Next Generation Thermal Protection Systems for Outer Planet Missions

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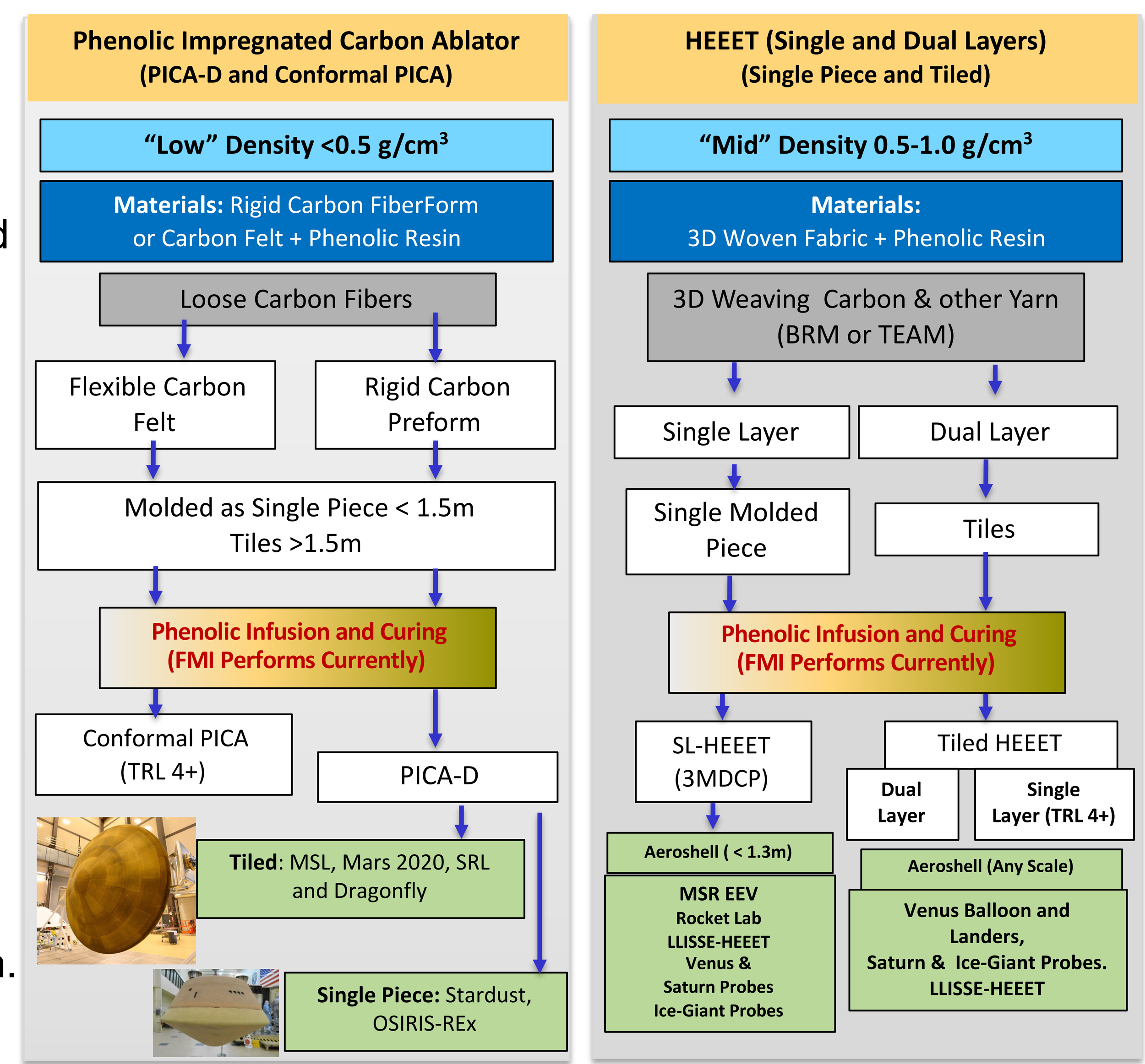
1. Summary

