KSC ENGINEERING AND TECHNOLOGY

KEA

CryoCube-1: A Cryogenic Fluid Management CubeSat

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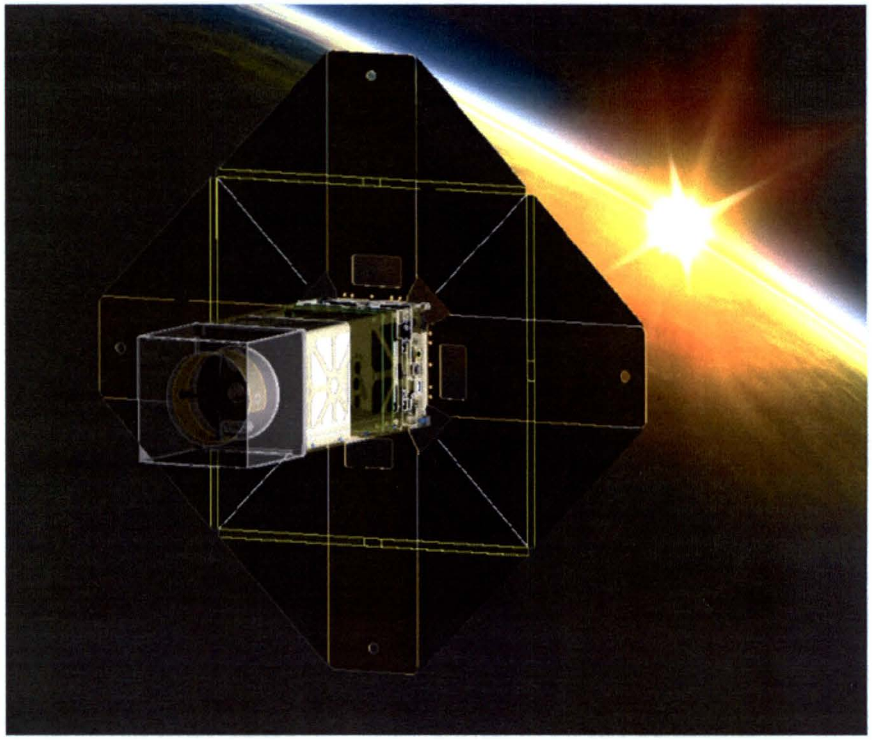
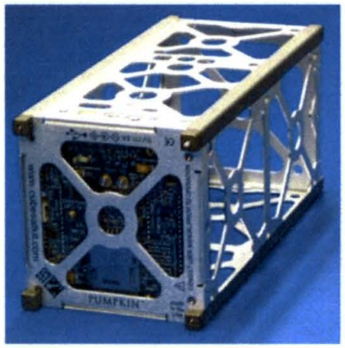
CryoCube Project Intro

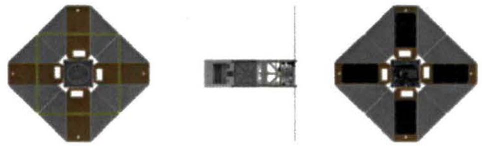
- CubeSat platform
- Cryogenic fluid management experiments
  - Fluid location sensing
  - Slosh characterization
  - Cryogenic fluid transfer
- Cooperative effort between private industry and NASA
  - SLI: Design, fabrication, major component procurement
  - KSC: Analysis, radio communications hardware
- Principle Investigators
  - Jared Berg– NASA
  - Phil Putman – Sierra Lobo

