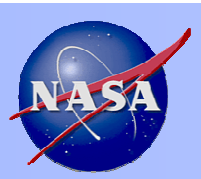
Note for LaRC Reviewers

This presentation is based on the tools and models developed and documented in NASA-TM-2014-218507.



Earth Entry Vehicle Design for Sample Return Missions Using M-SAPE

Jamshid Samareh
NASA

IPPW-12 Jun 15-19, 2015

(See NASA-TM-2014-218507 for Details)

Multi-Mission System Analysis for Planetary EDL (M-SAPE)

M-SAPE Contributors

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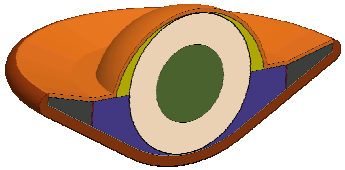
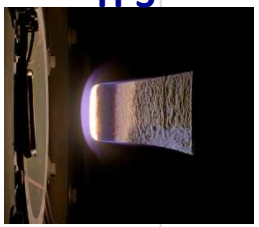
M-SAPE
(Summary)

- **What:** It is an integrated system analysis tool for analyzing and sizing of Earth entry vehicles for sample return mission applications.
- **Acronym:** **M**ulti-Mission Earth Entry Vehicle **S**ystem **A**nalysis for **P**lanetary **EDL**
- **Who:** LaRC, ARC, Virginia Tech, & Old Dominion University.
- **Disciplines:** Aero, aerothermal, flight mechanics, impact analysis, structure, thermal soak, TPS, …
- **Funding:** The In-Space Propulsion Technology Program (ISPT) & ESM.
- **Status?** Version 1 is complete.
- **Future Plan:** Currently developing a similar system for human Mars mission.

M-SAPE
(Earth Entry Vehicle EDL Environment)



TPS



Altitude

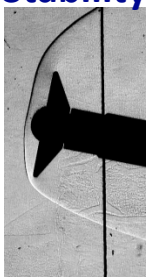
Max Heat Rate

Max Deceleration

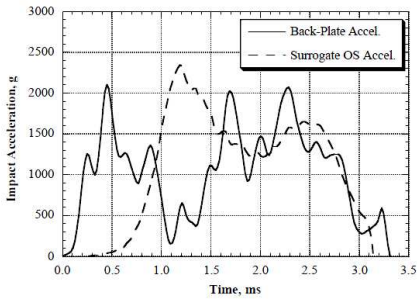
Velocity

time

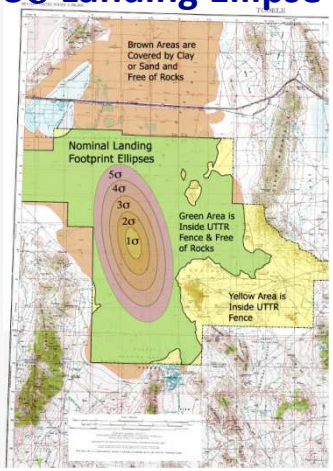
Aerodynamic Stability



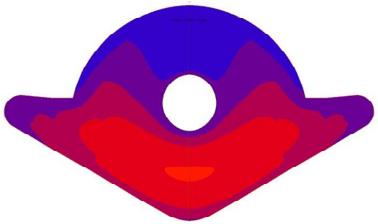
Impact



3σ Landing Ellipse



Thermal Soak



M-SAPE
(Disciplines)

