Tire Footprint Studies

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ABSTRACT

This presentation covers the results of tire footprint studies conducted in the Landing Gear Development Facility of the USAF Wright Laboratory at the Wright Patterson Air Force Base, OH. Tire footprint studies are essential in understanding tire wear mechanisms and computing tire tread wear rates. The power input into the tread is the driving force for tread wear. Variables needed for power input calculations include the footprint pressure and slip velocity distributions. Studies were performed on the effects of power input distributions due to vertical load, camber, yaw, inflation pressure and tire construction. For the present study, two tire constructions, one radial and the other bias, were selected. These tires were for the F-16 Block 30 Fighter aircraft, both of which were previously worn. The present study was limited to steady straight roll with a 14,000 lb vertical load, a 310 psi inflation pressure, zero yaw and camber. All tests were conducted on the Tire Force Machine (TFM) with a specialized sensor plate with embedded pressure sensors (X, Y and Z) and slip sensors (X & Y). All tests were conducted for a table speed of 1 in/s. Tests on the TFM show that the power intensity distributions and total power for both tire constructions are quite similar for straight roll. Later on, tests were also conducted on a modified dynamometer which was overlaid with a grit wear surface. The tire speed was maintained at 40 miles per hour and yaw was set to four degrees. Dynamometer tests showed that radial tires have more tread wear than the bias tire, however, in the field, radial tires have longer life. This is a dilemma.

PROBLEM

Included is the problem statement of low tire life.

- ***Excessive tire wear due to***
  - ***Large contact pressures***
  - ***Large slip velocity***
- ***Very few sorties/tire***
  - ***F-16 Block 30...8-12 landings***
  - ***F-16 Block 40 & 50...4-8 landings***

Figure 1.

OBJECTIVES

This slide states the objectives of the program. The main objectives are to quantify parameters affecting tread wear.

- ***Overall Objective: Increase tread life***
- ***Focussed Objective: Quantify operating conditions and tire design parameters affecting tread wear***
  - ***Operating conditions***
    - ***Load***
    - ***Takeoff/Landing profile (speed, yaw, camber, braking)***
    - ***Antiskid characteristics***
  - ***Tire design parameters***
    - ***Inflation pressure***
    - ***Tire construction (bias/radial)***

Figure 2.

NEEDS

This slide states the need to study footprint pressures and slips so that power intensity can be calculated for tread-wear computations. This data is needed for steady roll, yaw and braking conditions.

- ***Determine aircraft tire footprint slips and pressures to quantify power intensity due to***
  - ***Steady roll***
  - ***Yaw***
    - ***Steady (crosswind)***
    - ***Cornering***
  - ***Braking***
    - ***Steady (constant slip)***
    - ***Transient (antiskid)***

Figure 3.

TOOLS

The tools for carrying out this work are the Tire Force Machine (TFM) and specialized sensors which measure footprint pressures and slips.

- ***Experimental***
  - ***TFM***
    - ***Steady conditions only***
    - ***Low speed (2 in/s max)***
- ***Analytical/Computational***
  - ***FEM***

Figure 4.

APPROACH

The approach to this work is to perform roll tests on the TFM and measure footprint data using specialized equipment. The data will be analyzed for wear energy rate determination. Parameter studies will be performed to compare the performance of radial against bias tire for vertical load, yaw and camber.

- ***Perform Footprint measurements on TFM***
  - ***Slip velocity x (longitudinal) y (lateral)***
  - ***Contact force intensity x, y and z (normal)***
- ***Data Analysis***
  - ***Wear energy rate determination***
  - ***Parametric studies on F-16 tires***
    - * ***Type (Radial vs Bias)***
    - * ***Vertical Load***
    - * ***Yaw***
    - * ***Camber***

Figure 5.

SENSORS FOR TIRE FORCE MACHINE

This slide shows the layout of pressure and slip sensors and the direction of roll. Pressure sensors give X, Y and Z components of pressure, whereas slip sensors measure X and Y components. There are 37 pressure gages and 37 slip gages. The holes are 1/4 inch in diameter. The pressure sensors are level with the top of the plate whereas the slip sensors are 4 mils above the plate surface.

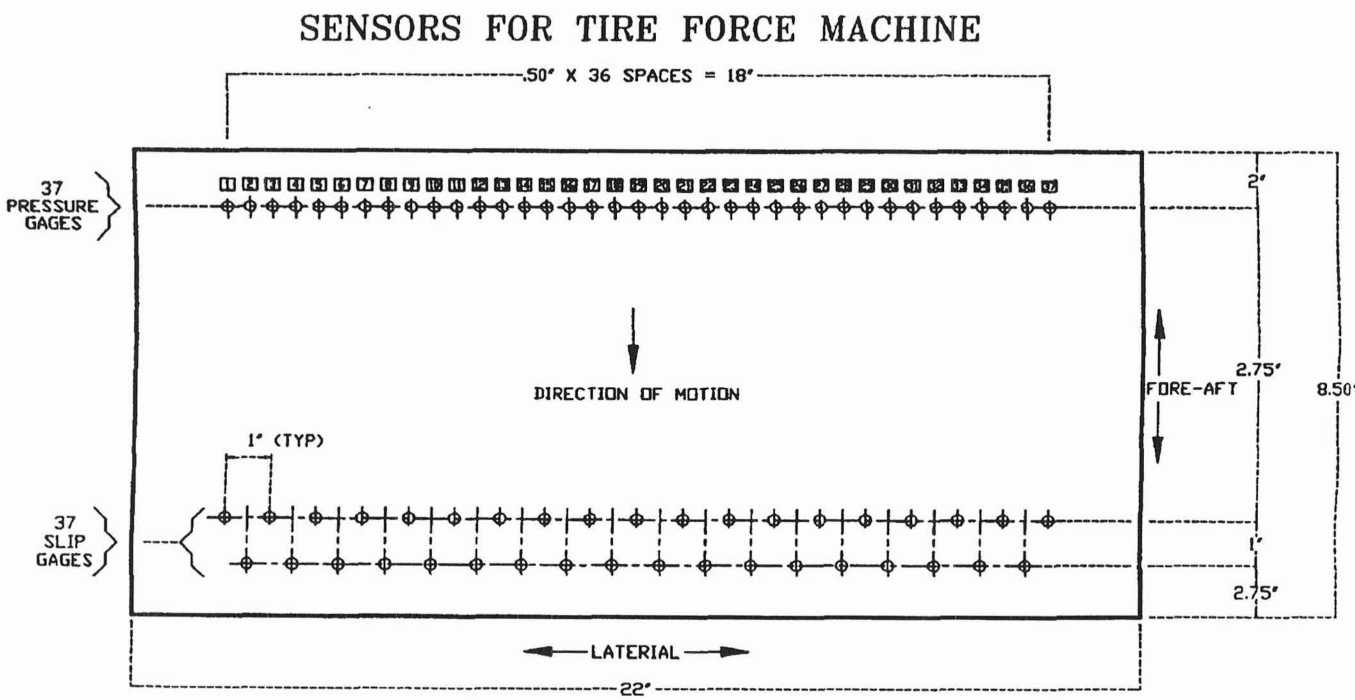

Figure 6.

