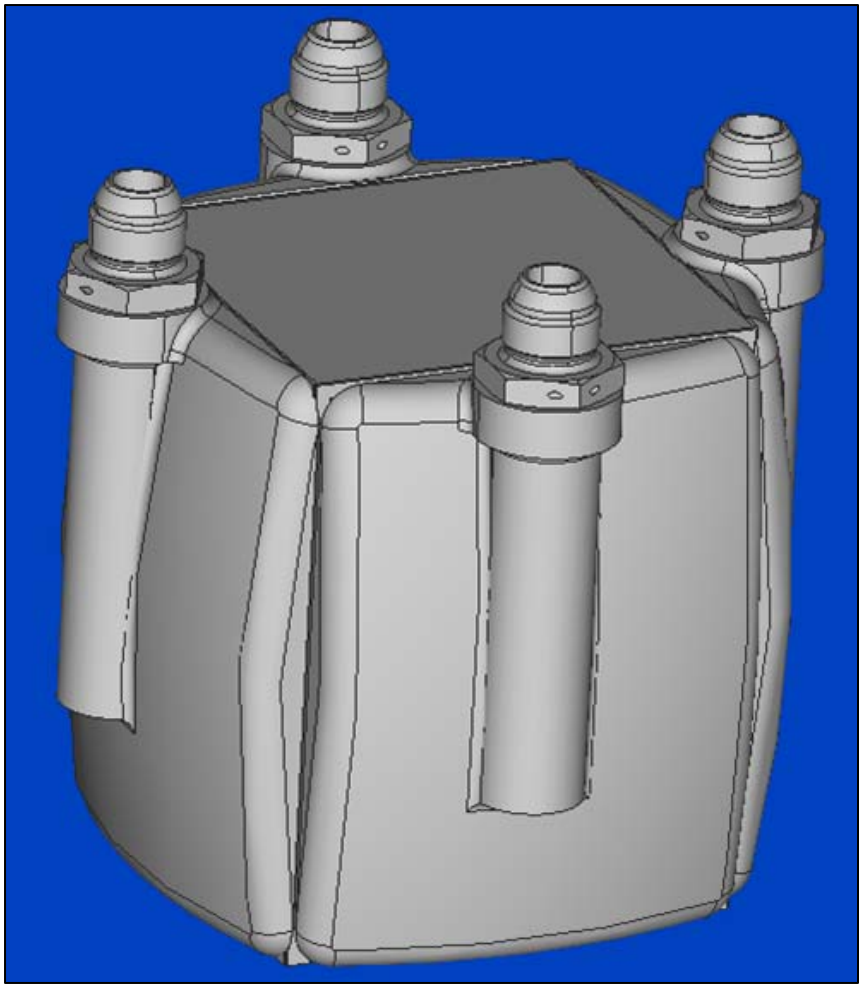
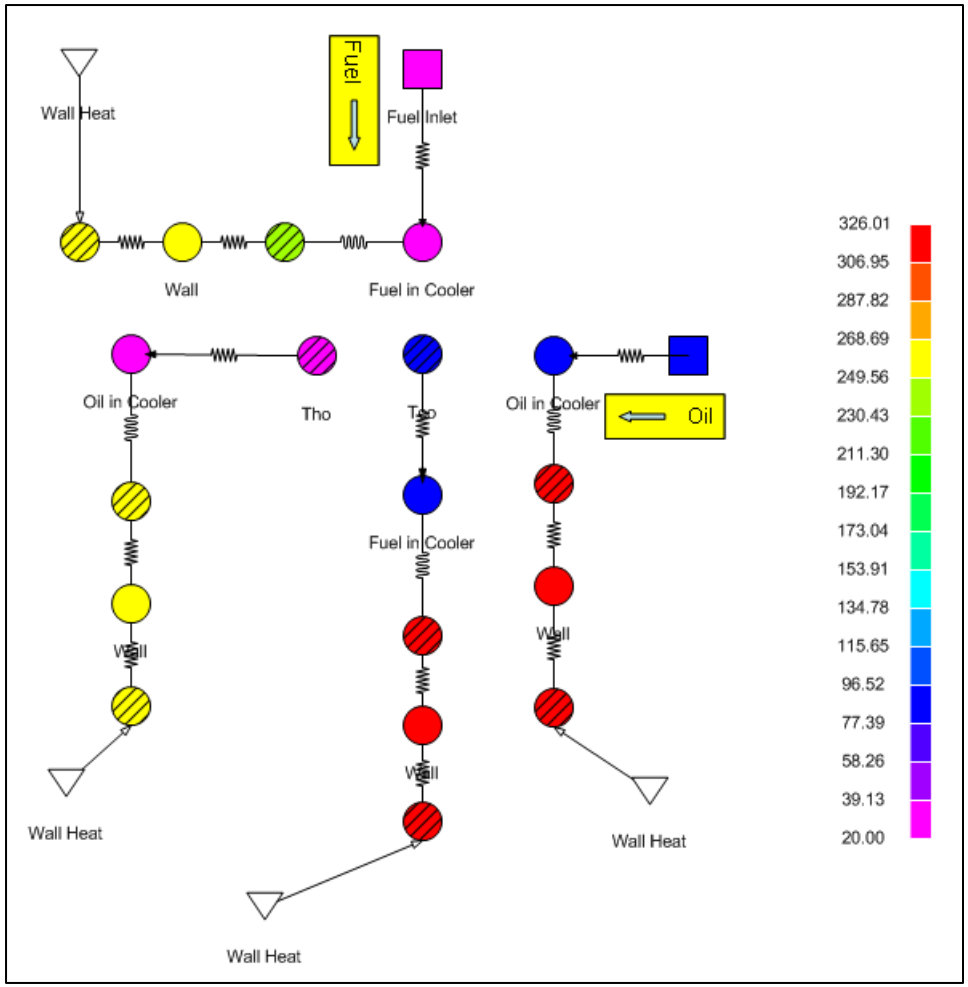
Fuel Cooled Oil Cooler Fire Test





