

RECENT DEVELOPMENTS OF THERMAL PROTECTION MATERIALS TO ENABLE LOWER COST SPACE MISSIONS.

A. Borner¹, M. Gasch², K. Peterson², J. Monk², M. Stackpoole², E. Venkatapathy², ¹Analytical Mechanics Associates, Inc. at NASA Ames Research Center (arnaud.p.borner@nasa.gov), ²NASA Ames Research Center.

Brief Presenter Biography: Dr. Arnaud Borner is AMA's Technical Lead supporting the Thermal Protection Materials Branch at NASA Ames Research Center. His research interests combine Venus mission concepts, TPS materials modeling, and the DSMC method.

Introduction: Starting with the Commercial Crew Program, a new paradigm has emerged at NASA. Rather than designing rockets and spacecrafts for every mission optimized to achieve science, NASA has begun to use a service-based model and utilizing public-private partnerships in developing vehicles that can bring broader benefits as well as lower the cost for NASA missions. Commercial companies own and operate those vehicles. This allows NASA to not design missions from the bottom up, which has cost, risk, and schedule savings implications. On the other side, the constraints require meeting the requirements in terms of mass, volume, power, etc.

By leveraging NASA-developed technologies, commercial companies can quickly demonstrate the commercial mission concept, and, through technology transfer, adopt needed technology to address supply chain problems. A downside is that the technology has to be sufficiently mature to be transferred by NASA, which means that it requires significant investment, expertise, and time to develop. Space entities are focused on rapid development with an emphasis on manufacturing and integration innovation with reduced cost and schedule and quick entrance into the market.

Thermal Protection Systems (TPS) are mission-critical, but their development takes years, and involve access to arc jets or unique test facilities. Therefore, their development is both risky and investment heavy. NASA ARC developed several new TPS materials over the last decade (C-PICA, S-PICA, HEEET, 3MDCP, 3DMAT, ADEPT woven TPS) and brought them to high TPS maturity, making them enablers for commercial space missions from LEO, Lunar Sample Return, Mars, and Venus missions. LEO missions are relevant to future Mars missions due to the comparable entry conditions.

External Partners' Missions: C-PICA [1] is a recent improvement on NASA's heritage PICA lightweight TPS ablator. C-PICA is now considered an enabling technology for New Frontiers and other NASA missions. C-PICA was infused into several missions from external partners. Varda Space Industries' Winnebago-1 spacecraft successfully returned to Earth from LEO on Feb. 21st, 2024, using a C-PICA heatshield. Inversion Space's Ray vehicle will test both ARC's C-

PICA and SIRCA TPS materials on a LEO return mission later in 2024.

The Kentucky Re-Entry Probe Experiment (KREPE) is another example of a low-cost flight experiment to demonstrate the use of small entry capsules to gather data with three instrumented Kentucky Re-entry and Universal Payload System (KRUPS) capsules. NASA Arc provided C-PICA, S-PICA, and a dry 3D woven material for three of the next KRUPS capsules scheduled to re-enter Earth from the ISS later in 2024.

Finally, Rocket Lab's low-cost mission to Venus, scheduled to launch in December 2024, will search for habitable conditions in Venus' cloud layer, making use of NASA ARC-provided HEEET [2] insulation layer heat shield, and SIRCA backshell TPS materials.

Future NASA Missions: NASA's ability to help commercial missions can lead to future low-cost missions for several reasons: Competition encourages lower cost; technology maturation is now done at an integrated system level; and a common design architecture between commercial and scientific applications requires no specialized engineering design. From an engineering perspective, both of these aforementioned commercial LEO capsules are capable of a Mars entry; the commercial payload must be replaced with a science payload.

Finally, several NASA mission concepts, that could be candidates for future SIMPLEx program calls, such as VATMOS-SR [3] and Nephelē [4], both proposing to target the Venusian atmosphere, would make use of the HEEET insulation layer TPS for part of their heat shield.



Fig. 1: Inversion Space's Ray spacecraft, pictured with a C-PICA heat shield. Image credit: <https://www.inversionspace.com/ray>, 02/21/24.

References: [1] Gasch M. et al. (2016) *AIAA 2016-1414*. [2] Venkatapathy R. et al. (2020) *Space Sci Rev*, **216**, 22. [3] Rabinovitch J. et al. (2023) *20th IPPW*, Abstract #55. [4] Gentry D. et al. (2023) *20th IPPW*, Abstract #131.