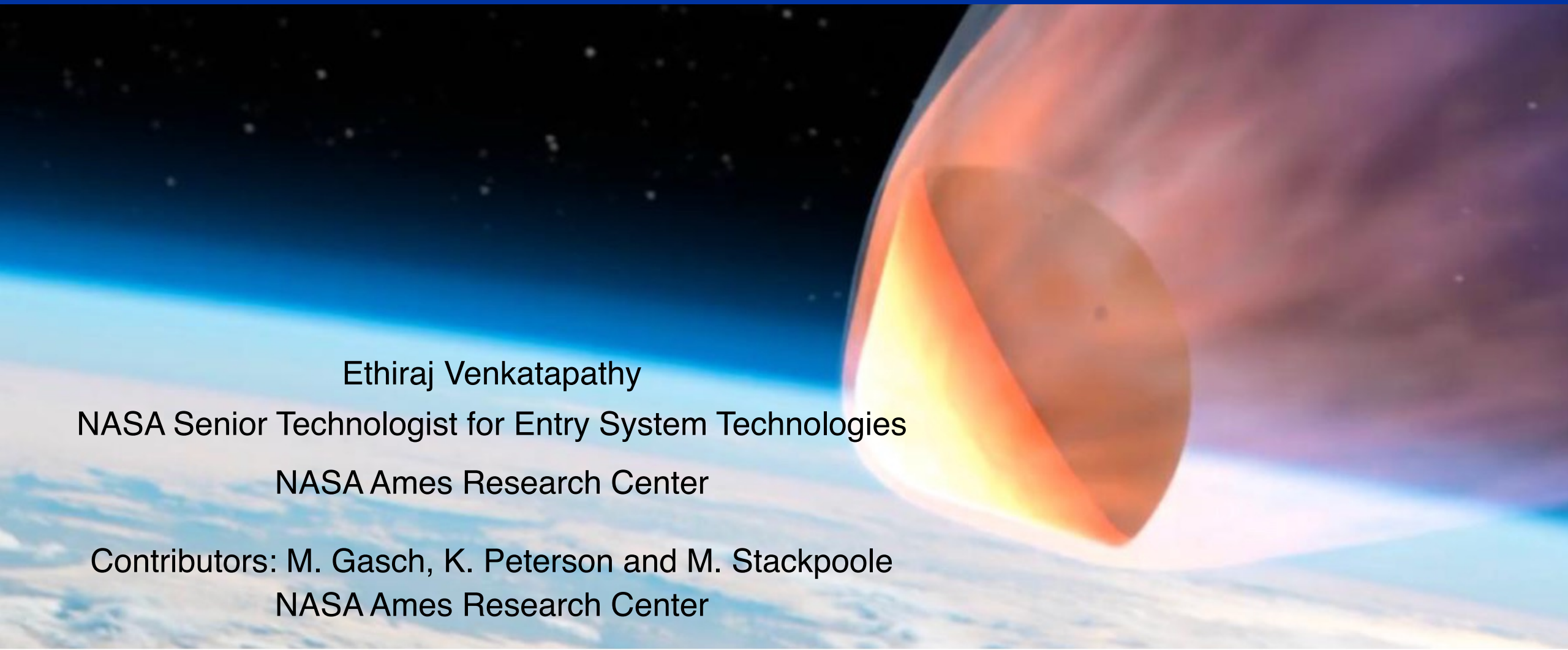
College of Engineering

12th Ablation Workshop

A Perspective on Ablative TPS Needs by Emerging Commercial Space and NASA's



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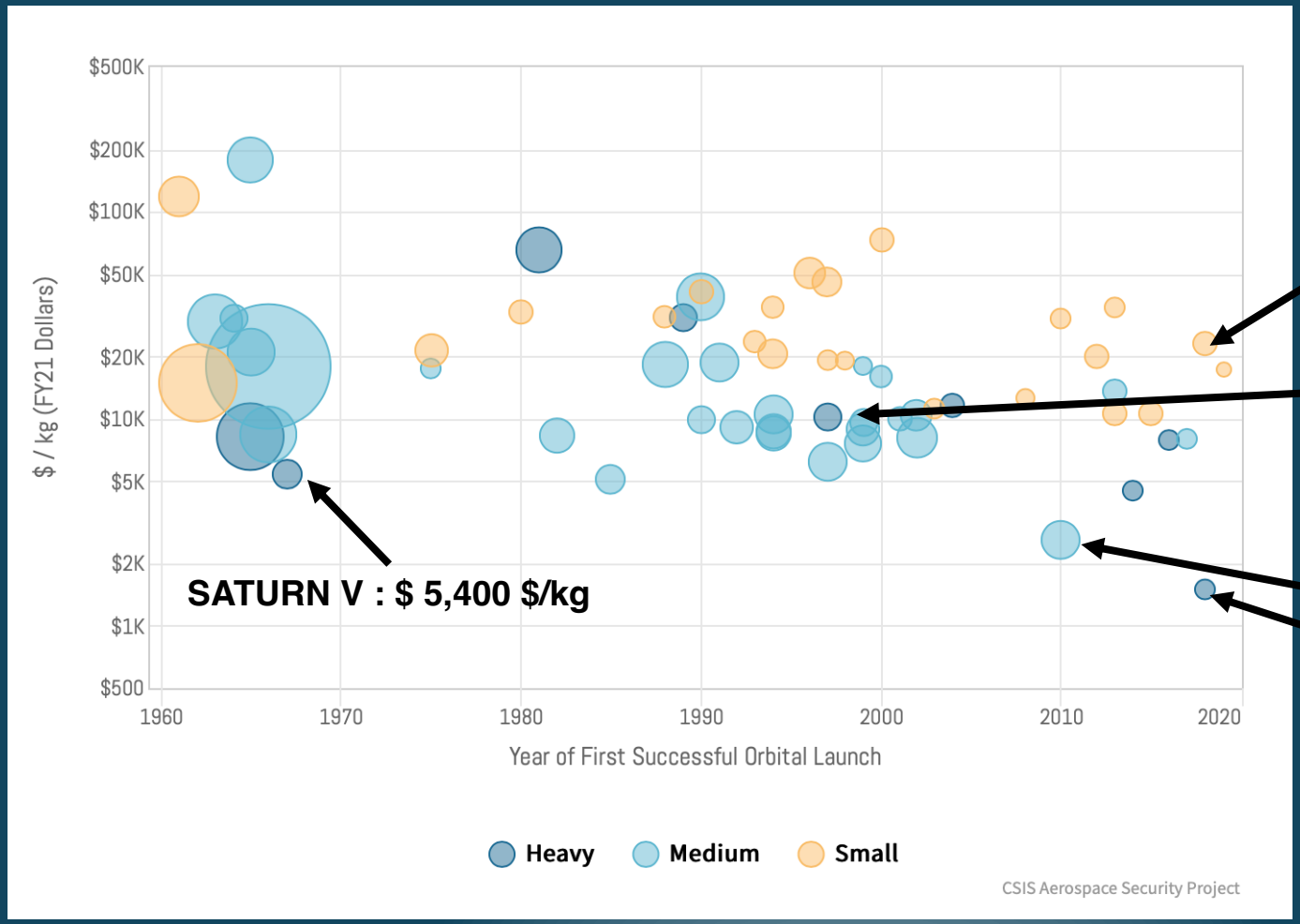
NASA Ames Research Center

Paradigm Shift is Happening!
Lowest Ever Launch Cost to LEO and the Trend is Expected to Continue



