Thermal Control Technologies for Europa Clipper Mission

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Pradeep Bhandari

A. J. Mastropietro, Razmig Kandilian, Jenny Hua, Sean Reilly, Paul Woodmansee, Tyler Schmidt & Mark Duran

NASA Jet Propulsion Laboratory

California Institute of Technology

Question:

Does Europa Clipper Mission Utilize Interesting & Innovative Technologies For Thermal Control?

Answer:

Yes it does, and that's why you are here to listen to my talk☺

Outline of Presentation

- **Conservation of Thermal Power & Harvesting of Waste Heat**
  - Key driver for Thermal Control Of Europa Clipper Mission
- **Overview of Clipper Mission & Spacecraft**
- **Heat Rejection System**
- **Key Thermal Control Technologies Employed**
  - High Performance Dual MLI Blankets
  - Two Passive Thermal Control Valves
  - Low Temperature Louvers
- **Summary**
- **Key Conclusions**

Motivation

- **Europa Clipper Mission and Europa Lander Concept Mission are both solar array powered designed to travel to ~5.6 AU**
  - 4% of Solar Flux near Earth

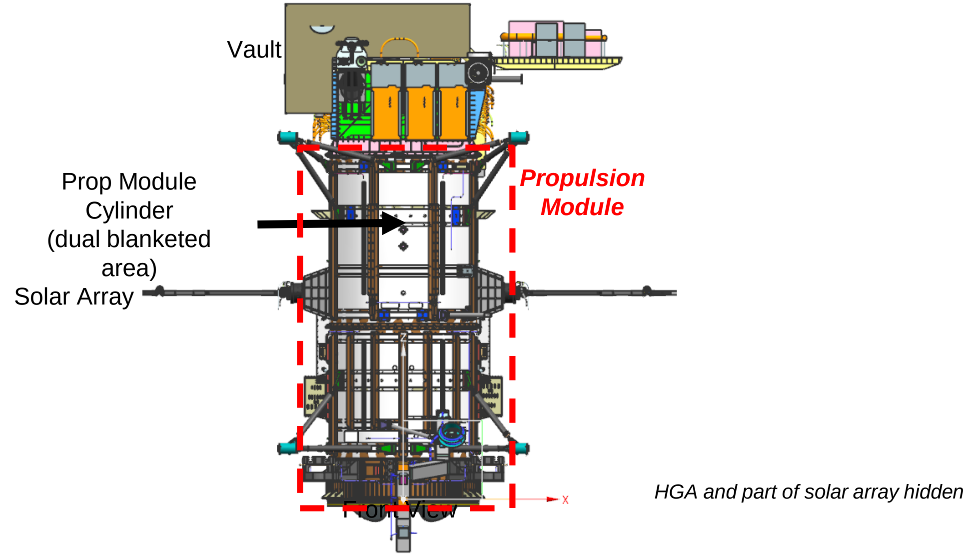
- **Therefore, they are both severely power constrained near Jupiter and Europa when the primary mission operations begin**

- **Hence the need for aggressive minimization of power required for Thermal control**

