National Aeronautics and
Space Administration

# Lightweight Damage Tolerant High-Temperature Radiators for Space Propulsion

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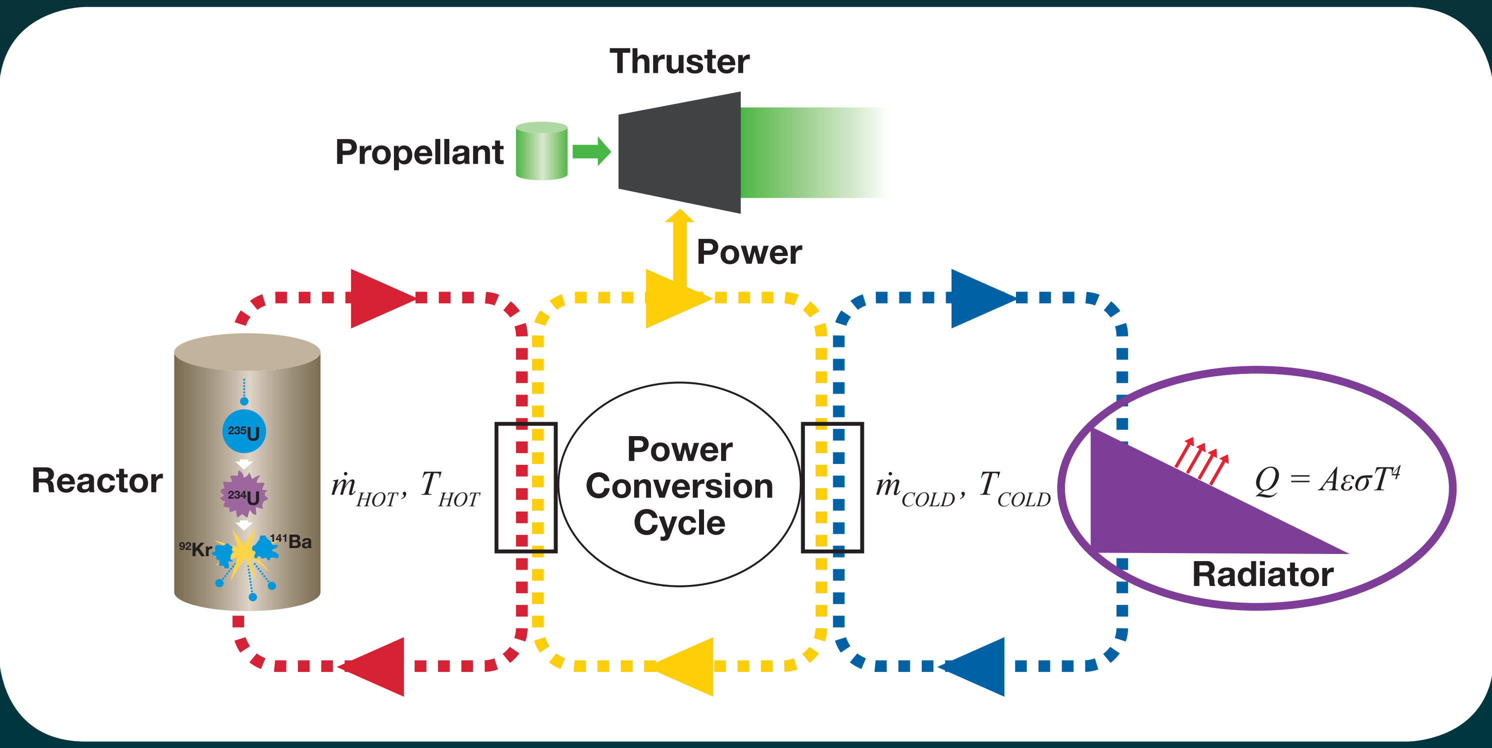
## Background and Motivation

*"Radiator advancement is perhaps the most critical thermal technology development for future spacecraft and space-based systems. Since radiators contribute a substantial portion of the thermal control system mass."*

Thermal Management Systems Roadmap (Technology Area 14), NASA 2012

Game-changing propulsion systems are often enabled by novel designs using advanced materials. Promising new technologies may require high operating temperatures and will benefit from the use of advanced lightweight materials in a heat rejection system. Radiator performance dictates power output for nuclear electric propulsion (NEP) systems. Carbon nanotubes (CNT) and carbon fiber materials have the potential to offer significant improvements in operating temperature, thermal conductivity, and mass properties.