ELECTRON: 23,100 $/kg

DELTA IV HEAVY: 10,600 $/kg

ARIANE 5G: 10,200 $/kg

FALCON 9: 2,600 $/kg

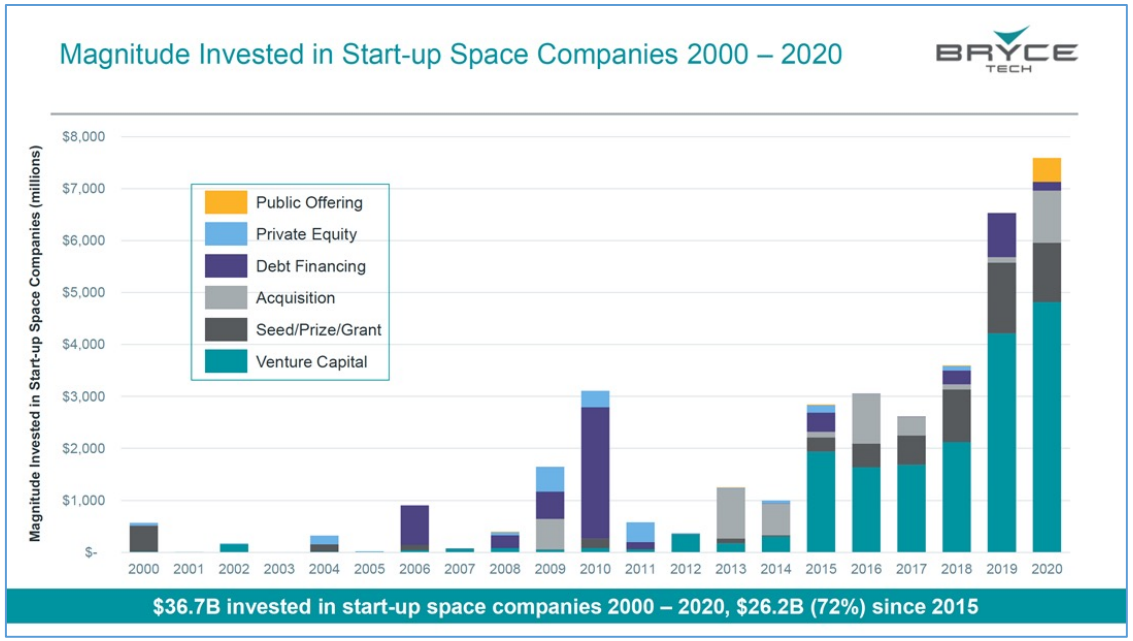
FALCON HEAVY : 1,500 $/kg

All Costs are in FY22 $s

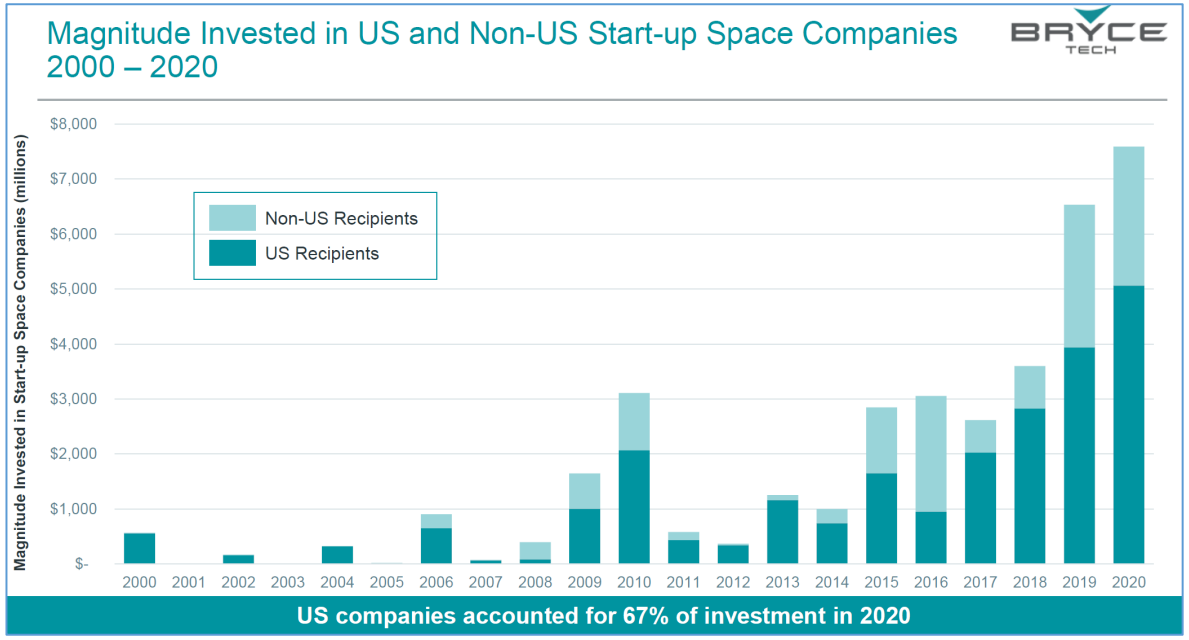
https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/

Phenomenal Growth in Commercial Investment

https://brycetech.com/reports/report-documents/Bryce_Start_Up_Space_2021.pdf



