Development Of FIAT-Based Parametric Thermal Protection System Mass Estimating Relationships For NASA's Multi-Mission Earth Entry Concept

Steven Sepka[1], Jamshid Samareh[2], and Robert Maddock[2]
[1] ERC/NASA Ames Research Center, Moffett Field, California
[2] NASA Langley Research Center, Hampton, Virginia

Introduction and Objective

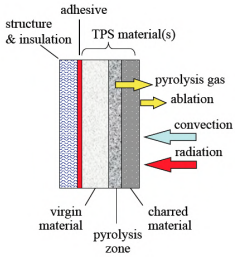
•As part of NASA's In-Space Propulsion Technology (ISPT) program, an integrated tool called the "Multi Mission System Analysis for Planetary Entry Descent and Landing" or M-SAPE tool is being developed

•Part of M-SAPE's evolution required the development of mass estimating relationships (MERs) to determine the vehicle's required Thermal Protection System (TPS) for safe Earth entry

•The objective of the current work is to develop MERs using FIAT-based correlations with as high an accuracy to FIAT prediction as possible for 840 different trajectories

•MERs for the vehicle forebody are the ablators PICA and Carbon Phenolic atop ACC, and for the backshell are the insulators SIRCA, Acusil II, SLA-561V, and LI-900.

•The MERs are accurate to FIAT prediction between 7 to 15% at one standard deviation



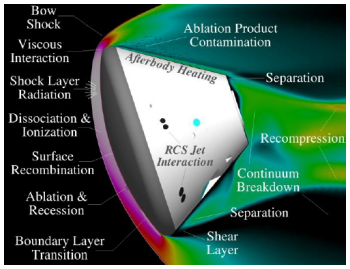
MER Constraints

•No margins were added to the thickness

•For the forebody ablators,15% of the trajectories were so mild as to have little or no material recession and were therefore discarded

•A maximum FIAT-predicted TPS thickness was selected to keep as high a MER accuracy as possible

•It should be emphasized that the useful range of the MERs is not the TPS thickness manufacturability range, which can be manufactured to a much higher thickness



Flight Trajectory Space

Flight Trajectory Parameter	Range of Values	Resolution
Entry Velocity [km/s]	10-16	1
Entry Flight Path Angle [abs. deg.]	5-25	5
Ballistic Coefficient [kg/m^2]	41.95 – 128.74	15.5 (max)
Total number of trajectories	840	-

Vehicle Geometry

	min	max
Nose Radius [m]	0.352	0.352
Vehicle Diameter [m]	0.75	2.25
Vehicle Mass [kg]	16.31	158.7
Payload Mass [kg]	5	30

FIAT Modeling

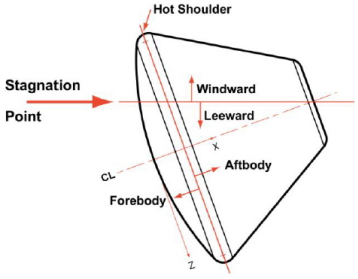
•The maximum temperature at the bottom face of the top material was 250°C

•An adiabatic back face of the material stack up

•A surrounding environment temperature of 21.3°C (for radiation from the spacecraft surface)

•1D planar geometry

•FIAT v2.6.1



Range of Predicted Environments

	Forebody	Backshell
Maximum heat flux [W/cm^2]	151 – 3767	2.3 – 58.1
Heat Load [J/cm^2]	3855 – 34453	59.4 – 531.0
Maximum pressure, atm	0.03 – 3.182	0.005 – 3.182

The predicted environments are flight conditions to which the TPS material has not been tested, so care must be used when applying the MER for a given flight condition

Results and Future Work

	PICA	CP/ACC	SIRCA	Acusil II	LI-900	SLA-561V
Recession [cm]	0.47 – 3.62	0.46 – 2.71	none	none	none	none
Accuracy to FIAT (one SD)	9.7%	8.6%	7.5%	6.6%	7.2	16.1%
Largest possible underprediction (%of FIAT)	0.49	0.75	0.85	0.88	0.85	0.61
MER thickness range [cm]	1.92-4.44	1.24-4.30	0.39-1.33	0.40-1.67	0.515-2.552	0.31-1.15
Thickness [cm] =	$1.993\left(HL^{0.105}\times EFPA^{0.3455}\right)$	$2.3667\left(HL^{0.1070}\times EFPA^{0.3745}\right)$	$0.6597\left(\frac{HL}{V^2}\right)^{0.5083}$	$0.8159\left(\frac{HL}{V^2}\right)^{0.5886}$	$0.7921\left[q_{max}^{0.2105}\times\left(\frac{HL}{V^2}\right)^{0.5783}\right]$	$0.5189\left(\frac{HL}{V^2}\right)^{0.4078}$

HL = heat load, J/cm^2
EFPA = entry flight path angle, absolute degrees
qmax = peak heat flux, W/cm^2
V = entry velocity, km/s

•MERs have been developed for TPS forebody and backshell

•The MERs are accurate to within 16% of FIAT prediction

•The MERs are only valid for a well-defined predicted thickness range

•The trajectory space to develop the MERs considers flight conditions to which the TPS material has not been tested, so care must be used when applying the MER for a given flight condition

•TPS materials can be manufactured to much a much greater thickness than the MER applicability range

•Future work would be in the development of MERs for additional material stackups and to update existing MERS with an expanded flight trajectory space