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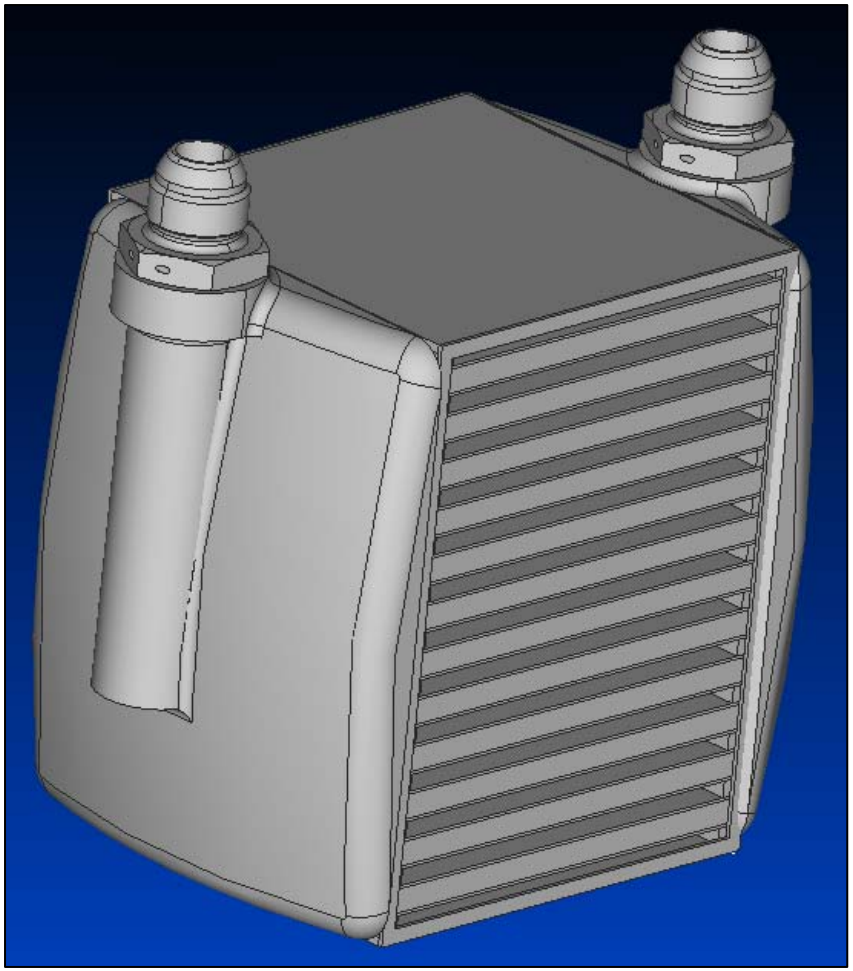


FCOC with cover removed showing exchanger

Description

•The Fuel Cooled Oil Cooler (FCOC) for oil-spray cooled generator on aircraft.

•Consists of compact cross-flow heat exchanger.

- •11 fuel and 12 oil layers
- •Fins spaced every 2 mm and 4.7 mm in height.
- •Fin thickness - 0.05 mm.
- •Material-Inconel 625.

•The cover plates - Al 2024-T6.

