COE CST Eleventh
Annual Technical Meeting

FAA COE CST Task #253:
Ultra-High Temperature Composites Thermal Protection Systems

Jan Gou, Jay Kapat, Derek Saltzman, Haonan Song

Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

Team Members

- **People**
  - PIs: Drs. Jan Gou & Jay Kapat
  - Students: Derek Saltzman & Haonan Song
- **Organizations**
  - Industry and Research Partners
  - Organizations Providing Matching Funds: University of Central Florida

Task Description

- **Materials Development**: Development of the buckypaper heat shield materials for ablative composites TPS in extreme environments
- **Process Optimization**: Process development for the buckypaper manufacturing towards high heat shielding efficiency on for ablative composites TPS
- **Testing & Performance Evaluation**: Ground testing of the buckypaper heat shield for ablative composites TPS with oxyacetylene torch/shock tube/rocket plume/arc jet test
- **Thermal-Mechanical Modelling and Validation**: Thermal-mechanical modelling and validation of ablative composites TPS with the buckypaper heat shield under aerodynamic heating

Schedule

2021 - 2022

- **Q1**: Design and fabrication of the buckypaper heat shield for ablative composites TPS
- **Q2**: Oxyacetylene Torch Test of the buckypaper heat shield for ablative composites thermal protection systems
- **Q3**: Process optimization of the buckypaper manufacturing using the layer-by-layer (LBL) self-assembly process
- **Q4**: Evaluation on heat shielding performance of the buckypaper for ablative composites TPS

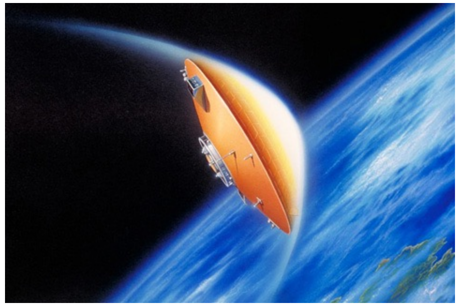
Goals

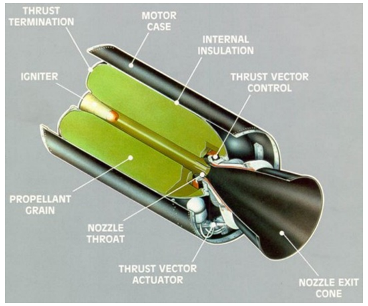
<u>Research Objective</u>:

Develop the buckypaper heat shield for **light weight**, **low erosion**, **cost effective** ablative composites thermal protection systems

