Application of Risk Informed Decision Making to a Highly Reliable Three-Dimensionally Woven Thermal Protection System for Mars Sample Return

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January 7th, 2020

Outline

- Context
  - Mars Sample Return
  - Three-dimensional weaving
  - Risk-Informed Decision Making
- Risk Elements
  - Mission Assurance
  - Technical Development
  - Cost
  - Schedule
- Findings for the Study
- Observations on RIDM

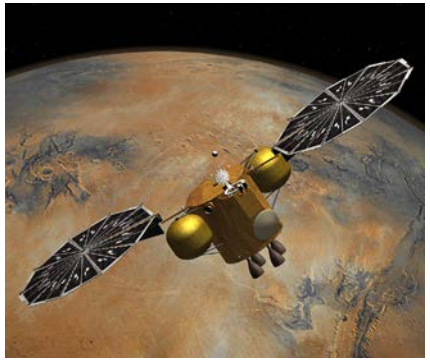
Mars Sample Return Campaign Overview

Collect rock and dust sample on Mars and return them Earth

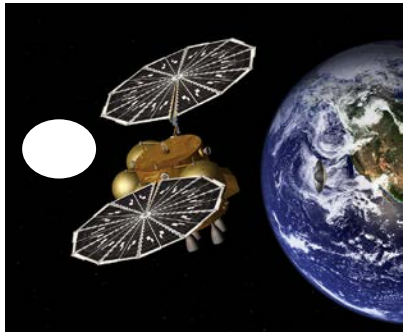
Mars 2020/24 Rovers collect samples

Mars Ascent Vehicle (MAV) lifts samples into orbit

Earth Return Orbiter (ERO) collects samples from MAV



Earth Entry Vehicle (EEV) released from ERO to enter atmosphere



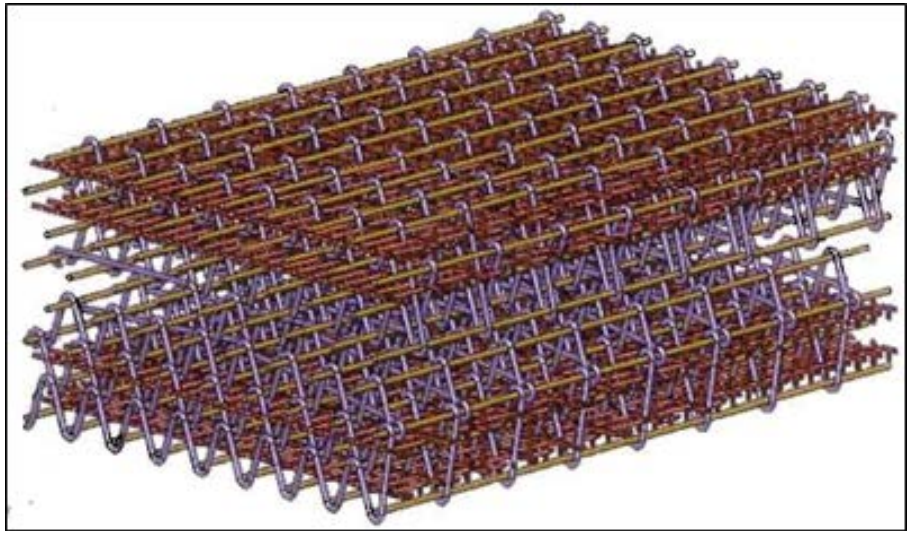
Earth Entry Vehicle (EEV) lands on Earth

[1]

MSR EEV is expected to carry unprecedented reliability requirements for planetary protection, which flow down to all sub-systems, including the thermal protection system (TPS)

Three-Dimensionally Woven Thermal Protection System

- Mechanical interconnections between layers provides high interlaminar strength
- Mitigates generation of in-plane cracks due to high temperature gradients
- Material properties tailored in through-the thickness direction



