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ENERGY DISSIPATION IN A ROLLING AIRCRAFT TIRE

Fourth Semiannual Status Report

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Progress Report

This project will extend an existing finite element tire model to calculate the energy dissipation in a free-rolling aircraft tire, and temperature build-up in the tire carcass. The model will provide a means of calculating the influence of tire design (geometry and materials) on the distribution of tire temperature.

A large portion of the project has concentrated on general improvements in the finite element tire model and comparisons of its calculations with various measurements made on pneumatic tires. Tire data provided by participants in the National Tire Modeling Program have been extremely valuable in validating the tire model. Load versus deflection data and footprint contact pressures have been realistically calculated for various types of tires, including aircraft tires. The tire model now provides a calculation of the cyclic energy change that accompanies rolling under load.

In the present reporting period, we have been focusing on energy loss measurements of aircraft tire material. A graduate student, Robert Hanson, completed the requirements for his Master's degree while working on the project. His thesis "Time-Dependent Thermo-Mechanical Properties of Aircraft Tire Material" demonstrates the feasibility of taking test specimens directly from the tire carcass for measurements of viscoelastic properties. The interaction of temperature and frequency effects on material loss properties was studied.

Also during the reporting period, the tire model was extended to calculate the cyclic energy change in a tire during rolling under load. Input data representing the 40x14 aircraft tire whose material loss properties were measured by Hanson are being used. We are now ready to begin programming the equations to calculate the distribution of temperature build-up in the tire.

The following is a more detailed description of the work done.

Tire Model Developments

The finite element tire model is now programmed with the following expression for strain energy in the tire carcass laminate.

$$\begin{aligned} U = \tfrac{1}{2} \iint [& A_{11}\varepsilon_s^2 + 2A_{12}\varepsilon_s\varepsilon_\theta + A_{22}\varepsilon_\theta^2 + A_{66}\varepsilon_{s\theta}^2 + 2B_{11}\varepsilon_s\chi_s \\ & + 2B_{12}(\varepsilon_{s\chi\theta} + \varepsilon_\theta\chi_s) + 2B_{16}(\varepsilon_s\chi_{s\theta} + \varepsilon_{s\theta}\chi_s) + 2B_{22}\varepsilon_\theta\chi_\theta \\ & + 2b_{26}(\varepsilon_\theta\chi_{s\theta} + \varepsilon_{s\theta}\chi_\theta) + 2B_{66}\varepsilon_{s\theta}\chi_{s\theta} + D_{11}\chi_s^2 + 2D_{12}\chi_s\chi_\theta \\ & + 2D_{16}\chi_s\chi_{s\theta} + D_{22}\chi_\theta^2 + 2D_{26}\chi_\theta\chi_{s\theta} + D_{66}\chi_{s\theta}^2]\, r\,ds\,d\theta. \end{aligned}$$

where ε_s, ε_θ, $\varepsilon_{s\theta}$ are nonlinear strain-displacement equations and χ_s, χ_θ, $\chi_{s\theta}$ are toroidal shell curvature-displacement equations. The cyclic energy change, u(s) in loaded rolling, is calculated from the above energy by substituting strain changes ($\Delta\varepsilon$) and curvature changes ($\Delta\chi$) for the corresponding ε's and χ's. The strain changes and curvature changes used are the differences between strains and curvatures in the inflated tire and those in the inflated and loaded tire. Figure 1 shows the distribution of cyclic energy change u(s) for the 40x14 aircraft tire inflated to 225 psi and loaded at 16,000 lb. The abrupt changes in the calculated curve occur at the contact boundary and at the turnup ends (material discontinuities).

The portion of the cyclic energy that is not recovered (energy dissipated per cycle) is given by $w(s) = \pi u \tan \delta$ where $\tan \delta$ is the loss tangent measured for the tire carcass material. It is at this point in the energy dissipation analysis where knowledge of the dependence of $\tan \delta$ on frequency, strain, and temperature is extremely important, as $\tan \delta$ alone determines the energy dissipation.