- With 2-layer HEEET and PICA-D (domestic) both at TRL 6, NASA has closed the TPS gap for the outer planet missions to Saturn and the Ice-Giants.
- Leveraging recent development, two related TPS, a single-layer HEEET and Conformal-PICA, if matured, our studies show mass savings (of the order of 50%) on the heat-shield and backshell for direct probe missions to Saturn, Uranus and Neptune.
- The proposed TPs development also enables aerocapture mission architecture to Neptune.
- With mass efficient TPS, not only faster aerocapture missions that cut the trip time by 50% possible, also allows for substantial payload mass increase, there by allowing for Orbiter, Probe and Lander all be inserted into orbit and then perform coordinated science.
- We seek OPAG's advocacy.

2. Background

- A mid density follow on to Dual-Layer or DL-HEEET, is under development to meet earth entry requirements: Single Layer or SL-HEEET is even more mass efficient and yet still applicable at high entry conditions.
- SL-HEEET, also referred to as 3D Mid Density Carbon Phenolic (3MDCP), is baselined as the heatshield for Mars Sample Return Earth Entry System Aeroshell .
- While 3MDCP will be at TRL 6 very soon, it is limited to seamless configuration for aeroshell diameters < 1.3m
- Expanding the capability to scales > 1.3m requires a tiled configuration with seams. The DL-HEEET solved this and, following a similar path, 3MDCP development with seams can be completed in a short time with reasonably small $.
- Similarly, Conformal-PICA (C-PICA) at TRL 4+ is a mass and cost efficient alternate to PICA and has same applicability as PICA. C-PICA applicability at all scales require demonstration of a seam design for tiled integration.
- These two TPS developments together offer new mission possibilities for Outer Planet and Ice Giant missions



2. Saturn Probes

- Saturn mission designers are generally interested in shallow entry that results in lower g-load during entry around 50g, which saves science instrument qualification cost and development schedule.
- Shallow entries result in higher heat-load ranging between (150 kJ/cm2 – 300 kJ/cm2), an order of magnitude higher than Venus or Sample Return missions which are in the ~ 20 kJ/cm2 range.
- To enable Saturn probe missions, TPS must offer protection but also be mass efficient to meet science mass requirements.

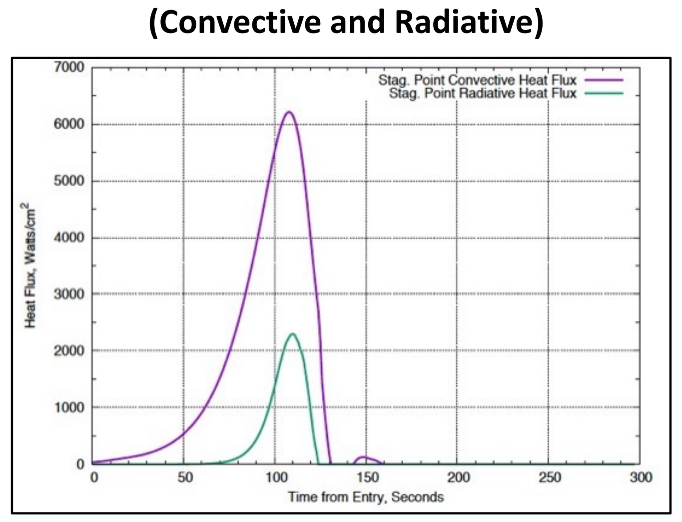
Heatshield:

- While DL-HEEET offers robust protection it could require ~50% of the mass of the entry system.
- Recent analysis performed shows Saturn Probe missions could significantly benefit from the use of single-layer HEEET (3MDCP) which had the potential to offer a mass savings of 30% - 50% over DL-HEEET.

Backshell:

- PICA can provide protection for the backshell. C-PICA, more efficient and equally robust, can provide (30% - 50%) mass savings compared to PICA. Every kg of mass reduction for the backshell helps with stability and results in 3 times overall mass savings.