F-16 BLOCK 30

This is a mesh plot of the vertical (Z) pressure for the bias and the radial F-16 Block 30 tires. Both plots look similar in shape and magnitude indicating that the normal pressures are nearly the same for these tires. In all runs, the tire is rolling towards the origin in the fore-aft direction. The table speed was 0.981 in/s for the radial tire and 0.913 in/s for the bias tire.

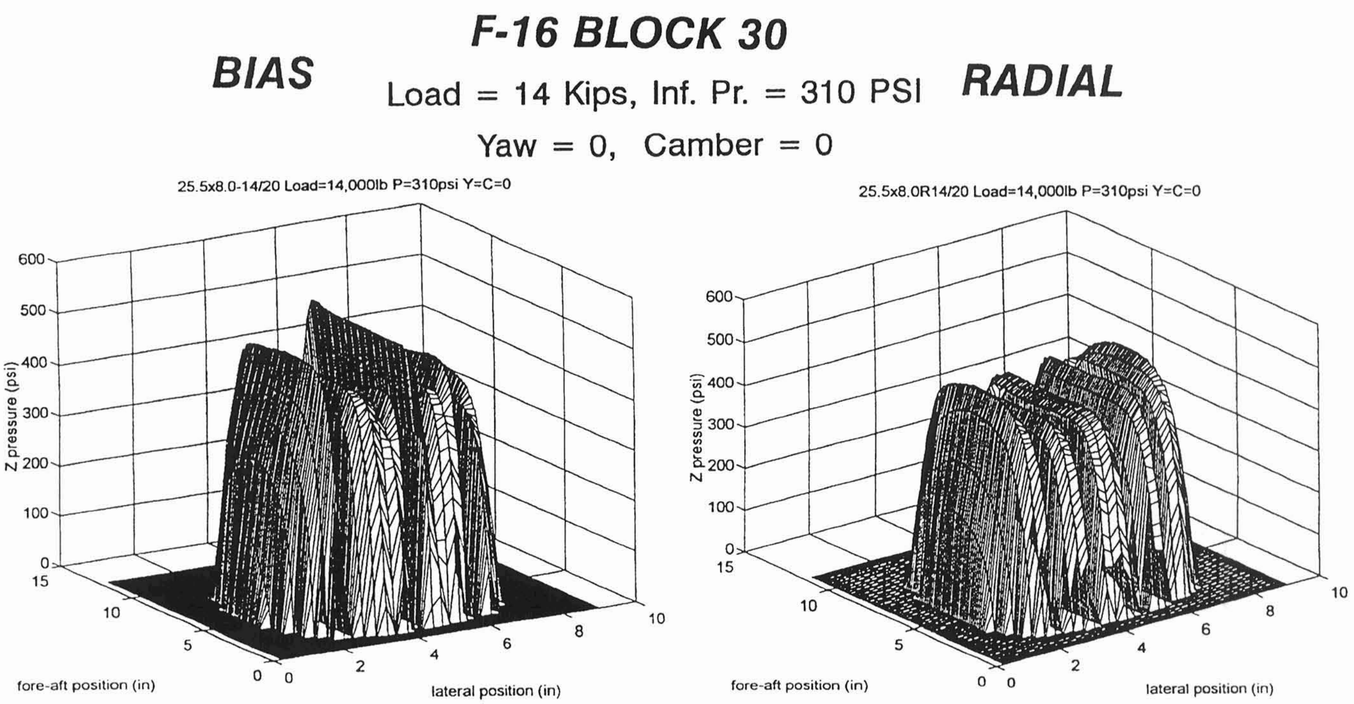

Figure 7.

X PRESSURE

This is a plot of the fore-aft (X) pressure distributions for both radial and bias tires. The total measured steady state X force is 140 lbs for the radial tire and 271 lbs for the bias tires. This compares favorably with the predicted integrated values of 265 lbs and 141 lbs. Therefore, the total dissipative power in these runs works out to be 137 in-lb/s for the radial tire and 247 in-lb/s for the bias tire.

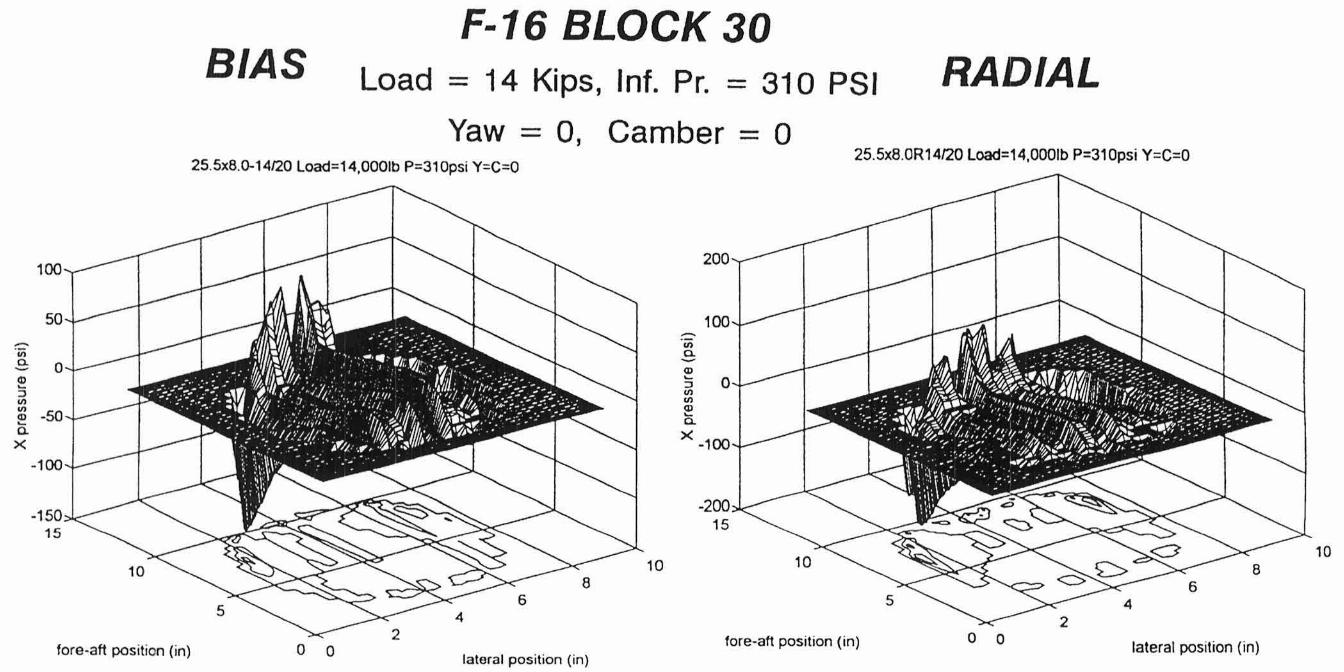

Figure 8.