Significant Monetary Investment in Space

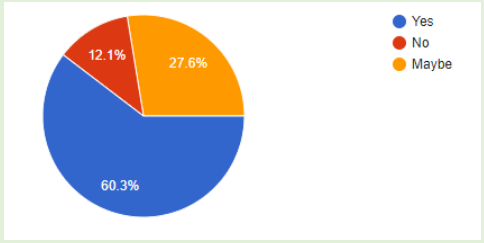
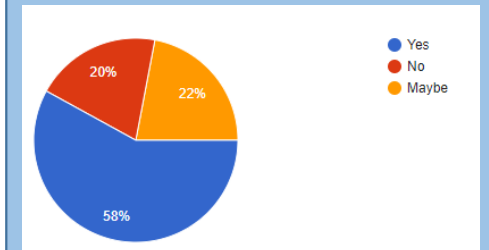
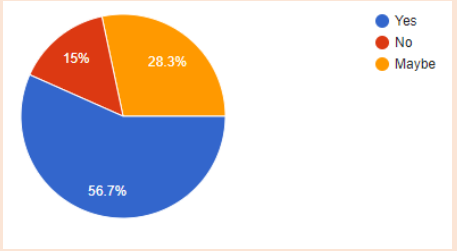
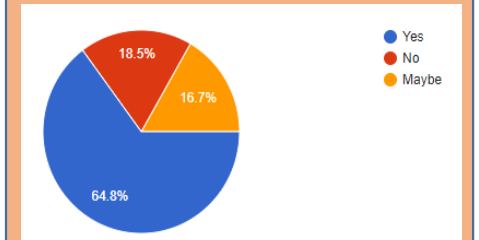
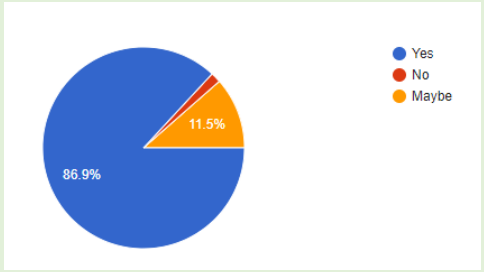
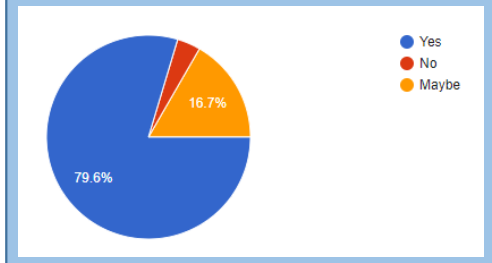
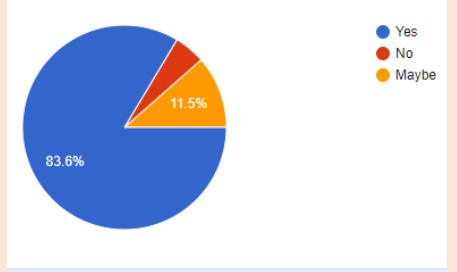
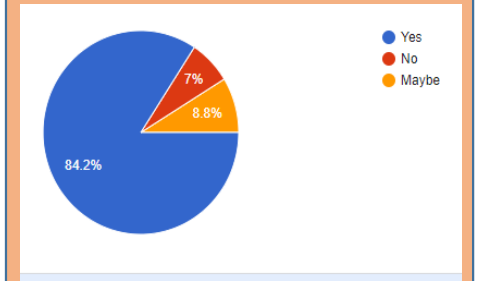


