Thermal-Stress Analysis of Reactors, Turbine Generators, Composite Mandrels, Pressure Vessels and CFRP Structures

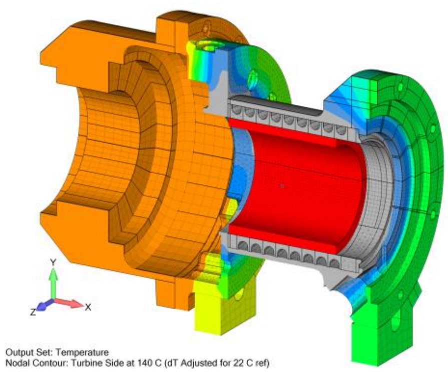
Predictive Engineering's Thermal-Stress Consulting Experience

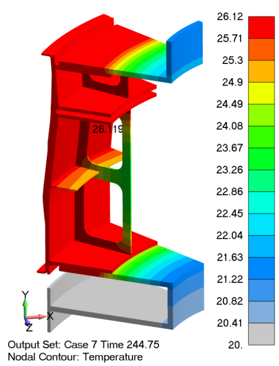
As FEA consultants with broad expertize in thermal-fluids (i.e., CFD consulting), thermal-stress analysis is one of our core competencies. We have done dozens of thermal-stress projects over the last 20+ years and we are very proud of our FEA consulting service record. This brief overview presents just a few of our more interesting case studies. If you don't see an example that matches your problem, don't be surprised that we haven't already done it and it is just not shown.

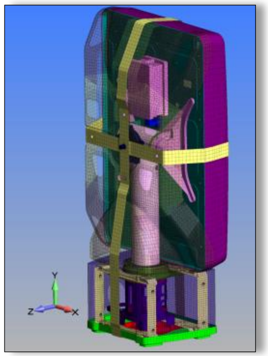
This overview provides a quick snapshot of a few of our thermal-stress consulting projects that we have done using Femap, NX Nastran and LS-DYNA:

- Thermal-Stress Analysis of 500kW Generator
- Thermal-Deflection Analysis of Composite Fabrication Mandrel
- Thermal-Stress Analysis of Hydrogen Reactor
- Thermal-Stress Analysis of Potted DC-AC Invertor and other Electronic Devices
- ASME Thermal-Stress Analysis of Thick-Walled LOX and RP1 Propellant Tanks
- Thermal-Stress Effects within Thick Composite Laminate
- Thermal-Stress Analysis of Water Cooled Stoker Grate
- Overview of General Thermal-Stress Projects

We pride ourselves on working closely with our clients in a collaborative manner to ensure that they get the right answer and importantly, the answer that fits their engineering goals and budget. Based on our years of experience as FEA consultants, we can often help improve our client's design with a few strategic comments. Our goal is to ensure our work is cost-effective and that our simulation effort "saves the client money" by ensuring that the design meets its mechanical objectives at the lowest possible manufacturing cost.