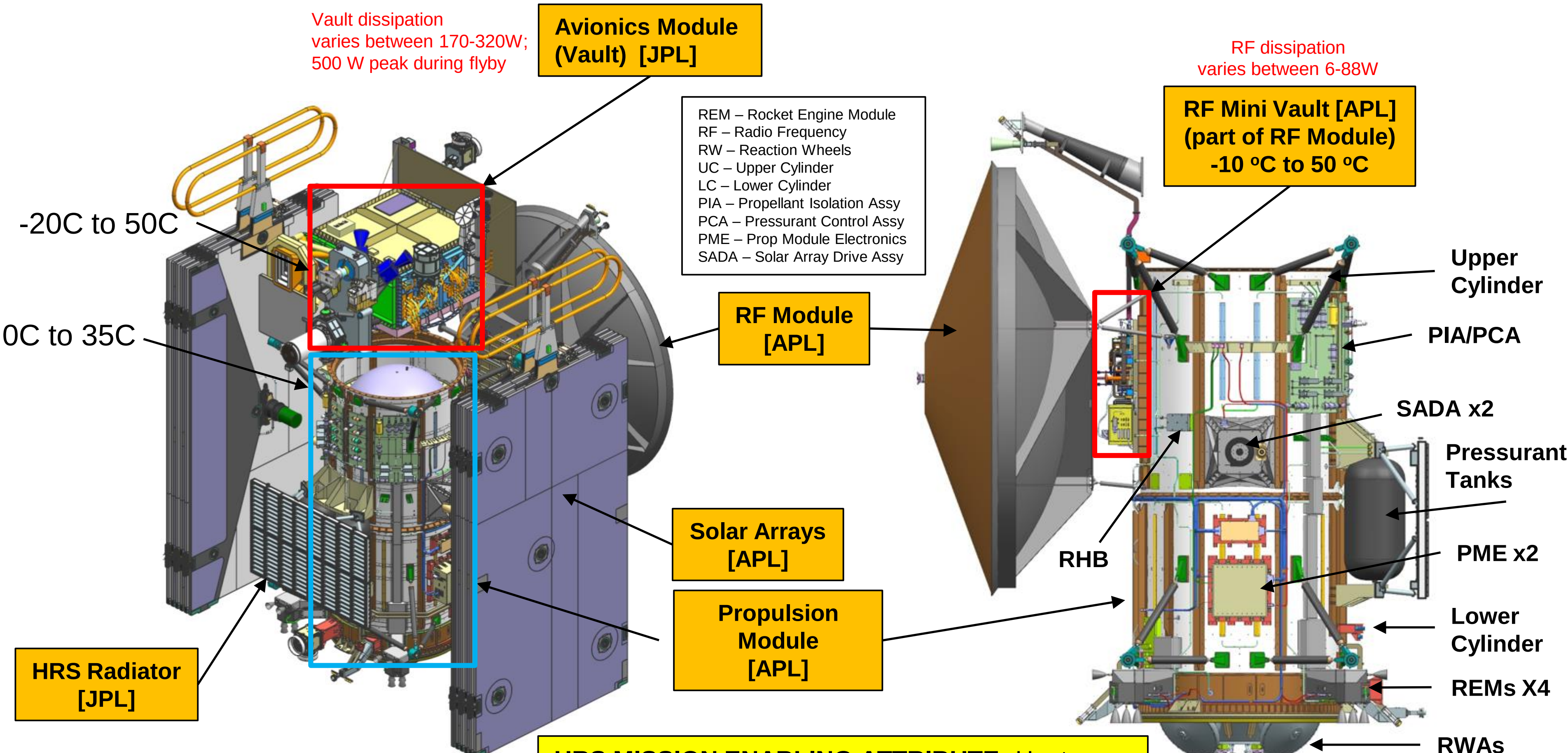
- **Four key Thermal Technologies utilized to achieve this goal**

Europa Clipper Background

- **The Europa Clipper spacecraft features a large propulsion module with a cylinder that is maintained between 0 and +35 °C**
- **Deep Space Planetary Mission to Launch in 2023 to Europa, a moon of Jupiter**
- **Vast majority of its heat loss is via MLI blankets**



Europa Clipper



HRS MISSION ENABLING ATTRIBUTE: Heat harvesting functionality is required to maximize electrical power available to instruments during flybys

Key Thermal Control Technologies Employed to Conserve Thermal Power

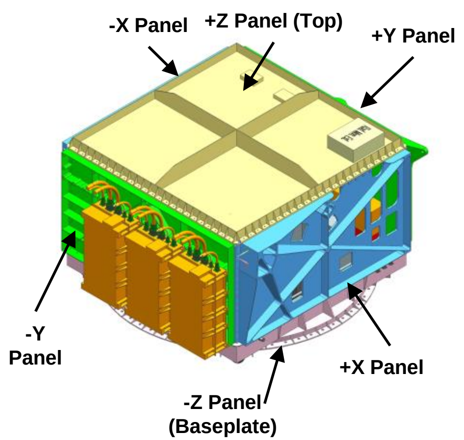
- **Pumped Fluid Single Phase Heat Rejection System (HRS)**
  - Harvest waste heat from components dissipating heat in the vault for use in the propulsion module
  - Remove waste heat from components and reject it to the HRS radiator
  - Isothermalize thermally controlled components in the vault as well in the propulsion module

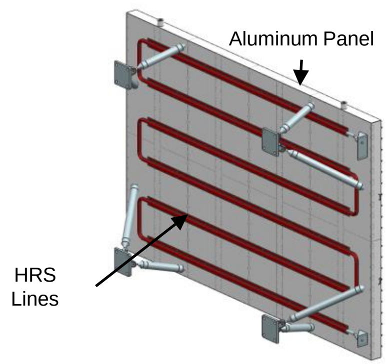
- **Dual MLI Blankets**
  - Minimize heat loss from propulsion module by using two MLI blankets separated from each other with their low emissivity surface facing each other between the two blankets
    - Potential is as much as a 50% reduction

