

Accurate Tire Models for Vehicle Handling Using the Empirical Dynamics Method

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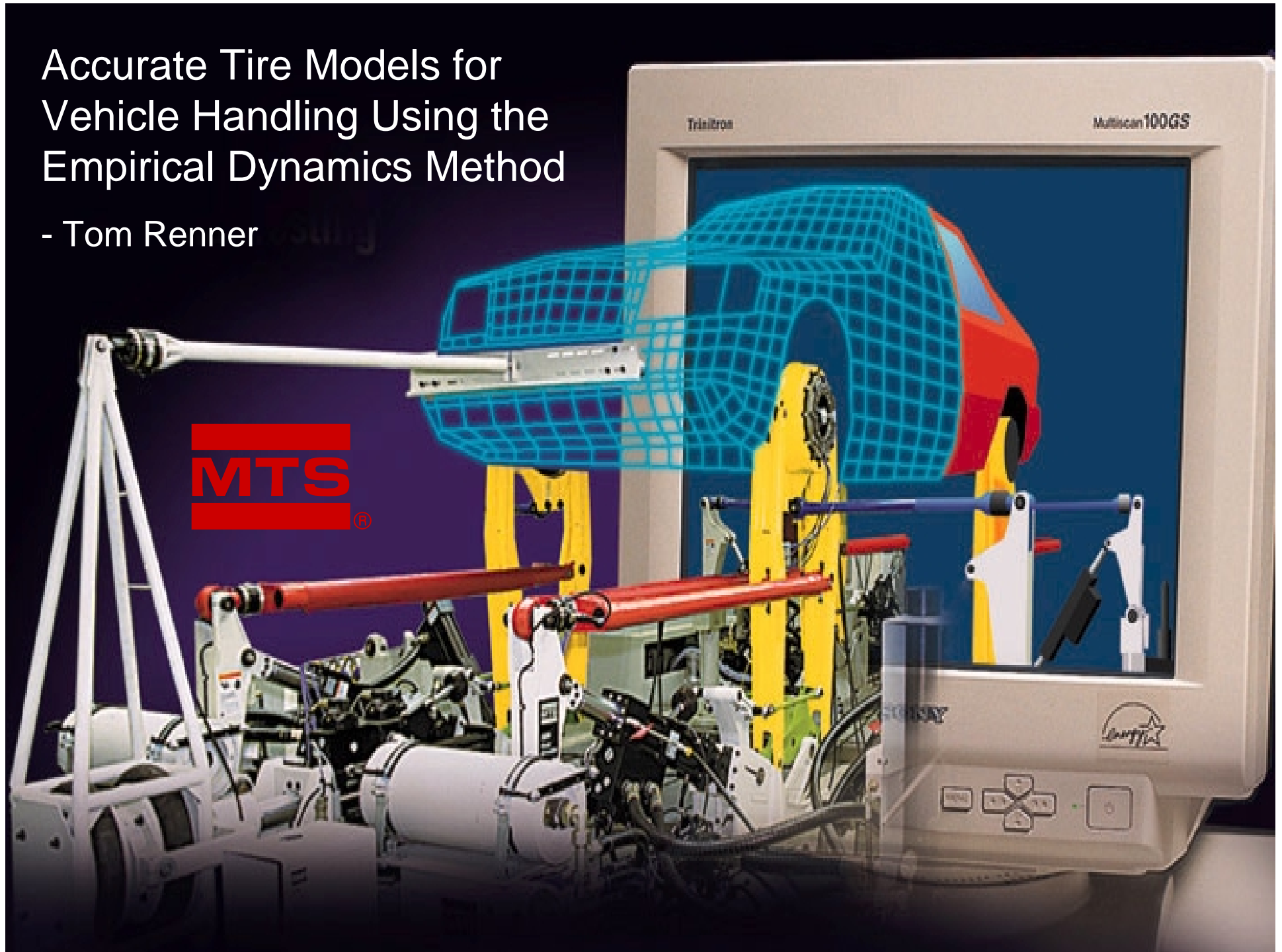
Modeling Integration Products and Services
MTS Systems Corporation

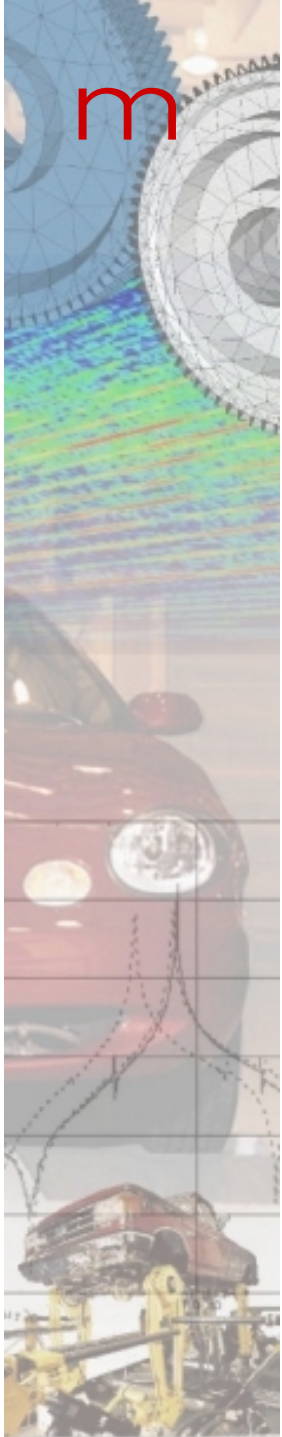
ABSTRACT:

Conventional models for tires are often inadequate to represent behavior over wide frequency ranges, and at large amplitudes. Empirical Dynamics Models provide a solution to this problem, via a nonlinear, dynamic, blackbox approach. These models accurately replicate both frequency and amplitude dependence effects without the limitations of conventional schemes. Examples of Empirical Dynamics Models will be presented for lateral force vs. slip angle and other inputs.

