A Dual Multilayer Insulation Blanket Concept to Radically Reduce Heat Loss From Thermally Controlled Spacecraft and Instruments

ICES Paper 2018-025

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Question:

Is there a design concept for MLI blankets that can radically reduce its heat loss & is practical/robust to implement for complex spacecraft

Answer:

Yes there is, and that's why you are here to listen to my talk☺

Outline of Presentation

- Need for less leaky blankets for Deep Space Solar Powered Missions
- Underlying factors & mechanisms affecting heat loss through MLI blankets
- Other concepts & their limitations
- Concept of Dual MLI blankets
- Analytical Predictions for Dual MLI Blankets
- Tests performed to validate analytical performance predictions
- Future Tests for more complex geometries
- Summary
- Key Conclusions

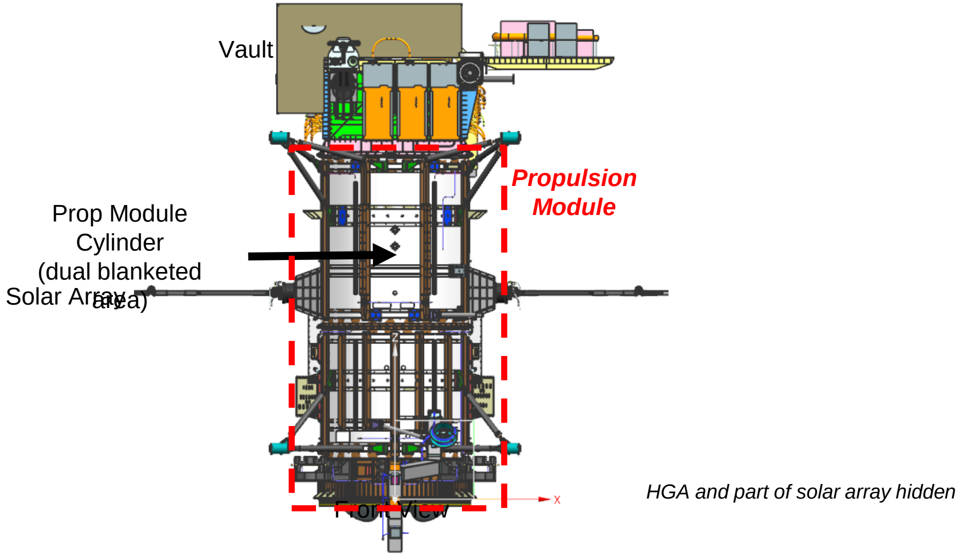
Motivation

- Europa Clipper Mission and Europa Lander Concept Mission are both solar array powered designed to travel to ~5.6 AU
- Therefore, they are both power constrained near Jupiter and Europa when the primary mission operations begin
- A better performing MLI blanket scheme (lower ε*) could provide significant power savings to both Europa missions

Europa Clipper Background

- **The Europa Clipper spacecraft features a large propulsion module with a cylinder that is maintained between 0 and +35 °C**

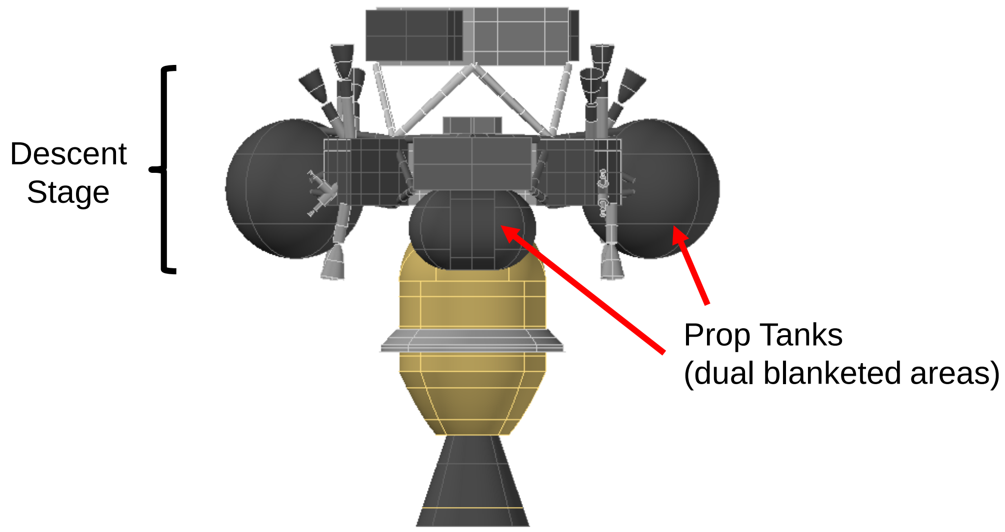
- **The dual blanket MLI concept is estimated to save as much as 80 W compared to a single blanket design**
  - Vast majority of heat loss from Propulsion Module is through MLI blankets



