RESULTS FROM RECENT NASA TIRE THERMAL STUDIES

John L. McCarty
NASA Langley Research Center

ABSTRACT

This paper describes the testing technique and some results from an experimental study to determine tire temperature profiles to aid in defining the strength and fatigue limitations of the tire carcass structure. This effort is part of a program to explore analytically and through experiment the temperature distribution in an aircraft tire during free roll and braked and yawed rolling conditions. The analytical effort, together with a comparison with the experimental results, is discussed in the paper by Clark in this publication (ref. 1).

LOCATION OF THERMOCOUPLES IN TIRE THERMAL STUDY

Figure 1 shows the approximate locations of the eighteen thermocouples installed within the carcass of several tires to support the thermal study. As noted in the figure, the thermocouples were mounted on the inner and outer walls of the tires and along an approximate midline at six radial stations. Most of the thermocouple installation was accomplished by implanting the sensors in holes drilled into the tire carcasses after the carcasses had been buffed prior to retreading.

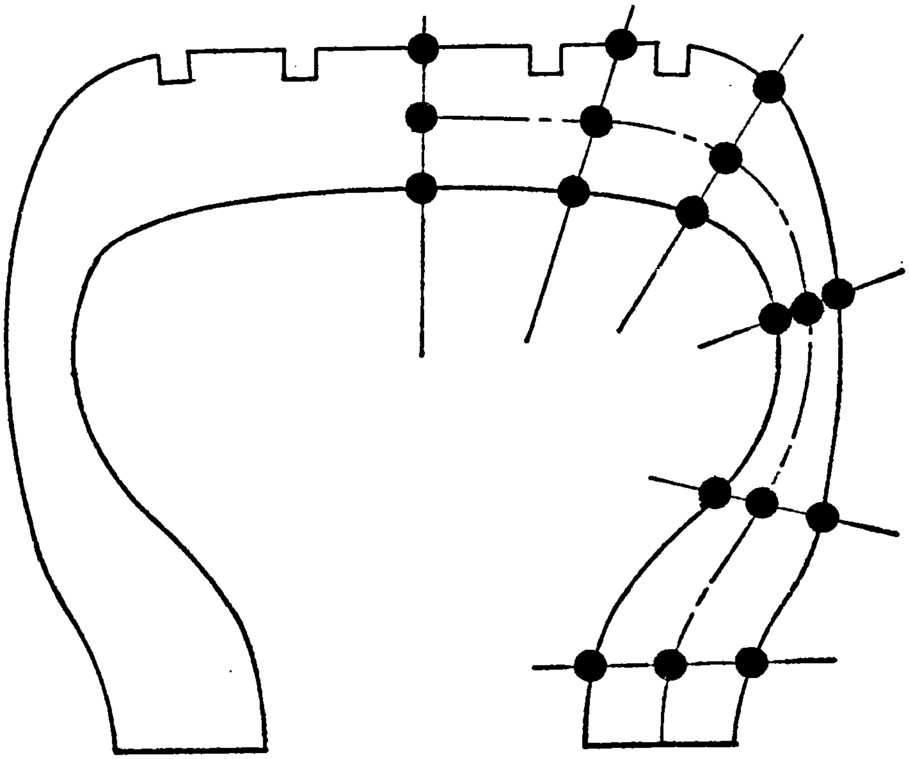

Figure 1

PHOTOGRAPH OF AN INSTRUMENTED TEST TIRE

Figure 2 is a photograph of a tire ready for testing, and shows how the outputs from the thermocouples were routed through a slip ring en route to a data logger located in the instrument section of the test vehicle pictured in figure 3. The tires for these tests were size 22 x 5.5, 12-ply rating, type VII aircraft tires.

