

- 154 cells
- Welding with 4 robots

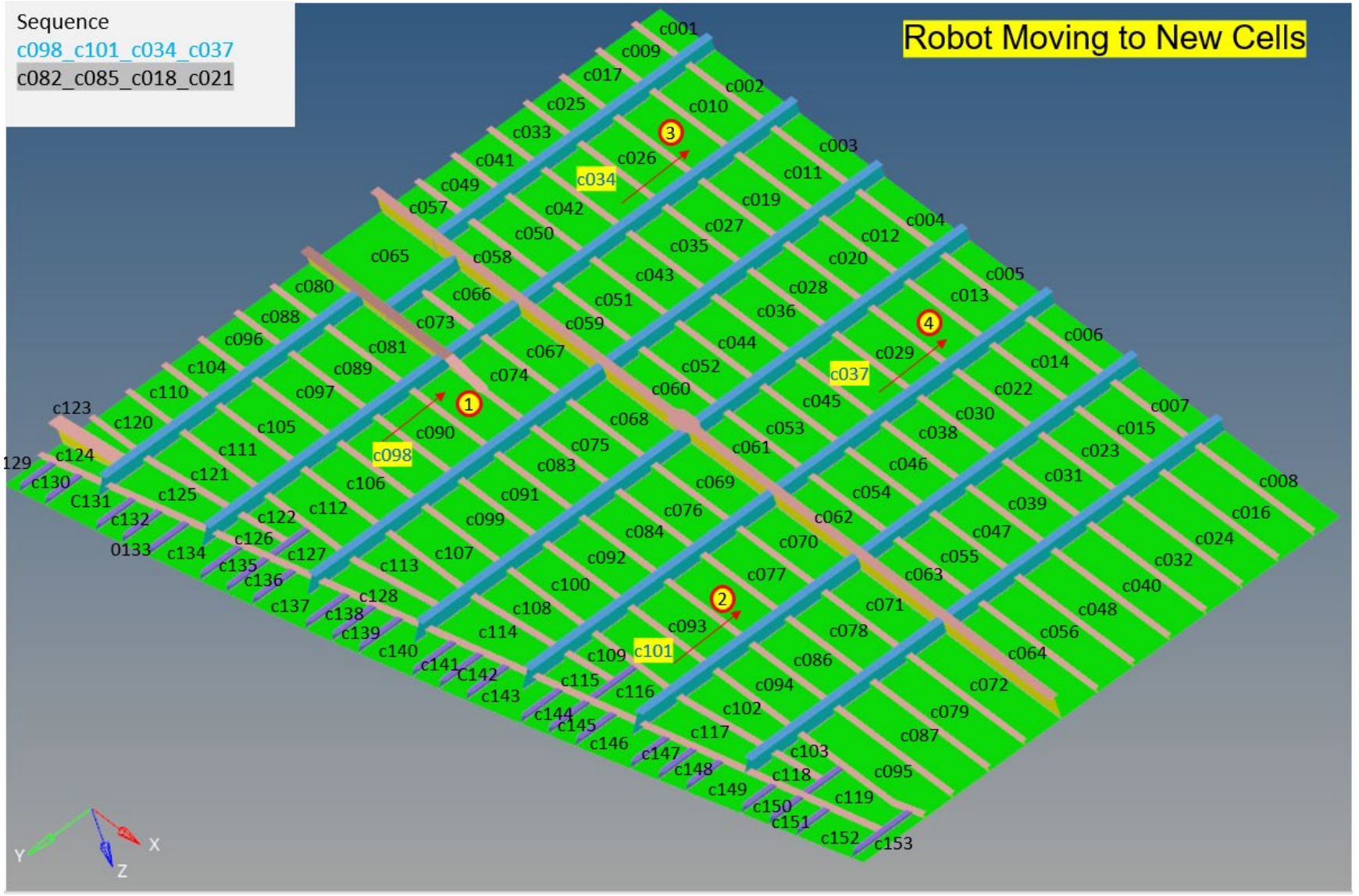


Predicted Temperature for c098_c101_c034_c037