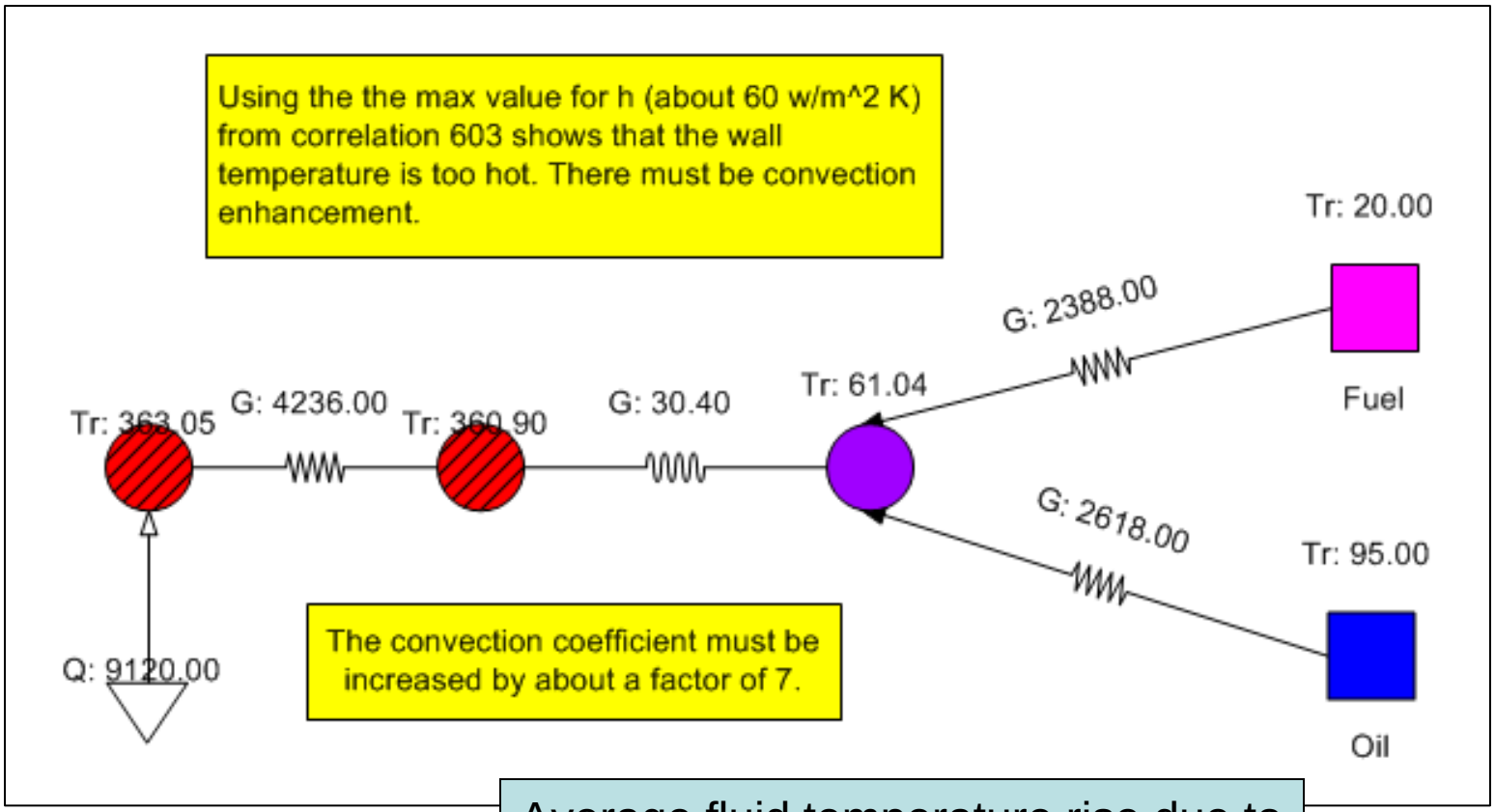
•Dimensions - approximately 4 in x 4 in x 5.4 in.

•Flow rate - fluid volumes exchanged every second.

- Goals
- Find fluid and wall temperatures after 15 minutes under conditions of onboard fire.
  - Wall temperature to be < 380 ^{o}C.
- Recommend any design changes.

- Boundary Conditions:
  - Heat flux of 120,000 watts/m2 is the assumed fire conditions.
  - Fuel and oil inlet temperatures are 20 ^{o}C and 95 respectively ^{o}C.

A simple enthalpy model is sufficient to show that the convective heat transfer from the smooth walls of the current design will have to be enhanced.

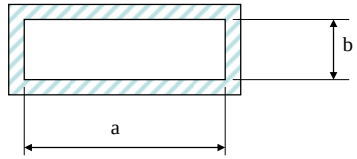


Average fluid temperature rise due to fire < 2 ^{o}C.