Y PRESSURE

This is a plot of the lateral (Y) pressure distribution for both radial and bias tires.

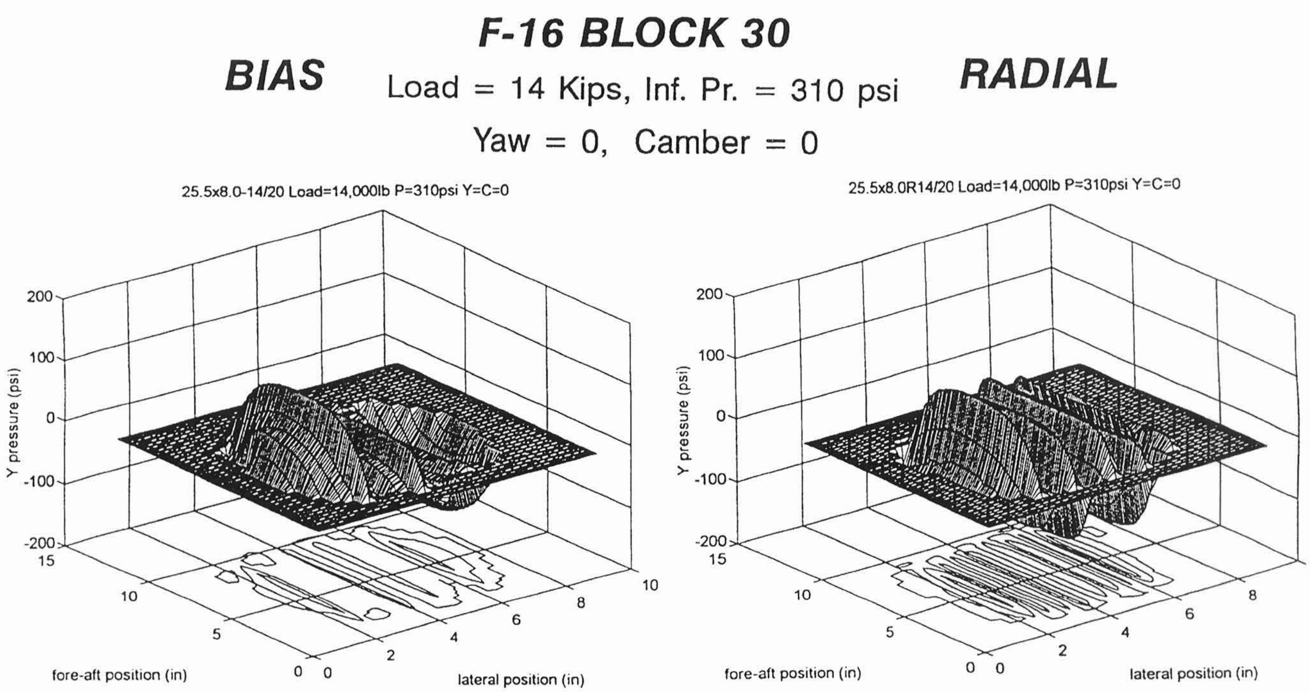

Figure 9.

TRACTION VECTOR

This is a plot of the traction vectors providing both magnitude and direction.

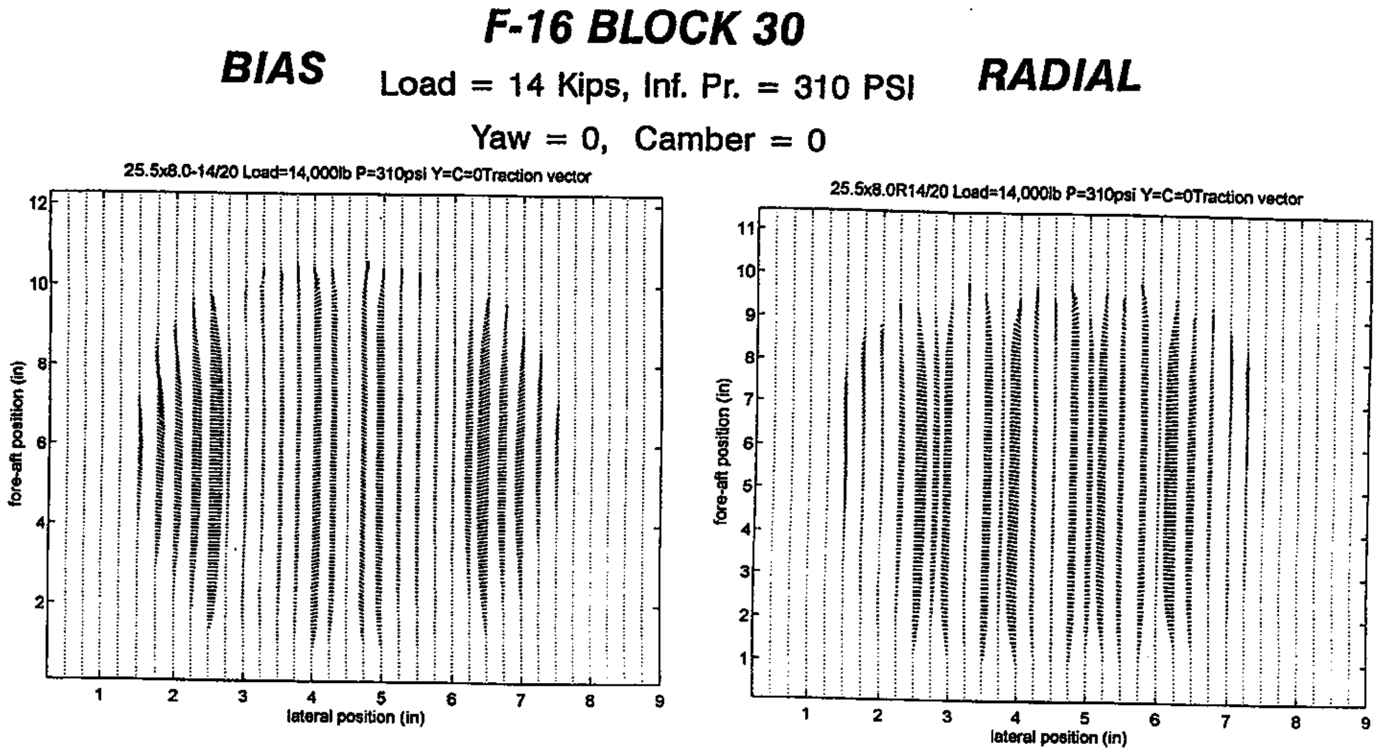

Figure 10.