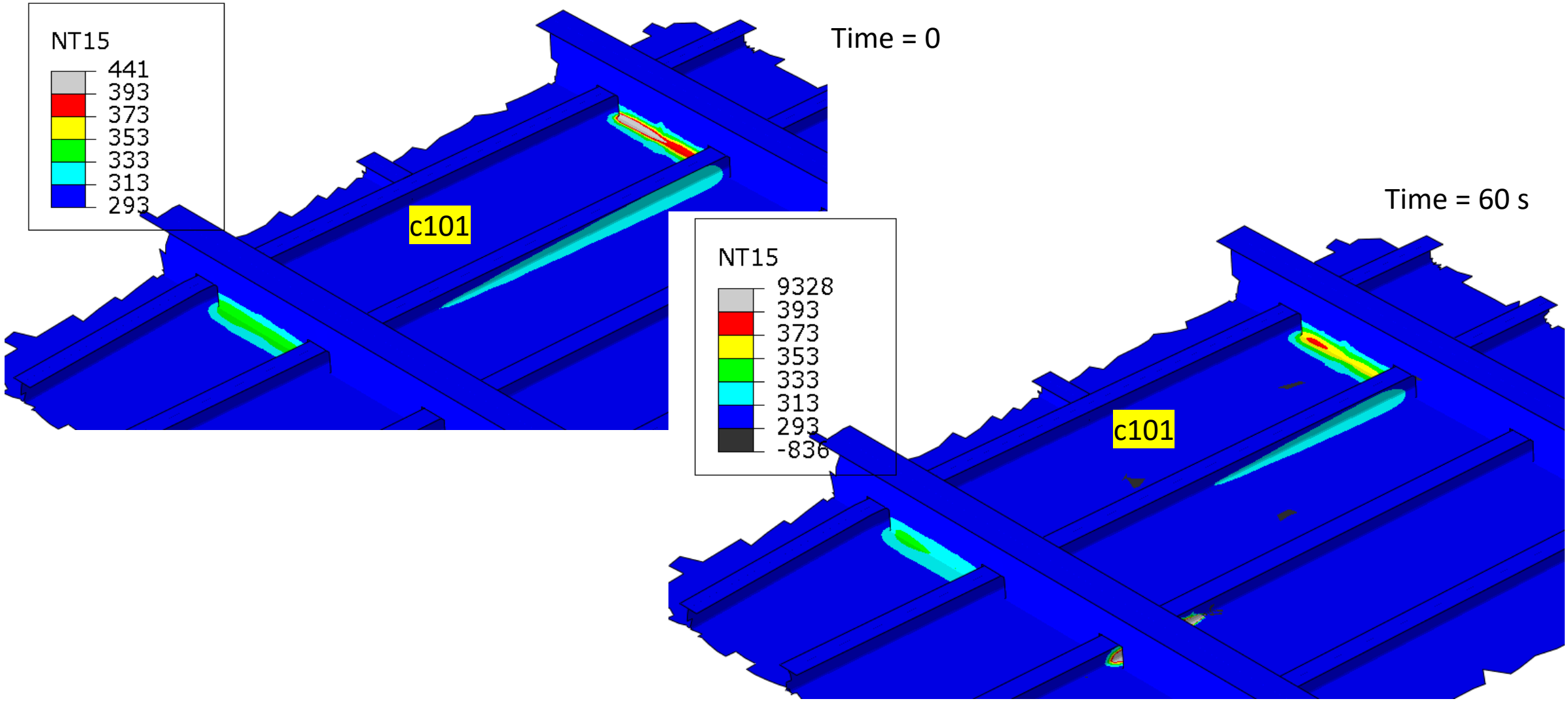
- Four local areas were selected to predict temperature



