DEVELOPING THE SMALL PARTICLE HEAT EXCHANGE RECEIVER FOR A PROTOTYPE TEST

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SunShot

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Project Partners

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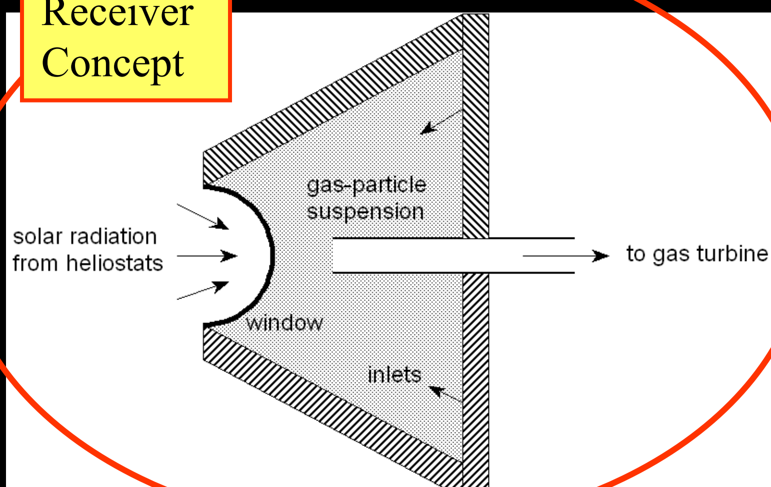
Presentation Outline

- Concept of the Small Particle Solar Receiver
- Project Objectives and Description
- Lab-Scale Component Testing
- Receiver window design (optical/mechanical)
- Radiation heat transfer and thermo/fluid dynamic modeling
- Challenges & Future work

Solar Central Receivers

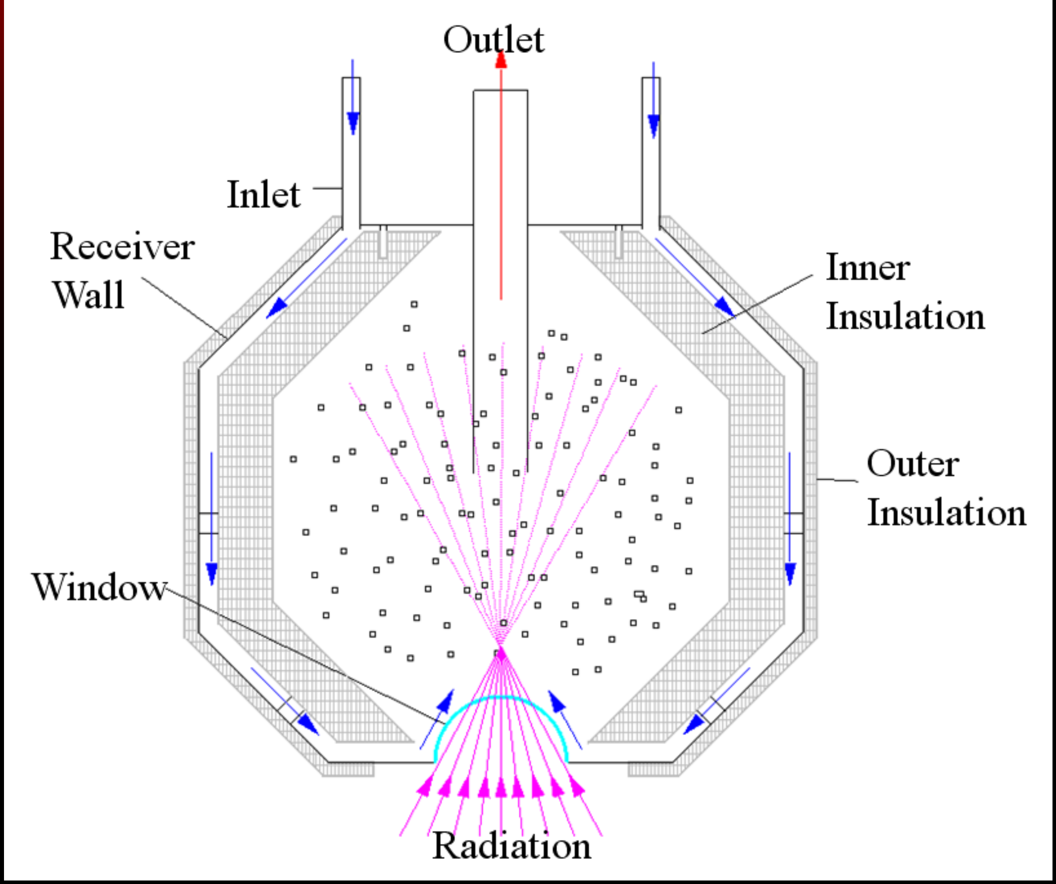
Commercial central receivers use either molten salt or steam as the coolant, and are limited to medium temperatures and moderate solar fluxes

"New" Receiver Concept



Our proposed technology, a gas-small particle receiver, can efficiently deliver the temperatures needed for a high-efficiency, gas turbine (Brayton cycle).

Small Particle Receiver Under Renewed Development at SDSU



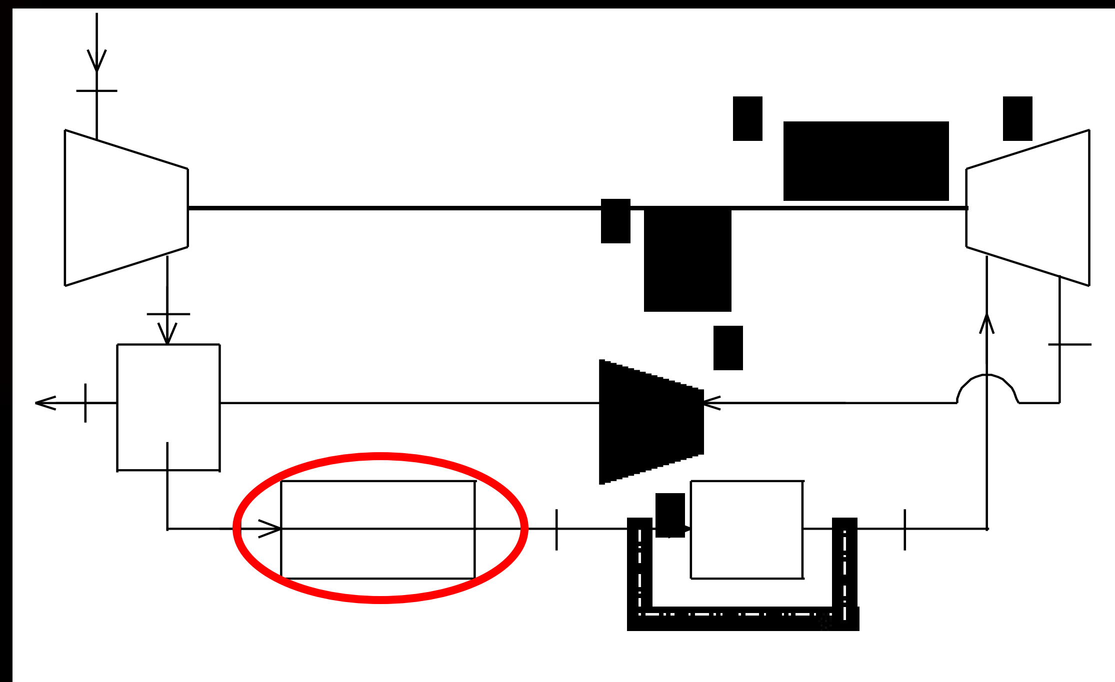
Conceptual Small Particle Receiver

Advantages:

- Radiation is absorbed by sub-micron carbon particles, which act as **selective**, efficient absorbers of solar radiation.
- Extremely high temperatures and flux levels are possible, because the absorbers are expendable.
- The carbon particles oxidize once they reach high temperatures.
- The small particles are at thermal equilibrium with their surroundings (no resistance to heat transfer).
- Pressure drops are minimized by removing tubes or foam absorbers.