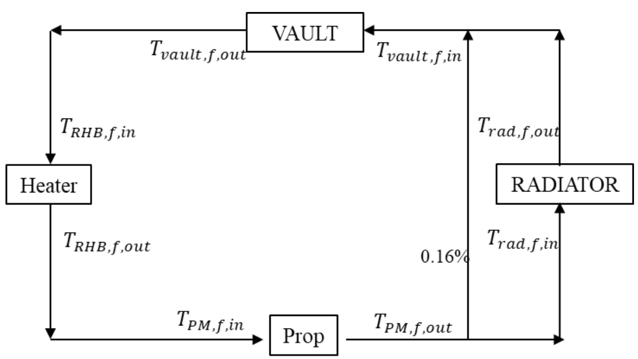
- **Two passive thermal control valves in series**
  - Two thermal control valves in series lead to significantly reduced HRS flow to radiator in cold conditions thereby reducing heat loss from spacecraft

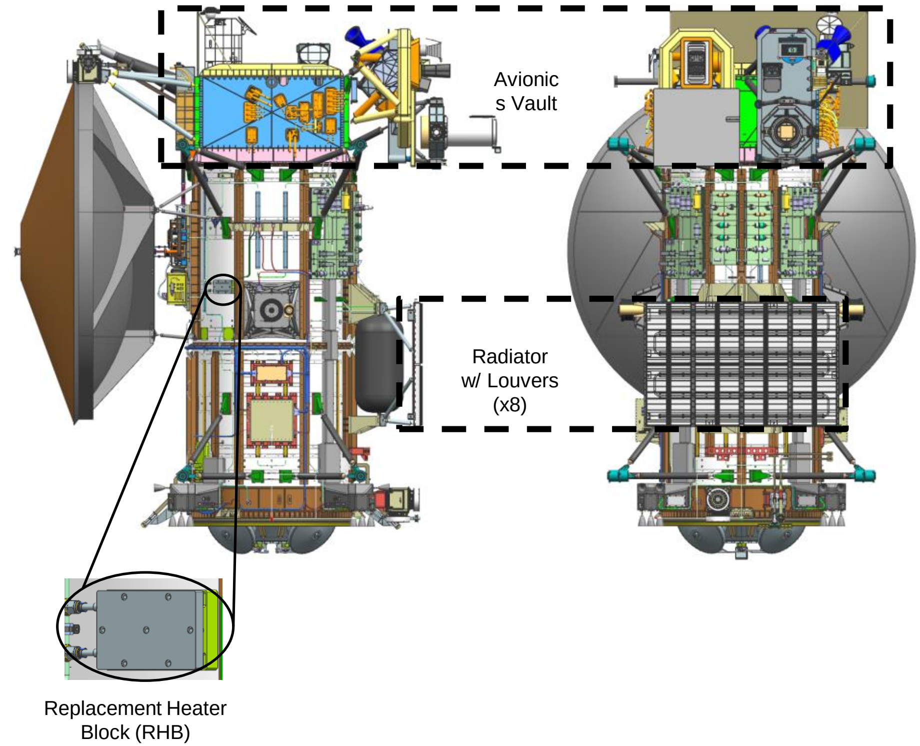
- **Low temperature louvers on HRS radiator**
  - Develop & utilize louvers that close at low temperatures to minimize heat loss from radiator in cold conditions