Heat Exchanger Efficiency used in *SINDA/G* Model to Calculate Outlet Temperatures

- Convection coefficient is calculated within the exchanger using *SINDA/G* Convection Correlation #518.
- NTU method is used for calculating heat exchanger efficiency.
- Efficiency used to compute fluid outlet temperatures given the inlet temperatures.

Correlation ID = 518



Description
- Rectangular duct
- Forced convection
- Internal flow
- Fully developed
- Laminar flow
- Average of constant wall heat flux & constant wall temp

$$h = \frac{k_{fluid}}{D_h} Nu$$

where :

Correlation Coefficients
- C_1 = aspect ratio = b/a

$$Nu = -0.1693 C_1^2 + 2.1230 C_1 + 1.2928$$

$$C_1 = \sqrt{\frac{MAX(a,b)}{MIN(a,b)}}$$

Additional Notes and/or Restrictions
- Re < 2,300 to 3,000 is customary

$$D_h = \frac{2ab}{a+b}$$

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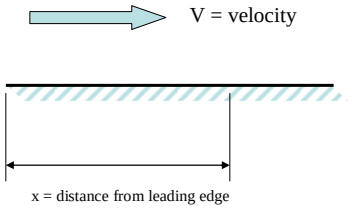
$$\varepsilon := 1 - \exp\left[\frac{1}{C_r}\left[NTU^{0.22} \cdot \left(\exp\left(-C_r \cdot NTU^{0.78}\right) - 1\right)\right]\right]$$

Efficiency for cross-flow heat exchanger.

Determination of Convection Coefficient on Cover Plates

Correlation ID = 603



Description
- Flat plate, local convection
- Forced convection
- External flow
- Turbulent flow

$$h = \frac{k_{fluid}}{x} Nu$$

where:

Correlation Coefficients
- None

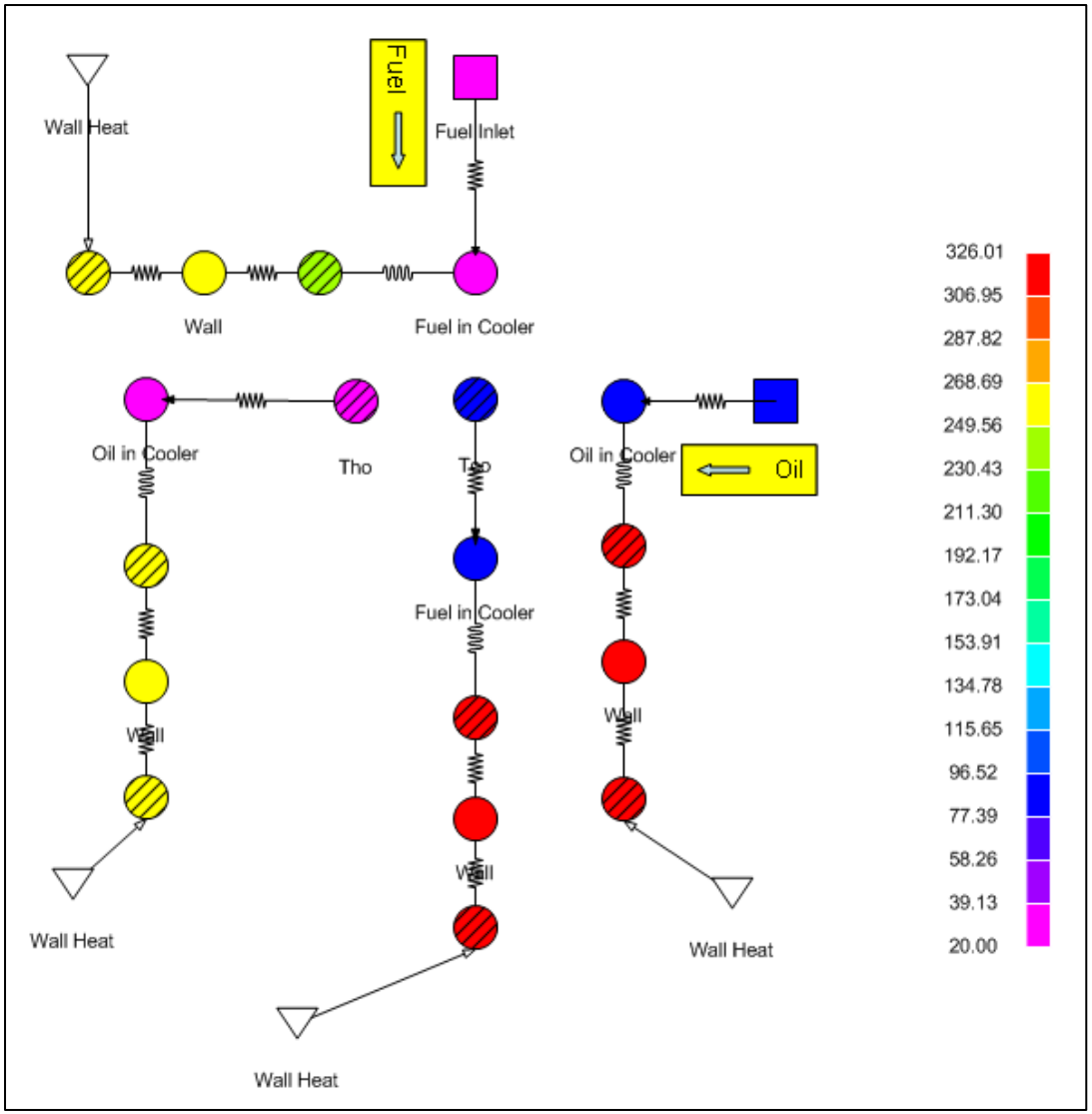
$$Nu = 0.029 \, \mathrm{Re}_x^{0.8} \, \mathrm{Pr}^{0.43}$$