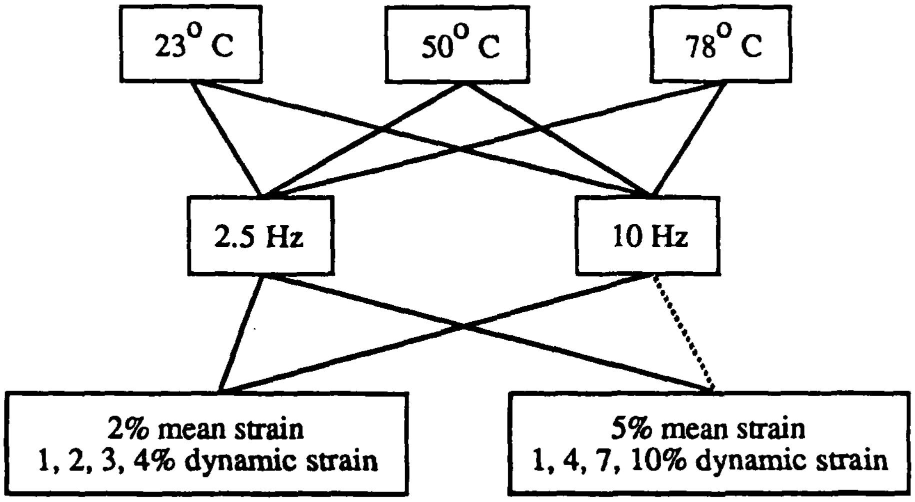
In another area, the tire model continues to be utilized for studies of tire/pavement contact pressure distributions, particularly those of the wide-base truck tire. This work is of interest to pavement design engineers who are concerned about the effect on the pavement of the impending change in the trucking industry from using dual conventional tires to the use of one wide base tire at each axle position.

Material Property Studies

Circumferential and meridional specimens (Fig. 2) were cut from the crown region of a 40x14 aircraft tire supplied by NASA. Some preliminary analyses and testing were done to determine the best way to grip the specimens to produce a uniform load in all plies. Because of the large number of plies (15), and soft matrix (rubber), it was not possible to use glued end tabs as is commonly done for testing hard composite specimens. The end constraint adopted (Fig. 3) uses square aluminum tubing which slips snugly over the 3/4 inch square specimens. The specimen ends are secured to the tubing by an array of six 1/8 inch machine screws in holes drilled directly through the tubing and the specimen. Load is transmitted to the specimen by the screws only, which insure that the inner plies receive the same extensional strain as the outer plies do.

Studies were made on the effect of specimen length (for gage strain uniformity) and on specimen width (for free edge effect). These led to the specimen dimensions given in Figure 3. Other tests determined the specimen conditioning (initial strain cycling) required to obtain repeatable results, and the time required for equilibrium when testing at elevated temperatures (at least one hour).

After the procedures for conducting dynamic tire material tests were developed, the test program diagrammed below was used to study the effects of temperature, frequency, and strain on viscoelastic properties. All testing was conducted under displacement control to provide a single harmonic strain



input, $\varepsilon(t) = \varepsilon_o + \varepsilon_1 \cos(\omega t)$. This expression defines the terminology mean strain (ε_o) and dynamic strain (ε_1).

The single harmonic strain input was found to produce a multi-harmonic stress response, confirming that the tire carcass is a nonlinear viscoelastic material. The phase angles of the first two stress harmonics were extracted from the data by a Fourier transform procedure. The phase angle of the first harmonic which alone determines the material loss tangent, was found to be independent of strain level. This important result is in agreement with the findings of Clark. The loss tangent was also observed to decrease slightly with increasing temperature, and to increase significantly with increasing frequency.

These material property measurements appear to be the first to be made on specimens cut from an actual tire. They complement the studies made by Clark and other researchers who have used tubular or other specially constructed tire material specimens. A paper for presentation at the next Tire Society Conference is being prepared to describe our material property studies.

