Explicit Pore Pressure Material Model in Carbon-Cloth Phenolic

The explicit model predicts some quantities that a prior implicit model cannot.

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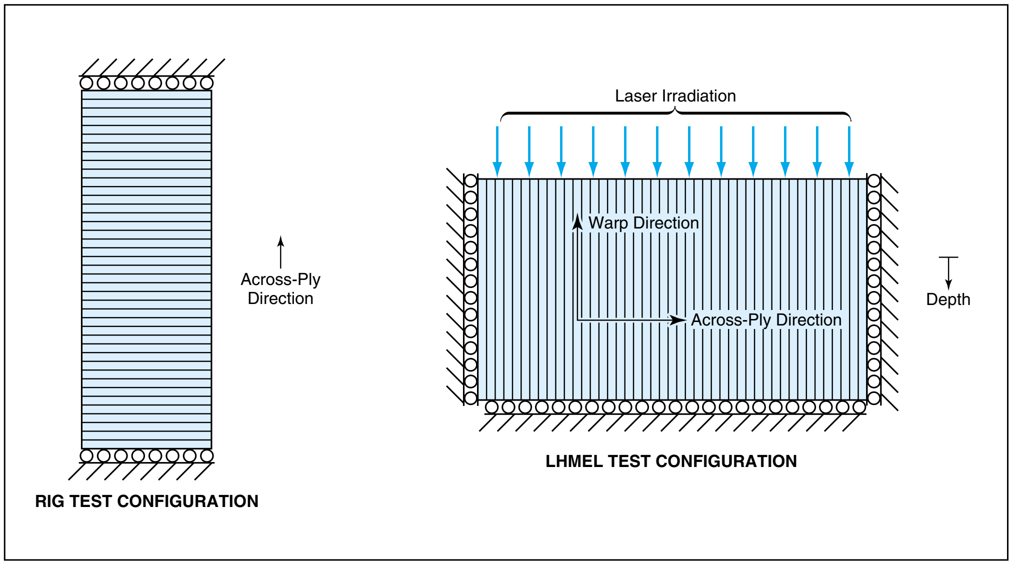
An explicit material model that uses predicted pressure in the pores of a carbon-cloth phenolic (CCP) composite has been developed. This model is intended to be used within a finite-element model to predict phenomena specific to CCP components of solid-fuel-rocket nozzles subjected to high operating temperatures and to mechanical stresses that can be great enough to cause structural failures. Phenomena that can be predicted with the help of this model include failures of specimens in restrained-thermal-growth (RTG) tests, pocketing erosion, and ply lifting.



An **RTG Test** is performed on a cylindrical specimen made of plies stacked along the axis and heated uniformly. The axial load and lateral strain are recorded versus temperature. A LHMEL test is performed on 1.5-by-1.5-by-0.75-in. (3.8-by-3.8-by-1.9-cm) specimen that is restrained on all sides except one, which is irradiated with a laser beam at a heating rate equivalent to that in an operating rocket nozzle. The temperature and pore pressure are measured at various distances from the irradiated surface.

Heretofore, an implicit formulation has been used to model the pore pressure. The differences between explicit and implicit models can be illustrated with the theoretical solution for stress and strain in an RTG test. The equations for the explicit case are:

$$\sigma_x = -\alpha_x E_x \Delta T + (2\nu_{xw} - 1)\sigma_p,$$

$$\varepsilon_\theta = (\alpha_w + \nu_{xw}\alpha_x)\Delta T + (1 - 2\nu_{xw}\nu_{wx} - \nu_{wf})\sigma_p/E_w, \text{ and}$$

$$\sigma_w = \sigma_f = \sigma_p$$

where
σ_x is the measured axial stress,
ε_θ is the measured lateral (circumferential) strain,
σ_w is the warp stress,
σ_f is the fill stress,
σ_p is the pore stress,
α_x is the across-ply coefficient of thermal expansion (CTE),
α_w is the warp CTE,
ΔT is the change in temperature,
E_x is the across-ply modulus of elasticity,
E_w is the warp modulus of elasticity,
ν_{xw} is the (across-ply)-warp Poisson's ratio,
ν_{wx} is the warp-(across-ply) Poisson's ratio, and
ν_{wf} is the warp-fill Poisson's ratio.

For the implicit case, the σ_p term is zero. The most obvious implication of this is that the fiber stresses (σ_w, σ_f) would also be zero for an implicit material model. At the same time, fiber failure is known to occur during RTG testing. Thus, the failure of RTG specimens cannot be predicted with an implicit material model, but can with an explicit model.

One aspect of the development of the explicit model was to ensure that the properties used in the equations came from tests performed at low heating rates, so that effects of pore pressure could be considered separately from other effects. Another aspect of the development of the explicit model is the use of an additional equation for the pore stress:

$$\sigma_p = P_p\eta,$$

where P_p is the pore pressure and η is the porosity of the CCP material. Here, the pore stress is regarded as the stress induced in the structure by the pore pressure. Because P_p had not been measured in an RTG configuration, for the purpose of testing and comparison, a pore-stress distribution versus temperature was assumed, then modified to correlate with measured RTG data. The only information known about the pore stress was that many RTG specimens had exhibited fiber failure at temperatures from 750 to 900 °F (399 to 482 °C). Knowing that the fiber stress equals the pore stress and the fiber tensile capability in this temperature range, it is possible to calculate a pore-stress data point.