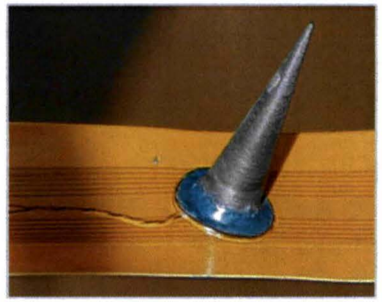


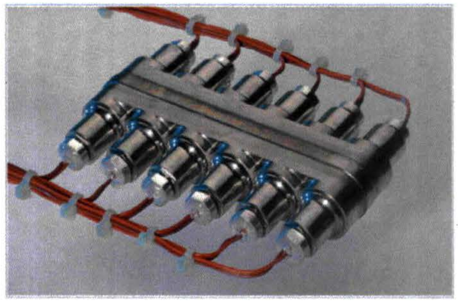


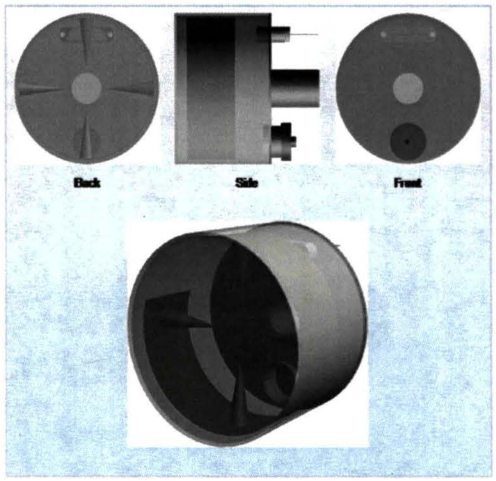
CryoCube Project Intro

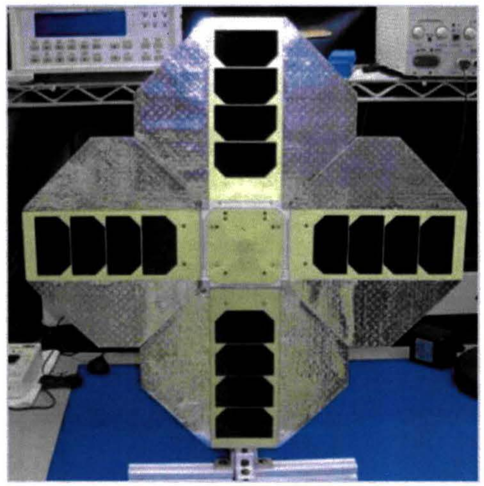
- CryoCube-1 (CC-1)
  - Liquid oxygen (LOX) working fluid
  - Solid-to-gas generator
  - Low temperature experiment tank
- Instruments
  - Cryo-Tracker sensor
  - In-tank camera
- Features
  - Combination sun shield / solar cell array
  - Magnet-torquer attitude control
  - Majority commercial off the shelf (COTS) components
- Selected for CubeSat Launch Initiative (CSLI)
  - Launch manifested 2014











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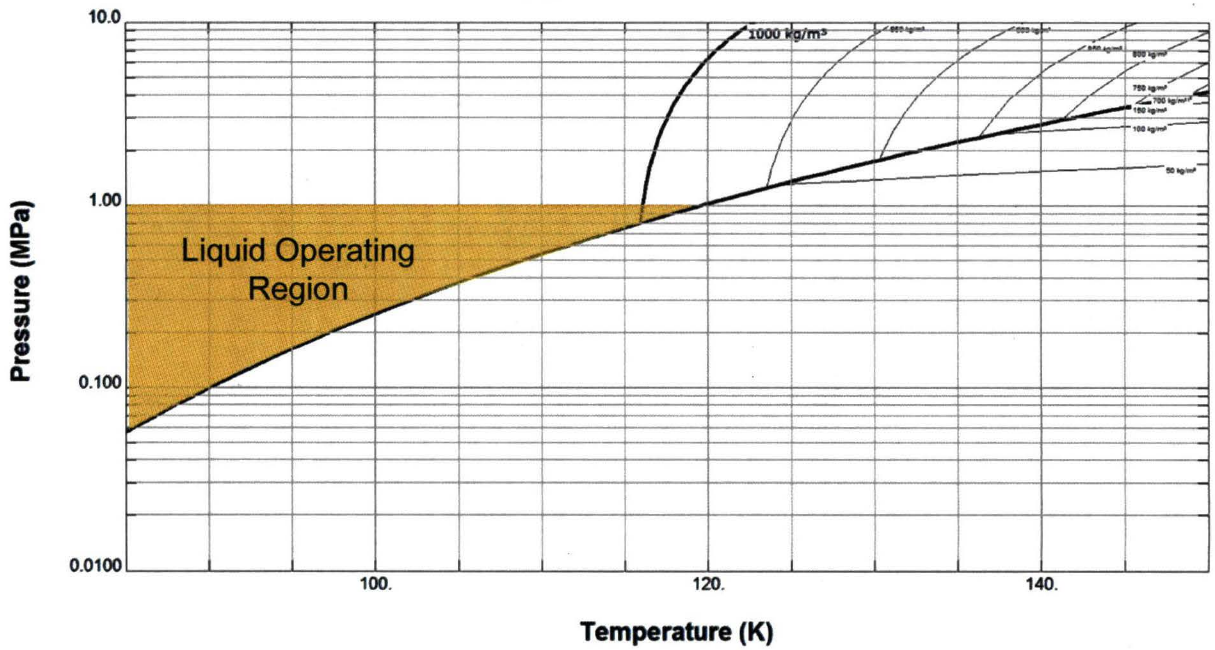
CryoCube Project Intro