Accurate Tire Models for Vehicle Handling Using the Empirical Dynamics Method

- Tom Renner





What is EDM?

- Empirical Dynamics ^(TM) Modeling
 - Nonlinear
 - Blackbox
 - Dynamic (memory)
 - Arbitrary inputs
 - Multiple inputs/outputs
 - Wide range of systems
 - “No ‘Buddy’ Does A Model Without... EDM”



Model Attributes

- Nonlinear = amplitude dependence
- Dynamic = frequency dependence
- Blackbox = direct input/output relationship

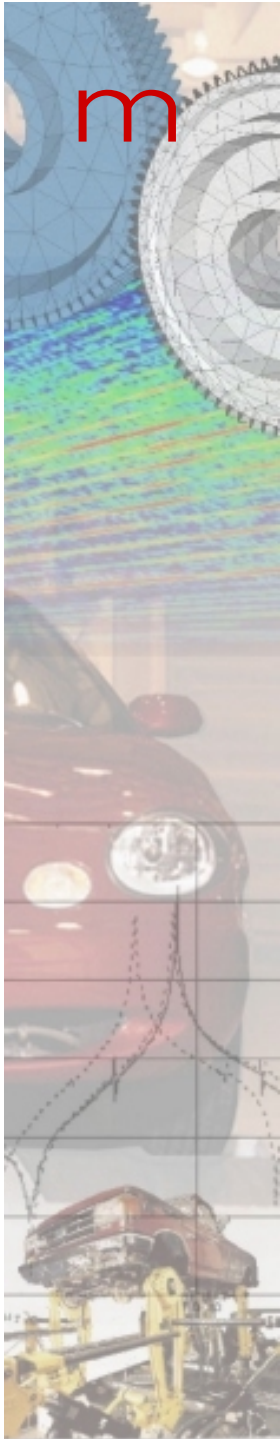
(Whitebox: first principles model using differential equations)



Features of Model Generation

- Neural Network
- NARMAX Model Structure
- Semi Parametric Model
- MTS Patented Enhancements

For further explanation of these features see the paper:
Accurate Models for Bushings and Dampers using the Empirical Dynamics Method,
by Andy Barber, presented to the 1999 ADAMS European User's Group,
posted at: http://support.adams.com/userconf/euc99/euc99_thu.htm



Flat-Trac[®] Tire Testing Machine

Specifications

Radial Position: 200 - 450 mm

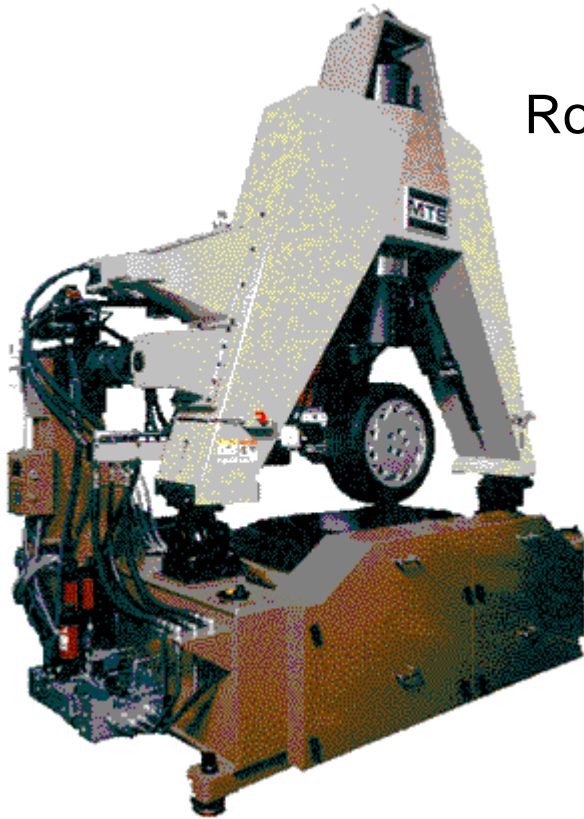
Radial Load: ± 25 kN

Lateral Load: ± 15 kN

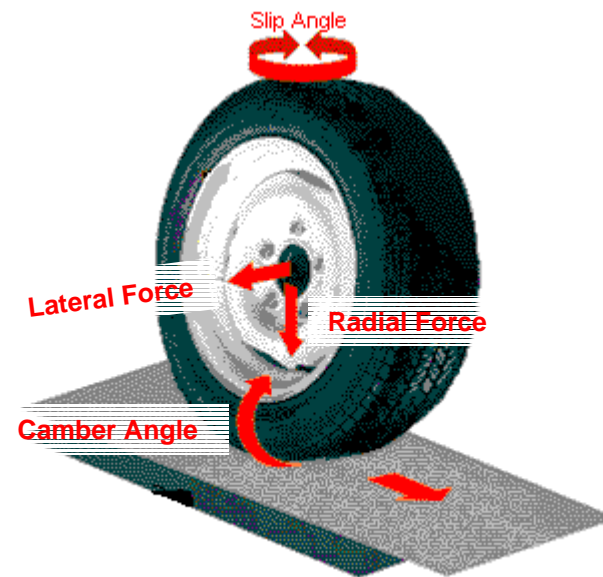
Slip Angle: $\pm 30^\circ$

Camber Angle: -10° , $+ 45^\circ$

Rotational Speed: 250 kph



T.E. Renner, MTS

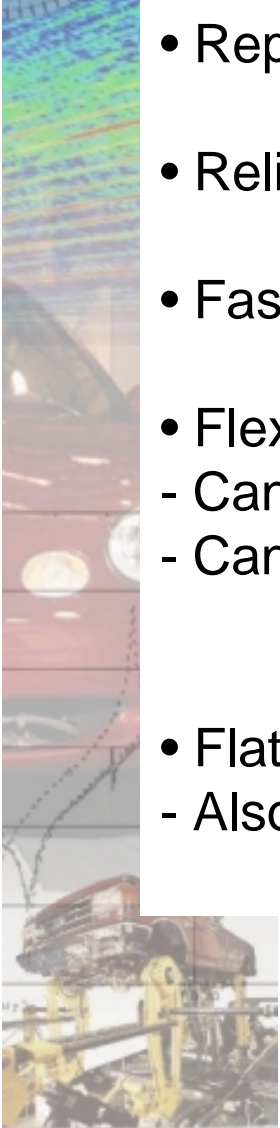


Adams User Conference, June 00



Advantages of Tire Testing with Flat-Trac[®]