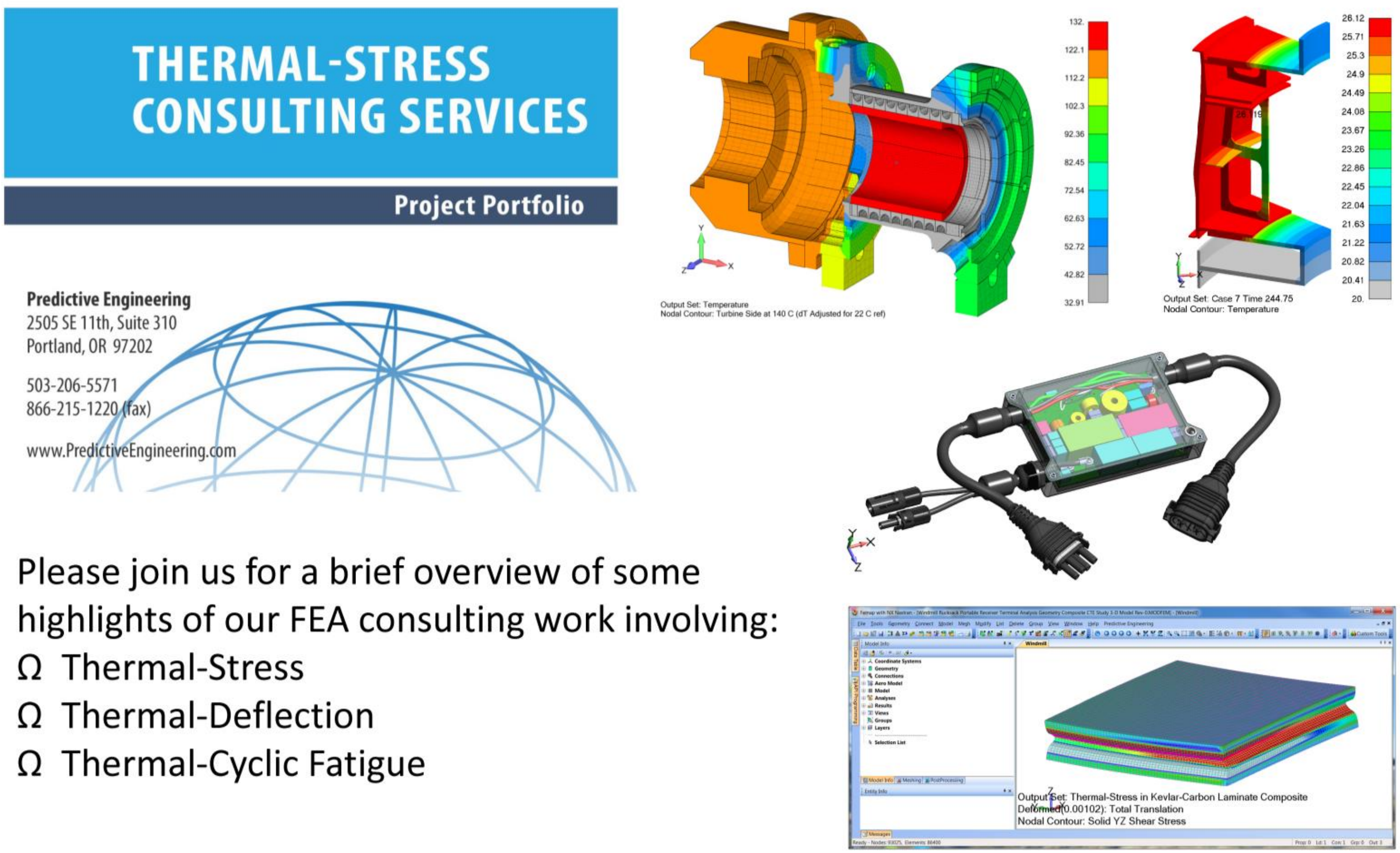






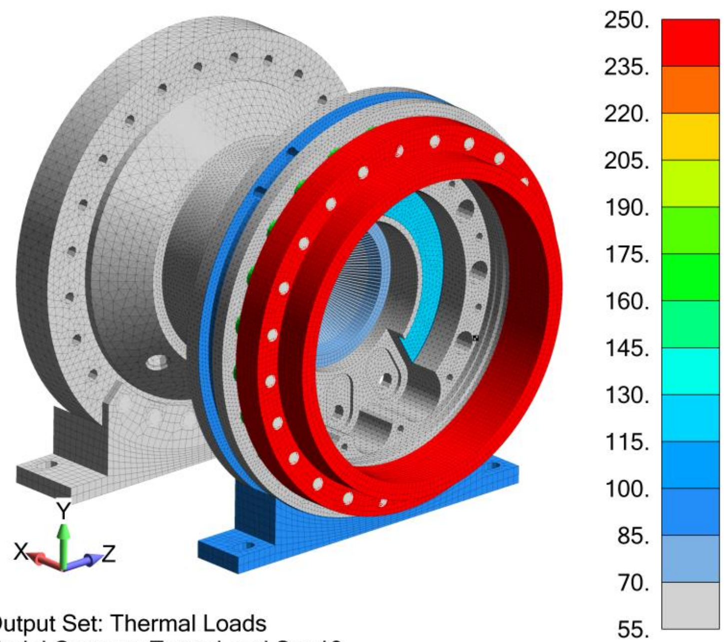
YouTube Video

If you are interested in a graphical overview of our thermal-stress consulting projects, take a look at our video: https://youtu.be/OCXXHL6USd8



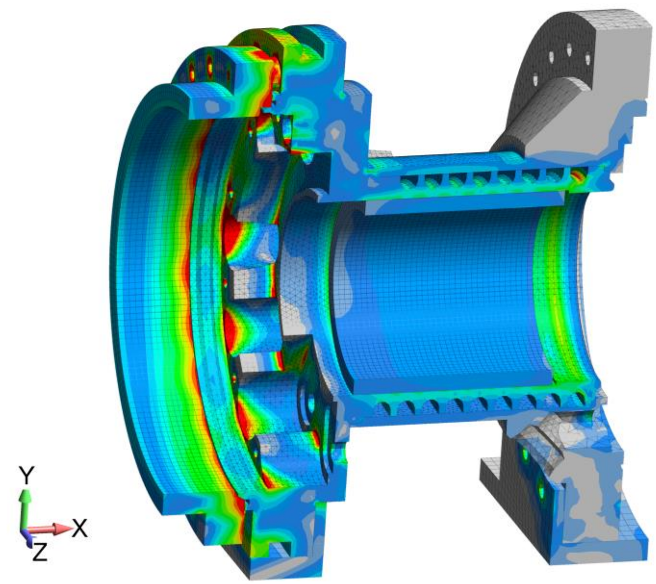
Thermal-Stress Analysis of 500kw Turbine Generator per ASME Section VIII, Division 2 Classification

THERMAL PROFILE FROM FIXED BOUNDARY CONDITIONS AND CFD THERMAL ANALYSIS



Output Set: Thermal Loads
Nodal Contour: Temp Load Set 10

THERMAL-STRESS RESULTS WITH MECHANICAL LOADS

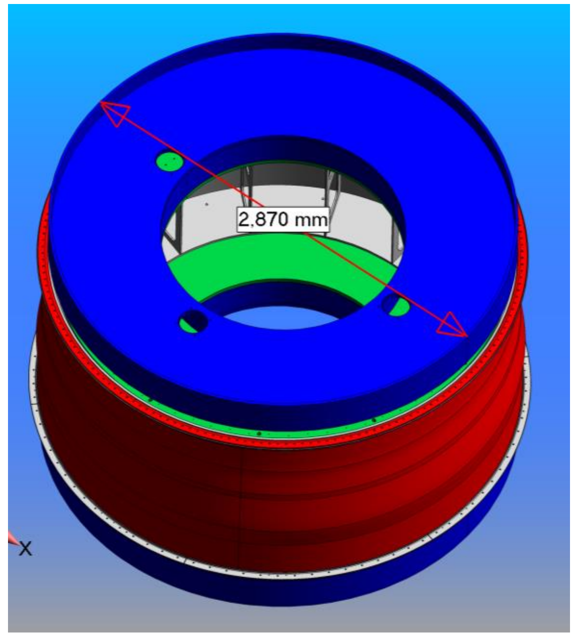


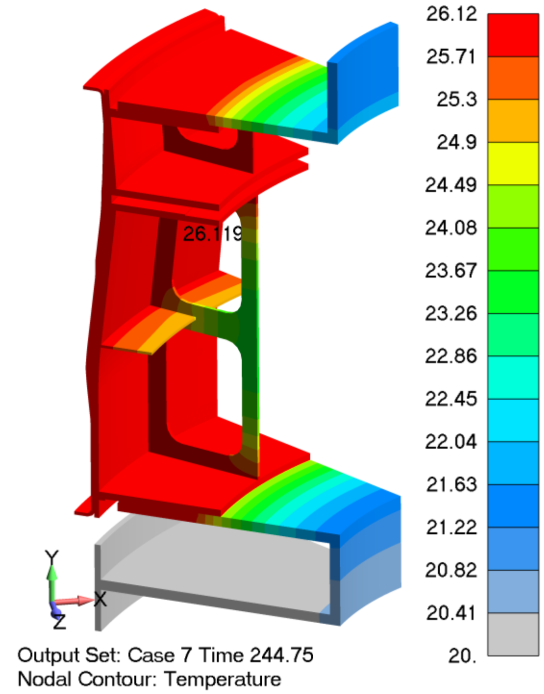
Output Set: Thermal-Stress in 500kW Turbine Generator
Nodal Contour: Nonlinear Solid Von Mises Stress

This high-power, compact generator spins at speeds up to 50,000 RPM thanks to friction-less magnetic bearings. The turbine side is pressurized and is considered an ASME-type pressure vessel and was classed under the ASME Section VIII, Division 2 rules. The generator side was water cooled and unpressurized. The thermal-stress challenge was managing the thermal expansion on the turbine's hot side against the water-cooled generator side. Besides the thermal loads, the analysis included bolt loads, turbine pressure loads and a 10g shock load. Our FEA consultants collaborated with the client to determine realistic thermal loads and assisted in the redesign of the water cooling channels. Upon re-analysis, stress margins were within ASME code specifications and allowed our client to certify the generator for general use in standard industrial environments with no special safety precautions. The generator has gone into service and is operating successfully.