Small Particle Receiver in a Gas Turbine Cycle

- Solar receiver goes in-line with the combustor.
- Advantages for Gas Turbines:
  - High efficiency
  - Low water consumption
  - Possible combined cycle
  - Ease of Operation



Recuperated Gas Turbine Cycle

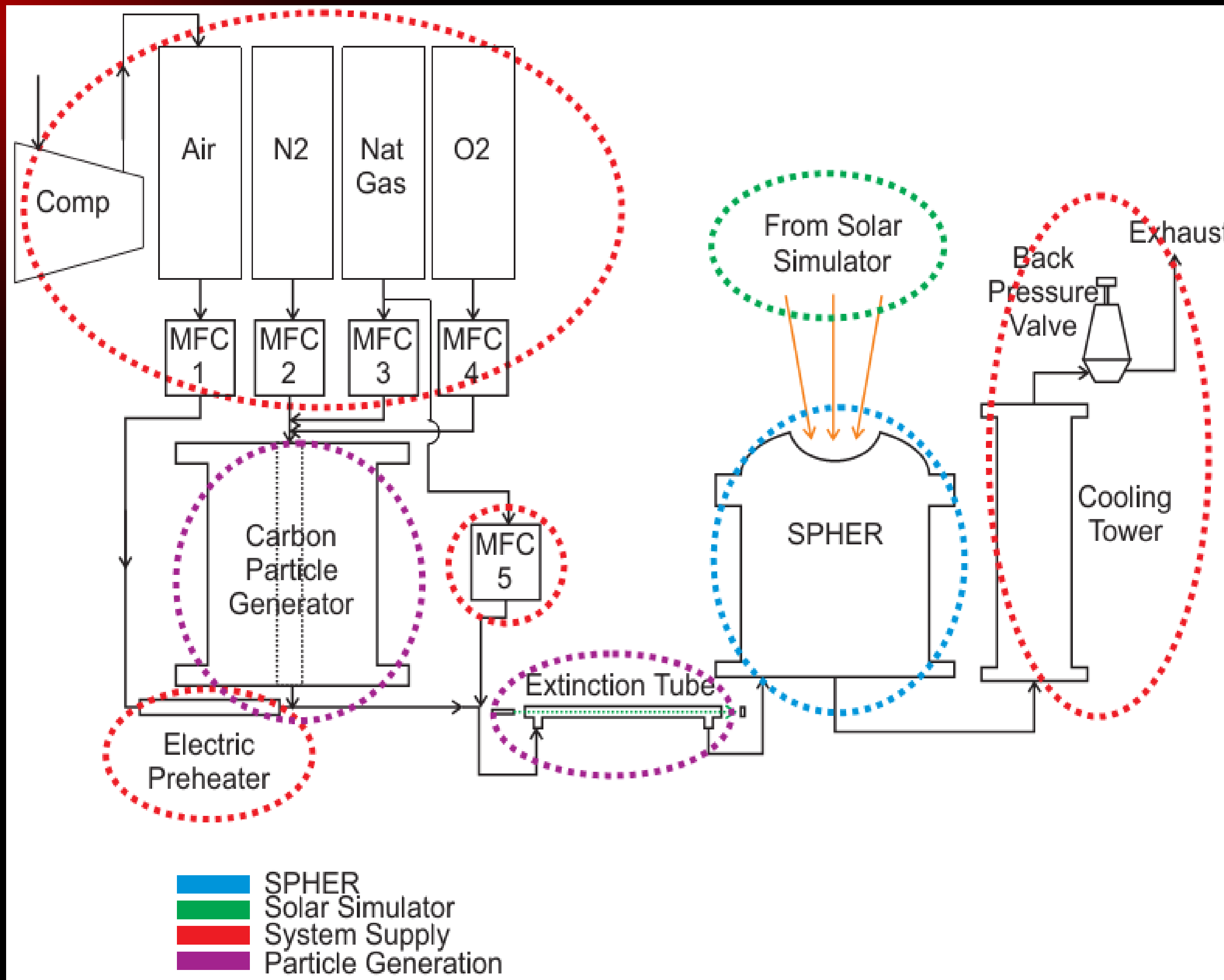
Project Objectives

- The objective of this project is to design, construct, and test a revolutionary high temperature small particle solar receiver in the multi-MW range that can be used to drive a gas turbine to generate low-cost electricity.
- A secondary objective is demonstrating for the first time a pressurized solar receiver with a window greater than 1 m in diameter.

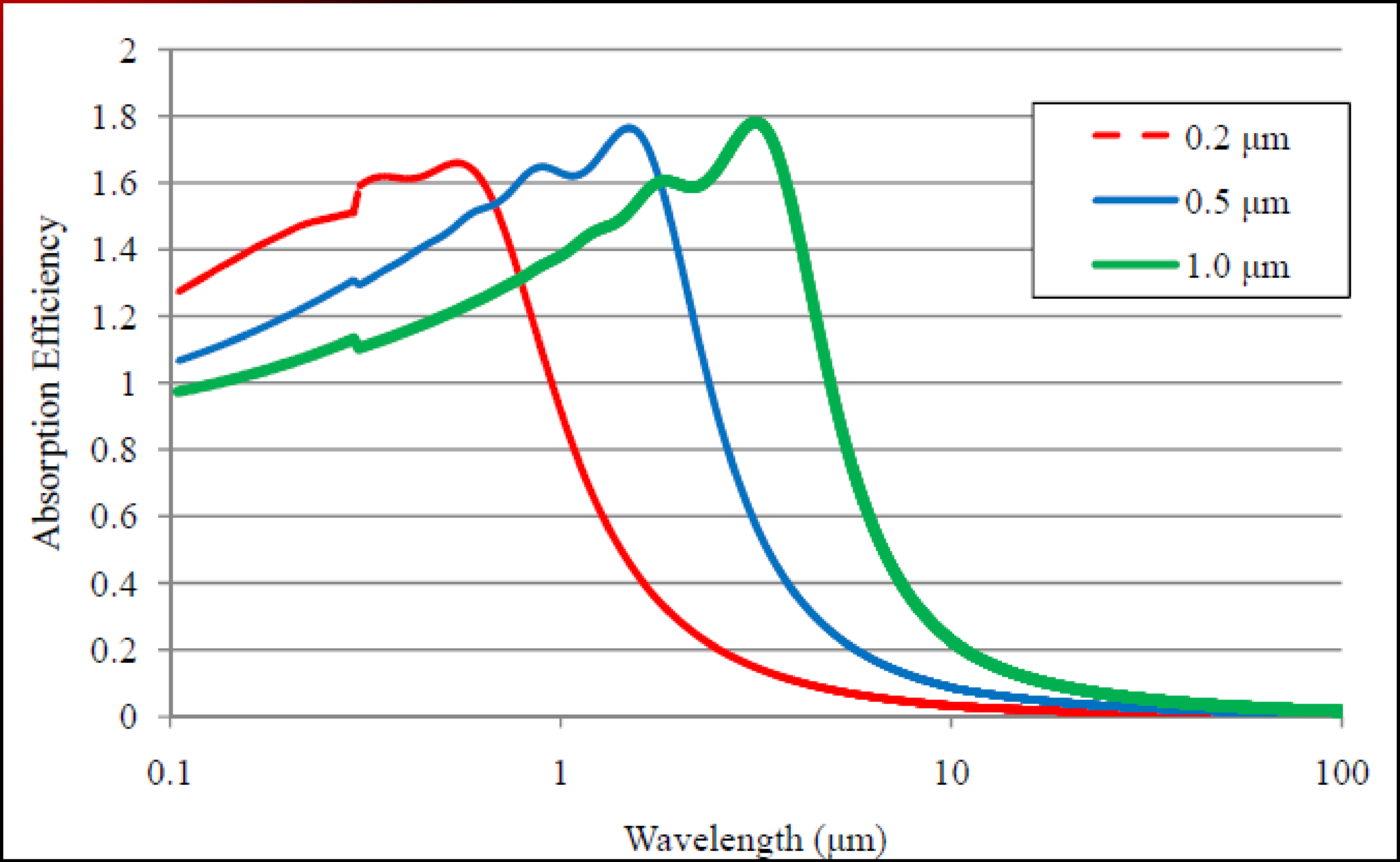
Project Description

- Phase 1
  - Lab-Scale Component Testing
  - Window and Seal Design
  - Full-scale Particle Generator Design
  - Receiver Modeling and Preliminary Design
- Phase 2 – Finalize Designs, Fabricate and Test Components
- Phase 3 – Assemble components and test receiver at the National Solar Thermal Test Facility at Sandia National Labs.