X SLIP VELOCITY

This is the slip velocity in the fore-aft (X) direction, measured in mil/s. Note that the peaks occur at the trailing edges of the contact patch. The slip velocity was calculated from the slips by using the central difference method. The data was manipulated such that at zero normal (Z) pressure, no slip velocity occurs. Note that the maximum slip occurs at the trailing edge of the tire.

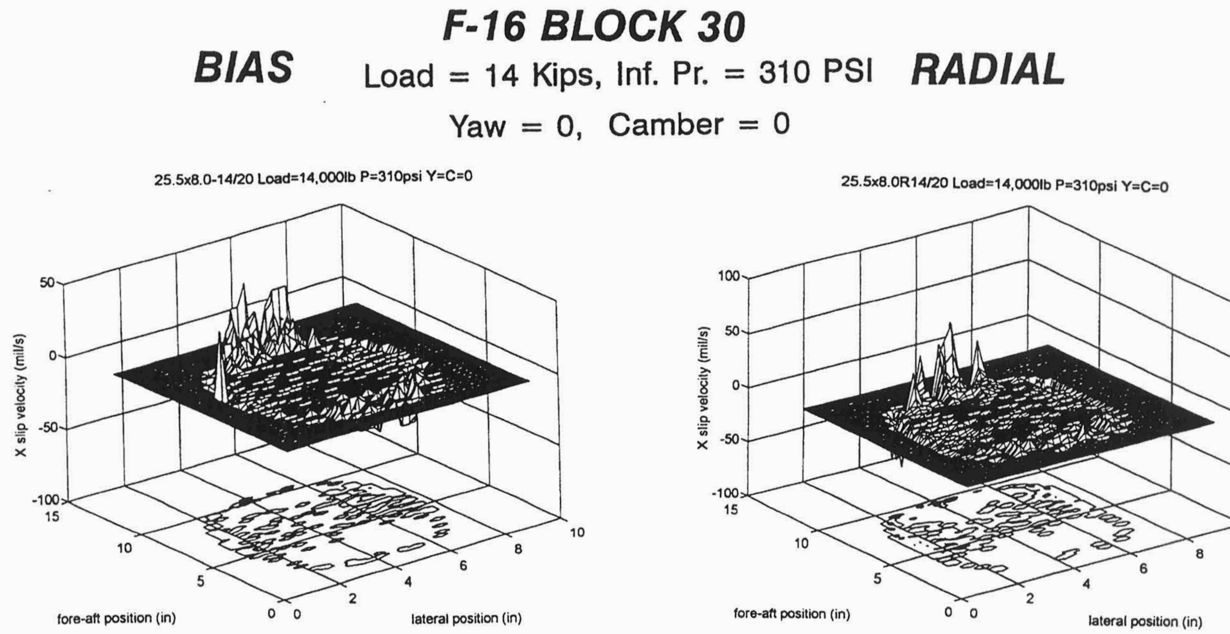

Figure 11.

Y SLIP VELOCITY

This is the slip velocity in the lateral (Y) direction, measured in mil/s. Note that the maximum values occur at the trailing and leading edges of the contact patch.

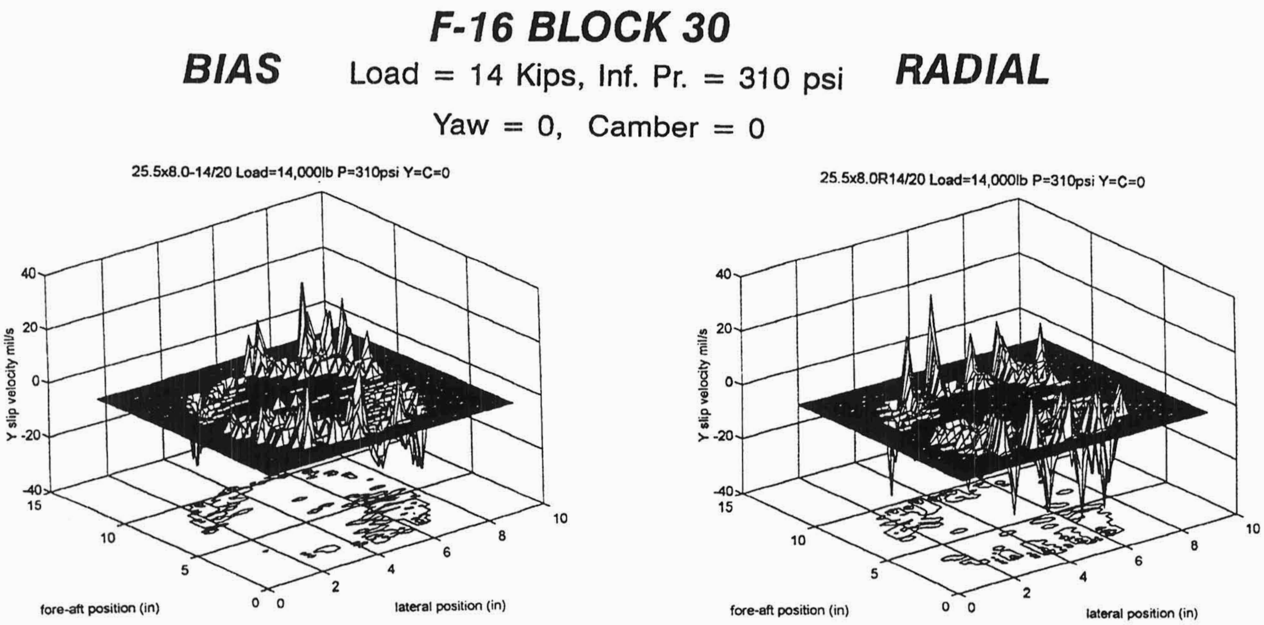

Figure 12.

SLIP VELOCITY MAGNITUDE

This is the slip velocity magnitude measured in mil/s. Note that the peaks occur at the trailing edge of the contact patch.