Travel

a review of project activity was given at the National Tire Modeling Program meeting held March 21, 1988, in Akron, Ohio.

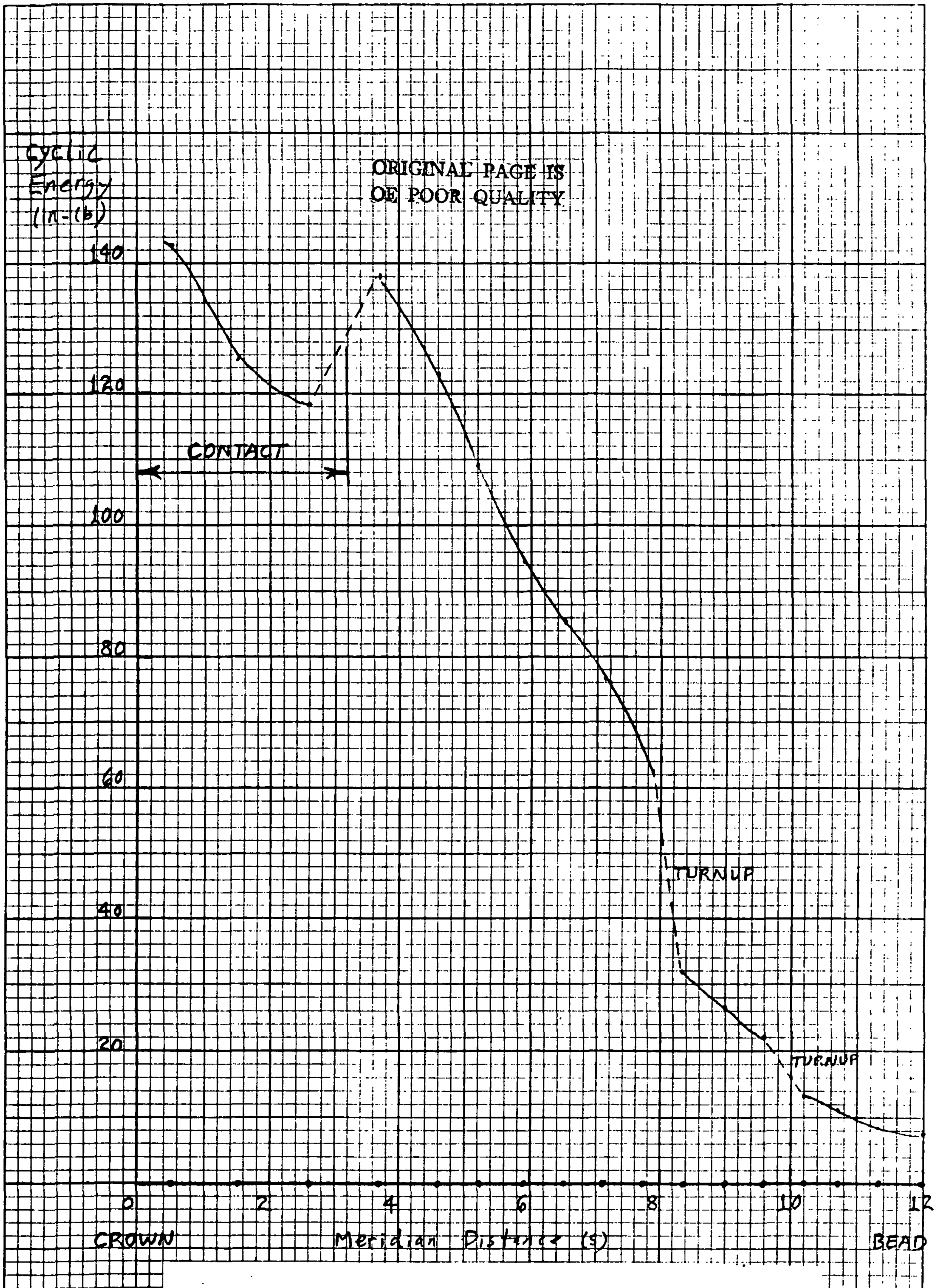


Figure 1. Cyclic energy change at 16,000 lb load.

