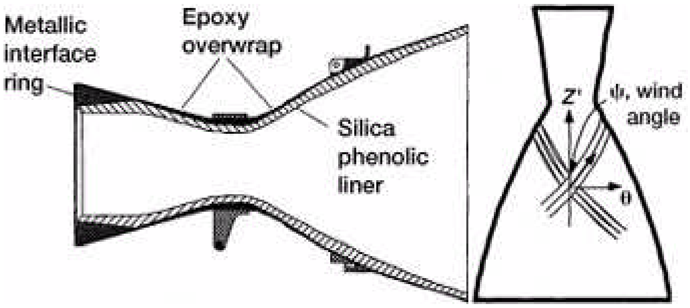
Composite Nozzle/Thrust Chambers Analyzed for Low-Cost Boosters

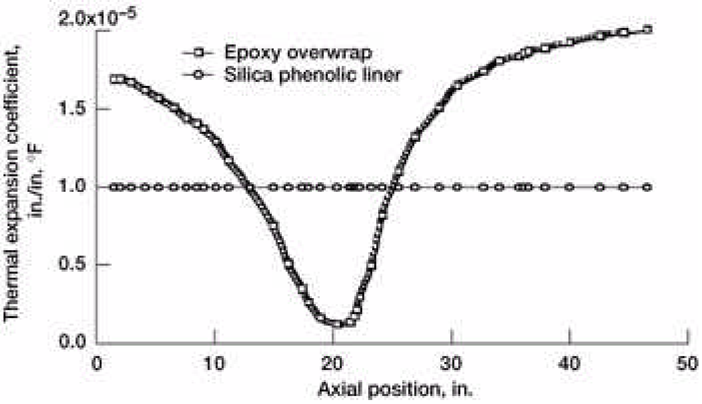
The Low Cost Booster Technology Program is an initiative to minimize the cost of future liquid engines by using advanced materials and innovative designs, and by reducing engine complexity. NASA Marshall Space Flight Center’s 60K FASTRAC Engine is one example where these design philosophies have been put into practice. This engine burns a liquid kerosene/oxygen mixture. It uses a one-piece, polymer composite thrust chamber/nozzle that is constructed of a tape-wrapped silica phenolic liner, a metallic injector interface ring, and a filament-wound epoxy overwrap (see the following illustration). This integral chamber/nozzle design minimizes engine operations costs because it simplifies engine refurbishment procedures.



Left: Thrust chamber/nozzle of 60K FASTRAC Engine. Right: Thrust chamber/nozzle showing filament wind angles.

A cooperative effort between NASA Lewis Research Center’s Structures Division and Marshall is underway to perform a finite element analysis of the FASTRAC chamber/nozzle under all the loading and environmental conditions that it will experience during its lifetime. The chamber/nozzle is a complex composite structure. Of its three different materials, the two composite components have distinctly different fiber architectures and, consequently, require separate material model descriptions. Since the liner is tape wrapped, it is orthotropic in the nozzle global coordinates; and since the overwrap is filament wound, it is treated as a monoclinic material. Furthermore, the wind angle on the overwrap (see the next illustration) varies continuously along the length of the chamber/nozzle. The angle is very shallow in the throat region and becomes steep toward the ends.

During early fabrication attempts, cracking of the liner posed a significant problem. The cracking was the result of residual stresses that developed during processing because of the large differences between the thermal expansion coefficients of the silica phenolic and the epoxy overwrap. The final figure shows the tangential thermal expansion coefficient as a function of the axial position for both the liner and the overwrap. Although the liner tangential thermal expansion coefficient is constant with position, the overwrap thermal coefficient varies considerably along the length because of the varying wind angle.



Tangential thermal expansion coefficient versus axial position.

A finite element analysis of the chamber/nozzle was performed under processing conditions. The results were instrumental in resolving the residual-stress cracking problem and helped to establish a representative analog using straight cylinders. The analyses verified that cylindrical analogs will duplicate the highest stress states in the nozzle, which occur at the nozzle throat. Furthermore, they helped to identify large discrepancies between the material strengths measured using the traditional dogbone configuration and the strengths measured in a cylindrical configuration.

Future analyses of the chamber/nozzle are planned to determine the residual stress levels for a variety of possible material systems, nozzle designs, and fiber architectures. The objective is to choose the optimal material system to minimize residual stresses. Furthermore, we plan to perform finite element analyses for all the loading and temperature conditions that the chamber/nozzle will experience during 60K FASTRAC Engine operation.

Lewis contact: Roy M. Sullivan, (216) 433-3249, Roy.M.Sullivan@grc.nasa.gov
Author: Roy M. Sullivan
Headquarters program office: OAT
Programs/Projects: ASTP, LCBT