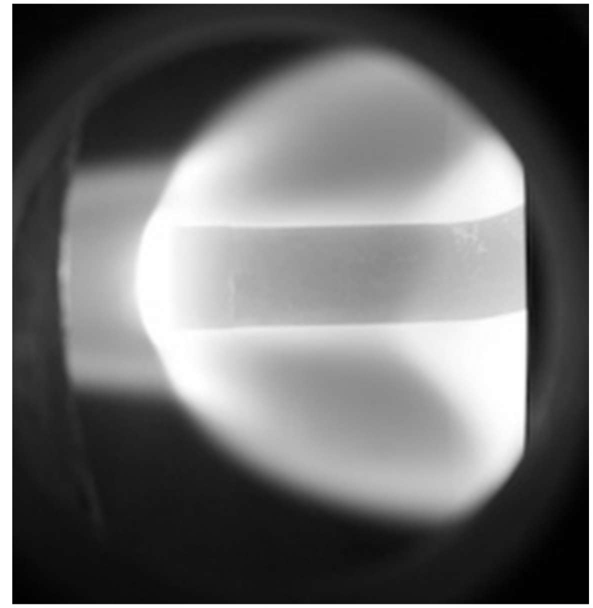
Thermal Protection System Aerothermal Screening Tests in the HYMETS Facility

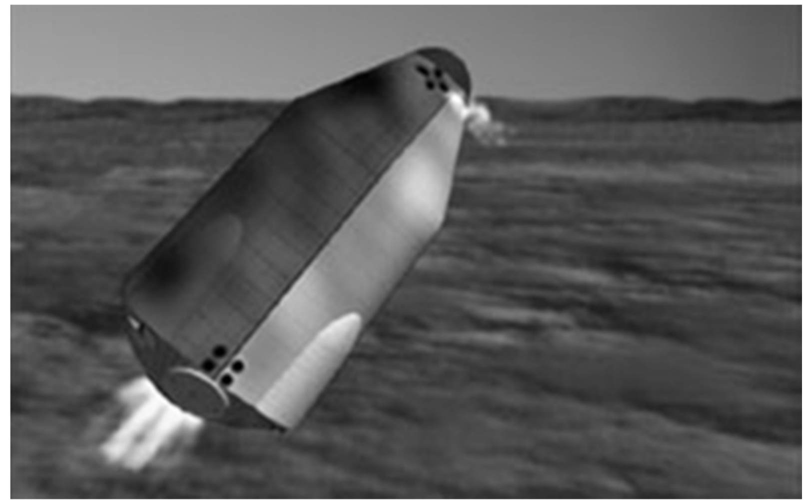


Christine E. Szalai; Jet Propulsion Laboratory, California Institute of Technology
Robin A.S. Beck, Matthew J. Gasch; NASA Ames Research Center
Antonella I. Alunni, Jose F. Chavez-Garcia; ERC, Inc.
Scott C. Splinter, Jeffrey G. Gragg; NASA Langley Research Center
Amy Brewer; Analytical Services and Materials, Inc.