Thermal-Deflection Analysis of Composite Fabrication Mandrel for Jet Engine Cowlings

Composite Jet Engine Cowling	Manufacturing Mandrel for Composite Manufacturing of Cowlings	FEA model to validate curing temperature and dimensions

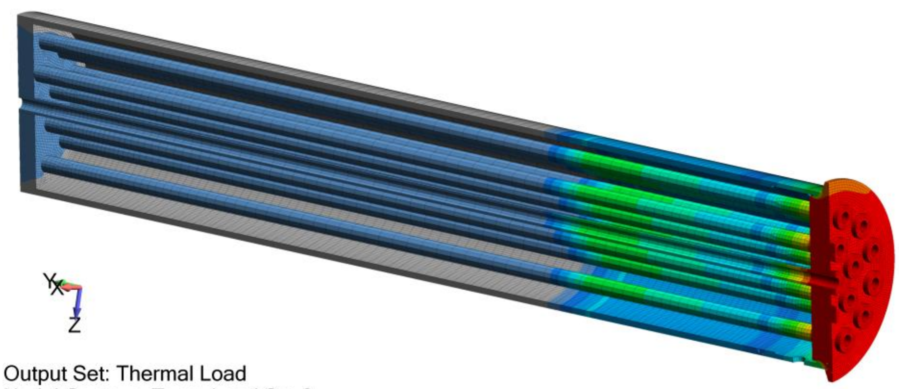




This FEA consulting project was done to verify the initial design concept and was then validated against experimental data. The mandrel was cyclic symmetric and required only a partial section to completely represent the full mandrel. A transient thermal analysis was done on the section to simulate the thermal ramp-up phase of the system. The thermal mass of the composite was assumed to be minor in comparison to that of the mandrel. As the mandrel heated up, deflections were calculated to ensure that the composite cowling would stay within its required specifications. Several design iterations were done with heating pads and insulating blankets to arrive at a final optimized design. The final FEA simulation was used to build the mandrel and take it into service.

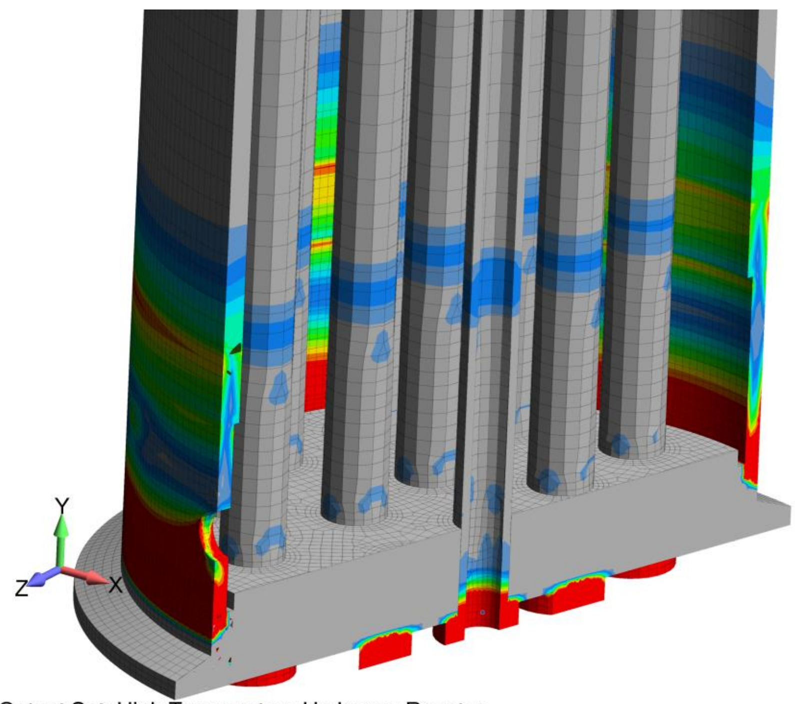
Thermal-Stress Analysis of Hydrogen Reactor

Thermal Hydrogen Reactor for Fuel Cell



Output Set: Thermal Load
Nodal Contour: Temp Load Set 9

Thermal-Stress During Steady-State Operation

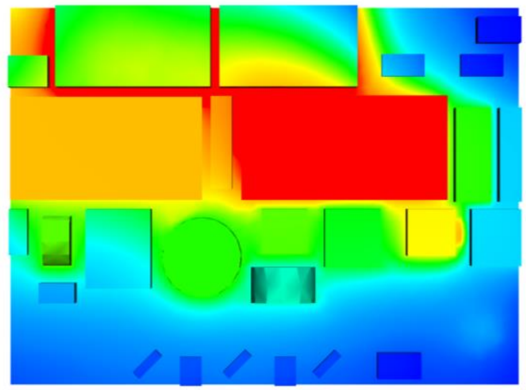


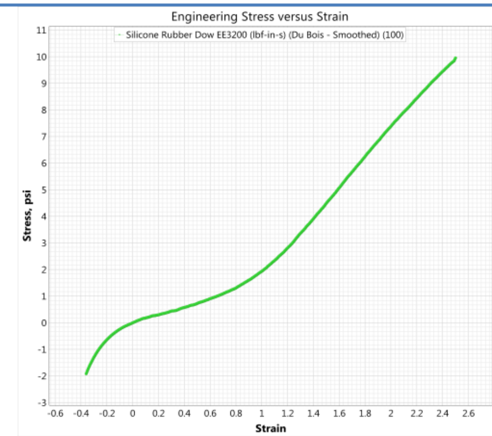
Output Set: High Temperature Hydrogen Reactor
Nodal Contour: Solid Von Mises Stress

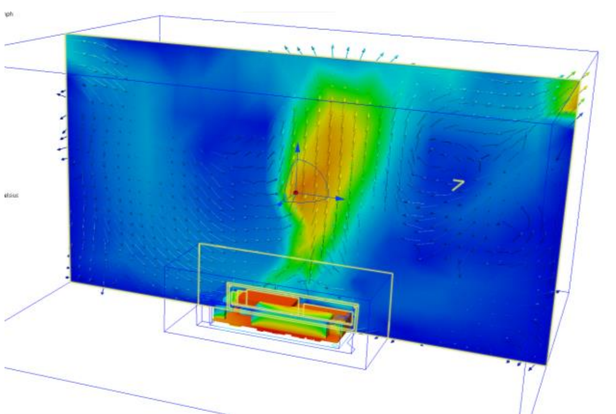
The biggest challenge on this project was the mapping of the client's experimental thermal loads onto a logical set of FEA boundary conditions. The reactor is used to convert natural gas into high-purity hydrogen gas to power a fuel cell. The client's equipment is typically located in remote sites and with a nominal supply of natural gas, can provide backup power for weeks. The reactor develops a high thermal gradient where the natural gas fuel source is fed into the reactor. The thermal-stress results were interrogated to determine weld joint stresses. A fatigue analysis was performed based on the varying operational loads of the reactor. Some analysis judgement was required to differentiate between real and artifact stresses along the weld boundaries. The design was modified through several iterations via collaborative face-to-face meetings with the client's design team. The final design is in service today.