Additional Notes and/or Restrictions
- Re < 350,000 to 500,000 is customary

$$\mathrm{Re}_x = \frac{Vx\rho_{fluid}}{\mu_{fluid}}$$

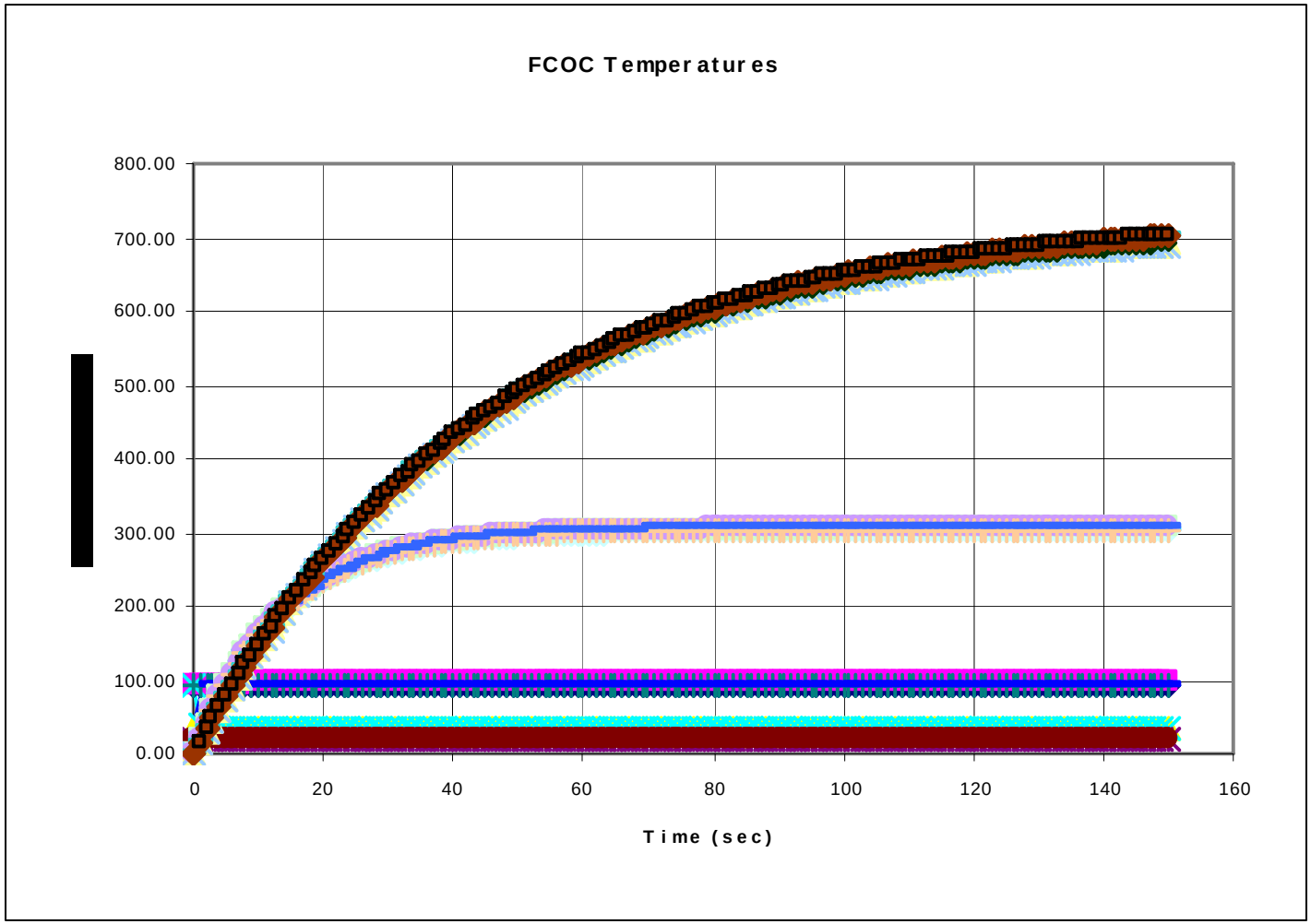
- Convection coefficients from the fluids to the cover plates were calculated using *SINDA/G* Convection Correlation #603 for turbulent convection over a flat plate.