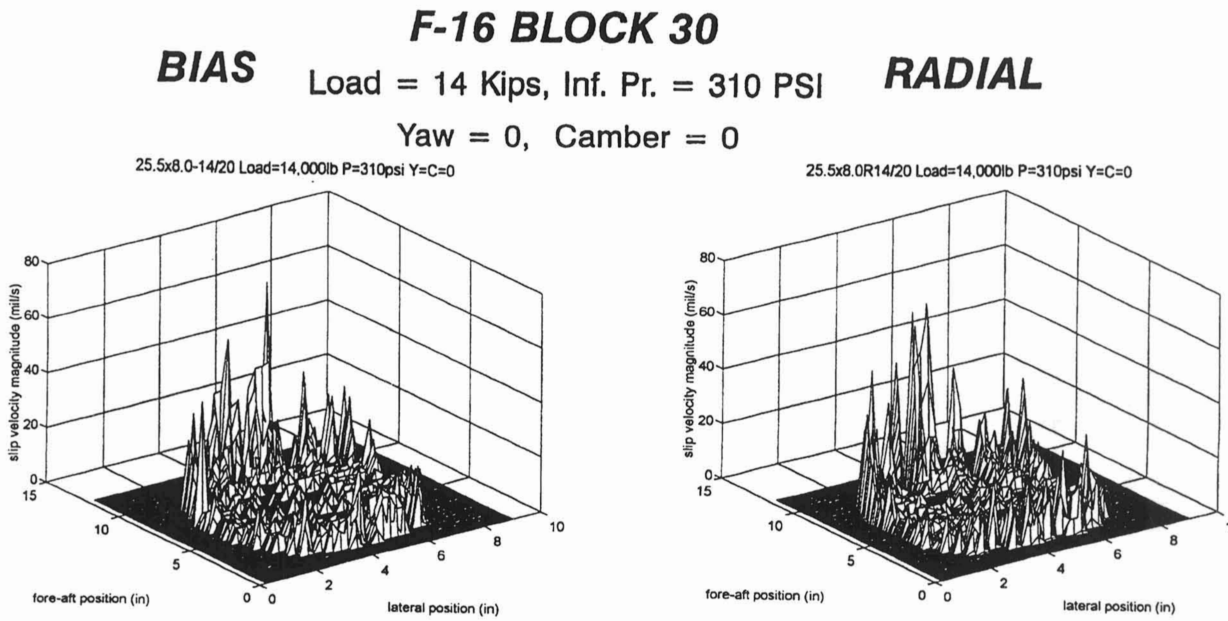

Figure 13.

SLIP VECTOR

This is the plot of the slip velocity vector giving both the magnitude and the direction. There is a lot of similarity between the two tires.

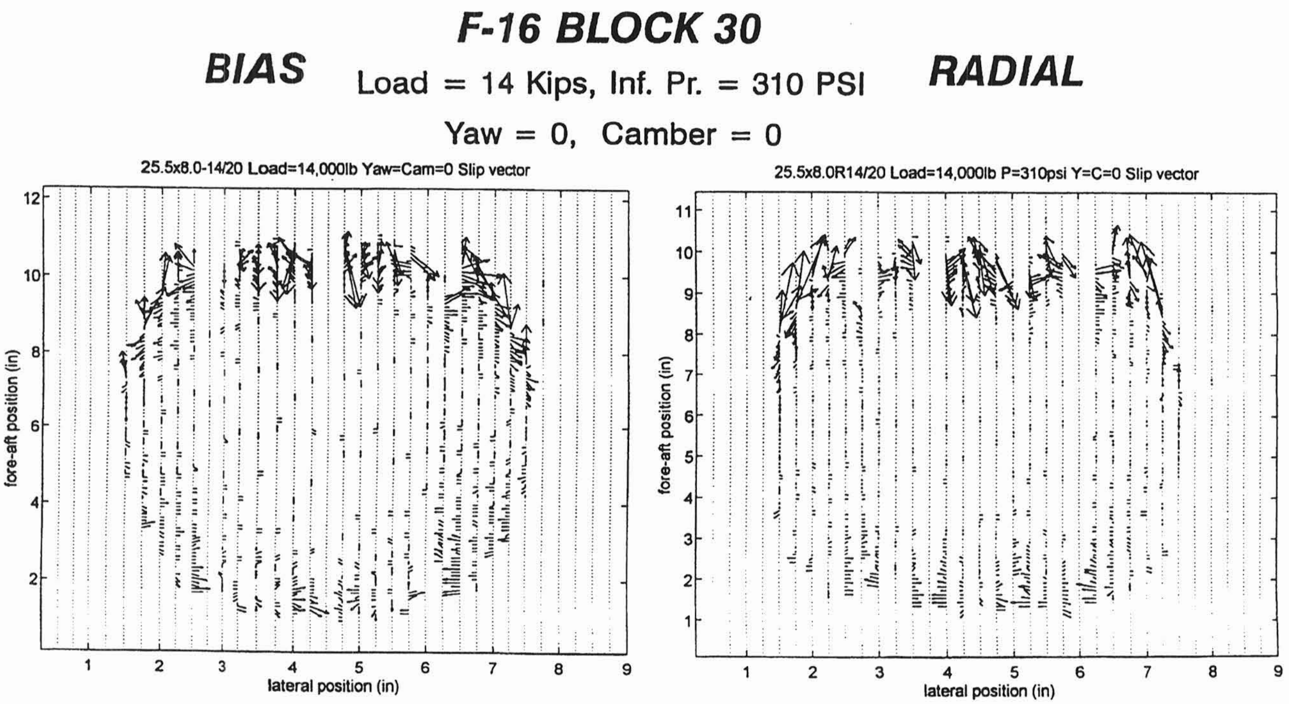

Figure 14.

Z PRESSURE

This is a contour plot of the normal (Z) pressure for the bias tire. When integrated over the contact area, it gives a total value of 15,565 lbs which compares favorably with the applied load of 14,000 lbs.

