Thermal Performance of a Cryogenic CubeSat Mission

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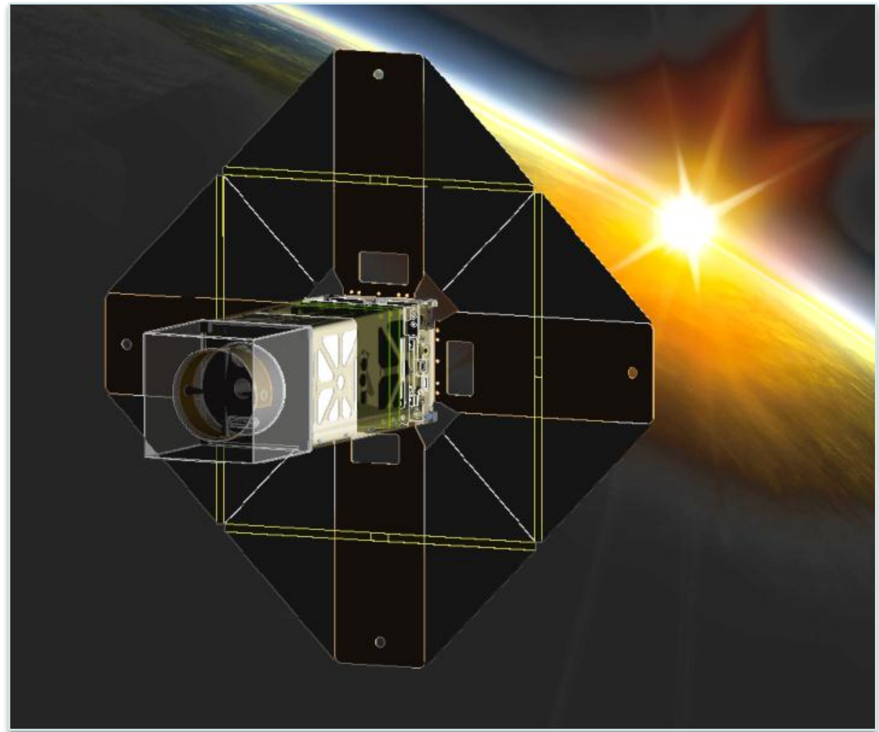
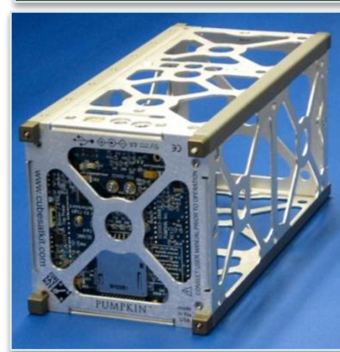
CryoCube Project Intro

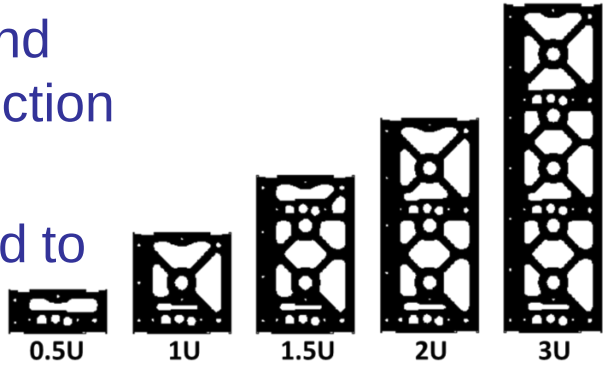
- CubeSat platform
- Cryogenic fluid management experiments
  - Fluid location sensing
  - Slosh characterization
  - Cryogenic fluid transfer
- Cooperative effort between private industry and NASA
  - SLI: Design, fabrication, major component procurement
  - KSC: Analysis, radio communications hardware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



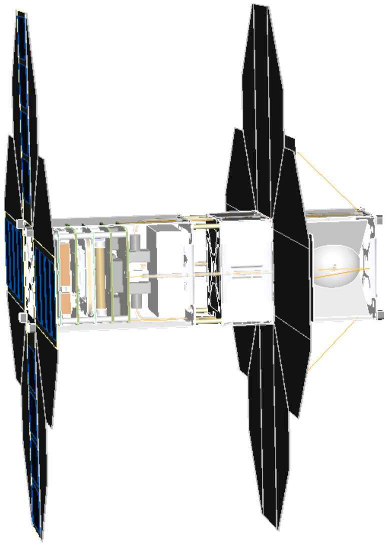


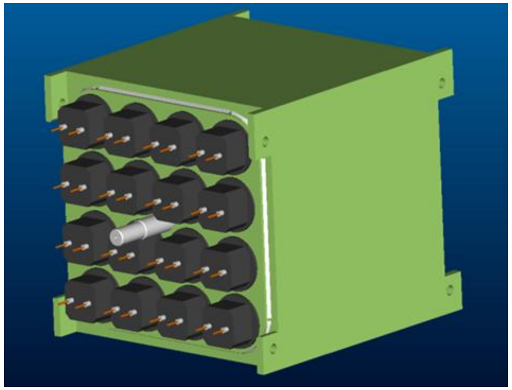
What is a CubeSat?