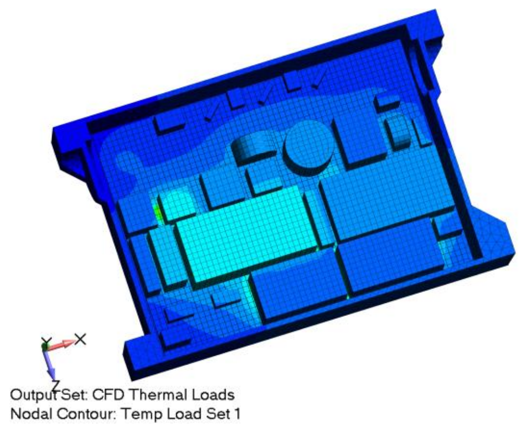
Thermal-Stress Analysis of Potted DC-AC Invertor and other Electronic Devices

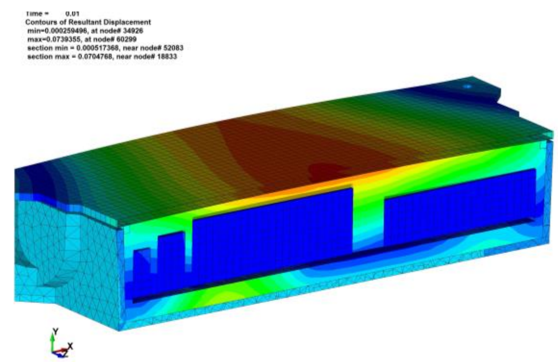
Thermal Analysis of DC-AC Invertor in Ambient Air (Convection / Radiation)	CFD to FEA Temperature Mapping	Thermal-Stress Analysis (LS-DYNA) with Silicon Pottant