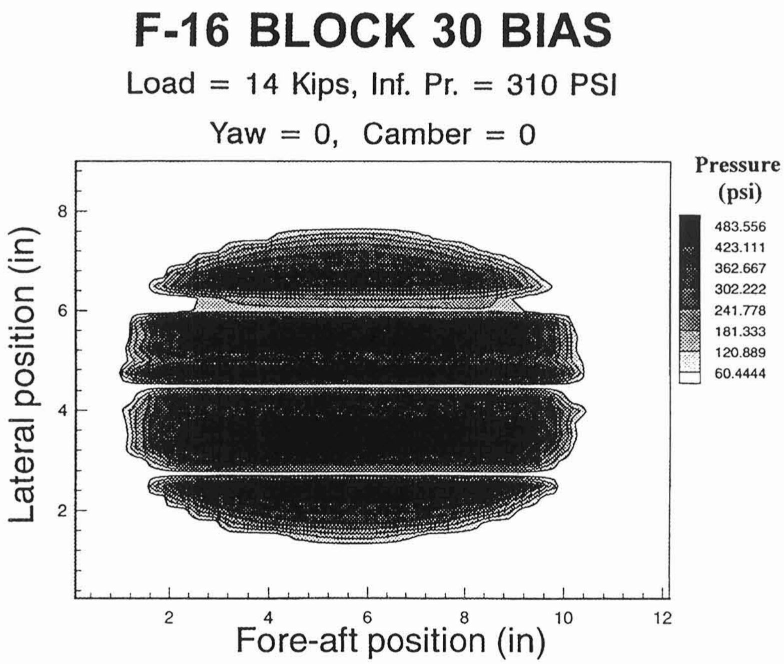

Figure 15.

SLIP VELOCITY MAGNITUDE

This is a contour plot of the slip velocity magnitude for the bias tire. Note that the slip velocity is maximum at the trailing edge of the contact patch. This data was manipulated by zeroing out values which occurred at zero contact pressure.

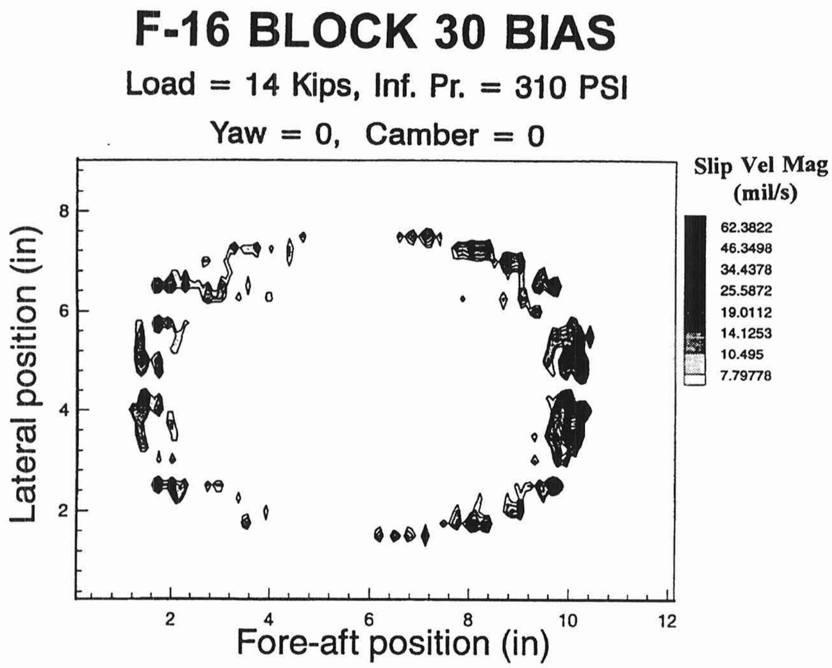

Figure 16.

POWER INTENSITY

This is a contour plot of the power intensity calculated by multiplying an assumed value of coefficient of friction (0.5) and the Z pressure by the slip velocity magnitude. Note that the maximum power intensity occurs at the front and back edges of the tire. The total dissipative power due to friction was determined by integrating this power intensity over the contact area. The resulting value was 22.0 in-lb/s for the bias tire.

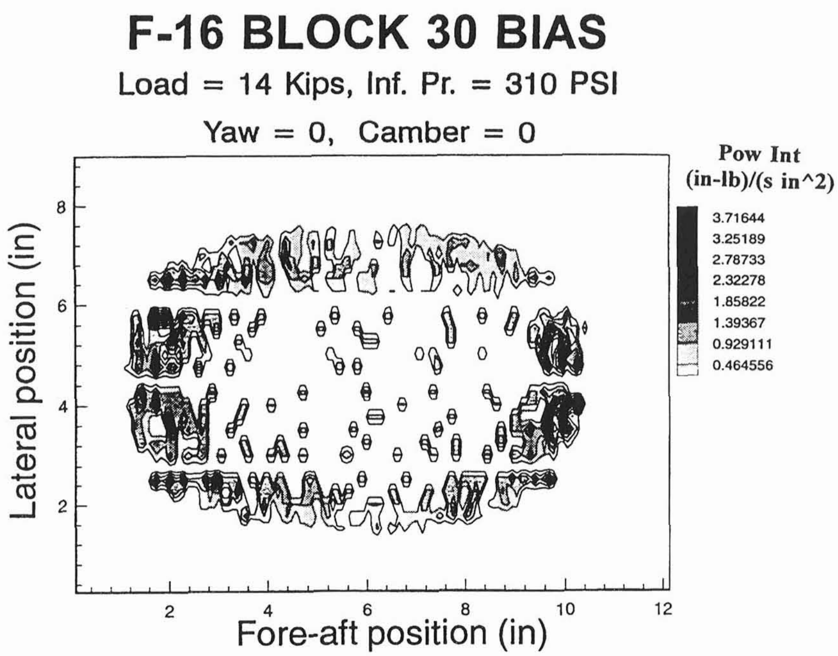

Figure 17.

Z PRESSURE

This is a contour plot of the normal (Z) pressure for the radial tire. When integrated over the contact area it gives a value of 15,095 lbs which compares favorably with the applied load of 14,000 lbs.

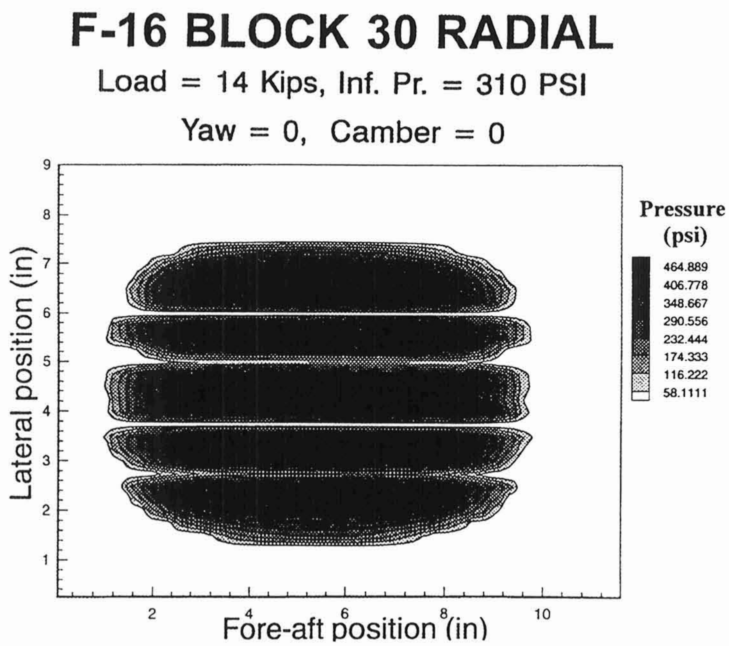

Figure 18.

