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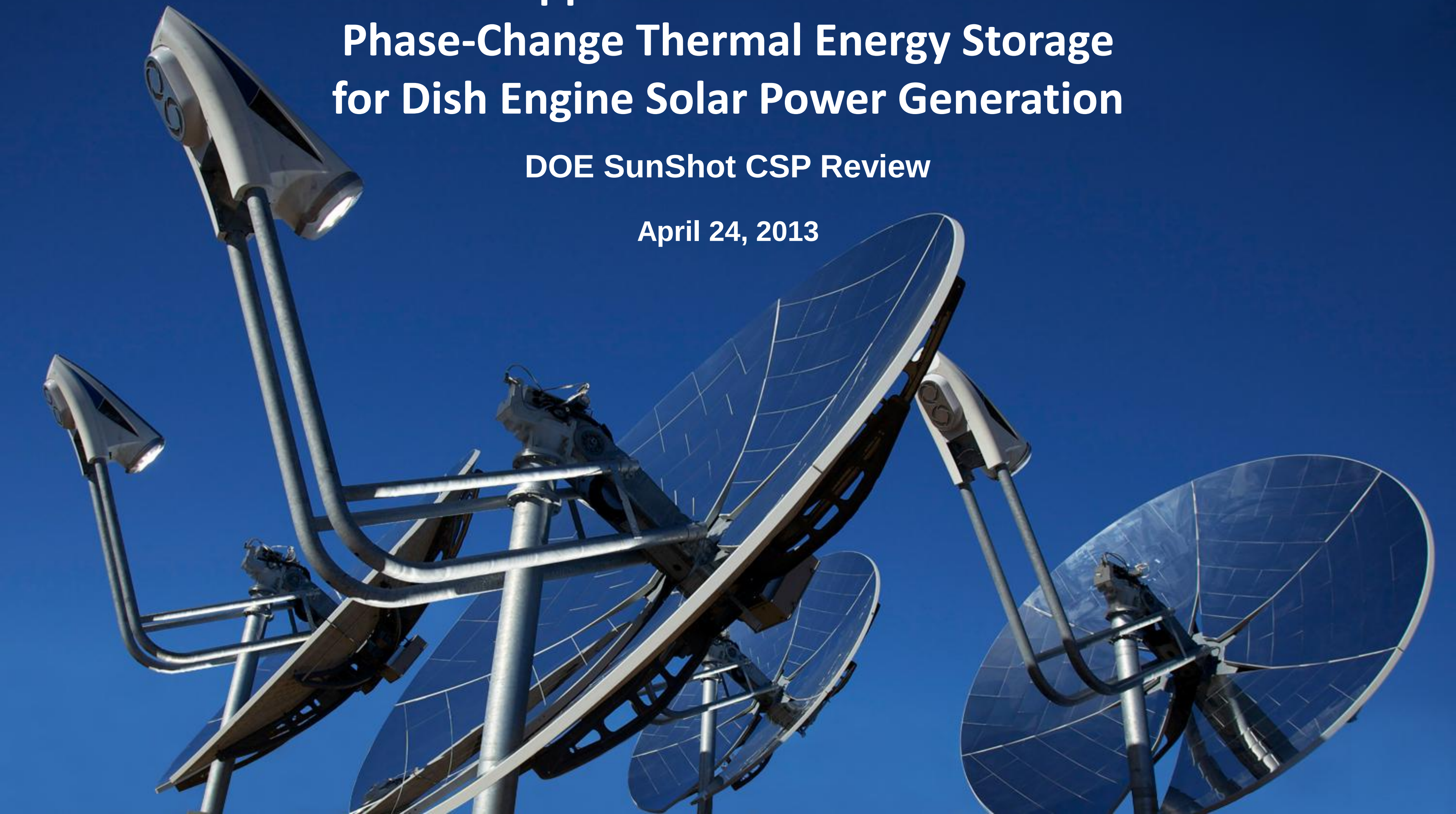
Innovative Application of Maintenance-Free Phase-Change Thermal Energy Storage for Dish Engine Solar Power Generation

DOE SunShot CSP Review

April 24, 2013



PROJECT OVERVIEW

Project Title:	Innovative Application of Maintenance-Free Phase-Change Thermal Energy Storage for Dish-Engine Solar Power Generation
Awardee:	Infinia Corporation
Principal Investigator:	Songgang Qiu
Presenter:	Maury White
Subcontractors:	Applied Research Lab, Penn State University Thermacore, Inc.
Project Period:	09/30/08 – 08/30/12 (Phase 1 and Phase 2)

PRESENTATION OUTLINE

- Background & Project Description
- Objectives and Goals
- System Design
  - Eutectic Salt Selection
  - Dish Concentrator Design Modification
  - Demonstrator Prototype Design
  - Thermal Energy Storage (TES) Module Design
  - TES Module Support/Attachment Design
- TES System Testing
  - Test Setup / Analysis
  - Results
- Accomplishments, Conclusions, & Path Forward

BACKGROUND & PROJECT DESCRIPTION

- The baseline TES approach for most Trough and Central Receiver Systems uses sensible heat capacity of molten salt
- This necessitates power converter operation over a range of temperatures which reduces integrated efficiency
- Freezing of molten salt needs to be avoided
- Phase Change Materials (PCM) provide a large increase in energy storage density by using latent heat of fusion for TES
- Infinia implemented an innovative approach of directly integrating a hermetically-sealed maintenance-free eutectic salt PCM storage module with a dish Stirling system
- This is believed to be the first ever TES system suitable for dish engine applications

OBJECTIVES & GOALS

Develop hermetically sealed, maintenance-free, phase-change thermal energy storage for dish-engine solar power generation

Demonstrate the practicality of integrating TES modules with a dish Stirling engine

