COE CST First Annual Technical Meeting: Ultra High Temperature Composites for Thermal Protection System (TPS)

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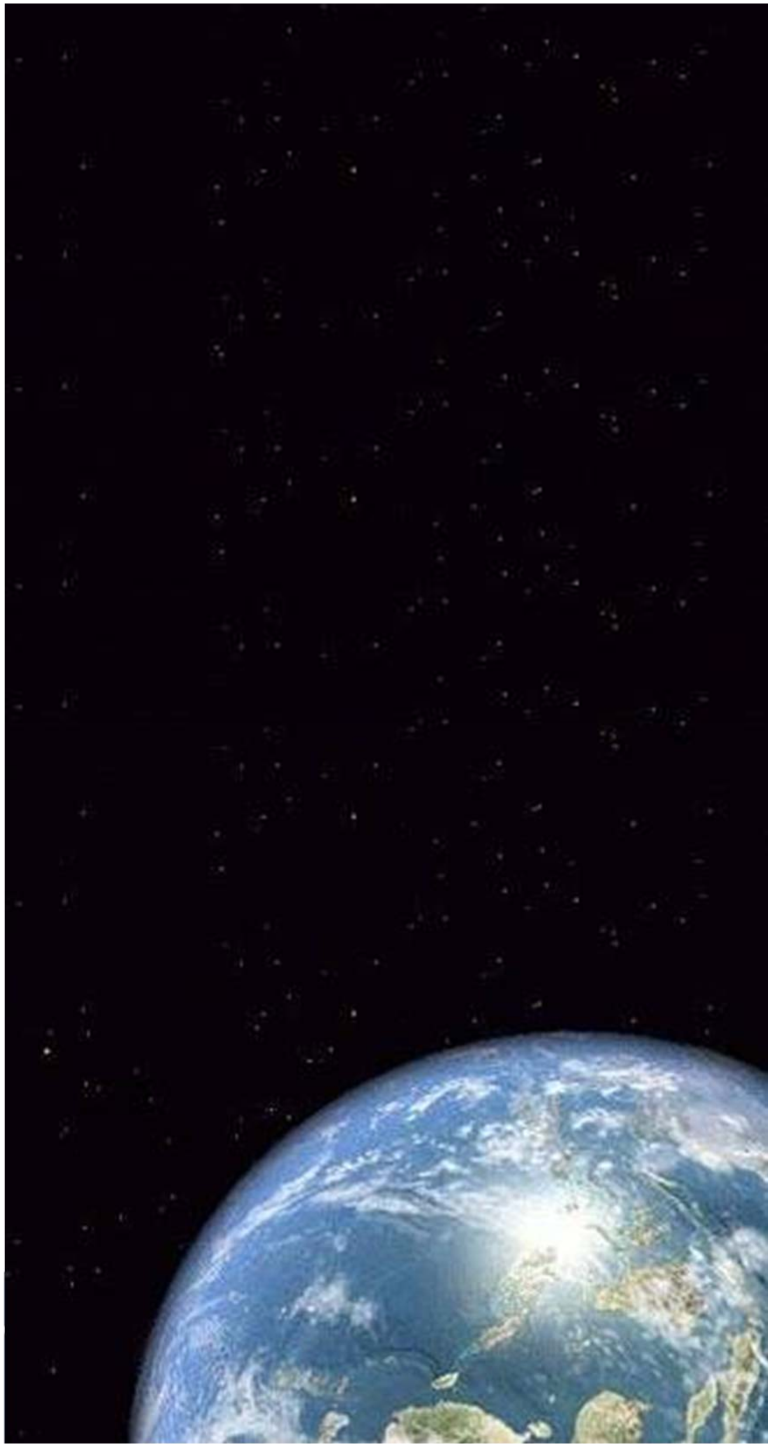


Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information
- Break

Team Members

- Dr. **Jan Gou**, Department of Mechanical, Materials and Aerospace Engineering, UCF
  - Polymer and ceramic nanocomposites
  - Thermal degradation modeling
- Dr. **Jay Kapat**, Department of Mechanical, Materials and Aerospace Engineering, UCF
  - Temperature and pressure measurement, thermal modeling
  - Ablation sensing
- Dr. **Linan An**, Advanced Materials Processing and Analysis Center, UCF
  - Polymer derived ceramics, high temperature sensors
- Dr. **Ali Gordon**, Department of Mechanical, Materials and Aerospace Engineering, UCF
  - Thermo-mechanical characterization and modeling
- **Students**: Jeremey Lawrence, James DeMarco, Jinfeng Zhuge

Research Task #253

Objective:

- Develop ultra high temperature, light weight, and cost effective nanocomposites with embedded health monitoring for **inherent safety and real-time assessment** of thermal protection system applications in hypersonic space vehicles