Robot Moving to New Cells



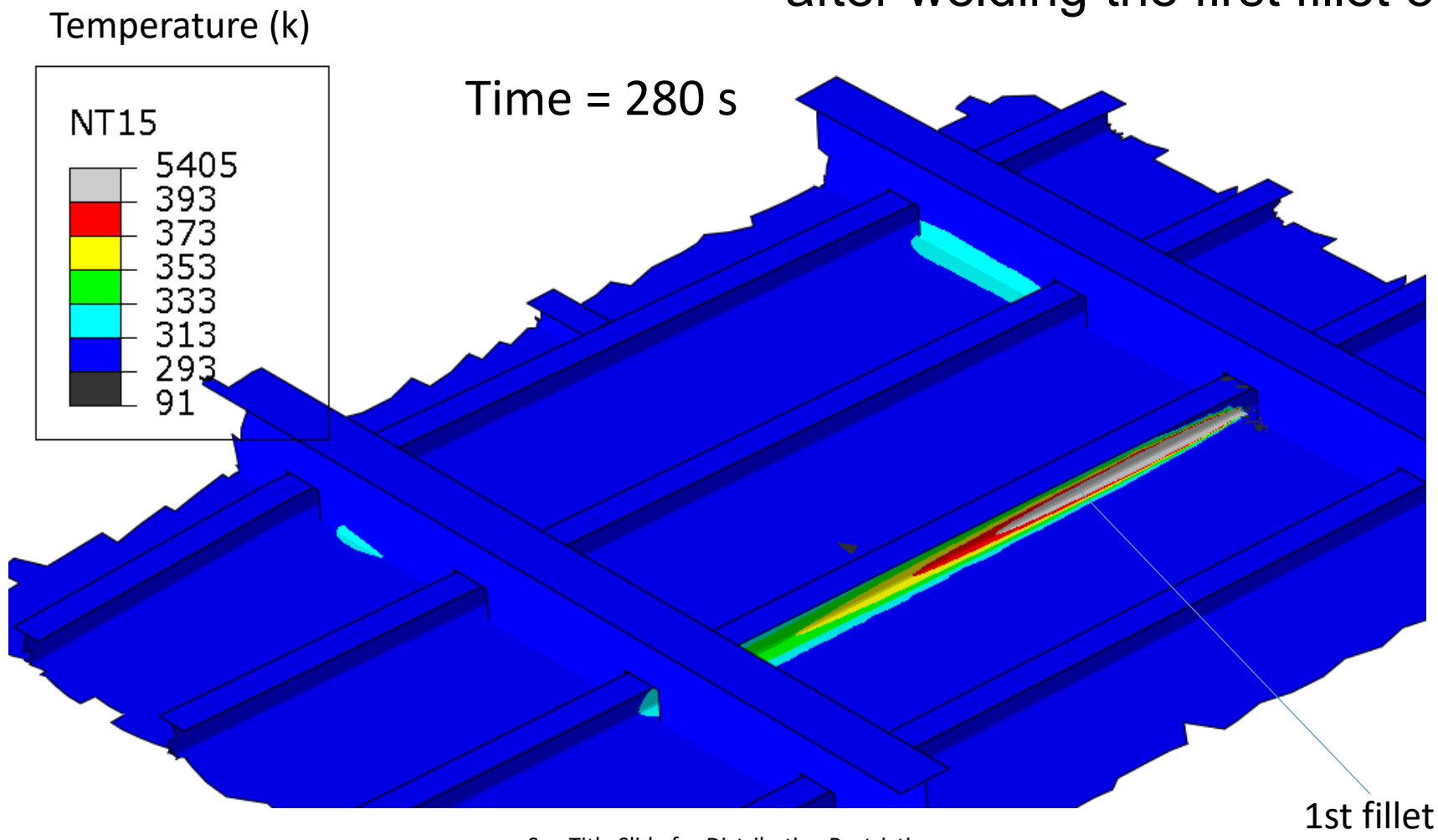
Cooling Time



See Title Slide for Distribution Restrictions

Cooling Time (cont.)