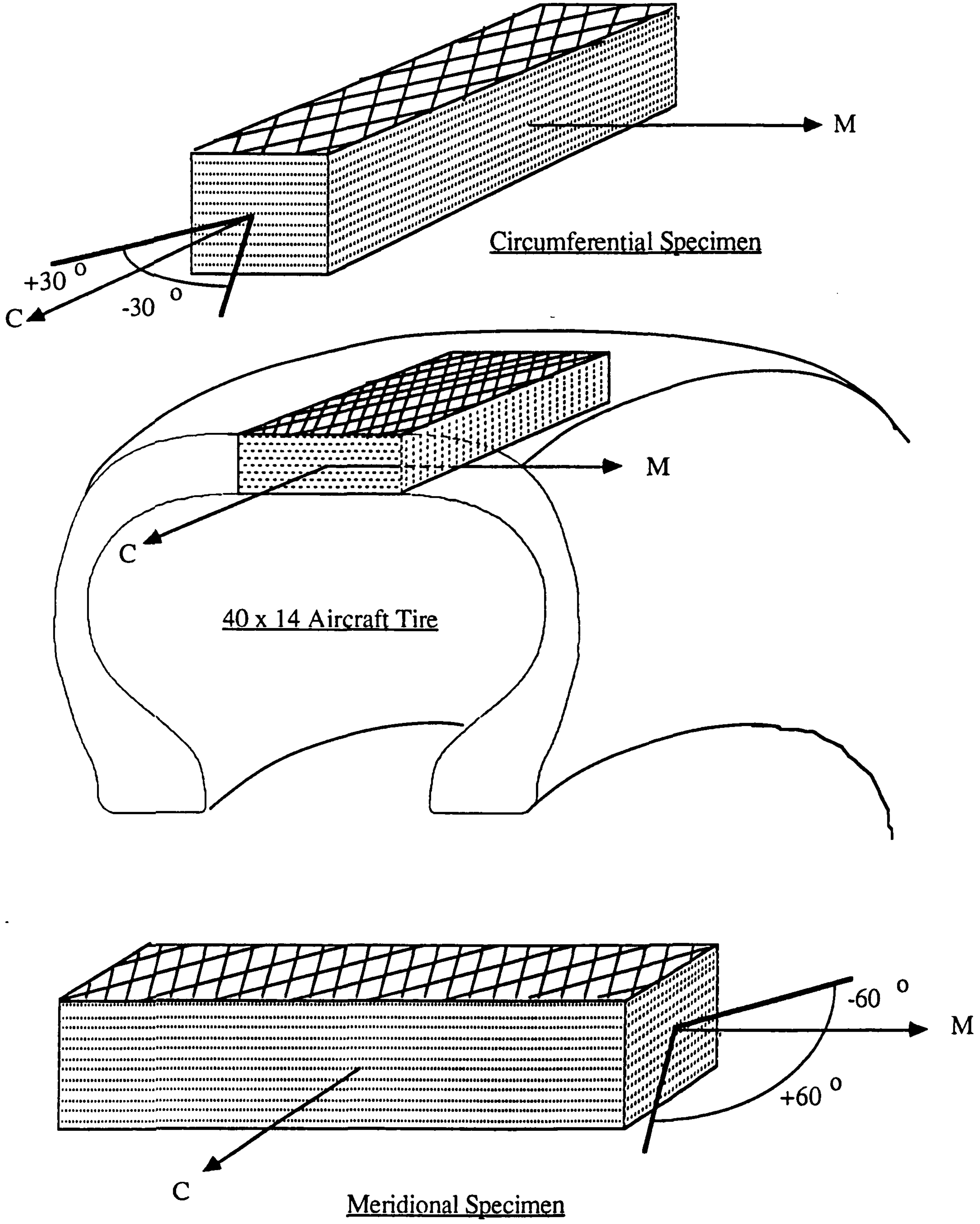


Figure 2. Tire material specimen orientations