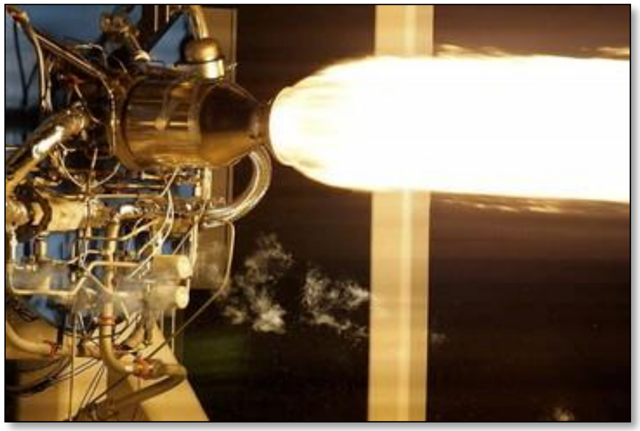


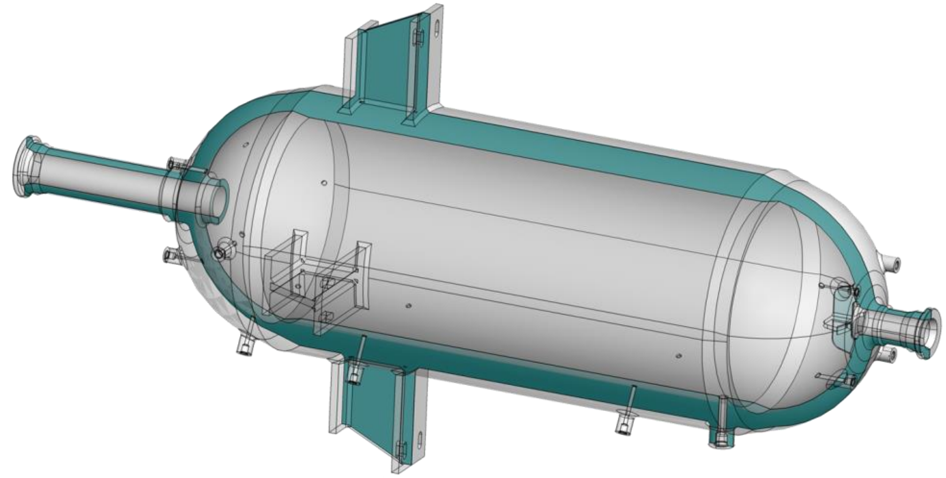


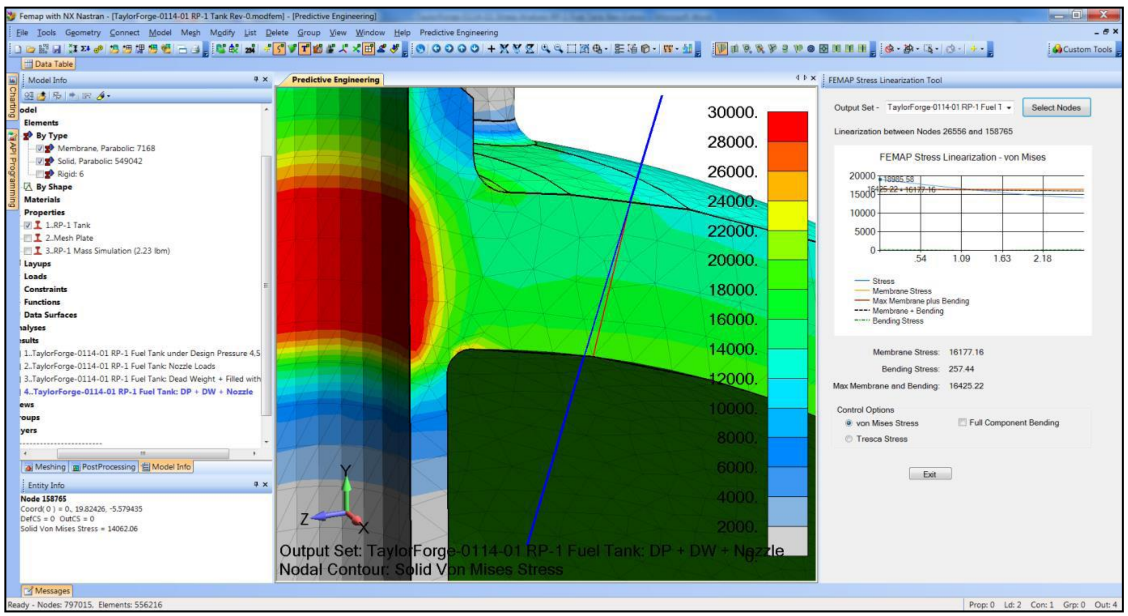


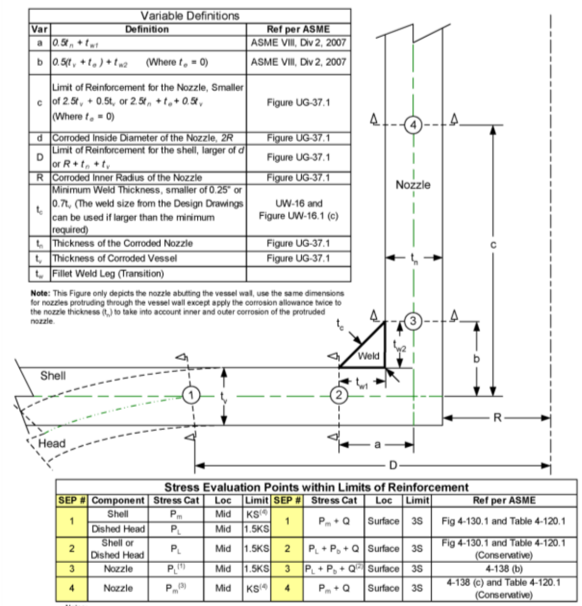
This FEA consulting project is rather pictorial in nature since its complexity would take many paragraphs to describe. The CFD simulation was used to generate a steady-state temperature field for the FEA structural analysis of the electronic circuitry potted within a low-strength silicone gel. The LS-DYNA simulation generated stress results at the chip to PCB connections and provided case deflections. Many other similar projects have been done by our team on chip led fatigue, thermal-stress in electronic assemblies and other electronic devices.

ASME Thermal-Stress Analysis of Thick-Walled LOX and RP1 Propellant Tanks









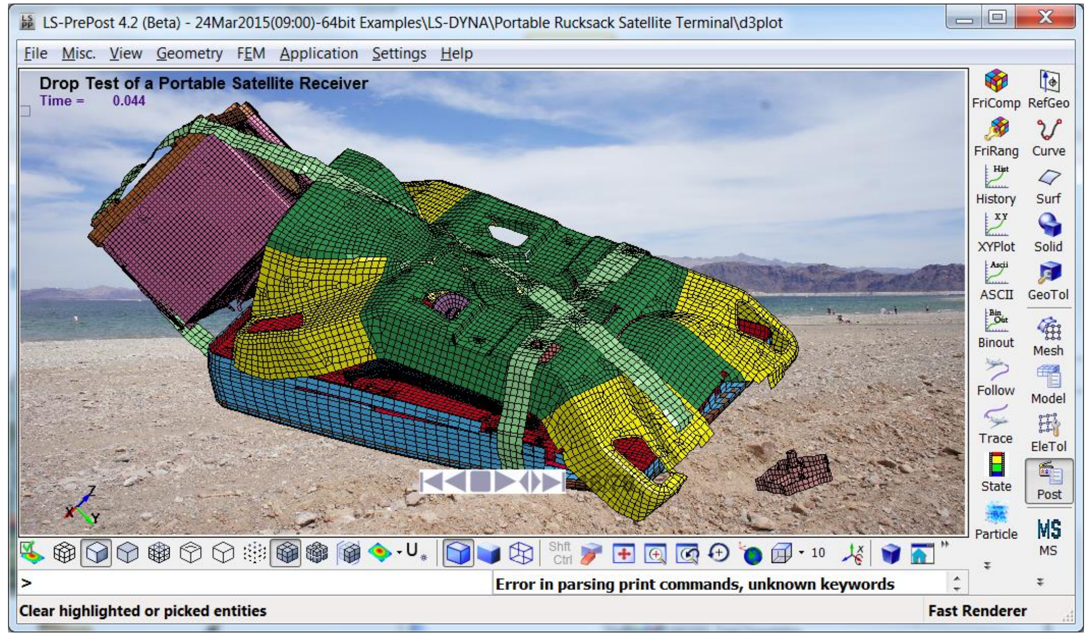
Variable Definitions		
Var	**Definition**	**Ref per ASME**
a	$0.5t_n + t_{w1}$	ASME VIII, Div 2, 2007
b	$0.5(t_v + t_e) + t_{w2}$ (Where $t_e = 0$)	ASME VIII, Div 2, 2007
c	Limit of Reinforcement for the Nozzle, Smaller of $2.5t_v + 0.5t_v$ or $2.5t_n + t_e + 0.5t_v$ (Where $t_e = 0$)	Figure UG-37.1
d	Corroded Inside Diameter of the Nozzle, $2R$	Figure UG-37.1
D	Limit of Reinforcement for the shell, larger of d or $R + t_n + t_v$	Figure UG-37.1
R	Corroded Inner Radius of the Nozzle	Figure UG-37.1
t_c	Minimum Weld Thickness, smaller of 0.25" or $0.7t_v$ (The weld size from the Design Drawings can be used if larger than the minimum required)	UW-16 and Figure UW-16.1 (c)
t_n	Thickness of the Corroded Nozzle	Figure UG-37.1
t_v	Thickness of Corroded Vessel	Figure UG-37.1
t_w	Fillet Weld Leg (Transition)	

Note: This Figure only depicts the nozzle abutting the vessel wall, use the same dimensions for nozzles protruding through the vessel wall except apply the corrosion allowance twice to the nozzle thickness (t_n) to take into account inner and outer corrosion of the protruded nozzle.

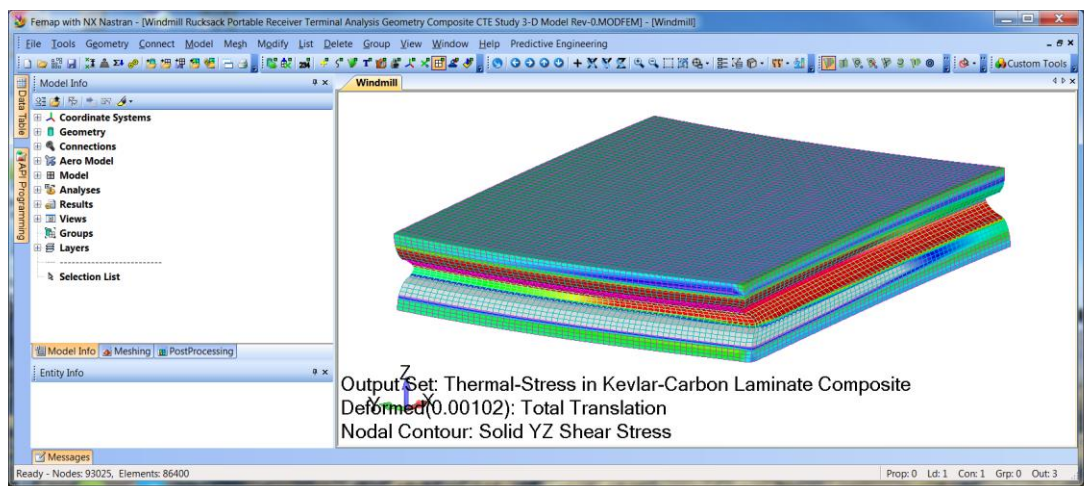
Stress Evaluation Points within Limits of Reinforcement									
SEP #	**Component**	**Stress Cat**	**Loc**	**Limit**	**SEP #**	**Stress Cat**	**Loc**	**Limit**	**Ref per ASME**
1	Shell	P_m	Mid	KS(4)	1	$P_m + Q$	Surface	3S	Fig 4-130.1 and Table 4-120.1
	Dished Head	P_L	Mid	1.5KS					
2	Shell or Dished Head	P_L	Mid	1.5KS	2	$P_L + P_b + Q$	Surface	3S	Fig 4-130.1 and Table 4-120.1 (Conservative)
3	Nozzle	P_L(1)	Mid	1.5KS	3	$P_L + P_b + Q$(2)	Surface	3S	4-138 (b)
4	Nozzle	P_m(3)	Mid	KS(4)	4	$P_m + Q$	Surface	3S	4-138 (c) and Table 4-120.1 (Conservative)