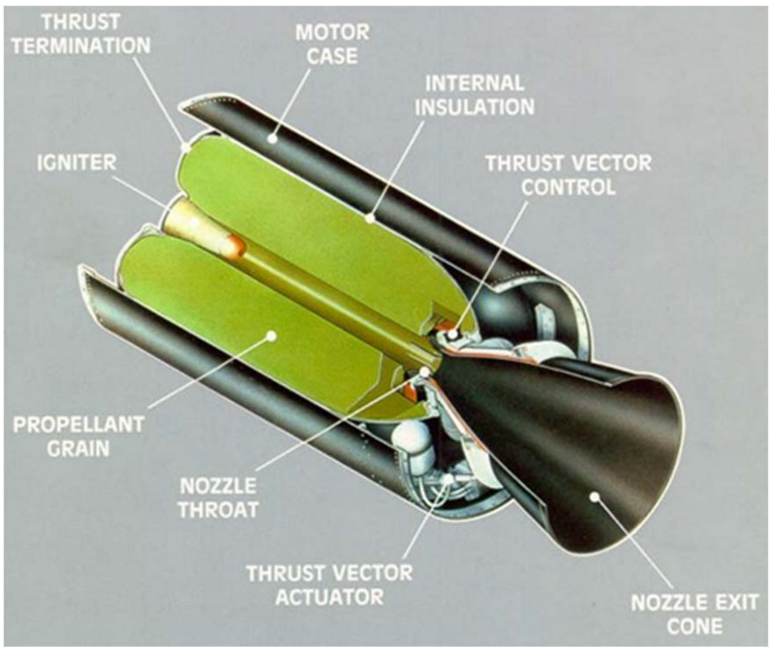
Goals:

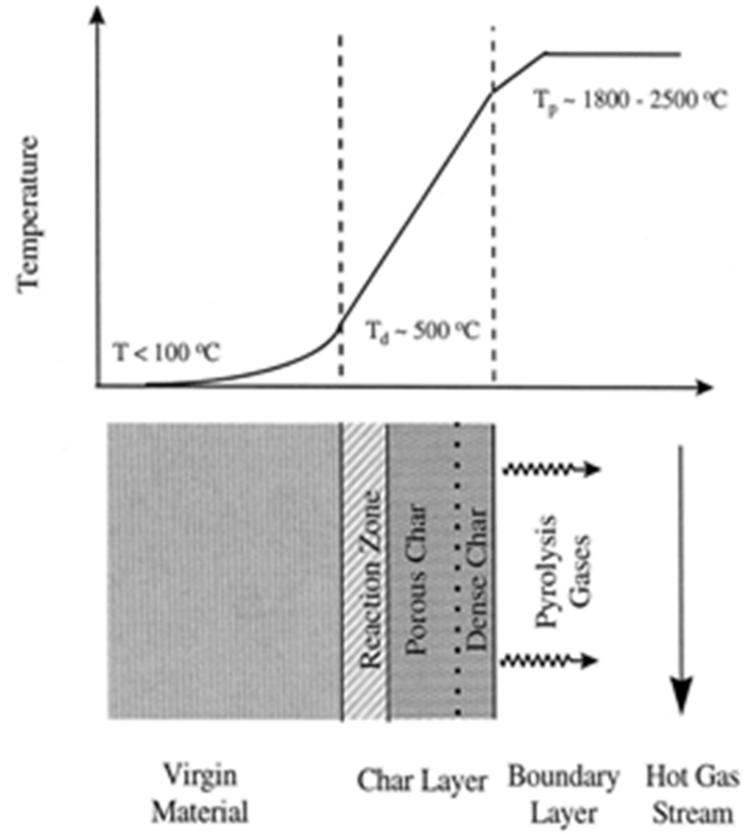
- Develop light weight and cost effective ablative materials against solid rocket exhaust plumes with Al_2O_3 at very high velocity
- Provide an analysis tool for the thermal degradation modeling of new ablative materials
- Provide ablation sensing to monitor the structural health of the ablative thermal protection system

The Delta II Carries 1,800 Pounds of Ablatives

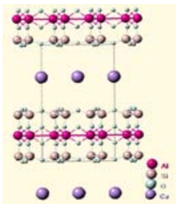
Current Approach

- PICA: Phenolic Impregnated Carbon Ablator
- SICA: Silicone Impregnated Carbon Ablator
- Carbon/Carbon Composites



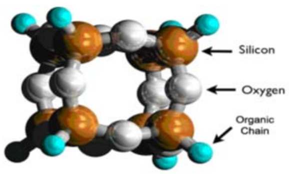


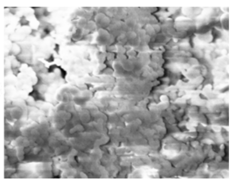
Nanocomposite Approach



Clay

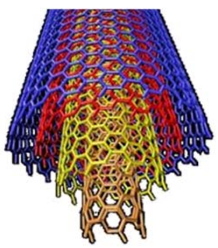
The suggested mechanism is that a protective silicate layer on the surface of condensed phase is formed to function as a barrier to limit O_2 supply, flammable gases, heat and mass transfer between the burning surface and underlying polymer at the elevated temperature.





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.