Europa Lander Background

- **The Europa Lander descent stage is also employing a dual blanket MLI concept to save heater power during cruise**
  - Roughly half the heat loss of descent stage is from descent stage tanks

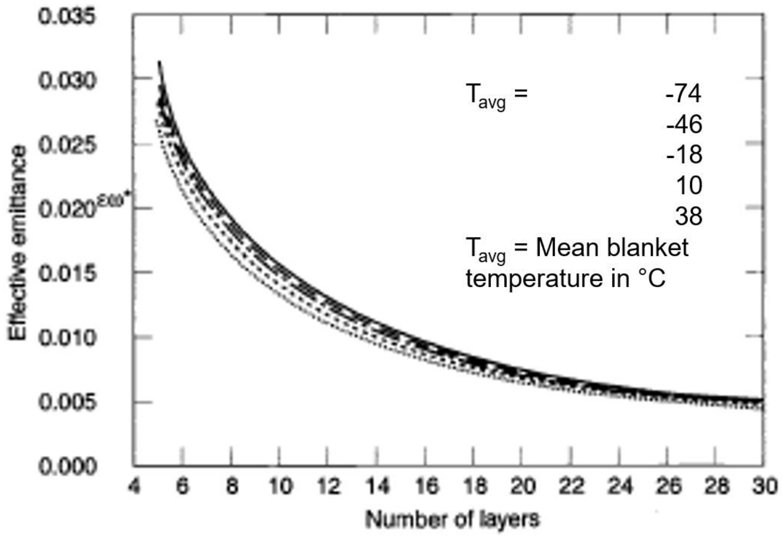
- **The dual blanket MLI concept is estimated to save 50 W compared to a single blanket design**



Key Factors Governing MLI Heat Loss

- The Lockheed equation was developed as an empirical correlation for test data of various blankets designed at Lockheed Corporation (now Lockheed Martin)

- The equation accounts for seams, number of layers, and temperatures
  - $\varepsilon_{eff} = \frac{7.30*10^{-8}(N)^{2.63}}{\sigma(N_S+1)}\left(\frac{1}{T_H^2+T_C^2}\right) + \frac{7.07*10^{-10}(0.043)(2)}{\sigma N_S}\left(\frac{T_H^{4.67}-T_C^{4.67}}{T_H^4-T_C^4}\right)$
  - N = layer density
  - N_S = number of layers
  - T_H = hardware sink temperature
  - T_C = cold sink temperature
  - Seams = factor of two for JPL
  - Performed analysis in Excel with a solver routine



- **Larger the no. layers, smaller the ε_{eff}**
  - But asymptotes > ~20 layers; **Stay with max 20 layers**
- **Larger the layer density, larger the ε_{eff}**
  - Proportional to power of 2.6! **Looser blankets are better than tighter**
- **More the no. of seams, higher the ε_{eff}**
  - Seams effectively increase local layer density – **Minimize seams**
- **Higher the Source or Sink Temp., lower the ε_{eff}**

