AEROSPACE INFORMATION REPORT

AIR5797

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Aircraft Tire Wear Profile Development and Execution for Laboratory Testing

RATIONALE

AIR5797 has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE

This SAE Aerospace Information Report (AIR) describes the current process for performing comparative wear testing on aircraft tires in a laboratory environment. This technique is applicable to both radial and bias tires, and is pertinent for all aircraft tire sizes.

This AIR describes a technique based upon "wear" energy. In this technique, side wear energy and drag wear energy are computed as the tire is run through a prescribed test program. The specifics that drive the test setup conditions are discussed in Sections 4 through 7. In general, the technique follows this process:

- A test profile is developed from measured mechanical property data of the tires under study.
- Each tire is repeatedly run to the test profile until it is worn to the maximum wear limit (MWL). Several tires, typically 5 to 10, of each tire design are tested.
- Wear energy is computed for each test cycle and then summed to determine total absorbed wear energy.
- An index is calculated for each tire design. This is accomplished by dividing the total linear inches of wear at the most worn point into the total wear energy.
- The indexes are then normalized to provide a comparative wear rate.

The described technique is not meant to provide an absolute wear rate or wear index because the technique does not produce results that allow the user to say a tire will last for a specific number of landings. However, it does provide a comparative index. It will make a distinction from one tire design to another by indicating a percentage difference in abrasive wear rate under representative operational conditions. The technique has been demonstrated in a number of test programs and is shown to have an extremely high correlation to field data. Supporting data is included in Section 9.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

Cornering and Wear Behavior of the Space Shuttle Orbiter Main Gear Tire

Author(s): Daugherty, Robert H.; Stubbs, Sandy M., NASA Center: Langley Research

Report Number: SAE PAPER 871867

2.1.2 U.S. Government Publications

None.

2.2 Definitions

CONICITY: The condition of an asymmetric tire construction that causes a tire to generate a lateral force.

FOOTPRINT: The shape of a loaded tire in its contact patch. The shape varies based on the loading, and the inflation pressure of the tire.

LIFE CYCLE COST (LCC): Total cost of an object or system, factoring in everything from production, life, maintenance, and disposal.

MAXIMUM WEAR LIMIT (MWL): The maximum number of cords that can be worn through before the tire is no longer safe to use, as determined by the tire manufacturer.

Py: Tire tread contact pressure distribution in the lateral or y-direction.

Px: Tire tread contact pressure distribution in the longitudinal or x-direction.

PLYSTEER: The turning moment produced from the tire in straight roll. This is created by the construction of the tire.

3. TIRE PREPARATION

3.1 Tire Conditioning

Before break-in, a tire is conditioned by mounting it on a suitable rim, inflating it to the unloaded rated inflation pressure, and allowing it to remain in this condition for 24 hours at ambient temperature, between 60 °F (15 °C) and 100 °F (38 °C).

3.2 Break-in Procedure

After conditioning, a tire is subjected to taxi rolls to perform “break-ins.” The test tire is inflated to the unloaded rated inflation pressure, and then rolled at taxi speeds for a one-mile taxi roll, followed by a two-mile taxi roll. Each taxi is performed at the tire’s rated, or usage load. The taxi speed is typically 20 to 40 mph (32 to 64 kph). The tire is cooled to ambient before starting any of the taxi break-in rolls.

3.3 Tire Inflation

During tire wear testing the inflation pressure is set to either a rated or a field usage pressure. Typically, the tire pressure is not corrected for flywheel curvature, and the footprint contact pressure on the internal drum is similar to a flat plate contact pressure.

4. MECHANICAL PROPERTIES

Mechanical property tests are conducted on each of the tire designs that are to be tested.

4.1 Mechanical Properties - Dynamometer

Sinusoidal yaw sweeps (described in 4.1.1) and brake sweeps (described in 4.1.2) are performed using the internal drum dynamometer prior to conducting wear testing. The resulting data is input into the wear energy model, as described in Section 7, and the dynamometer surface is prepared as described in Section 6. Figures 1 and 2 show the coordinate system used throughout dynamometer testing. Figure 3 shows an example of the collected data. The linear regression equation is utilized in generating the wear model.

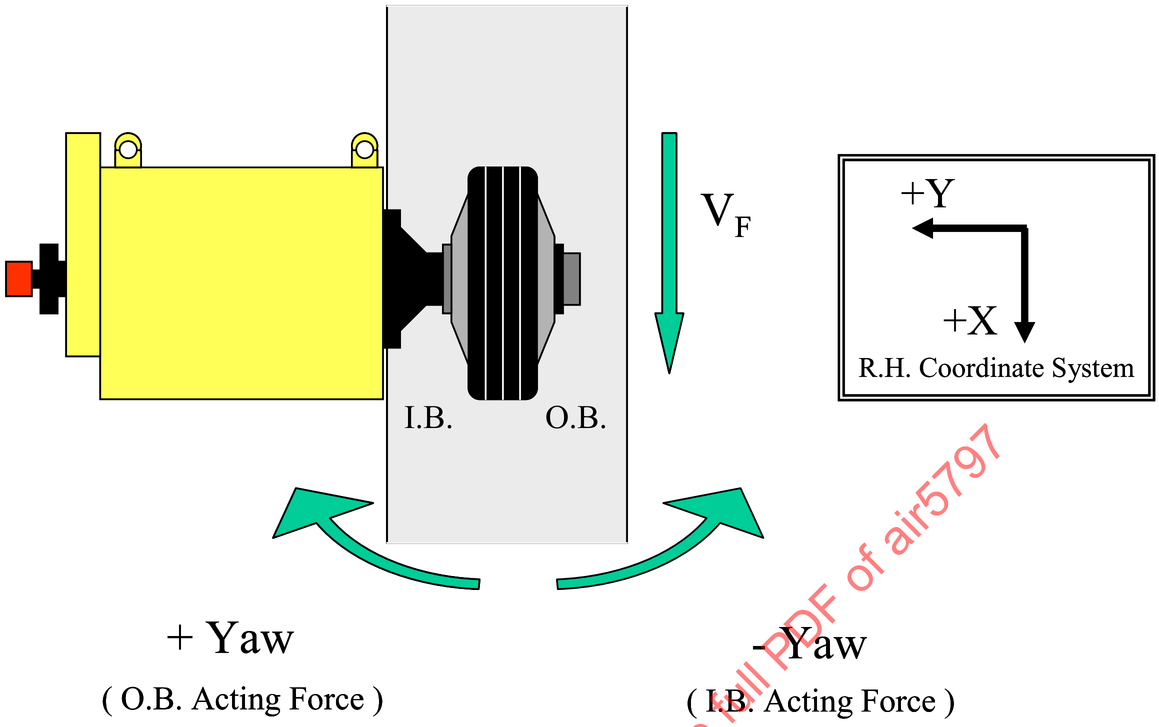

FIGURE 1 - COORDINATE SYSTEM

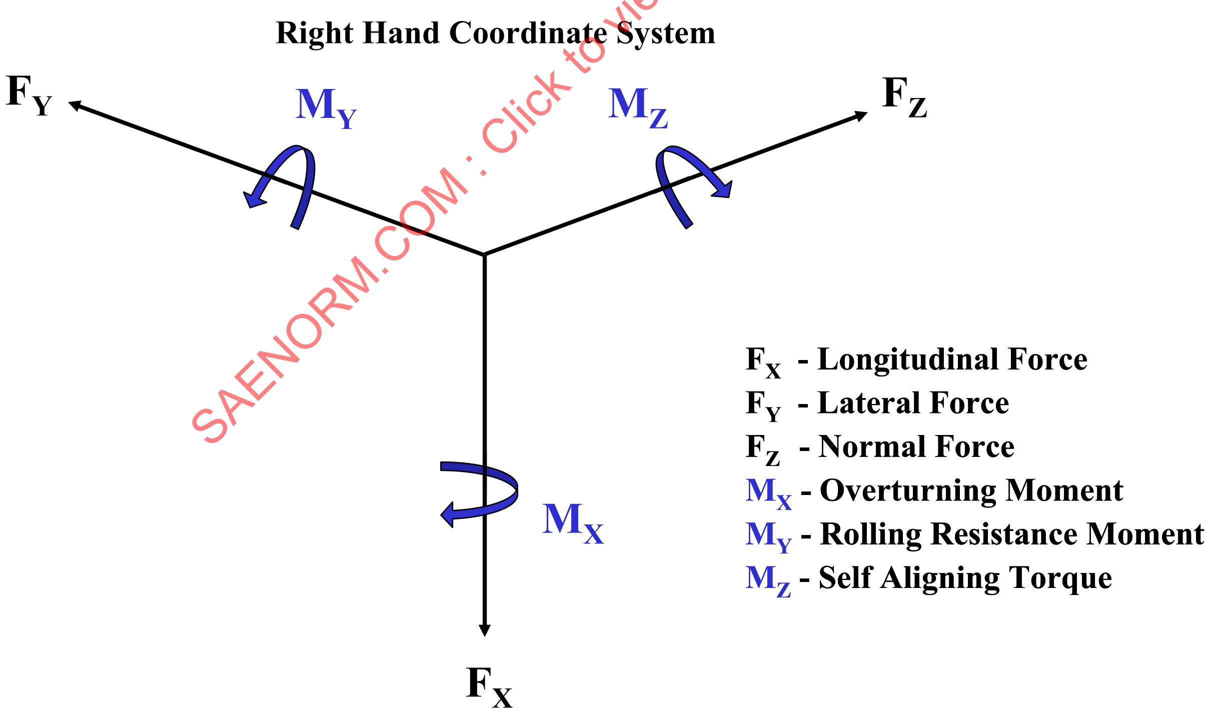

FIGURE 2 - FORCE AND MOMENT DIAGRAM

All coordinate systems referenced in this document have an origin coincident with the tire/wheel centerline and the axle centerline.

4.1.1 Sinusoidal Yaw Sweep

A sinusoidal yaw sweep of ±5 degrees is performed with the vertical load and inflation pressure maintained at test conditions. The flywheel velocity is held within the 20 to 40 mph (32 to 64 kph) speed range, typical of aircraft taxi-way turning operations. These speeds are also those at which the turns will occur in the actual wear test profile.

The relationship between side load and yaw angle is established for the tire designs under test. This value is used to predict the side load forces the tire will see while yawing, and becomes a driver in the tire's wear energy model.

Equation 1 is determined through linear regression by utilizing the data collected on one tire of each design under test.

$$F_Y = m\psi + b \qquad \text{(Eq. 1)}$$

where:

F_Y = Side Load (dependent variable)

m = slope of data

Ψ = yaw angle

b = side load offset due to ply steer, conicity, and tire asymmetries

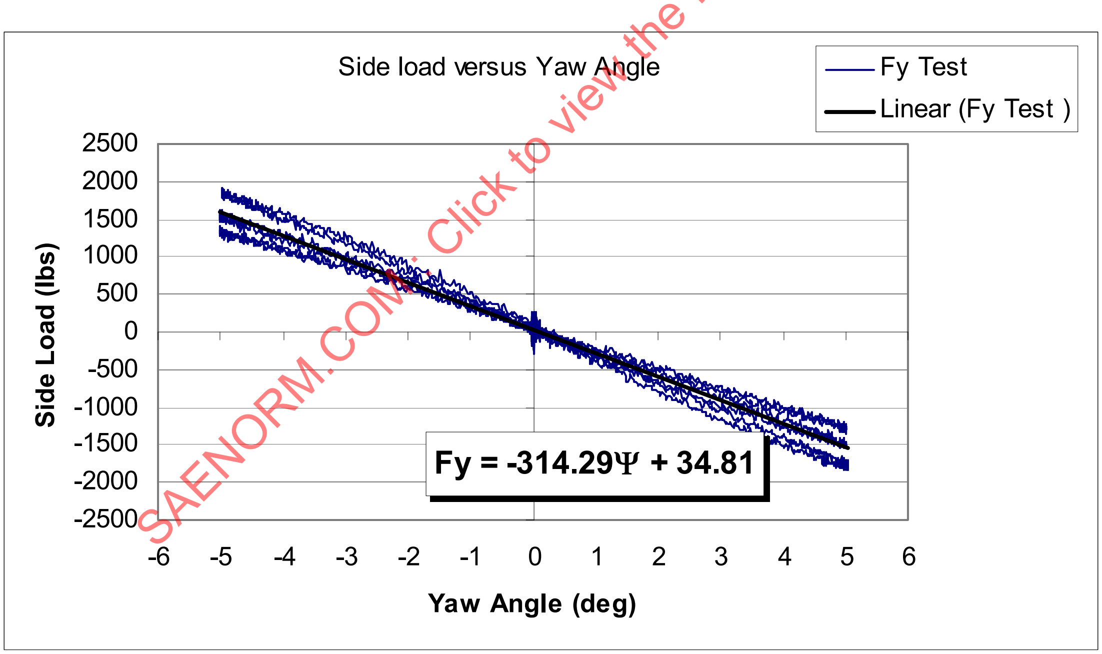

FIGURE 3 - YAW SWEEP DATA

4.1.2 Braking Sweep

During this event, the vertical load and the flywheel velocity are held constant. The flywheel speed is typically set at a value between 40 and 80 mph (64 and 129 kph). The brake force is ramped up until approximately 10% slip is achieved. This data is regressed as follows:

$$Y = A\left(F_X / F_Z \right) \quad \text{(Eq. 2)}$$

where:

Y = Percent slip

A = Constant

F_X = Drag load

F_Z = Vertical load

This test predicts drag loads that will be seen during testing, and feeds the wear energy model. Figure 4 depicts a graphic example of this data, gathered from multiple test tires. In this plot, the X-axis represents the coefficient of friction (Mu) which is equal to F_X / F_Z. The Y-axis represents the difference in test tire speed and flywheel speed expressed as a percentage.

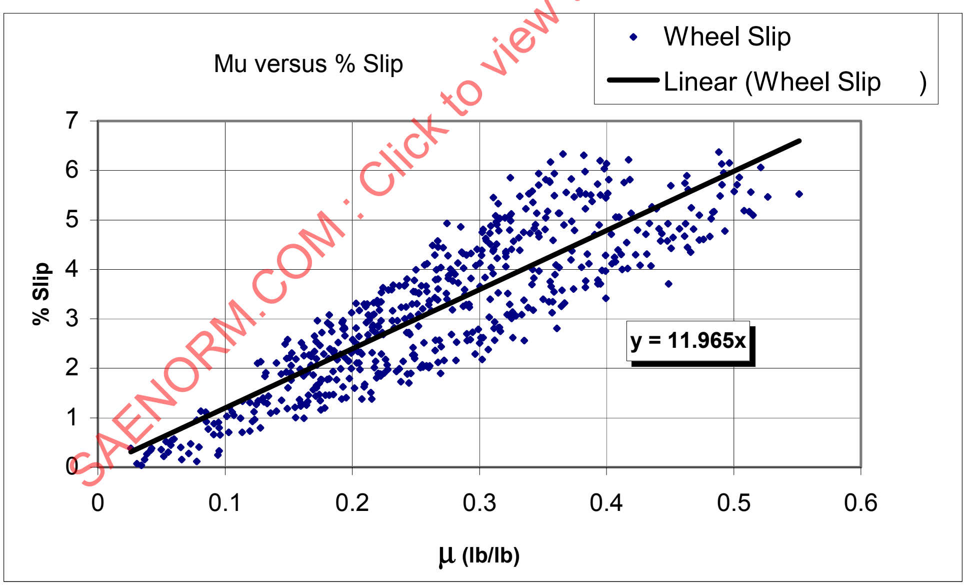

FIGURE 4 - SLIP DATA

4.2 Supplemental Information - Tire Force Machine Footprint Data

To develop tire footprint pressure distribution data, the tire is inflated to test pressure, mounted on a suitable yoke or mandrel, and rolled over a flat surface. The Tire Force Machine (TFM) located at the LGTF at Wright Patterson AFB, Ohio is one test platform that is capable of performing this type of test. The TFM allows a tire to be rolled at slow speeds at controlled vertical loads, yaw angles, and camber angles. The machine measures and records the tire reaction forces and moments, table speed, table position, tire deflection, tread contact pressures in the x, y, and z directions, and tread contact slip in the x and y directions. Figure 5 graphically depicts the TFM and shows the coordinate system used during this testing.

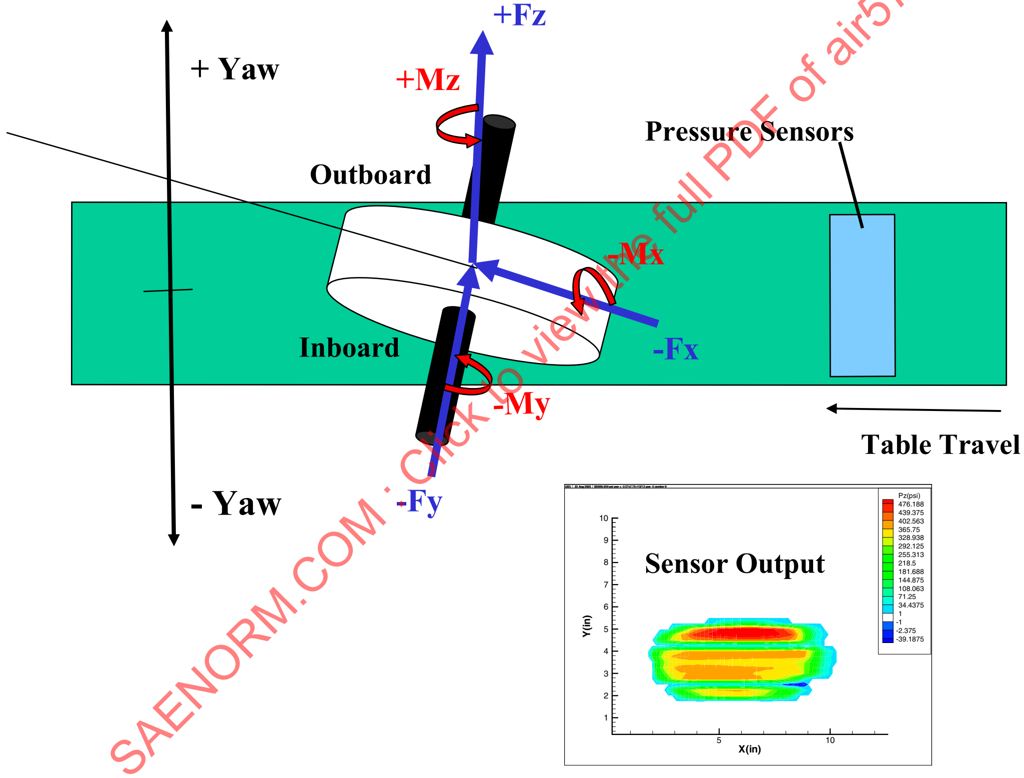

FIGURE 5 - FORCE AND MOMENT DIAGRAM - FOOTPRINT

4.2.1 Load Surface

The loading surface used to measure the tread contact forces is a flat aluminum plate (TFM table). At least one full tire revolution should be completed before the test tire reaches the sensor array. This allows the tire’s reaction forces to stabilize before being measured by the sensor array. To maintain a uniform friction coefficient, assure accurate data development, and conduct an effective test, any contamination on the surface of the flat metal plate should be removed prior to testing the tires.

The load surface and sensor array includes the capability to measure tread contact pressure in each of the x, y, and z directions, and tread slip in the x and y direction.

4.2.2 Yaw Angle and Tire Speed

Footprint Data is typically collected at yaw angles of 0, ±3, and ±5 degrees, with the test tire driven down the test surface at a speed of approximately 2 in/s (50 mm/s).

4.2.3 Py and Px Footprints

The data from the tread contact shear stresses, as measured by the Py and Px sensors, is important when determining wear patterns. Experience has shown that the areas where the highest shear forces are present are normally the areas of highest wear rates. The tire wear pattern can often be predicted by evaluating Py values during yawed rolling and Px values during un-braked straight rolling. Proper balance between turning and braking in the test profile is established using this information. Additionally, these parameters are used in the wear profile development stage.

5. ENERGY CALCULATIONS

5.1 Side Wear Energy

Side Wear Energy is a theoretical quantity derived from the distance traveled in the Y-direction multiplied by the force in the Y-direction (Reference 2.1.1). The distance traveled in the Y-direction is approximated as the roll distance is multiplied by sine of the yaw angle. This calculation has shown excellent correlation between predicted and measured energy levels. Equation 3 shows this equation:

$$SWE = \sin(\psi) \cdot d_X \cdot F_Y \quad \text{(Eq. 3)}$$

where:

SWE = Amount of energy from side forces wearing the tire

Ψ = Yaw angle

d_X = Roll distance in X-direction

F_Y = Force on tire in the Y-direction

5.2 Drag Wear Energy

Drag Wear Energy is also a theoretical quantity developed at the Wright-Patterson LGTF during developmental tire wear testing. The drag wear energy is calculated using Equation 4:

$$DWE = \%slip \cdot d_X \cdot F_X \quad \text{(Eq. 4)}$$

where:

DWE = Amount of energy from drag forces contributing to tire wear

%slip = Amount of slip seen by the tire

d_X = Roll distance in the X-direction

F_X = Force on tire in the X-direction

Percent Slip is defined in Equation 5:

$$\%slip = \frac{R_F\omega_F - R_T\omega_T}{R_F\omega_F} \qquad \text{(Eq. 5)}$$

where:

- $\%slip$ = Amount of slip seen by the tire
- R_F = Radius of the flywheel
- ω_F = Angular velocity of the flywheel
- R_T = Tire rolling radius at full speed and vertical load
- ω_T = Angular velocity of the tire

5.3 Power

Because this AIR is specifically focused on abrasive tread wear, precautions are taken during tire testing to prevent tire rubber reversion, which results from a tire getting too hot. If the rate at which a tire absorbs energy is high enough, the tread will get hot enough for the rubber to revert. These temperatures can cause tread property and wear surface changes to create inconsistent test data. Efforts should be made to keep power (rate of wear energy input) levels low enough to avoid these high temperatures and the resulting reverted rubber buildup. Additionally, the wear rate can become non-linear at high energy levels. Presently, thermal degradation wear should be assessed as a part of the field wear evaluation.

5.4 Total Wear Energy

The Total Wear Energy is the sum of Equation 3 and Equation 4. Both the rate of tire wear and its wear pattern can be controlled by changing the type of energy the tire absorbs. For instance, changing the ratio of side energy to drag energy changes the wear pattern, while the rate of tire wear is controlled by changing the amount of total energy per test cycle.

6. WEAR SURFACE

Tire wear comparisons are particularly dependent upon the consistency of the dynamometer's surface. The wear surface used for testing, under the process described in this AIR, is 120-grit Aluminum Oxide paper applied directly to the flywheel. Due to minor inconsistencies between production runs of this material it is recommended that all grit paper used for a given test program be from the same production run. With each new tire tested, the surface is changed by a new application of grit paper. Talc is applied to the dynamometer surface during tire wear runs to prevent rubber buildup. The applied talc level is increased during braking and turning maneuvers when increased removed rubber is anticipated.

7. WEAR MODEL

7.1 Field Conditions

If engineering judgment dictates, field worn tires may be obtained to determine typical field wear patterns. In lieu of actual worn tires, photographs can be utilized to see wear patterns. The contour of the field worn tires and the footprint data collected, as described in 4.2, is used to determine the required ratio of drag to side energy to produce wear patterns similar to the patterns most often seen in the field.

7.2 Tire Cross Sections

To accurately determine the available linear wear thickness, it is desirable to obtain a cross section of each tire design under study.

7.3 Spreadsheet

The information gained from Equations 1 through 5, when placed in a spreadsheet, is used to develop a wear model. An example wear model is shown in Figure 6.

PROGRAMMED VALUES					PREDICTED VALUES				Rolling Radius		12.7	
Time (sec)	Speed (mph)	Radial Force (lbs)	Brake Force (lbs)	Yaw Position (deg)	Predicted Fy (lbs)	Predicted Slip (%)	Predicted Distance (ft)	Predicted Drag Force (lbs)	Predicted Side Energy (ft-lbs)	Predicted Drag Energy (ft-lbs)	Net Side Wear Energy (ft-lbs)	Tire Revs
0.00	0	6000	0	0	140			120			0	
16.00	80	6000	0	0	140	0.00	939	120	0	0		
17.00	80	12800	0	0	140	0.24	117	256	0	73	0	17.6
17.50	80	12800	0	0	140	0.24	59	256	0	36	0	8.8
18.00	80	12800	0	0	140	0.24	59	256	0	36	0	8.8
18.02	80	12800	50	0	140	0.29	2	306	0	2	0	0.4
18.50	80	12800	500	0	140	0.71	59	756	0	317	0	8.8
20.50	80	12800	2700	0	140	2.79	235	2,956	0	19,384	0	35.3
27.50	80	12800	2700	0	140	2.79	821	2,956	0	67,843	0	123.5
27.51	80	12800	0	0	140	0.24	1	256	0	1	0	0.2
34.01	40	12800	0	0	140	0.24	572	256	0	354	0	86.0
36.01	30	12800	0	0	140	0.24	103	256	0	64	0	15.4
38.01	30	12800	0	2.5	-1,985	0.24	88	256	3,811	55	-3811	13.2
55.01	30	12800	0	2.5	-1,985	0.24	748	256	64,772	463	-64772	112.5
57.01	30	12800	0	0	140	0.24	88	256	269	55	269	13.2
59.01	30	12800	0	-2.3	2,095	0.24	88	256	3,700	55	3700	13.2
76.01	30	12800	0	-2.3	2,095	0.24	748	256	62,895	463	62895	112.5
78.01	30	12800	0	0	140	0.24	88	256	247	55	247	13.2
79.01	30	12800	0	0	140	0.24	44	256	0	27	0	6.6
							3,920				-1471	589.4
								Predicted Total Energy	Predicted Side Energy	Predicted Drag Energy		
								224,976	135,695	89,282		
						Ratio side versus drag			60.3%	39.7%		

FIGURE 6 - EXAMPLE WEAR MODEL

The columns in the wear model are defined as follows:

Predicted F_Y: Equation 1 (see 4.1.1)

Predicted Slip: Equation 2 (see 4.1.2)

where:

F_X = Predicted Drag column in model

F_Z = Radial Force column in model

Predicted Distance:

$$d = v \cdot t \quad \text{(Eq. 6)}$$

where:

d = Predicted Distance

v = Tire velocity in feet per second

t = Time in seconds

Predicted Drag Force:

$$DragForce = F_B + 0.02 \cdot F_Z \quad \text{(Eq. 7)}$$

where:

DragForce = Predicted drag force

FB = Brake Force column in model

FZ = Radial Force column in model

The value 0.02 represents a typical free rolling drag as 2% of the vertical load.

Predicted Side Energy: Absolute value of Equation 3 (see 5.1)

Predicted Drag Energy: Equation 4 (see 5.2)

Net Side Wear Energy: Sum of Equation 3 and Equation 4

Wear energies are adjusted by changing braking time, yawing time, speed during braking, yaw angle, and brake force.

7.3.1 Speed

Speed during yawing is set to a typical taxi speed. In this example, it was set at 30 mph (48 kph). The speed during braking is set at a value that allows a representative brake application speed, but keeps heat generation low enough to stay in the abrasive wear regime. This speed value is increased or decreased depending on the wear pattern required, and tire characteristics.

7.3.2 Yaw Angle

Yaw angles are adjusted to produce zero net side energy. Yaw in one direction will be larger than the opposite direction to account for ply steer, conicity, and other factors affecting the symmetry of the tire. Yaw angles are determined by using the information from the Mechanical Properties Tests described in 4.1.

Negative side force in the model implies that the force is acting in the negative Y-direction.

7.3.3 Brake Force

The brake force is determined by using data from the Braking Sweep Test described in 4.1.2. Typically, a brake force that produces between 2 and 4% wheel slip is chosen. This value is determined by using the composite mu-slip curve.