- CubeSats are miniaturized satellites
- Form factor of these satellites are broken into units called U's
- Each U is 10 cm x 10 cm x 10 cm (1 liter) and has a mass ≤ 1.33 kg
- U platform is standardized which largely has kept complexity low for education use
- Large utilization of commercial off-the-shelf (COTS) components
- Cost/complexity of production, integration, and operation is low (full development and production costs for spacecraft ~$200K/U)
- CubeSat form factor and design standardized to enable deployment from a common system

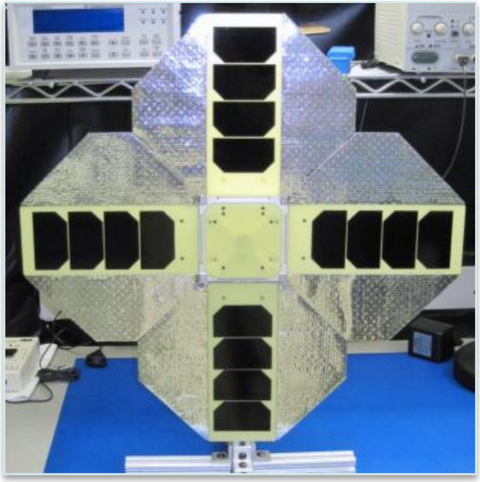


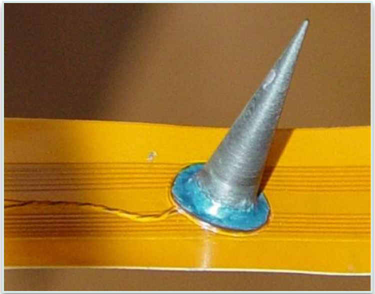
CryoCube Project Intro





- 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 October 2014





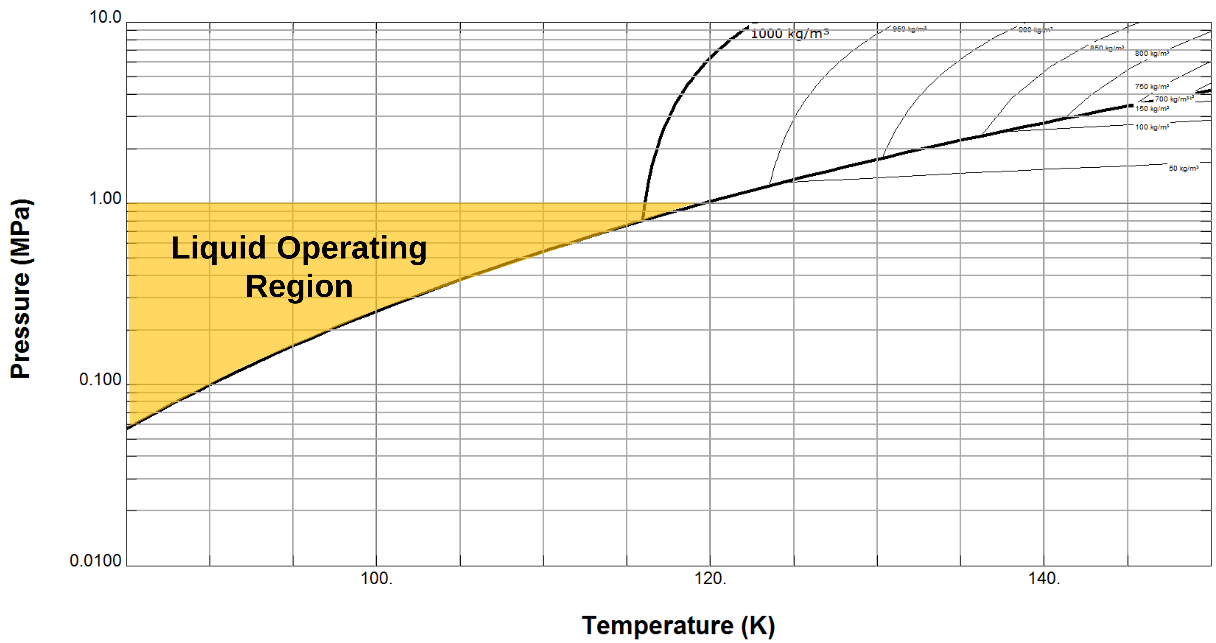
CryoCube Project Intro

- Goal: Analyze thermal performance of CC-1
  - Reduce experiment tank temperatures into regime appropriate for LOX condensation (< 120 K @ 1 MPa)
    - Passive cooling only
    - Low weight
    - Small size