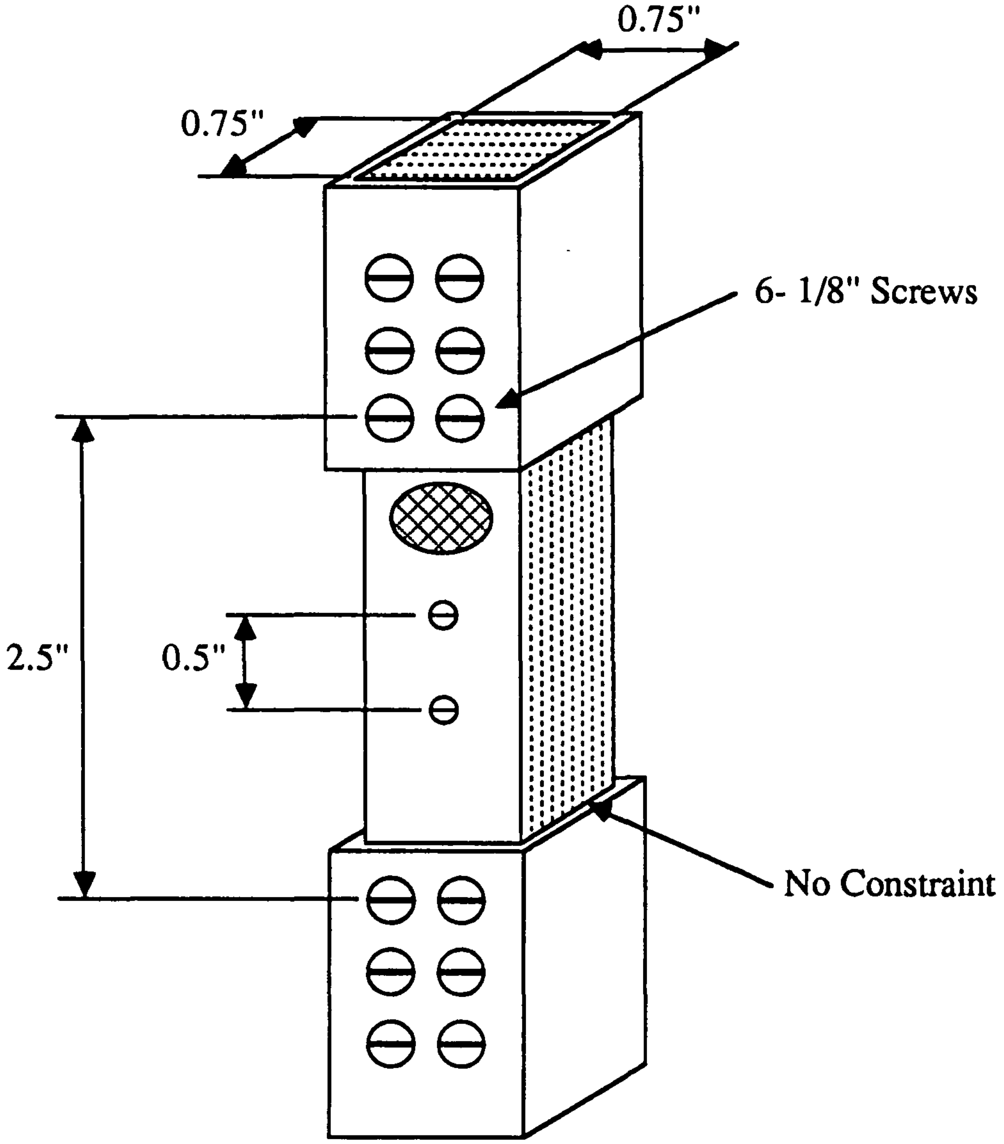


Figure 3. Bolted end constraints