- Goal: Analyze thermal performance of CC-1
  - Reduce experiment tank temperatures into regime appropriate for LOX condensation (< 119 K @ 1 MPa)
    - Passive cooling only
    - Low weight
    - Small size

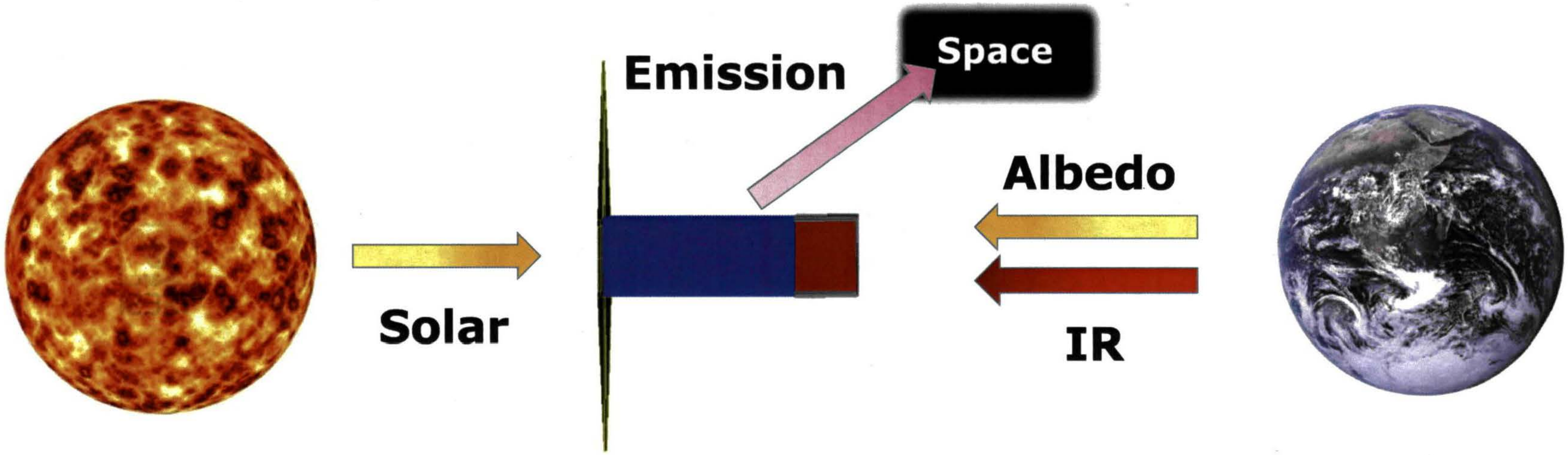
- Investigate design sensitivity to material and optical properties
- Determine effects of different orbit parameters
- Develop preliminary operational guidelines

Oxygen Phase Plot



Energy Balance

- Radiation follows Stefan-Boltzmann relation $q = \varepsilon\sigma A\Delta T^4$