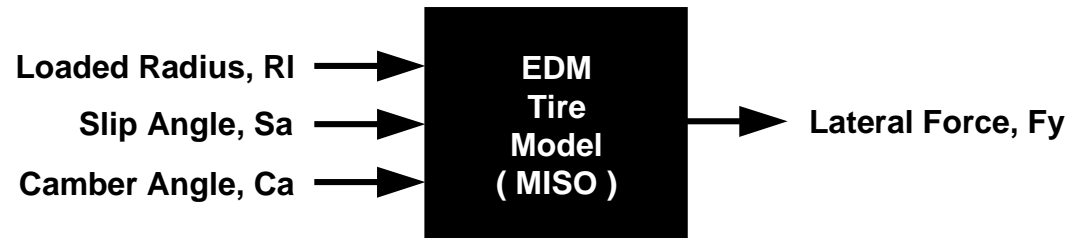
- Repeatabile - More repeatable than data from a test track.
- Reliable - Don't have to rely on weather or test track availability.
- Faster - Can collect data for model generation in less than an hour.
- Flexible
 - Can create random excitation files with specific frequency content
 - Can test a tire with conditions beyond what it will see on the road so model will contain capability.
- Flat surface approximates road better than a Road Wheel test machine.
 - Also can apply different abrasive surfaces to steel belt.





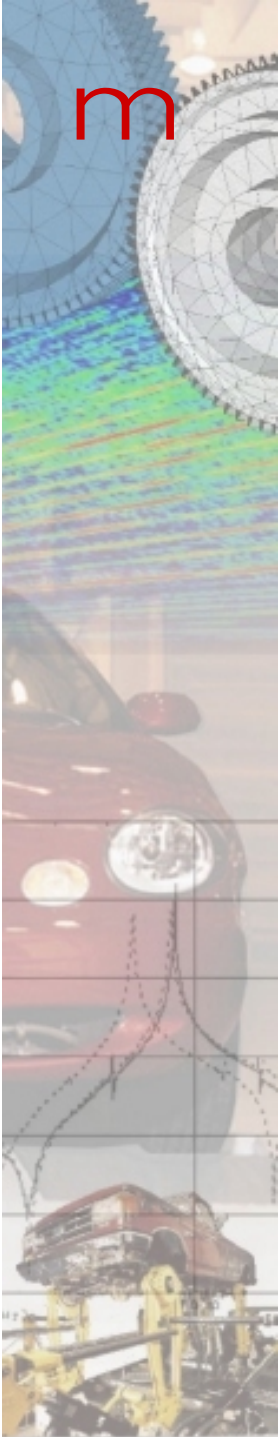
Two Test Cases

Case 1: **MISO** - **M**ultiple **I**nput, **S**ingle **O**utput

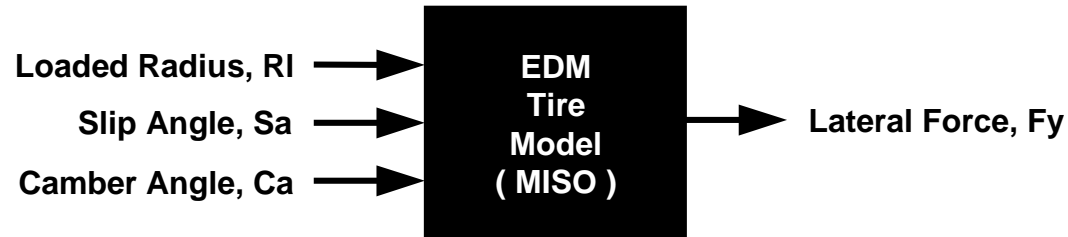


Case 2: **SISO** - **S**ingle **I**nput, **S**ingle **O**utput

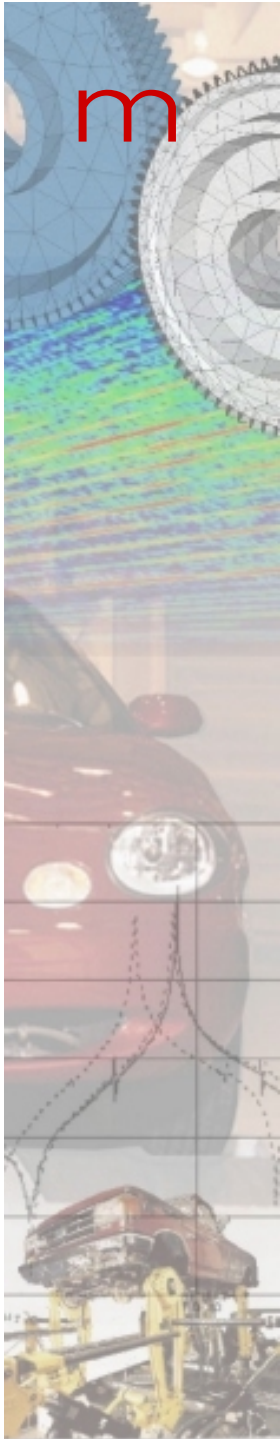




Case 1: MISO



- Excitation
 - Random Signal
 - Stationary, Gaussian, Orthogonal
 - Shaped Power Spectral Density $\sim 1/f^2$
 - Bandwidth limited to 5 Hz
 - Sampling Parameters
 - 51.2 pts/sec
 - Duration: ~ 1 minute