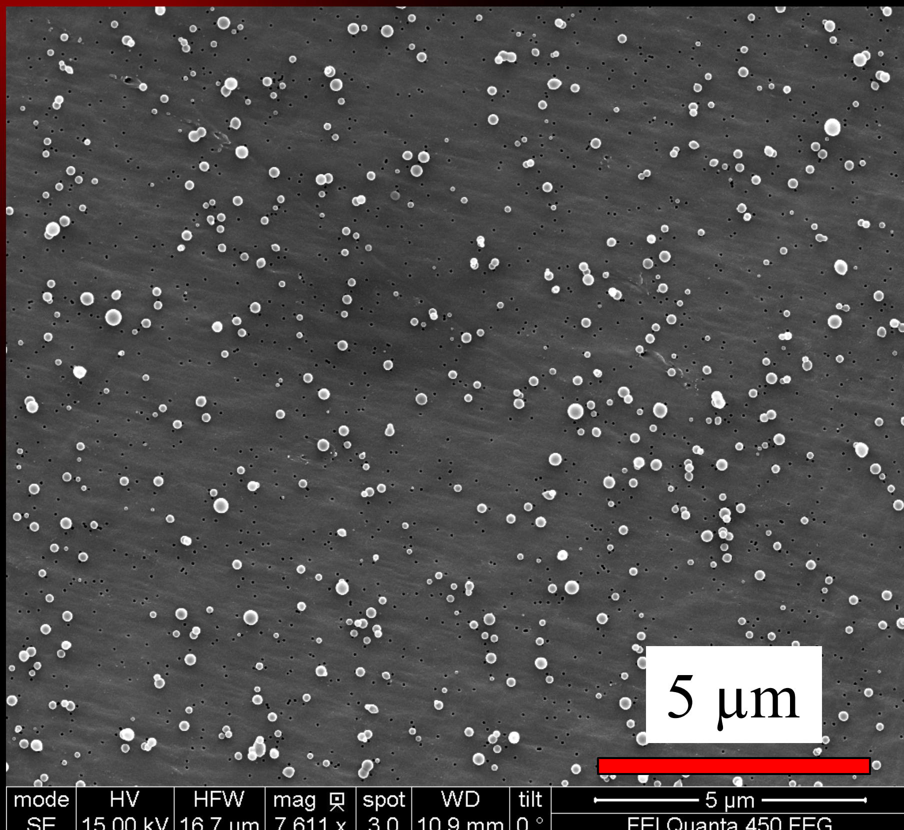
Lab-Scale System



Single Particle Absorption Efficiency vs. Wavelength



Scanning Electron Micrograph (SEM) of Particles on a Filter



Use two techniques to measure the size:

- Angular Light Scattering
- Count particles on the filter using ImageJ

Comparing DPS data to SEMs

(DPS = Diesel Particle Scatterometer using angular light scattering)

Natural Gas Flow Rate (SCCM)	SEM Size (nm)	DPS Size (nm)	Difference (nm)
20	178	181	3
20	177	175	2
40	275	250	15

- DPS data matches SEM analysis to within a few nanometers.

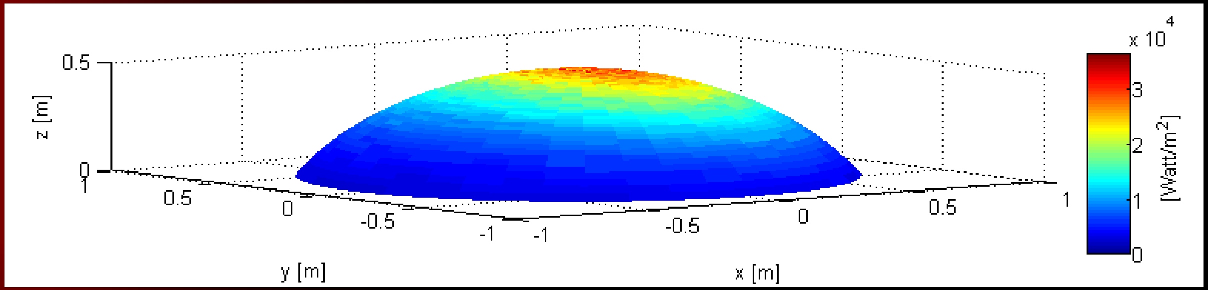
Nitrogen Flow Rate = 600 SCCM
Temperature = 1000 degrees C

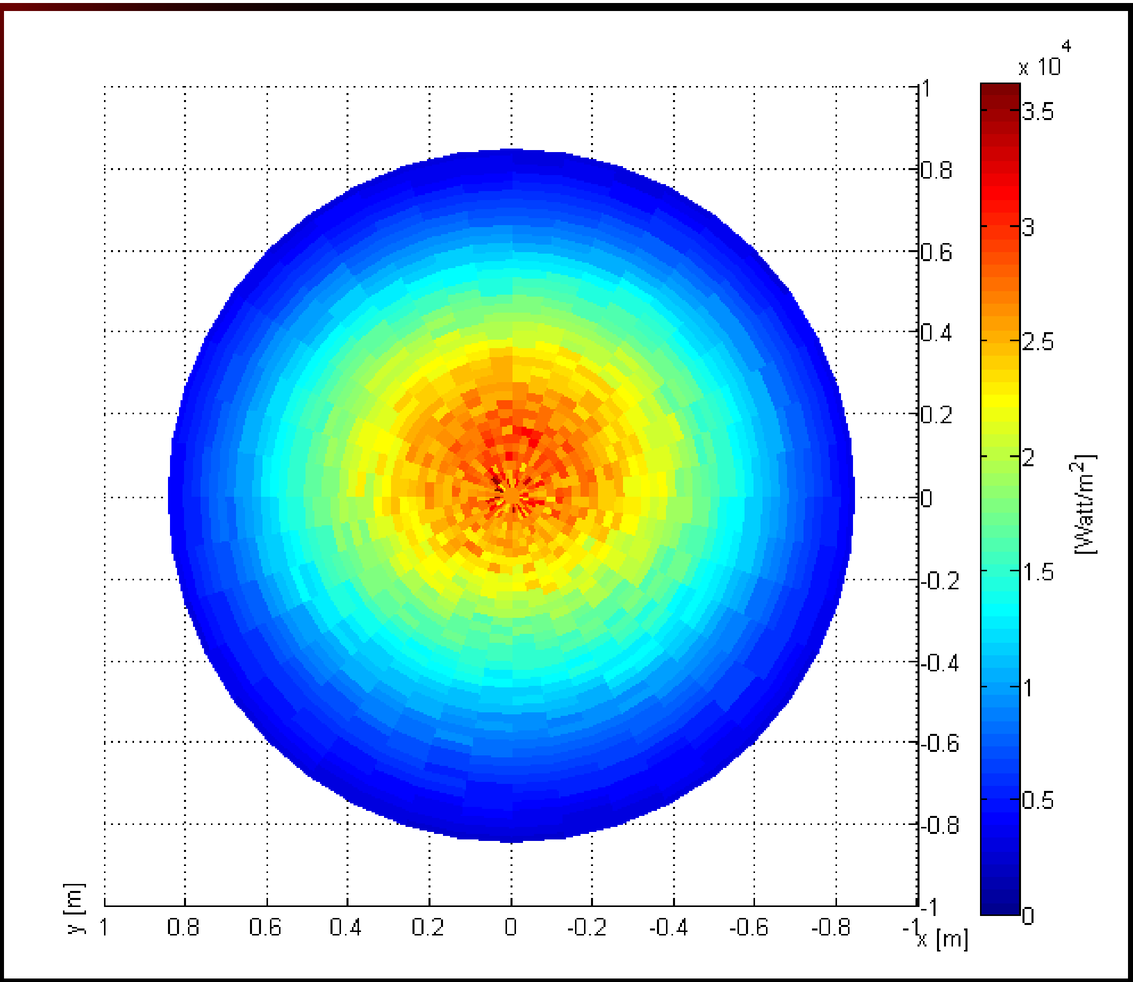
Window and Mount Design

Window Optical Analysis

- Start with optical constants (n and k) of quartz.
- Use Generalized Fresnel Equations to determine transmission, reflection, and absorption
- MIRVAL calculates incident radiation from heliostat field (modified for spectral calculations)
- In-house code traces rays interacting with the window and entering receiver.