Foreign Competition Increasing

Note: These investments are over a 20-year period across all space sectors. The trend is expected to continue due to economic benefits, and geo-political turmoil with Space becoming the high-ground

28 commercial space companies participated in the Additive Manufacturing TPS Workshop (3/22)
One of the goals was to seek Industry perspective on NASA's role

Key Results from the Survey Prior to Workshop

Launch Vehicles and Landers	Earth Entry from LEO	Military Hypersonic Vehicles	Commercial Hypersonic Vehicles
1. Are you interested in considering NASA developed TPS for near-term (~2 years) applications?			
			
2. Are you interested in collaborating with NASA for mid and longer-term (> 2 years) applications?			
			

“Industry looks to NASA for core knowledge and technology”
- Finding from the AM TPS Workshop

Outlook for NASA Missions

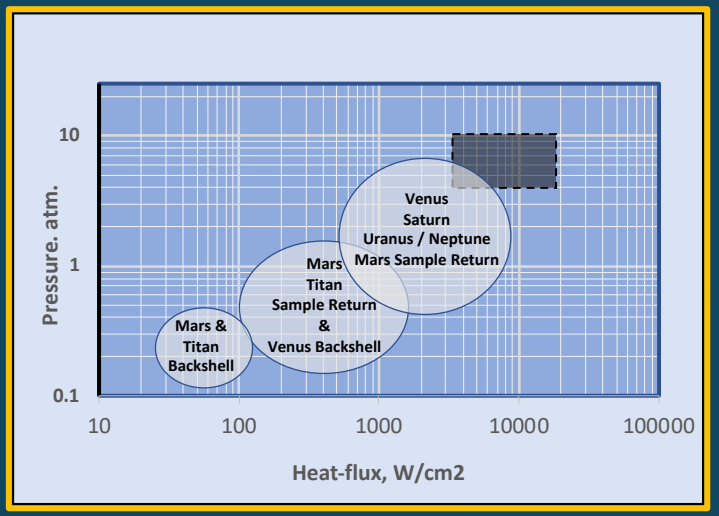
- Human Missions:
  - LEO Return (ISS)
    - Space-X Crew, Boeing, Sierra Space*
  - Future Commercial Space Station
    - Blue Origin, Nanoracks, Northrop Grumman
  - CiS Lunar and Lunar Return
    - Orion*, Starship*(?)
  - Mars (too far away)

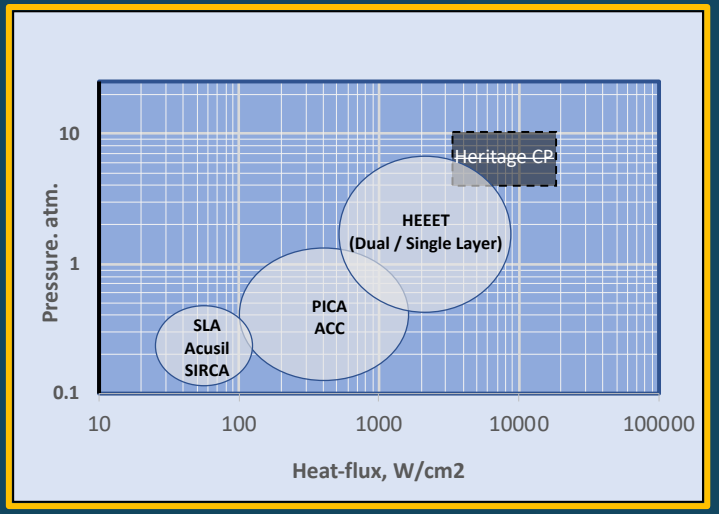
* TBD

- Planetary Missions: Cadence (2 – 4)/ Decade
  - (2027 – 2032)
    - MSR (SRL and EES), Dragonfly and DAVINCI
  - (2033 – beyond)
    - NF-5 (may or may not require TPS),
    - Uranus Orbiter and Probe (UOP) Flagship Mission