North Probe - Stag. Heat flux vs time (Convective and Radiative)



Saturn Probe Mission TPS Trade Studies with Heritage Carbon Phenolic, Dual- and Single-Layer HEEET

Title	Relative Velocity, km/s	Ballistic Coefficient, kg/m2	Stag. Press, Pascals	Heat-flux, W/cm2	Heat Load, J/cm2	TPS		Mass Frac. TPS/Entry
				Total	Total	TPS	Areal Density, kg/m2	
SL-HEEET vs Heritage Carbon Phenolic (HCP)	30	490	6.74 E+05	3808	173060	SL-HEEET	51.816	0.143
	30	490	6.74 E+05	3808	173060	HCP	85.004	0.234
SL-HEEET vs Heritage Carbon Phenolic (HCP)	30	250	2.91 E+05	3103	129435	SL-HEEET	35.418	0.192
	30	250	2.91 E+05	3103	129435	HCP	56.680	0.306
Dual Layer (DL) HEEET vs Single Layer (SL) HEEET	30	250	2.39 E+05	2981	129613	DL- HEEET	48.352	0.261
	30	180	2.10 E+05	2813	115417	SL-HEEET	30.819	0.137
East vs North	31	180	2.2 E+05	2975	131391	SL-HEEET	33.929	0.151
	41	180	2.86 E+05	8484	312863	SL- HEEET	52.319	0.232
Compariosn of SL-HEEET, HCP and DL-HEEET	30	151	1.76 E+05	2653	108399	SL-HEEET	28.626	0.255
	30	151	1.76 E+05	2653	108399	HCP	52.567	0.469
	30	151	1.76 E+05	2653	108399	DL-HEEET	39.632	0.354

Use of SL-HEEET (3MDCP) combined with C-PICA can result in significant mass savings and provide additional opportunities for enhanced science mission.

3. TPS Enabling Aerocapture to Achieve "Faster and Better" Science for Ice Giant Missions

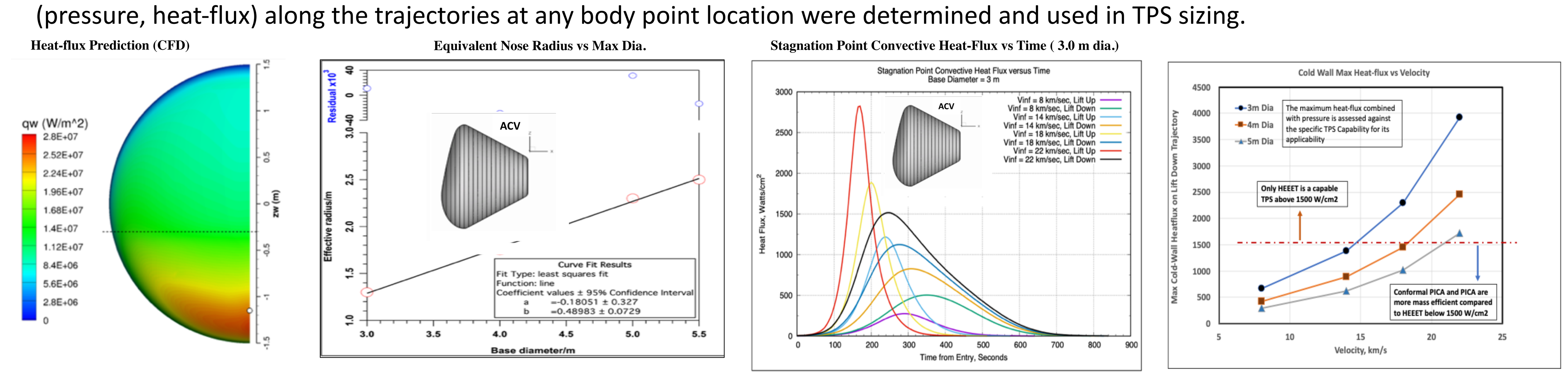
Aerocapture mission architectures can provide significant advantage over traditional propulsive insertion in multiple ways:

1. **Reduced trip time** significantly by ~ (4- 8) years (30% -50%), compared to propulsive insertion total trip time of (12 – 17) years
2. **Improved science payload mass to accommodate probe(s) and lander with mass efficient TPS**
3. **Better Science** - Orbiter, probe(s) and lander together can be inserted into orbit to perform coordinated in-situ measurements simultaneously (during probe descent)

- Progress made in GN&C for lift-guided entry missions (MSL, Orion EFT1, Mars 2020), experience gained in flying large (~ 5m) lifting blunt-bodies in the past 20 years, have made aerocapture as "go do" engineering.
- An aerocapture mission will require a mass efficient TPS that can handle extreme heat-load, ~ (100 kJ/cm2 – 500 kJ/cm2).

Approach to Assessing TPS mass fraction for Neptune-Triton Aerocapture

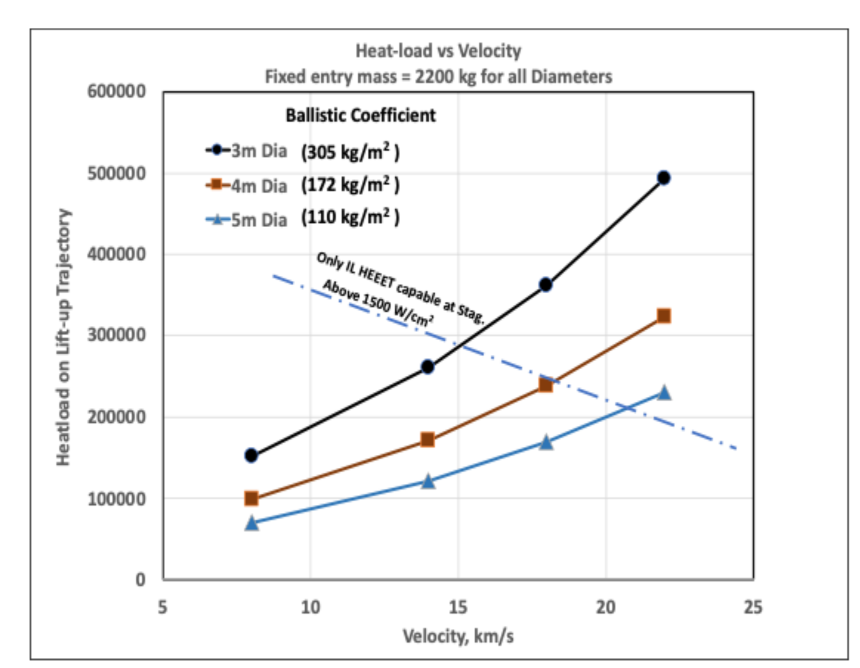
- To assess the TPS choices and and associated mass, a wide range of conditions were evaluated: entry velocities that will reduce the trip by 4 – 8 years (approach velocities of (8, 14, 18 and 22) km/s, for an entry mass of 2200 kg and for aeroshell diameters of (3, 4 and 5) m.
- In order to achieve aerocapture with a blunt body, the geometry chosen was the well studied ACV shown in the figures. The optimized (and patented) geometry can provide L/D of 0.6 but for the current study we limited the L/D to 0.44
- For every geometry, and for every approach velocity, we determined the undershoot and overshoot aerocapture trajectories around Neptune that reaches Triton.
- Next, by performing CFD simulation at selected points, and combining it with engineering correlation, aerothermal quantities (pressure, heat-flux) along the trajectories at any body point location were determined and used in TPS sizing.