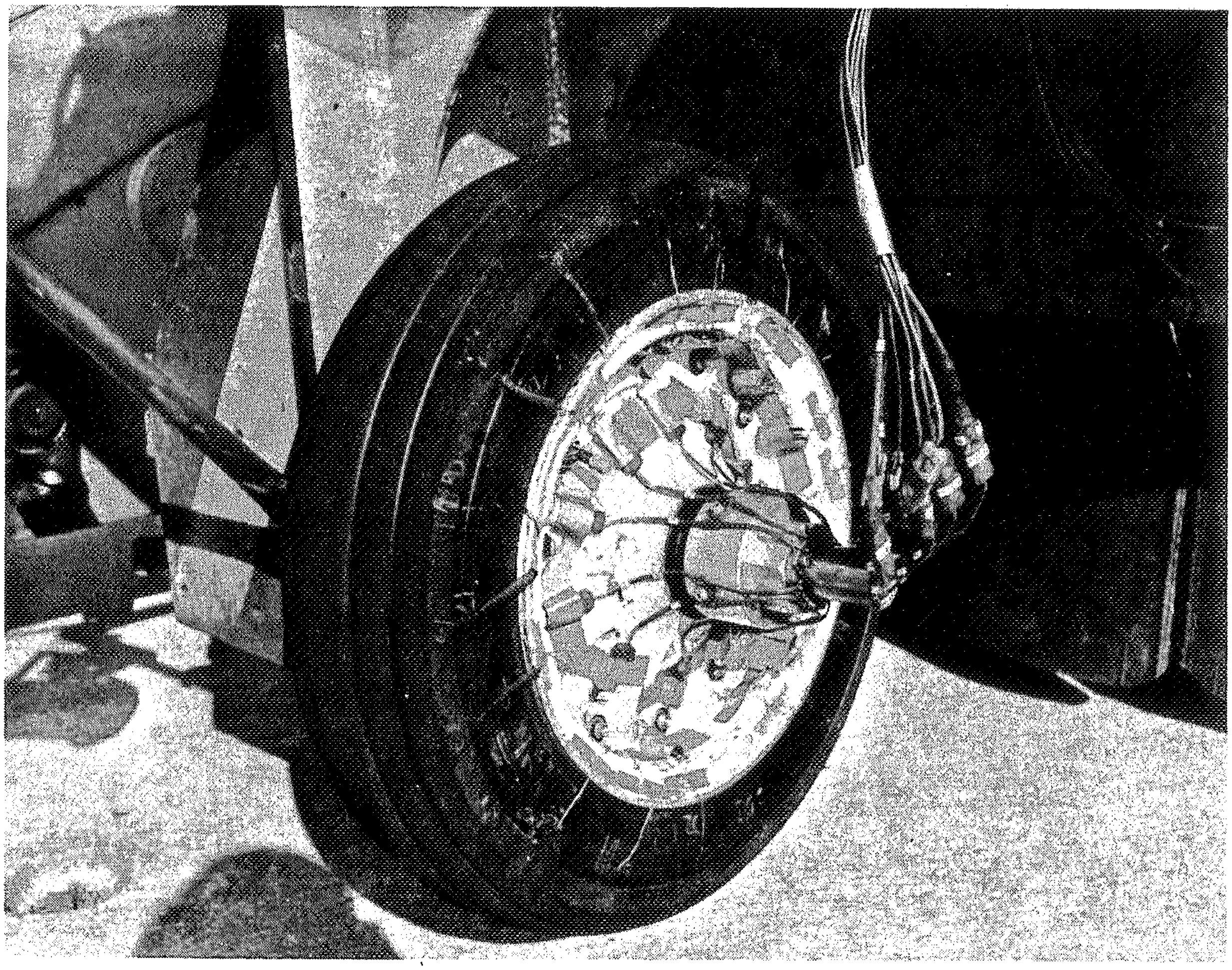

Figure 2

INSTRUMENTED TIRE TEST VEHICLE

Figure 3 is a photograph of the powered ground test vehicle used in this investigation. This vehicle consists of a truck which has been modified to accommodate a tire test fixture and supporting equipment. For the tests described here, the tires were vertically loaded to 4000 pounds and driven at 20 mph, except for one series where speeds were increased to 50 mph, over a known distance with temperature measurements recorded every 10 seconds. Data were taken with the tire free rolling, yawed rolling, and at fixed slip ratios to simulate braked-rolling conditions.