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*

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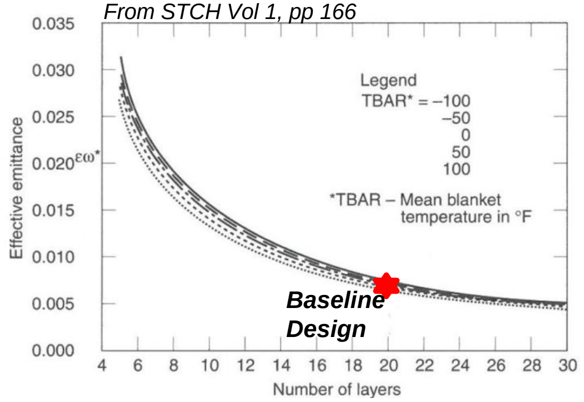
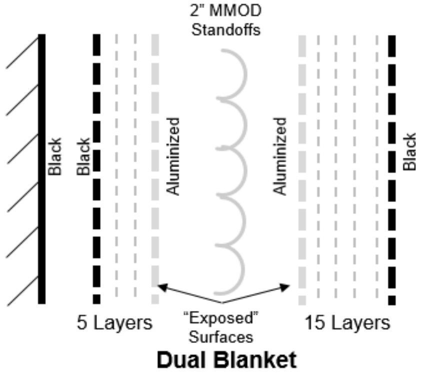


- **Dual Stack (*Proposed*):**
  - ***Break MLI into two blankets** but keep the total number of layers the same*
    - *No mass impact*
  - *And have **low emissivity** coating on the exposed interstitial surfaces of each blanket*



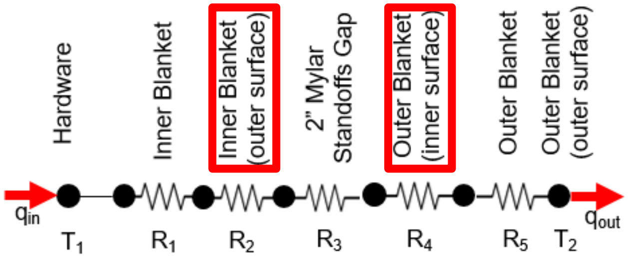
Dual Stack Configuration

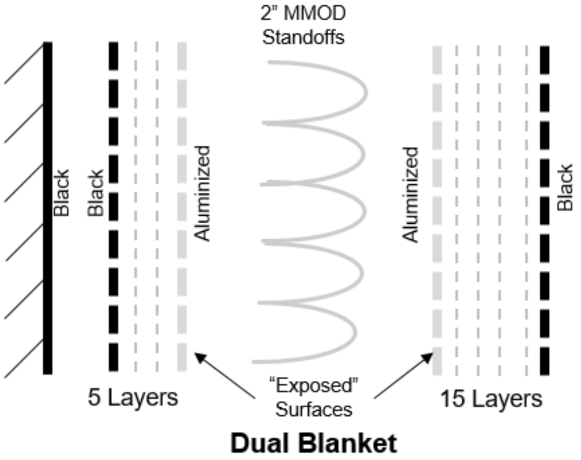
- **The potential power savings for the dual stack configuration could be significant and achieved with almost no mass increase**
  - **As much as 50% reduction**

- If needed, additional strategies could be implemented to reduce the risk of contaminating the internal surfaces during I&T activities
  - More stringent handling requirements and constraints
    - Until after the outer MLI blanket is installed
  - Design venting paths to reduce contamination during outgassing