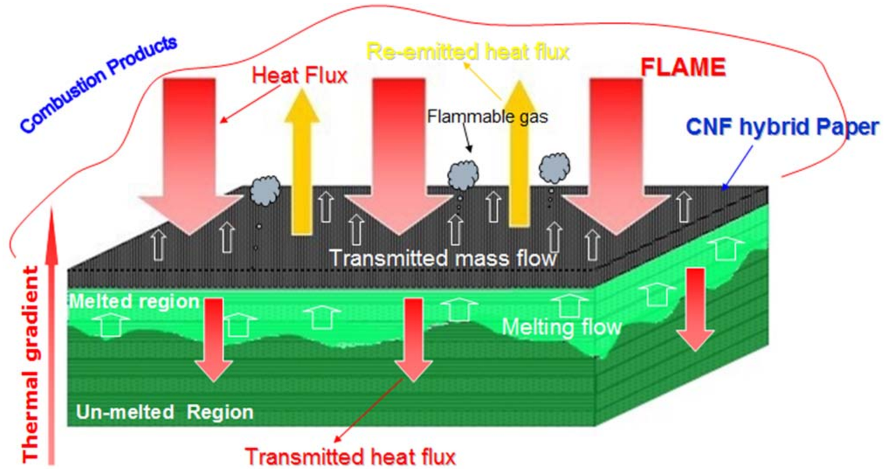


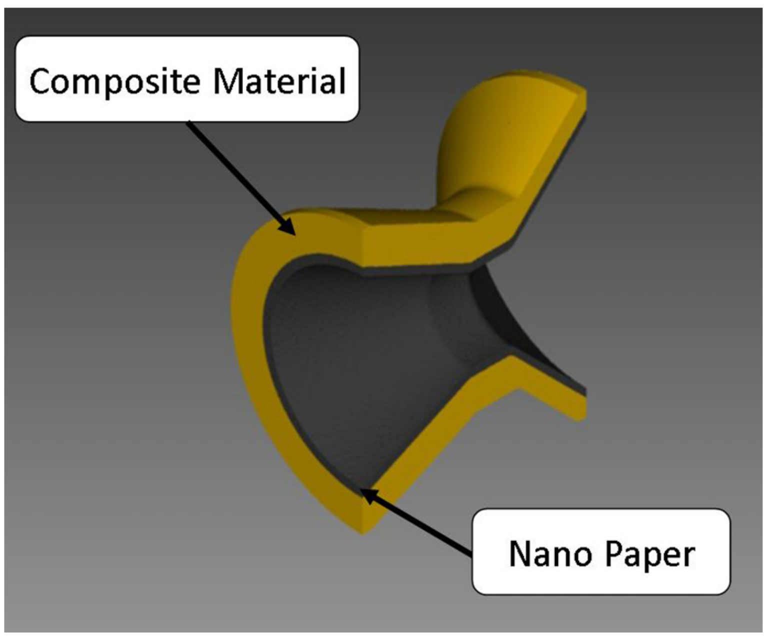
CNT or CNF

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.

Ceramic Nanocomposites

- Conducting heat in one direction, along the alignment of the nanotubes, but reflecting heat at right angles to the nanotubes
- High anisotropy of thermal conductivity of the nanopaper: in-plane and through-thickness direction





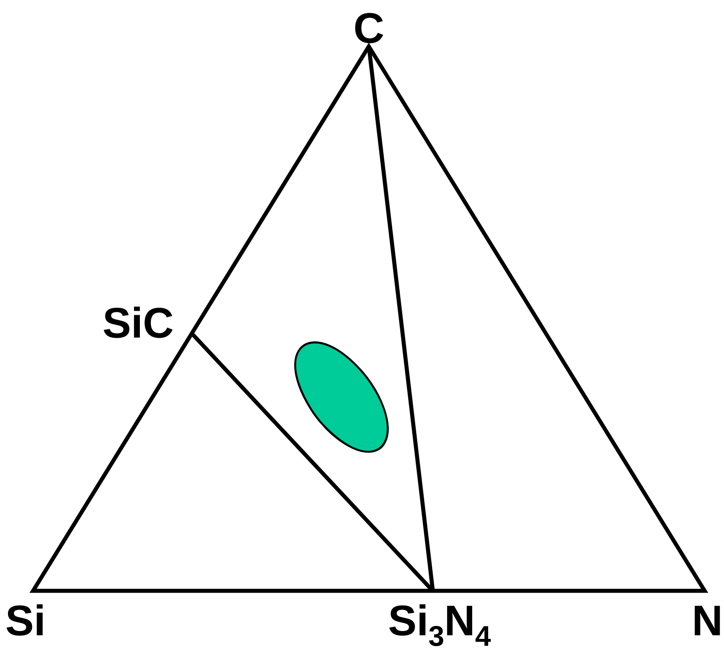
Ablation Performance of Nanocomposite

- Permeability of the nanopaper
- Thermal stability of nanoparticles
- Dispersion of nanoparticles
- Quality of char formation
- Thermal conductivity
- Heat capacity

Polymer Derived Ceramics (PDC)

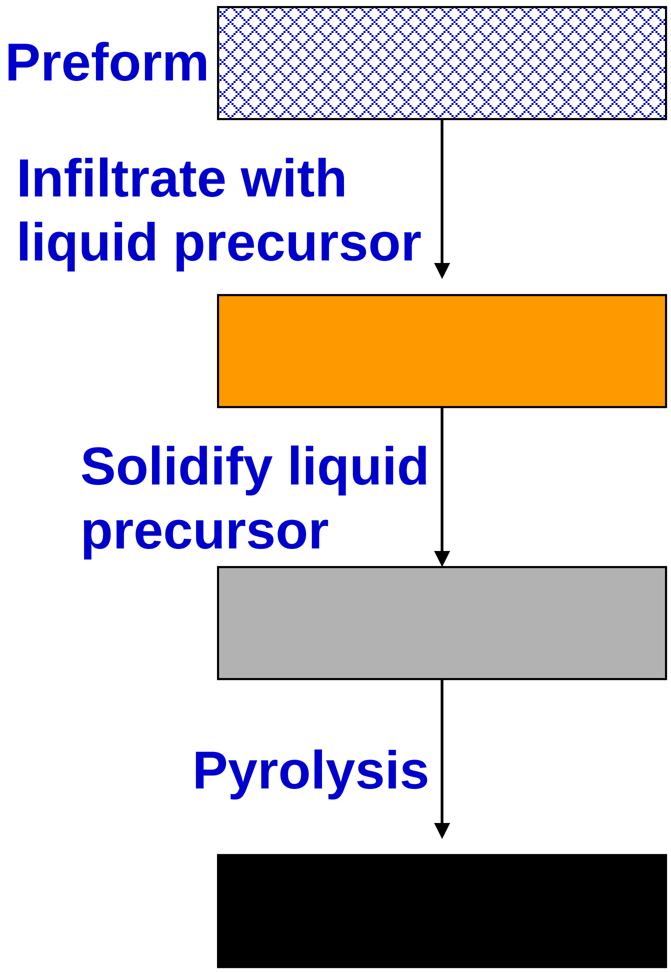
Starting materials → Chemical synthesis → **Polymer precursor** → Cross linking → **Infusible preceramic network** → Pyrolysis 800-1000 ºC → **Amorphous Ceramics**