## Radiator Requirements

What is needed in radiators for space power and propulsion?

- Low mass
- Efficient Radiation
- Small Areal Density
- Damage tolerance
- Areal densities of 2–4 kg/m$^2$

What is currently available

- Conventional — metal or composite
  - High mass
- Low operating temperature
- Does not meet the areal density requirement
- Performs as required in the environment

## Radiator Material Comparison

| Fin Material | High Temperature Tolernce (Want HIGH) | Axial Thermal Conductivity (Want HIGH) | Density (Want LOW) |
|---|---|---|---|
| Aluminum | Low | Moderate | Low |
| Molybdenum | High | Moderate | High |
| Carbon-Carbon Composite | High | Moderate | Low |
| Carbon-Polymer Composite | Low | Moderate | Moderate |
| Bare Carbon Fiber | High | High | Low |

Ref. 1

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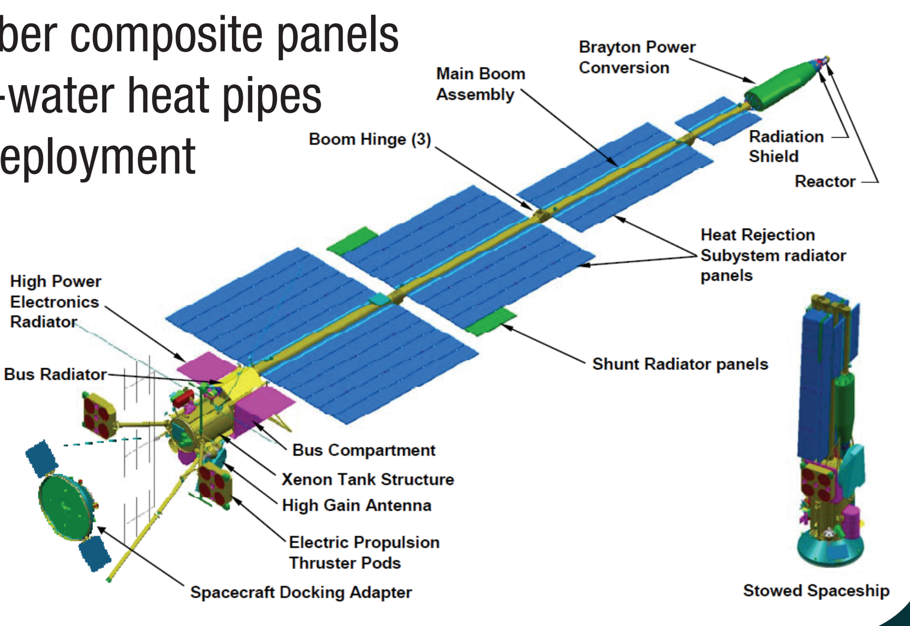
## JIMO Radiators

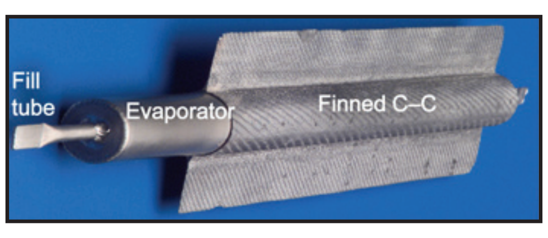
- Operating temperature: 100°C
- Main fluid loop: NaK
- Carbon fiber composite panels
- Titanium-water heat pipes
- Scissor deployment