Schematic of model that incorporated calculation of exchanger exit fluid temperatures using NTU methodology and calculation of convection to fuel and oil by correlations.

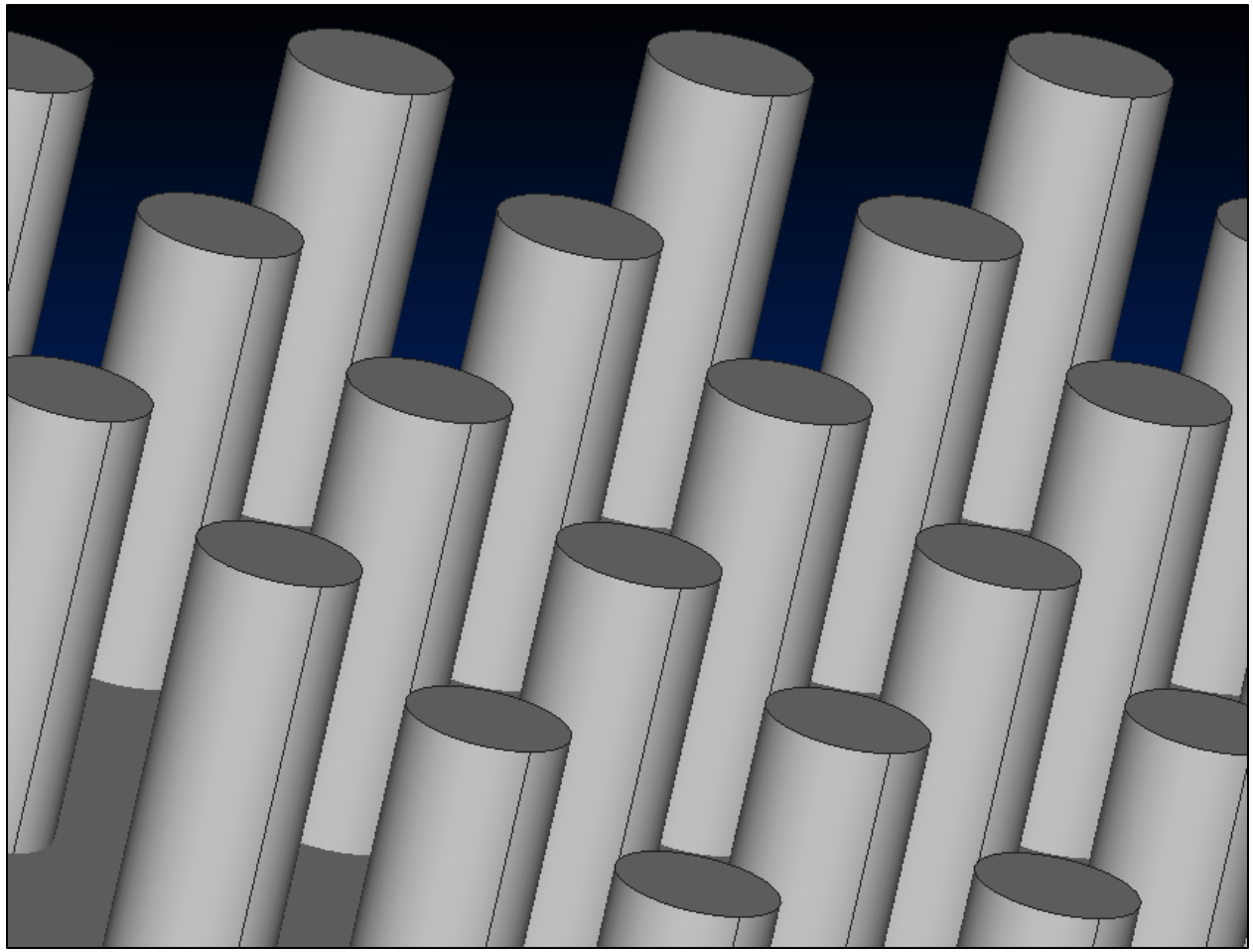


Results

The wall temperatures greatly exceeded the adverse service specifications.



A Design Recommendation:
Attach pin fins to the cover plates.