These objectives support DOE goals to increase the use of CSP in the USA and the 2020 Levelized Cost of Energy (LCOE) goal of 5¢/kWh

- Increased energy production per system module
- Low capital cost solution for TES
- Low maintenance solution
- Reduced CSP system cost due to relaxed optical requirements
- Provide dispatchability for solar power generation

SYSTEM DESIGN

OVERVIEW

Project Innovation: Dish Stirling Thermal Energy Storage (TES) using NaF/NaCl eutectic salt Phase Change Material (PCM) with both latent and sensible heat storage

Component Design :

- Eutectic Salt Selection
- Dish Concentrator Design Modification
- Demonstrator Prototype Design
- TES Module Design
- TES Module Support Design

Challenges/Goals:

- Heat Pipe Wick Limitations, Low Salt Conductivity
- Improved Capacity Factors for Dish/Stirling CSP
- Reduced Levelized Cost of Electricity (LCOE)

SYSTEM DESIGN

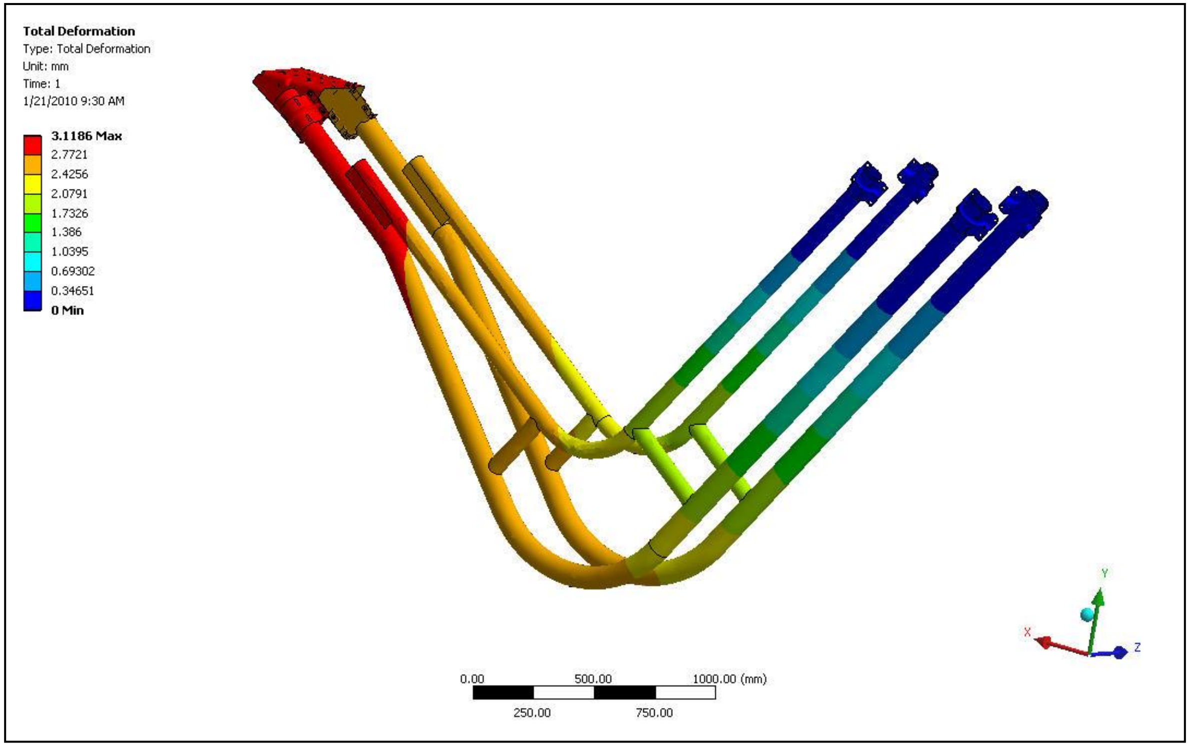
Eutectic Salt Selection

- **83 candidate PCM salts investigated**
- **Prioritized selection criteria:**
  - Melting temperature
  - Cost
  - Latent heat
  - Specific heat
- **Sodium chloride – sodium fluoride eutectic selected: NaCl (65)/NaF (35)**
  - Melt Temp: 675 °C
  - Cost: $0.50/kg
  - Heat of fusion: 700 kJ/kg
  - Specific heat: 1.3 kJ/kg/°C
  - Density: 1970 kg/m^3

SYSTEM DESIGN

Dish Concentrator Design Modification

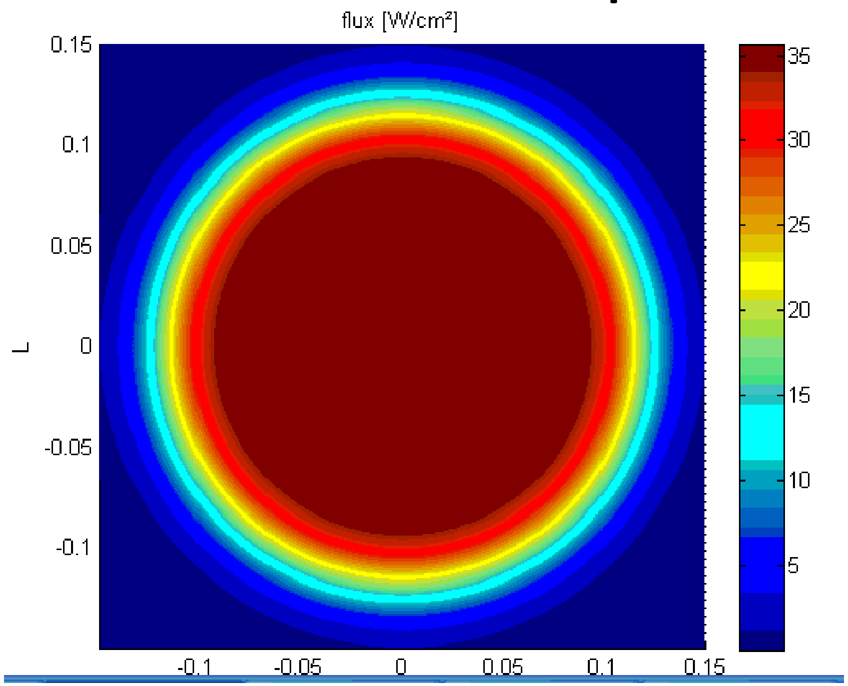
Modified Boom-arm to support additional weight and CG change

