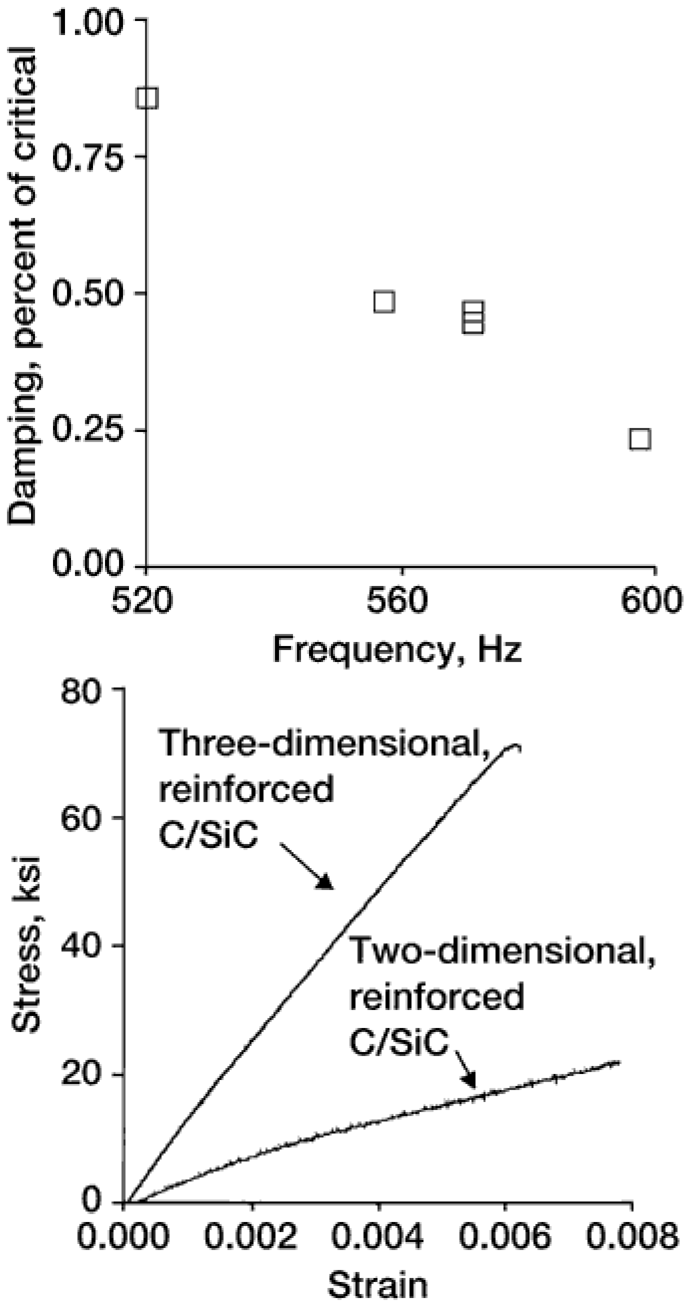
Novel Vibration Damping of Ceramic Matrix Composite Turbine Blades Developed for RLV Applications

The Reusable Launch Vehicle (RLV) represents the next generation of space transportation for the U.S. space program. The goal for this vehicle is to lower launch costs by an order of magnitude from $10,000/lb to $1,000/lb. Such a large cost reduction will require a highly efficient operation, which naturally will require highly efficient engines. The RS–2200 Linear Aerospike Engine is being considered as the main powerplant for the RLV. Strong, lightweight, temperature-resistant ceramic matrix composite (CMC) materials such as C/SiC are critical to the development of the RS–2200. Preliminary engine designs subject turbopump components to extremely high frequency dynamic excitation, and ceramic matrix composite materials are typically lightly damped, making them vulnerable to high-cycle fatigue. The combination of low damping and high-frequency excitation creates the need for enhanced damping. Thus, the goal of this project has been to develop well-damped C/SiC turbine components for use in the RLV.

Foster-Miller and Boeing Rocketdyne have been using an innovative, low-cost process to develop light, strong, highly damped turbopump components for the RS–2200 under NASA's Small Business Innovation Research (SBIR) program. The NASA Glenn Research Center at Lewis Field is managing this work. The process combines three-dimensionally braided fiber reinforcement with a pre-ceramic polymer. The three-dimensional reinforcement significantly improves the structure over conventional two-dimensional laminates, including high through-the-thickness strength and stiffness.

Phase I of the project successfully applied the Foster-Miller pre-ceramic polymer infiltration and pyrolysis (PIP) process to the manufacture of dynamic specimens representative of engine components. An important aspect of the program has been the development of the manufacturing process. Results show that the three-dimensionally braided carbon-fiber reinforcement provides good processability and good mechanical stiffness and strength in comparison to materials produced with competing processes as shown in the graphs.



Left: Dynamic characterization. Right: Static characterization.

The RS–2200 turbopump turbine blades are susceptible to high-frequency vibration with motion dominated by leading- and trailing-edge motion. The most effective approach to controlling these vibrations is by increasing internal damping. Baseline C/SiC damping appears to decrease as a function of frequency and is too small, less than 0.2 percent for the turbine applications. Phase I results show that fiber architecture has little effect on damping. Previous research indicates that incorporating highly damped materials in the form of particulate fillers and coatings increases damping substantially. Several materials were identified that could be added to the base material to enhance damping, in particular, compounds containing boron. BN has a critical damping value as high as 2 percent.

The next step of this work will include end-to-end component development, encompassing process development and refinement, structural design, and structural dynamic testing. Damping materials will be incorporated into the material in the form of coatings and particulates, and the polymer infiltration and pyrolysis manufacturing will be modified to optimize mechanical behavior. The physical and mechanical properties of these materials will be completely characterized as a function of temperature and of microcracking caused by sustained centrifugal loads.

Foster-Miller and Boeing Rocketdyne will use these properties to design and manufacture insertable blades for the RS–2200 turbopump. The blades will be dynamically tested under simulated environmental and operational engine conditions.

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