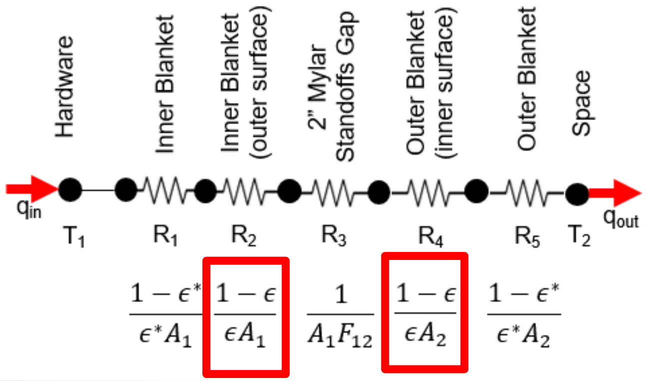
Dual Stack Heat Flow Network

- 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



Analysis Methodology

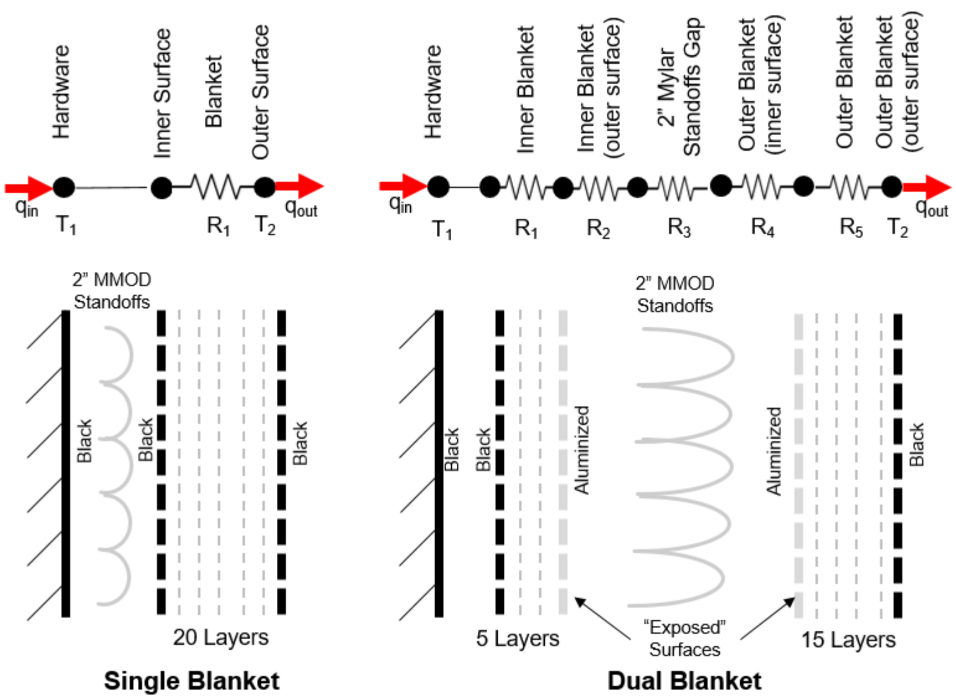
- **The Lockheed equation was employed to make analytical predictions**
  - All predictions and test results for ε* are defined from hardware to outermost MLI surface

Simple Example To Illustrate Concept:

- **Dual Blanket (15+5 layers)**
  - ε* of each of the two individual blankets = 0.05
  - ε of exposed surfaces of blankets facing each other = 0.04
  - **ε_{eff}* for dual blanket = 0.01**

- **Single Blanket (20 layers)**
  - ε* of each of the two individual blankets = 0.05
  - **ε_{eff}* for single blanket = 0.025**

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



Test Matrix

- **Investigated effects of**
  - Single vs dual blanket scheme
  - Black vs aluminized surfaces
  - Dacron netting vs embossed
  - Number of layers
  - Staggering the seams
  - Locations of the standoffs

- **Baseline** blanket design is a 20 layer Dacron layup

- **Leading concept** for dual blanket design is 5 layer embossed + 15 layer Dacron ***(aluminized interior surfaces on both blankets)***

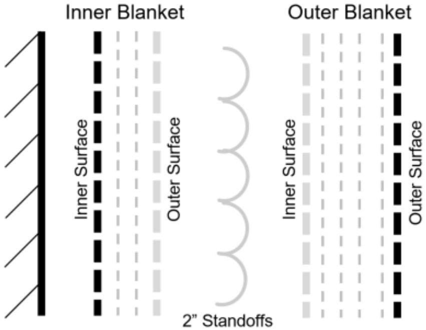
- Innermost and outermost layers were black for all tests to isolate the effect of single vs dual blankets