Case 1: MISO

Test setup

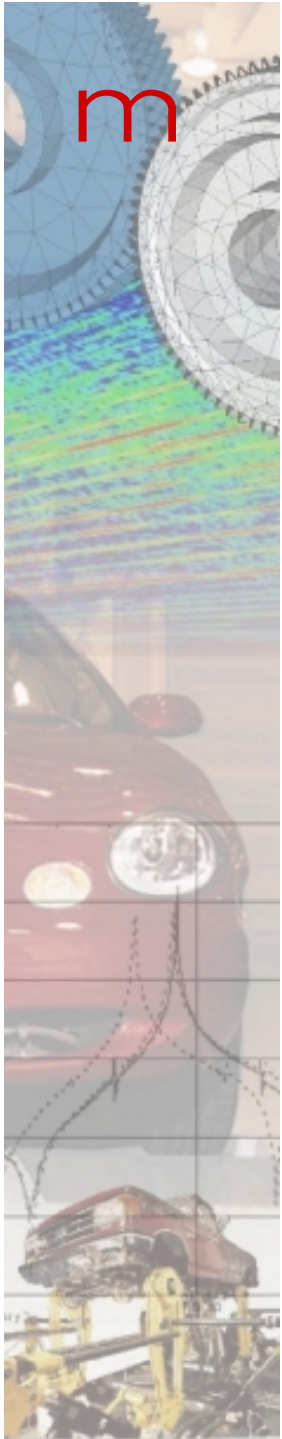
Specimen

- Passenger Car Tire: P205/65R15

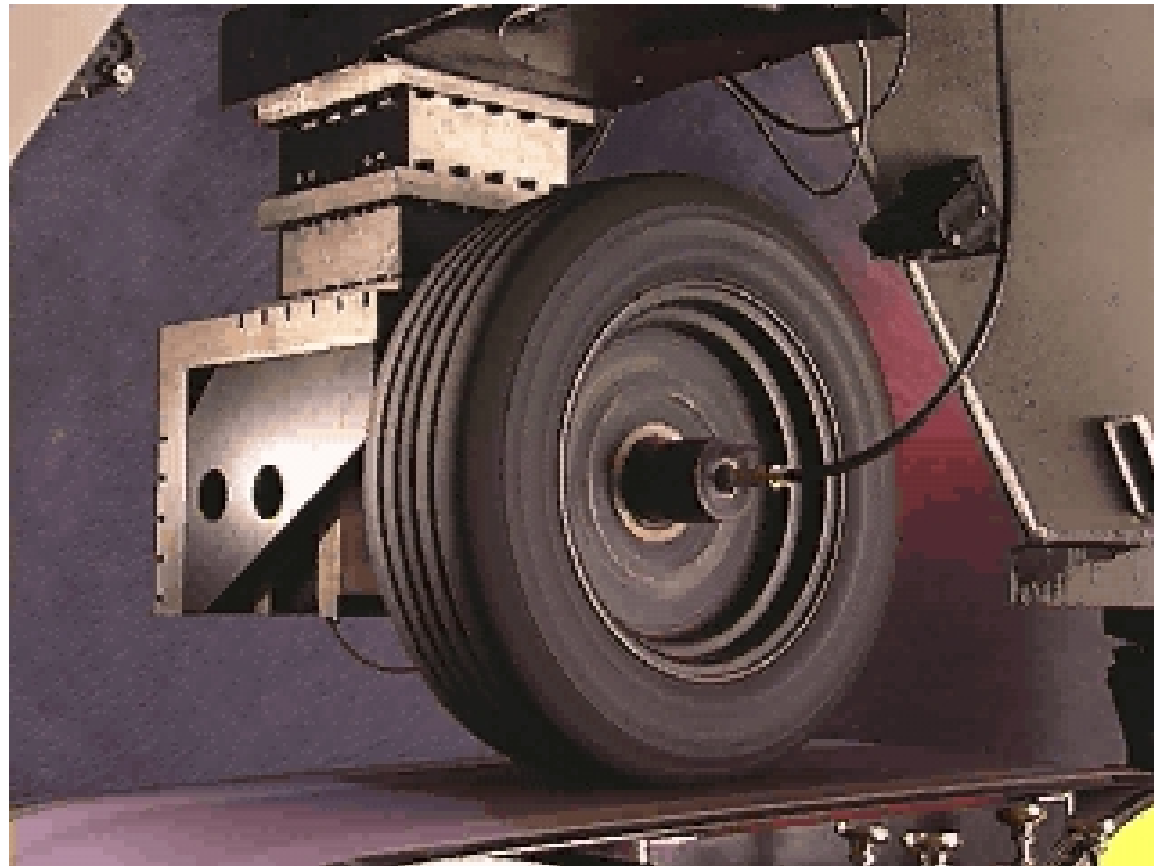
Flat-Trac setup

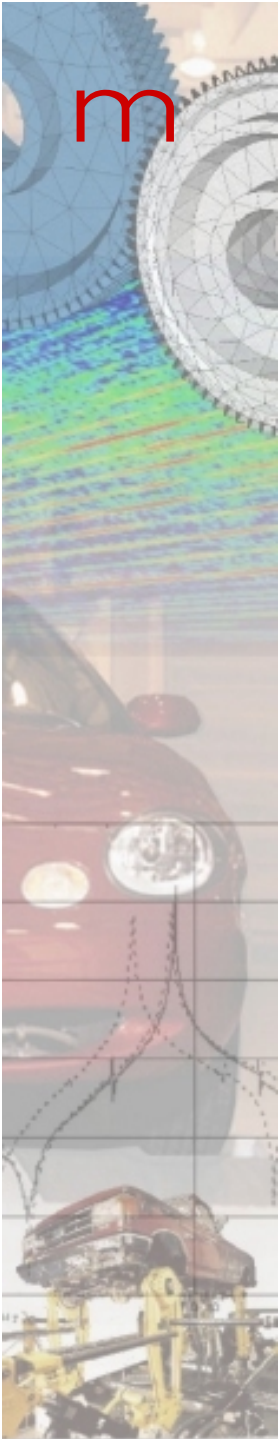
(Values held constant during test)