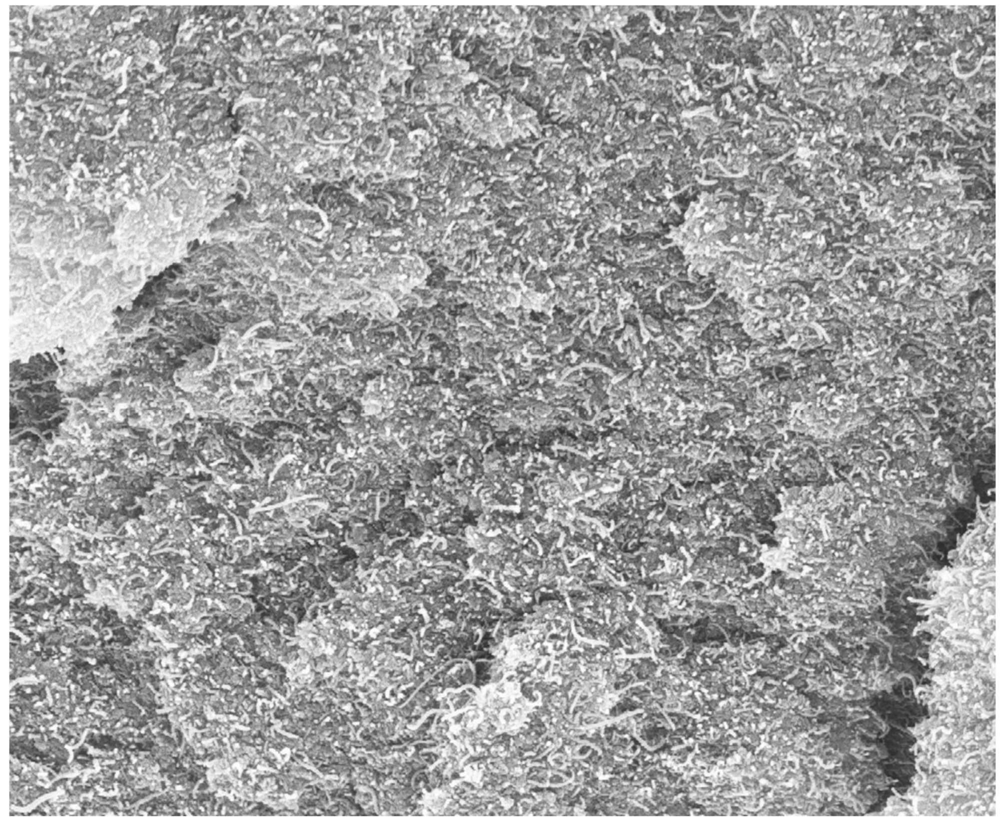
SiCN Ceramics



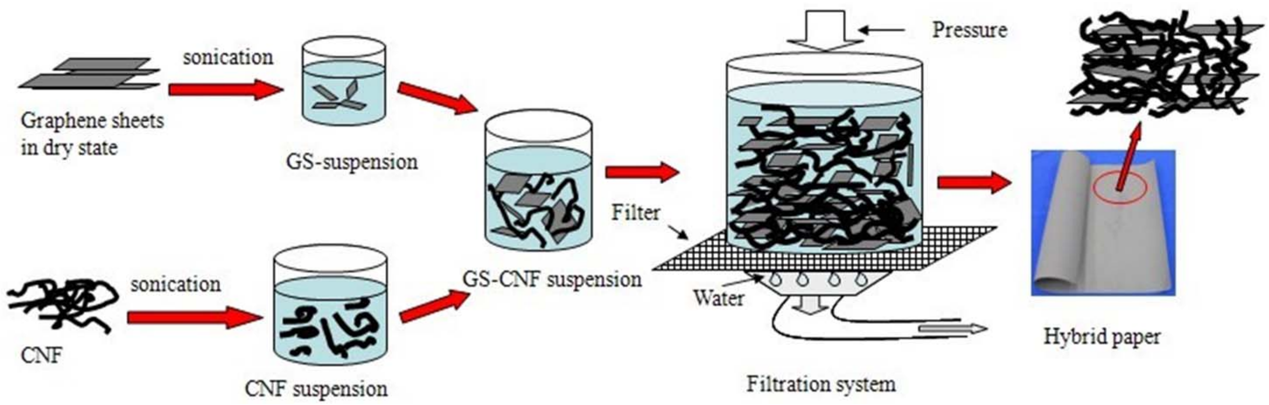
	SiCN	SiC	Si_3N_4
Density (g/cm^3)	2.0-2.3	3.17	3.19
E-modulus (GPa)	~150-200	400	320
Poisson's ratio	0.17	0.14	0.24
CTE ($x10^{-6}/K$)	~3	3.8	2.5
Hardness (GPa)	15-20	30	28
Strength (MPa)	500-1000	420	700
Thermal Shock FOM	~3000	250	880