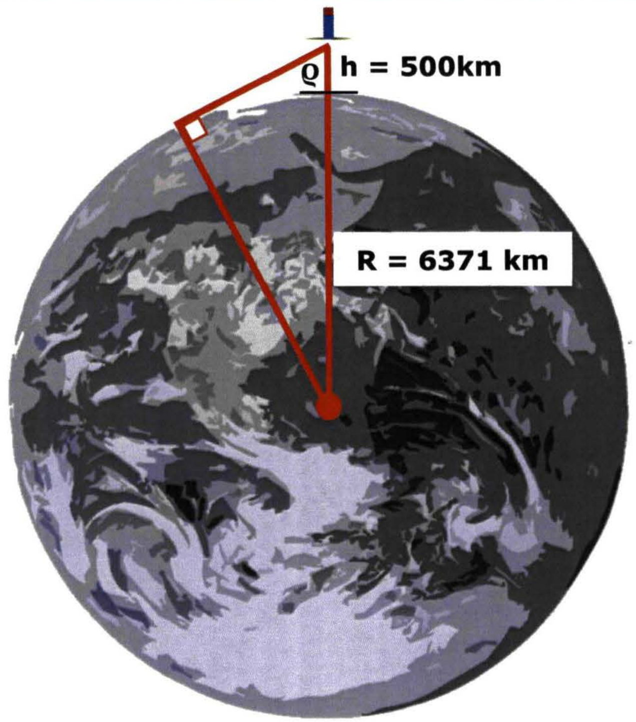
$$\underbrace{G_s A\alpha_t}_{\textbf{Solar}} + \underbrace{q_{IR} A\varepsilon_b(\sin\rho)^2}_{\textbf{Earth IR}} + \underbrace{G_s aA\alpha_b K_a(\sin\rho)^2}_{\textbf{Albedo}} = \underbrace{\sigma\varepsilon_b A\Delta T^4 - \sigma\varepsilon_t A\Delta T^4}_{\textbf{Emission}}$$

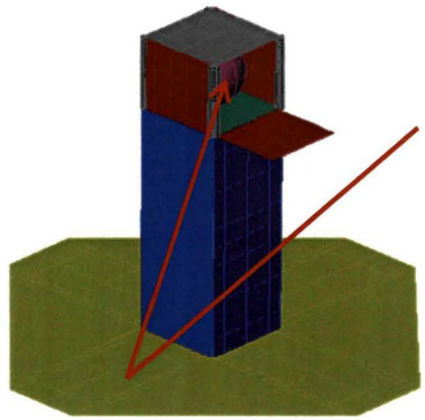
G_s= Solar radiation
ρ = Earth view angle
α_t = Solar absorptivity of top
K_a = Albedo factor (0.664 + 0.521 ρ – 0.203 ρ^2)
α_b = Solar absorptivity of bottom

a = Average albedo of Earth
q_{IR} = Earth IR
A = Area
ε_t = Emissivity of top
T = Temperature
ε_b = Emissivity of bottom

Considerations

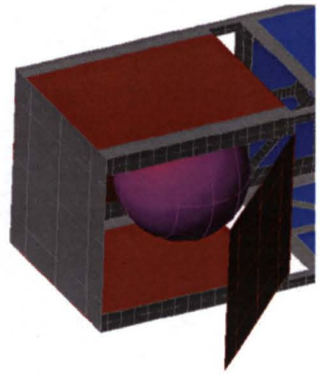
- Angular size of Earth
  - Like having face 10″ away from 55″ TV and trying not to look
  - 2ϱ =136˚at h = 500 km
  - High relative temperature (250K)
  - Sun shield ineffective for Earth IR
- Reflections
  - Reflective insulation bounces radiation into unwanted areas
  - Complicated arrangements hard to visualize mentally
- Materials comparison
  - Intuitive "best" choice may not be optimal
  - Absorption and re-emission



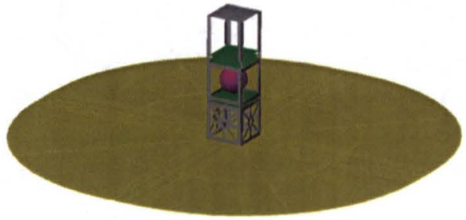


Design Space

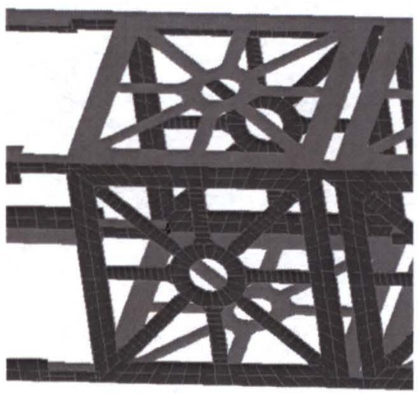
- Actuated doors
  - Must expose tank directly to deep space
  - Permanently exposed tank absorbs too much Earth IR
  - Active doors can open in eclipse, closed rest of orbit
  - Optical properties of inside and outside of