- Inflation Pressure: 35 psi, (regulated)
- Loaded Radius: 313 mm, (about 4500 N)
- Speed: 50 kph (7 rev / sec)
- Output filters: 20 Hz lowpass, Butterworth

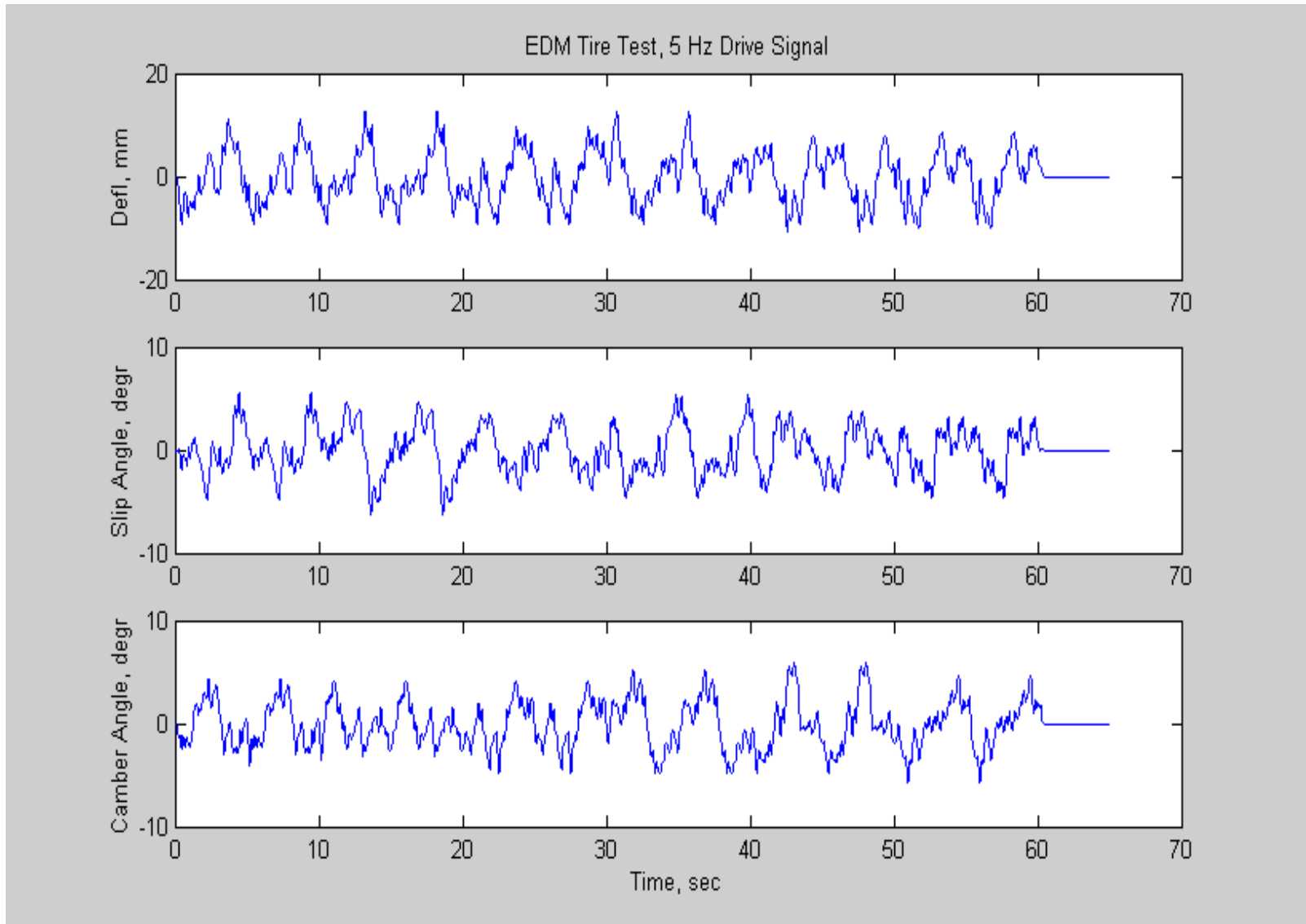


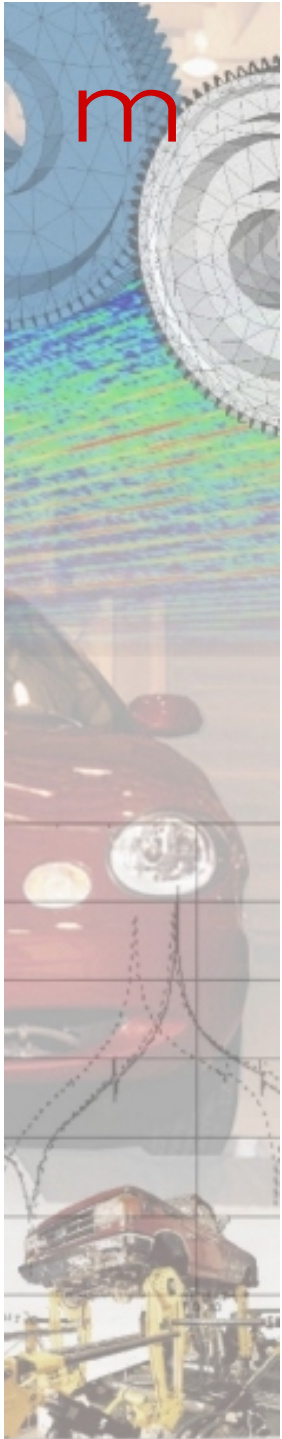
Excitation File Play Out





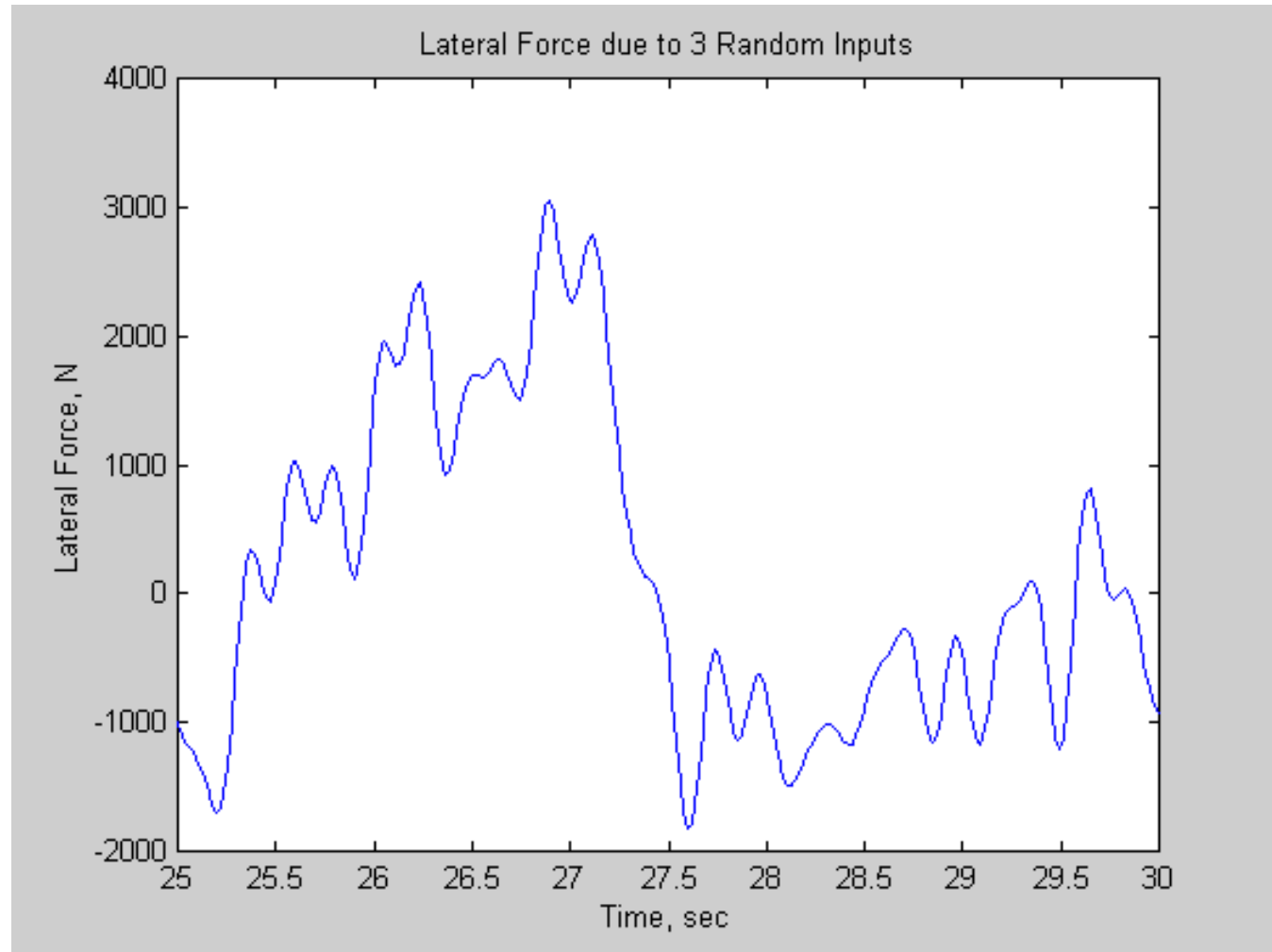
3 Channel Response Time History

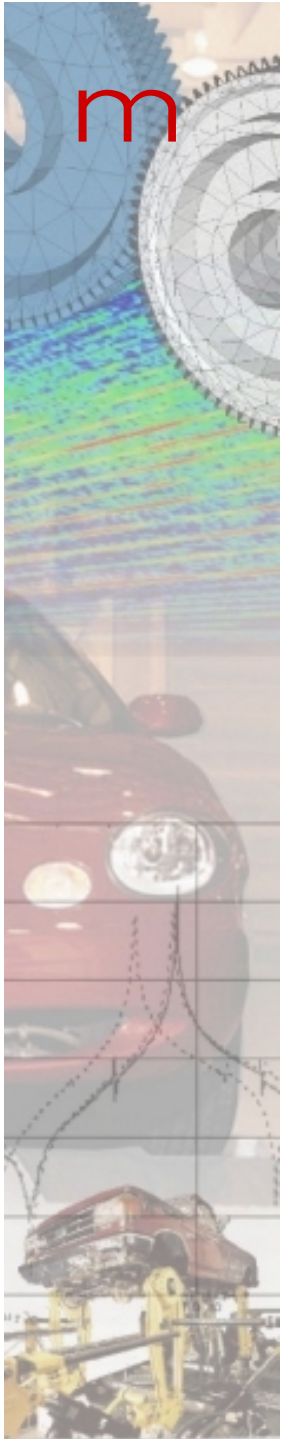




Measured Time History