Europa Clipper HRS

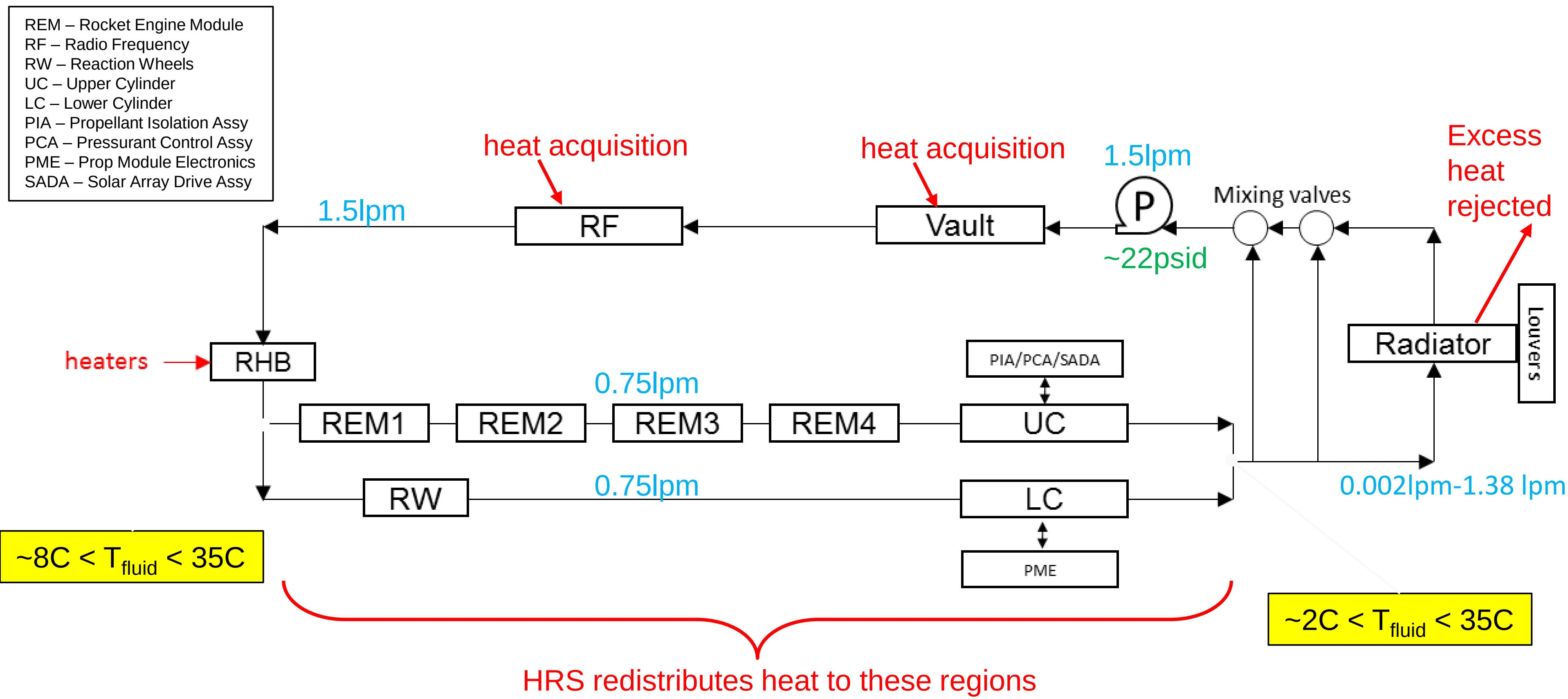






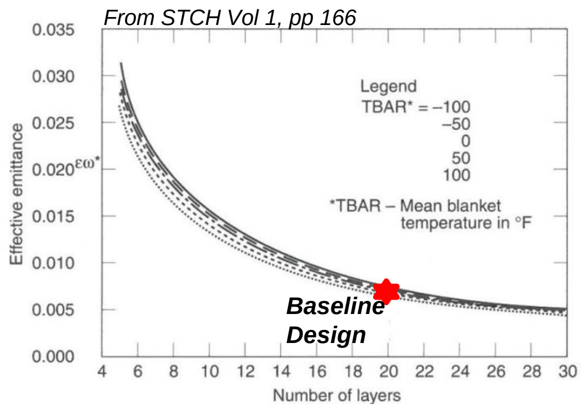


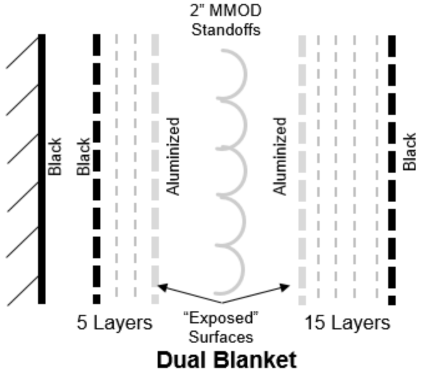
Simplified Clipper HRS Schematic



Potential Improvements to MLI

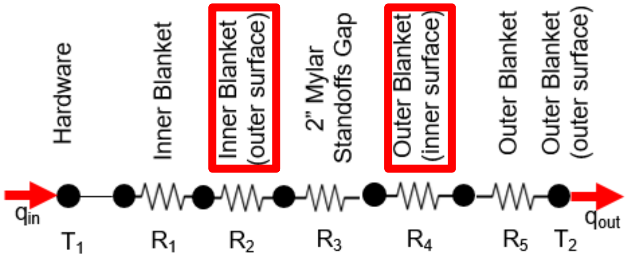
- **Single Stack (*Traditional*):**
  - **Increase number of layers to improve ε***
    - Has diminishing returns due to conductive shorting of layers contacting each other
    - *There is a direct mass impact associated with the additional number of layers used*
- **Dual Stack (*Proposed*):**
  - ***Break MLI into two blankets*** *but keep the total number of layers the same*
    - *No mass impact*
  - *And have* ***low emissivity*** *coating on the exposed interstitial surfaces of each blanket*
- **The potential power savings for the dual stack configuration could be significant and achieved with almost no mass increase**
  - ***As much as 50% reduction***