SLIP VELOCITY MAGNITUDE

This is a contour plot of the slip velocity magnitude for the radial tire. Note that the slip velocity is maximum on the trailing edge of the contact patch. This data was manipulated by zeroing out values which occurred at zero contact pressure.

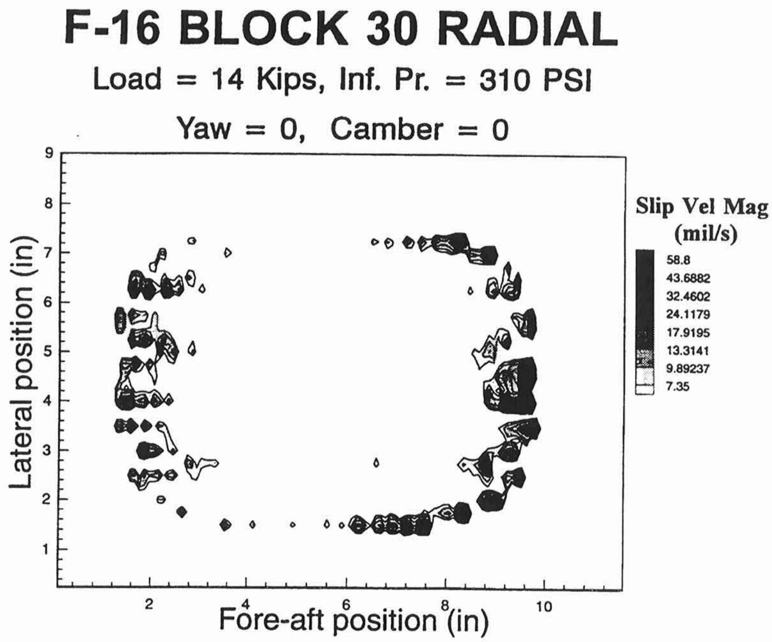

Figure 19.

POWER INTENSITY

This is a contour plot of the power intensity for the radial tire. This was calculated by multiplying an assumed value of coefficient of friction (0.50) by the Z pressure and the slip velocity magnitude. Note that the maximum power intensity occurs at the front and back edges of the tire. The total dissipative power was 23.6 in-lb/s for the radial tire.

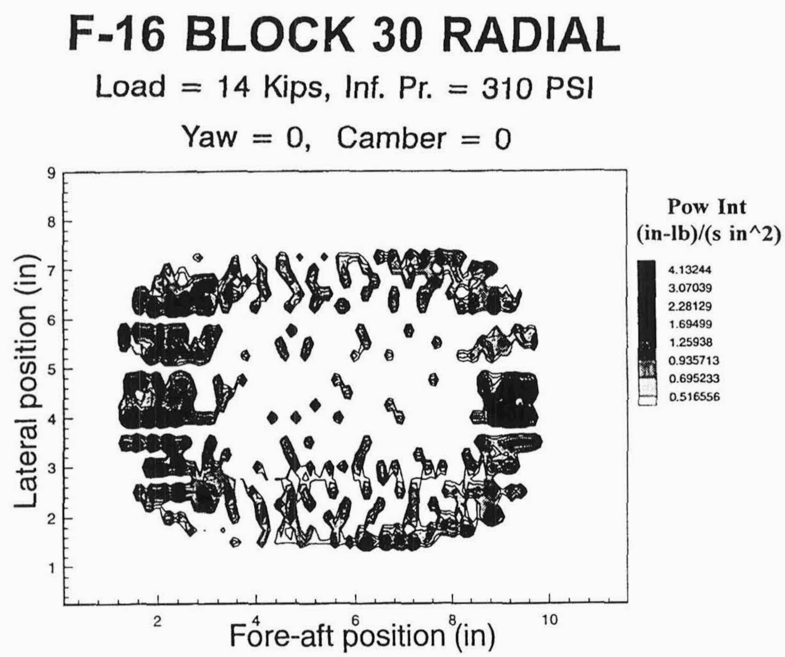

Figure 20.

POWER INTENSITY

This is a mesh plot of the power intensity distributions for the two tires.

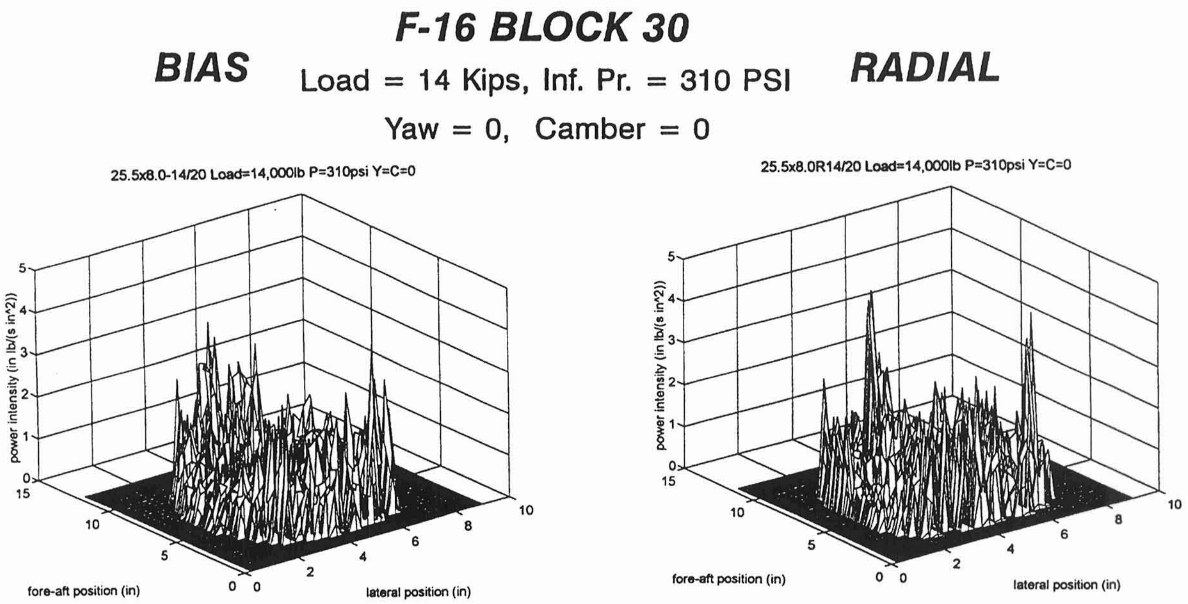

Figure 21.