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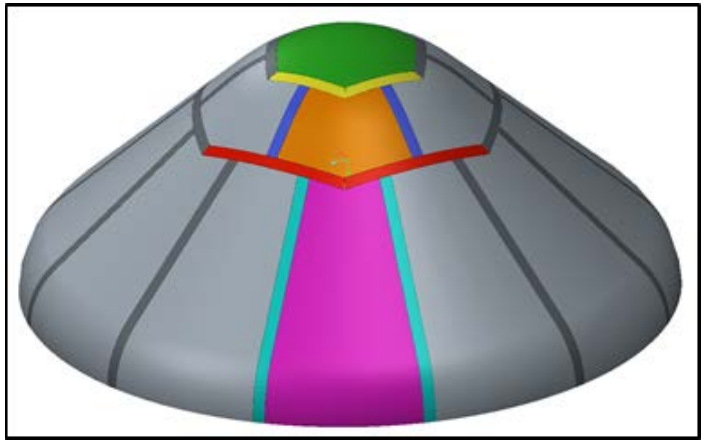
3D Woven Variants

- Heatshield for Extreme Environments Technology (HEEET)
- HEEET 6k Recession Layer
- Insulation Layer Only Tiled
- 3D Woven Single Piece
- Insulating Layer Only Single Piece
- Dry Woven Single Piece
- 3D Carbon-Carbon



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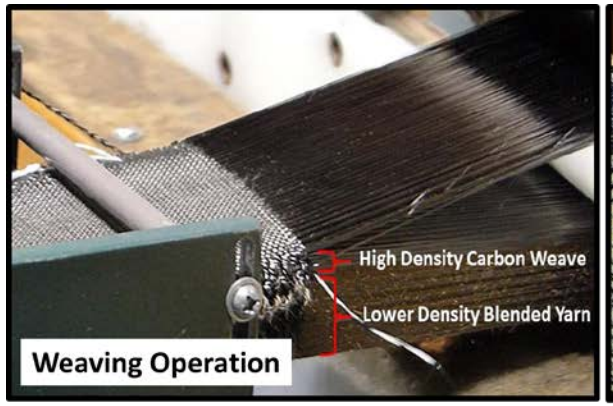
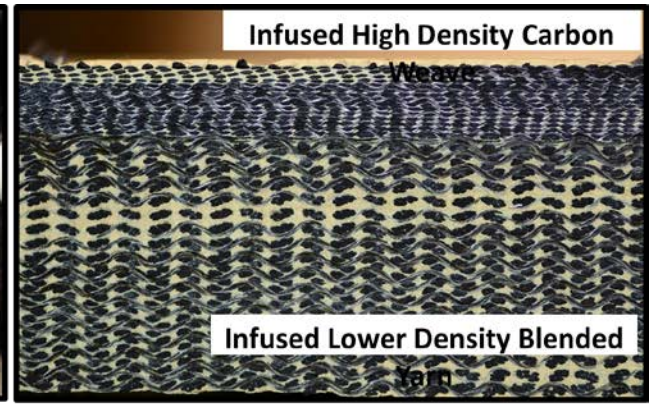
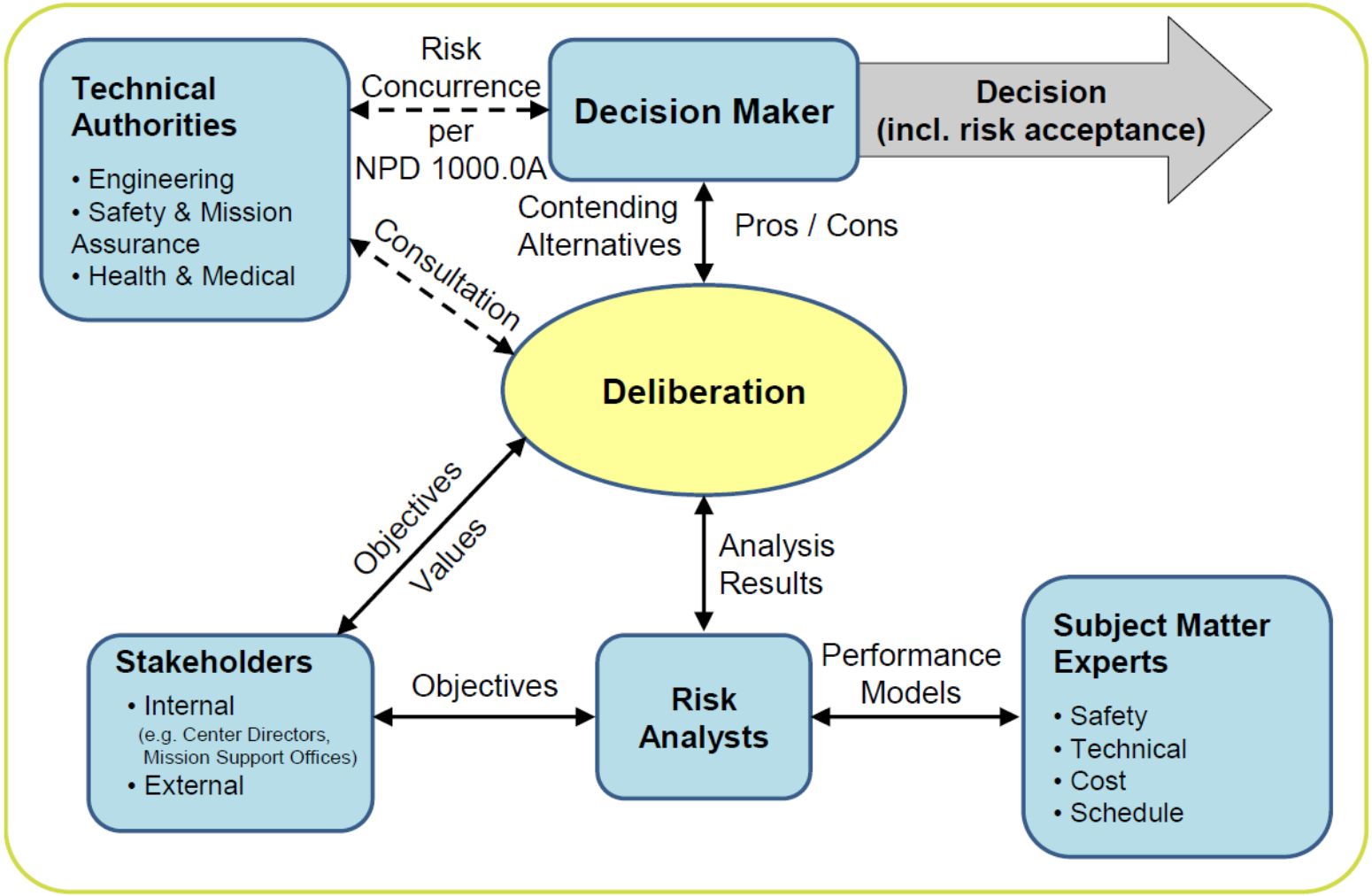