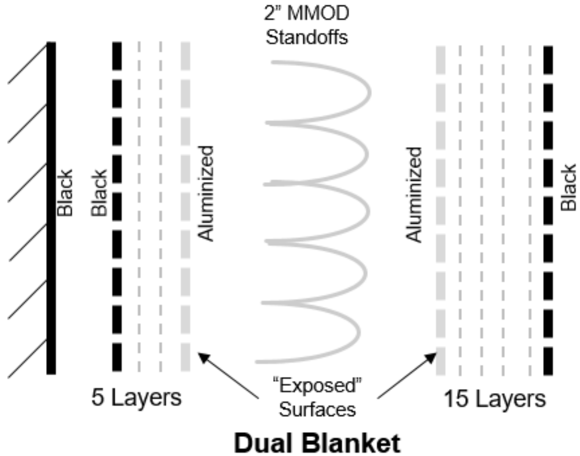


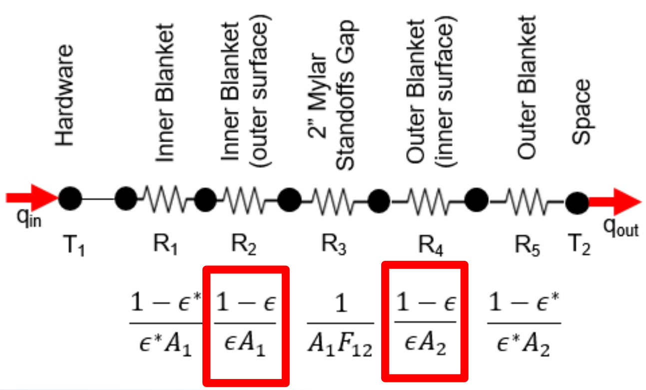
Dual Stack Heat Flow Network

- **The dual blanket concept leverages *separated aluminized surfaces* (shown in red boxes) on the outside and inside of blankets to reduce the overall ε***
  - These create an extra radiation resistance



- **In a single 20 layer blanket, these two layers would be conductively shorted by the seams and interstitial contact caused by crushing of the blanket**

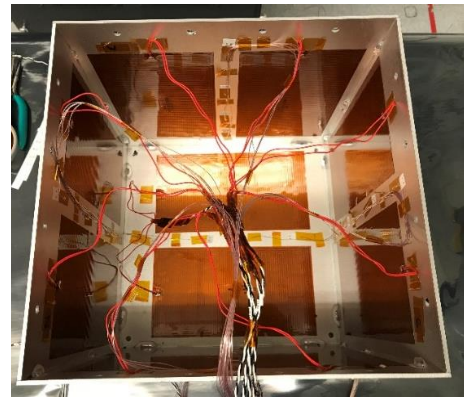




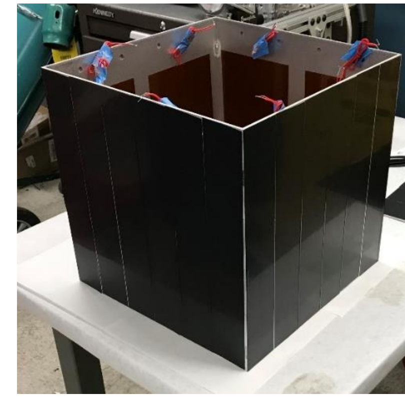
$$\frac{1-\varepsilon_1^*}{\varepsilon_1^*} + \frac{1}{\varepsilon_{1,o}} + \frac{1}{\varepsilon_{2,i}} + \frac{1-\varepsilon_2^*}{\varepsilon_2^*} = \frac{1}{\varepsilon_{eff}}$$

Test Article & Results

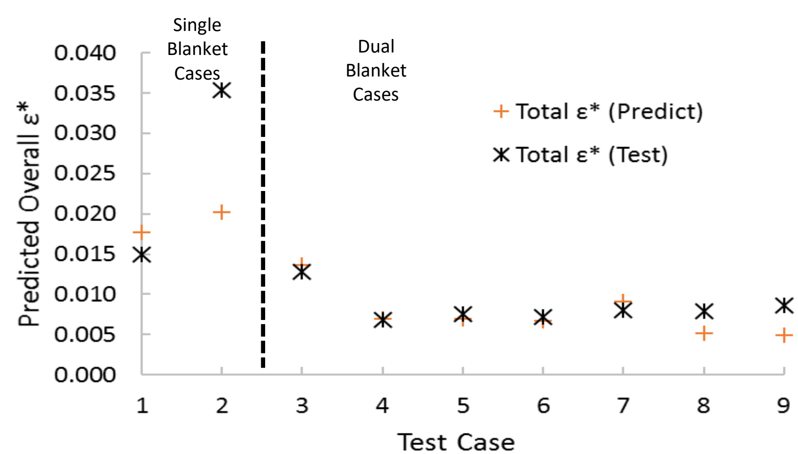
- 1ft x 1ft x 1ft aluminum cube with 1/8” thick sides
- The ε* values from testing were calculated at each of the three test temperatures and averaged in the table below – using Lockheed Martin Equation for MLI
- In general, pre-test predictions matched the test results very well
- Dual blanket schemes had about half the heat loss of the single blanket baseline