Window Solar Absorption Maps





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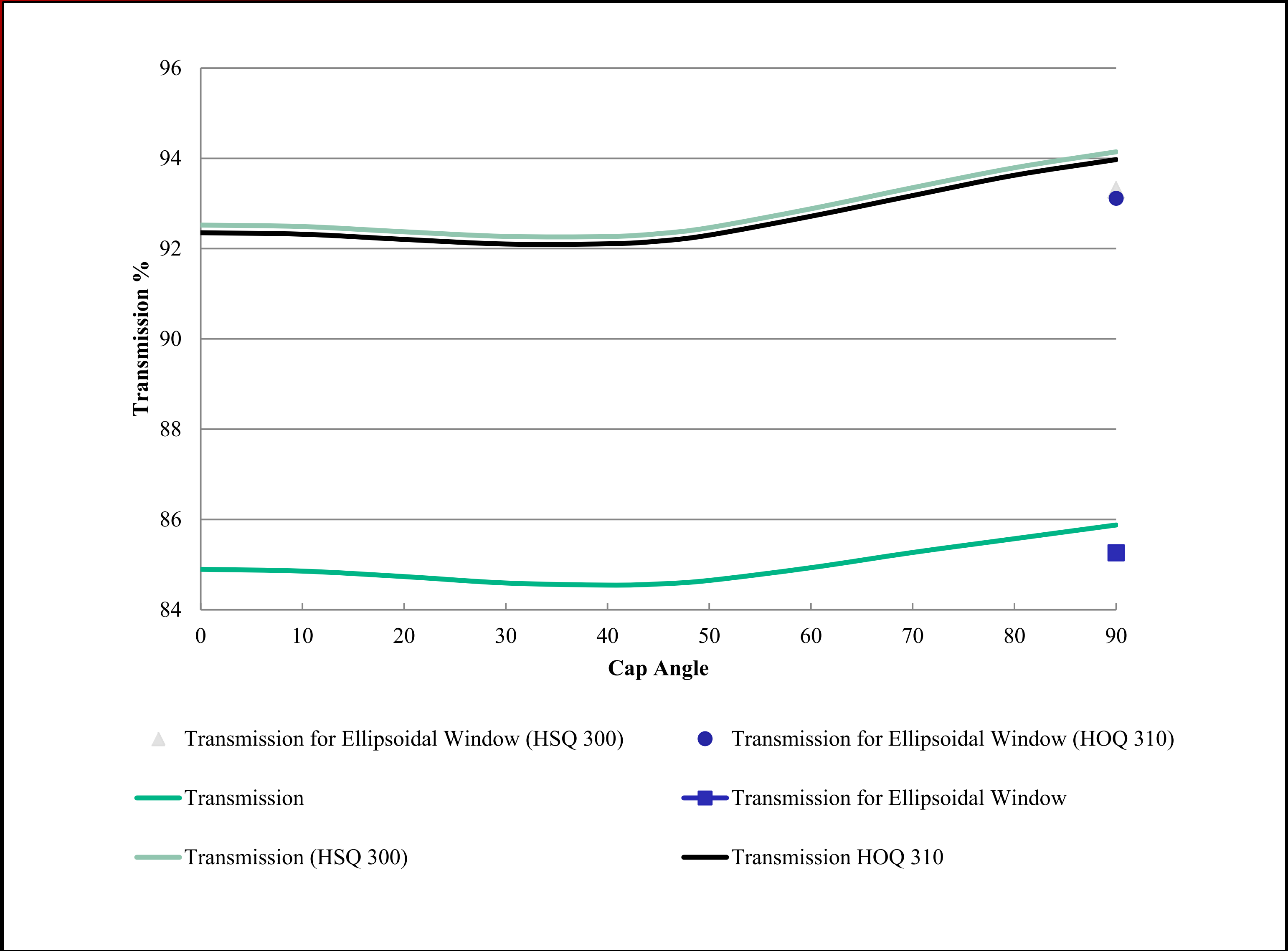
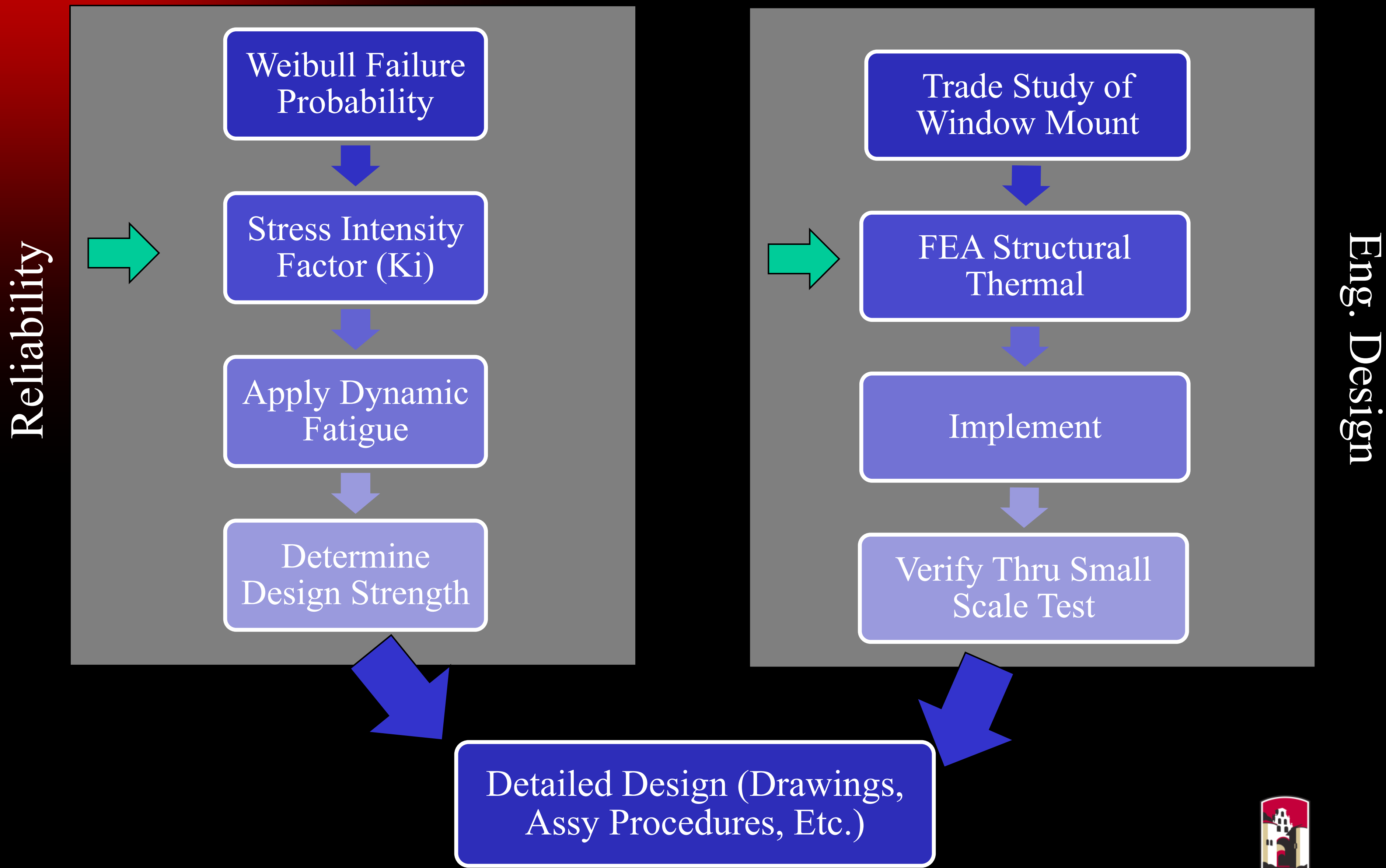
Window Transmission vs. Cap Angle