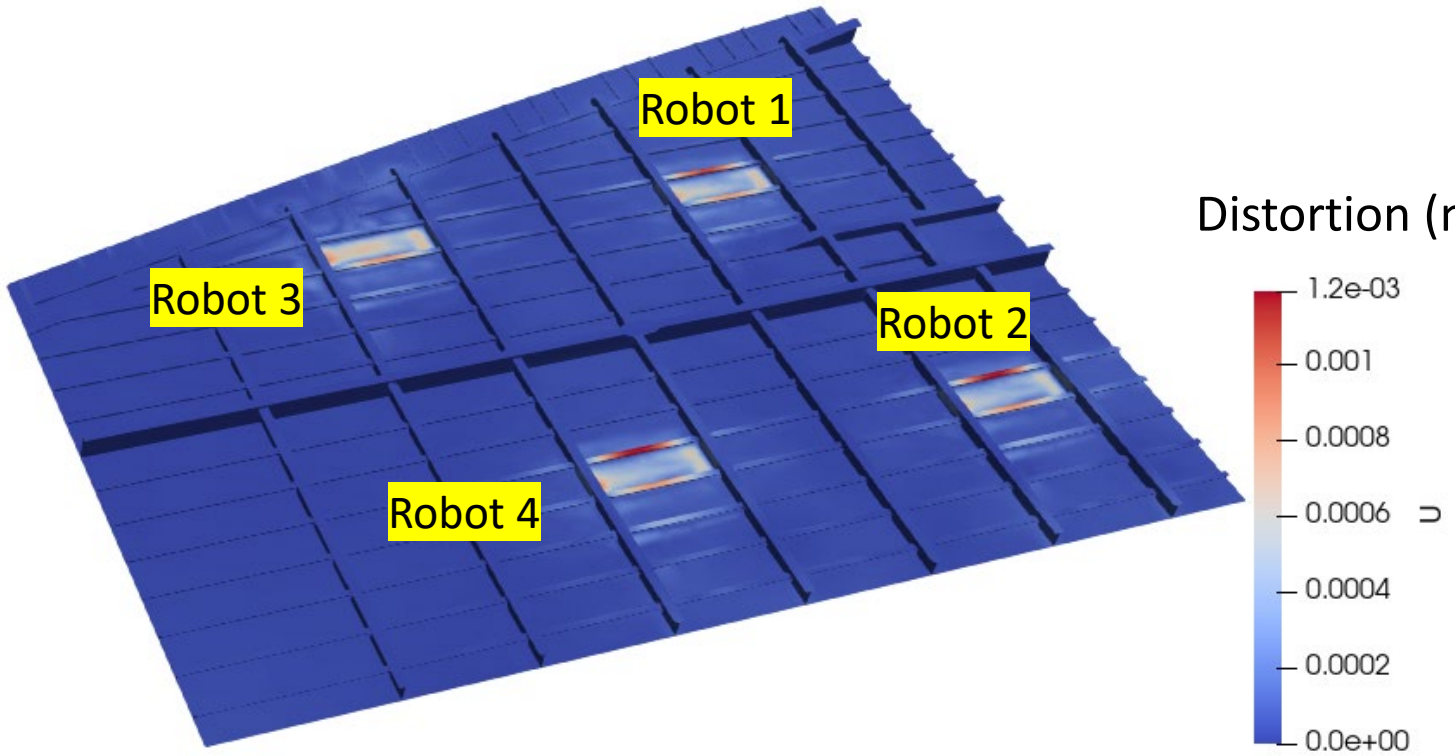
Previous welds cool to near room temperature after welding the first fillet of c082



See Title Slide for Distribution Restrictions

DR-Weld Analysis of the Full Panel

- Refining the current version of DR-Weld (CPU version) to reduce memory requirement from 40GB to 20GB
- Reduced computational time from 100+ days to ~10 days (estimated)



Next steps

- To obtain another 10x speed-up or higher
  - Further optimize the algorithm to map nodal temperature input to integration points
    - Or pre-process the nodal temperature to integration temperature input prior to the start of the simulation
  - Convert it to GPU code