Test Article (Interior)



Test Article (Exterior, bottom missing)



Current Work on Dual MLI

- Conducted a ½ height scale test with the Propulsion Module Simulator cylinder (in 3m, 10' chamber)
  - *Included feedthroughs, electronics box simulators, and more*

- Tested with the 20 layer baseline design (test case 1) and the 5 layer embossed kapton + 15 layer Dacron design (test case 4)

- Test data currently being analyzed

Full Height
Prop Module

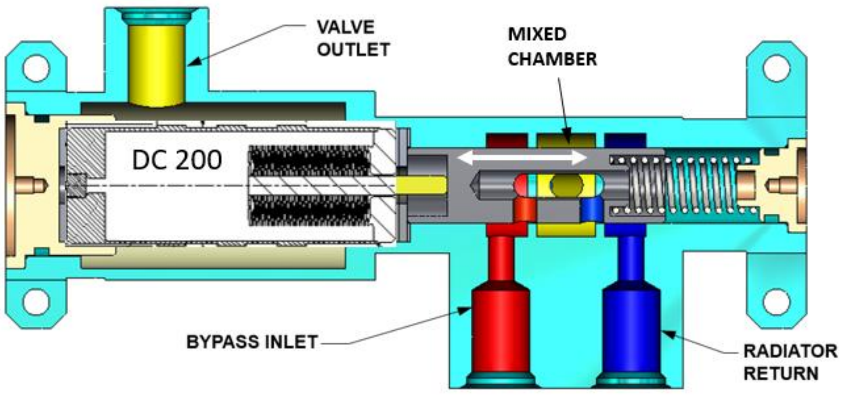
1/2 Height
Prop Module

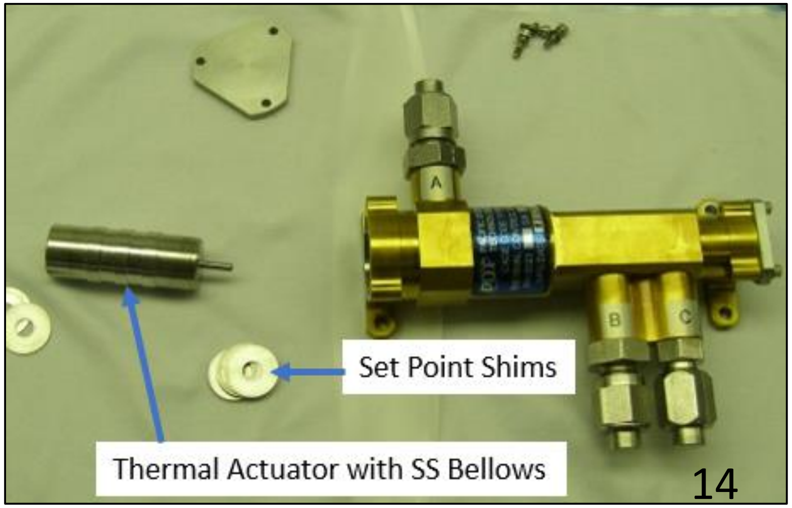
Thermal Control Valve

- **Passive valve, actuated by thermal expansion & contraction of high CTE oil**
  - Opens/closes ports to direct flow fraction towards or away from radiator depending on its temperature

- **Fully closed in radiator direction (cold conditions)**
  - **Min. 4% flow towards radiator; 96% bypassed**
  - **Vice versa for hot conditions**