Baseline → Case 1

Leading concept → Case 4

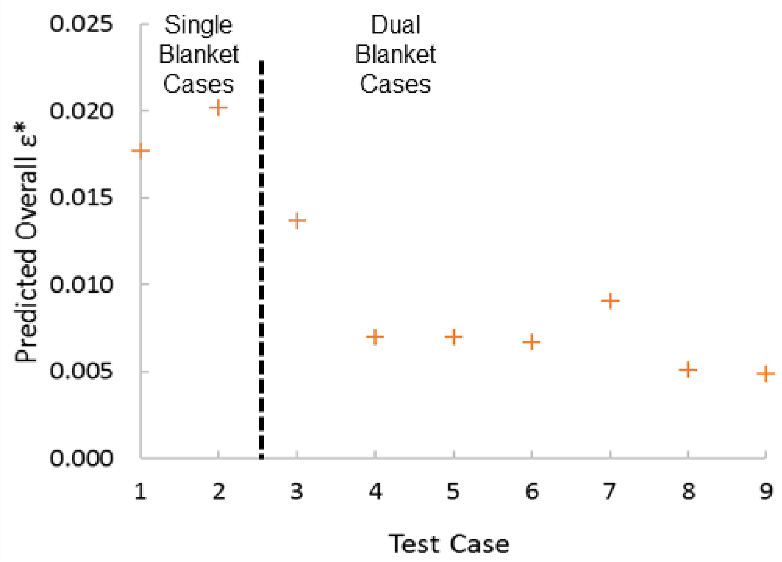
		Inner Blanket				Outer Blanket			
Case	2" Standoffs	Inner Surface	# Layers	Outer Surface	2" Standoffs	Inner Surface	# Layers	Outer Surface	Seam Modifications
1	Yes					CK	20, DAM	CK	
2	Yes					CK	20, DAM	CK	Extra seams
3		CK	5, EAK	CK	Yes	CK	15, DAM	CK	
4		CK	5, EAK	AM	Yes	AM	15, DAM	CK	
5		CK	5, DAM	AM	Yes	AM	15, DAM	CK	
6		CK	5, EAK	AM	Yes	AM	15, DAM	CK	Staggered
7	Yes	CK	5, EAK	AM		AM	15, DAM	CK	Staggered
8		CK	15, EAK	AM	Yes	AM	15, DAM	CK	
9		CK	15, EAK	AM	Yes	AM	15, DAM	CK	Staggered

CK = carbon filled black kapton
AM = aluminized mylar
EAK = embossed aluminized kapton
DAM = Dacron netting and aluminum mylar



Analytical Predictions

- Dual blankets were predicted to have roughly 1/2 the ε* value of baseline single blanket
- ε = 1 for black kapton surfaces (assumed); ε = 0.04 for aluminized surfaces
- Differences in blanket areas were accounted for in each configuration's calculations
- Total ε* values in table are based on external MLI areas for each case

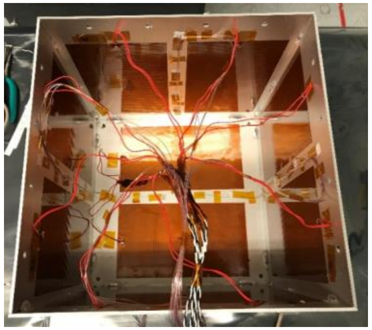


Case	Blanket Scheme	Total ε*
1	20 CK, DAM, CK	**0.0177**
2	20 CK, DAM, CK (extra seams)	**0.0202**
3	5 CK, EAK, CK + 15 CK, DAM, CK	**0.0137**
4	5 CK, EAK, AM + 15 AM, DAM, CK	**0.0070**
5	5 CK, DAM, AM + 15 AM, DAM, CK	**0.0070**
6	5 CK, EAK, AM, 15 AM, DAM, CK (staggered seams)	**0.0067**
7	2" + 5 CK, EAK, CK + 15 CK, DAM, CK (staggered seams)	**0.0091**
8	15 CK, EAK, AM + 15 AM, DAM, CK	**0.0051**
9	15 CK, EAK, AM + 15 AM, DAM, CK (staggered seams)	**0.0049**