- Investigate design sensitivity to material and optical properties

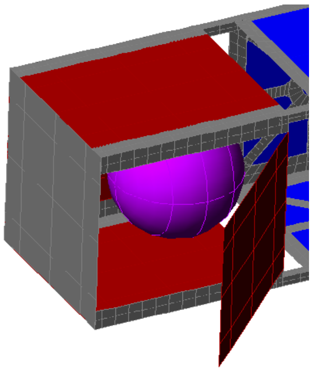
- Develop concept of operations to facilitate performance

Oxygen Phase Plot

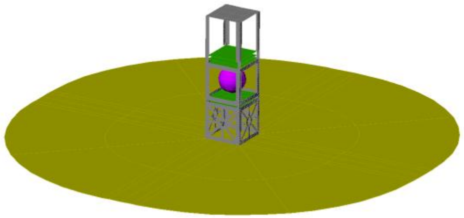


Design Space

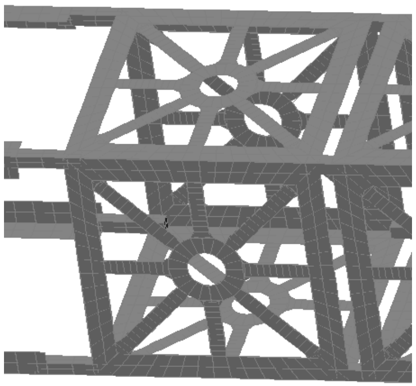
- Actuated doors
  - Must expose tank directly to deep space
  - Permanently exposed tank absorbs too much Earth IR
  - Active doors can open in eclipse, closed rest of orbit
  - Optical properties of inside and outside face

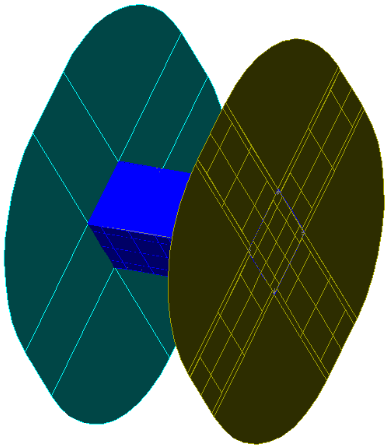


- Shield
  - Rounded edges
  - Single regular shield will not block Earth IR
  - Large shield, middle mounted tank?
  - Double shield?
  - Shields can reflect radiation back onto tank (glint)



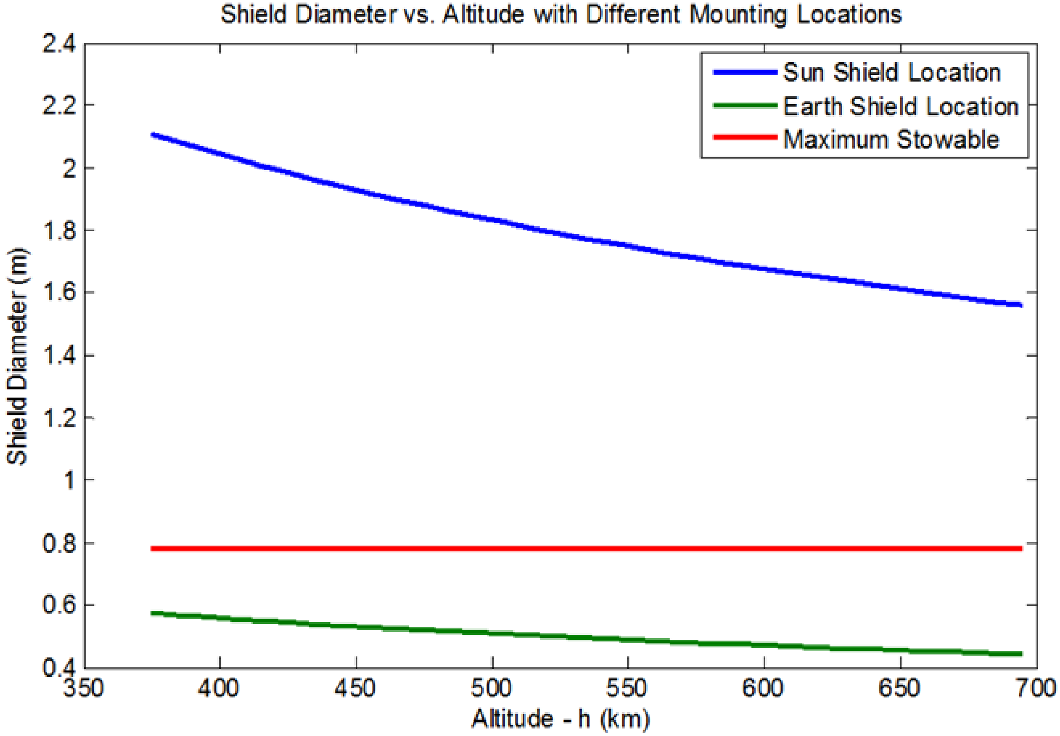
- Tank
  - Shape
  - Effectiveness of fins
- Isolation between segments
  - Material
  - Length