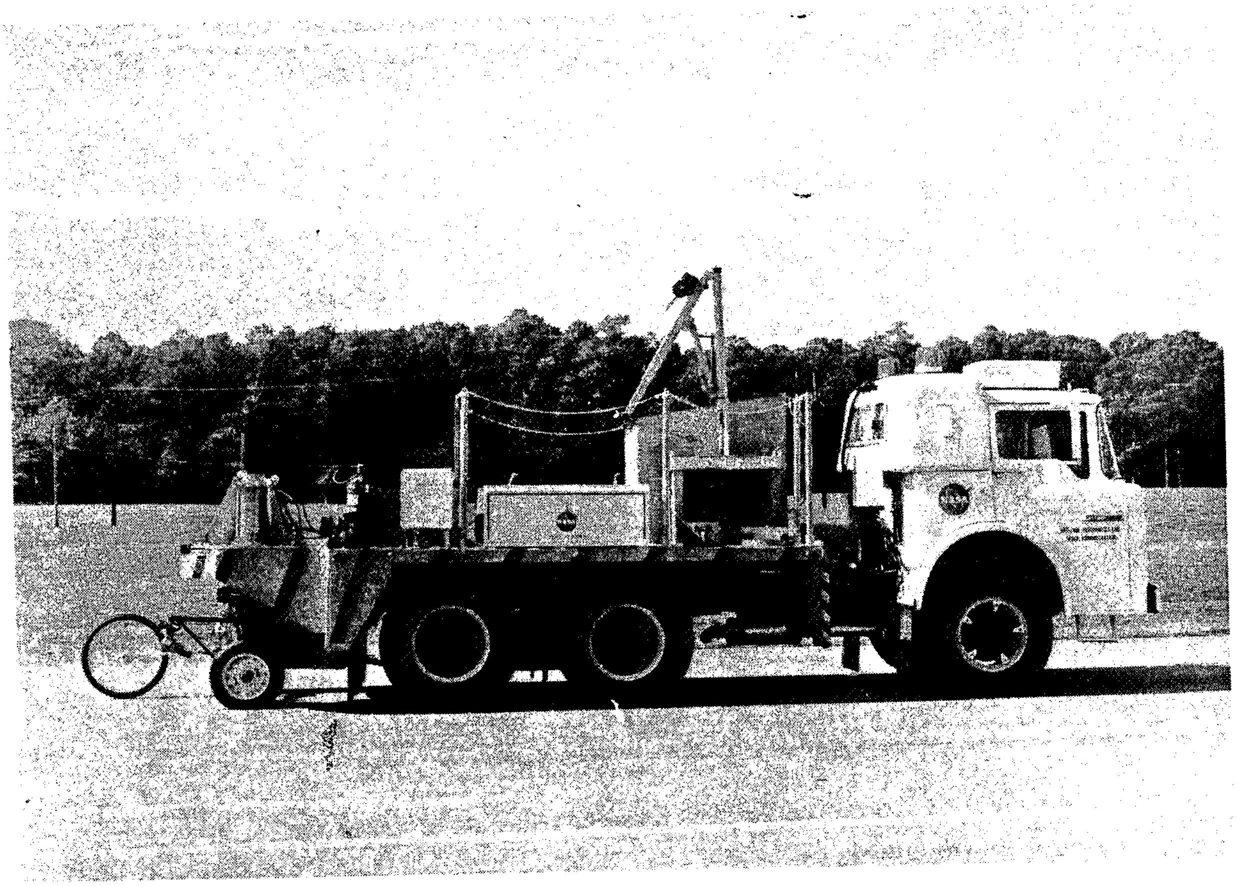

Figure 3

TYPICAL TEMPERATURES THROUGH THE TIRE CARCASS DURING FREE ROLLING

Figure 4 presents the time history of temperature buildup in six of the thermocouples as the tire in the free-rolling mode made two and a half passes of about 6500 feet each down an asphalt runway. As noted on the figure, the test tire was raised from the pavement surface following each pass while the test vehicle was being turned around for the return trip. The thermocouples were selected to illustrate the temperature rise through the tire carcass in the shoulder and bead areas. The figure clearly demonstrates that in both areas the rate of temperature buildup, and hence the magnitude of the temperature, is greatest along the interior wall, decreases through the carcass, and is lowest along the exterior wall. As would be expected because of tire flexure, the temperatures in the shoulder area are greater than the corresponding temperatures in the bead area.