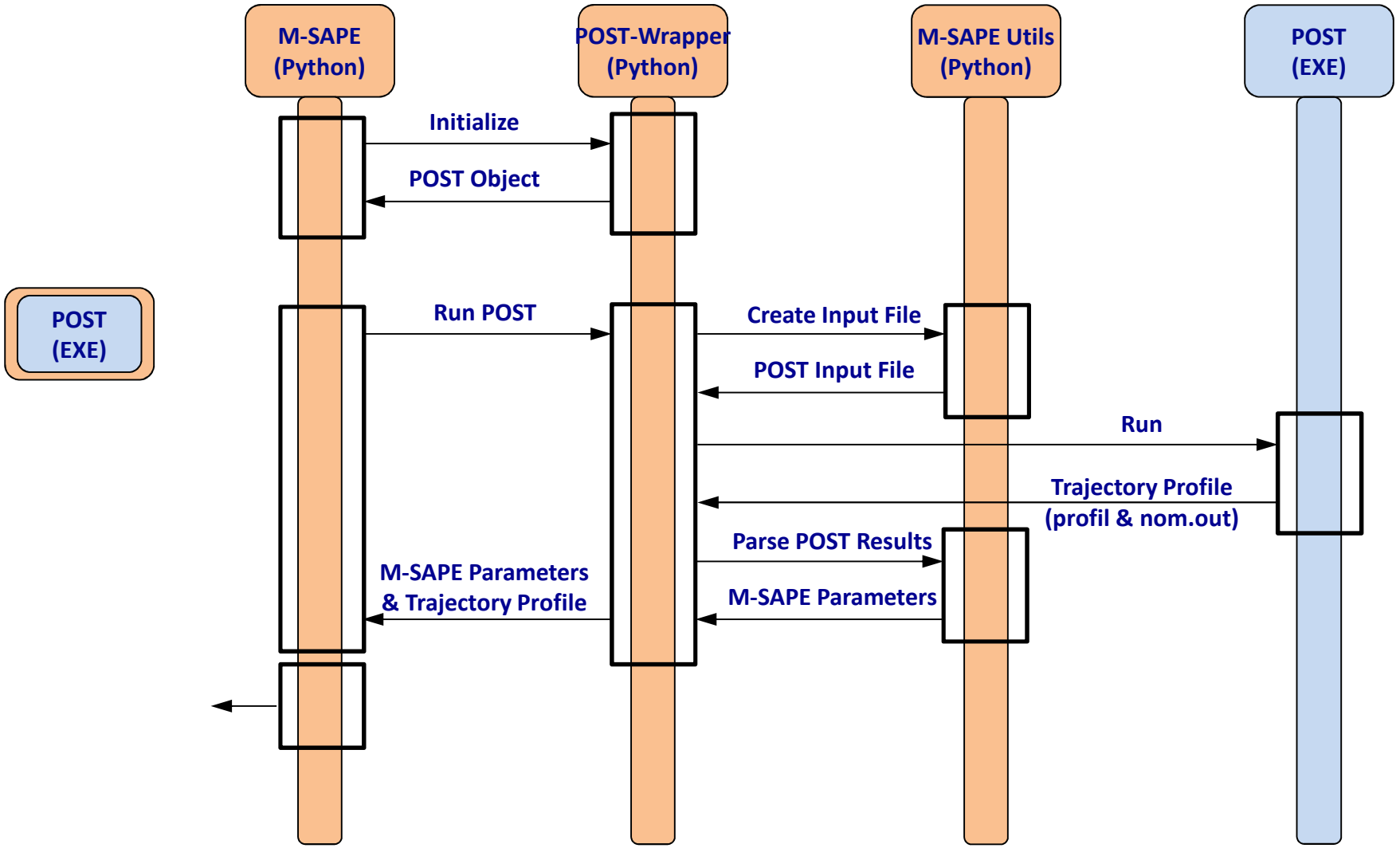
“The whole is greater than the sum of its parts.”

Design or Dependency Structure Matrix for MMEEV

	Database	Geometry Module	Mass Sizing & Packing	Flight Mechanics	Aerodynamics	Aerothermodynamics	TPS Sizing	Structural Analysis	Impact Analysis	Thermal Soak
Database	**Database**	Geometry Variables	Packing Arrangements	Entry Conditions						
Geometry Module	Geometry Parameters	**Geometry**	OML	OML	OML	OML	OML	OML	OML	OML
Mass Sizing	Overall Mass & Size	Overall Mass & Size	**Mass Sizing & Packing**	Mass				Mass	Mass	
Flight Mechanics	Flight Conditions			**Flight Mechanics**	Flight Conditions	Flight Conditions		Entry Loads	Terminal Velocity	
Aerodynamics	Aerodynamic Coefficients			Aerodynamic Coefficients	**Aerodynamics**			Aerodynamic Loads		
Aerothermodynamics	Thermal Constraints			Thermal Constraints		**Aerothermodynamics**	Thermal Environment		Thermal Environment	Thermal Environment
TPS Sizing	TPS Mass		TPS Mass				**TPS Sizing**	Bondline Conditions	Bondline Conditions	TPS Interface Condition
Structural Analysis	Structural Mass		Structural Mass		Aeroelastic Displacements			**Structural Analysis**		
Impact Analysis	Energy Absorber Stroke	Energy Absorber Stroke	Energy Absorber Mass						**Impact Analysis**	Impact Displacements
Thermal Soak	Thermal Soak Constraints							Temperature Field	Temperature Field	**Thermal Soak**
Approach	Flat Files & SQL	Scripts & CAD	Scripts & CAD	3DOF	Experimental Data & CFD	SG, TS, & DPLR/LAURA	FIAT	Eng. Approx. & NASTRAN	Eng. Approx. & LS-DYNA	Marc 2D-Axisymmetric