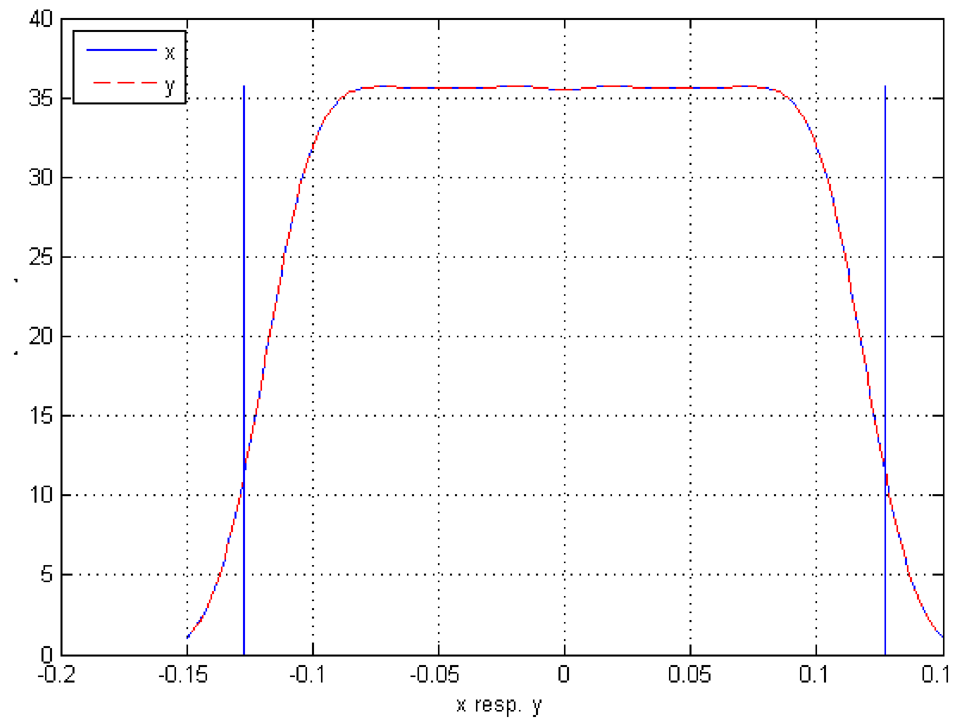


SYSTEM DESIGN

Dish Concentrator Design Modification

Oversized dish to provide simultaneous heat for TES and engine

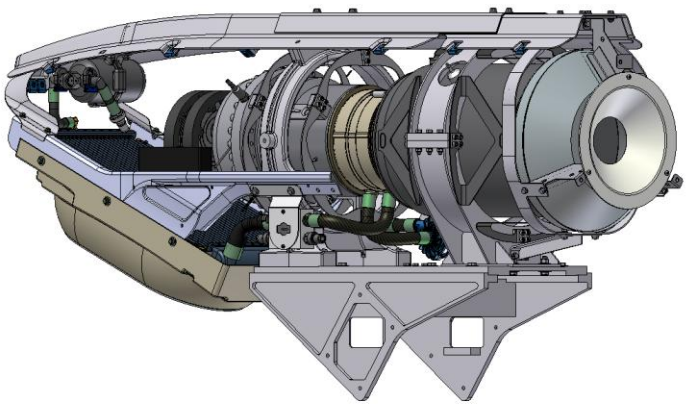


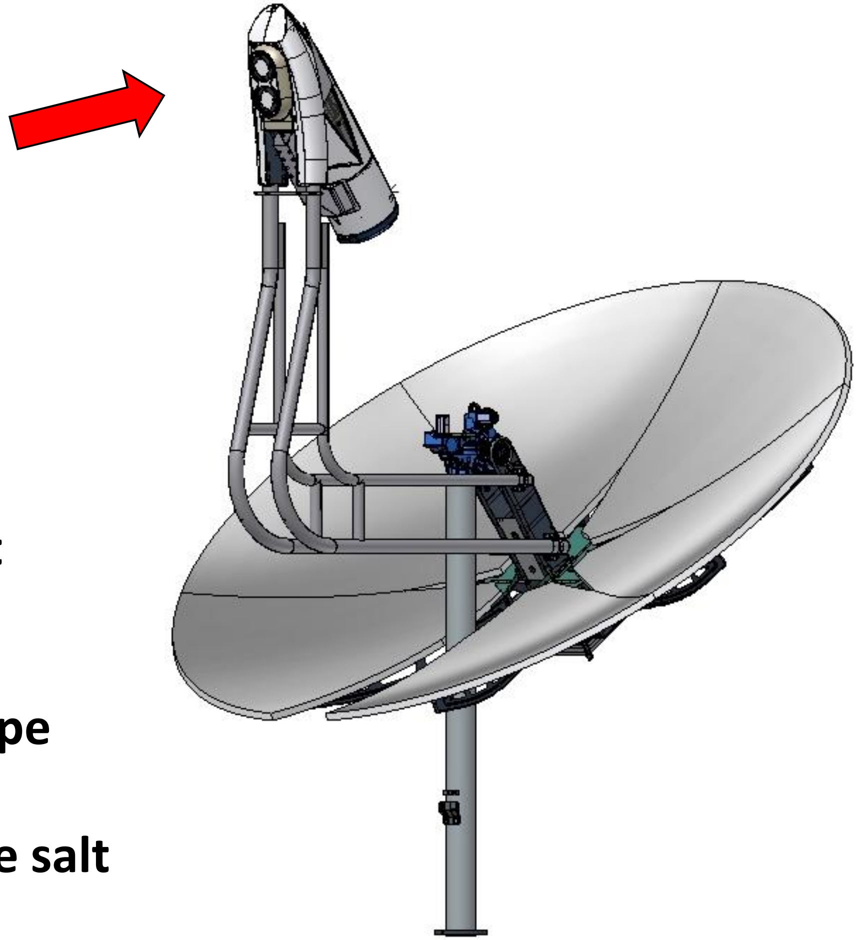


20% Larger Dish 2 Dimensional Flux Distribution Plot

SYSTEM DESIGN

Demonstrator Prototype Design





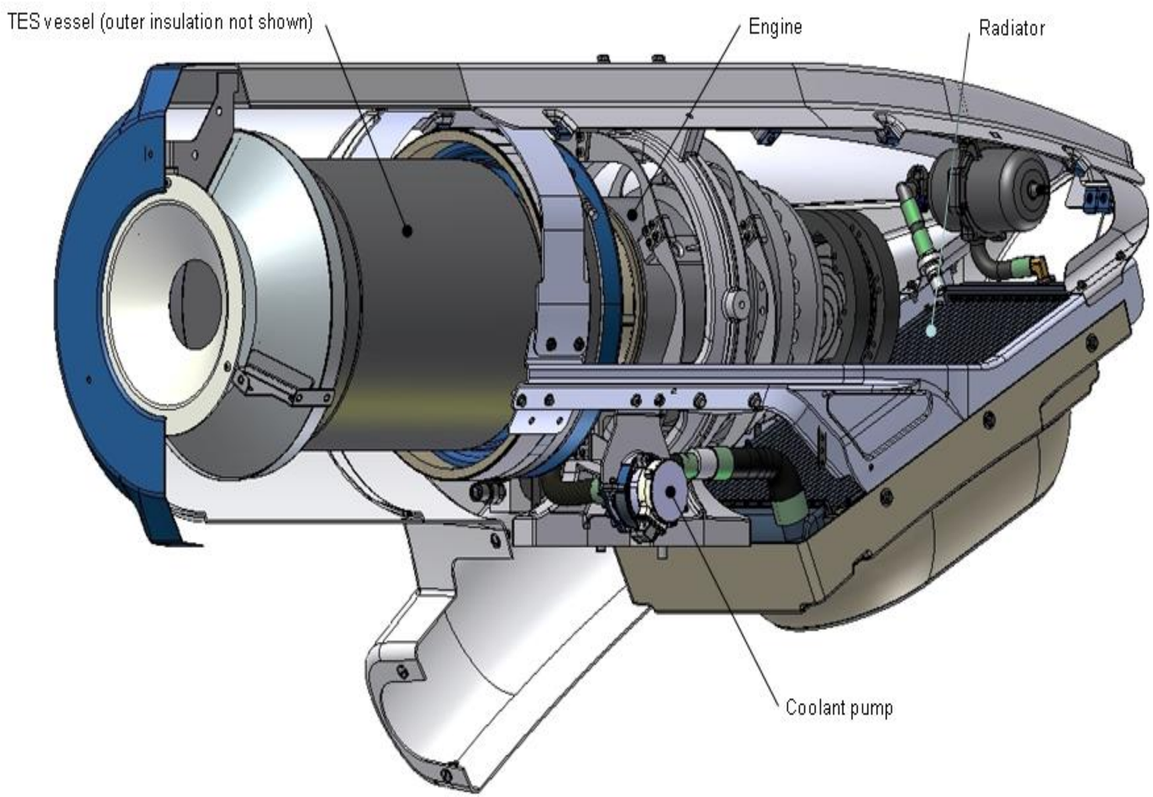
PCM volume is sized to generate 3kWh net electric power from TES; about 35 kg PCM

When solar energy is available, the heat pipe system is designed to permit simultaneous operation of the engine and charging of the salt

SYSTEM DESIGN

Thermal Energy Storage (TES) Module Design

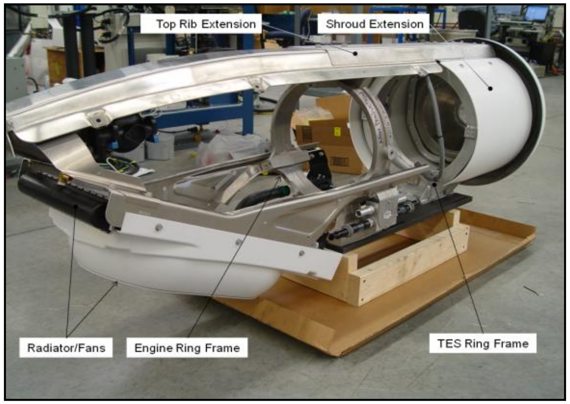
TES module incorporates solar absorber and is welded to engine heater head