POWER PER UNIT LENGTH

This is a plot of power per unit width plotted in the lateral direction which was determined by integrating the power intensity along the fore-aft direction.

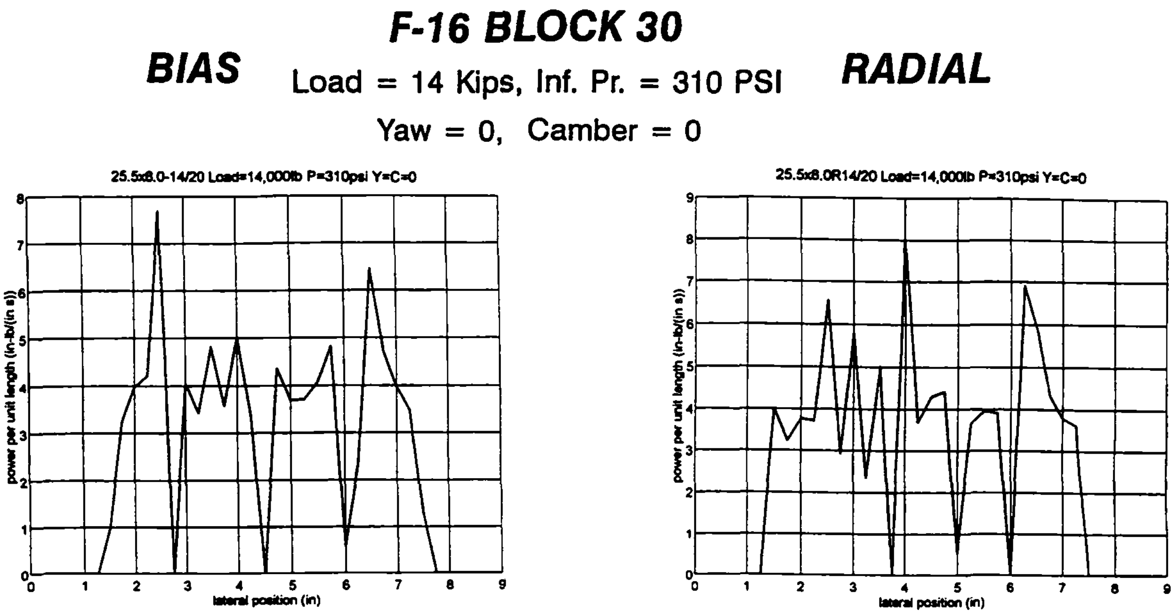

Figure 22.

RESULTS

Tabulated results for both bias and radial tires. All values are very similar.

	BIAS	RADIAL
Table speed (in/s)	.913	.981
Maximum slip (mil)	31.3	49.1
X-Pressure range psi	(-122,94)	(-147,106)
Y-Pressure range psi	(-113,126)	(-132,115)
Traction Vector psi	(0,129)	(0,148)
Z-Pressure range psi	(0,544)	(0,523)
X-Slip Velocity mil/s	(-70,50)	(-63,64)
Y-Slip Velocity mil/s	(-25,30)	(-35,35)
Slip Velocity Magnitude mil/s	(0,70.2)	(0,66.1)
Power Intensity in-lb/(s-in^2)	(0,4.2)	(0,4.6)

MEASURED (INTEGRATED) TOTAL VALUES

	BIAS	RADIAL
Fx (lb)	271 (265)	140 (141)
Fy (lb)	182 (6)	157 (199)
Fz (lb)	14,000 (15,565)	14,000 (15,291)
Power (in-lb/s)	(22.0)	(23.6)

Figure 23.

WL DYNAMOMETER TIRE WEAR RESULTS SUMMARY

This is a plot of the actual tire wear on the bias and the radial tires which were run on a modified external drum dynamometer overlaid with an abrasive material glued to the wheel surface. The tire was run with four degrees of yaw at 40 mph. Tread wear was quantified by measuring the maximum groove depth on the tire tread. Note that on the dynamometer for four degrees of yaw, the radial tire wears much faster than the bias tire. However, in the field, the radial tires have longer tread life.

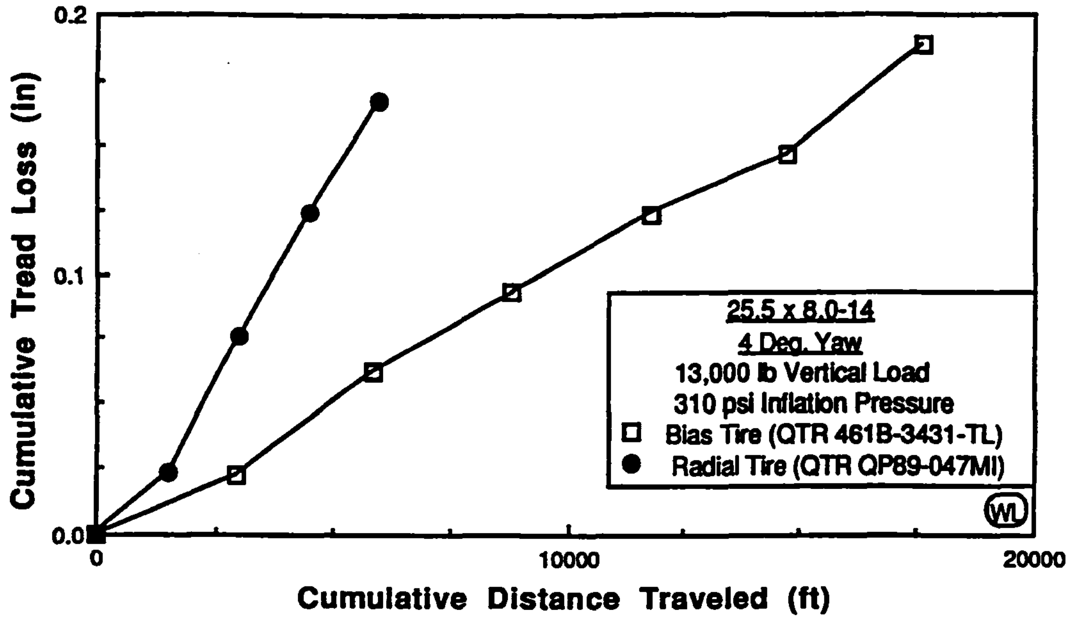

Figure 24.