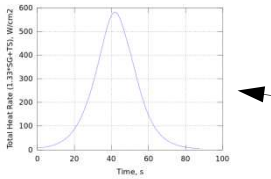
Columns are inputs, and Rows are outputs

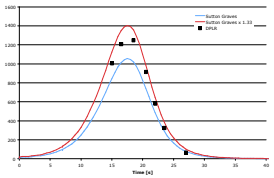
M-SAPE
(Integration, UML Sequence Diagram)

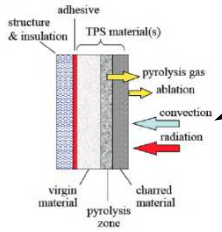


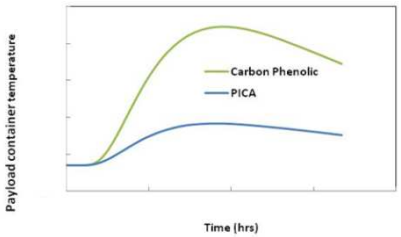
M-SAPE

(Integration, Mission Dependent)









POST (EXE)

Vehicle (Matlab)

Aerotherm (Python)

TPS (Python)

Th. Soak (Python)

Database (Python)

Report (Python)

Integration (Python)

3DOF (EXE)

FIAT (EXE)

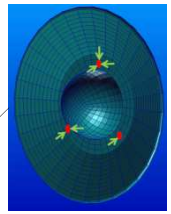
Unlatch (EXE)

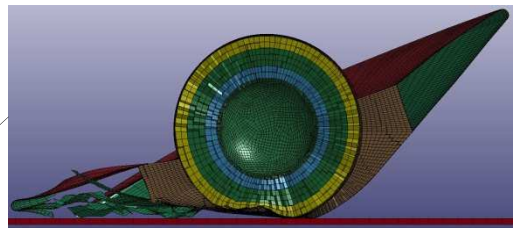
NASTRAN (EXE)

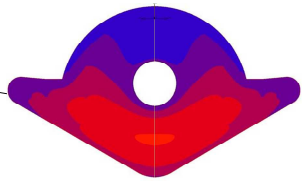
LS-DYNA (EXE)

Marc (EXE)

Para. Aero (?)