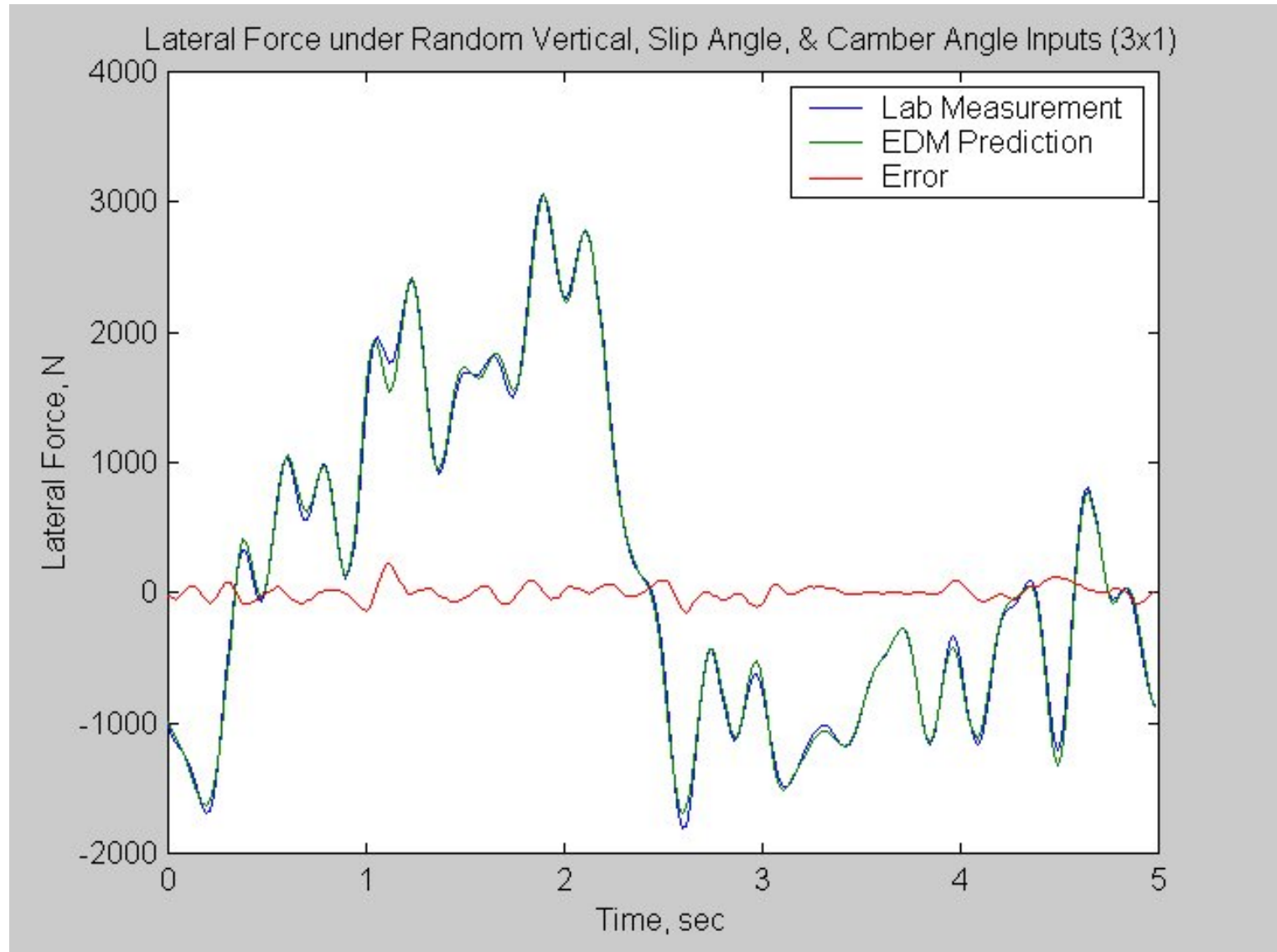
Lateral Force





Model Predicted Time History

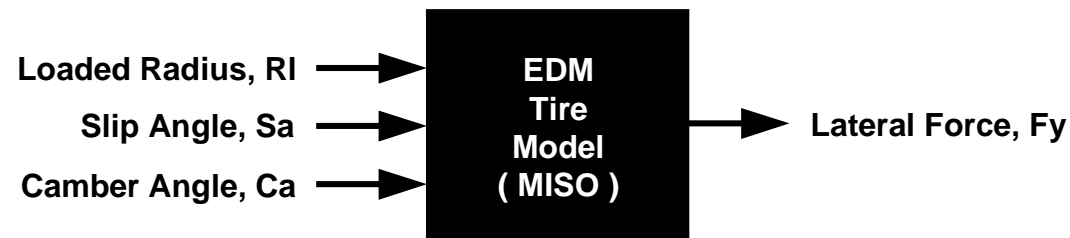
Lateral Force





Case 1: MISO, Conclusions

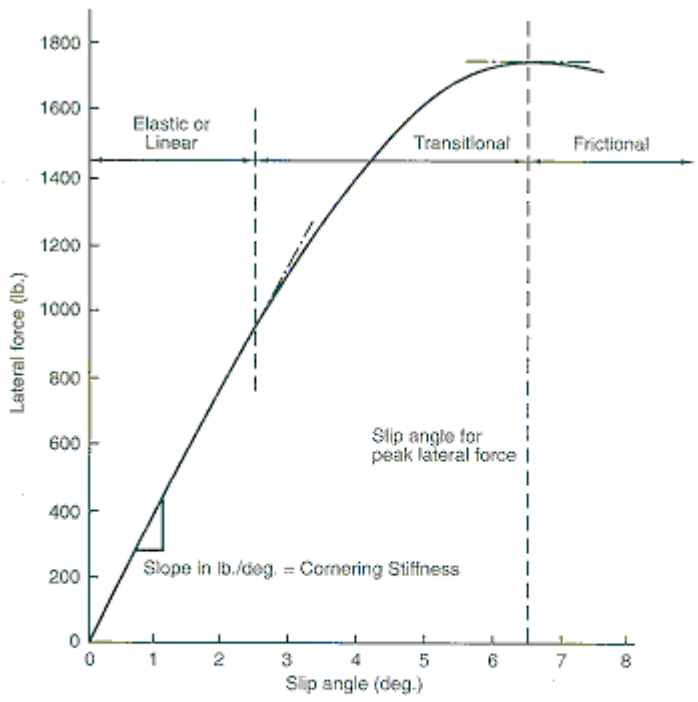
- Easy to create 3 input 1 output model
 - Took about half an hour to generate the model after the data was taken.
- Accuracy was very good.
- Proves that this Empirical Dynamics technique can produce tire models suitable for handling studies.