- DL-HEEETT is TRL 6 and it is scalable to any size through the use of a tiled architecture. SL-HEEET is capable and mature but the seam required has not been demonstrated. PICA and Conformal PICA are also mature but the heatflux range for which they are capable is limited and also the seam required for tiled PICA/C-PICA has not been demonstrated for heat-fluxes > 300 W/cm2.
- Implementation of a tiled aeroshell using 3MDCP, PICA or C-PICA can be addressed through engineering development similar to the successful DL-HEEET.
- While DL-HEEET is applicable across the entire aerocapture design space, it is too heavy and the TPS mass fraction ranges between (22% -67%)
- SL-HEEET is more mass efficient for all cases but it is not as efficient as PICA or Conformal PICA for heat-flux < 1500 W/cm2.
- C-PICA is more mass efficient due to its insulative nature compared to PICA. C-PICA is less expensive and also more compliant making it very attractive for large diameter aeroshells

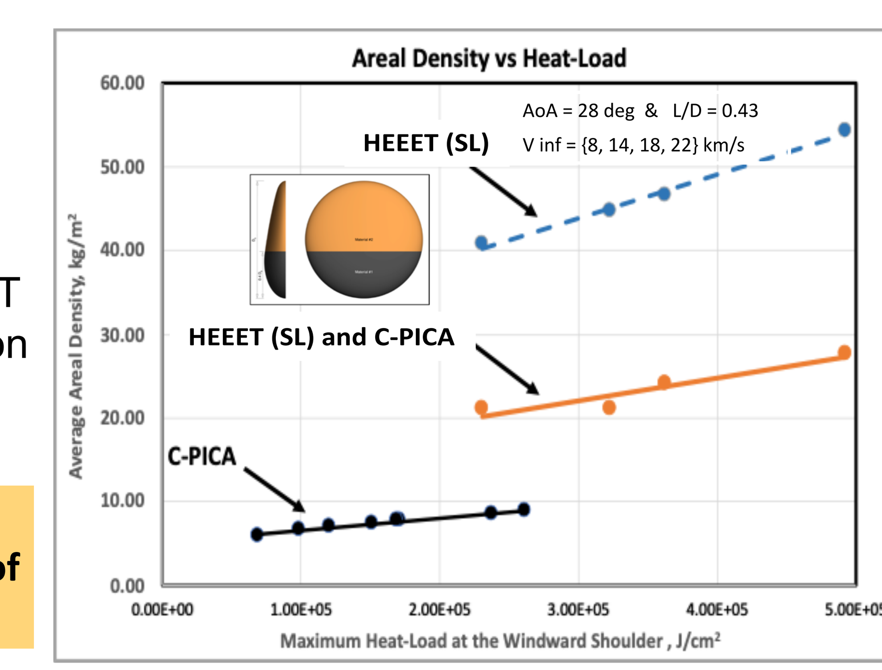
TPS Material	Density	TRL of Tiled System for Ice Giant	Peak Heat-flux Limit, W/cm2	Peak Pressure Limit.
PICA	0.25 g/cc	4+	~1500	1 atm
Conformal PICA	0.25 g/cc	4+	~1500	1 atm
HEEET (Single-Layer)	0.7 g/cc	5	3500+	5 atm
HEEET (Dual-layer)	~ 1.0 g/cc	6	➢ 3500	> 5 atm

Note: PICA is at TRL 9 (OSIRIS-REx, Stardust) as a single piece as well as for tiled system (MSL, Mars 2020) at heatflux < 350 W/cm2. Ice Giant conditions are more severe and require tile-gap filler development



- For all cases where the peak heat-flux is < 1500 W/cm2, Conformal PICA is the most mass efficient.
- For cases where heat-flux is > 1500 W/cm2, use of SL-HEEET on the wind-side and C-PICA on the lee-side of the heat-shield results in lowest mass

Overall mass fraction range by the use of C-PICA or the combination of C-PICA and SL-HEEET (5% - 20%)



4: Summary and Recommendations

- Use of SL-HEEET (3MDCP) and C-PICA is recommended for outer planet missions as they result in significant mass savings without impacting mission risk. Experience in addressing seam development for DL-HEEET will allow us to mature SL-HEEET and C-PICA to any scale.
- SL-HEET and C-PICA are at already TRL (4 to 5) and the remaining development is more of an engineering task.
- Given outer Planet missions of opportunity is in the early to mid 2030's, there is sufficient time to develop the above two TPS.
- We seek the support and advocacy of OPAG in ensuring tiled SL-HEEET (3MDCP) and C-PICA are matured in a timely manner.