High TRL ABLATIVE TPS

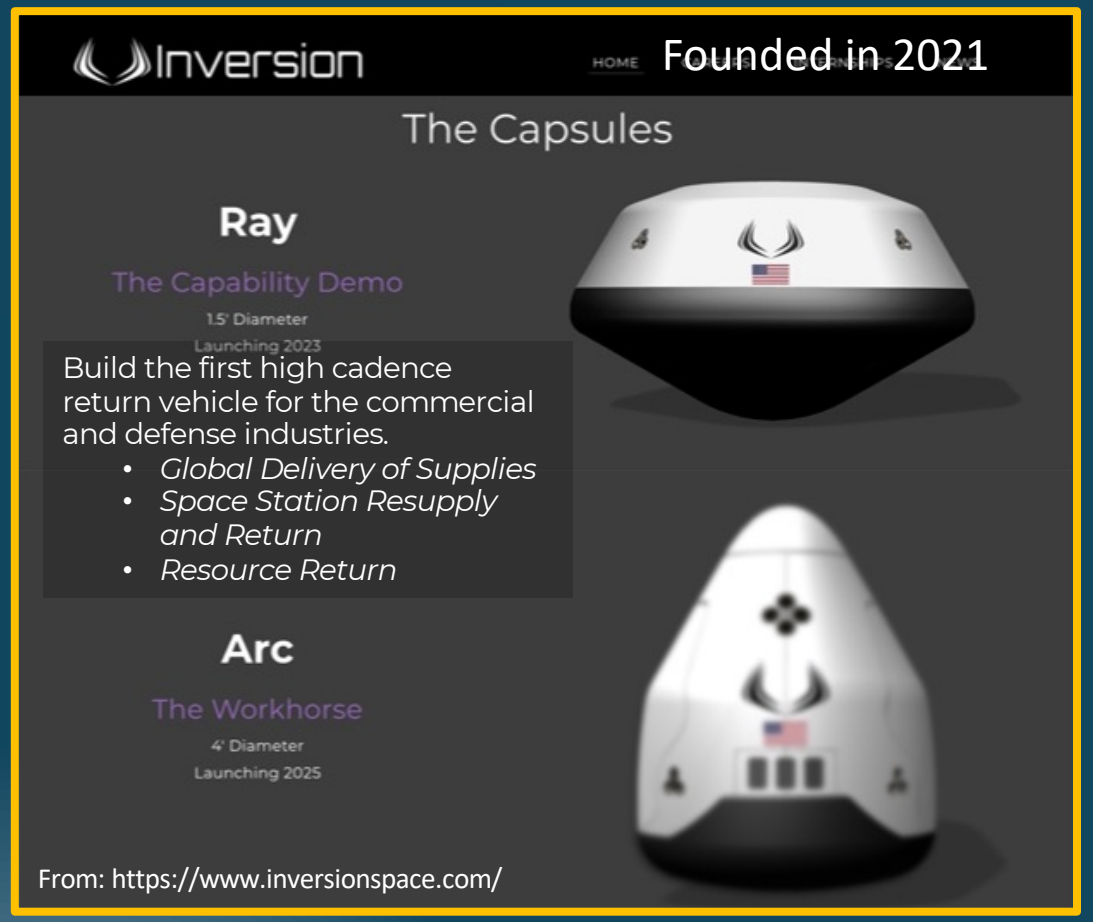
1. SLA (LM)
2. Acusil-2 (Peraton)
3. *SIRCA (NASA)*
4. PICA (NASA) and PICA-X
5. *C –PICA (NASA)*
6. *AVCOAT (TEXTRON)*
7. *BLA (Boeing)*
8. ACC (LM)
9. 3-D Woven (NASA)





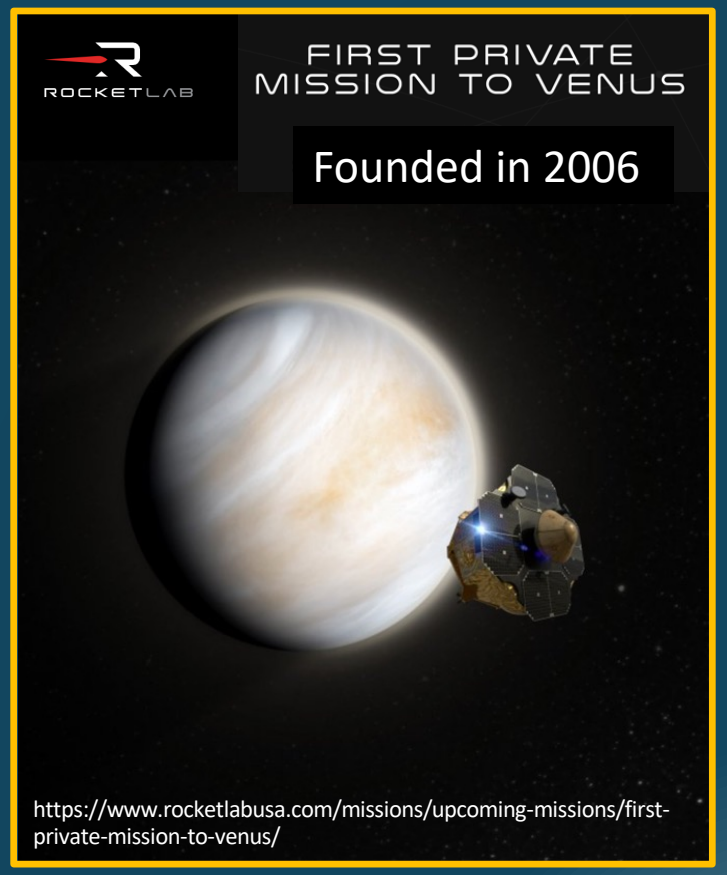
SOA High TRL ablative TPS can meet planned current and future mission needs except for Jupiter Probe (top blacked out area due to atrophy of Heritage CP).