Window Mechanical Design Process



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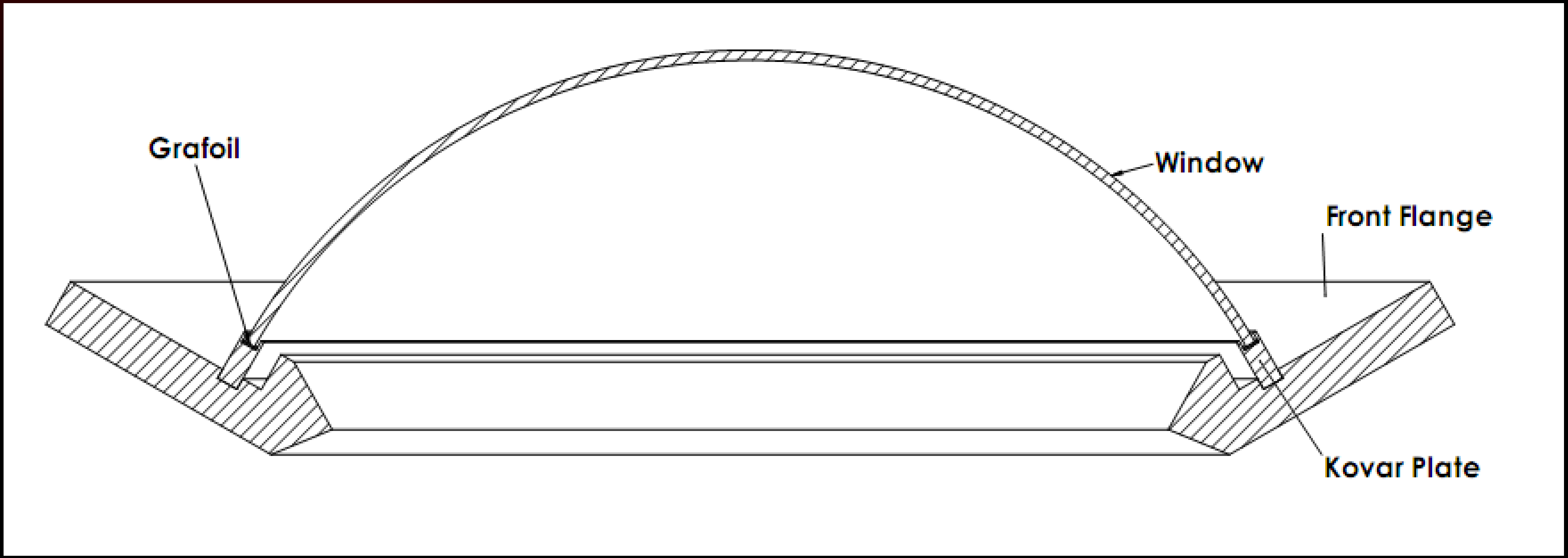
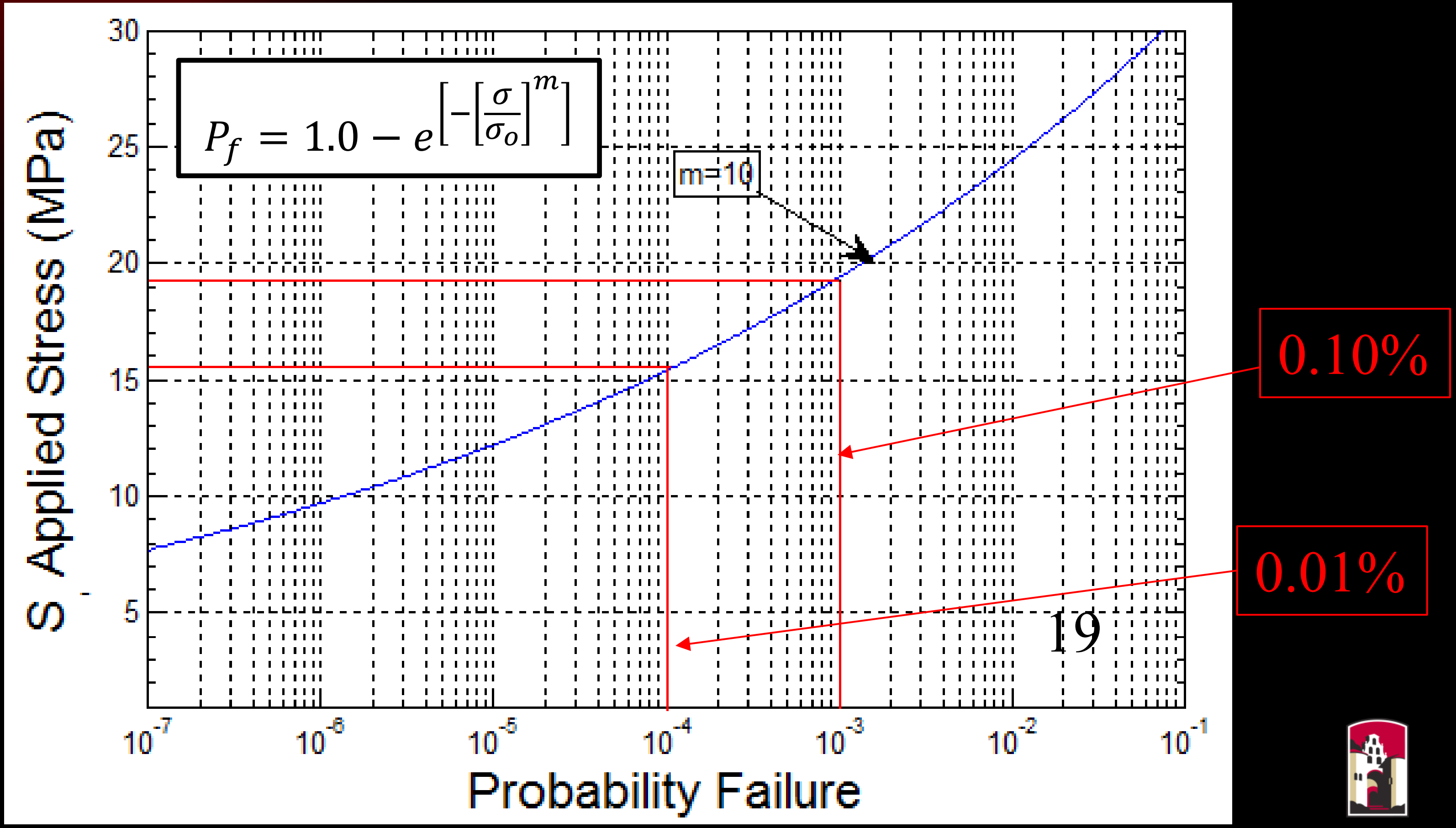
Hemispherical Cap window and Mount