42nd AIAA Thermophysics Conference
Honolulu, Hawaii
27 – 30 June 2011

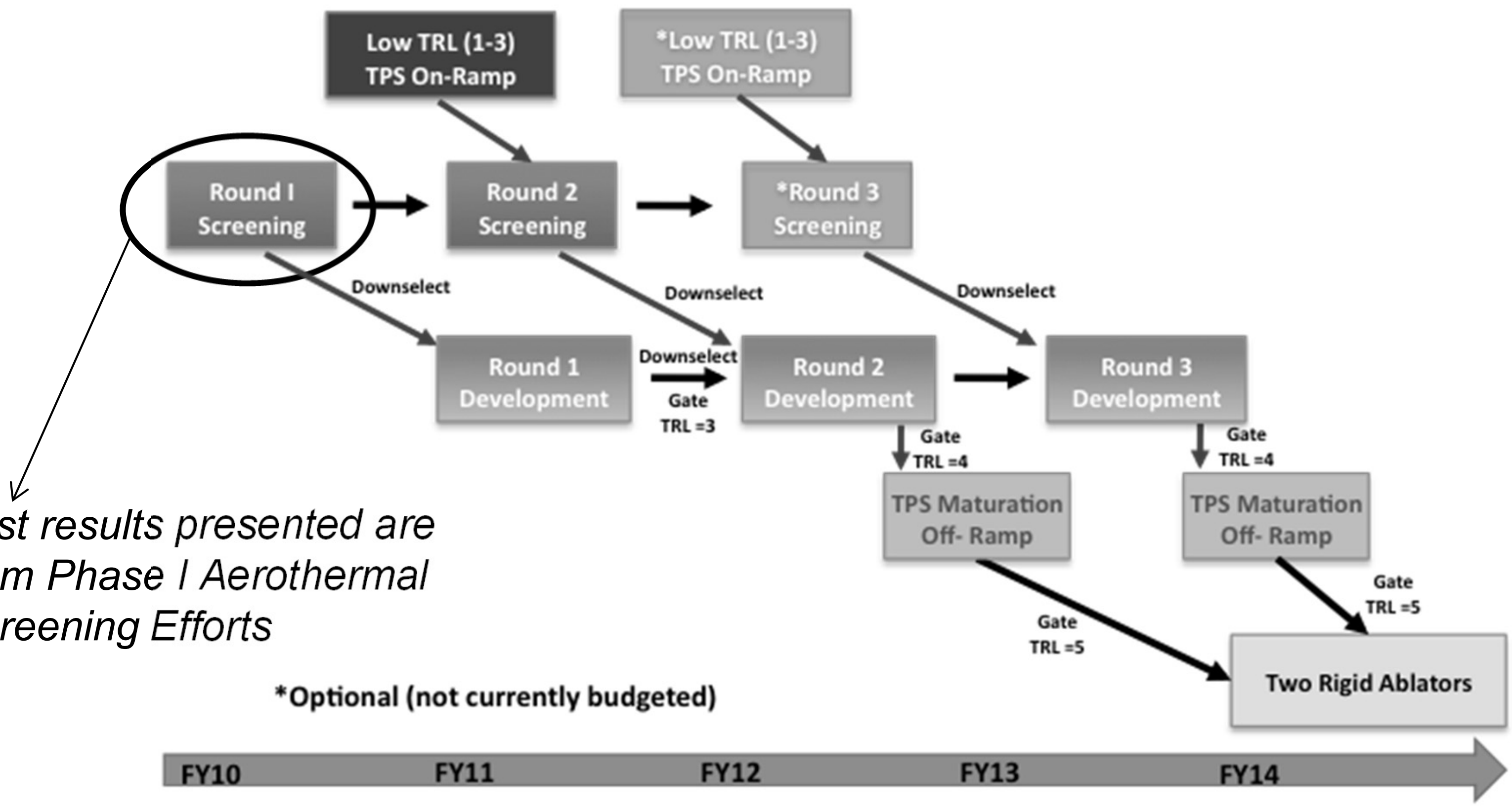
Introduction

- NASA's desire to land larger payloads on Mars (10s of metric tons) has renewed interest in alternative technologies for entry, descent, and landing (EDL)
- The Entry, Descent, and Landing Technology Development Project is tasked to develop advanced Thermal Protection System (TPS) materials
  - Development of lighter weight TPS materials is required to support either mid L/D rigid systems or hypersonic inflatable/deployable aerodynamic decelerators
  - Development includes both rigid and flexible ablators



Rigid Ablator Technology Development Approach

- Define key performance parameters and develop evaluation criteria to describe successful development
- Competitively procure rigid ablative material candidates
- Perform thermal and structural screening tests
- Downselect “best” concepts for further maturation



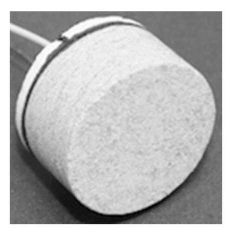
Test results presented are from Phase I Aerothermal Screening Efforts

HYMETS Aerothermal Screening Test Objectives

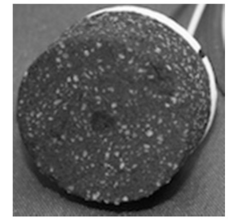
- Assess survivability of material concepts at relevant Mars aerocapture heating conditions in both air and Martian plasma environments
- Obtain recession data for material concepts at relevant Mars aerocapture heating conditions in both air and Martian plasma environments
- Obtain surface temperature and backface thermal response of material concepts at relevant Mars aerocapture heating conditions in both air and Martian plasma environments

Material Candidates

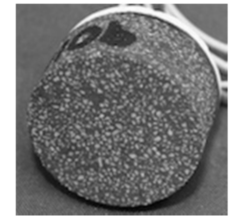
- Poly-Imide Refractory Ablator System (PIRAS-22) and PhenCarb-28 - *Applied Research Associates*
- Boeing Phenolic Ablator (BPA) – *Boeing*
- Carbon-Carbon/CalCarb and Monolithic Ablator (MonA) – *Lockheed Martin Space Systems*
- 3-Dimensional Quartz Phenolic (3DQP) and Avcoat – *Textron*
- Phenolic Impregnated Carbon Ablator (PICA) – state of the art rigid ablator
  - Samples produced from residual Mars Science Laboratory (MSL) heatshield materials (Fiber Materials, Inc.)