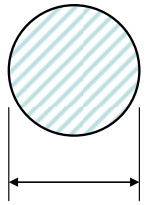


Pins of 2mm diameter and 6 mm long were considered.

SINDA/G Convection Correlation #708 was used to compute convection coefficient from the pins.

Correlation ID = 708

Description
- Cylinder
- Horizontal
- Natural convection
- Laminar or turbulent flow
- Constant wall temperature



D = diameter of the cylinder

$$h = \frac{k_{fluid}}{D} Nu$$

where:

$$Nu^{1/2} = 0.6 + \frac{0.387 Ra_D^{1/6}}{\left[1 + \left(\frac{0.559}{\mathrm{Pr}}\right)^{9/16}\right]^{8/27}}$$

$$Ra_D = \frac{g\beta D^3 \Delta T \rho^2}{\mu^2} \mathrm{Pr}$$

Correlation Coefficients
- None

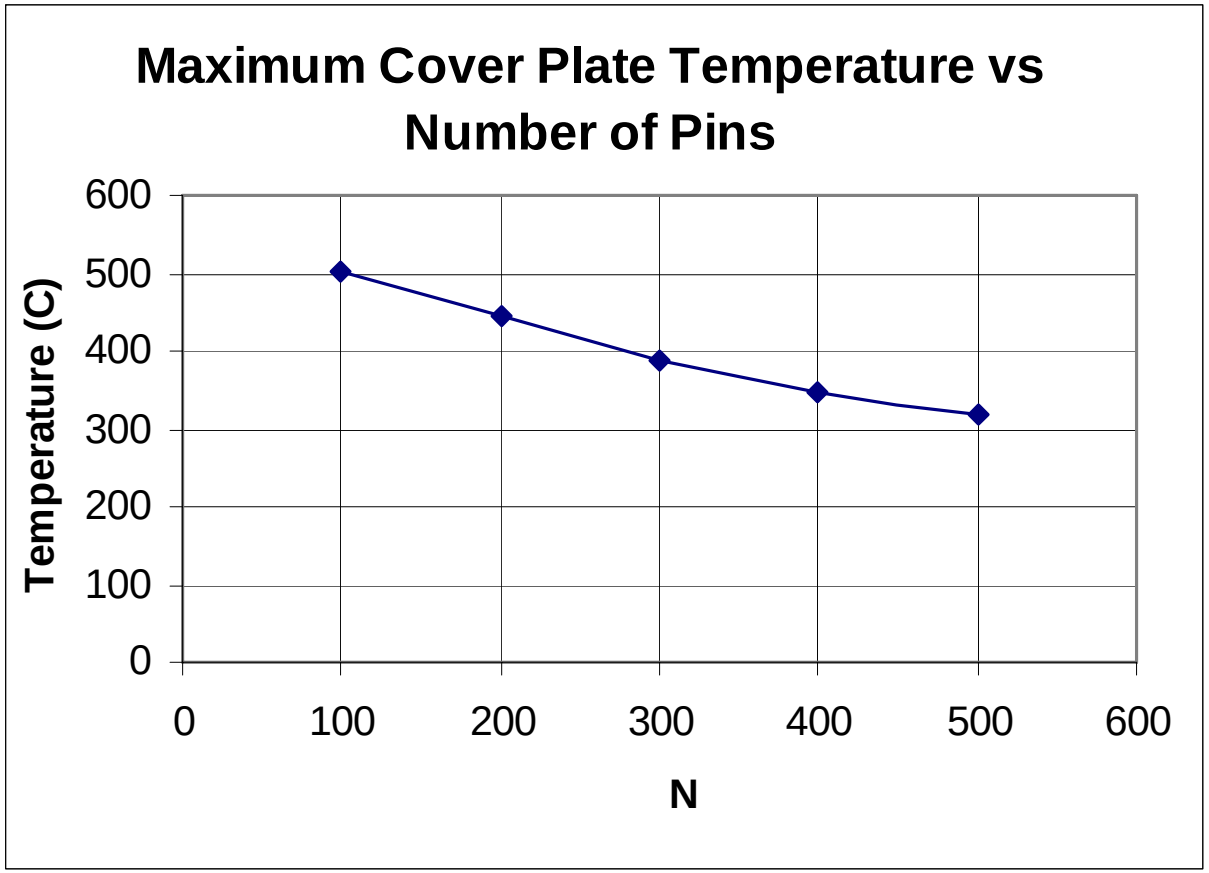
Additional Notes and/or Restrictions
- $10^{-4} < Ra < 10^{12}$

Pin efficiency and overall efficiency were computed and used to determine overall convection coefficient.