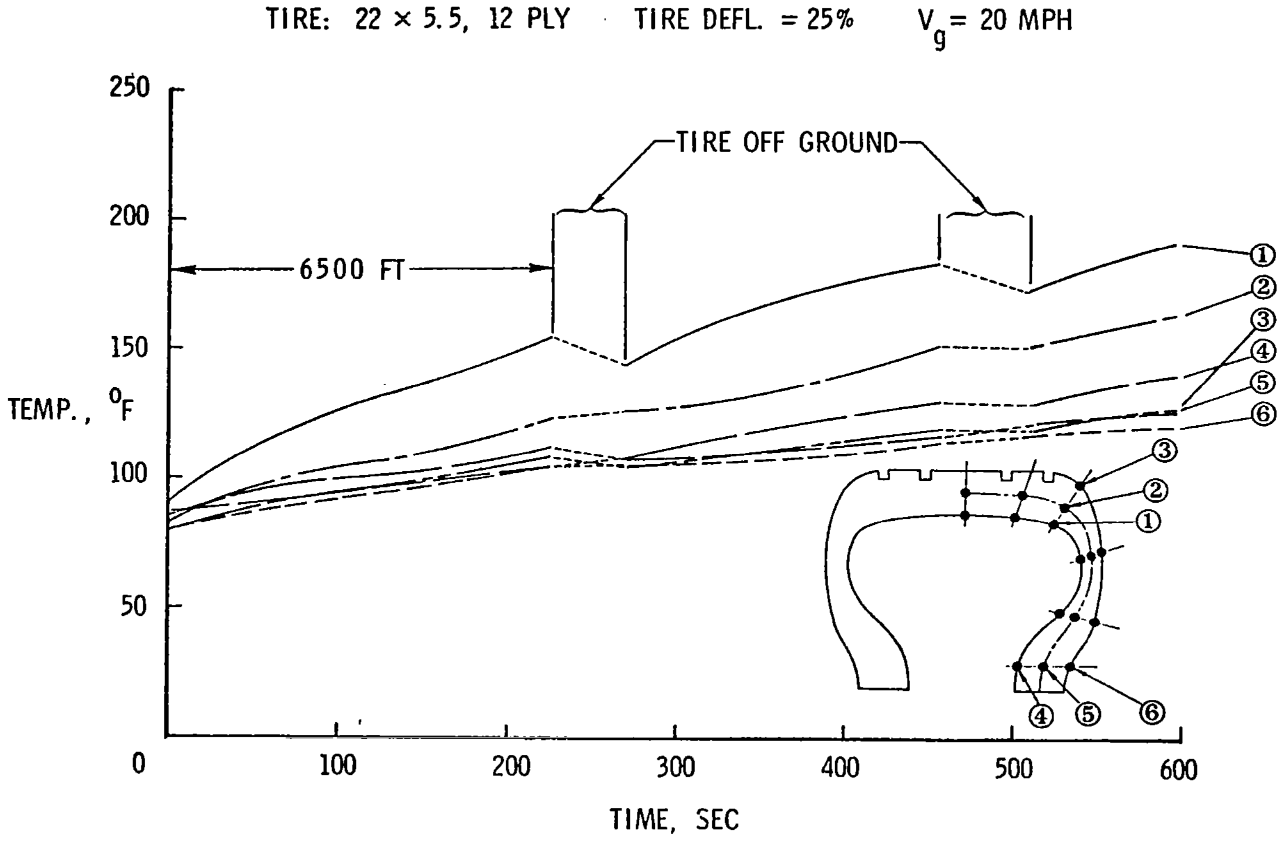

Figure 4

TYPICAL INTERIOR TIRE CARCASS TEMPERATURES DURING FREE ROLL

Temperature data from the six thermocouples installed along the tire internal wall are presented in figure 5 as a function of the free-roll distance. It is interesting to note that the maximum temperature was measured not in the center of the tread nor in the shoulder area, but between the two. The temperature in the bead area is again shown to be well below the other measured tire internal temperatures.

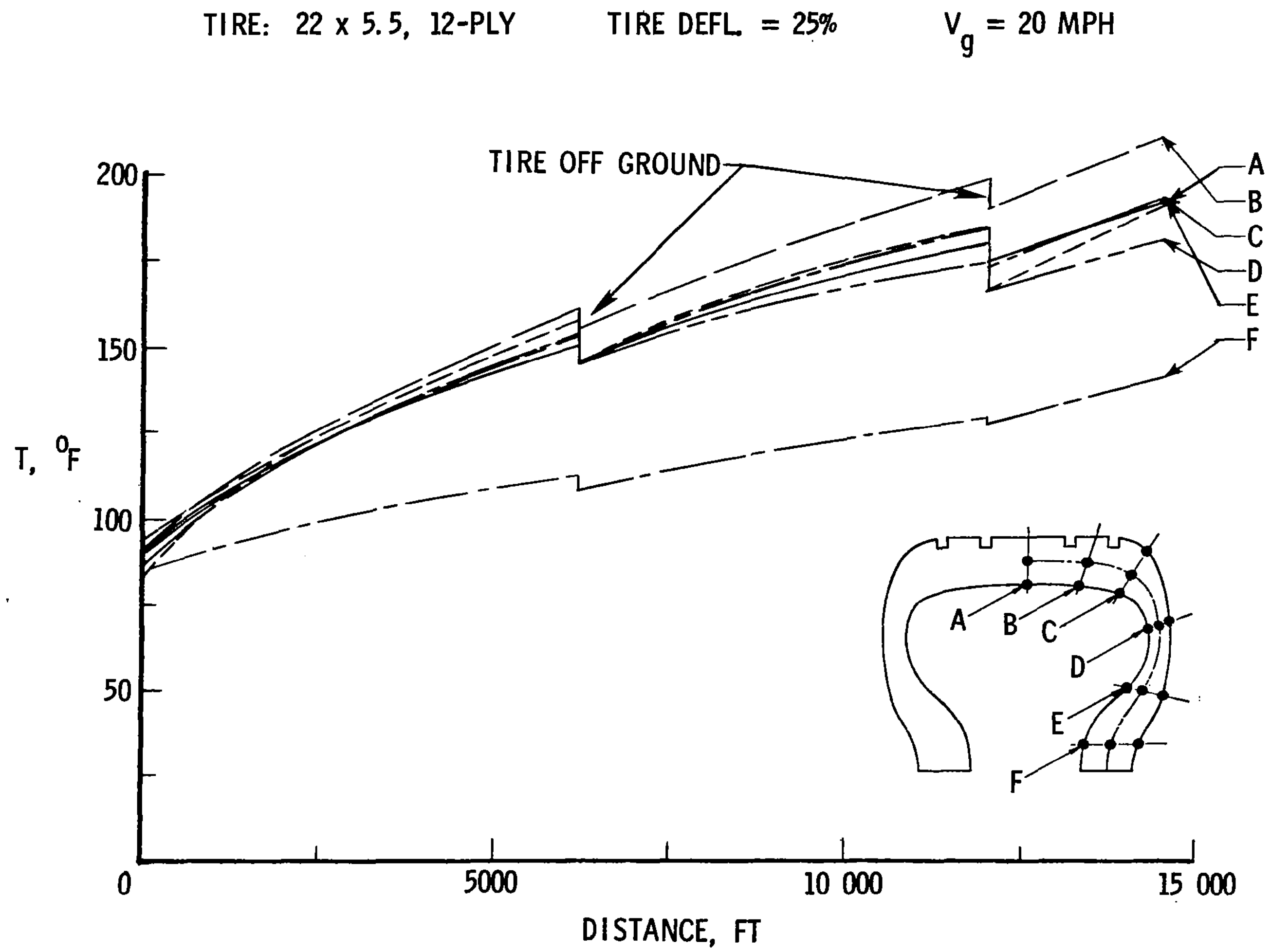

Figure 5

EFFECT OF TIRE DEFLECTION

Figure 6 illustrates the effect of tire deflection δ on the distribution of temperature within the tire carcass after the tire had free-rolled for a distance of 5000 feet. The different deflections in this case were obtained by changing the tire inflation pressure while maintaining the 4000-pound vertical loading. Although data are lacking in the tread region, similar tests on other tires showed little effect of tire deflection on temperatures in that area. However, the figure shows a pronounced effect on temperatures in the sidewall region. The higher temperatures associated with the greater deflections are attributed to the more severe sidewall flexing which increases with tire deflection. Similar trends were observed when the tire deflection was changed by varying the vertical load while maintaining a fixed inflation pressure.