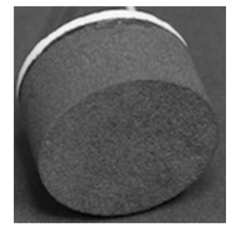
PICA



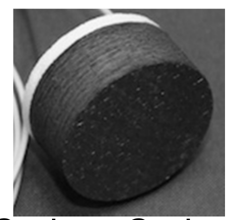
PIRAS-22



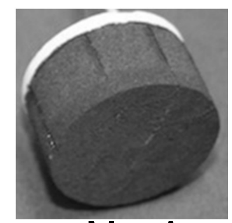
PhenCarb-28



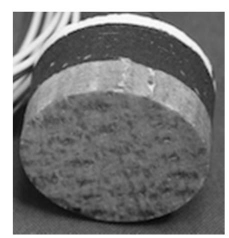
BPA



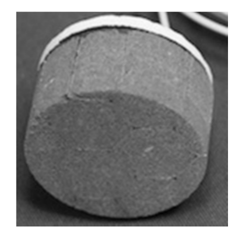
Carbon-Carbon



MonA



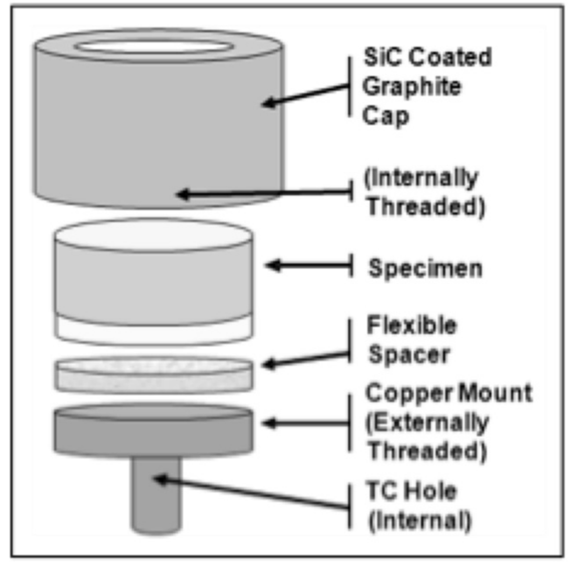
3DQP



Avcoat

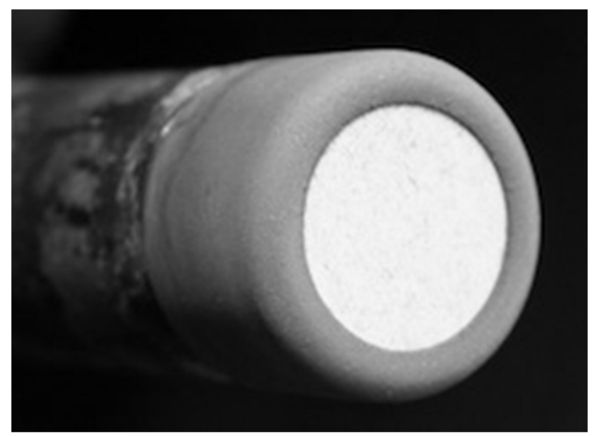
Test Article Design

- 1"D, 0.5" thick specimens
- Type K thermocouple installed on back of specimen
- 1.3"D total outer diameter of assembly in graphite cap