- Shield
  - Rounded edges
  - Single regular shield will not block Earth IR
  - Large shield, middle mounted tank?
  - Double shield?
  - Shields can reflect radiation back onto tank

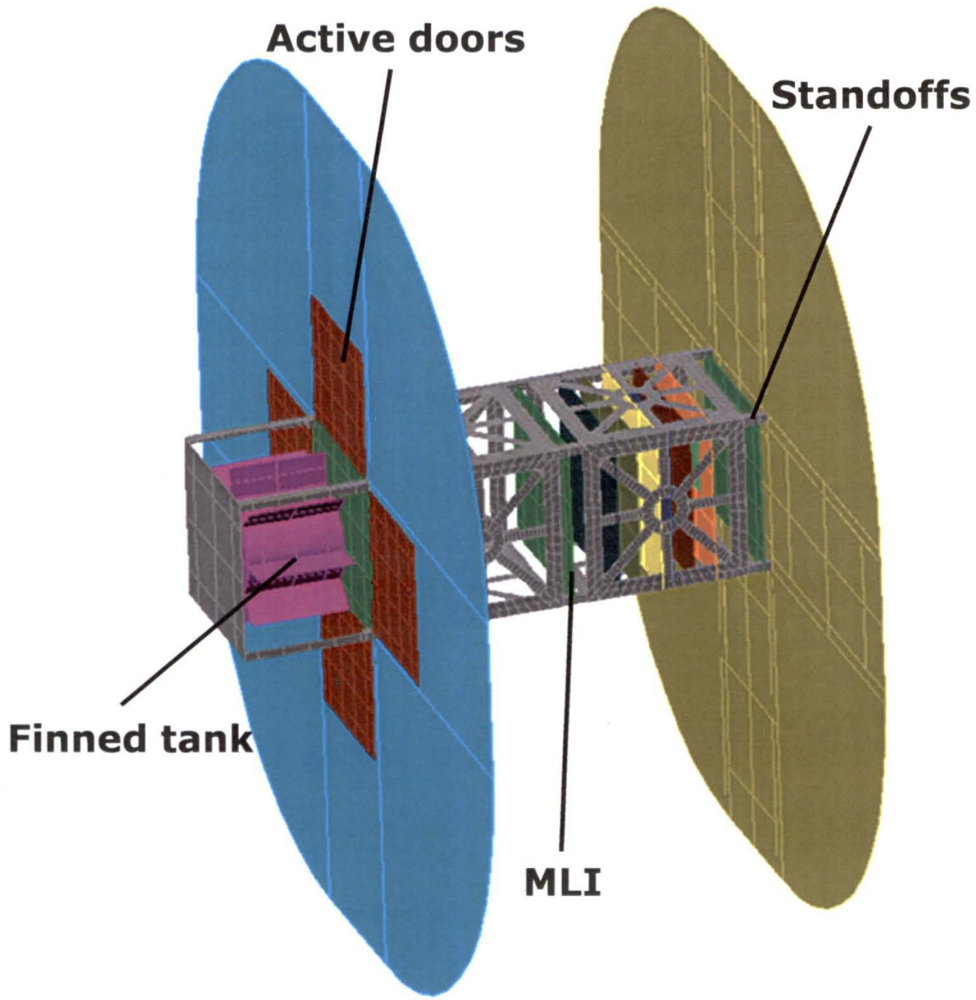


- Tank
  - Round or cylindrical?
  - Effectiveness of fins
- Isolation between segments
  - Material
  - Length