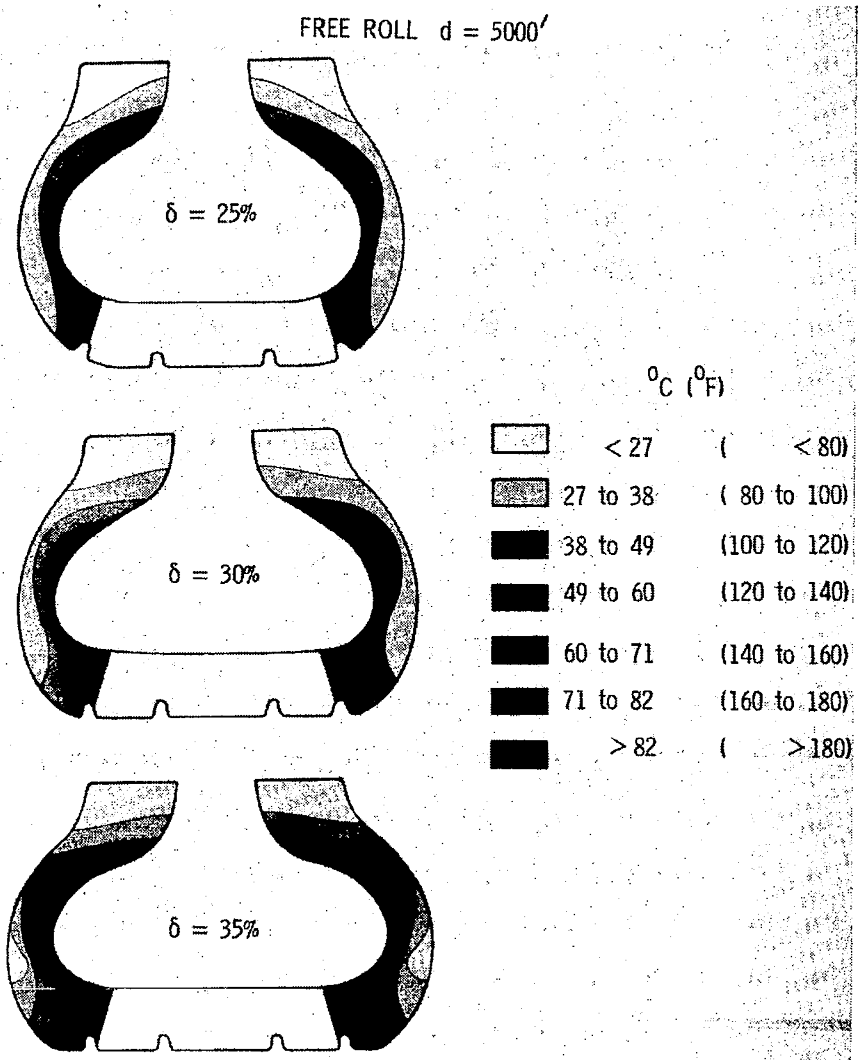

Figure 6

EFFECT OF YAW ANGLE

To examine the effect of yaw angle ψ on tire temperature distribution, a series of free-rolling tests was conducted where the tire was yawed to 3° and 6°. Because only one side of the tire was instrumented, two passes were required at each yaw angle with the tire yawed first in one direction (+3°, for example) and then in the other direction (-3°, for example) to complete the temperature picture. The results are illustrated in figure 7 which presents the tire temperature profiles after having traveled 7000 feet. The figure shows a considerable temperature build-up with yaw angle in the tread area and in the "downwind" sidewall of the tire with an accompanying cooling effect on the "upwind" side. The reduced temperature on the "upwind" side is apparently due to the stress relieving which occurs in the "upwind" sidewall when the shoulder area on that side is forced to roll partially into the footprint. Conversely, the greater tire distortion on the "downwind" side as the yaw angle is increased would account for those higher temperatures. The higher temperatures in the tread area can be explained by the increased scrubbing action in the tire footprint that is associated with increasing yaw angle.