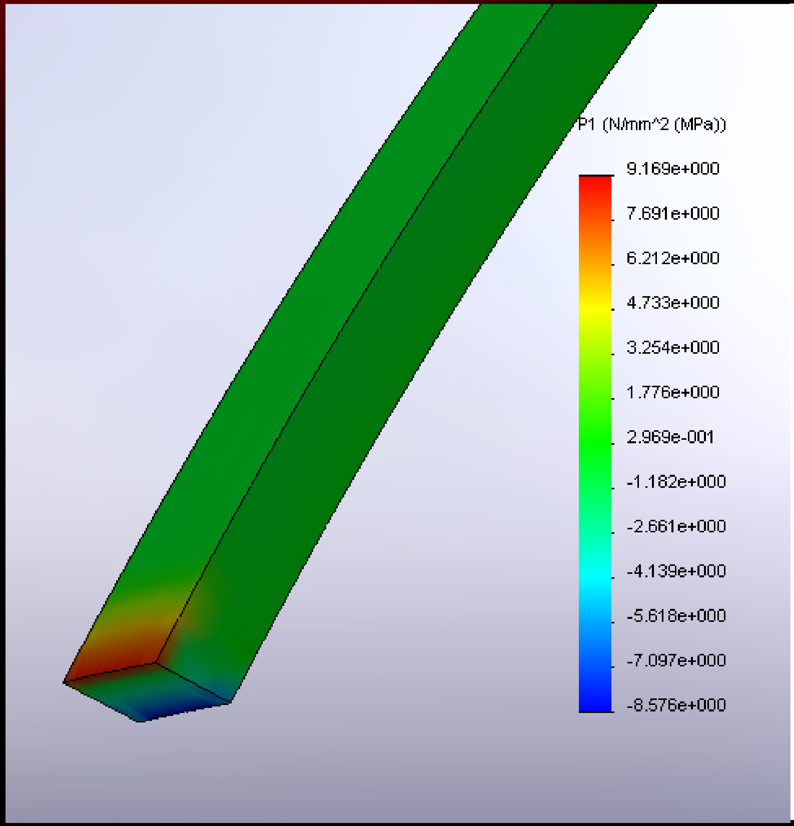


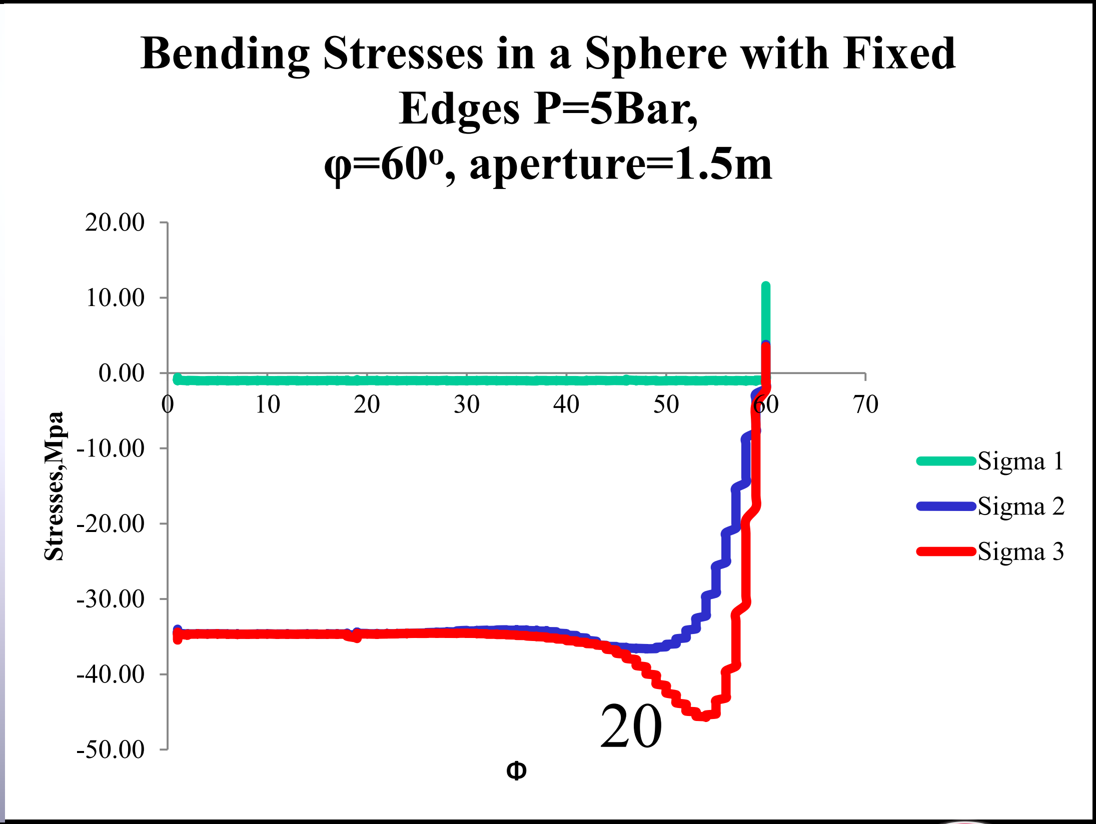
Failure Probability

- Based on Weibull Probabilistic Failure (Static Strength), characteristic strength = 38MPa, m=10
- At .01% take FS of 2, arrive at $\sigma_{acceptable}$~7.5MPa