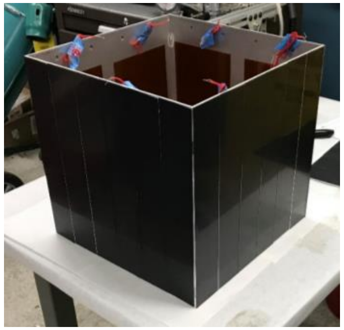
Test Article & Chamber Configuration

Test Article

- 1ft x 1ft x 1ft aluminum cube with 1/8” thick sides
- Qty 2 heaters per side of the cube
- Qty 4 Type E, 36 AWG thermocouples per side of the cube
- Black kapton tape exterior
- Cables exit from center of the bottom face of cube



Test Article (Interior)

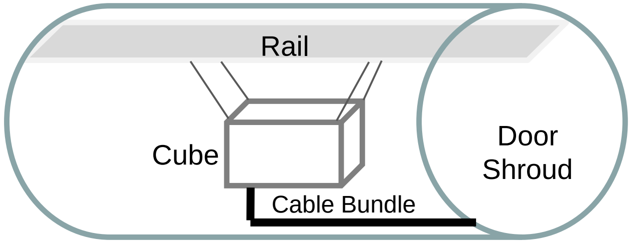


Test Article (Exterior, bottom missing)

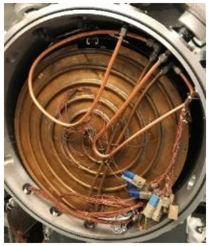
Chamber Configuration

- 2ft x 3ft chamber at ETL (chamber 12)
- Copper door shroud (painted black on interior side)
- Test article suspended in chamber with stainless steel wire attached to a rail

Test article suspended from railing

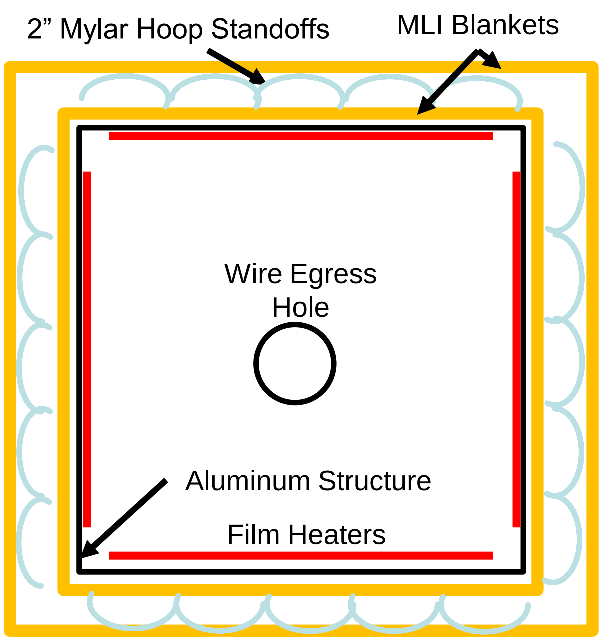


Chamber Schematic

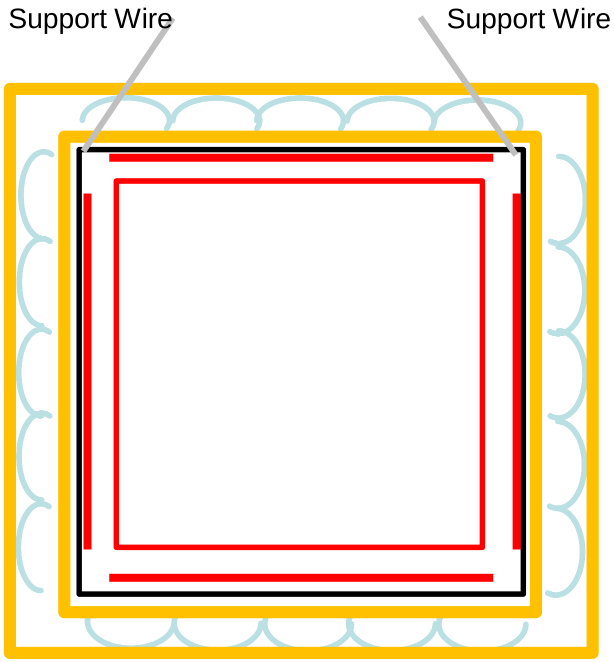


Copper door shroud (opposite side was black)