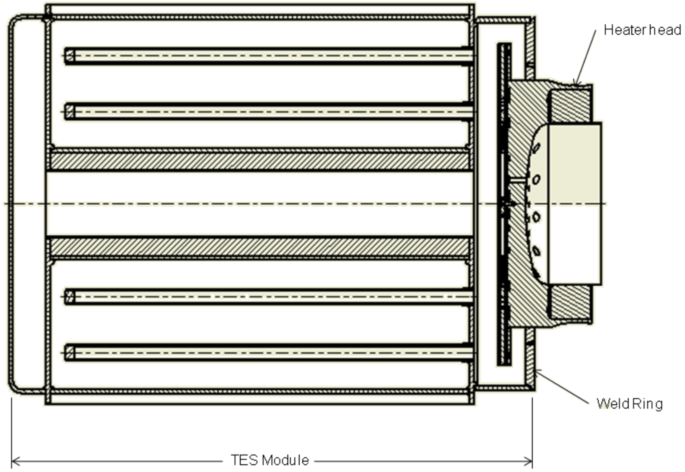


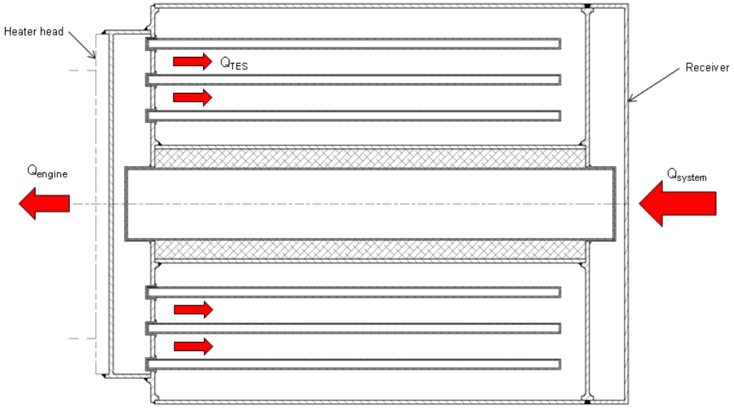
SYSTEM DESIGN

Thermal Energy Storage (TES) Module Design

Modified engine shroud and TES concept for integration with engine heater head



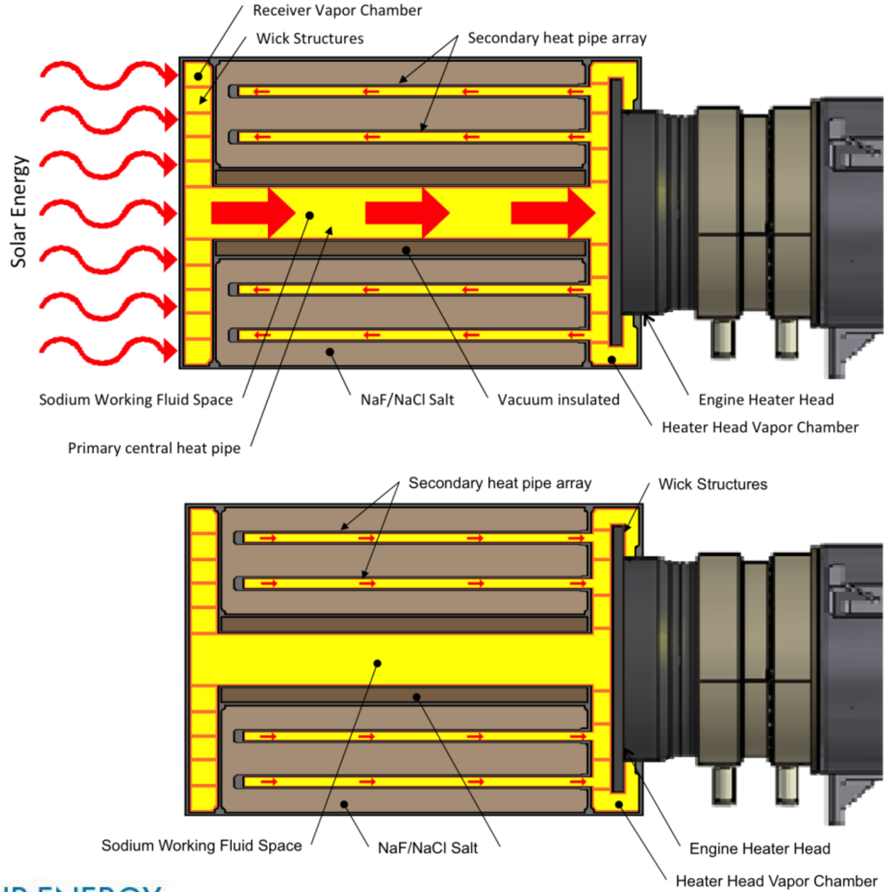




SYSTEM DESIGN

Thermal Energy Storage (TES) Module Design

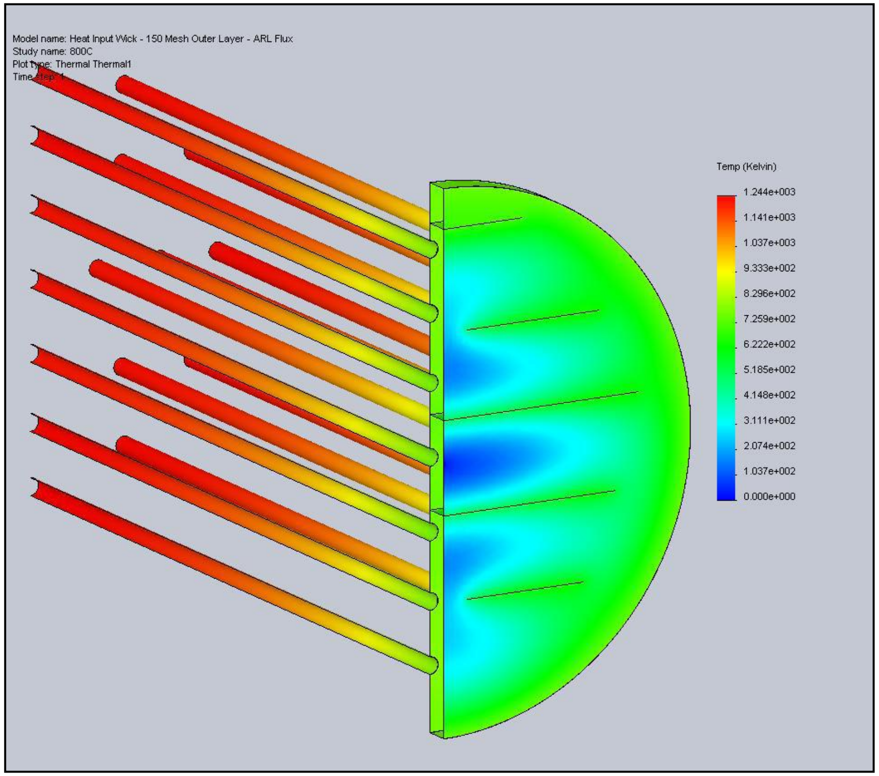
TES module integration with heater head: photo (left), mode concept (right)