Emerging Commercial Space Companies - VARDA and Inversion



- Both companies have plans for the first LEO flight test in 2023 and a second flight test soon afterwards.
- Both companies are planning ~6 to 12 flights per year in the near term.
- Both companies have engaged NASA for Tech Transfer of C-PICA and are using it for their first mission

Emerging Commercial Space Companies – Rocket Lab and Impulse



- Privately funded missions to Venus (Rocket Lab) and Mars (Impulse) 2025/2027
- Both companies have engaged NASA for potential TPS tech transfer
- Possible business strategy: Compete for NASA robotic missions
  - Initially focus on inner solar system
  - Focus on sample return and outer planet missions in the longer term

Commercial Space Missions, Ablative TPS Needs and Approach

- No viable options for off-the-shelf, commercially available ablative TPS
  - Companies either
    - Develop their own TPS (time and money)
    - Acquire the technology from NASA
- Almost all companies are planning on “Vertical-Integration” to control cost and risk (quality, schedule, supply chain issues, etc.)
  - In-house manufacturing, assembly and integration
- Leveraging existing NASA TPS
  - Allows them to achieve their goal in the near-term
  - Once they establish in-house manufacturing, they can improve TPS
- Companies look to NASA for innovative and cost effective TPS options

Commercial Space has Two Key TPS Requirements: **Cost and Robustness**

Costs: Can be grouped into 3 categories

1. R&D costs (TRL 1-5/6),
2. Fixed (e.g. manufacturing and integration equipment)
3. Reoccurring costs per mission (e.g. TPS manufacturing and integration)

A Strategy:

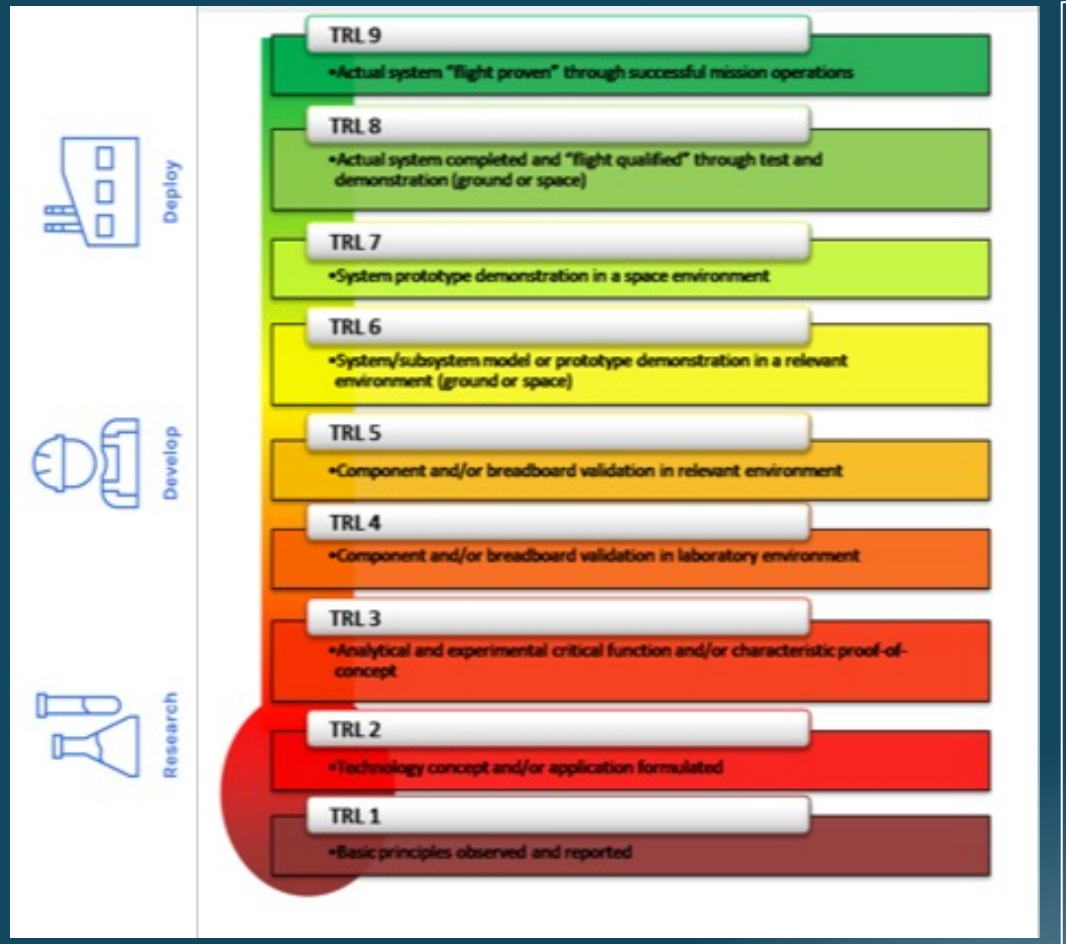
- Look to NASA to perform R&D and transfer technology
- Through ”Vertical Integration” control reoccurring costs