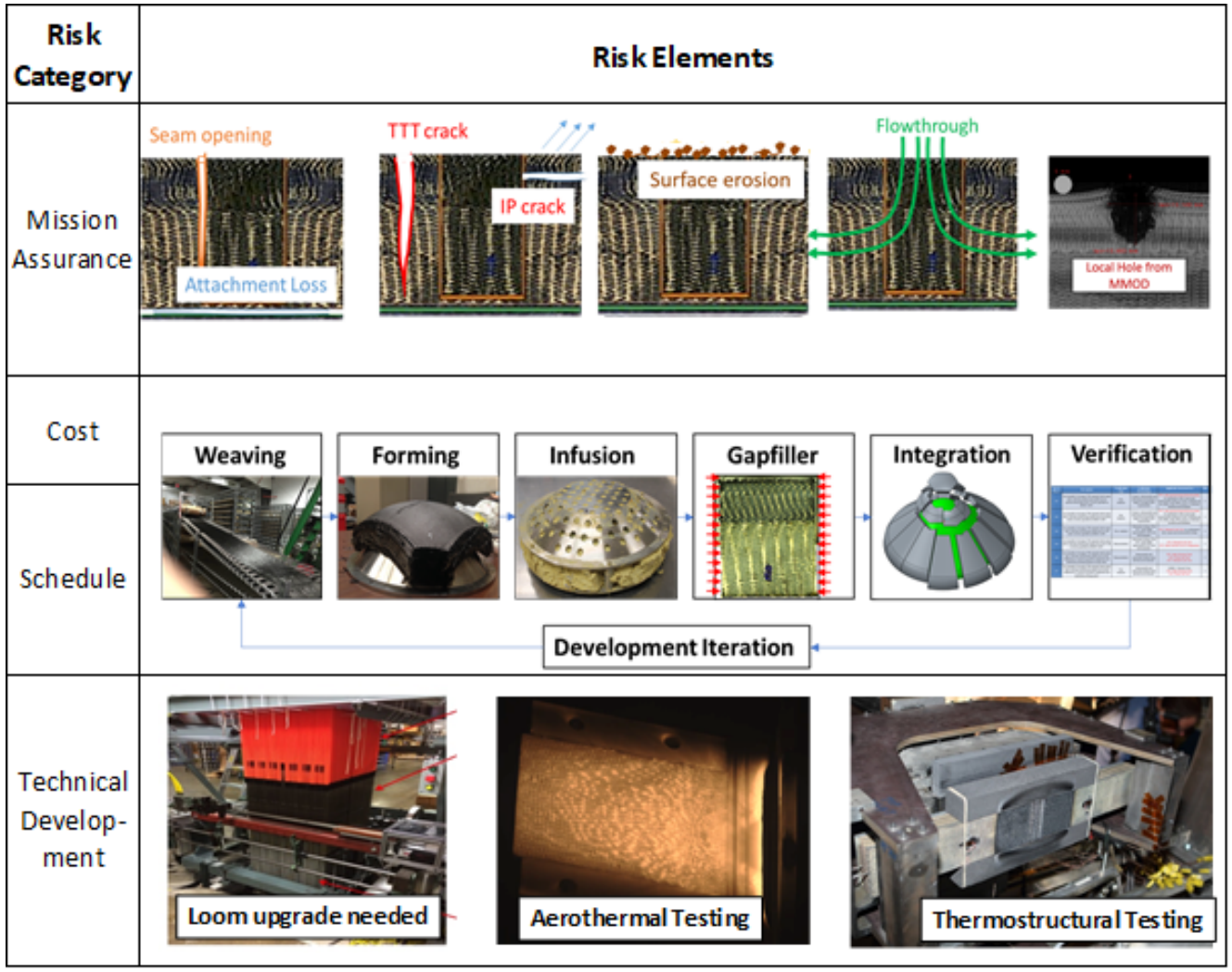
NASA Risk Informed Decision Making

- Deliberative process for making robust decisions
- Employed for major architecture and design decisions characterized by high stakes and uncertainty



[3]

Summary of Risk Elements



Summary of Risk Elements

- Mission Assurance
  - Residual risk of failure occurring during mission, must account for both nominal and off-nominal performance (e.g. MMOD strike)
- Technical Development
  - Risk that the required technical maturity will not be achieved on schedule, including both system certification and manufacturing capabilities
- Schedule
  - Risk of failure to meet schedule requirements
- Cost
  - Risk of failure to meet budget requirements

Mission Assurance

Risk		Trade Space						
Mission Assurance		HEEET	6K Recession Layer Tiled	Insulating Layer Only Tiled	3D Woven Single Piece	Dry Woven Single Piece	Insulating Layer Only Single Piece	3D C-C Single Piece
Failure Mode	Load Case							
Local Hole	MMOD, Shock, Integration	2	2	1	2	1	1	1
Surface Erosion (Mechanical)	Entry	2	1	1	3	1	1	3
Seam Opening	Cold Soak, Entry	2	1	2	3	3	3	3
Flow Through	Entry	2	2	1	3	1	2	3
Cracking	Cold Soak, Shock	3	3	3	3	3	3	3
Attachment Failure	Cold Soak, Entry	2	2	2	2	2	2	1
Shape Stability	Entry	2	2	2	2	2	2	1

Rating Scale	
0	Inadequate
1	Marginal
2	Adequate Margins
3	No Credible Risk

Technical Development

Risk	Trade Space						
Technical Development	HEEET	6K Recession Layer Tiled	Insulating Layer Only Tiled	3D Woven Single Piece	Dry Woven Single Piece	Insulating Layer Only Single Piece	3D C-C Single Piece
Weaving 60" Width	3	3	3	1	1	2	1
Areal Property Variation in Formed Part	3	3	3	2	2	2	1
Attachment to Substrate	2	2	2	2	2	2	1
Certifiability	1	1	1	2	2	2	1