Test Article Schematic



Top View



Side View

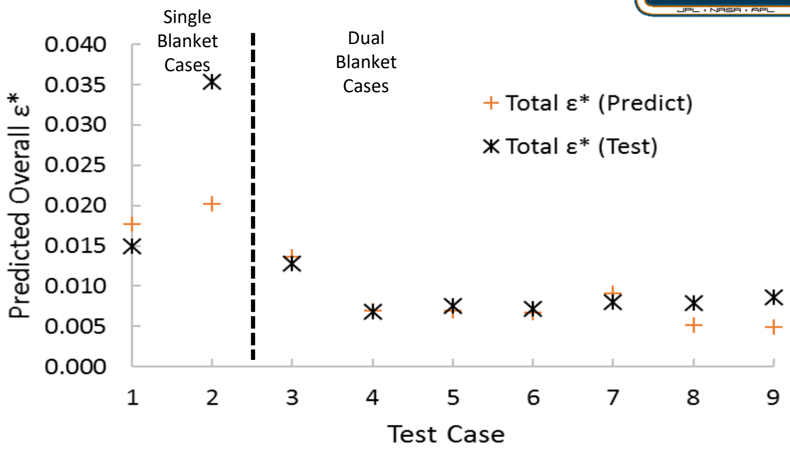
Test Results

- The ε* values from testing were calculated at each of the three test temperatures and averaged in the table below

- **In general, pre-test predictions matched the test results very well**

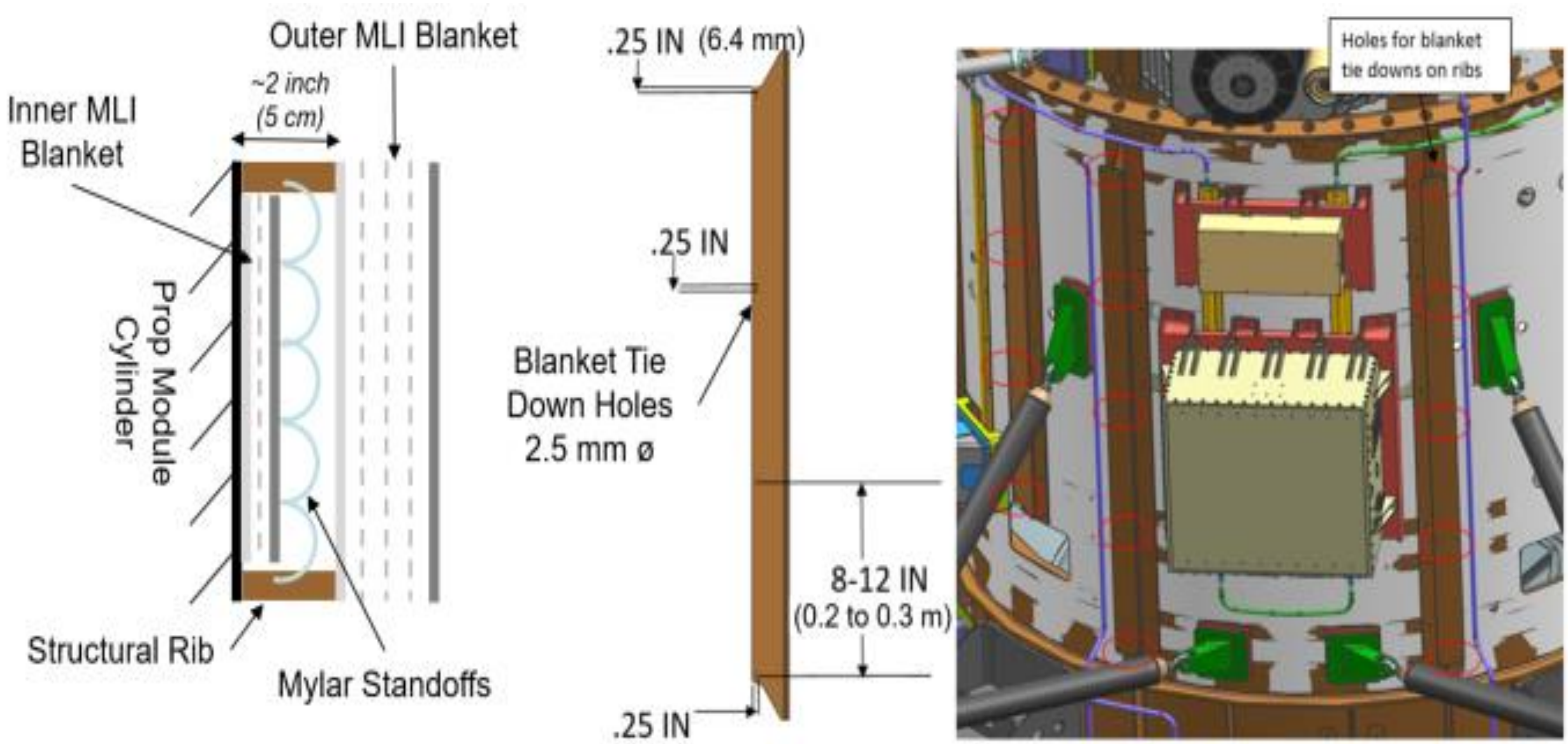
- **Dual blanket schemes had about half the heat loss of the single blanket baseline**
  - Using two 15 layer blankets instead of 5 + 15 layer blankets was not better for performance
  - Staggered seams was not effective and may have been worse for performance
  - Dual blankets contacting each other (case 7) was almost as effective as separating them