Robustness:

- Avoid TPS (mission) failure => Robustness
  - Can afford mass to buy robustness (use more capable but heavier TPS)
- Emerging space companies want immediate mission success, can’t fail in the first few missions.
  - Can take “educated” risks once the have mission/flight experience
  - Achieve reduction in mass and cost in the future w/o compromising robustness

Commercial companies want NASA to continue to develop innovative ablative TPS but with the emphasis on reducing reoccurring costs without compromising robustness

NASA Approach to Technology Maturation (TRL)

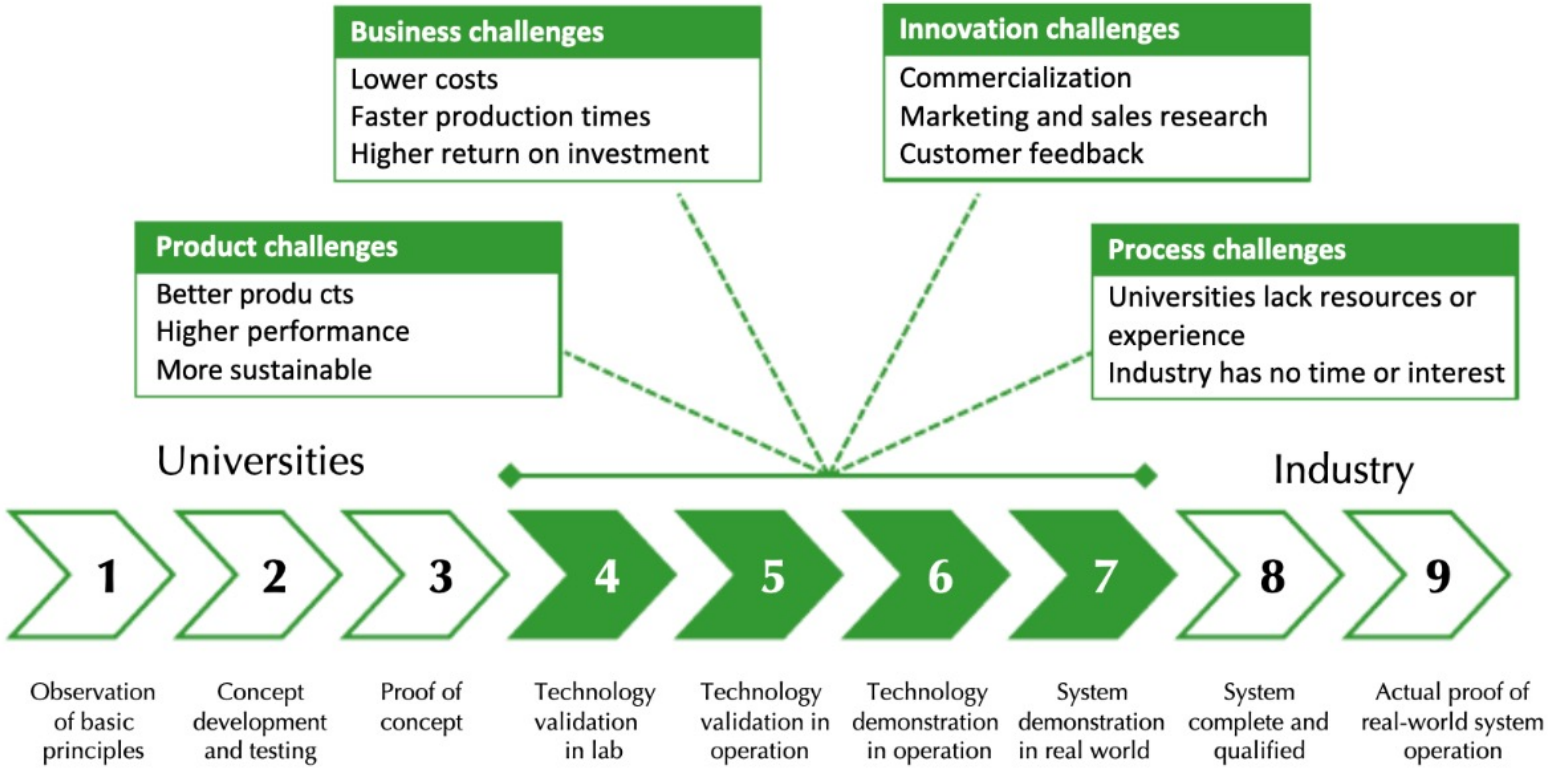


- NASA's technology maturation does not address cost, manufacturing and integration (CM&I) explicitly.
- NASA's tech maturation focus is on capability. Projects working with industry to figure out cost for M&I.
- Manufacturing and Integration Readiness Levels (MRL[1] and IRL[2]) were developed and adopted by DoD.
  - MRL and IRL go hand-in-hand with TRL
  - Many commercial companies have adopted them
- In developing the family of 3-D Woven TPS, we paid attention to manufacturing and engaged industry from TRL 2-3 stage and transferred technology

Rethink NASA's approach in responding to the needs of commercial space companies

1. *"Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes (GAO-02-701)" (PDF). July 2002.*
2. Sauser, B., Gove, R., Forbes, E., & Ramirez-Marquez, J. E. (2010). Integration maturity metrics: Development of an integration readiness level. *Information Knowledge Systems Management, 9*(1), 17–46.

Challenges have Many Facets and Common Across Many Industries



Ref: Hensen, J.L.M., Loonen, R.C.G.M., Archontiki, M., Kanellis, M. (2015). Using building simulation for moving innovations across the "Valley of Death". REHVA Journal, Volume 52, Issue 3, pp: 58-62

What should NASA do differently?

- We need to rethink NASA's Tech Maturation Approach with Cost (Reoccurring) as a metric
  - **Design-out** costly features and **design-in** cost-effective ones.
    - e.g., Ablative TPS could be agnostic to structure, seamless/ reduced # of parts, multi-functional or multi-use
  - Look for robust solution rather than optimal.
    - TPS mass is tradeable with robustness
  - Assess and develop options for cost-effective manufacturing and integration (M&I) from TRL (2-3)
    - "It is always greener on the other side" - Cost-effective (Automation?) vs Disruptive (3D printing?)
  - Develop QA processes (inspection, acceptance spec, etc.) with cost and schedule in mind
    - Features and flaws start at manufacturing and in integration. Not all lead to failure.
  - Develop process scale-up approaches - makes tech transfer easier.
    - M&I from research to commercial scale and associated development should start around TRL 4-5
- Sustainability – Most TPS in use by NASA missions have experienced atrophy/supply chain issues
  - Develop options for raw materials, processes and for vendors