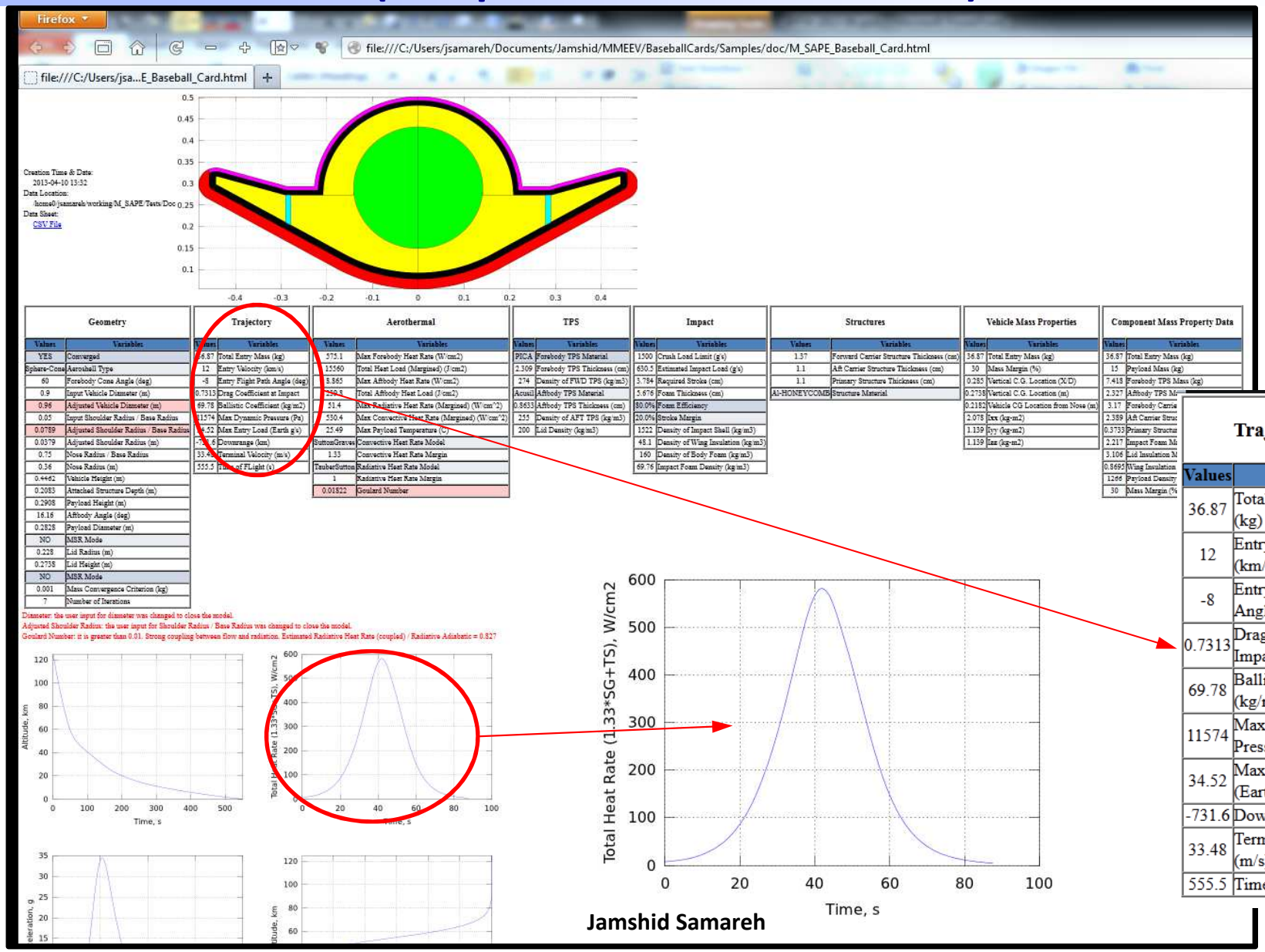






M-SAPE

(Sample Result Baseball Card)

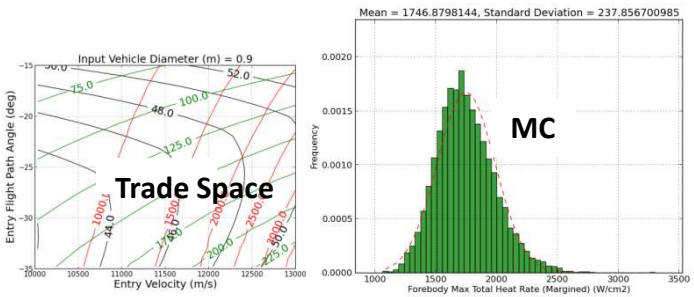


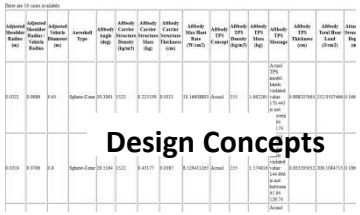
Trajectory

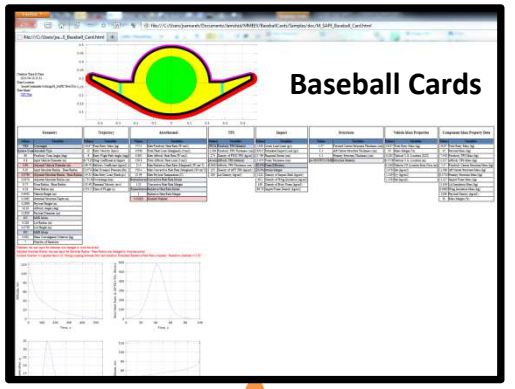
Values	Variables
36.87	Total Entry Mass (kg)
12	Entry Velocity (km/s)
-8	Entry Flight Path Angle (deg)
0.7313	Drag Coefficient at Impact
69.78	Ballistic Coefficient (kg/m2)
11574	Max Dynamic Pressure (Pa)
34.52	Max Entry Load (Earth g's)
-731.6	Downrange (km)
33.48	Terminal Velocity (m/s)
555.5	Time of FLight (s)

M-SAPE
(Web Portal)