Rating Scale	
0	Inadequate
1	Marginal
2	Adequate Margins
3	No Credible Risk

Cost

Relative Cost Comparison

System Cost		HEEET MSR		3D Woven Single Piece		Insulating Layer Only Single Piece	
Cost Categories	**Detail**	**Cost (Normalized Relative to Baseline HEEET)**	**Uncertainty (±)**	**Cost (Normalized Relative to Baseline HEEET)**	**Uncertainty (±)**	**Cost (Normalized Relative to Baseline HEEET)**	**Uncertainty (±)**
Dev. Cost	Weave Dev.	0	-	4	2	4	2
	Design	1	-	2	1	2	1
	Components + Integration	2.5	-	2.5	-	2.5	-
	Testing	5	1	4	1	4	1
Mfg. and Integration	Weave	12	2	6	2	6	2
	Forming + Infusion + Machining						
	Carrier + Integration						
Property Testing		0	-	1	-	1	-
Certification		10	3	5	2	5	2
Documentation		0	-	0	-	0	-
Project Mgmt. + Systems Eng.		6	-	5	-	5	-
Total		**36.5**	**6**	**29.5**	**8**	**29.5**	**8**

Schedule

Relative Schedule Comparison

HEEET			3D Woven Single Piece		
Event Description	**Time (months)**	**Uncertainty (months)**	**Event Description**	**Time (months)**	**Uncertainty (months)**
Weave Procurement	6	-	Weave Procurement	6	-
Raw Material Purchase/Processing, Loom Startup and Verification	7	1	Loom Development (from construction to startup and verification)	24	6
Time to weave ESH Dev Coupons, MDU, and flight material	9	2.25	Time to weave flight material (no MDU/ESH)	3	0.75
Form last batch of flight material	1	-	Form flight material	3	-
Infuse last batch of flight material	1.5	0.5	Infuse flight material	2	0.5
Machine last batch of flight material	4	-	Machine flight material	2	-
Integration	6	-	Integration	1	-
CT Scan	2	1	CT Scan	1	1
Certification	6	3	Certification	6	3
Total	**42.5**	**7.75**	**Total**	**48**	**11.25**

Summary for MSR EEV TPS

- An risk analysis framework has been developed to assess relative risk between different 3D woven TPS alternatives for MSR EEV, applicable to the information state of the design process
- 3D Woven Single Piece carries the lowest mission assurance risk of all options, due to lack of seams and certification experience from HEEET development
- However, a single piece designs carries higher uncertainty regarding cost, schedule, and technical development, largely due to manufacturing concerns

Observations on RIDM Application

- The RIDM procedural framework for eliciting expert opinion brought to light some unexpected results
- The primary difficulty encountered was quantitative representation of uncertainty given the low information state of the design process
- As requirements are refined and additional data becomes available, increasingly quantitative analysis tools can be used to support more accurate risk assessment and uncertainty characterization

Questions?

References

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[2] Gage, P. J., et al, “Overview of Heatshield for Extreme Entry Environments,” URL: https://discovery.larc.nasa.gov/discovery/pdf_files/25_HEEET_Technology_Overview_(HEEET-1002).pdf.

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[5] Tran, H. K., Henlines, W. D., Hsu, M. –t. s., Rasky, D. J., Riccitiello, S. R., NASA Ames Research Center, Moffett Field, CA, U.S. Patent Application for "Low-density resin impregnated ceramic article having an average density of 0.15 to 0.40 g/cc" United States of America Patent 5,536,562, 14 March 1994.

[6] National Aeronautics and Space Administration, NASA Schedule Management Handbook, Washington DC: National Aeronautics and Space Administration, 2010.

[7] Needels, J., and Gage, P. J., Technical Basis for Deliberation: Highly Reliable 3D Woven Thermal Protection System for Mars Sample Return, 2018.

[8] NPR 8000.4B Agency Risk Management Procedural Requirements, National Aeronautics and Space Administration, Washington, DC, 2017.