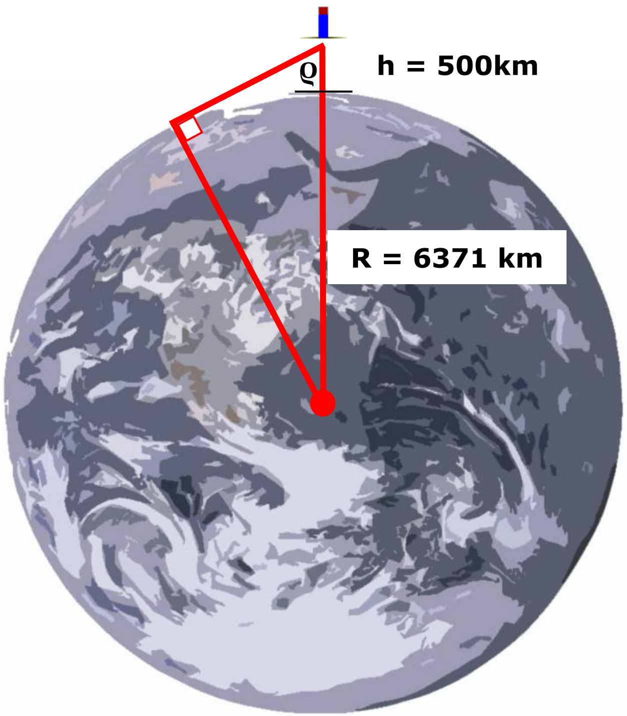


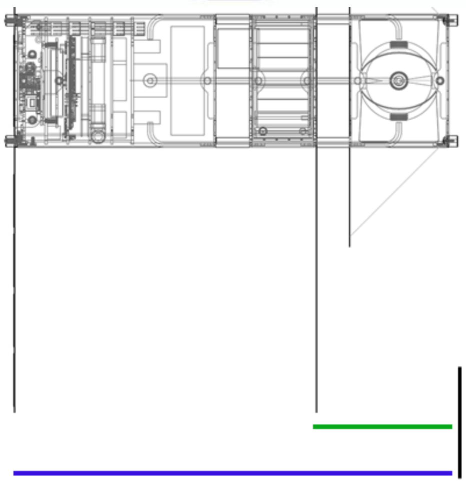


Geometric Considerations

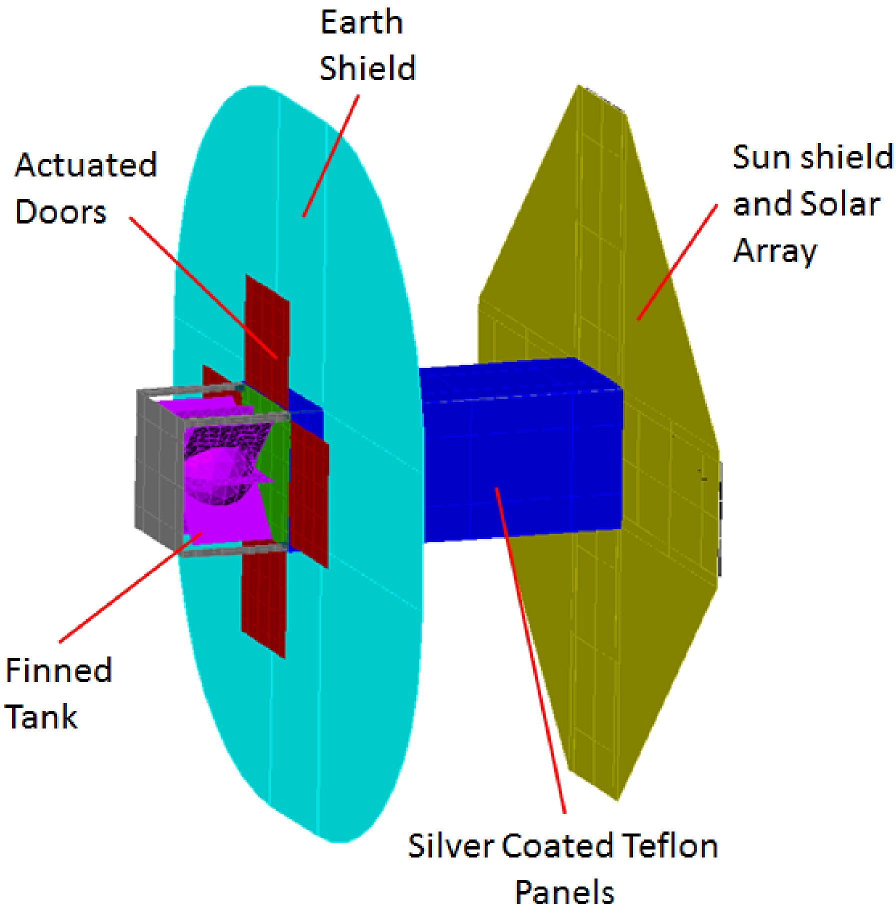
- Angular size of Earth
  - Like having face 10” away from 55” TV and trying not to look
  - 2ρ =136˚at h = 500 km
  - High relative temperature (250K)
  - Sun shield ineffective for Earth IR