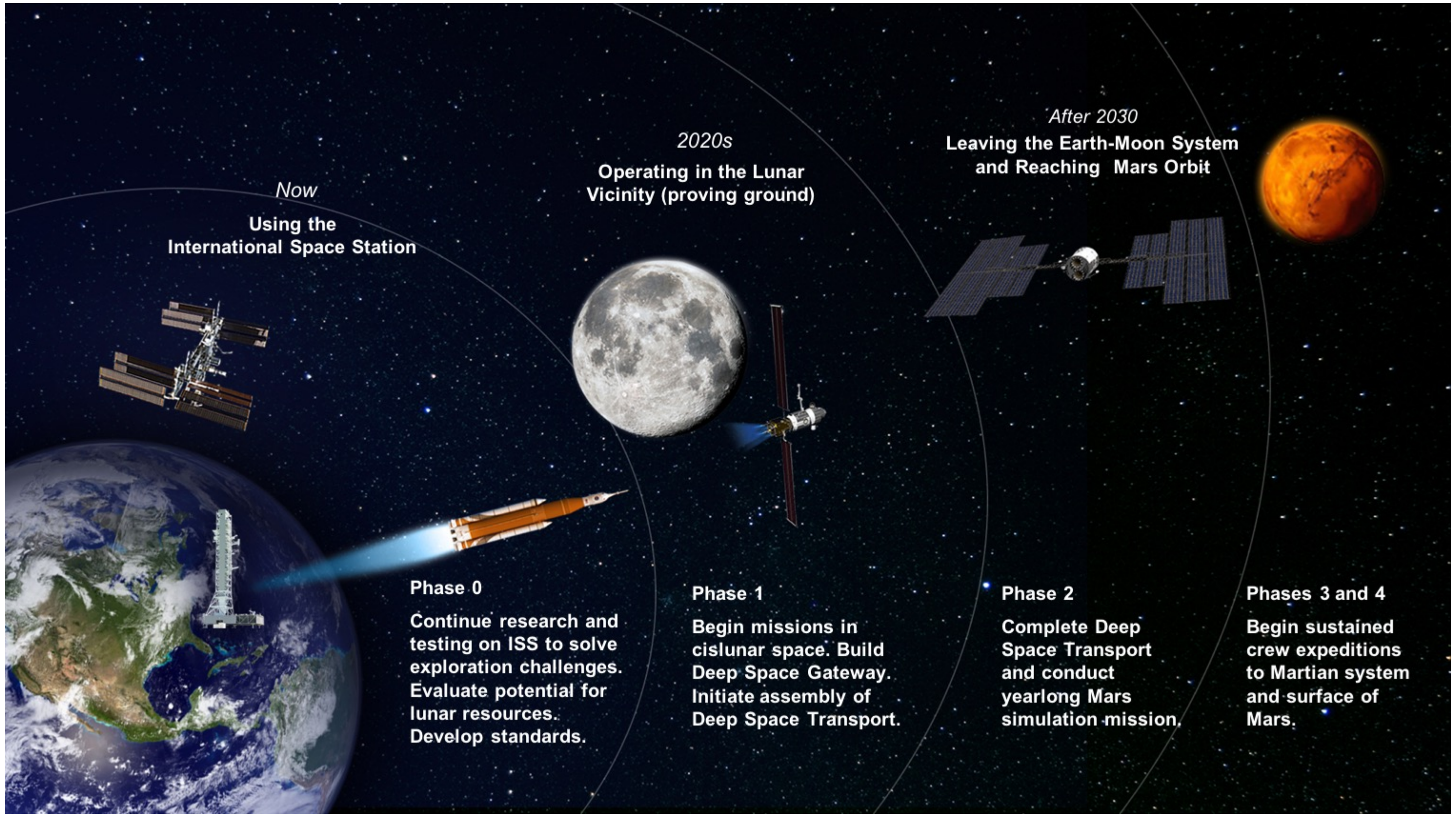
<u>Relevance to Commercial Space Industry:</u>

The buckypaper heat shield potentially can be used for a variety of applications such as planetary entry vehicles, spacecraft launch vehicles, hypersonic vehicles, combustion chambers, gas turbine blades, and heat exchangers in ultra-high temperature and ultra-high pressure extreme environments.





Why Composites Thermal Protection Systems?



Artemis Program (Credit: NASA)