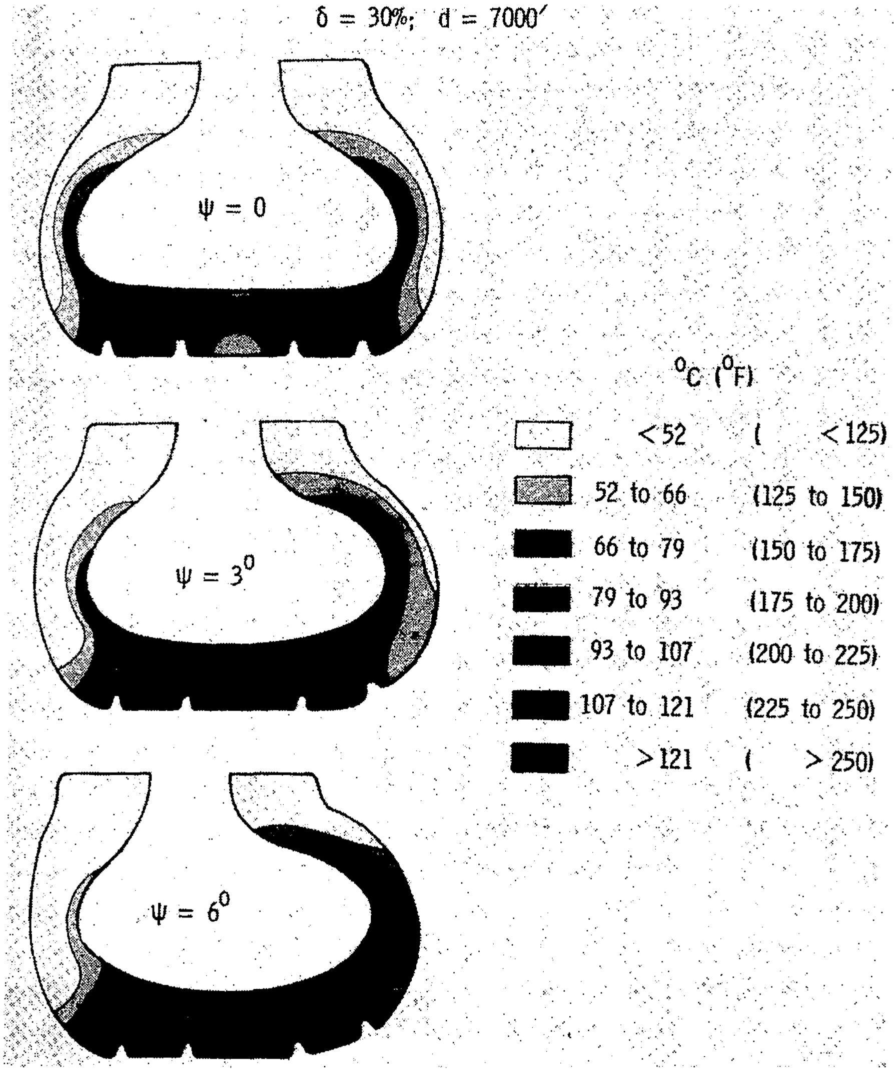

Figure 7

EFFECT OF BRAKING

Driving the test tire at fixed slip ratios provides a means for evaluating the effect of braking on the temperature buildup in the tire carcass. Figure 8 presents the temperature profiles after the tire had traveled 7000 feet first in free roll and subsequently at slip ratios of 5 and 10 percent. The figure shows that the influence of braking is essentially limited to the tread area. Minimal changes are noted in the temperature profiles of the sidewall regions.