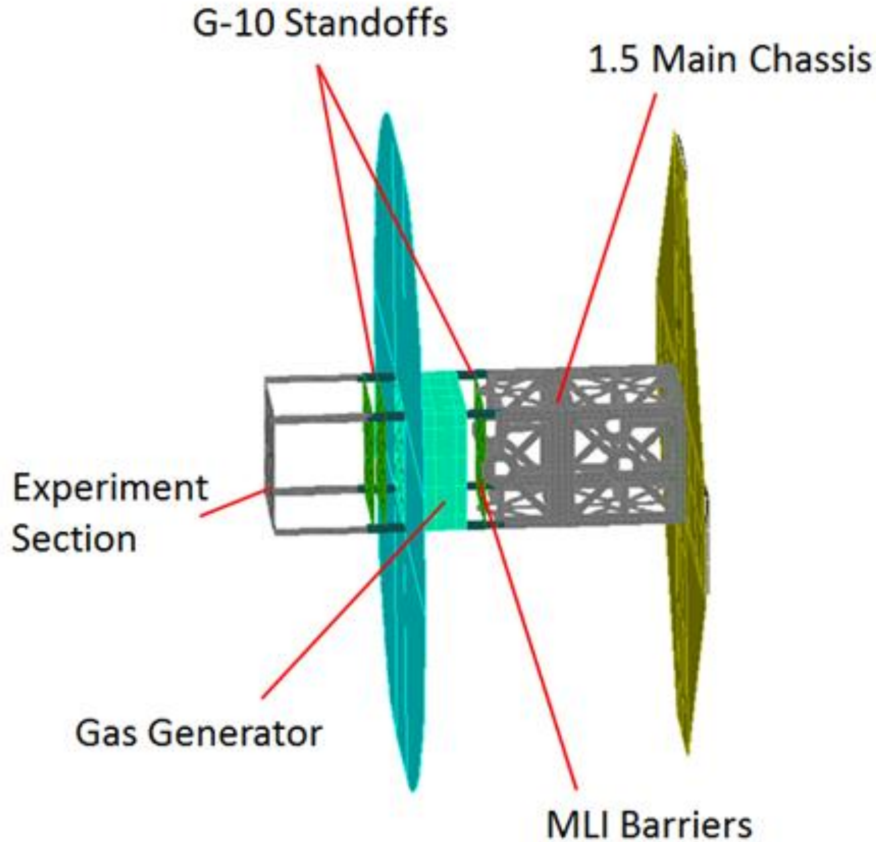






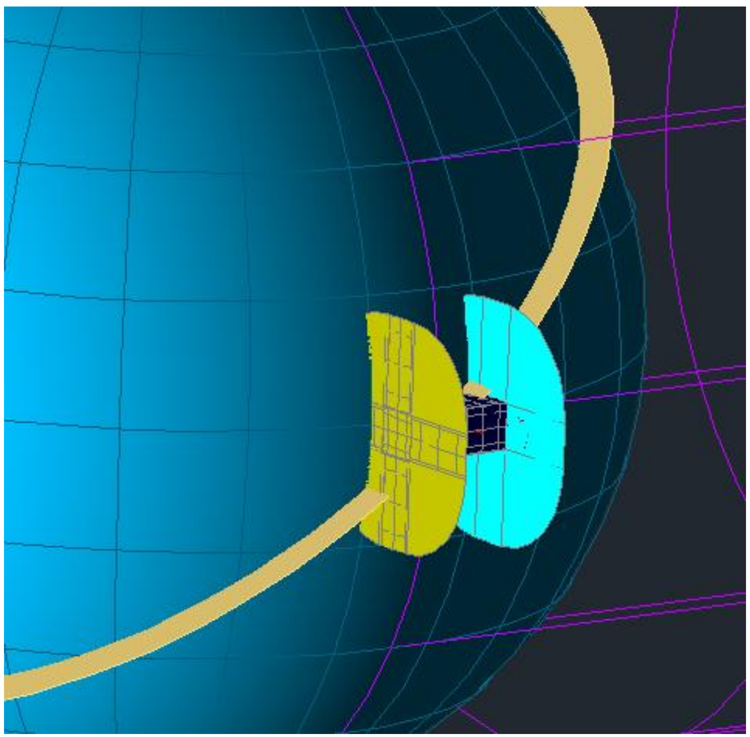
Current Design



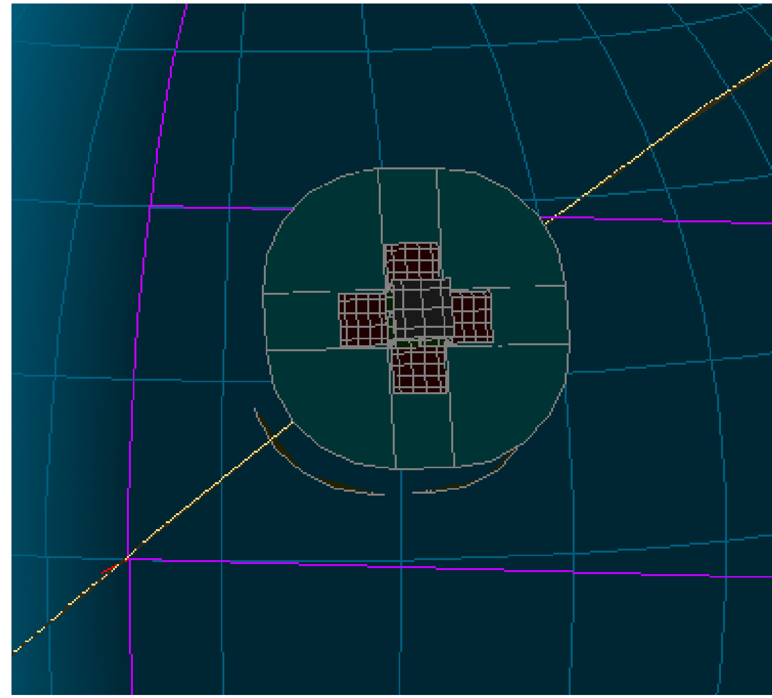


Concept of Operations

- Attitude control
  - Sun and nadir pointing
  - Magnet torquers
  - Optimizes shield usage
  - Requires continuous control