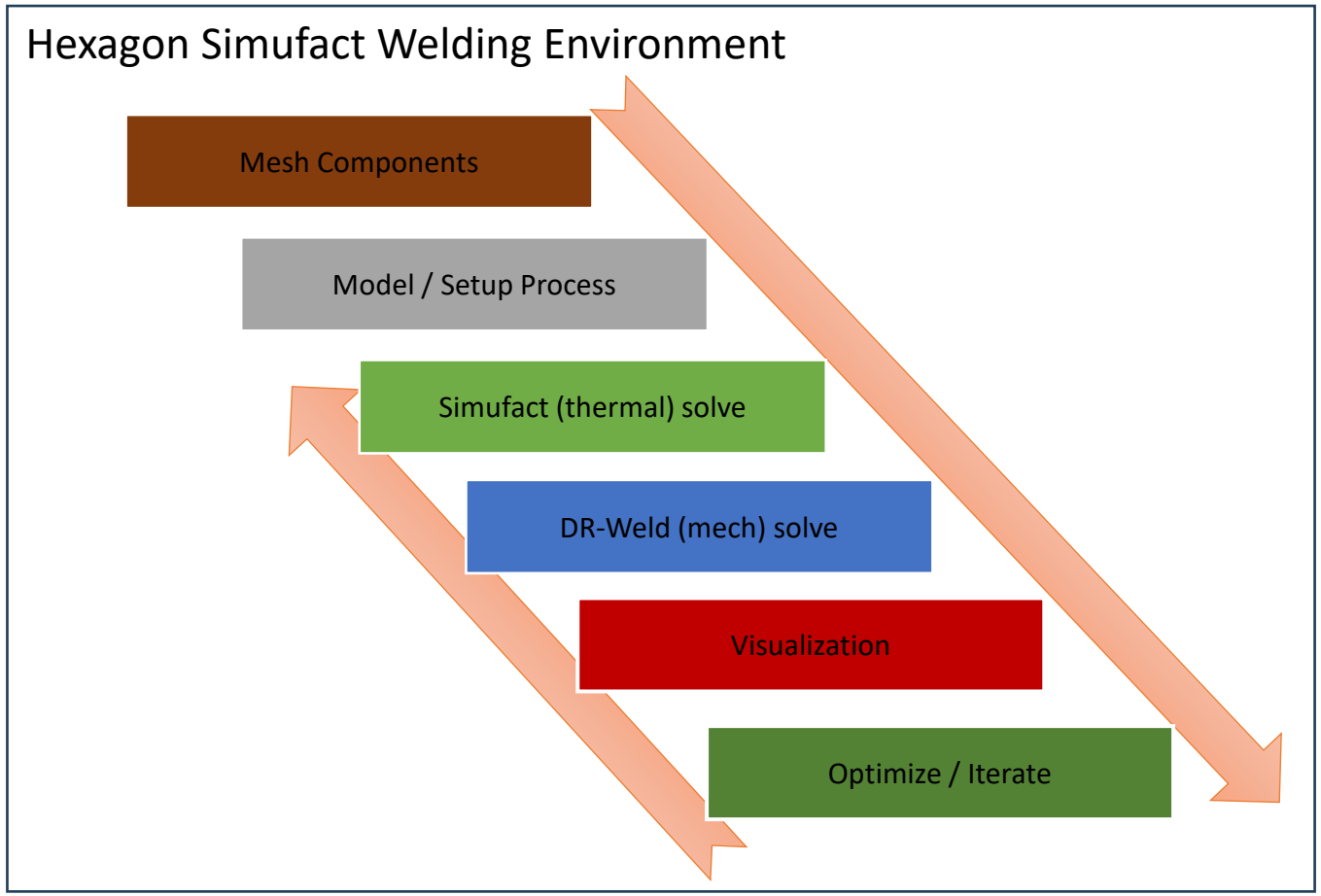
Hexagon Process Flow (GUI)

Desired Outcome

- Elegant welding process simulation solution
- Helps engineers solve the problem without spending time modeling
- Process is expedited by modeling automation
- Software interprets results and provides suggested improvements or iterates to a solution

Criteria for Success

- Fast – Expeditious Solution Turnaround
- User-Friendly
- Accessible to Manufacturing Engineers
- Single-Software Installation (vs. multiple integrated tools)



Summary

- A fast solver for welding simulation is under development by leveraging ORNL code, DR-Weld.
- DR-Weld is further developed for ship building applications by adding shell elements.
- A step-by-step approach was taken to develop the fast solver. DR-Weld is able to predict reasonable distortion trend and magnitude as measured in experiment and as predicted by Abaqus.
  - One-Tee model
  - One-cell model
  - Multiple-cell model
  - Full panel model
- DR-Weld showed the ability to simulate the welding process of a full panel with transient elastic-plastic analysis with good accuracy and fast speed, which is not possible with other FEA software.