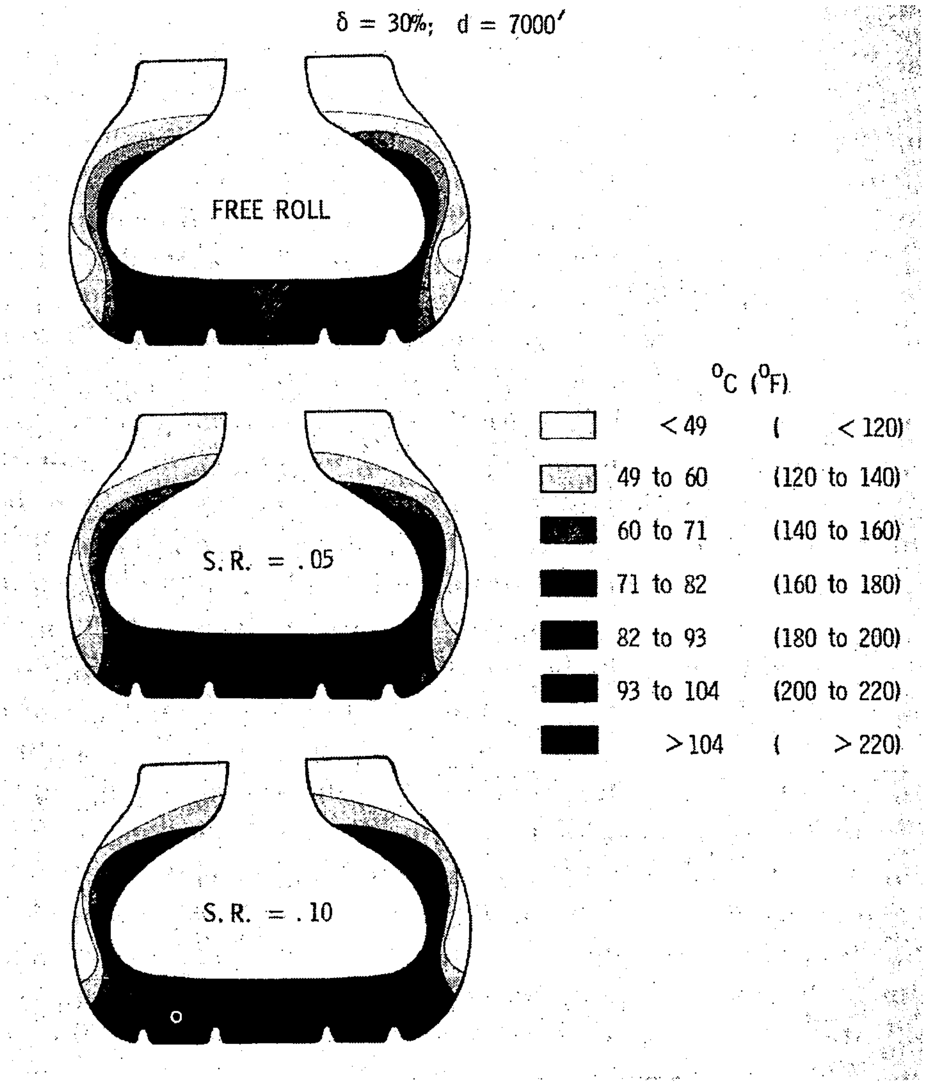

Figure 8

EFFECT OF SPEED

Over the speed range of these tests, the influence of wheel speed on the tire temperature distribution is almost insignificant. As observed in figure 9, the sidewall temperature after free-rolling 7000 feet is essentially unaffected and only moderate increases can be seen in the tread temperature as the speed is increased. The rise in tread temperature at higher speeds is perhaps the result of the higher frequency squirming action which has been observed in the tire footprint.