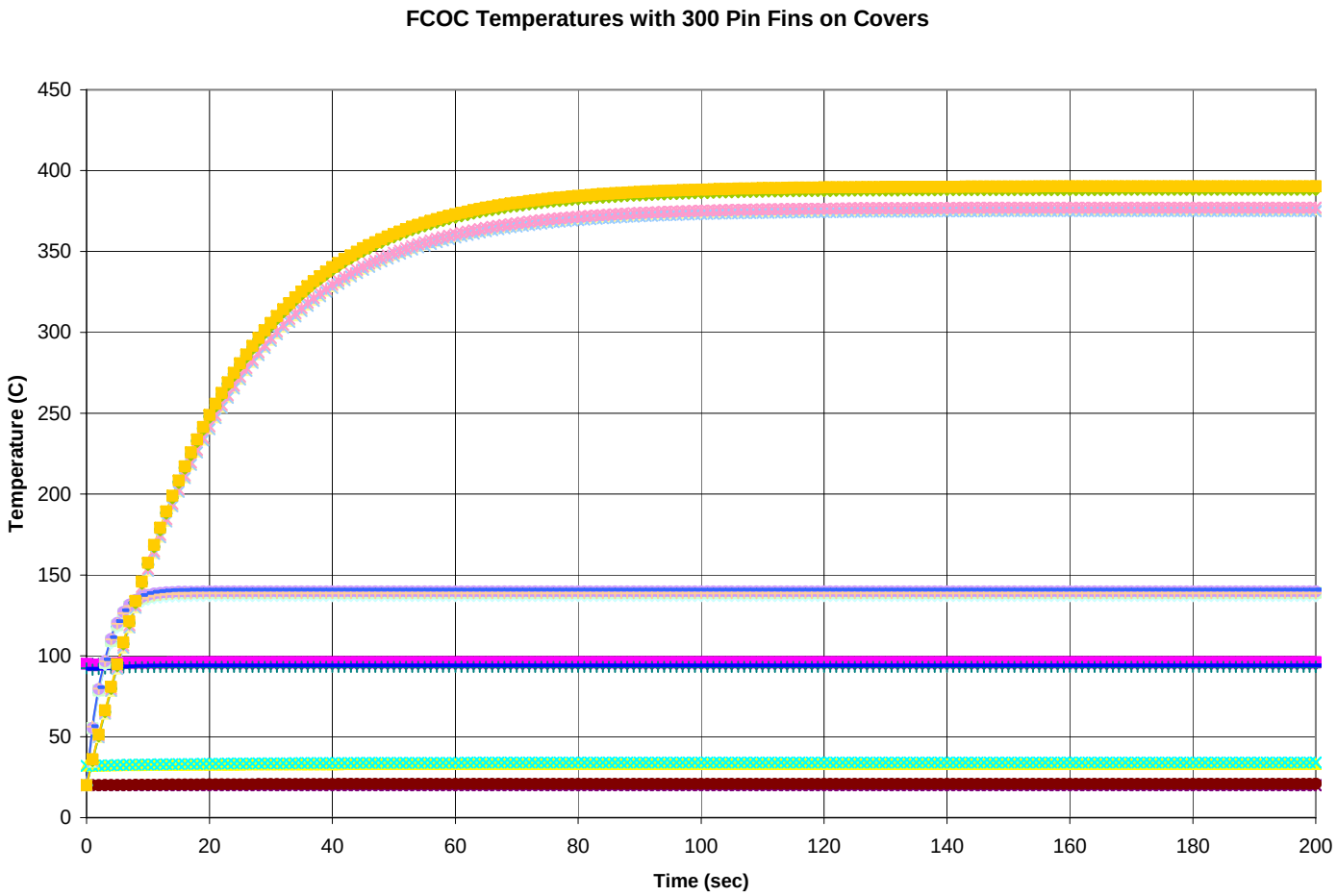
$$\eta_f := \frac{\tanh(m \cdot l) + B}{(B + m \cdot l)(1 + B \cdot \tanh(m \cdot l))}$$

$$\eta_o := 1 - \frac{N \cdot A_f}{A_t} \cdot \left(1 - \eta_f\right)$$

It was found that 300 pin fins to the surface of the cover plates would be sufficient to meet adverse service temperature specifications.



Results With 300 Pins on Each Cover Plate



Conclusions and Recommendations

- Current design fails adverse service requirements for wall temperatures from an onboard fire.
- Convective heat transfer from FCOC exterior walls to fluids needs to be enhanced to meet these requirements.
- Pin fins were considered as an enhancement in a simple analysis.
    - Preliminary analysis showed that an arrangement of 300 pins on each surface would suffice.
- Modeling Recommendations
    - Future models should incorporate temperature dependent properties of the working fluids since convection coefficients are dependent on these properties.
    - CFD analysis of flow on any fin configurations might be performed and velocity results used to compute convection coefficients in thermal model