Thick-wall, high-pressure liquid oxygen (LOX) tanks experience thermal fatigue conditions rarely seen in normal pressure vessels. Our FEA consultants teamed with our client's design team at Taylor-Forge and SpaceX to develop realistic cryogenic transient-thermal profiles for the liquid oxygen filling and nitrogen back-filling of the tanks. These loads were then used to drive the stress model. All results were classed under ASME BPVC Section VIII to certify the tanks as fit-for-service under operating, upset and fatigue conditions.

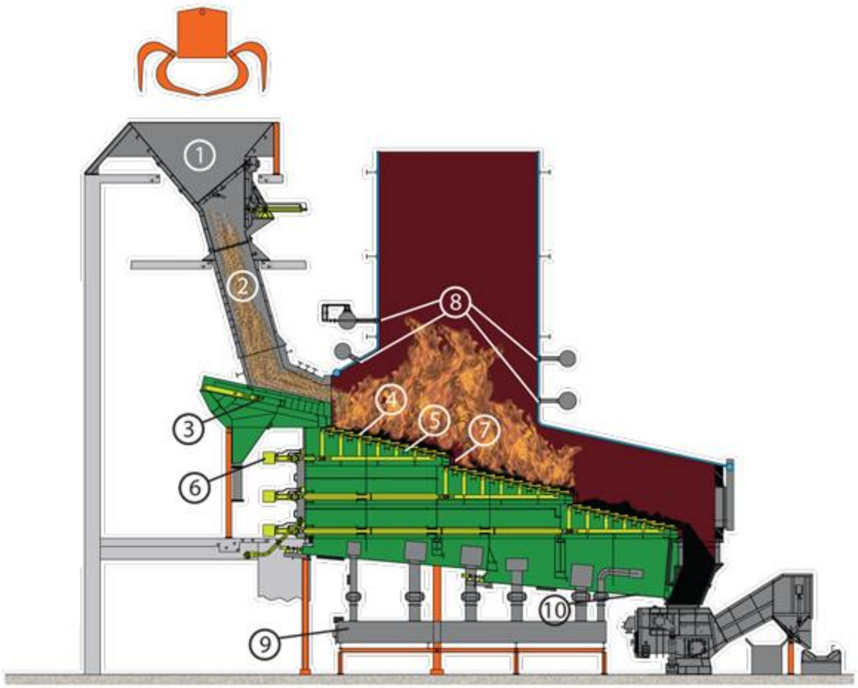
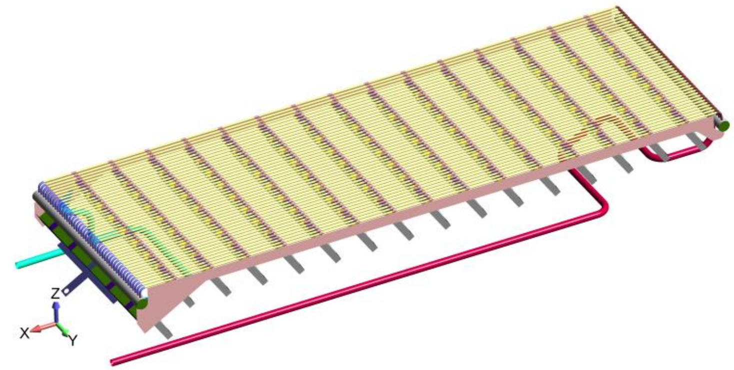
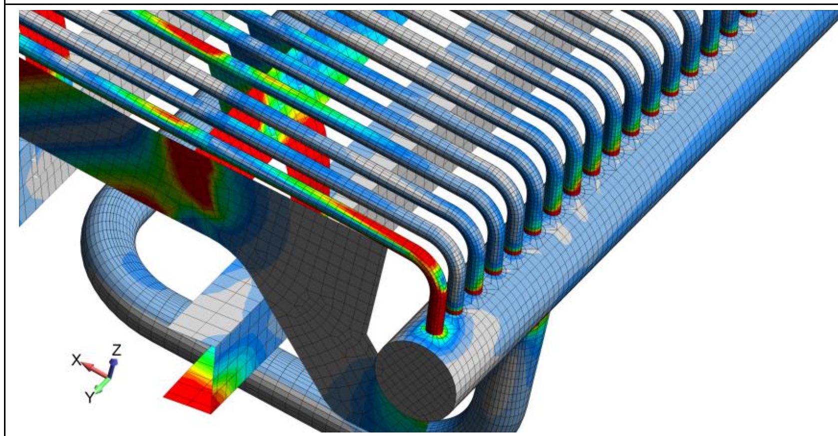
Thermal-Stress Effects within Thick Composite Laminate for Military Electronics



Along with a LS-DYNA drop test simulation, the composite laminates used in the device were analyzed for thermal-stress failure given sub-zero temperatures. The solid composite FEA model evaluated the resin bond between the Kevlar and carbon layers. Drop-Test and Thermal-Stress results were combined to demonstrate the survivability of the design under harsh military conditions. The satellite receiver is now in use.