$$V*\Delta T*CTE=A*\Delta L$$



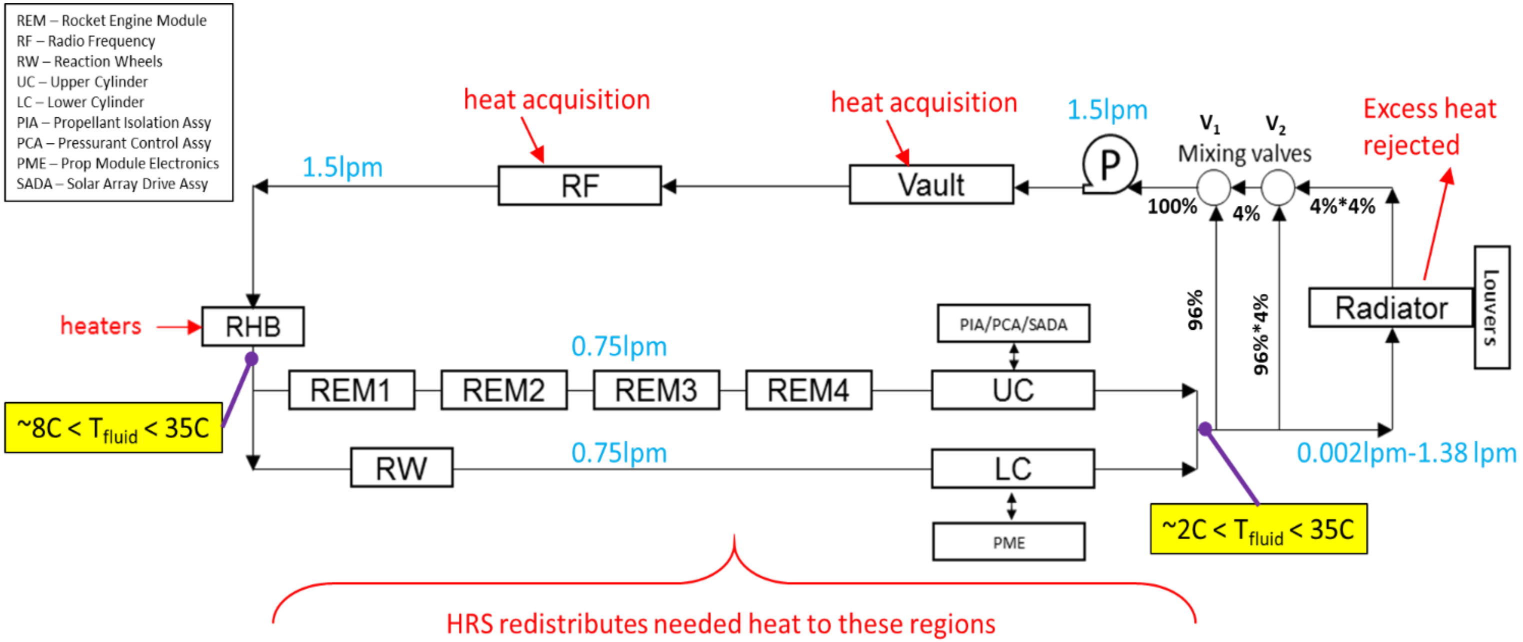


Two Thermal Control Valves In Series

- Unfortunately, in cold conditions, even a 4% leak flow into the radiator leads to excessive heat loss to radiator in cold conditions
- Since the flow coming into the radiator is warm and that going out is very cold, even a small flow heat capacity multiplied by the large delta-T leads to large heat flow into the radiator
  - Q = mdot*Cp*dT = 30 W/C * 4% * 100 C = 120 W!!
- The reason for this limitation on the minimum practical flow is the required clearance between the valve spool and its housing to avoid jamming concerns
  - This leads to a leak flow even when the valve is fully closed in the radiator direction

Two Thermal Control Valves In Series

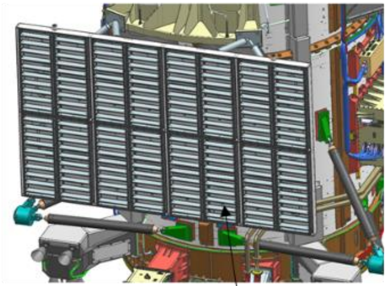
- To overcome this penalty, an innovative configuration using two valves in series was employed
- This led to a drastic reduction in overall leak flow, from 4% to 0.16%
  - = 4% * 4%
- Which then led to a flow heat loss to the radiator of only 5 W
  - = 4%*120 W
- A development test confirmed this flow reduction