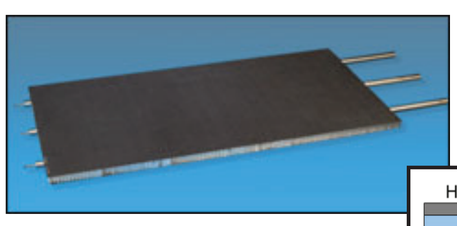



Ref. 1, 2, 3

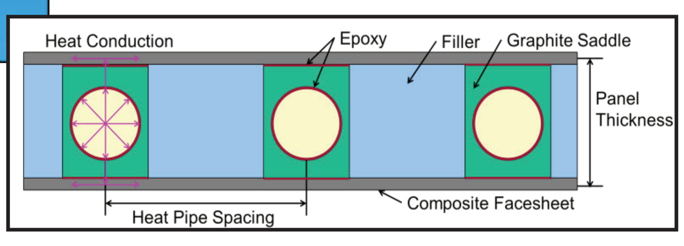
## Typical Convential Fin Construction

Wrapped Fin



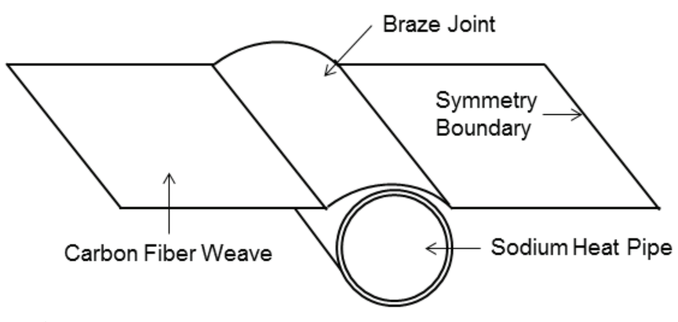



Structural Panel

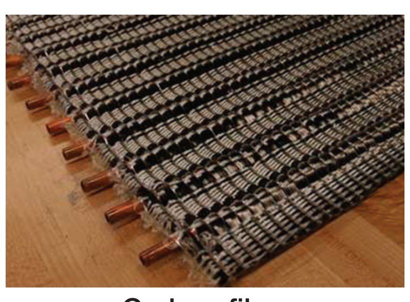



## Possible Designs

- Separate structural from thermal
- Use woven high thermal conductivity carbon fibers with no matrix material
- Attach fibers directly to metal heat pipe through high temperature brazing
  - Ceramics to metal




Ref. 4



Carbon fiber radiator design

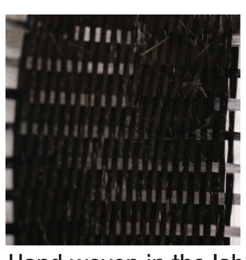
Ref. 5

## Characteristics of Pitch Carbon Fiber K13D2U

- Low density (2.2 gm/cm$^3$)
- High axial thermal conductivity (800 W/mK)
- Broad operating temperature range (0–>2000°C)
- High emissivity (0.8)
- Readily available
- No readily available woven textile material

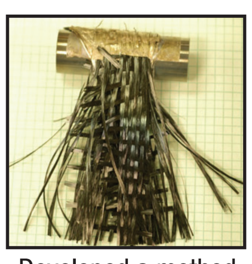
## Manufacturability of Fins

- No commercial mats made with this material
- Hand woven in the laboratory
- Collaborated with a textile manufacturer* to develop a method to weave fibers on a mass scale

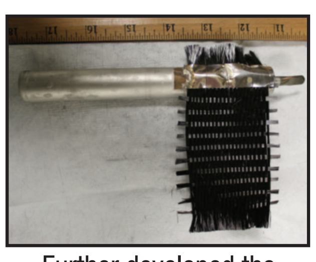


Hand woven in the lab

First articles were with unwoven fibers across tube



Developed a method to hand weave fibers in the laboratory



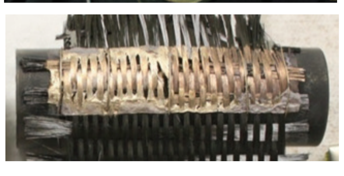
Further developed the hand weaving method

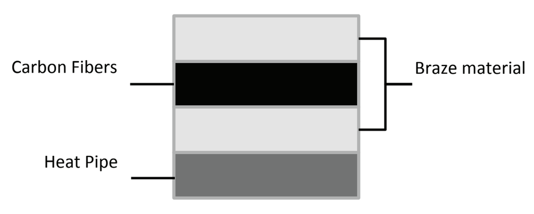
Textile from Manufacturer

* Textile Engineering and Manufacturing

## Attachment

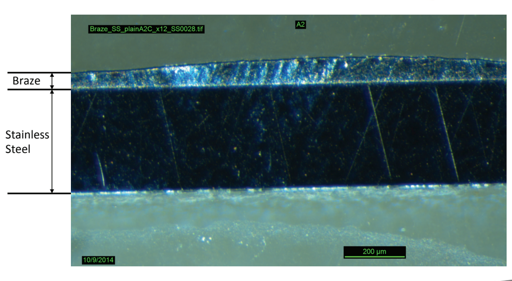
- Two important considerations for attachment
  - Thermal contact
  - Strength of attachment