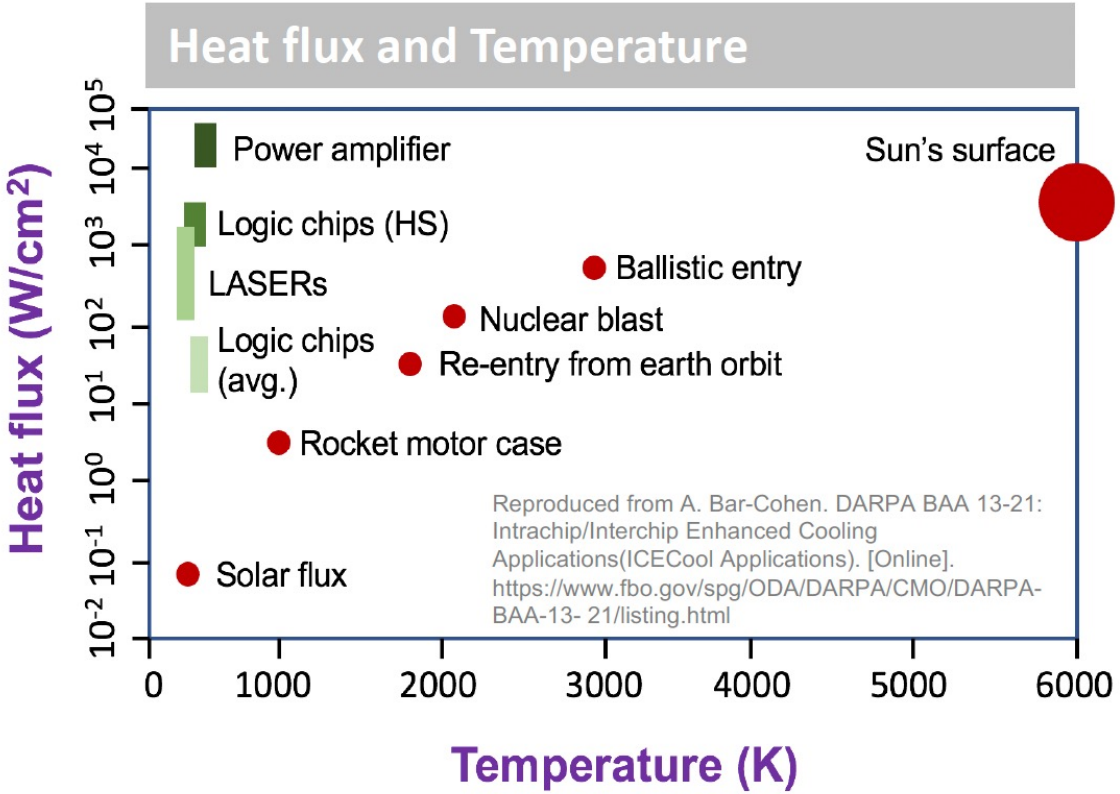
1 manned crew to Mars costs **$1B**

1 pound of payload to Mars costs **$1M**

1 pound of payload to LEO costs **$1,000**

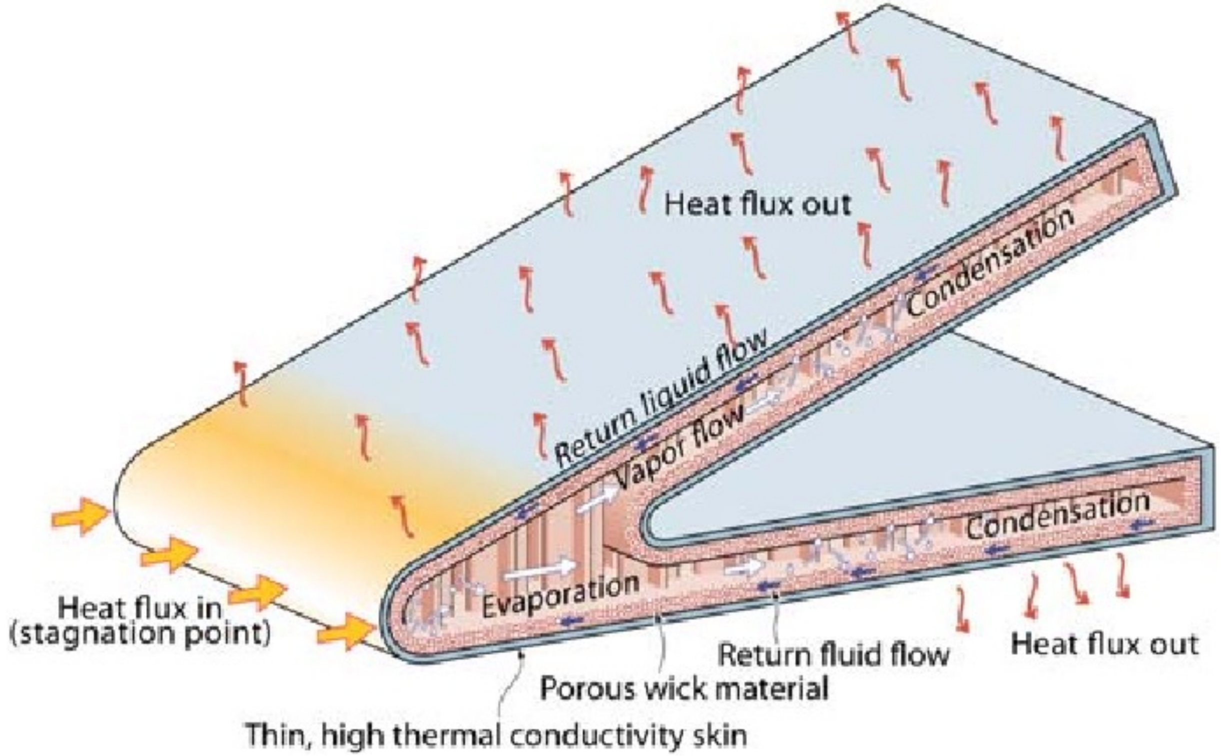
Ablative Composites Thermal Protection Systems for Atmospheric Entry Spacecraft