Sun pointing – When in direct sun
Doors closed
Long axis parallel to sun rays

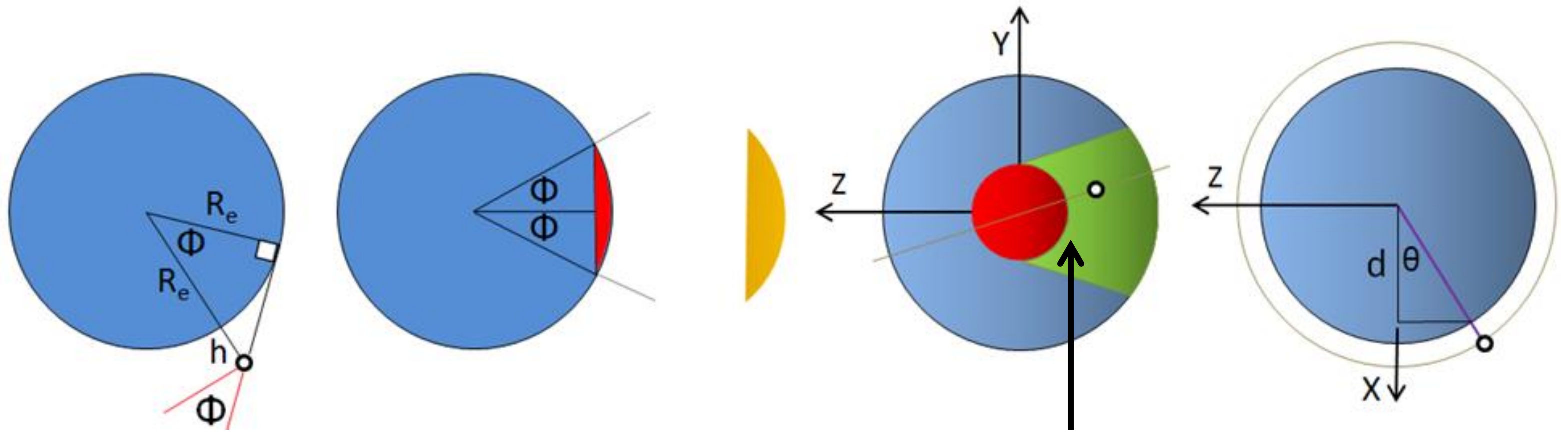


Nadir pointing – During eclipse

Doors open

Long axis normal to earth surface

Door Actuation Scheme



Red + Green regions are good

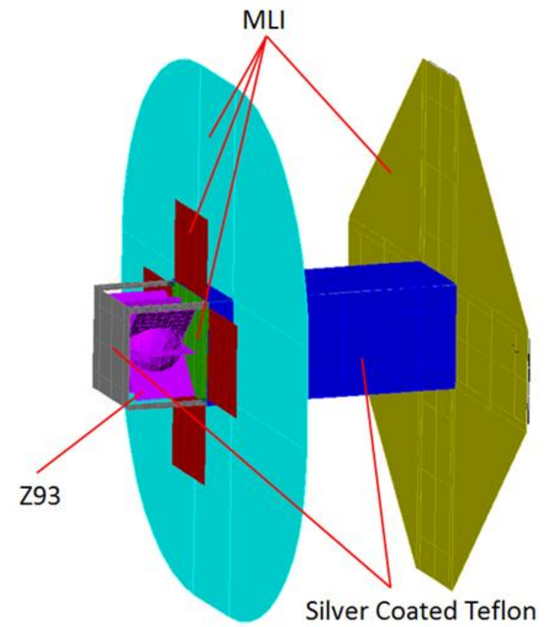
- Doors always open in eclipse
- During other orbit epochs, door opposite of earth may open
- This region depends on orbit altitude, sun position, and position in orbit