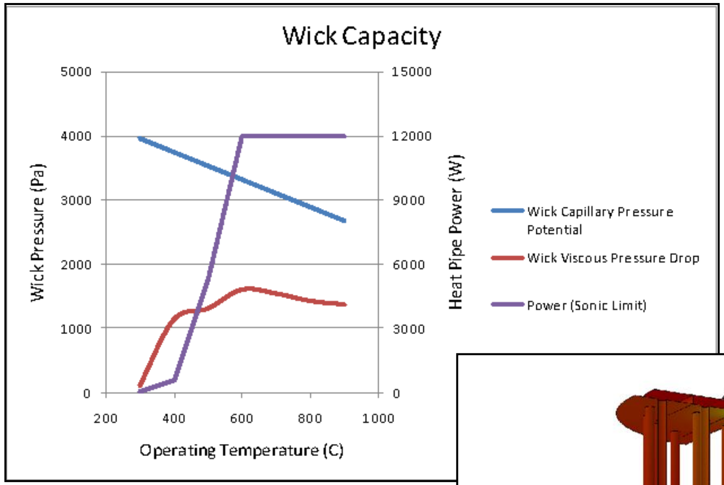


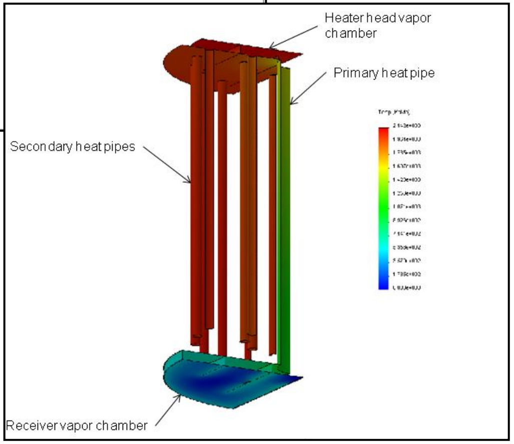
SYSTEM DESIGN

Thermal Energy Storage (TES) Module Design

Heat pipe wick analysis by Thermacore



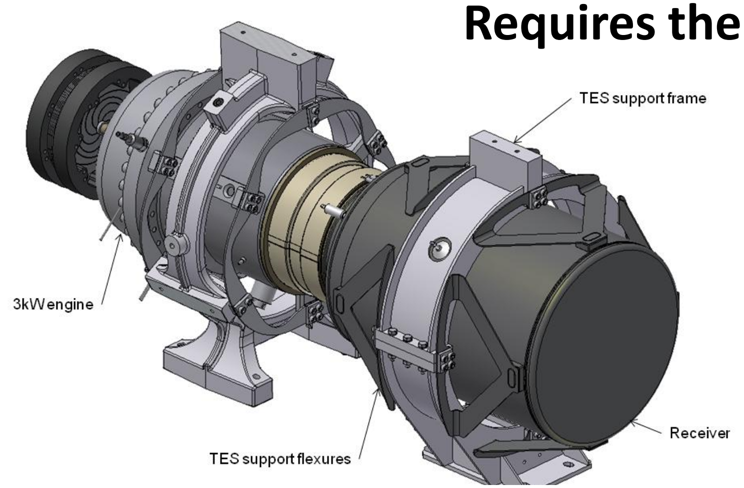


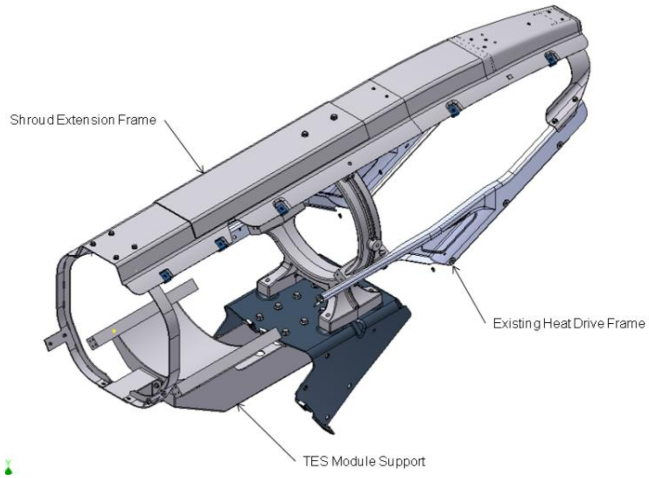


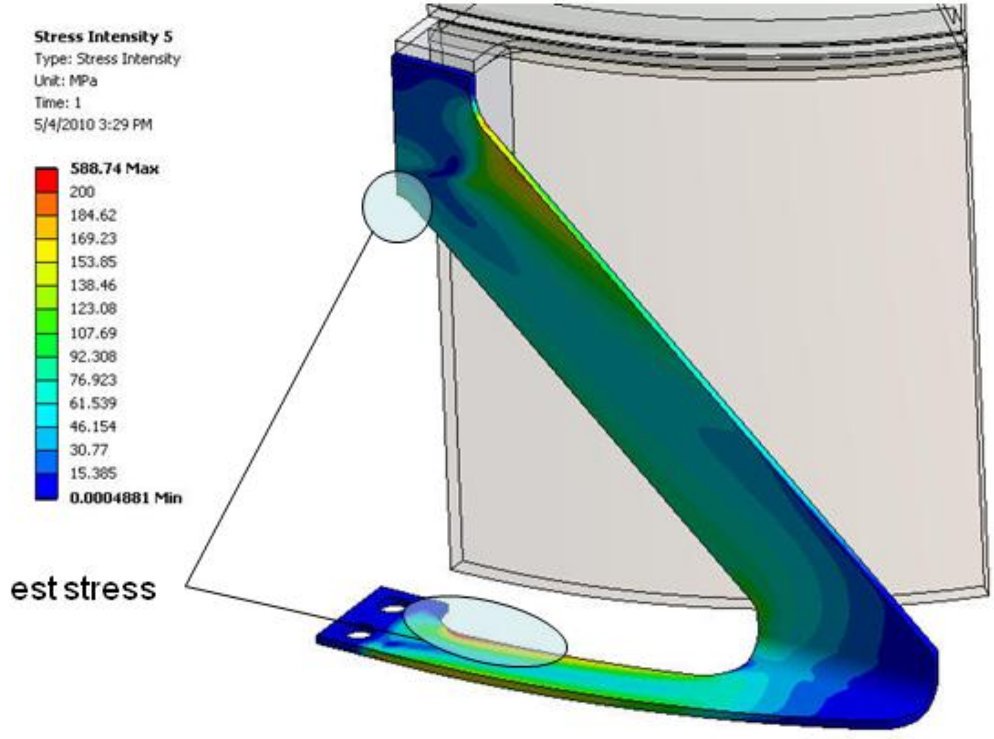
SYSTEM DESIGN

TES Module Support Design

Requires thermal and vibration isolation



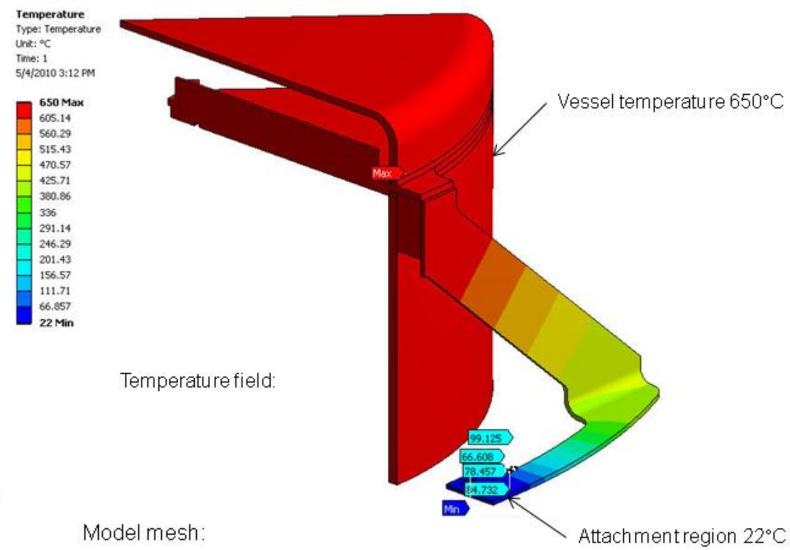




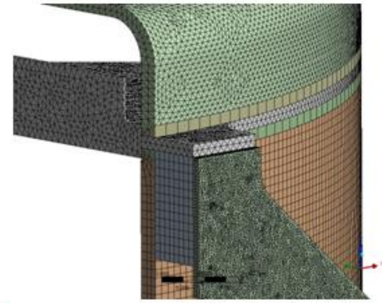
SYSTEM DESIGN

TES Module Support Design

TES module support structure required extensive design and analysis



Model mesh:



TES SYSTEM TESTING

TES Test Setup

The engine/TES module was tested in the lab with the axis in both vertical and horizontal orientations.

Heat was supplied using an induction heater with a ceramic susceptor, which in turn delivered radiant heat energy to the receiver portion of the TES module.