NASA's Mars 2020 Perseverance Rover Landing



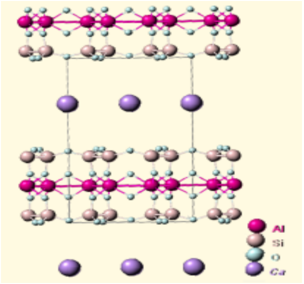
Non-Ablative Composites Thermal Protection Systems for Hypersonic Vehicles

Hypersonic Vehicle (Credit: DARPA)



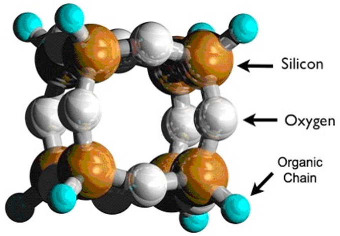
Material Architecture of Sharpe Leading Edge of Hypersonic Vehicles (non-ablative thermal protection systems)

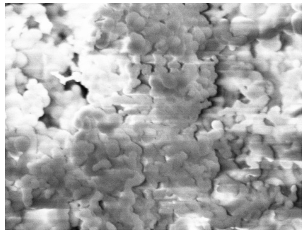
Nanostructured Materials Enabled TPS



Clay

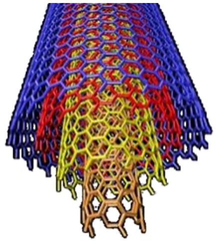
The suggested mechanism is that a protective silicate layer on the surface of condensed phase is formed to function as a barrier to limit O_2 supply, flammable gases, heat and mass transfer between the burning surface and underlying polymer at the elevated temperature.





POSS

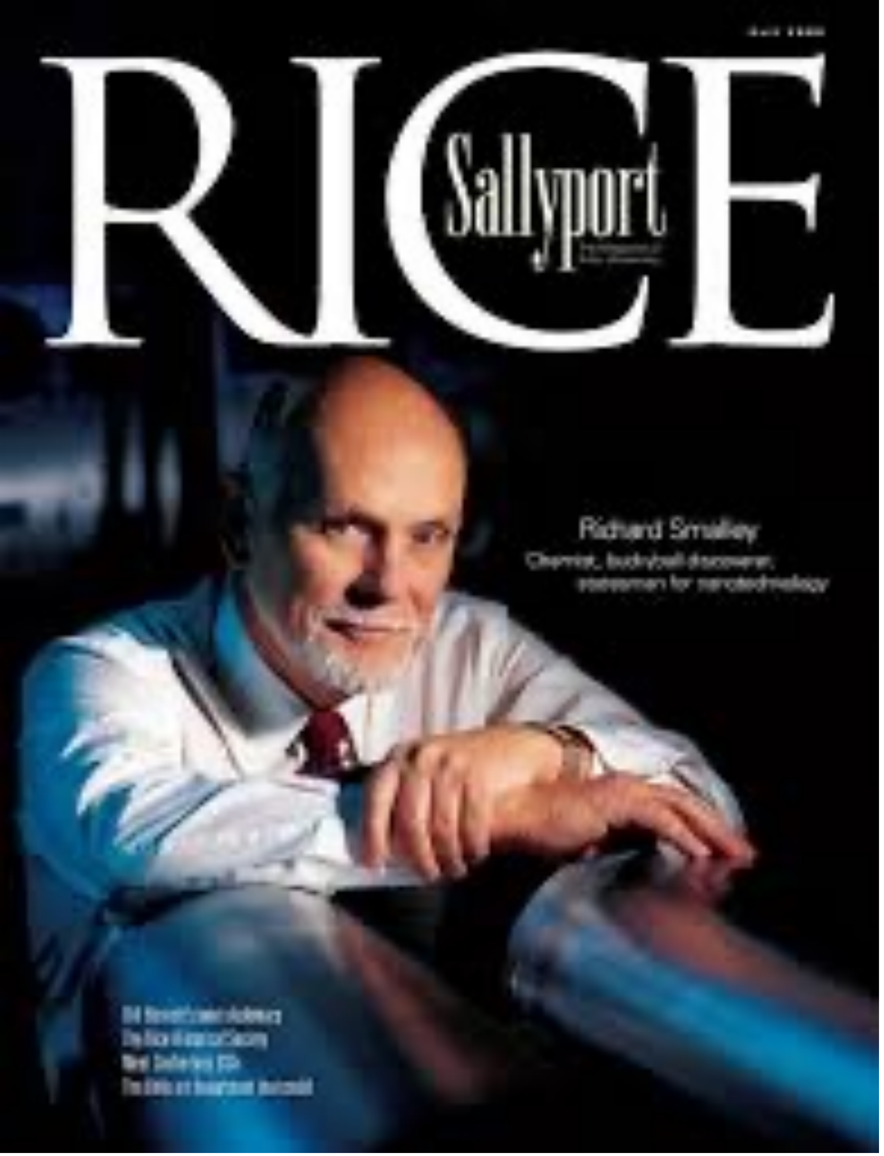
POSS (polyhedral oligosilsesquioxane) is a cage-like structure, organic groups were attached on each corner; at ~300-350°C, Si-C bond cleavage, and to form ceramic –like char, which act as an insulating barrier and protect the underling subtract.