$$\Phi = arccos\left(\frac{R_e}{R_e + h}\right)$$

$$\Phi_{new} = arccos\left(\frac{R_e \cos(\theta)}{R_e + h}\right)$$

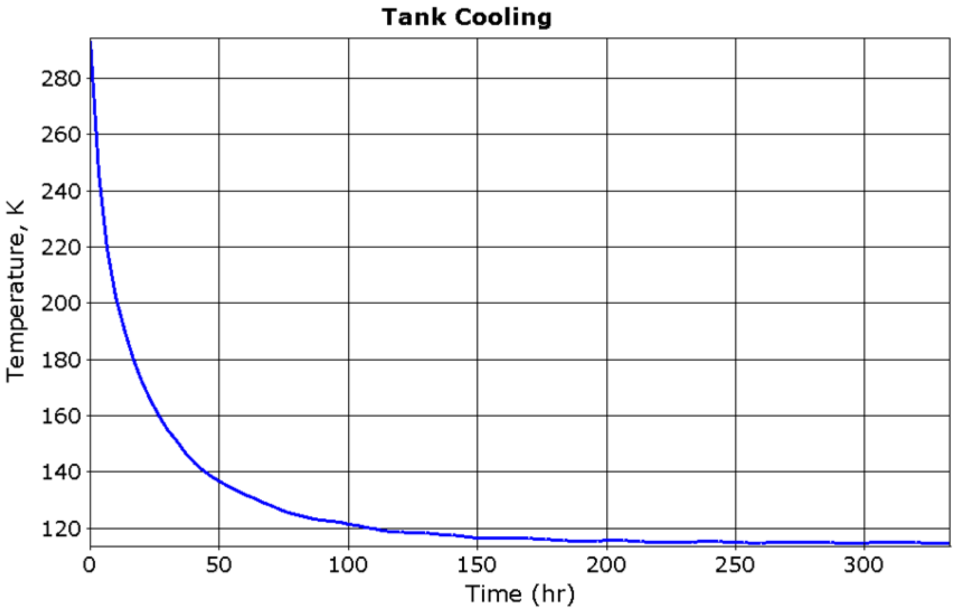
Material Degradation

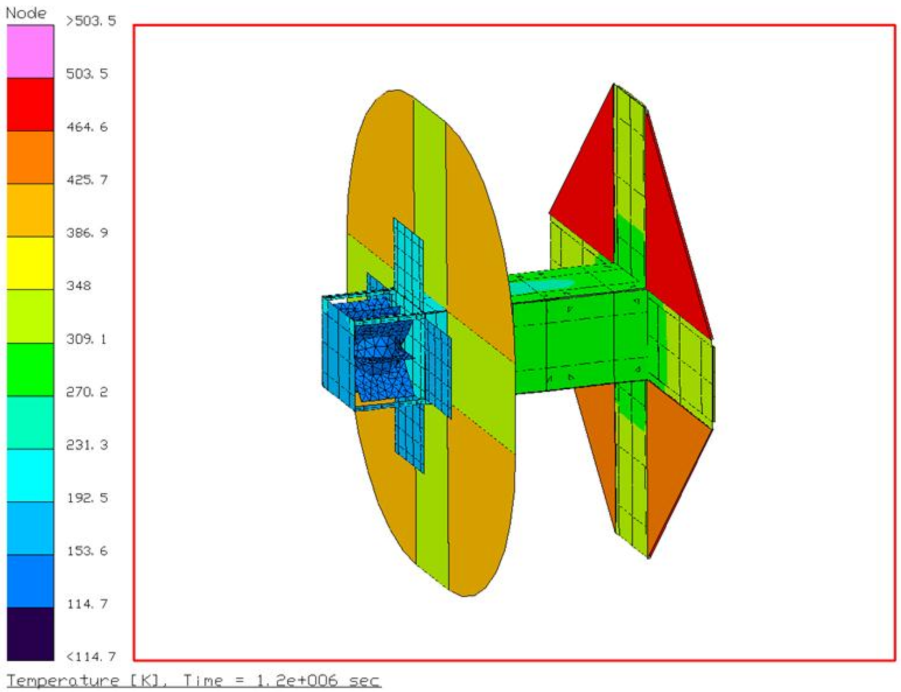
- All optical materials lose performance on orbit due to environmental factors
  - Radiation bombardment
  - Outgassing
  - Contamination
  - Elemental oxygen
  - Low temperatures



- Some critical surfaces on CC-1
  - Tank
  - Radiator panels
  - Radiation shields
- Extensive on-orbit data exists for material deterioration
  - Short mission life limits negative effects

Thermal Performance





- Extended time required to reach steady cold temperature
- Performance margins are acceptable (~ 3-7K, ~15-30%)
  - *Donabedian 2003, Spacecraft Thermal Control Vol II, pp. 472,476*

Non-Optimal Material Performance

Material Altered	Effect	Absorbtivity (α)	Emissivity (ε)	Effective Emissivity (ε*)	Tank Temp. (K)
Z93	Radiation degradation	0.19	0.91	n/a	113.2
Z93	Ground contamination	0.18	0.91	n/a	113.1
Z93	Degradation and contamination	0.21	0.91	n/a	113.1
Silver Teflon	Radiation degradation	0.07	0.8	n/a	112.8
Silver Teflon	Perturbation	0.07	0.8	n/a	113.1
Silver Teflon	Perturbation	0.05	0.8	n/a	112.6