Test Article Assembly

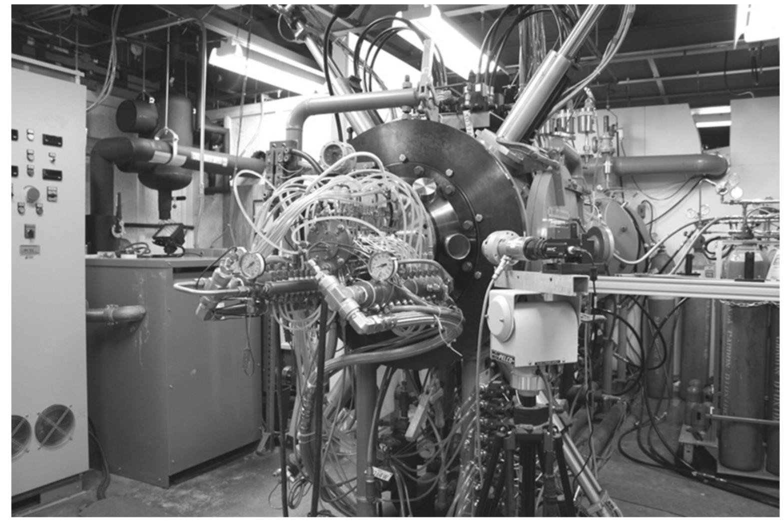
Ablator Test Specimen Configuration



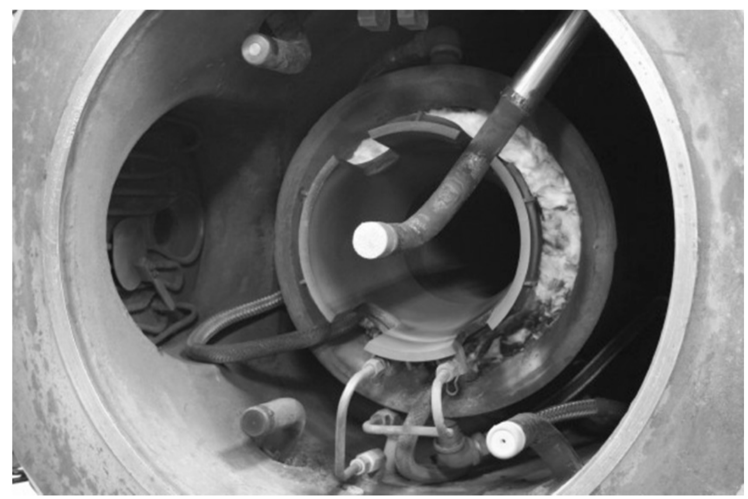
Integrated Test Article Assembly

HYMETS Arc Jet Facility, NASA Langley

- Arc Jet facilities produce representative high-enthalpy flow environments
- HYMETS can provide air and simulated Martian test gas
  - Simulated Martian environment is 71% CO_2, 24% N_2, 5% Ar
  - Higher percentage of nitrogen and argon than actual Martian environment prevents excessive electrode oxidation
- Facility instrumentation includes slug calorimeter, stagnation pressure probe, pyrometer, digital video



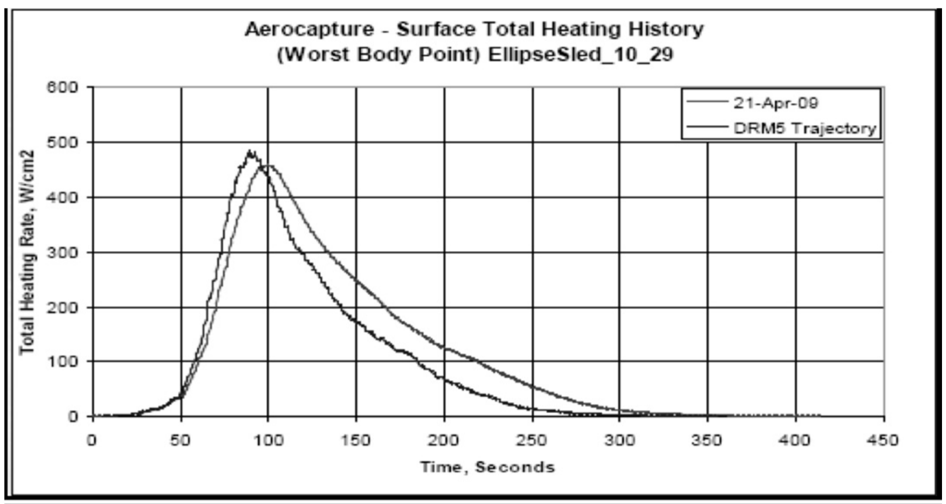
HYMETS facility

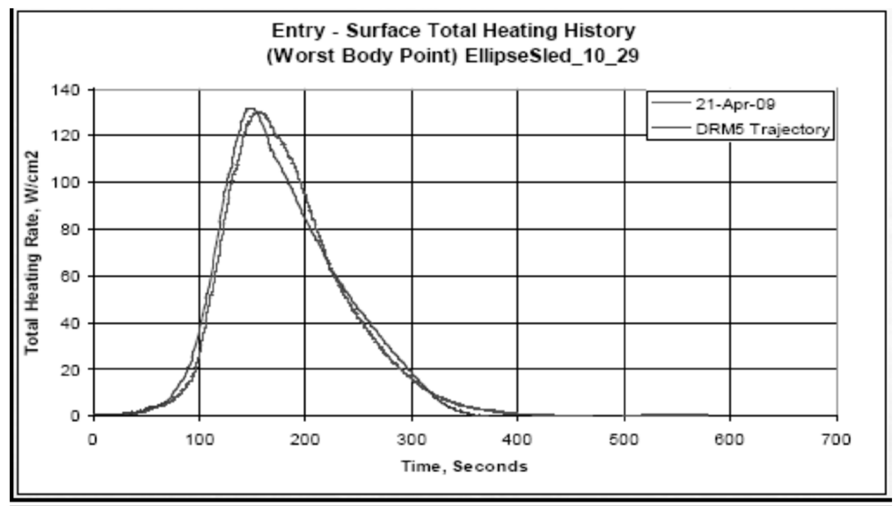


Probe arrangement in chamber

Test Condition

- Test condition derived from aerothermal analyses of a mid L/D ellipsled concept from the EDL Systems Analysis Mars Design Reference Architecture 5.0
- Dual pulse heating environment; highest heating rate experienced during aerocapture
- Facility capabilities limited maximum heat flux to 300 W/cm^2 at a stagnation pressure of 3.5 kPa