Case 2: SISO

Text Book Slip Angle vs Lateral Force Plot (Sa vs Fy)





Case 2: Two Excitation Files

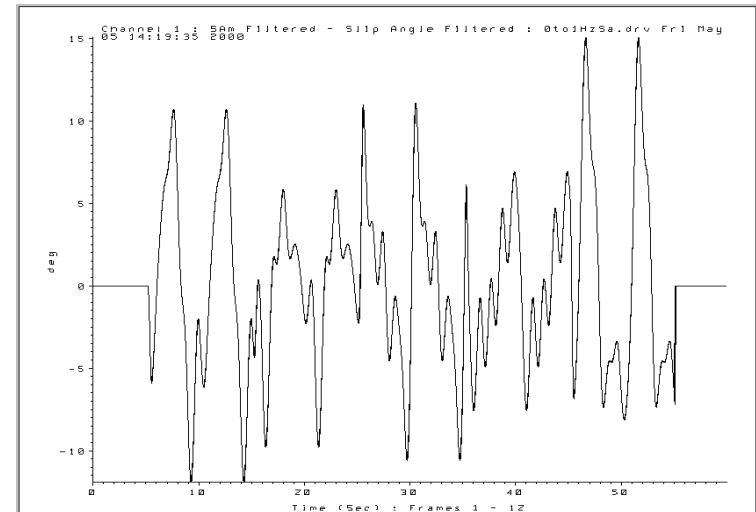
Slip Angle, Sa

EDM
Tire
Model
(SISO)

Lateral Force, Fy

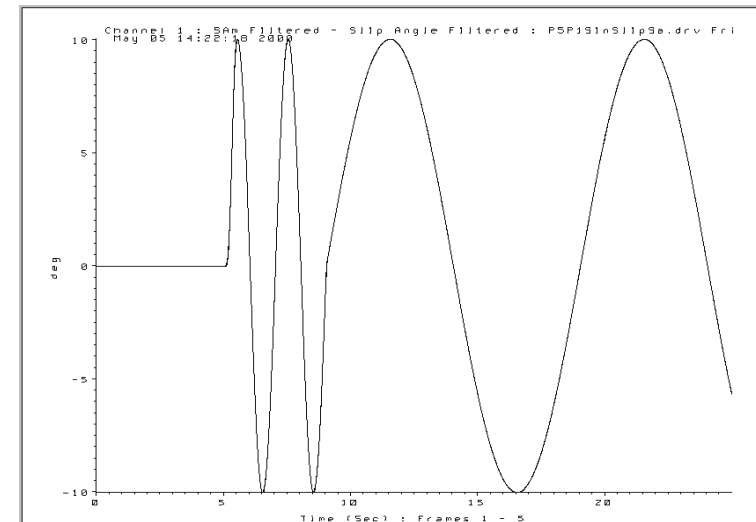
File 1: Training File

- Used to **generate** the model
- Random: Stationary, Gaussian
- Slip Angle amplitude: +/- 15 deg