Carbon Nanopaper/PDC Composite



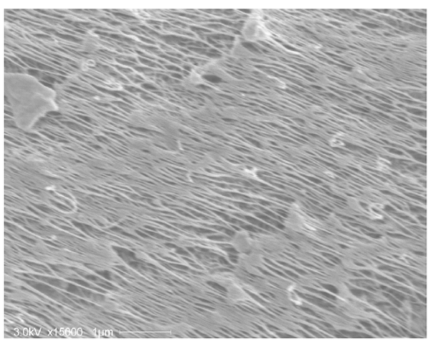


Nanopaper Manufacturing



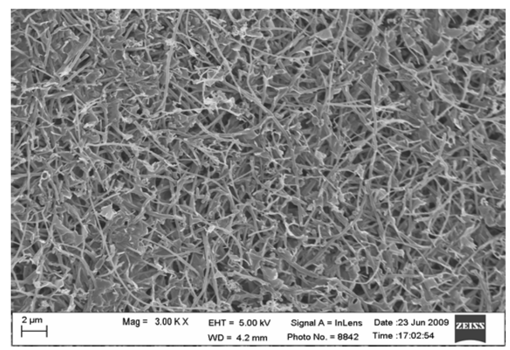
Microstructural Characteristics

- *Porosity*
- *Thickness (5-10 um)*
- *Orientation*
- *Permeability*
- *Thermal stability*
- *Thermal conductivity*
- *Heat capacity*