Test Condition

- Test duration selected to balance obtaining meaningful recession and char depth without overheating the specimen backface
- Low density specimens (PICA, MonA) tested at a duration of 15 sec
- Higher density specimens tested from 20 to 25 sec
- For some materials, test durations were adjusted for second specimen based on performance of first specimen

Material	Vendor	Average Bulk Density of Test Specimens (g/cc)
PIRAS-22	Applied Research Associates	0.367
PhenCarb	Applied Research Associates	0.467
BPA	Boeing	0.450
Carbon-Carbon	Lockheed Martin	1.560
MonA	Lockheed Martin	0.318
Avcoat	Textron	0.536
3DQP	Textron	1.012
PICA	Fiber Materials, Inc.	0.273

Test Results for Tests in Air

Sample ID	Material	Cold Wall Heat Flux (W/cm^2) - Slug Calorimeter (±10%)[3]	Stagnation Pressure (kPa) (±0.2%)[2]	Test Time (sec)	Mass Loss (g)	Stagnation Point Recession (mm)	Peak Surface Temperature (°C)	Peak Backface Temperature (°C)
42534-1	PICA	292	3.5	15	0.40	1.346	2207	503
42534-2	PICA	293	3.5	15	0.38	1.321	2223	467
5000-1	Carbon-Carbon	273	3.5	15	0.16	N/A*	1827	777
5000-2	Carbon-Carbon	289	3.5	10	0.10	0.254	1674	606
ARA-9015	PhenCarb	297	3.5	20	1.02	0.813	2134	272
ARA-9016	PhenCarb	289	3.5	20	0.99	1.067	2137	274
BBB1	MonA	309	3.5	15	0.58	1.778	2180	341
BBB2	MonA	321	3.5	15	0.50	2.464	2121	324
BPAFG-B-01	BPAFG	297	3.5	20	0.96	2.311	2121	399
BPAFG-B-02	BPAFG	308	3.5	20	1.01	2.108	2148	391
P22-9005	PIRAS-22	298	3.5	15	0.67	0.356	2190	275
P22-9006	PIRAS-22	303	3.5	20	0.80	0.356	2192	327
Av-P42-1M	Avcoat	297	3.5	20	1.34	0.584	2080	282**
Av-P42-2M	Avcoat	304	3.5	20	1.13	0.432	2076	268
Av-P42-3M	Avcoat	306	3.5	20	1.29	0.940	2071	265
TB-1	3DQP	306	3.5	25	0.91	-0.025	1859	328
TB-2	3DQP	308	3.5	25	0.92	0.000	1852	N/A***