Langley Firewall

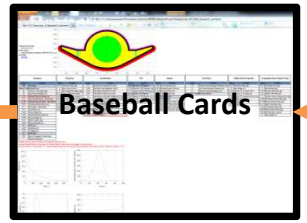




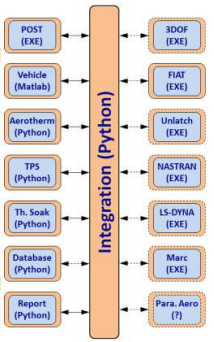


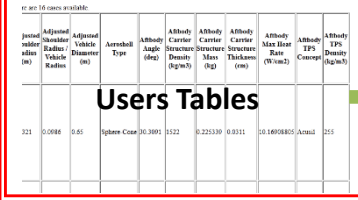
Web Portal

User Space



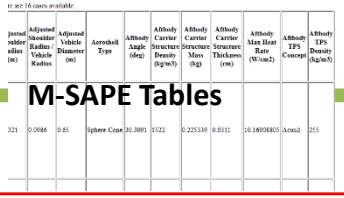
Run M-SAPE





Users Tables

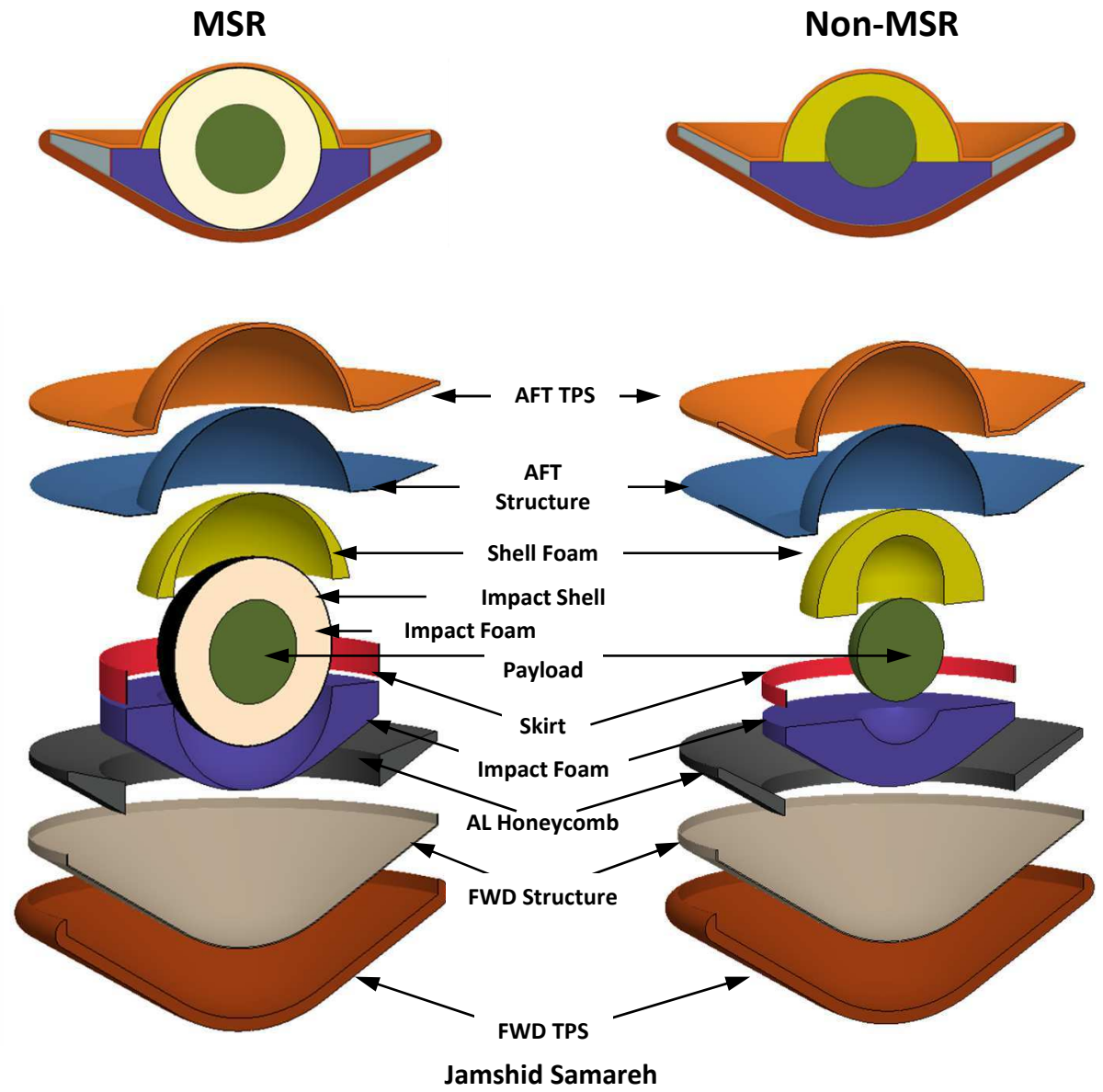