The explicit and implicit models were compared in analyses of data from (1) RTG tests (2) high-heating-rate tests of a different type called "LHMEL" because they were performed in a facility called the "Laser Hardened Materials Evaluation Laboratory." The figure depicts the basic RTG and LHMEL configurations. Both models were found to be equally capable of predicting the axial stresses and lateral strains measured in the RTG tests. The explicit model was found to surpass the implicit one by being able to predict a reasonable fiber stress. On the basis of fiber stress, the explicit model can predict failures of RTG specimens.

Both models were also found to predict similar results for most quantities analyzed with respect to the LHMEL tests. The explicit model was found to surpass the implicit one by being able to predict reasonable mechanical strain and stress in the warp direction. This ability leads to the prediction of pocketing erosion in LHMEL tests. Moreover, the explicit model can also be used to indicate the depth, temperature, and time of occurrence of a pocket.

The analyses revealed that the predictions of the implicit and explicit models are similar except in the cases of certain stress and strain components associated with free expansion under a thermal load. For prediction by the explicit model, these stress components have been shown to be useful for predicting material failures of a CCP used in a solid-fuel rocket motor. Such failures cannot be predicted as easily, if at all, by use of the implicit model. The only major disadvantage of the explicit model is that in order to use it, one must have accurate values of pore pressure, data from low-heating-rate tests, and porosity; standard procedures for measuring these quantities have not yet been established.

This work was done by Danton Gutierrez-Lemini and Curt Ehle of Thiokol Corp., Inc., for **Marshall Space Flight Center**. *Further information is contained in a TSP (see page 1).*
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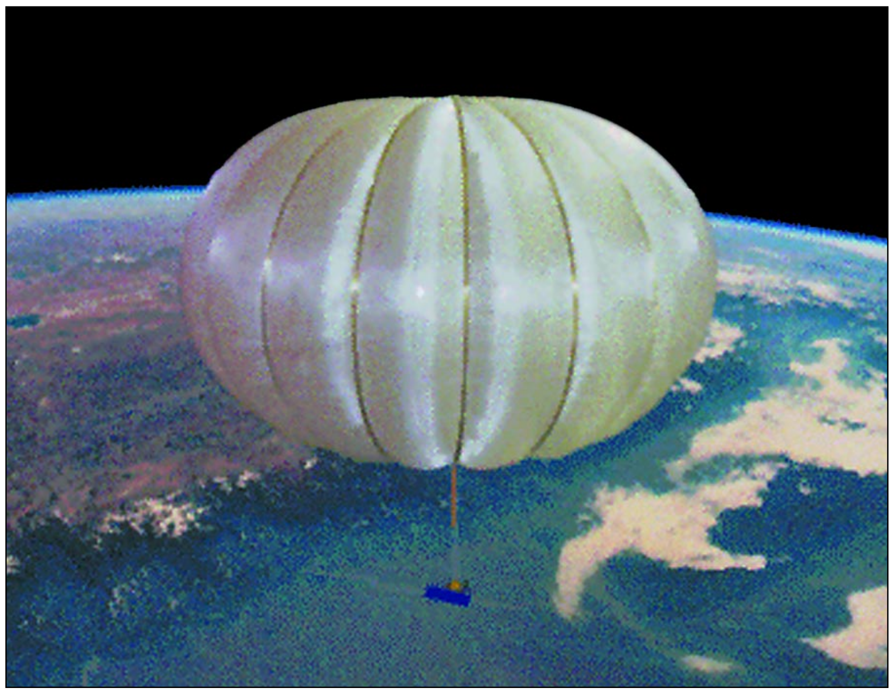
Meshed-Pumpkin Super-Pressure Balloon Design

Masses of long-life, high-altitude balloons could be decreased substantially.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved, lightweight design has been proposed for super-pressure balloons used to carry scientific instruments at high altitudes in the atmosphere of Earth for times as long as 100 days. [A super-pressure balloon is one in which the pressure of the buoyant gas (typically, helium) is kept somewhat above ambient pressure in order to maintain approximately constant density and thereby regulate the altitude.] The proposed design, called "meshed pumpkin," incorporates the basic concept of the pumpkin design, which is so named because of its appearance (see figure). The pumpkin design entails less weight than does a spherical design, and the meshed-pumpkin design would reduce weight further.



This **Pumpkin Balloon** weighs less than a spherical balloon of equal payload capacity. The corresponding meshed pumpkin balloon would have only a fraction of the weight of a pumpkin balloon.

The basic idea of the meshed-pumpkin design is to reinforce the membrane of a pumpkin balloon by attaching a strong, lightweight fabric mesh to its outer surface. The reinforcement would make it possible to reduce the membrane mass to one-third or less of that of the basic pumpkin design while retaining sufficient strength to enable the balloon to remain at approximately constant altitude for months.

For example, the pumpkin balloon shown in the figure is made from a complex composite of polyester fabric, adhesive, polyethylene terephthalate film, and polyethylene film. The balloon has an areal mass density of 62 g/m^2 and a total mass of 2,800 kg. The balloon can carry a payload of 1,600 kg at an altitude of 33 km. One corresponding meshed-pumpkin design calls for reinforcement of the membrane with a 1-by-1-in. (2.54-by-2.54-cm) mesh of polybenzoxazole scrim fiber of 25 denier (a lineal mass density of about 2.8 mg/m). With this reinforcement, the complex composite membrane could be replaced by a simple polyethylene film 0.5 mil (12.7 μm) thick, reducing the mass of the balloon to <400 kg. The mesh would provide a strength of 400 N/m, giving a factor of safety of 5, relative to the strength required for a pumpkin balloon with a bulge radius of 8 m.

This work was done by Jack Jones and Andre Yavrouian of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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