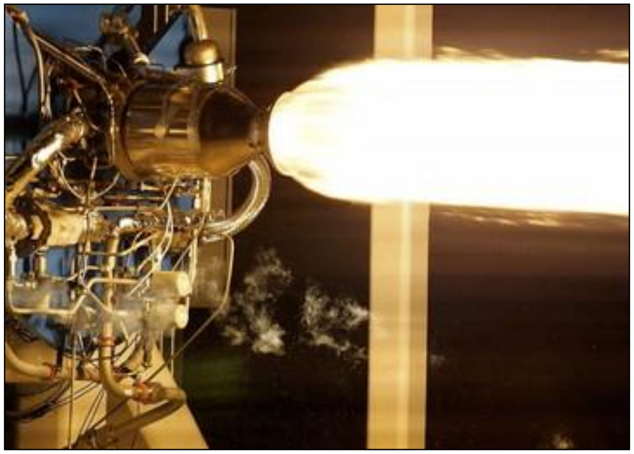
Thermal-Stress Analysis of Water-Cooled Stoker Grate

ORGANIC BURNING FURNACE WITH STOKER GRATE AT THE BOTTOM	THERMAL-STRESS RESULTS
	 

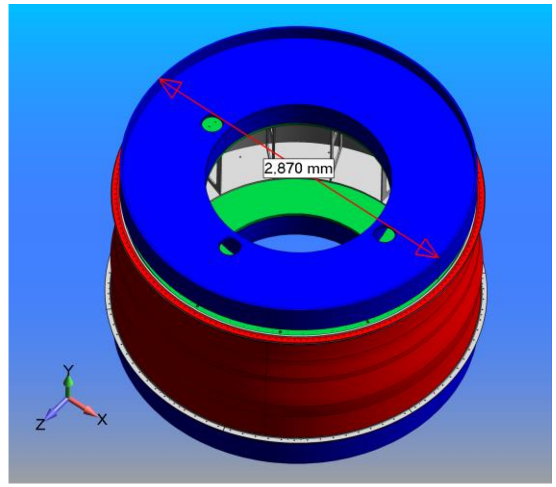
We would be remiss not to include a classic example of thermal-stress analysis with this water-cooled stoker grate. The grate uses cast iron castings facing the burning material with their undersides cooled with the array of piping shown above. The complete system is vibrated to move the ash load off of the grate and into a conveyor system. Our FEA consulting group has done the vibratory analysis work along with this thermal-stress work. The objective of the thermal work was to reduce weld breakage due to cyclic thermal loading. The thermal differential between the cold pipes and the hot grate tends to tear apart the grate unless carefully managed. FEA results were then used to minimize the stresses along critical weld lines and have significantly improved fatigue life for the stoker grate. The reduction in warranty costs directly paid for our FEA service work.

Summary of General Thermal-Stress Consulting Experience at Predictive Engineering

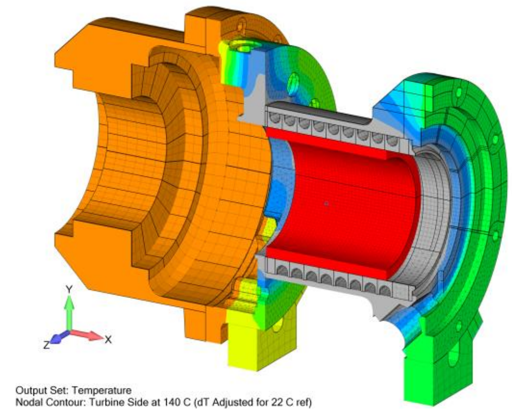
LOX and RP1 Fuel Tanks



Composite Curing Mandrel

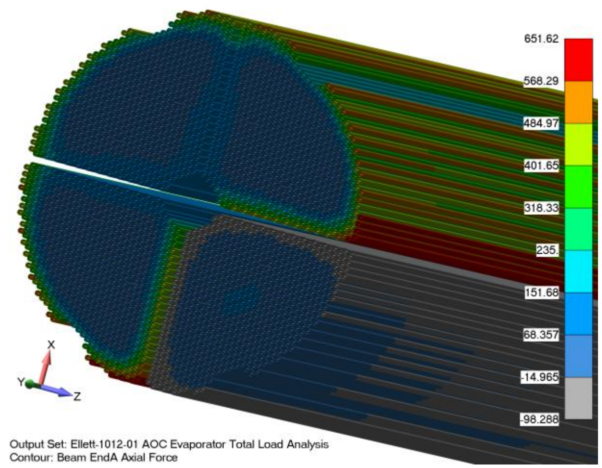


500kW Turbine Generator

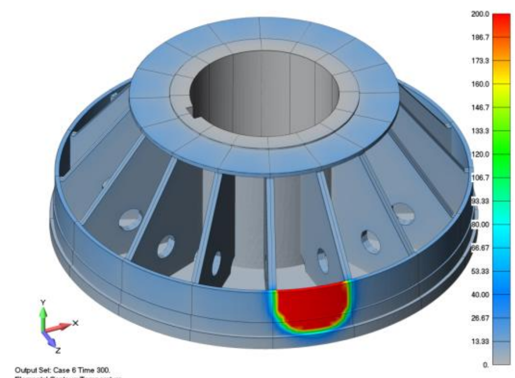


Solar Panel DC to AC Power Converter

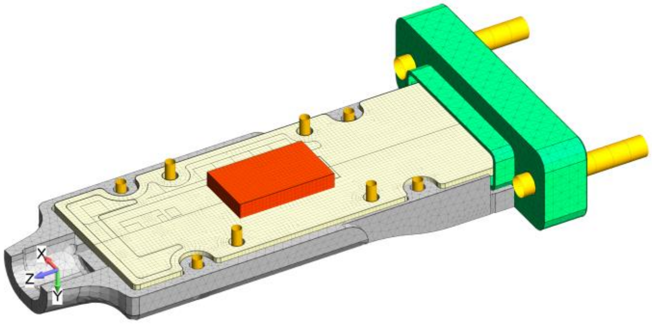
Thermal Differential Expansion ASME Tube Sheet Pressure Vessel



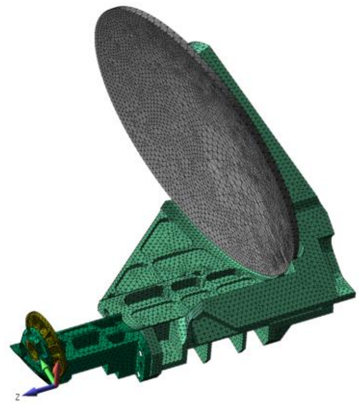
Thermal-Stress Fracture Hydroelectric Generator Thrust Collar



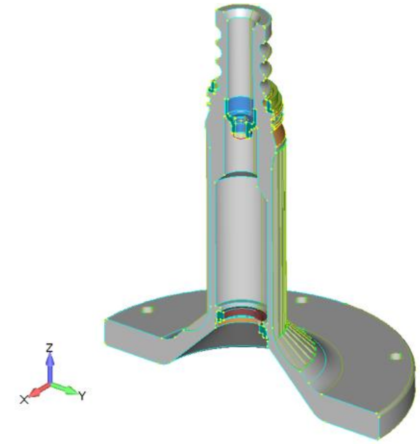
Thermal-Fatigue Analysis of Active Optic Cable