Upload



M-SAPE Tables

Offline

Vehicle Geometry



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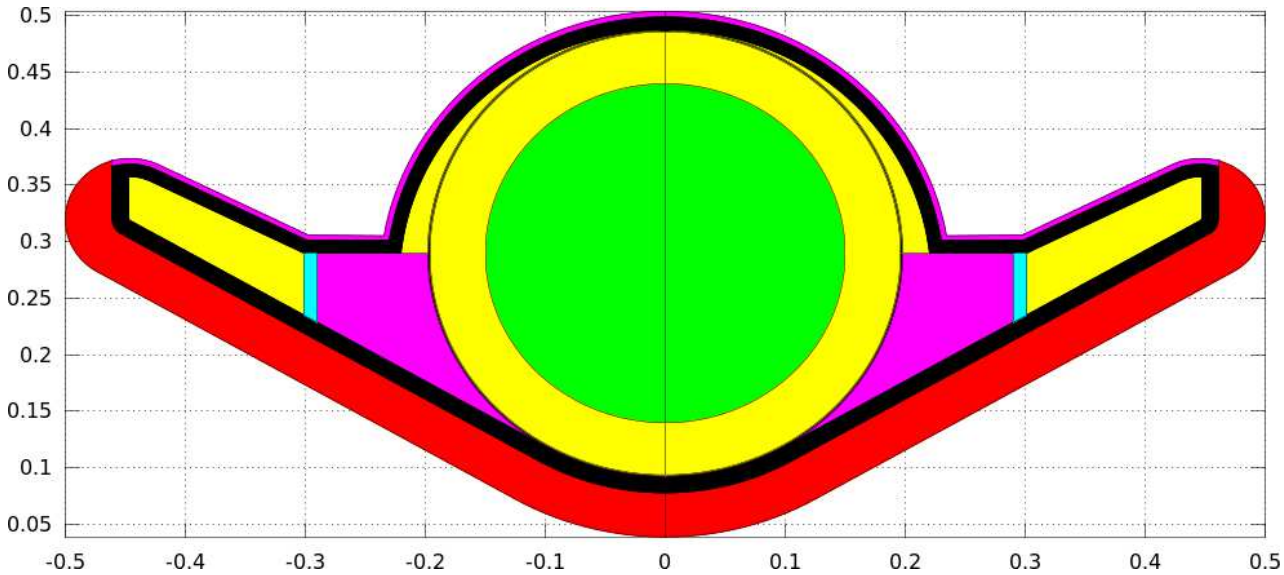
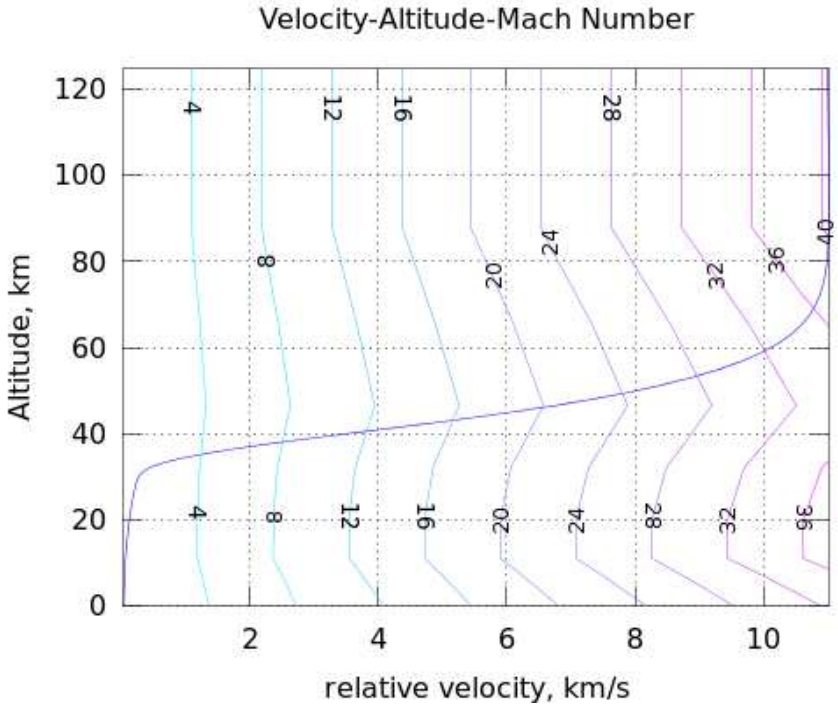
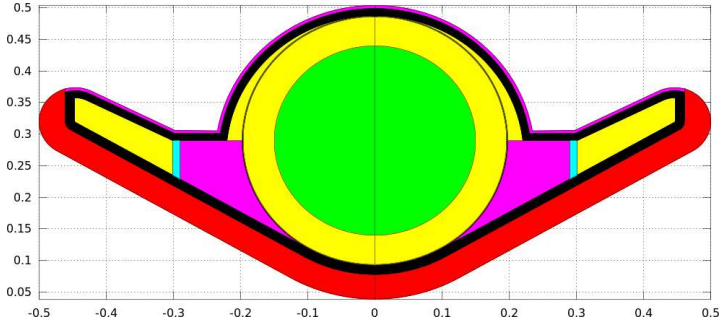
Vehicle Sensitivities
(Sample Baseline Model)