Conventional Test Stand

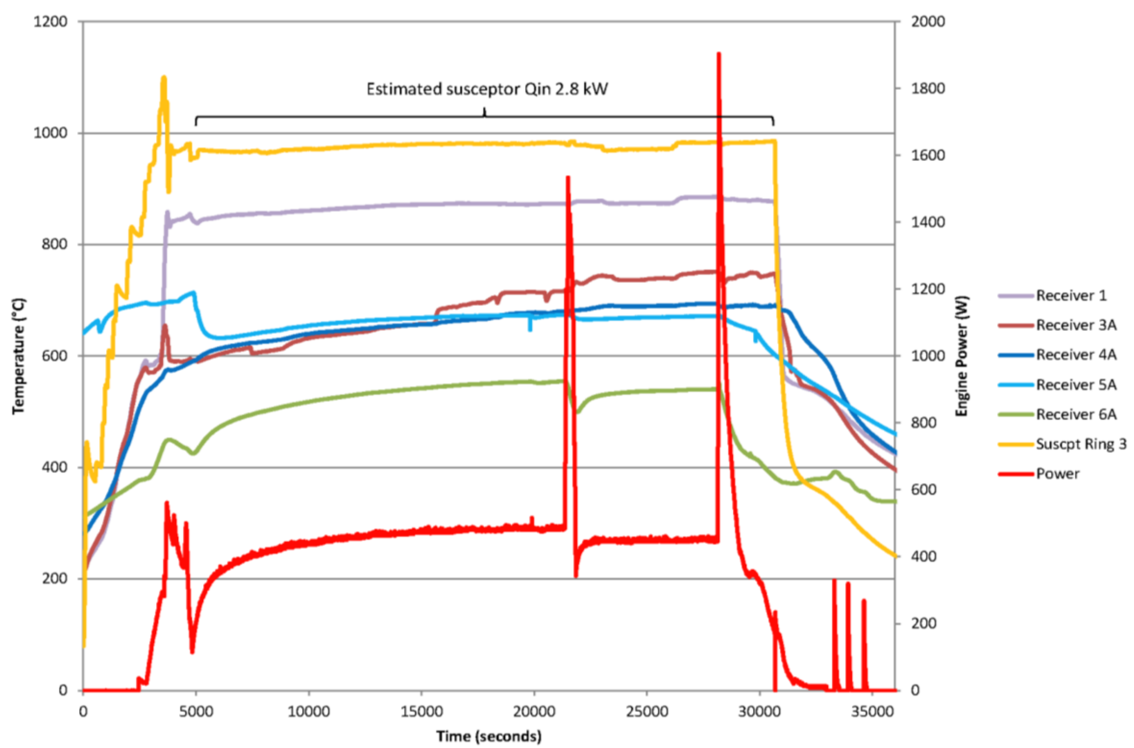
Modified TES Test Stand

TES SYSTEM TESTING

Test Results – Axis Vertical

Testing with the engine at the top (high noon case) is the worst orientation for returning sodium condensate to the evaporator by capillary pumping against gravity to the heater head heat pipe vapor chamber, then back down the central heat pipe to the receiver.

Heat pipe wick limitations limited heat input to about 2.8 kW, which was inadequate to run the engine with minimal output and fully melt salt



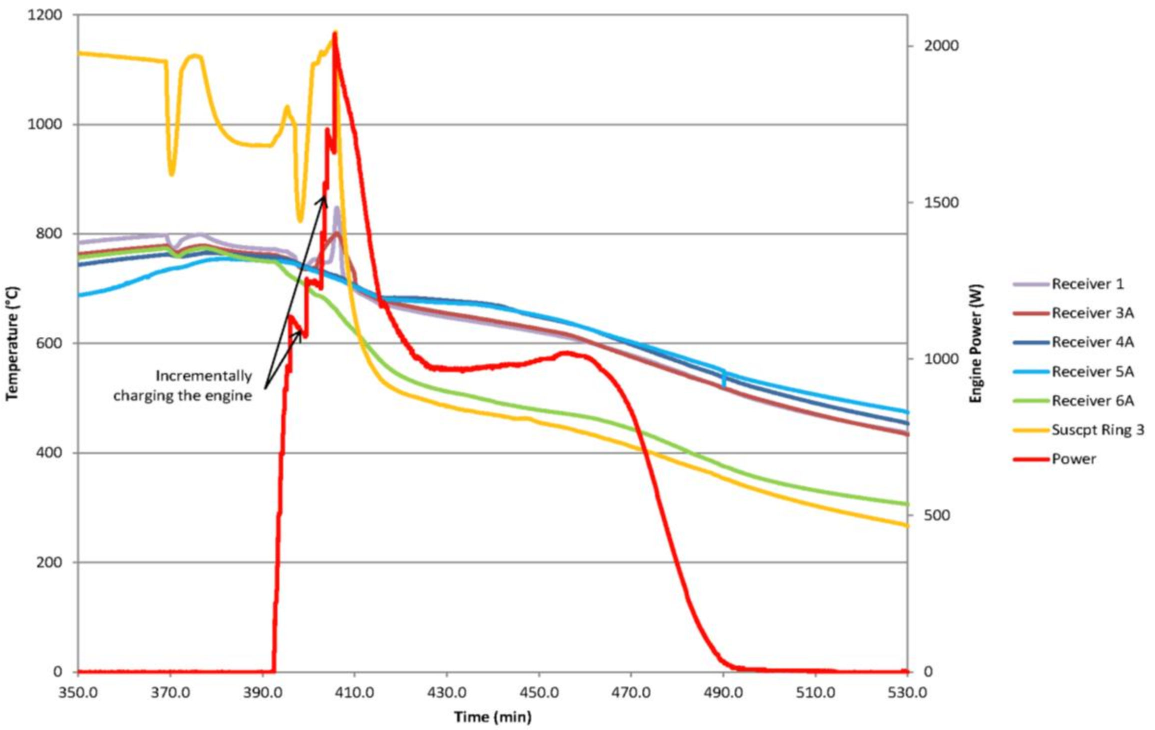
Integrated TES Test Results, Vertical Mounting

TES SYSTEM TESTING

Test Results – Axis Horizontal

Converting the test stand to a horizontal orientation was done as a diagnostic tool.

The salt was fully melted and operation on TES after removing heat input successfully extracted 1.32 kWh of engine electrical output, which is 44% of the design target.



Integrated TES Test Results, Horizontal mounting

ACCOMPLISHMENTS, CONCLUSIONS, & PATH FORWARD

Accomplishments

Basic functionality of the TES/engine system was successfully demonstrated in the laboratory. This was a technology breakthrough, although performance fell short of targets. Major repairs due to two breaches of the absorber by artifacts of the initial direct induction heater prevented more comprehensive testing.

Conclusions

Heat pipe wick to return sodium condensate is inadequate in current design when the TES module is in its gravity-adverse (vertical) orientation.

Salt conductivity enhancement or closer heat pipe spacing would be beneficial.

Path Forward

Further testing with the existing unit would provide more comprehensive data. Upgrading the sodium heat pipe network through analysis, redesign and demonstration should provide significant improvement.

INFINIA

Thank you

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