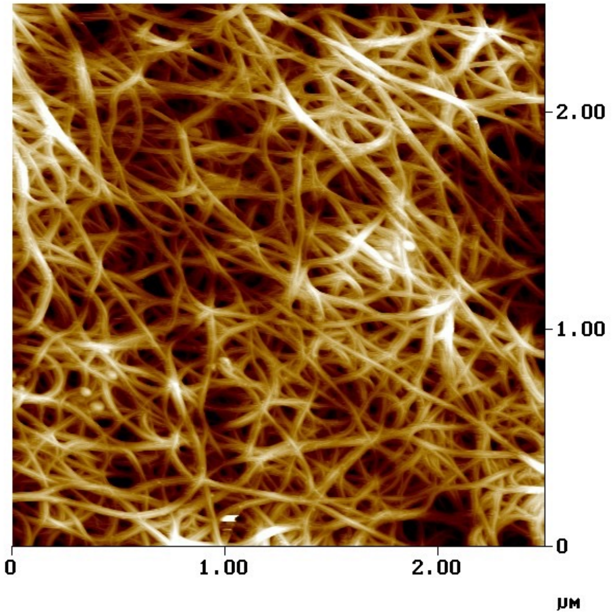
CNT or CNF

The nanocomposities based on carbon nanotubes are capable of forming a continuous network-structured protective layer, which acts as a heat shield for the virgin polymer below the layer.

Buckypaper
(Single-Walled Carbon Nanotube)