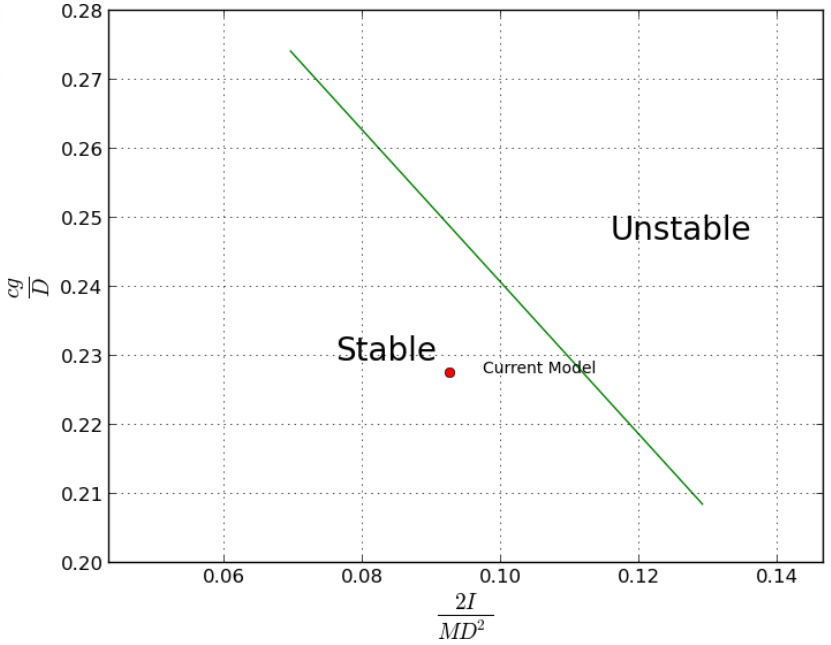
Parameters	Values
Crush Load Limit (Earth g's)	3000
Entry Flight Path Angle (deg)	-25
Entry Velocity (m/s)	11000
Payload Diameter (m)	0.3
Payload Mass (kg)	6
Forebody TPS Concept	PICA
Input Vehicle Diameter (m)	1



Vehicle Sensitivities
(Sample Baseline Model)