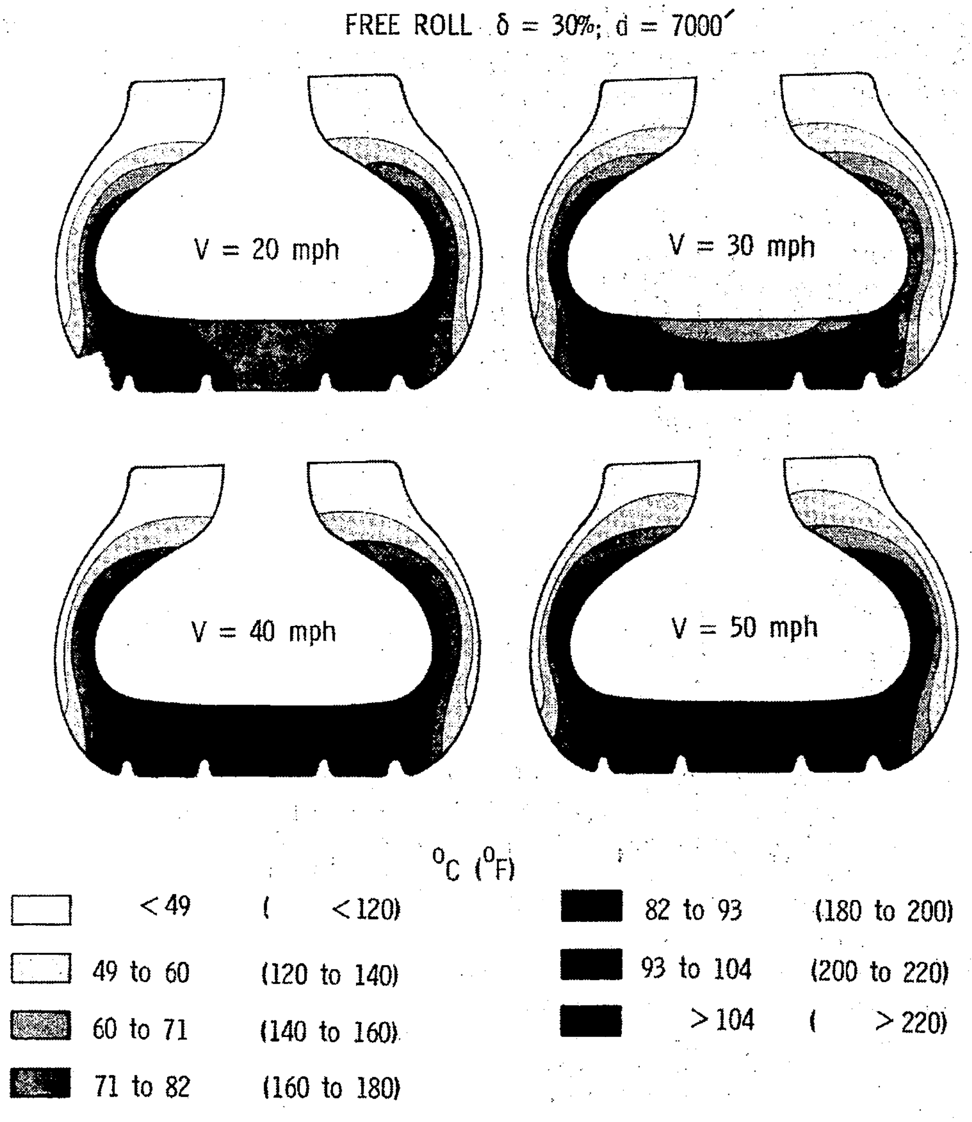

Figure 9

TIRE EQUILIBRIUM TEMPERATURES

The question arose during the course of this investigation as to whether the tire carcass would assume an equilibrium temperature profile if permitted to free roll for an indefinite period. To answer the question, many passes were made in both directions along a 7000-foot runway at 20 mph with a very brief turn-around time between passes to minimize any tire cooling. It became apparent after the tire had traveled approximately 65,000 feet that each thermocouple was approaching an equilibrium value. The final temperature profile, obtained after the tire had traveled in excess of 80,000 feet, is presented in figure 10 and shows temperatures approaching 300° F near the shoulder area. Note again that, particularly in the sidewall region, the temperatures along the inner wall are considerably greater than those near the outer surface. Also note that the centerline tread temperatures are somewhat lower than other temperatures in the tread.

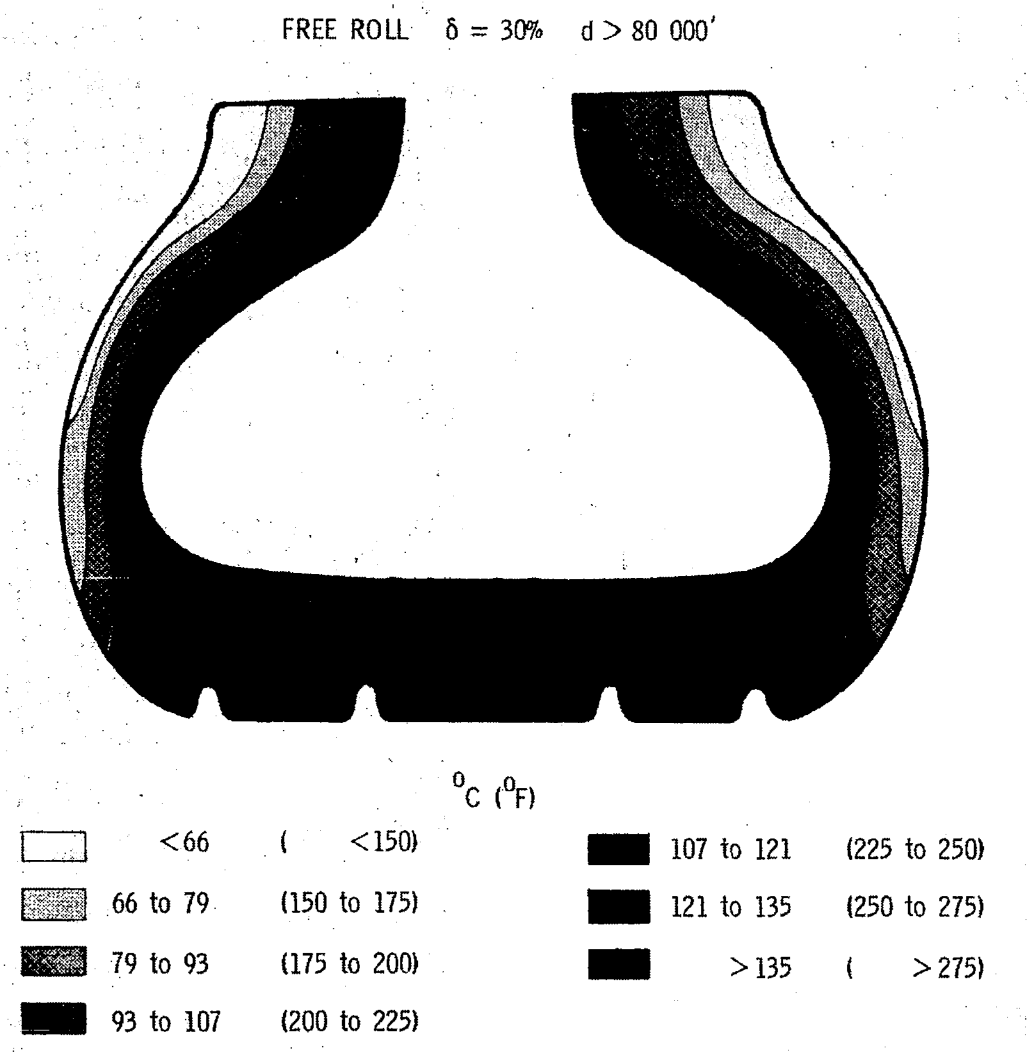

Figure 10

CONCLUDING COMMENTS

The results from a program to study tire temperature profiles to aid in defining the strength and fatigue limitations of an aircraft tire carcass structure suggest the following concluding comments.

- A testing technique has been developed for successfully measuring the thermal characteristics of a rolling tire.
- Tire shoulder and sidewall temperatures increase with increasing tire deflection due to either overload or underinflation.
- Tire tread and "downwind" sidewall temperatures increase with yaw angle.
- Large temperature increases are noted in the tread region during increased braking.
- Changes in ground speed (over the test range to 50 mph) produce insignificant effects on the temperature buildup in the tire carcass.

REFERENCE

1. Clark, Samuel K.: Heat Generation in Aircraft Tires. Tire Modeling, NASA CP-2264, 1983, pp. 193-210.