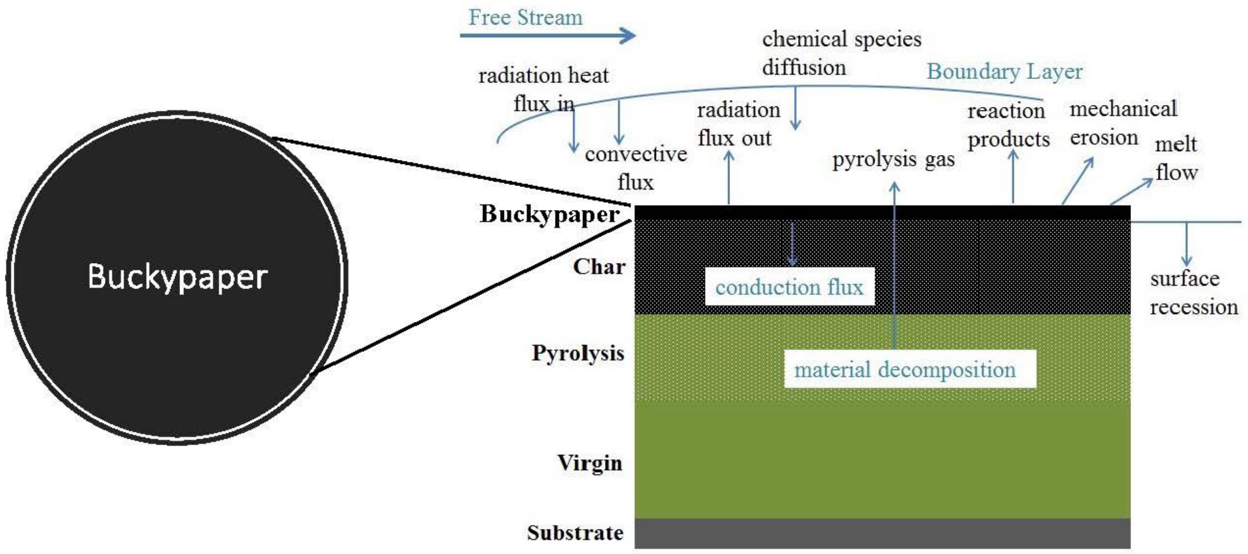


Dr. Richard Smalley (1943-2005)
1996 Nobel Prize in Chemistry



Buckypaper Heat Shield

Heat-shield for Extreme Entry Environment Technology (HEEET)



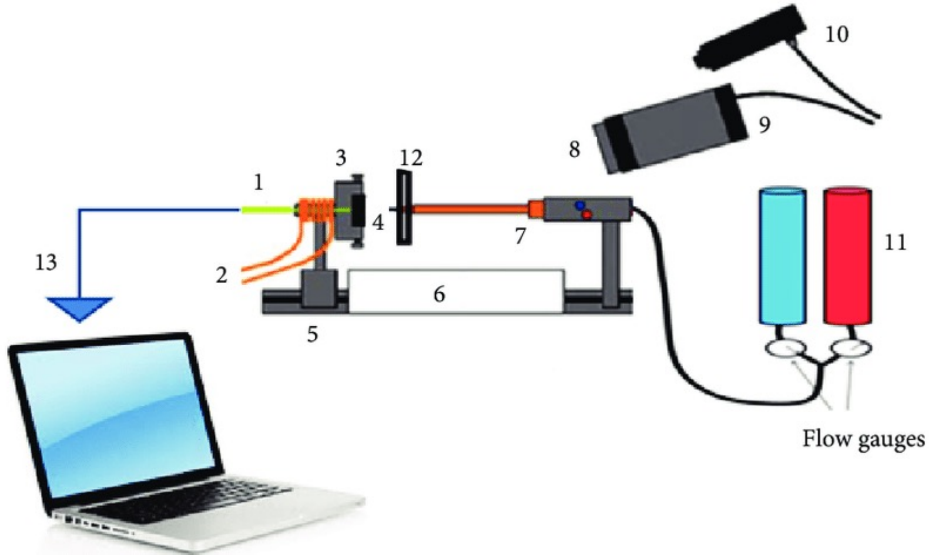
Control and Optimization of Microstructure & Properties:

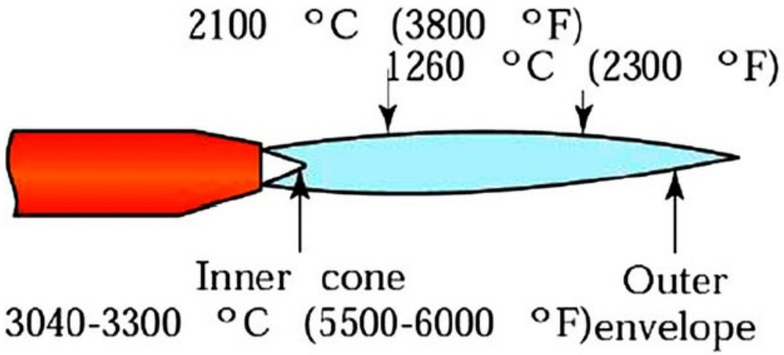
- ❑ Permeability of buckypaper
- ❑ Thermal stability
- ❑ Dispersion uniformity
- ❑ Quality of char formation
- ❑ Heat capacity and thermal conductivity