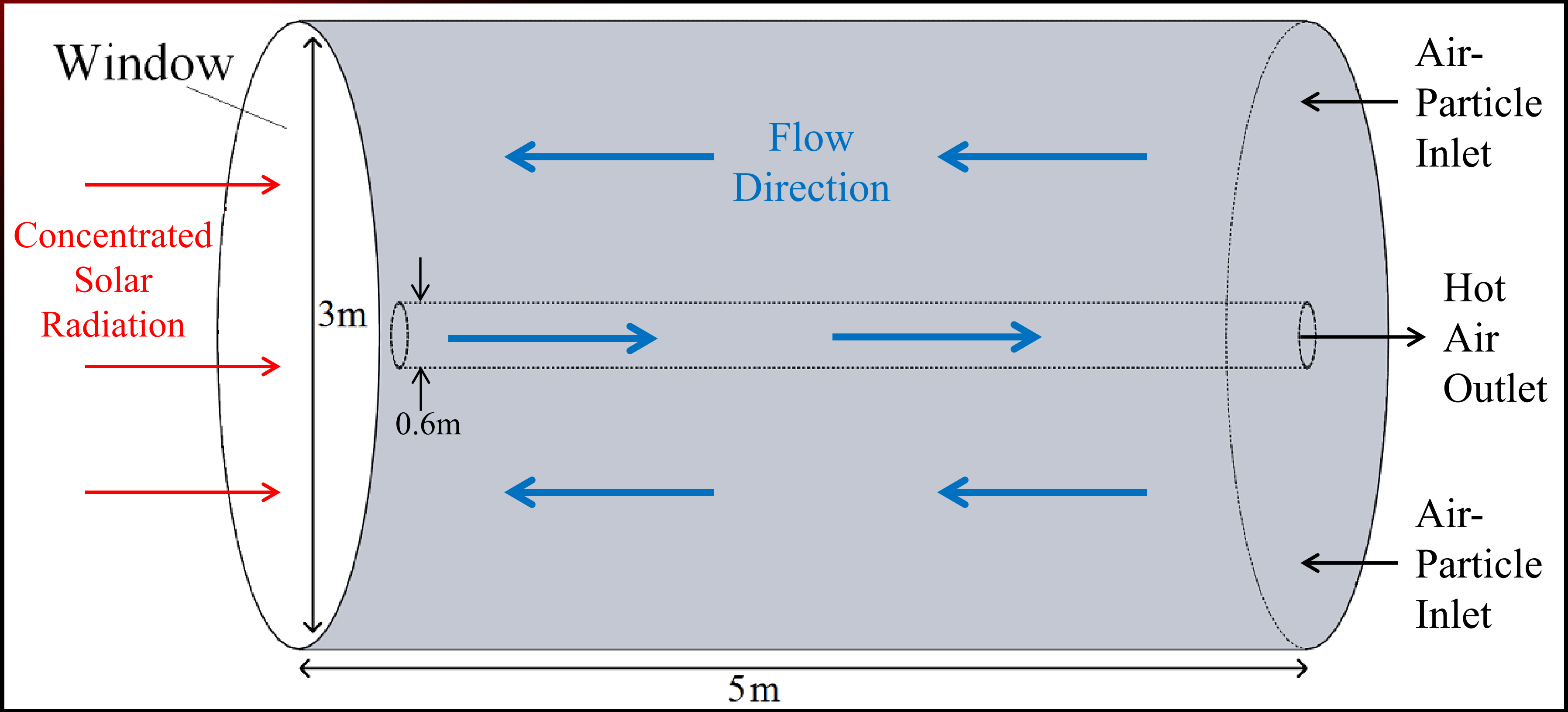
Principle Stresses in Spherical Cap



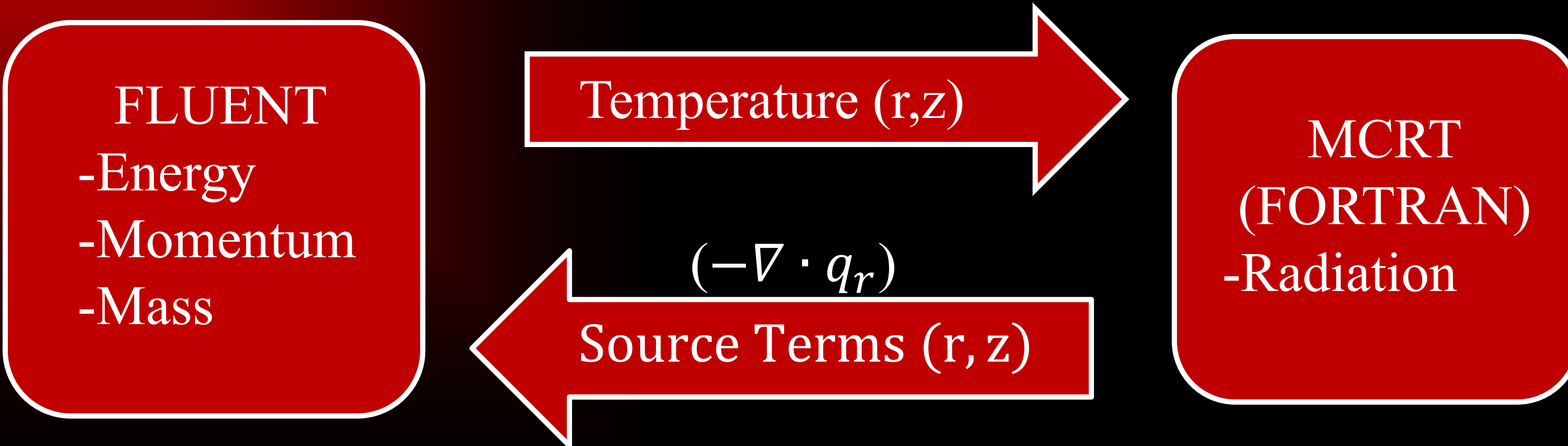


Receiver Fluid Dynamic and Radiation Modeling

Schematic of 2-D Receiver Model

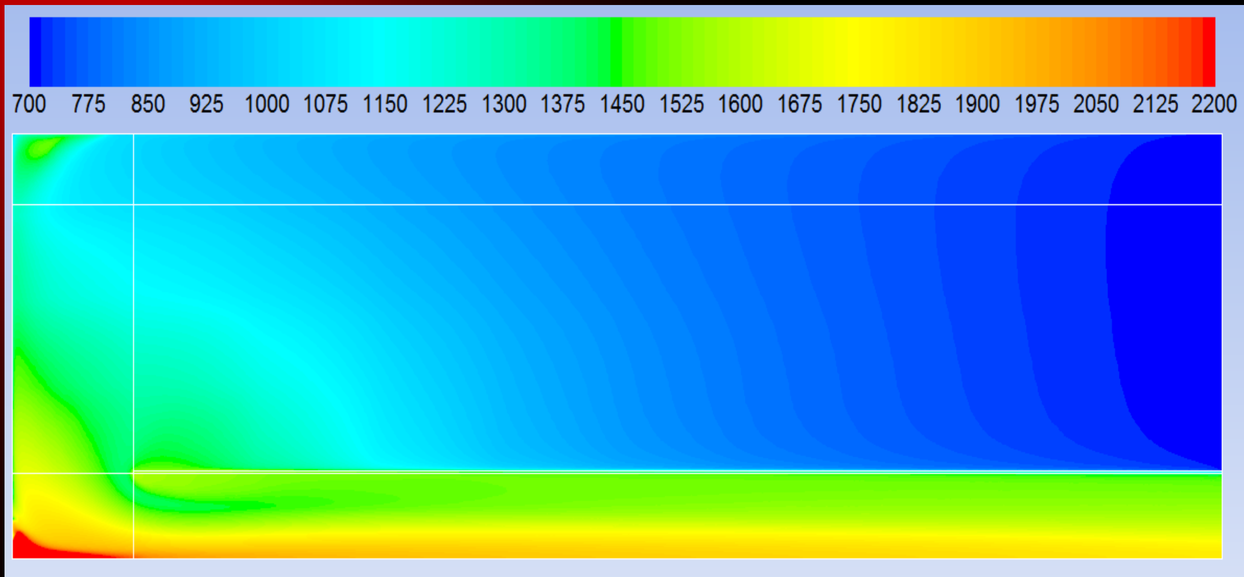


Model Program Overview

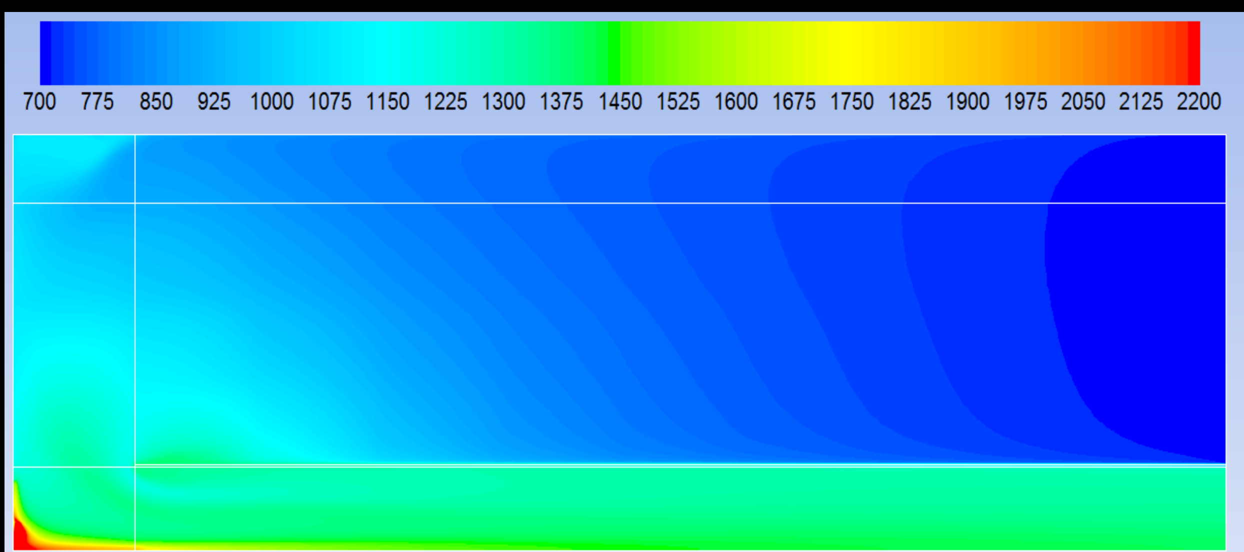


- Fluent solves energy, momentum, & mass equations
- Temperature data is passed to FORTRAN code
- MCRT solves radiative transfer equation
- Volumetric source terms $(-\nabla \cdot q_r)$ are passed to FLUENT
- Process iterates until convergence