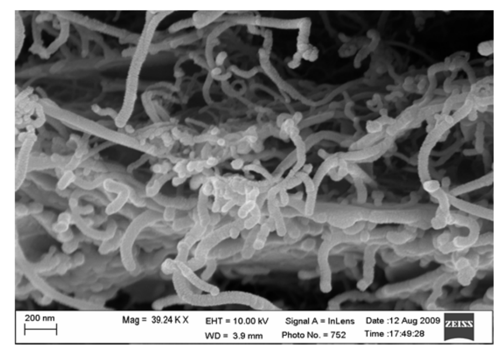


Aligned MWNT

CNF/POSS

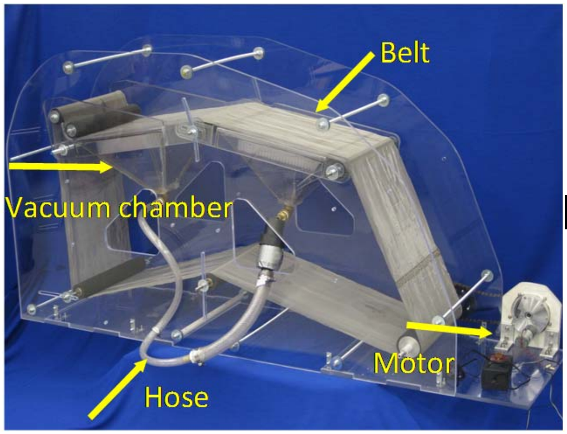


CNF/Nanoclay

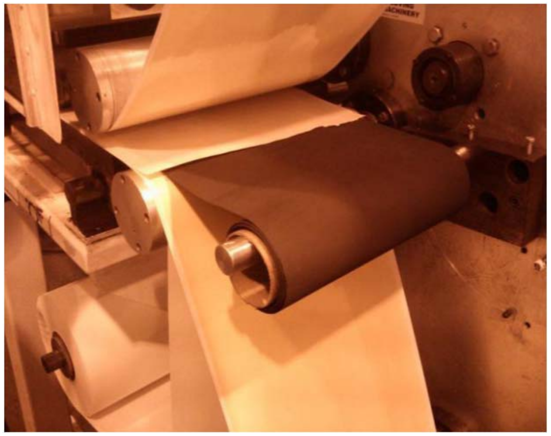


CNT/Graphite Nanoplatelets

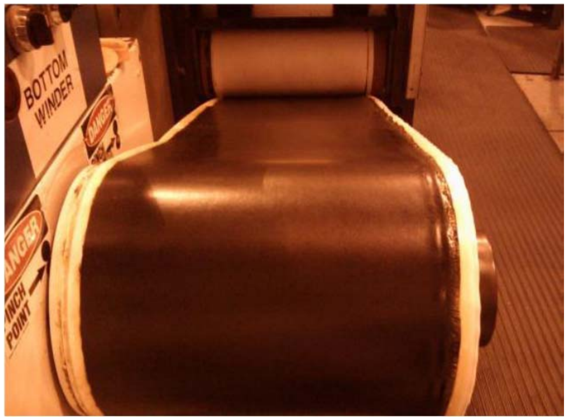
Process Scalability



Infiltration System

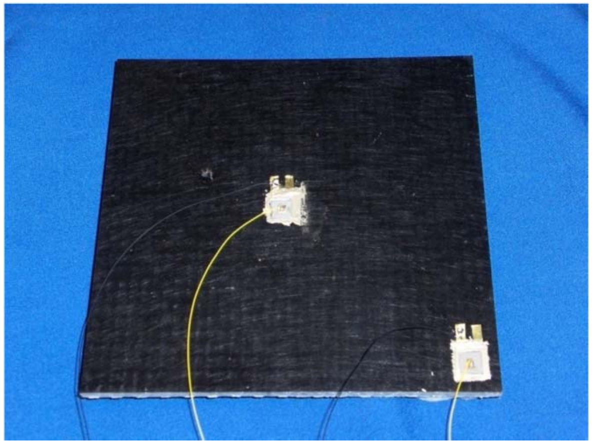


Compressing System



Prepreg System

Autoclave Process

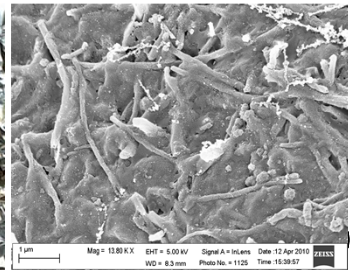


Composite Panel

Heat Release Rates

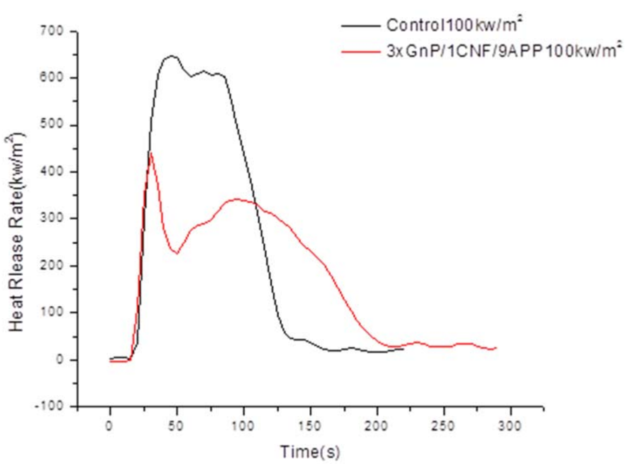
Test Sample (Φ76mm)