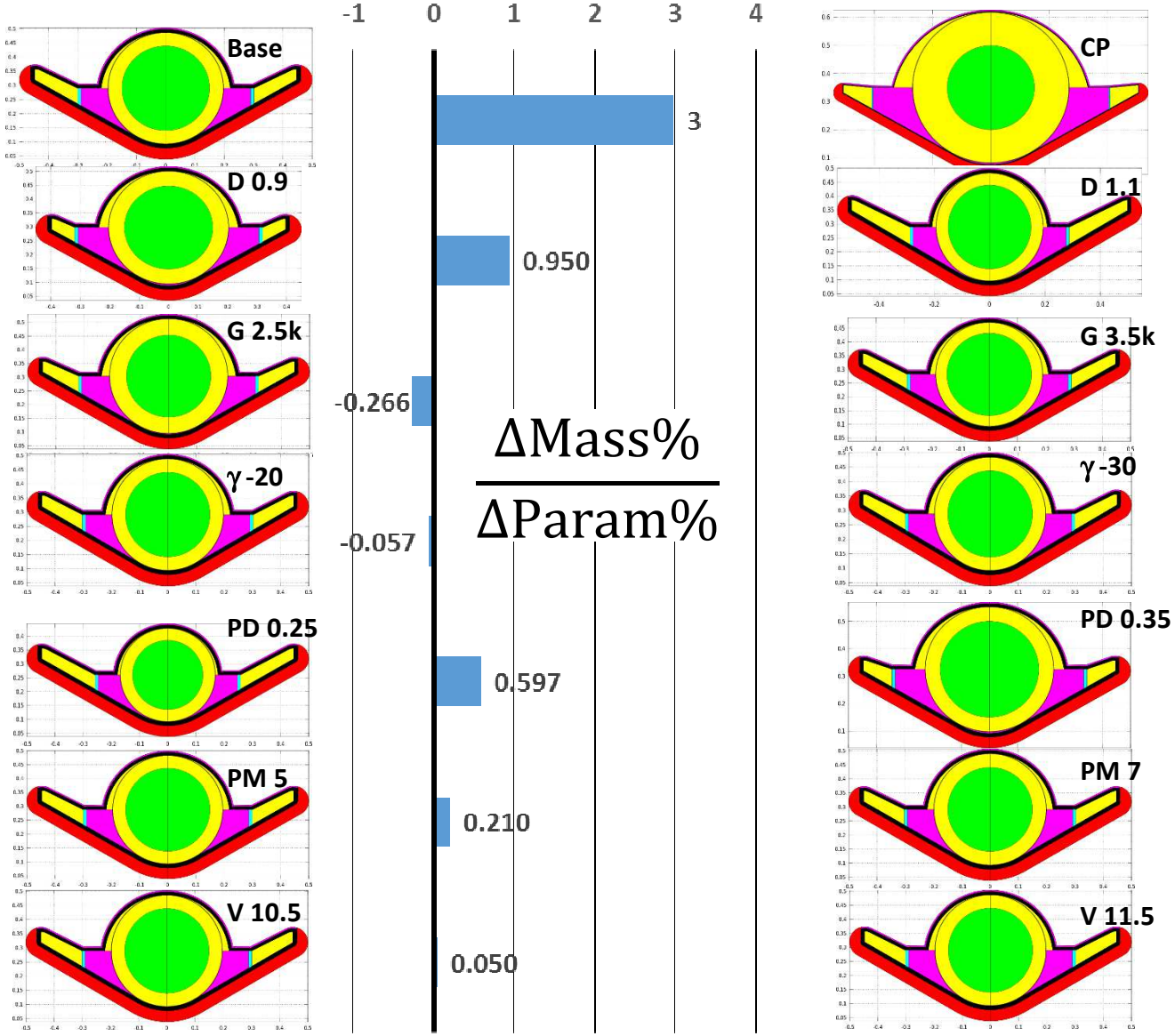




Vehicle Sensitivities (Cont.)

Case Name	D-1.0-B	CP	ΔDiameter		ΔCrush Load		ΔFlight Path Angle		ΔPayload Diameter		ΔPayload Mass		ΔEntry Velocity	
Vehicle Diameter (m)	1	1.08	0.9	1.1	1	1	1	1	1	1	1	1	1	1
Crush Load Limit (Earth k g's)	3	3	3	3	2.5	3.5	3	3	3	3	3	3	3	3
Entry FPA (deg)	-25	-25	-25	-25	-25	-25	-20	-30	-25	-25	-25	-25	-25	-25
Payload Diameter (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.25	0.35	0.3	0.3	0.3	0.3
Payload Mass (kg)	6	6	6	6	6	6	6	6	6	6	5	7	6	6
Entry Velocity (km/s)	11	11	11	11	11	11	11	11	11	11	11	11	10.5	11.5
Aerodynamic Stability	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Max Heat Rate (W/cm2)	918	1452	1027	840	944	903	826	995	879	972	901	934	776	1107
Forebody TPS Mass (kg)	13.9	64.0	11.5	16.5	14.0	13.8	14.3	13.6	13.8	14.1	13.8	13.9	13.8	14.0
Total Heat Load (kJ/cm2)	7.6	12.5	8.5	6.9	7.8	7.5	8.4	7.0	7.2	8.1	7.4	7.7	6.8	8.5
Max Payload Temp. (C)	18	45	17	18	18	18	18	17	18	18	18	18	18	18
Total Entry Mass (kg)	36.5	108.6	33.6	40.6	38.6	35.4	37.0	36.2	33.6	40.9	35.2	37.8	36.4	36.6
ΔMass% / ΔP%		3		0.95		-0.27		-0.06		0.60		0.21		0.05

Vehicle Sensitivities (Cont.)



Concluding Remarks

- The current version of M-SAPE was used to perform system analysis and sensitivity analysis of an Earth entry vehicle for sample return missions.
- For the sample baseline design:
  - Selection of TPS concept has the most impact on the design.
  - Vehicle size may be dictated by the required aerodynamic stability.
  - Higher payload diameter and mass result in heavier vehicles.
  - Lower impact g-load would result in heavier vehicles.
  - Entry flight path angle and velocity have less impact on mass compared to other parameters.