Results - Mass-Flow Rate Variation



- 4kg/s
- 5 MW
- 1547 K outlet
- 86.3% receiver efficiency



- 6kg/s
- 5 MW
- 1325 K outlet
- 90.4% receiver efficiency

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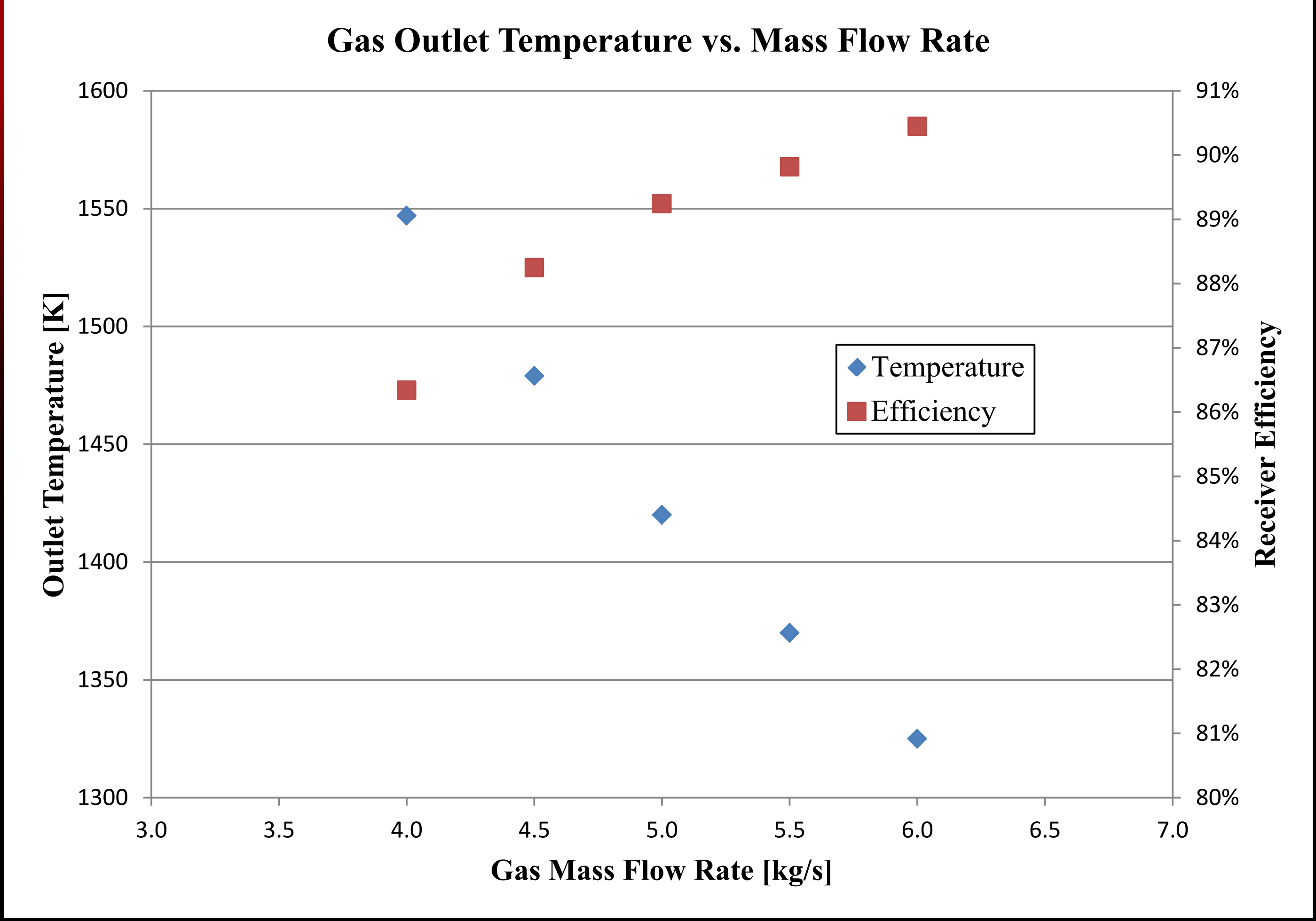
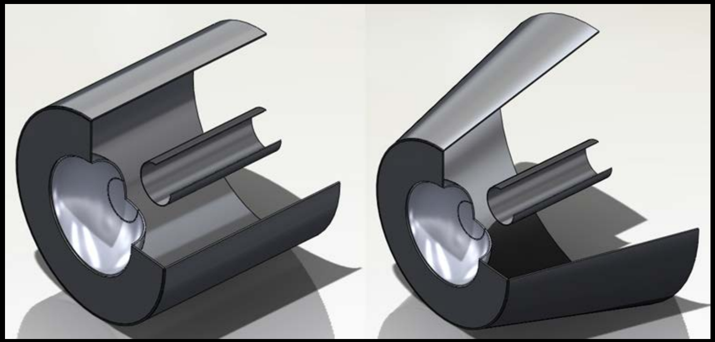
Results - Mass-Flow Rate Variation



- Input power is Gaussian-distributed 5 MW for all five cases

Capabilities of the newest Software

- Three-Dimensional Model.
- Arbitrary axisymmetric geometries.



- Solar irradiation from heliostat field
- Window included in the MCRT model.

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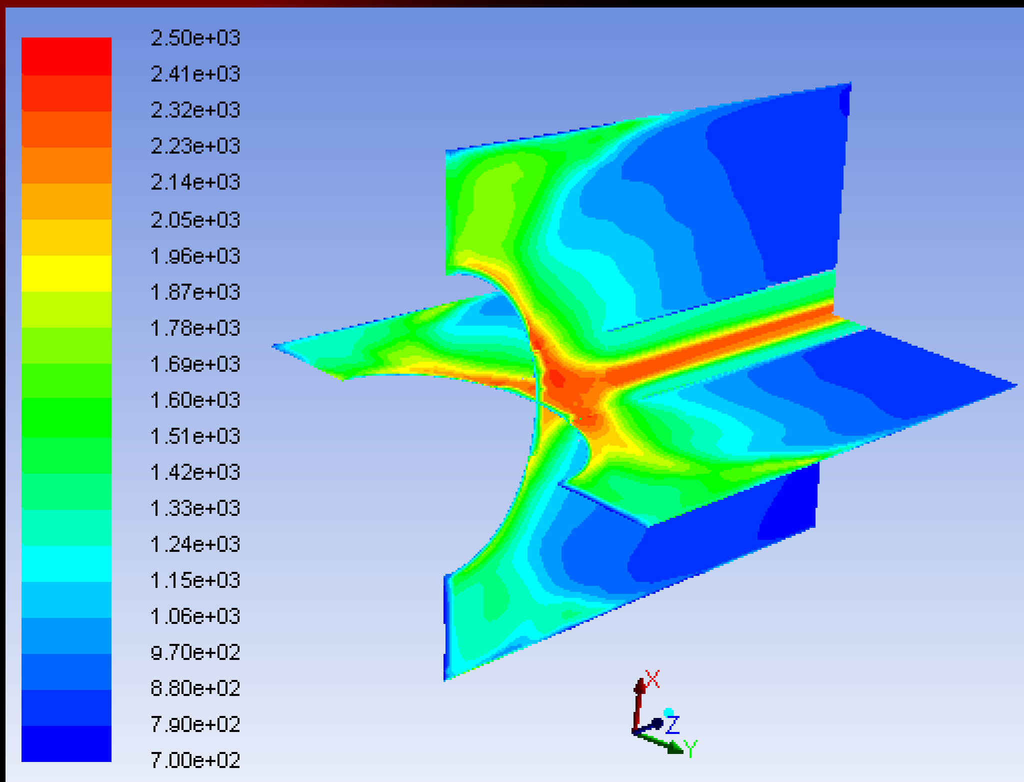
3-D Model Results



Temperature field (K)

SIMULATION CONDITIONS:
Time: 12pm on March 21st
Mass flow: 4kg/s

RESULTS:
Outlet temperature: 1450 K
Efficiency: 90%
Pressure drop: 91 Pa
Maximum wall temperature: 1450 K

Challenges to Date

- Particle Generator does not work well at higher pressures.
  - Undergoing redesign with Senior Project Team
- Exact optical constants of glass not available at all wavelengths.
  - Did bracketing calculations. Evaluating measurement of constants.
- 3-D calculations take a long time (days)
  - Considering GPU, supercomputer, and cluster options.
- Staffing may not match tasks exactly
  - Working to strengths available

Future Work in Phase 1

- Use three-dimensional coupled model to perform preliminary receiver design
- Complete window thermal and mechanical design (includes seal)
- Redesign particle generator and perform component lab-scale testing at 5 atm.
- Design full-scale particle generator.

Acknowledgements

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Thank you for your Attention!