Char

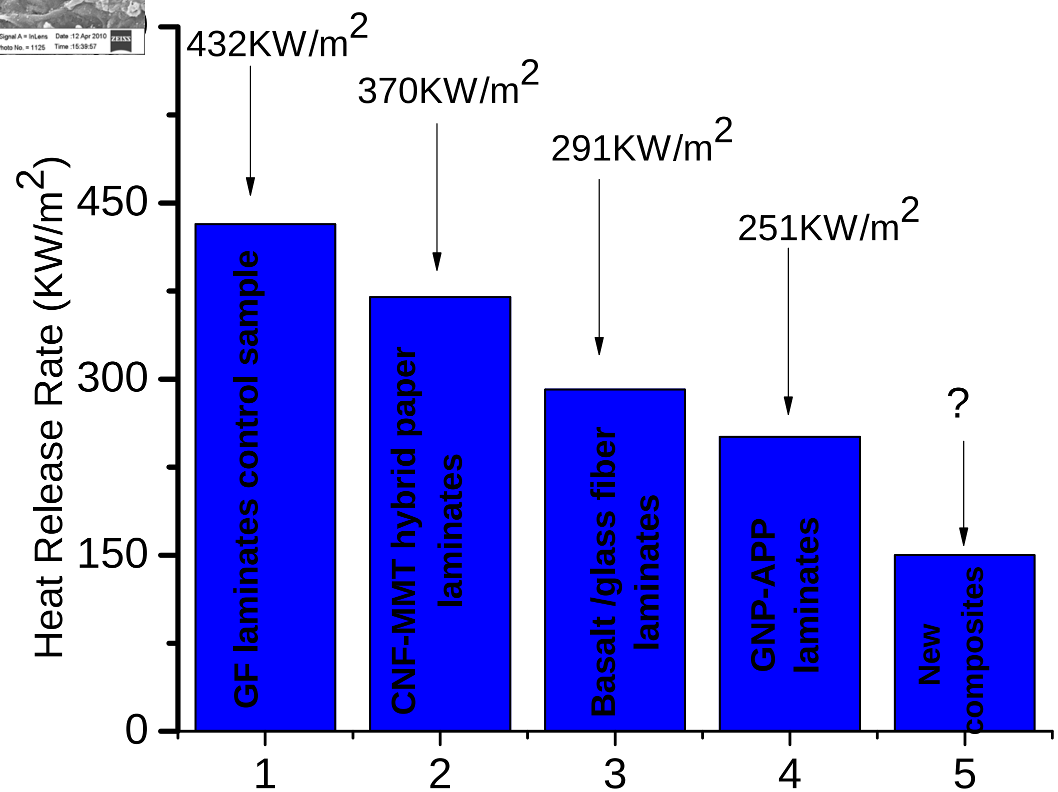


SEM

Char Forming

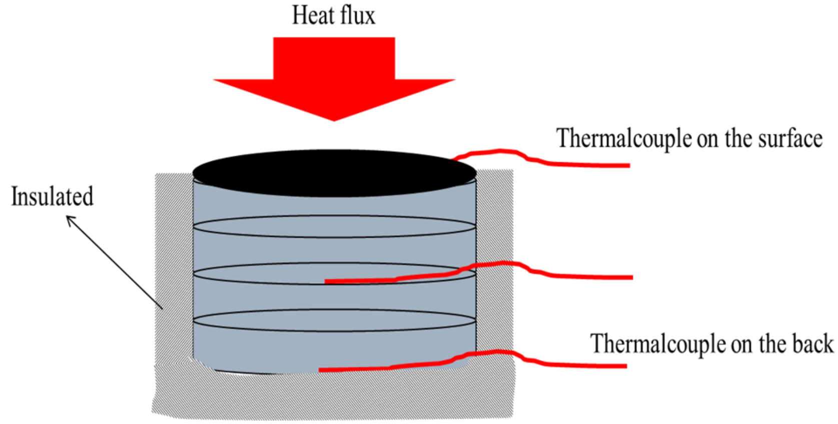


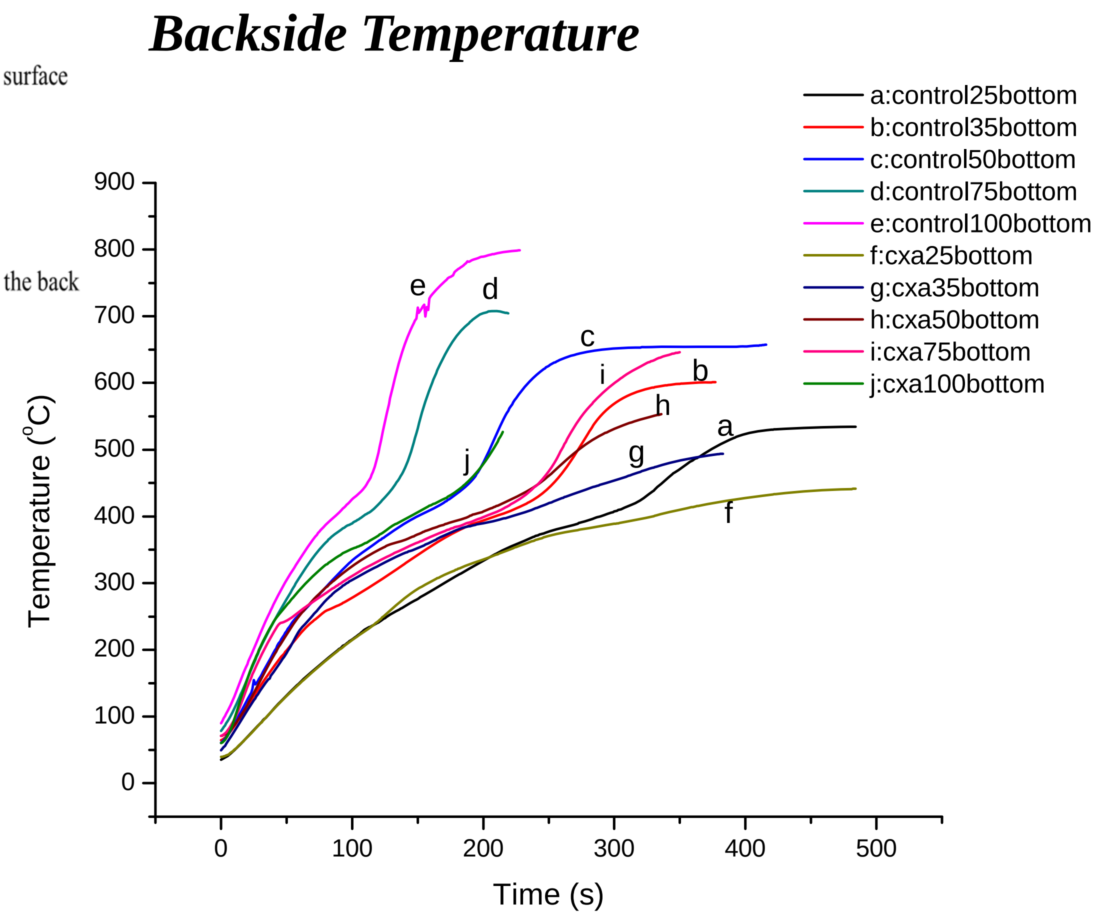
Heat Release Rates (HRRs)