*RSI detachment from overheating

**no electronic cool-down data obtained

***T/C lead wire shorted to copper backplate

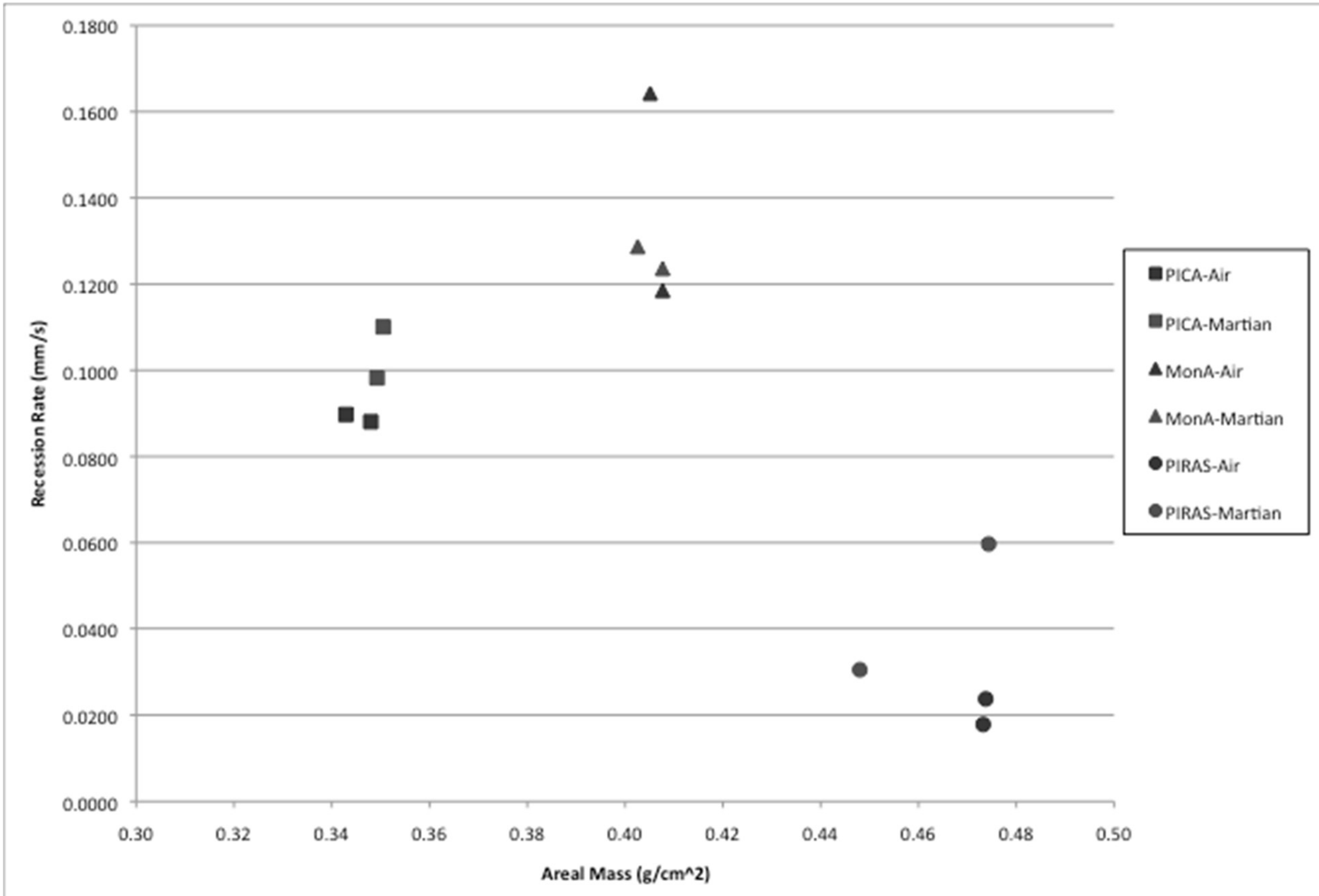
Test Results for Tests in CO_2

Sample ID	Material	Cold Wall Heat Flux (W/cm^2) - Slug Calorimeter (±10%)[3]	Stagnation Pressure (kPa)	Test Time (sec)	Mass Loss (g)	Stagnation Point Recession (mm)	Peak Surface Temperature (°C)	Peak Backface Temperature (°C)
42534-3	PICA	309	3.9	15	0.46	1.473	2218	562
42534-4	PICA	316	3.9	15	0.45	1.651	2226	560
5000-3	Carbon-Carbon	296	3.9	10	0.15	N/A*	1785	700
5000-4	Carbon-Carbon	301	3.9	10	0.15	0.254	1759	694
ARA-9017	PhenCarb	339	3.9	20	1.04	1.092	2103	273
ARA-9018	PhenCarb	Not functional	3.9	20	1.01	1.422	2080	287
BBB3	MonA	297	3.9	15	0.61	1.930	2148	339
BBB5	MonA	357	3.9	15	0.62	1.854	2141	357
BPAFG-B-03	BPAFG	346	3.9	20	1.11	2.057	2087	409
BPAFG-B-04	BPAFG	389	3.9	20	1.12	2.388	2113	422
P22-9007	PIRAS-22	300	3.9	15	0.68	0.457	2164	269
P22-9008	PIRAS-22	371	3.9	20	0.85	1.194	2174	324
Av-P43-5M	Avcoat	307	3.9	20	1.30	1.270	2109	272
Av-P43-6M	Avcoat	314	3.9	20	1.30	1.092	2109	277
TB-3	3DQP	Not functional	3.9	25	1.00	0.152	1883	N/A**
TB-4	3DQP	Not functional	3.9	25	0.96	-0.483	1880	N/A**
TB-5	3DQP	Not functional	3.9	15	0.71	0.127	1869	250

*RSI detachment from overheating

** Back of sample overheated, melted TC sheath and TC shorted to sting

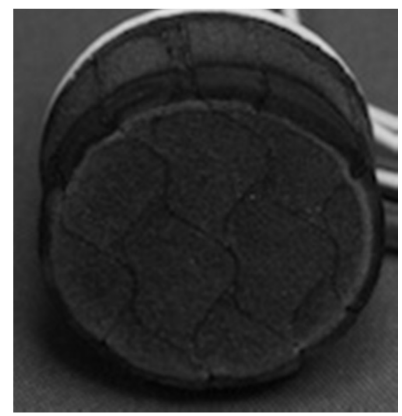
Recession Rate Comparison (Areal Mass < 0.5 g/cm^2)