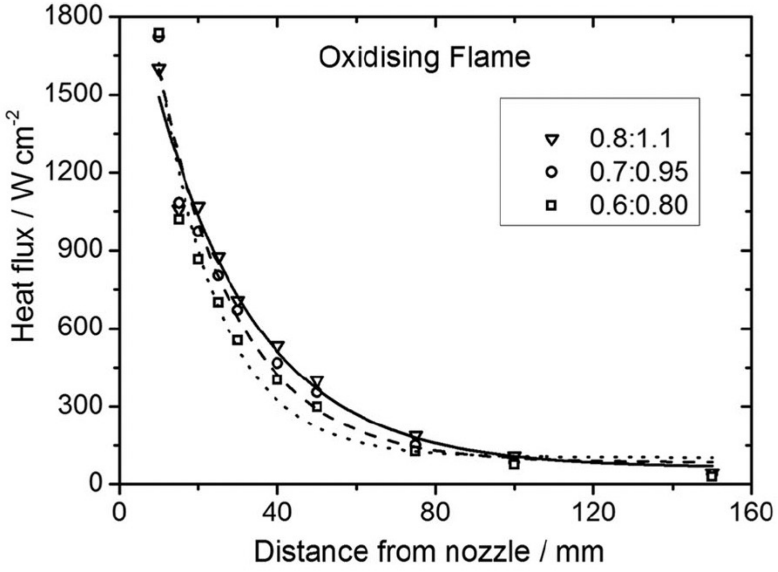
Heat Shield Design with the Buckypaper:

- **Anisotropic thermal conductivity for efficient heat dissipation**. Heat dissipation on the planar surface to avoid hot spots due to anisotropic thermal conductivity in the planar direction and through-thickness direction.
- **High strength and stable char for mechanical integrity**. The resulting chars are structurally weak and susceptible to mechanical erosion under high compression and shear loading, severely reducing the lifetime of the TPS. Reducing spallation or erosion of the char can enable use of less ablative materials thereby reducing the total weight of TPS.