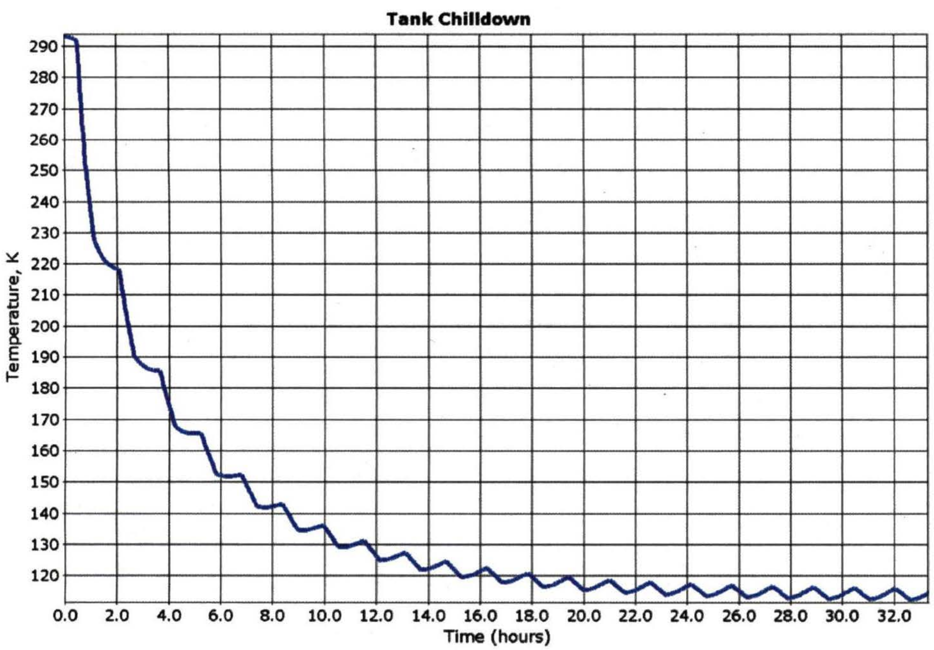
Current Design

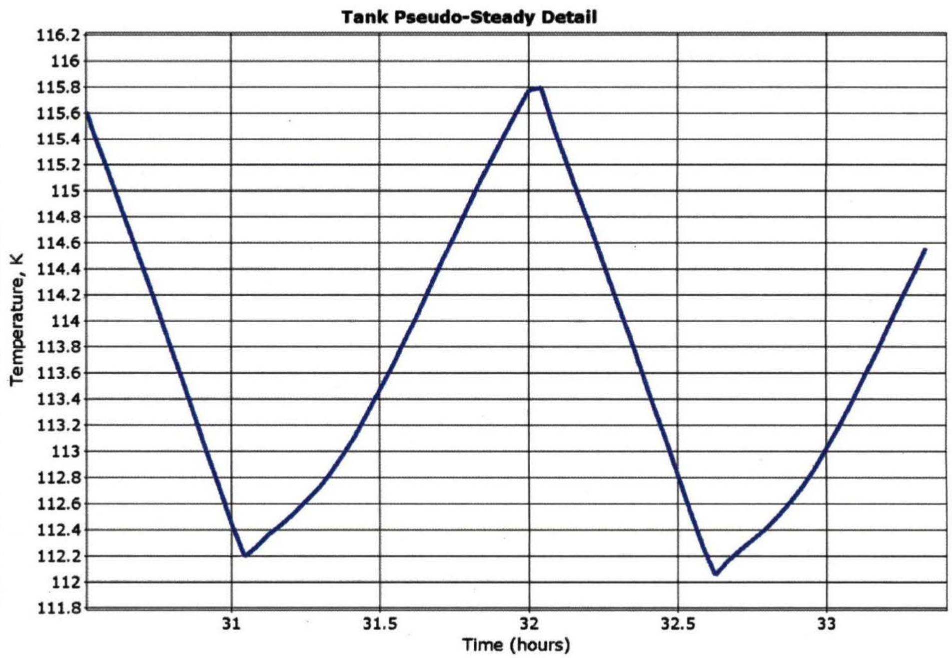
- Cylindrical tank
  - Better view factor than sphere
  - Number of fins optimized
- Double shield
  - Blocks all Earth IR in eclipse
  - Small stowage space
- Active doors
  - Open during eclipse
  - Adaptable behavior
  - Requires power and control
- Isolation
  - Long G-10 standoffs separate structure
  - Multi-layer insulation (MLI) between segments
  - More complicated structure



Results

- Pseudo-steady state reached at 100,000-120,000 s from 293K
- Below 119K limit
- Slight cooling trend continues asymptotically





Future Work

- Model refinement
  - Adjusting materials, conductors, and geometry based on prototype testing
  - Adding additional components
  - Adding fully-coupled fluid system model of gas generator system to capture condensation (Feasibility determined by hand calcs)
- Testing
  - Precisely measure heat loads and parasitic sources
  - Determine coefficients for contact conduction
    - May reduce conduction but increase radiation
  - Qualify systems for vacuum operation
- Validation
  - Full system testing in vacuum chamber
  - Check model accuracy
  - Refine margins