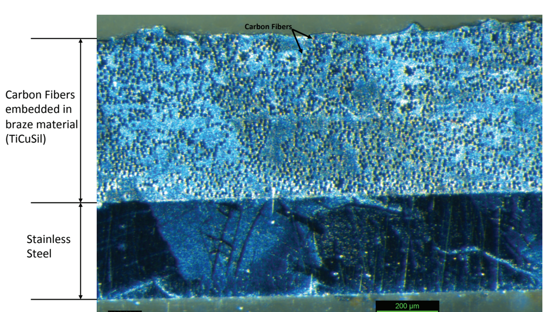


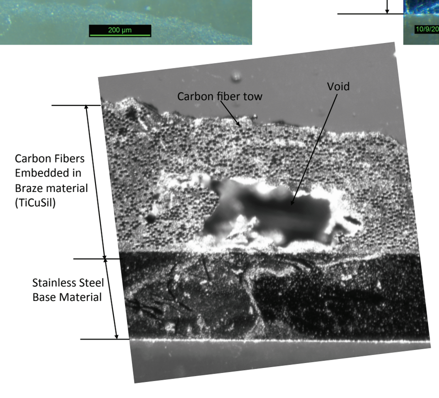



- With carbon fibers
  - More dense weave, brazing quality drops with internal heating
    - Radiative losses
  - Isothermal furnace-external heating of all components

## Attachment – Braze Material Only and Braze with Carbon Fiber Only

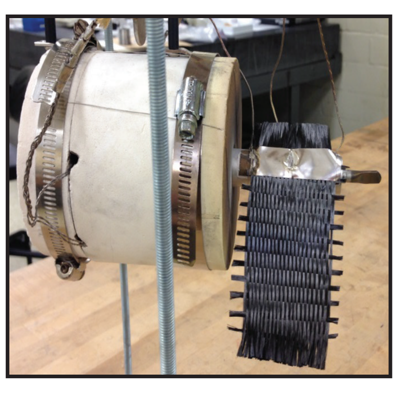


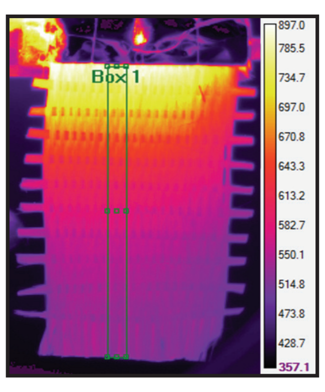



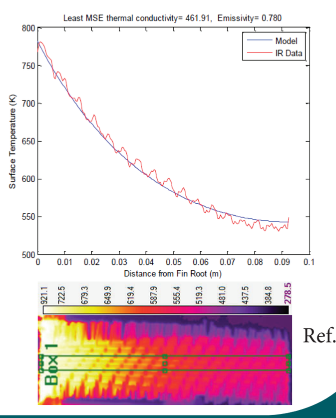

## Test Setup for Heat Pipe Sample

- Left image is current setup for testing heat pipe samples.
- Right IR image is a heat pipe with fin sample under test.
- Analysis of the surface temperature indicates:
  - Power rejected per meter of heat pipe ~980 W/m
  - A specific power of 38.1 kW/kg for that fin.






TEAM woven mat on heat pipe



Ref. 6

## Future Work

- Continue improving brazing technique
- Build a demonstration unit
- Continue to reduce experimental uncertainties
- Continue to look for potential opportunities for further advancement and implementation


### References

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5. D.G. Walker, E.A. Vineyard, R. Linkous, Modeling and Analysis of a Heat Exchanger with Carbon-Fiber Fin Structures, <http://www.heatpumpcentre.org/en/projects/completedprojects/annex%2033/publications/Documents/Vineyard%20carbon%20fiber%20hx.pdf>, accessed June 4, 2014.
6. Tomboulian, B.N., Lightweight, High Temperature Radiator for In-Space Nuclear-Electric Power and Propulsion, PhD Dissertation, U. Mass, 2014