- Case 7 is closest to flight configuration (for large blankets) except it did not have engineered separators, hence flight implementation could be have even better performance



	Case	Blanket Scheme	Total Predicted ε*	Total Test ε*	Test/ Predict	Case #/ Baseline (Test)
Baseline	1	20 CK, DAM, CK	0.0177	0.0150	0.85	-
	2	20 CK, DAM, CK (extra seams)	0.0202	0.0354	1.75	2.36
	3	5 CK, EAK, CK + 15 CK, DAM, CK	0.0137	0.0128	0.93	0.85
Leading concept	4	5 CK, EAK, AM + 15 AM, DAM, CK	0.0070	0.0068	0.97	0.45
	5	5 CK, DAM, AM + 15 AM, DAM, CK	0.0070	0.0075	1.07	0.50
	6	5 CK, EAK, AM, 15 AM, DAM, CK (staggered seams)	0.0067	0.0072	1.07	0.48
Leading concept	7	2" + [CK, 5EAK+ AM] + [AM, 15 DAM, CK] (staggered seams)	0.0091	0.0080	0.88	0.53
	8	15 CK, EAK, AM + 15 AM, DAM, CK	0.0051	0.0079	1.55	0.53
	9	15 CK, EAK, AM + 15 AM, DAM, CK (staggered seams)	0.0049	0.0086	1.76	0.57

Proposed Implementation of Dual Blanket Scheme for Europa Clipper



Blanketing Schematic

Structural Rib and Blanket Tie Down Scheme

CAD Snapshot of Prop Module

Future Work

- Conduct a ½ height scale test with the Propulsion Module Simulator cylinder (in 3m, 10’ chamber)
  - <u>Include feedthroughs, electronics box simulators, and more</u>

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

Full Height
Prop Module

1/2 Height
Prop Module

Summary

- **MLI performance is a driver of the power required for Europa missions**

- **We have investigated different methods for improving performance**
  - Dual stack MLI concept
  - Modified seams implementation
  - Embossed vs Dacron construction

- **Dual blankets schemes had roughly half the ε* values of the baseline blanket design with negligible change to mass**

Conclusion

- ***A dual blanket MLI scheme has the potential to save roughly 50% of the current thermal power of the prop module cylinder with little to no mass impacts***

- **Future testing is planned to**
  - Validate results of this development test for more complex flight like configurations
  - Determine realistic range of ε* values to use for thermal modeling
  - Choose final flight blanket design

Acknowledgements

- This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

- Government sponsorship acknowledged

Questions & Answers?