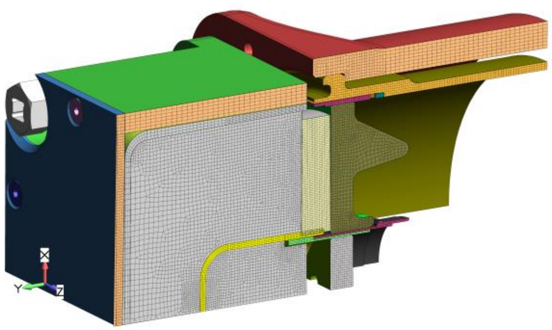
Thermal-Deflection Optical Telescope



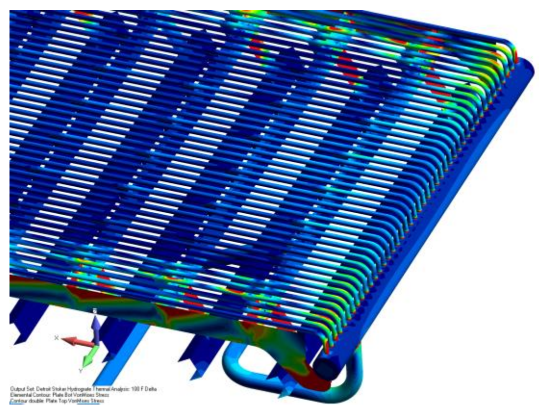
Plasma Tube with Brazed Inserts



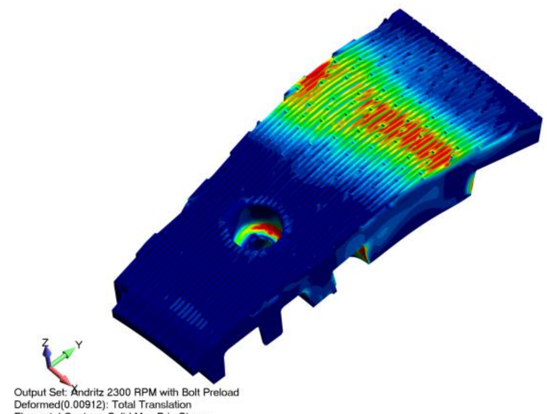
High-Voltage Thermal-Shock Deflection Simulation



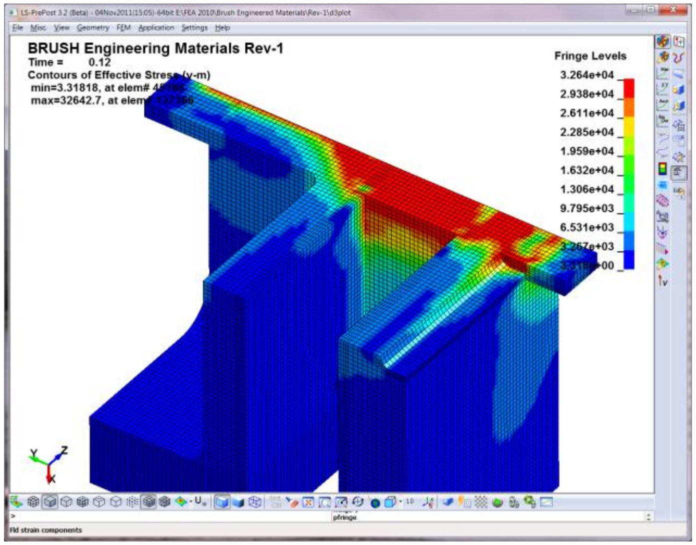
Thermal-Stress Analysis of Water Cooled Furnace Grate



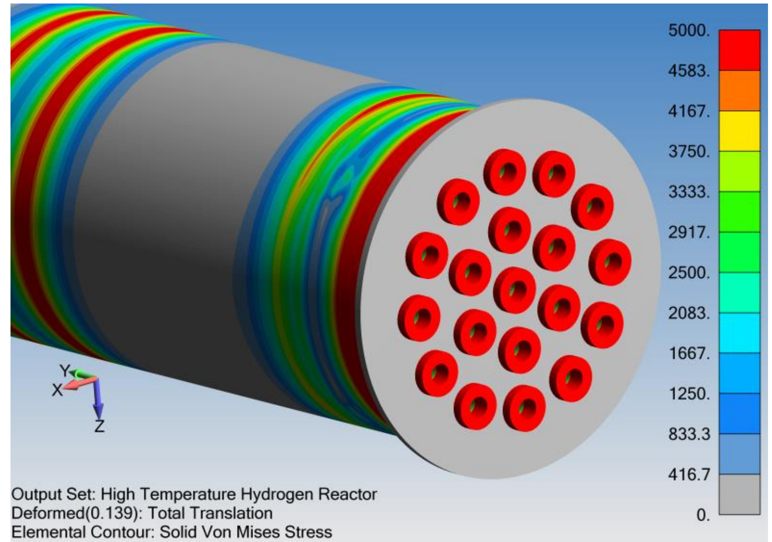
Thermal-Shock Stress Analysis of Pulp Refiner Plate for the Paper Industry



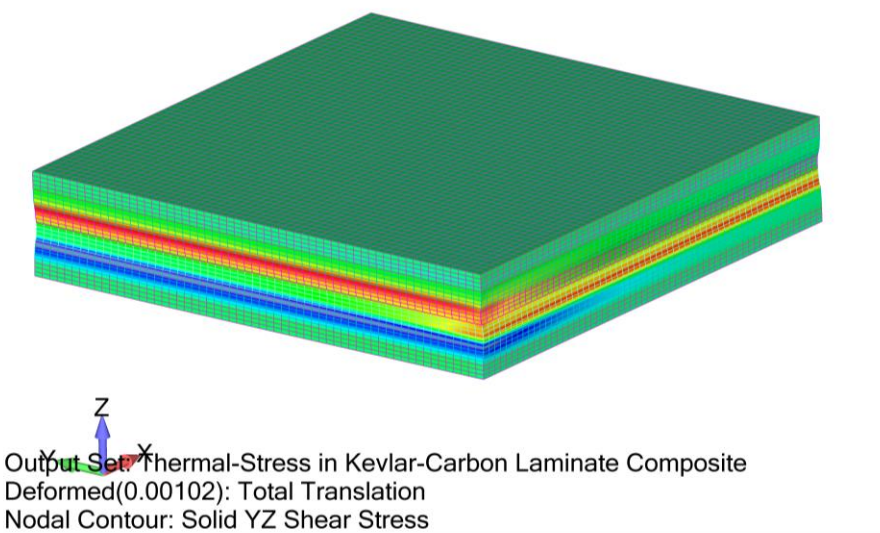
Thermal-Residual Stress Electron Beam Welding



Thermal-Stress in High-Temperature Hydrogen Reactor



Thermal-Stress in Kevlar-Carbon Laminate Composite



Thermal-Stress of Steam Power Supply Piping