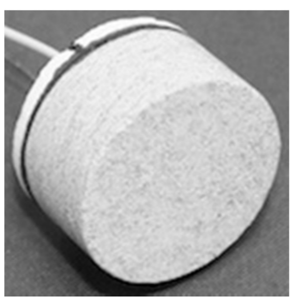
Conclusions for Materials with an Areal Mass < 0.5 g/cm^2

- Increased recession rate in CO_2 observed for PICA and PIRAS-22
  - Additional oxygen available in dissociated CO_2 plasma stream
- Variable recession results for MonA likely due to material variability
  - R&D material; manufacturing processes not yet controlled

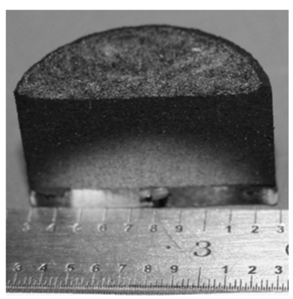
PIRAS-22



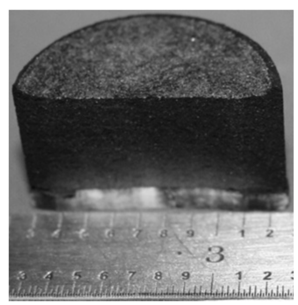
MonA



Pre-Test PICA

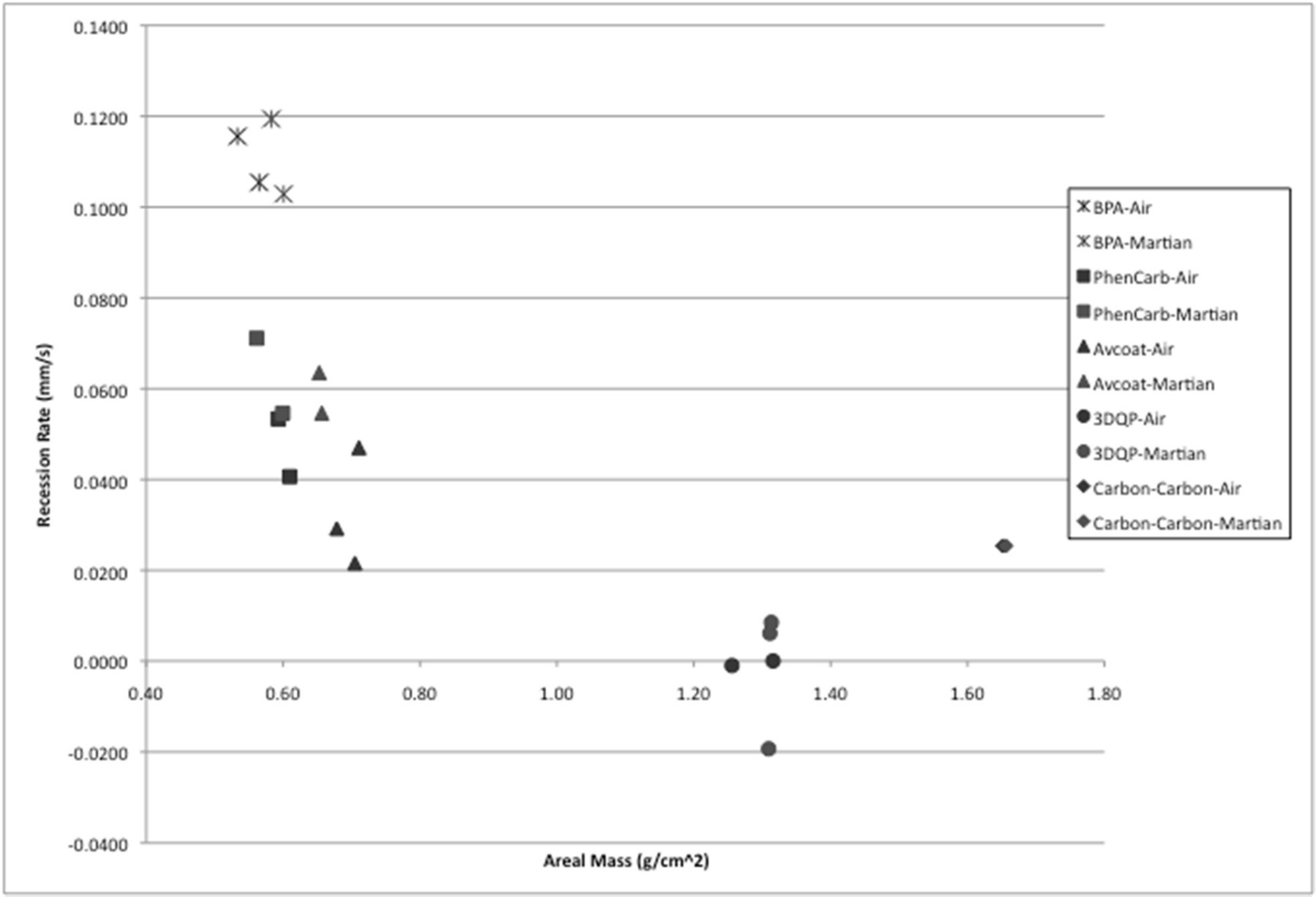


Post-Test PICA (Air)



Post-Test PICA (CO_2)

Recession Rate Comparison (Areal Mass > 0.5 g/cm^2)

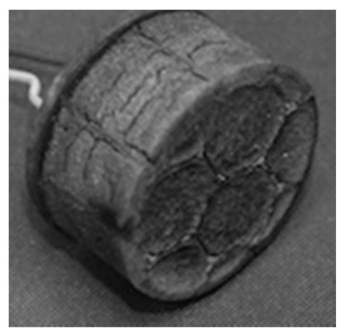


Conclusions for Materials with an Areal Mass > 0.5 g/cm^2

- BPA showed insensitivity to test gas, and experienced the highest recession rate
- PhenCarb-28 and Avcoat showed some variability in recession results, but in general there was more recession in the CO_2 environment
- Glass melt layer seen on 3DQP specimens, and specimens experienced little recession