Z93	Perturbation	0.21	0.94	n/a	112.8
Z93	Perturbation	0.14	0.47	n/a	121.1
Z93	e* degradation from cold	0.21	0.83	n/a	114.1
MLI	e*= 0.06	n/a	n/a	0.06	114.9
MLI	e* =0 .06, full deg Z93	0.21	0.83	0.06	116.1
MLI	Perturbation	n/a	n/a	0.09	115.2
MLI	Perturbation	n/a	n/a	0.12	115.4
MLI	Perturbuation	n/a	n/a	0.18	115.4
MLI+Z93	Stacked case	0.21	0.83	0.18	116.9

- Tank Z93 coating critical
  - Emissivity must be maintained
  - Tolerant of increased absorptivity due to shielding

Conclusions

- Design is feasible
  - Tolerant of expected material degradation
  - Understanding of sensitive surfaces
- Performance margin acceptable at this stage
  - Model includes on board heat sources, parasitic heat leaks
  - Model needs to be correlated to reduce risk
  - Integrated thermal-fluid model would be ideal
- Thermal system manufacture and integration critical
  - Sensitive surfaces must be clean, undamaged
  - Difficult with CubeSat payload status
- Future work
  - Integrate gas generator system
  - Correlate with thermal vacuum tests

Acknowledgements

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  - AES (Advanced Exploration Systems)
- Sierra Lobo Inc.

Questions

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