Oxy-acetylene Torch Testing



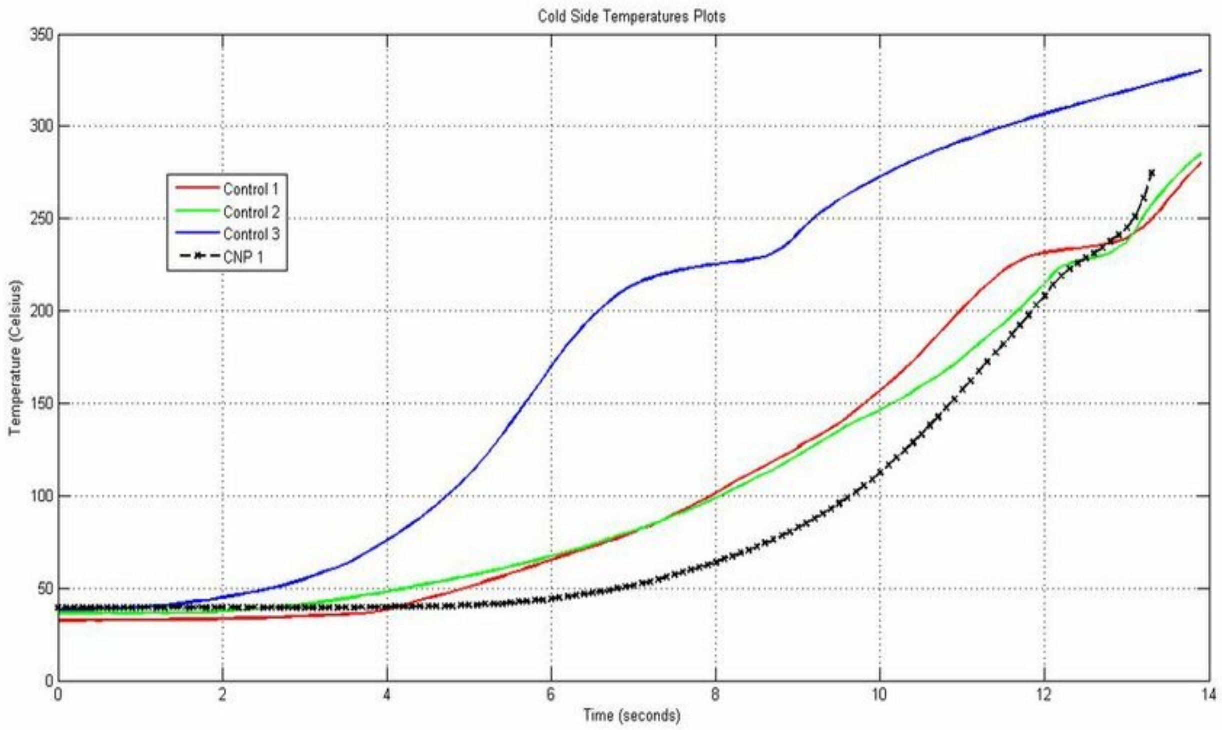




Oxy-acetylene Torch Test

- ❑ Fully equipped with IR camera, heat flux sensor, thermal couples and data acquisition system.
- ❑ Variable heat flux. There are adjustable distances (test positions) between the composites panel and the torch tip.
- ❑ Insulation Index and Erosion Rate of insulating materials

Oxy-acetylene Torch Testing



Back-side temperature of composites thermal protection system with the buckypaper heat shield

Publications, Presentations, Awards, & Recognitions (2021-2022)

PUBLICATIONS

- H. N. Song, D. Saltzman, J. Kapat, J. Gou, "Processing and Characterization of Continuous Carbon Fiber Reinforced Silicon Oxycarbide Ceramic Matrix Composites," *Proceedings of the ASME 2021 International Mechanical Engineering Congress and Exposition (IMECE2021),* November 1-5, 2021 (Virtual Conference)

PRESENTATIONS

- J. Gou, "Science and Technology of Multi-Functional Buckypaper Composites," *NSF REU HYPER Program Seminar*, June 25, 2021
- J. Gou, "Recent Progress in Composite Thermal Protection Systems (TPS)," *FAA AST R&D Quick Look*, August 17, 2021
- H. N. Song, "Processing and Characterization of Continuous Carbon Fiber Reinforced Silicon Oxycarbide Ceramic Matrix Composites," *ASME 2021 International Mechanical Engineering Congress and Exposition (IMECE2021),* November 1-5, 2021
- J. Gou, "Recent Progress in Composite Thermal Protection Systems (TPS)," invited seminar, Department of Mechanical and Aerospace Engineering, University of Miami, November 5, 2021
- J. Gou, "Ablation Modeling and Simulation of Polymer Nanocomposites for Thermal Protection Systems," invited lecture, *Prof. Joseph Koo WebSymposium on Polymer Nanocomposites*, Advanced Materials WebCongress 2021, November 16-18, 2021
- J. Gou, "Ultra-High Temperature Composite Thermal Protection Systems in Extreme Environments," *CECS Virtual Seminar Series*, March 18, 2022

Publications, Presentations, Awards, & Recognitions (2021-2022)

AWARDS

- PI: Jan Gou, Co-PI: Subith Vasu and Artem Masunov, “Ultra-High Temperature Ablative Composites Thermal Protection Systems in Extreme Environments,” *UCF Interdisciplinary Exploration Seed Grant*, $60,000, 01/01/2022-12/31/2022

RECOGNITIONS

- J. Gou, Fellow of International Association of Advanced Materials (IAAM), Sweden

Conclusions and Future Work

- **Final Remarks**
  - The buckypaper heat shield improved the ablative performance of composites thermal protection systems.
  - The microstructures and thermal properties of the buckypaper can be tailored towards high heat shielding performance of ablative composites TPS.
- **Next Steps**
  - Multi-functionalities of the buckypaper heat shield integrating heat shielding with other functionalities, such as electromagnetic performance (e.g., radar-absorbing, radar-penetrating, etc.)
  - The buckypaper heat shield for non-ablative composites thermal protection systems
  - Thermal-mechanical modeling and validation of the buckypaper heat shield for composites thermal protection systems