- Carbon-carbon specimens had identical recession rate in both air and CO_2 environments

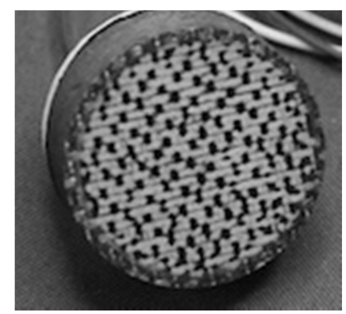
BPA

PhenCarb-28



Avcoat

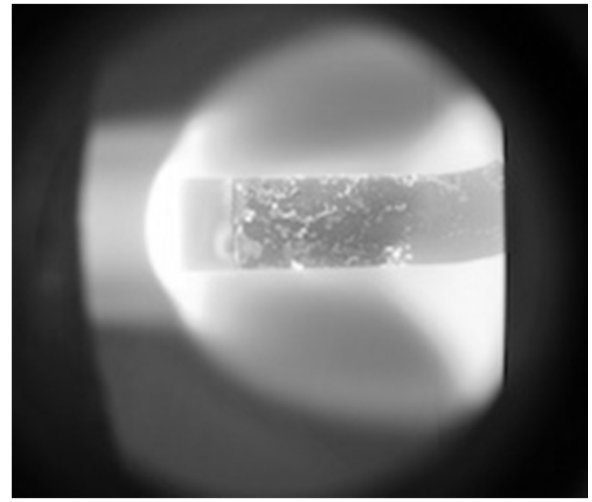
3DQP



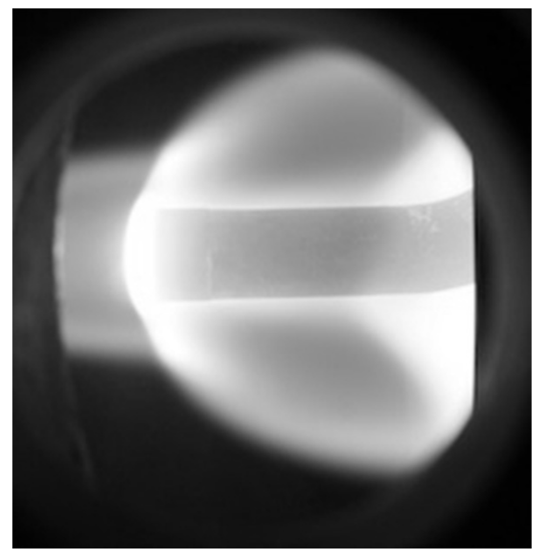
Carbon-Carbon

Conclusions

- All test objectives successfully met
  - All materials survived heating condition
  - Recession, surface temperature, and backface temperature data obtained in both air and simulated Martian environment
- These results, with other thermal and structural screening test data, were utilized in the overall evaluation and down-selection process for further material maturation



Test in Air



Test in CO_2

Acknowledgments

- This work was supported by the Entry, Descent, and Landing Technology Development Project (EDL-TDP) under the Exploration Technology Development Program (ETDP) and under the Exploration Technology Development and Demonstration Program (ETDD)
- The work of the first author was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration