Measurement and Modeling of Tire Forces on a Low Coefficient Surface

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by:

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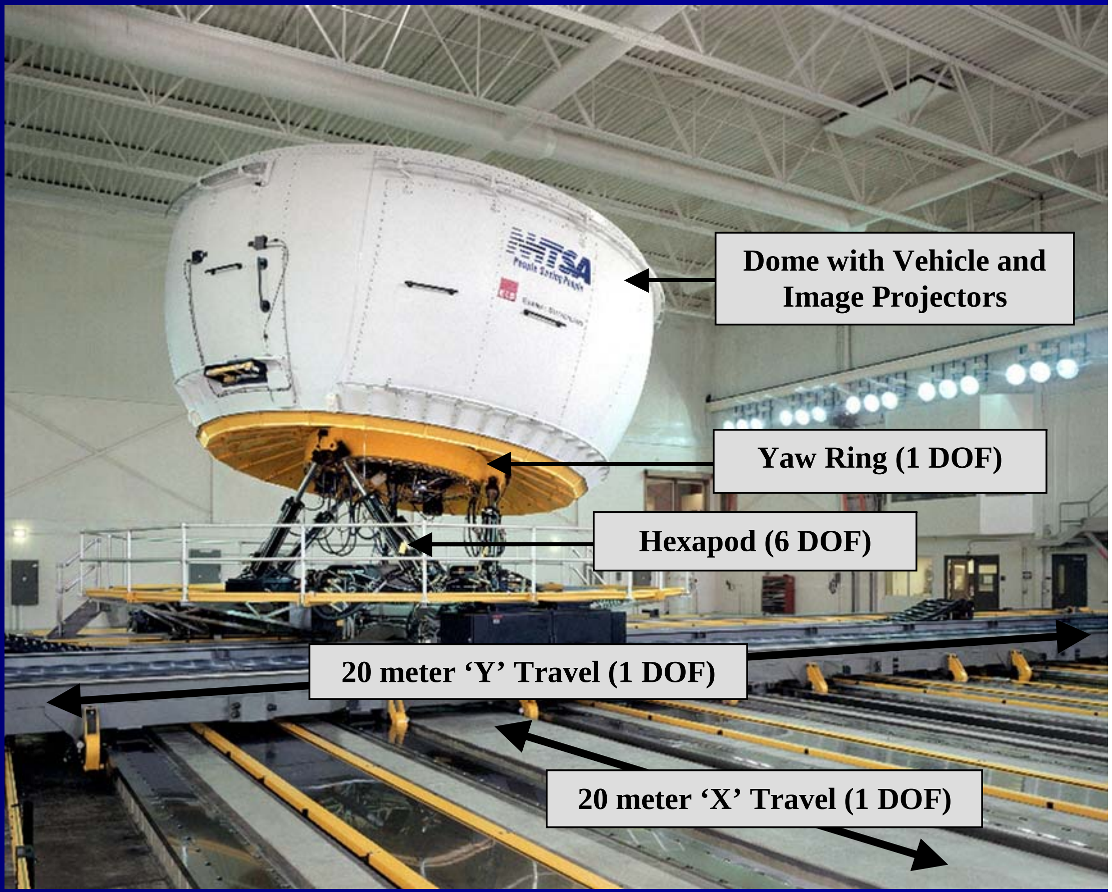
Overview

- Introduction
- Objectives
- Tire Model
- Tire Properties
- Results
- Conclusions

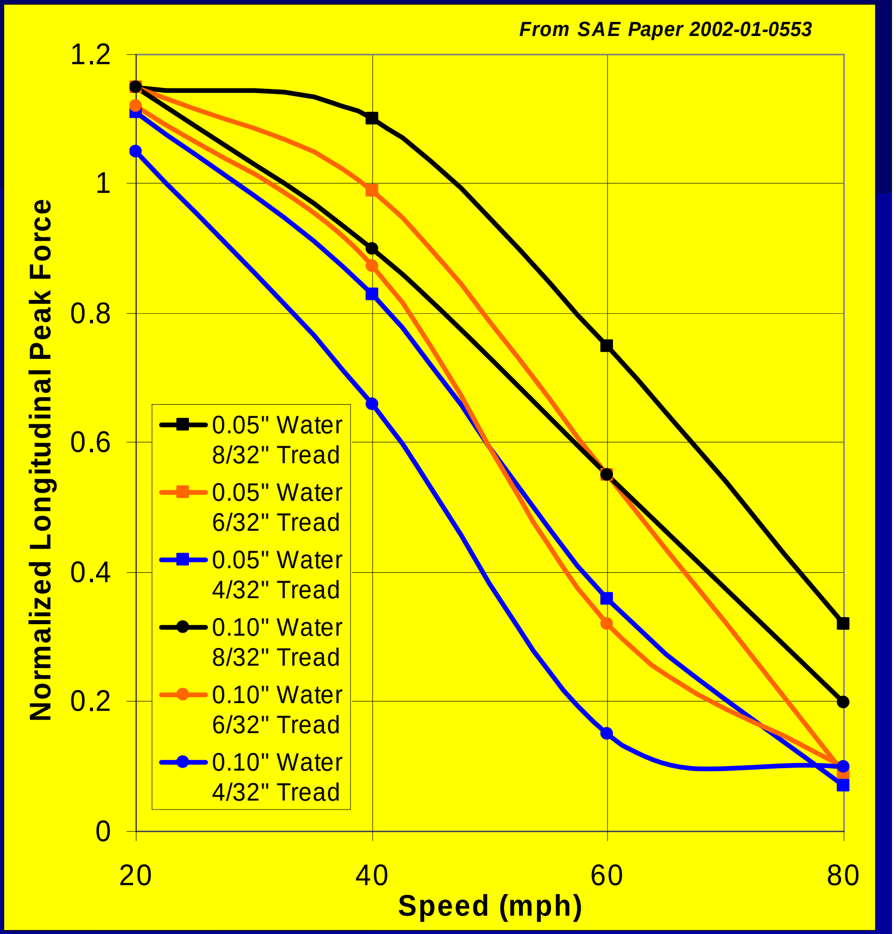
National Advanced Driving Simulator (NADS)

- 20 m x 20 m X-Y platform
- 330-degree yaw ring
- Hexapod mounted on 6 actuators
- 360-degree field of view
- Four full-size vehicle cabs
- Four actuators at cab "suspensions"
- Driver feels feedback on all controls



Testing Objectives:

- To develop a tire model for a slippery road to test ESC and other advanced vehicle technology studies
- Peak Coefficient of friction <0.6 to ensure ESC activation
- Speed dependent model – all other tire properties are fixed
- Testing on laboratory surface (3M surface); variations in roadway micro and macro textures not accounted for
- Selected 4/32" tread depth and 0.05" of water depth, to get a peak about 0.6 at 50 mph



Testing Facility and Tires:
TIRF at CALSPAN (General Dynamics)

Surface Used: 3M 80-grit-polycat sandpaper

Goodyear Eagle RSA
P225/60R16

All Tires Shaved
to 4/32” Tread Depth
All Tire Pressures at 34 psi

Testing Matrix

- **Discrete Cambering At Zero Slip Angle**
  - Normal loads: 40, 80, 120, 160 and 200% of reference load.
  - Wet test speeds: 30, 45, 60 and 75 mph (4 tests) & Dry test speed: 30 mph (1 test)
  - Inclination angles: -10, -8, -6, -4, -2, 0, 2, 4, 6, 8 and 10°
- **Quasi-Static Steering / Cornering**
  - Inclination angle: 0°
  - Slip angle sweep: 0 to -20 to +20 to 0° at a rate of 3 deg/sec
  - Normal loads: 40, 80, 120, 160 and 200% of reference load.
  - Wet test speeds: 30, 45, 60 and 75 mph (4 tests)
- **Quasi-Static Braking / Driving**
  - Inclination angle: 0°
  - Slip ratio sweep: 0 to -50% to +50% to 0 || Ramp time (0 to 50%) of 1.5 sec
  - Normal loads: 40, 80, 120, 160 and 200% of reference load.
  - Wet test speeds: 30, 45, 60 and 75 mph (4 tests) & Dry test speed: 30 mph (1 test)
- **Quasi-Static Combined Steering / Braking / Driving**
  - Inclination angle: 0°
  - Normal loads: 100% of reference load.
  - Steady state slip angles: -6, -4, -2, 0, 2, 4, and 6°
  - Slip ratio sweep: 0 to -50% to +50% to 0
- Ramp time (0 to 50%) of 1.5 sec
  - Wet test speeds: 30, 45, 60 and 75 mph (4 tests) & Dry test speed: 30 mph (1 test)

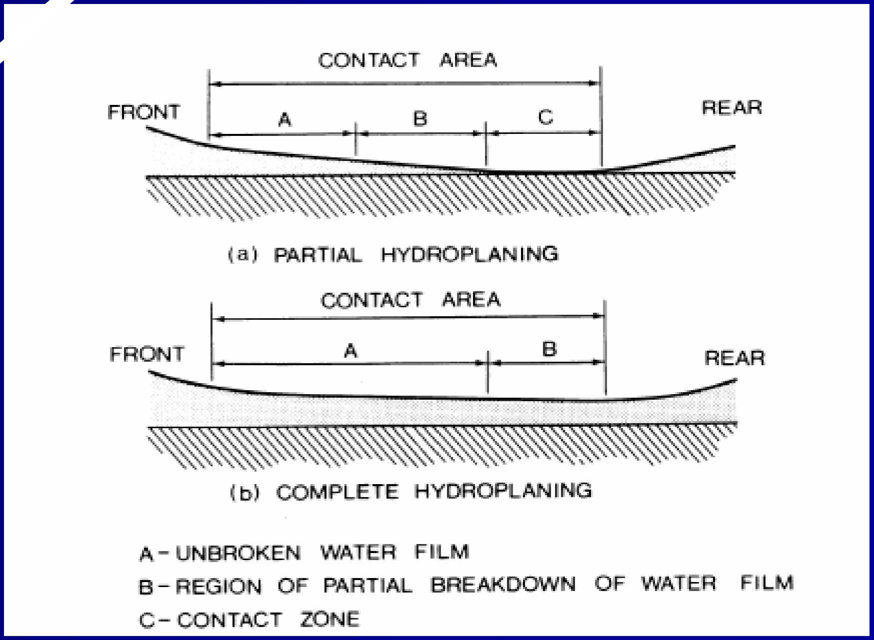
Tire Wet Contact Phenomena

- At low speed
  - Water affects boundary conditions, lowering friction
  - Difference between dry and wet surface not high

- At higher speed
  - Viscosity induces retardation of water displacement making a wedge of water
  - Difference between dry and wet forces is higher

- At a particular speed, the film covers all the contact surface: Hydroplaning fluids do not sustain shear forces comparable to direct tire contact

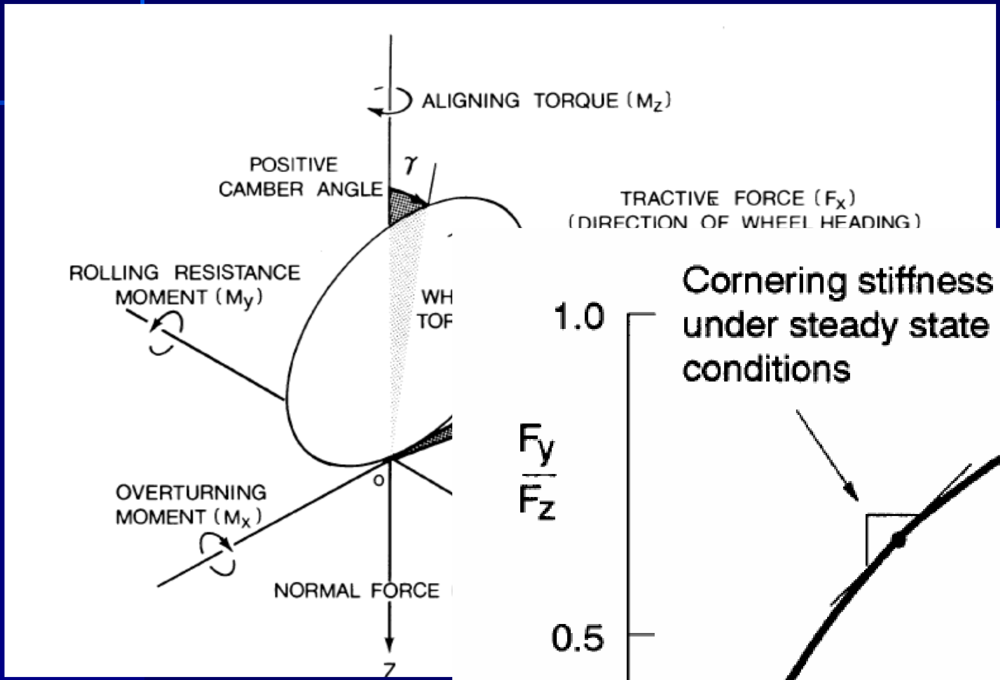
Testing Goal

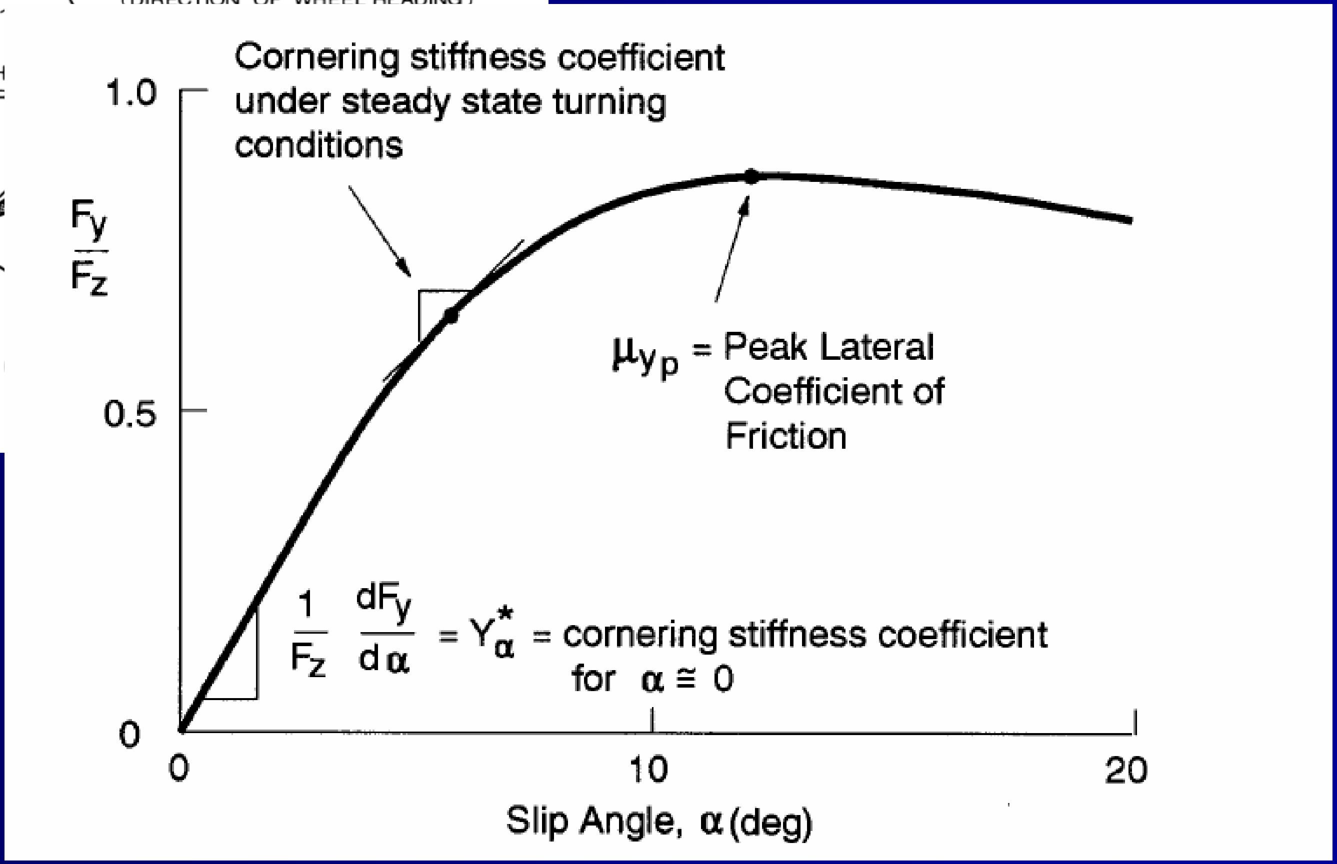


Tire Model

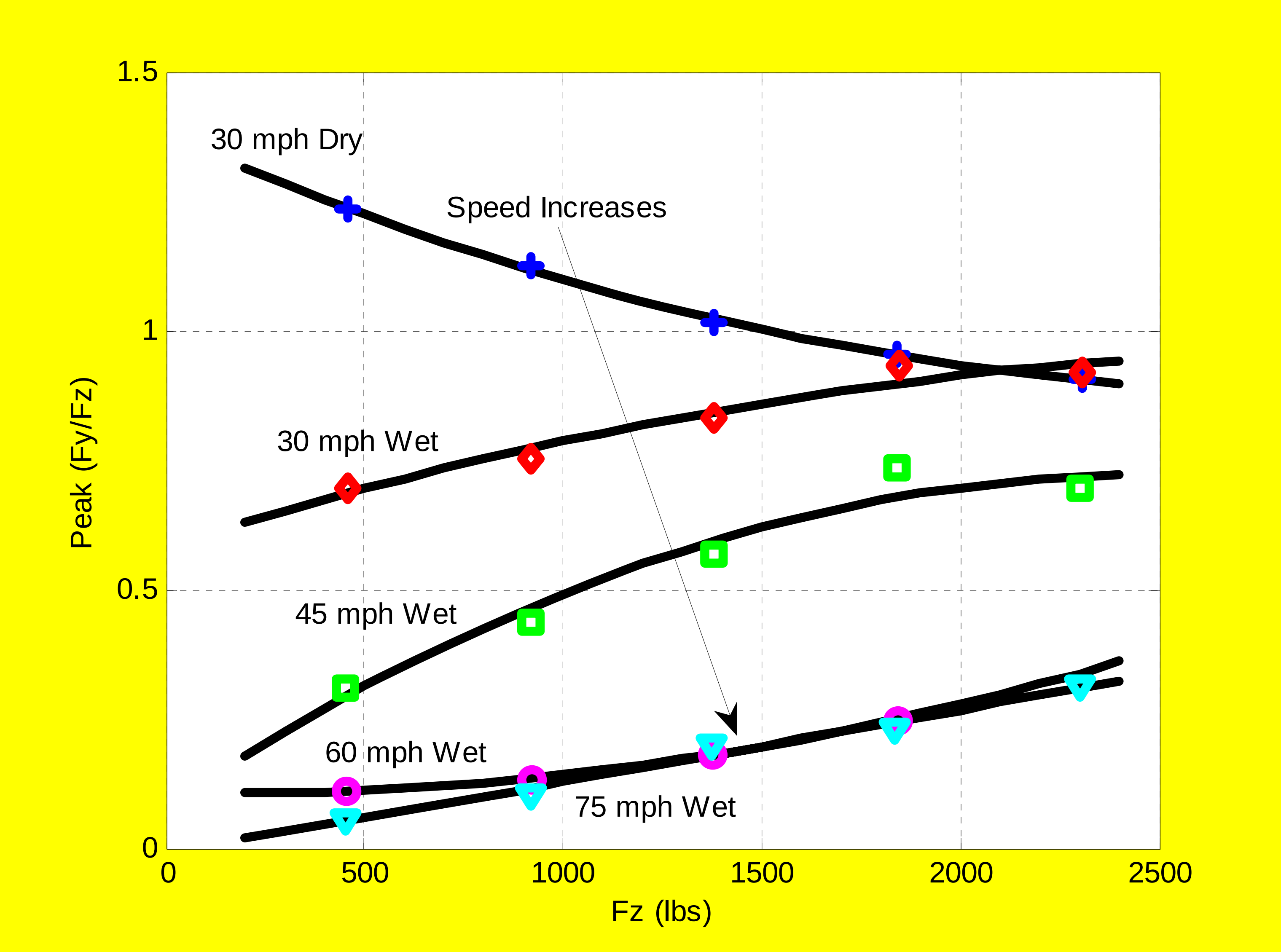
- Semi-empirical based on the brush model
- Friction peak values are fitted to polynomials in function of loads
- Lateral and longitudinal frictions are different
- Stiffnesses are polynomial functions of vertical loads
- Good predictions for combined slips (lateral and longitudinal)
- All parameters are physical parameters
- Linear interpolation between measured data at different speeds is used to model speed dependency

Tire Fundamental Physical Properties

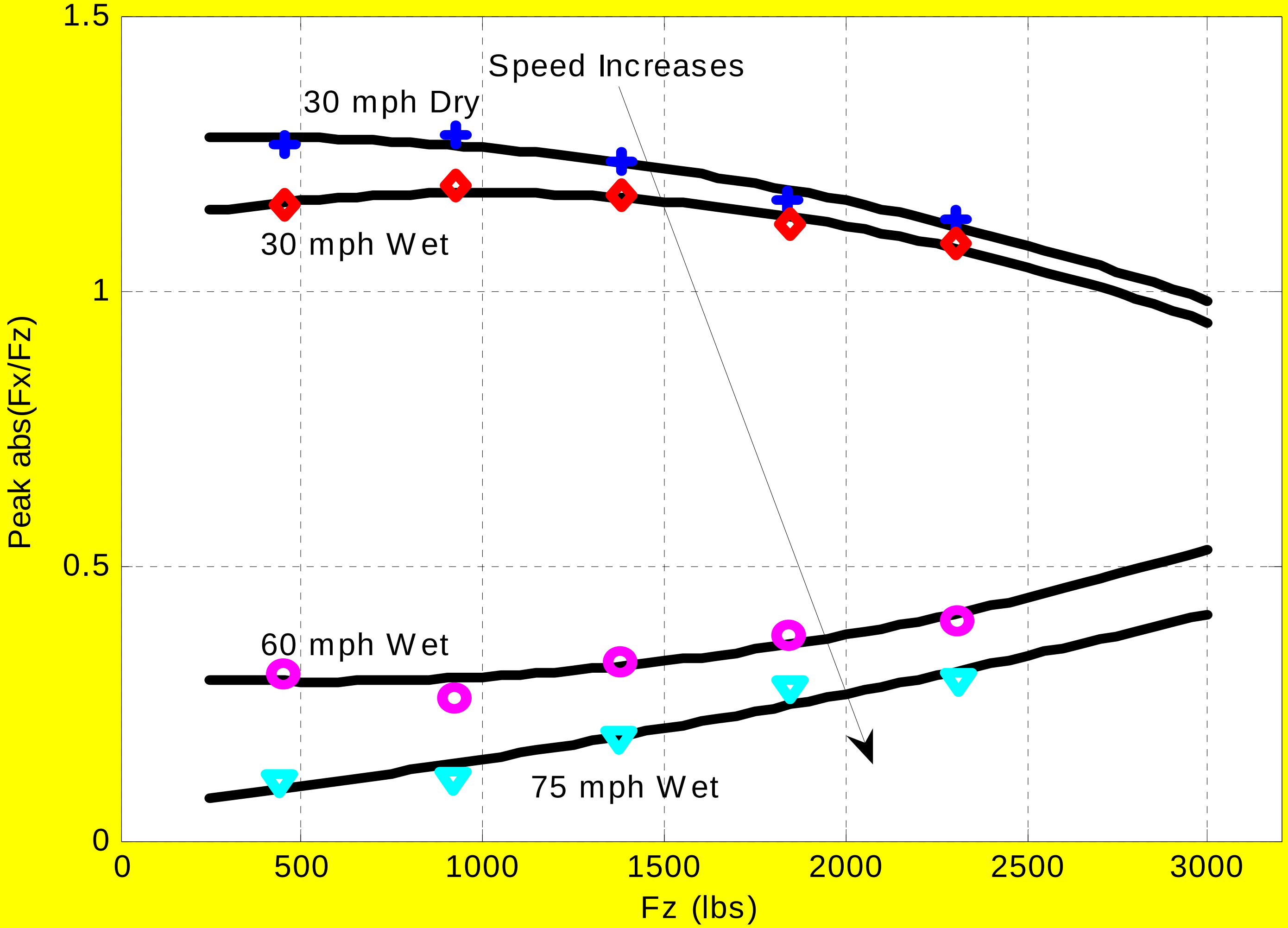




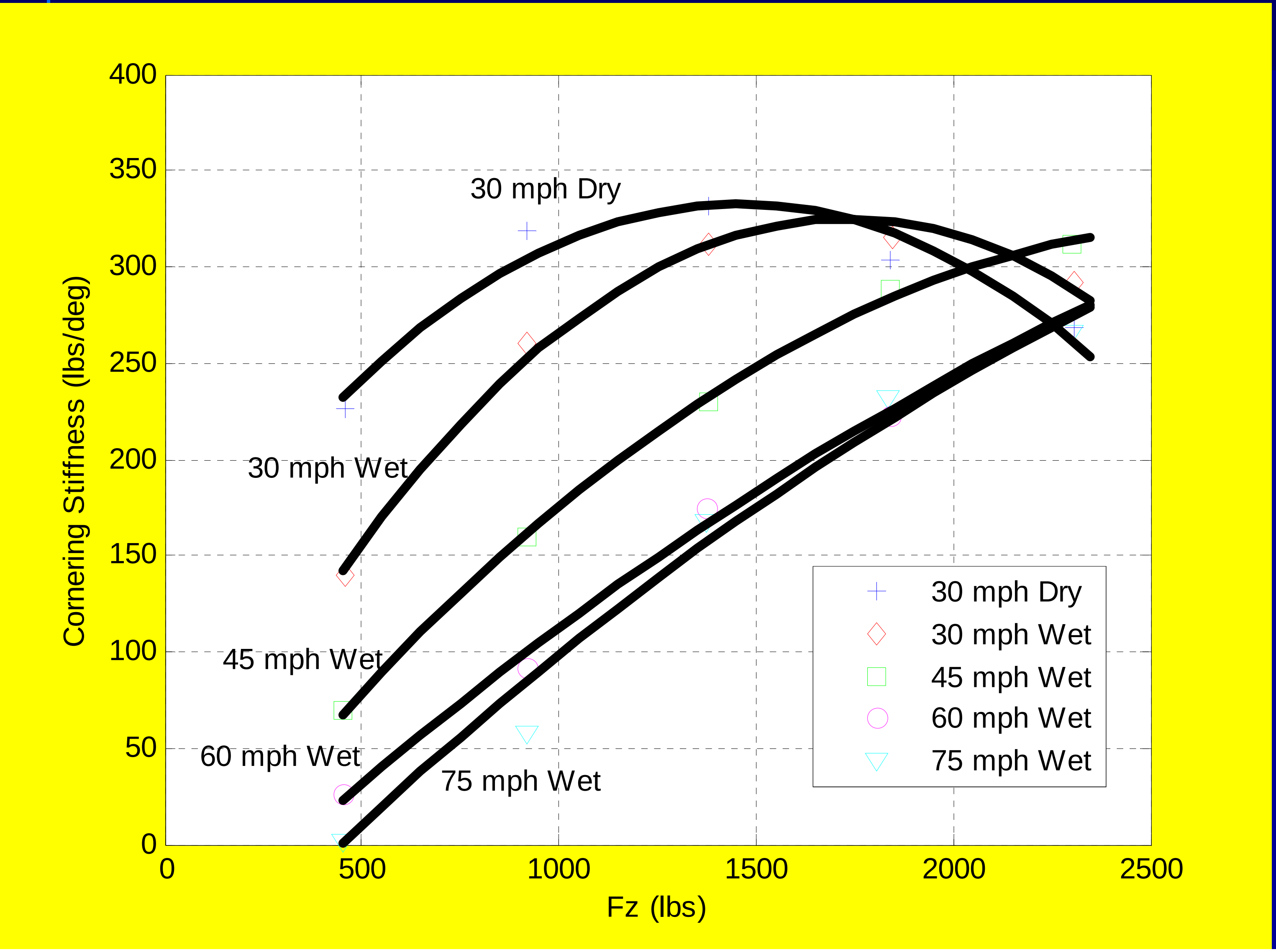
Lateral Peak Coefficient of Friction



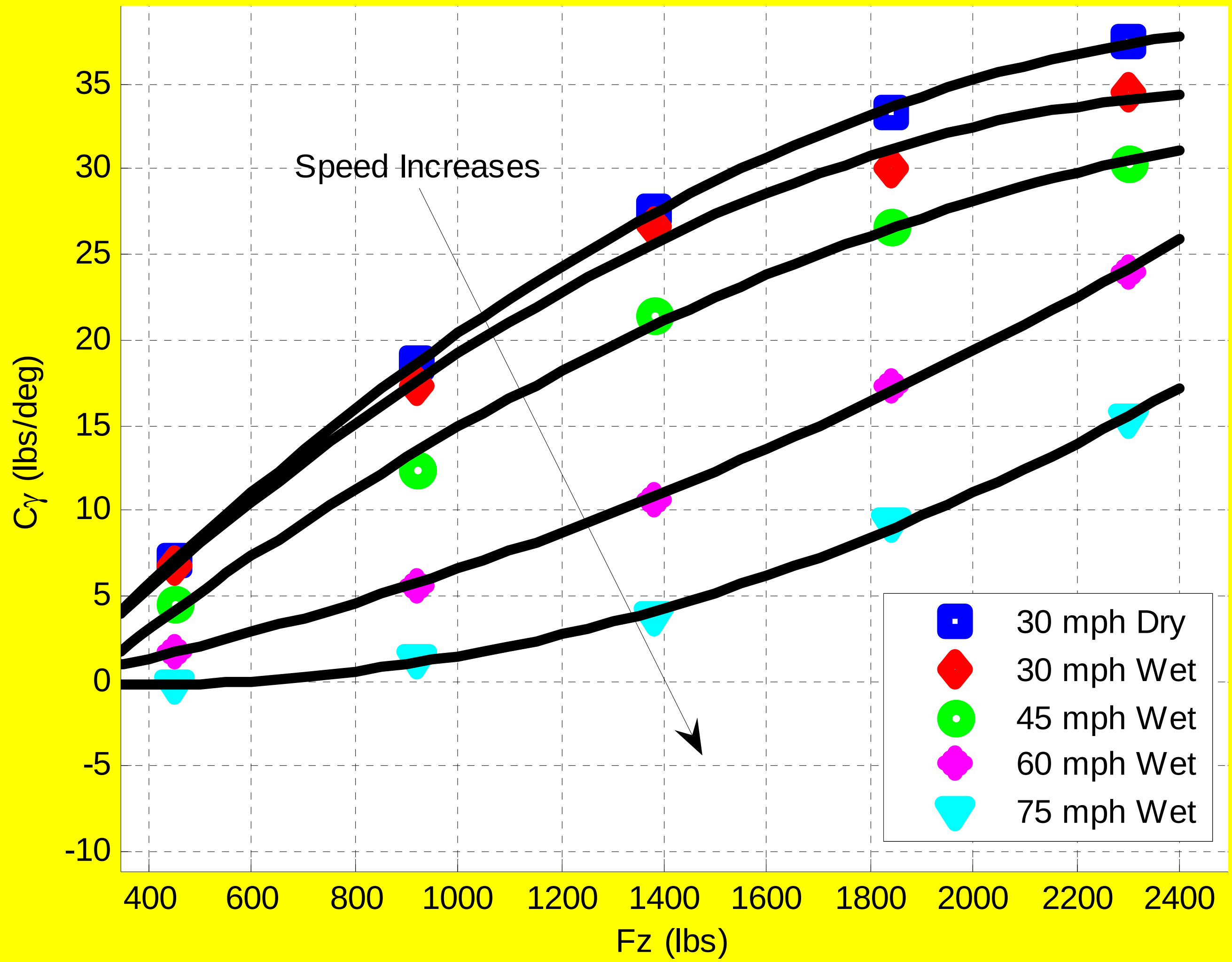
Longitudinal Peak Coefficient of Friction



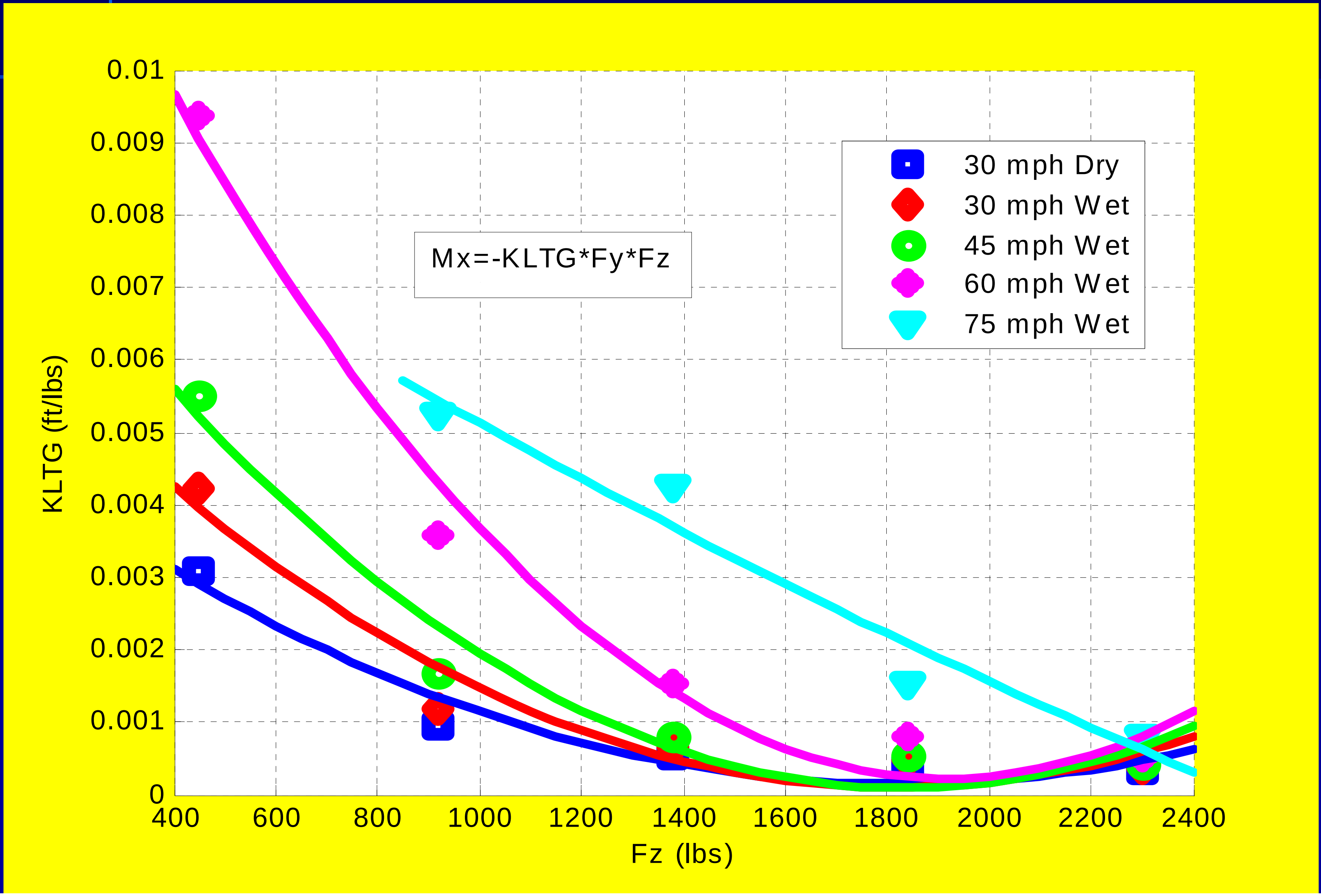
Effective Lateral Stiffness



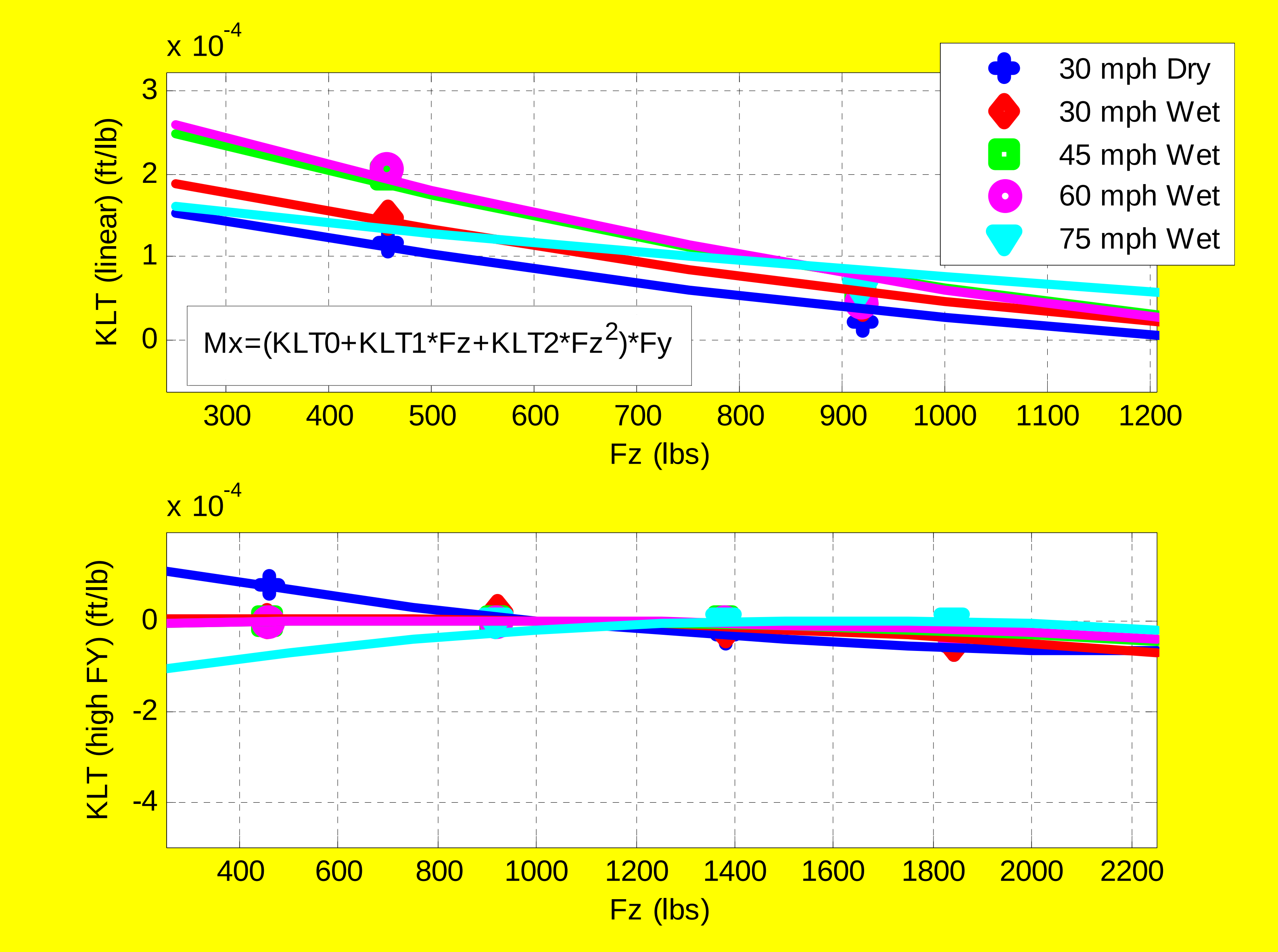
Inclination Angle Stiffness



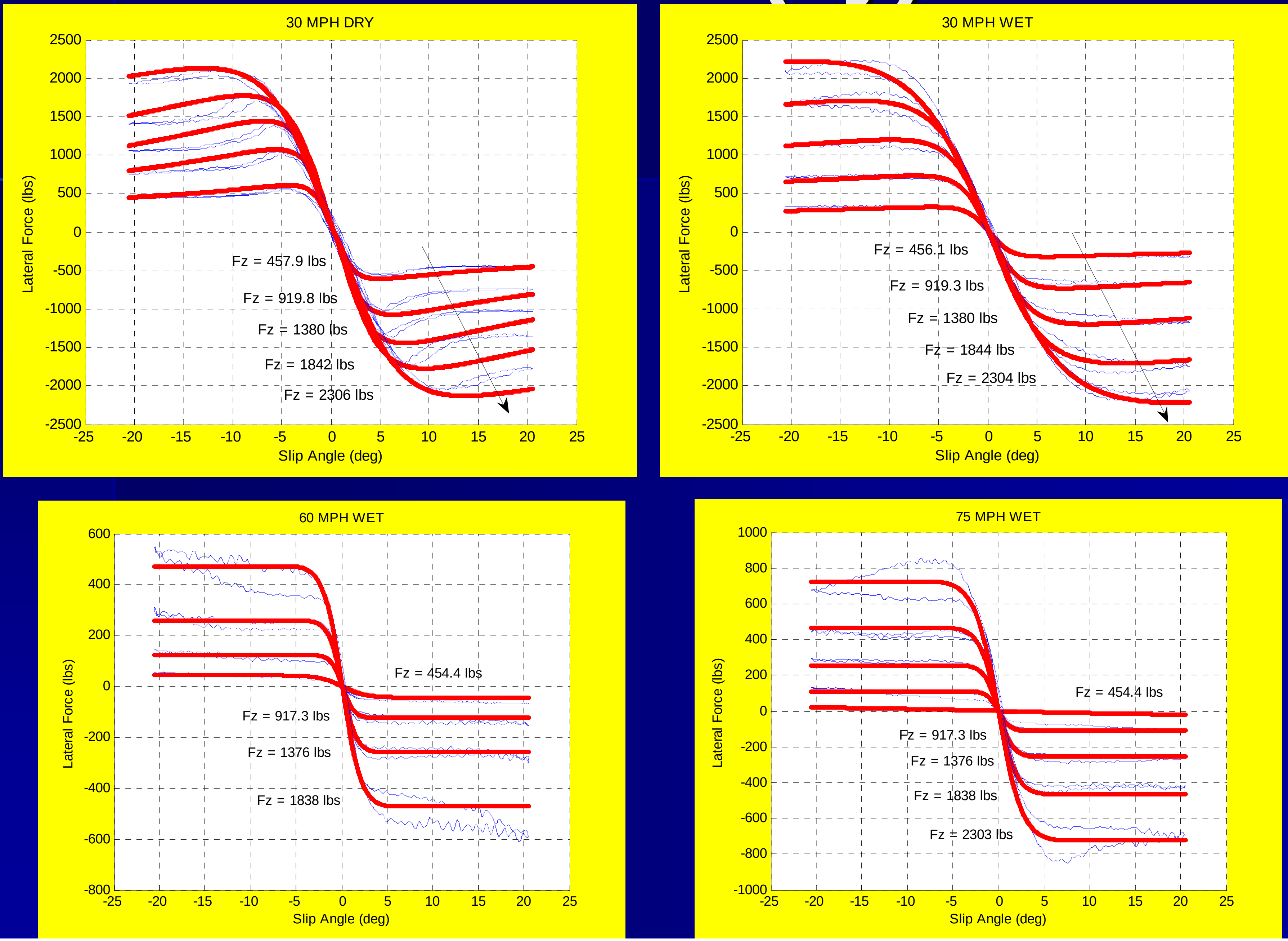
Overturning Moment Inclination Angle Stiffness



Overturning Moment Stiffness

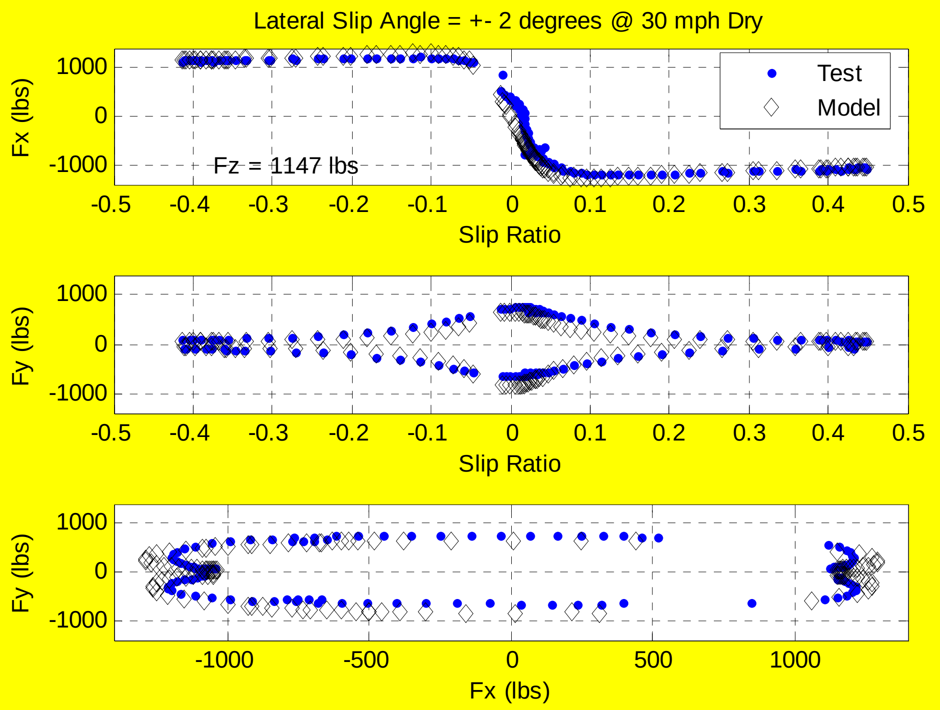


Results (Fy)

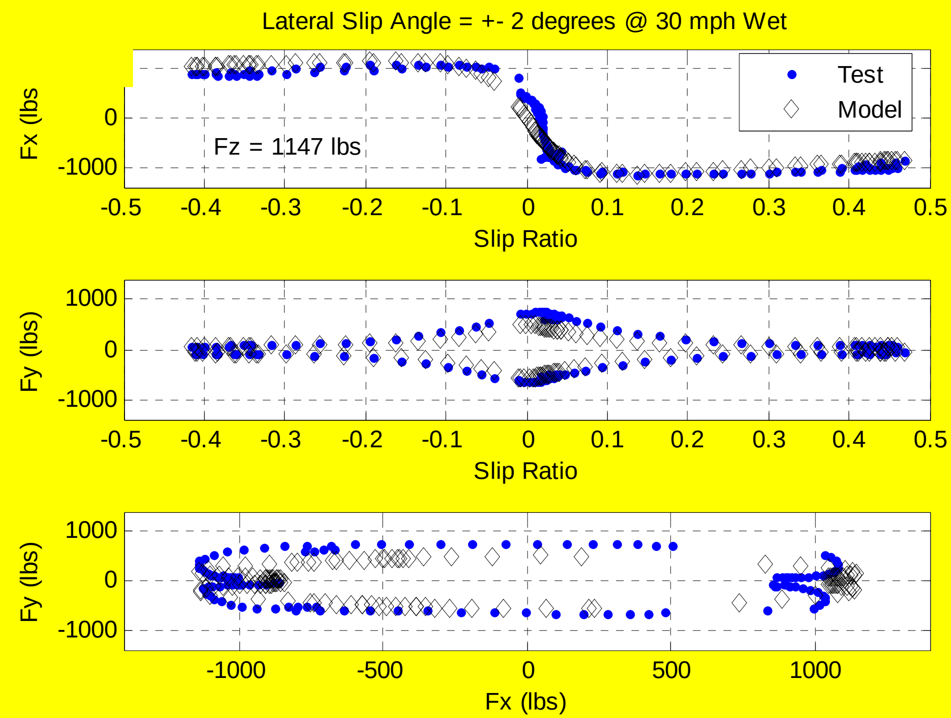


30 MPH DRY
Lateral Force (lbs)
Slip Angle (deg)
Fz = 457.9 lbs
Fz = 919.8 lbs
Fz = 1380 lbs
Fz = 1842 lbs
Fz = 2306 lbs
30 MPH WET
Lateral Force (lbs)
Slip Angle (deg)
Fz = 456.1 lbs
Fz = 919.3 lbs
Fz = 1380 lbs
Fz = 1844 lbs
Fz = 2304 lbs
60 MPH WET
Lateral Force (lbs)
Slip Angle (deg)
Fz = 454.4 lbs
Fz = 917.3 lbs
Fz = 1376 lbs
Fz = 1838 lbs
75 MPH WET
Lateral Force (lbs)
Slip Angle (deg)
Fz = 454.4 lbs
Fz = 917.3 lbs
Fz = 1376 lbs
Fz = 1838 lbs
Fz = 2303 lbs

Combined

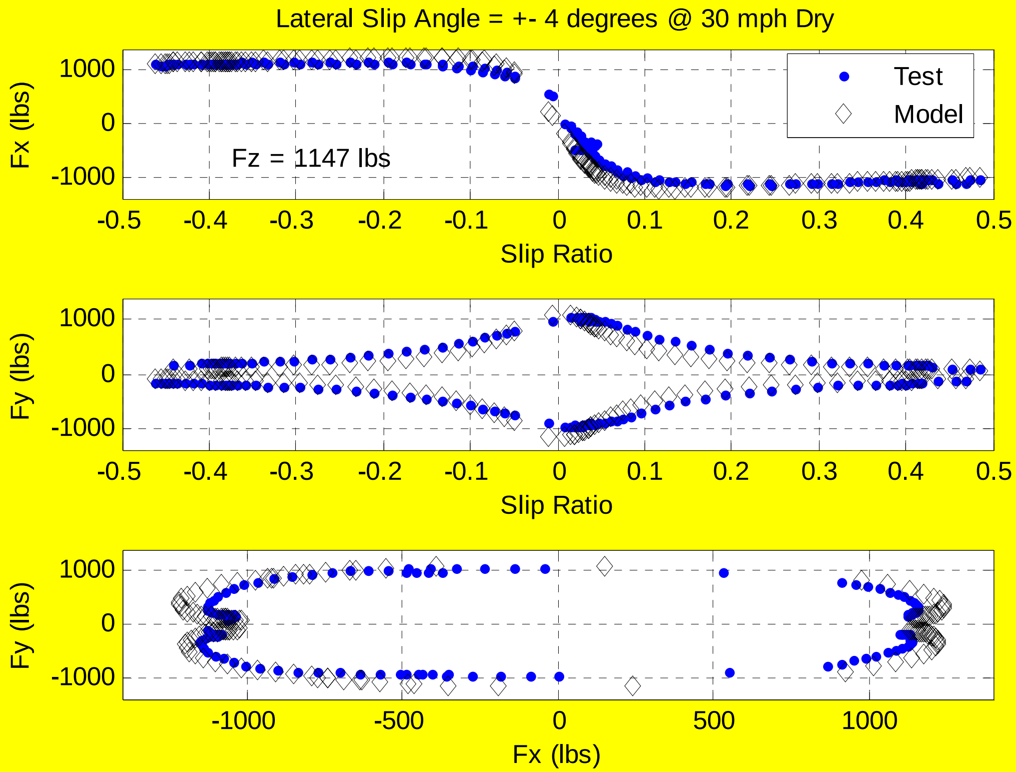


Lateral Slip Angle = +- 2 degrees @ 30 mph Dry
Fx (lbs)
Fy (lbs)
Slip Ratio
Fx (lbs)
Test
Model
Fz = 1147 lbs

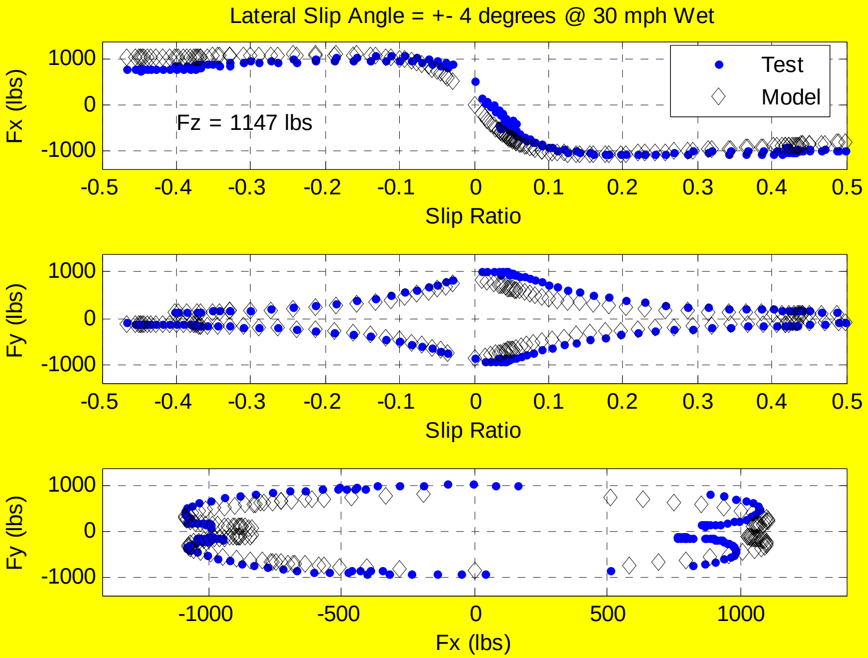


Lateral Slip Angle = +- 2 degrees @ 30 mph Wet
Fx (lbs)
Fy (lbs)
Slip Ratio
Fx (lbs)
Test
Model
Fz = 1147 lbs

Combined

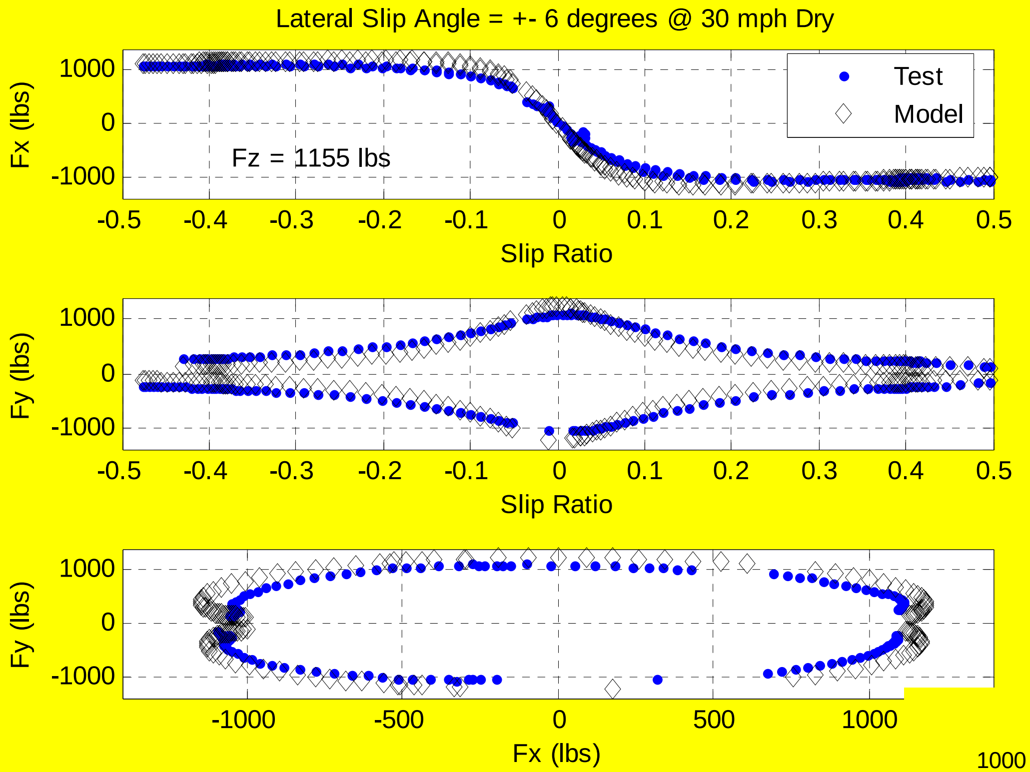


Lateral Slip Angle = +- 4 degrees @ 30 mph Dry
Test
Model
Fz = 1147 lbs
Fx (lbs)
Fy (lbs)
Slip Ratio
Fx (lbs)

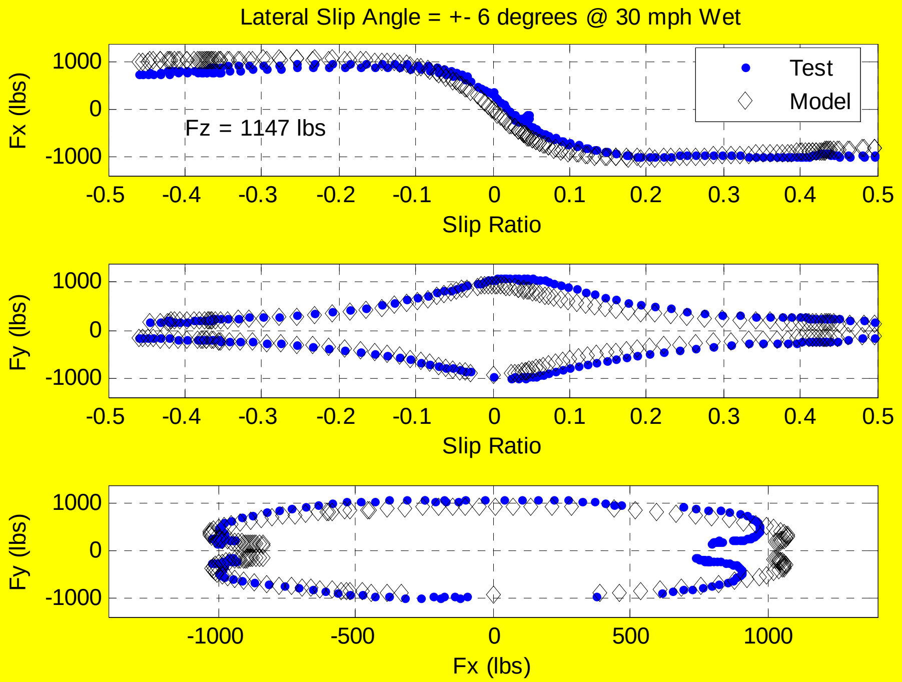


Lateral Slip Angle = +- 4 degrees @ 30 mph Wet
Test
Model
Fz = 1147 lbs
Fx (lbs)
Fy (lbs)
Slip Ratio
Fx (lbs)

Combined



Lateral Slip Angle = +- 6 degrees @ 30 mph Dry
Test
Model
Fz = 1155 lbs
Fx (lbs)
Fy (lbs)
Slip Ratio
Fx (lbs)



Lateral Slip Angle = +- 6 degrees @ 30 mph Wet
Test
Model
Fz = 1147 lbs
Fx (lbs)
Fy (lbs)
Slip Ratio
Fx (lbs)

Important Differences with On-the-Road Tires/Surfaces

- Tires were shaved, aging effects is ignored (tire properties change with age and environment)
- NHTSA studies indicated the average tread depth for in-service tires is about 7/32”, yet we used 4/32” to meet peak coefficient of friction target value
- Variations of tread depth, water depth, tire pressure, tire construction, surface texture, and tread patterns are not addressed
- Speed is the only variable affecting the model
- The results from the model is physically sound – compares well with experimental results and can be used to validate ESC systems

Conclusions

- Longitudinal and lateral force and moment data were collected

- Test conditions were created such that a high coefficient of friction was generated at low speeds and a lower coefficient was generated at high speeds

Conclusions (cont.)

- Tire parameters were calculated from the test data

- Parameters were verified by comparing calculated forces to measured forces

Questions ?

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