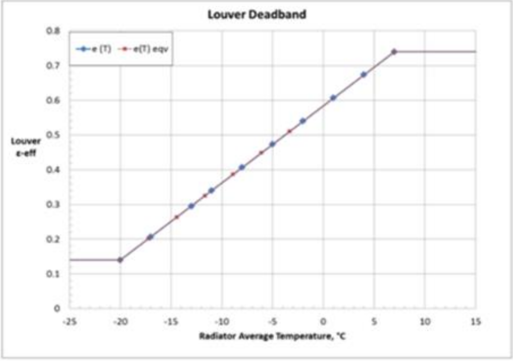
Louvers for Clipper

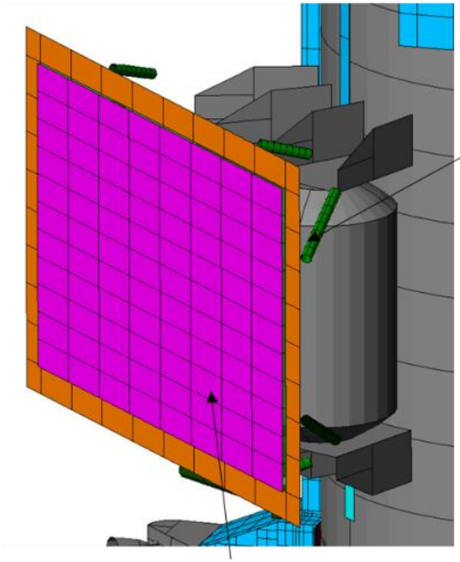
- **Louver employed in Clipper to modulate the heat loss from the HRS radiator**
  - *High emittance in hot cases (maximize heat loss)*
  - *Low emittance in cold cases (minimize heat loss)*

Radiator with Louvers



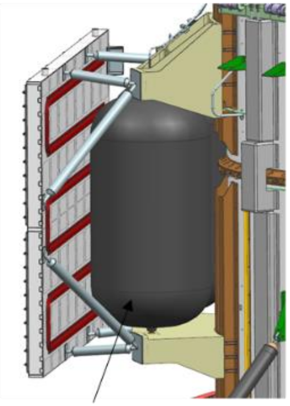
Total Radiator Area (without Louver Frame area removed) = 1.6 m x 1.08 m





Radiator and Louver Material = Al 6061
Thickness = 1 mm
Surface: Louver ε*
(Radiator surface will be white paint)
Frame represents equivalent area of all 8 Louvers

MLI located between Radiator and Pressurant Tanks



Pressurant Tanks

Low Temperature Louver

- **Traditional louvers rely on a relatively narrow allowable temperature range of -50 C to +50 C, with an operational (control range or dead-band) of about 20 C within this**
- **In the case of Clipper, since the heat flow to it from the HRS flow is designed to be minimal (<10 W), the radiator attains a very low temperature of ~ -95 C**
  - *This is below the low allowable limit of -50 C for traditional louvers*
- **This leads to louver operational temp. range of 150 C, significantly larger than 100 C for traditional louvers**
- **Additionally, louver for Clipper needed to operate & survive at -95 C, significantly < -50 C for traditional louvers**
- **Hence a low temperature louver study was conducted by Sierra Nevada Corporation (supplier of louvers to Clipper) in collaboration with JPL**

Key Louver Requirements:

- ***Fully open at 0 C to allow for max. heat loss from radiator in hottest conditions***
- ***Max. operating temp. of +50 C in hottest conditions***
- ***Fully closed at -95 C***
  - *To minimize heat loss from radiator in coldest conditions*
  - *To minimize survival heater power required to ensure that HRS fluid (Freon-11) does not freeze*
    - *F.Pt -111 C*

Low Temperature Louver Design & Trades

- A bimetal actuator that has a smaller change in length with a given temperature change compared to traditional bimetals is employed for Clipper louver
  - TM-5 instead of TM-2

- This allows for accommodating the larger temperature range that will be experienced by this lover without over-stressing it

- A detailed trade-study was performed to study various concepts for temperature modulation for Clipper radiator and those led to the choice of the louver as the baseline

Trade-Off Concepts Studied

- Wax or motor actuated driven MLI blanket flap
  - To open or close the radiator's view to space based on cold/hot conditions

- A heat switch array between the HRS tubing and the radiator
  - To vary the thermal coupling between the HRS fluid and the radiator depending on cold or hot conditions

- Utilizing the traditional state of the art louver bimetal coils
  - To allow them to reach stressed states once they hit the hard stops

- Dual (stacked on top of each other) traditional louvers on the radiator
  - To minimize their heat loss in cold conditions while not significantly decreasing their heat loss capability in hot conditions

- No louvers on the radiator

Summary & Conclusions

- **Due to severe shortage of thermal control power near Europa/Jupiter, four key thermal control technologies are employed by the Clipper Mission**
  - Mechanically pumped fluid loop heat rejection system
  - Dual MLI blankets
  - Two passive thermal control valves in series
  - Low temperature wider dead band louvers
- **The viability of these technologies have been demonstrated in various stages of maturity by extrapolation from heritage or new development tests**
- **All these technologies will provide either direct or modified versions for use in a wide variety of flight projects**

Acknowledgements

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Questions & Answers?