  - Heritage shuttle era reusable TPS also facing constituent supply chain issues

Collaborative approach focused on cost-effective ablative TPS right from the beginning.
With academia, vendors and manufacturing experts, and with commercial space companies.

What should NASA do, in addition?

Investment within NASA need to be focused on specific challenges (TRL 2 - TRL 5/6) with recurring costs in mind:

- Computational materials and modeling expertise - application of tools *
  - To predict and understand new material performance/behavior
  - Failure modes - what features and flaws lead to failure or not *
- We are exploring “Simulate as we Fly” leveraging data from ”relevant” tests.
  - Can we predict “ good enough” material properties (at temperature) rather than just by testing?*
  - Can we develop understanding of “facility to facility” and “facility to flight“ differences which will allow us to use appropriate test facilities at appropriate stage of development for cost effectiveness
  - Can we develop “good enough” thermal response model at early development stage?
  - Can we predict performance boundaries using higher fidelity simulations?
    - Arc jet or other test facilities do not allow us to explore performance “Cliffs” and are expensive.
- Verification through analysis in combination with testing*
  - Will require understanding the nuances in manufacturing and integration process.
  - Leverage development in digital manufacturing, automated quality control and integrated analysis approaches as needed

* NASA is investing in aspects of these already – tailoring and application to specific TPS can have great benefit

Concluding Remarks

- Commercial space (CS) industries are taking advantage of NASA expertise and technologies in TPS (ablative and reusable) to meet their immediate needs.
- Industry looks to NASA for innovative and cost-effective TPS in the near and longer term.
- NASA needs to create new ways of partnering with Industry, leverage existing expertise, tools and collaborations with Universities and other Govt' institutions and new approaches to meet the commercial industries need for "Cost-effective" TPS.
- Final Thought: Frequent CS flights or approaches such as KREPE/KRUPS offer opportunities to get "relevant" flight data on a variety of materials.
  - How would that change our approach?

Acknowledgements

- The perspectives presented here are a result of conversations that have been on-going with multitude of folks in Industry, NASA and elsewhere.
    - Specifically, the Additive Manufacturing Workshop, conducted over 18 months provided insights from both within NASA and with Industry participants. Mr. Stan Bouslog (NASA JSC) Co-chaired the AM TPS Workshop and Dr. Adam Sidor (NASA JSC) and Mr. Craig Stephens (NASA AFRC) were critical to the success.
- The perspectives/recommendations presented here are personal views and not that of NASA.