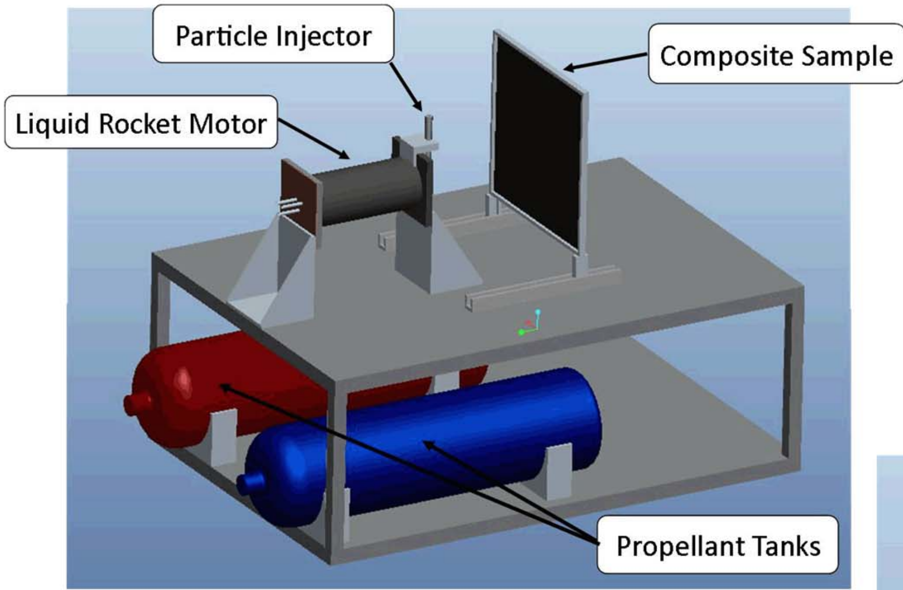
Nanopaper Optimization

Temperature Profile





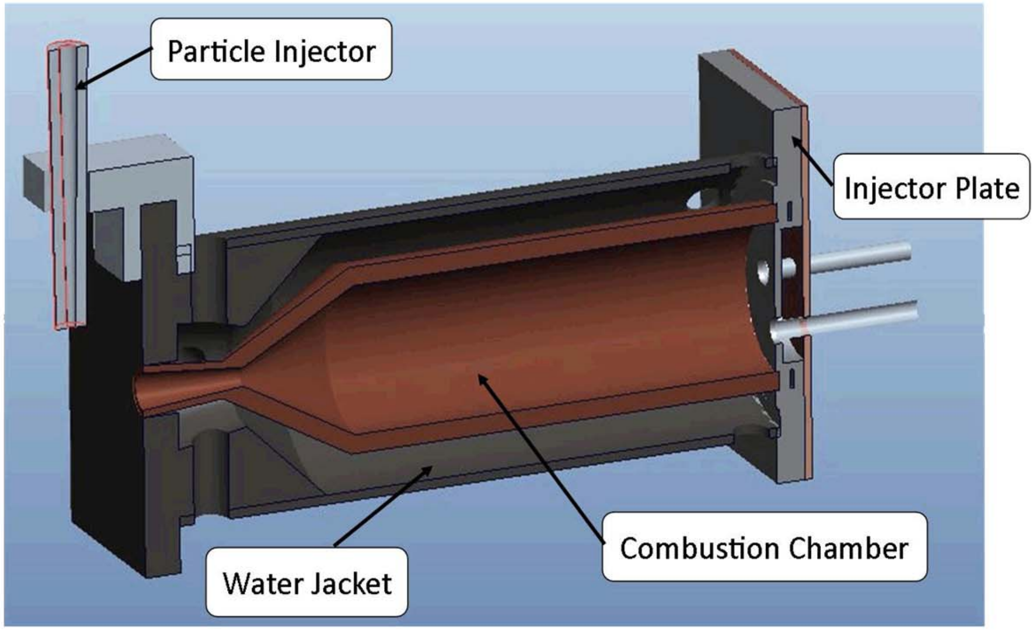
Next Step - Ablation Testing



- Simulated Solid Rocket Motor (SSRM) is a small scale, liquid-fueled rocket burning kerosene and oxygen.
- Heat flux of 700 W/cm^2 at 1 inch from the nozzle
- Support sample size of 12”x12”
- Minimum burning time of 10 seconds
- Particle injection mass flow rate of ~ 20 lb/hr
- High exhaust velocity

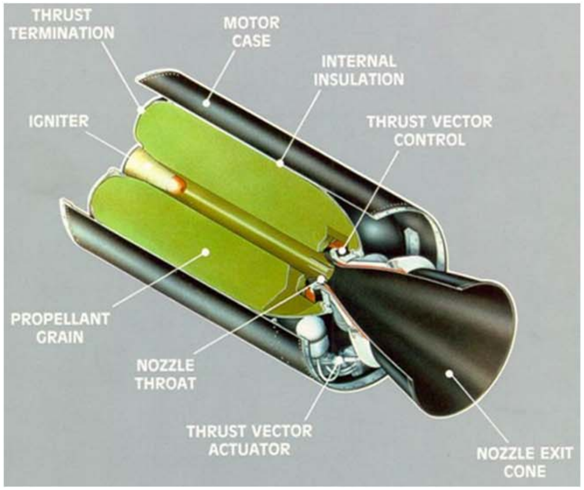
Ablation Performance

- Surface Temperature
- Backside Temperature - backside heat soaked temperature
- Ablation rate – peak erosion depth



Next Step - Thermal Degradation Modeling and Ablation Sensing

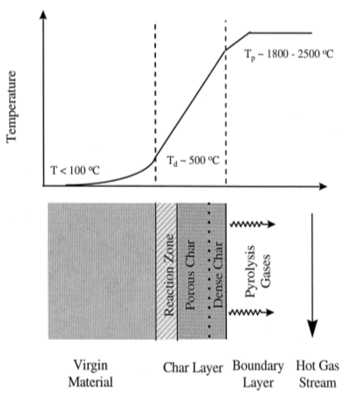
- Damage modeling and life prediction under thermal- and pressure-loading conditions
- Integrated health monitoring with embedded sensors for real-time assessment

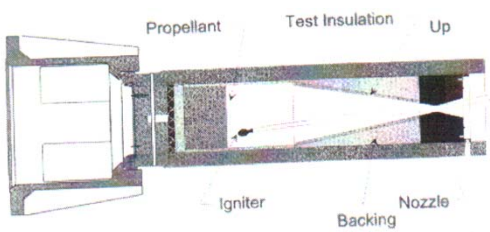


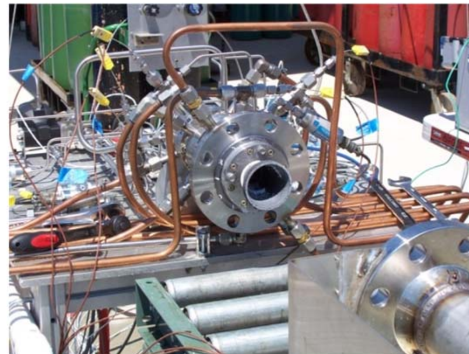
Industrial Collaboration

Significance of Innovation

- Carbon nanofiber composites are lightweight materials that could be used in rocket applications
- Increases ablation resistance to allow higher temperatures
- Makes nozzles lighter and more durable







Water-cooled workhorse rocket engine with ATK/Plasma processes nozzle test setup

ATK/Plasma processes test with eductor attached to workhorse engine

Technical Objectives

- Conduct testing on CNF nozzles
- Optimize nozzle manufacturing process
- Provide reliable and repeatable test rig to subject CNF nozzle materials to high temperatures and dynamic pressures of liquid and gaseous propellant rocket motors

Applications

- Solid rocket motor nozzle materials (for NASA, DoD, and commercial missile, spacecraft, and launch vehicle applications
- Liquid rocket nozzle and/or throat insert material
- Material for other high temperature, long-life applications

Contact Information

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Thank You!