- Shaped Power Spectral Density $\sim 1 / F^2$
- Bandwidth limited to 1 Hz
- Sampling Rate: 204.8 pts / sec
- Duration: 100 sec



File 2: Test File

- Used to **test** the model
- Sine waves:
 - 2 cycles: 0.5 Hz, +/- 10 deg
 - 2 cycles: 0.1 Hz, +/- 10 deg
- Sampling Rate: 204.8 pts / sec



Sa vs Fy

Test setup for both excitation files

Specimen

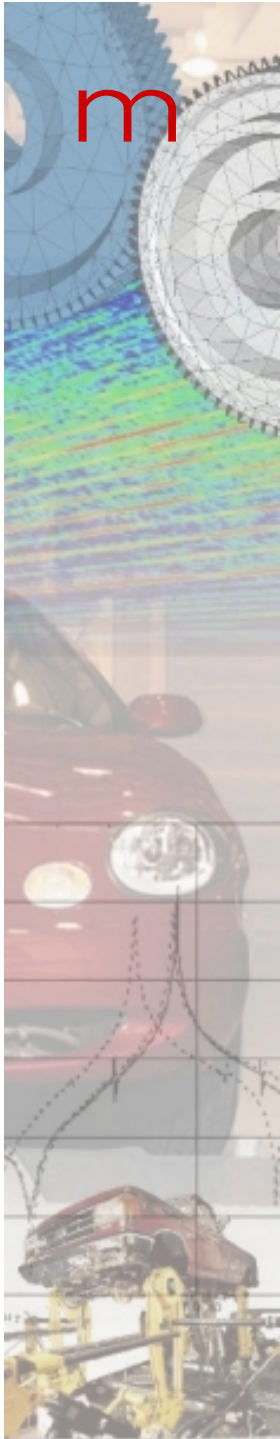
- Passenger Car Tire: P205/65R15

Flat-Trac setup

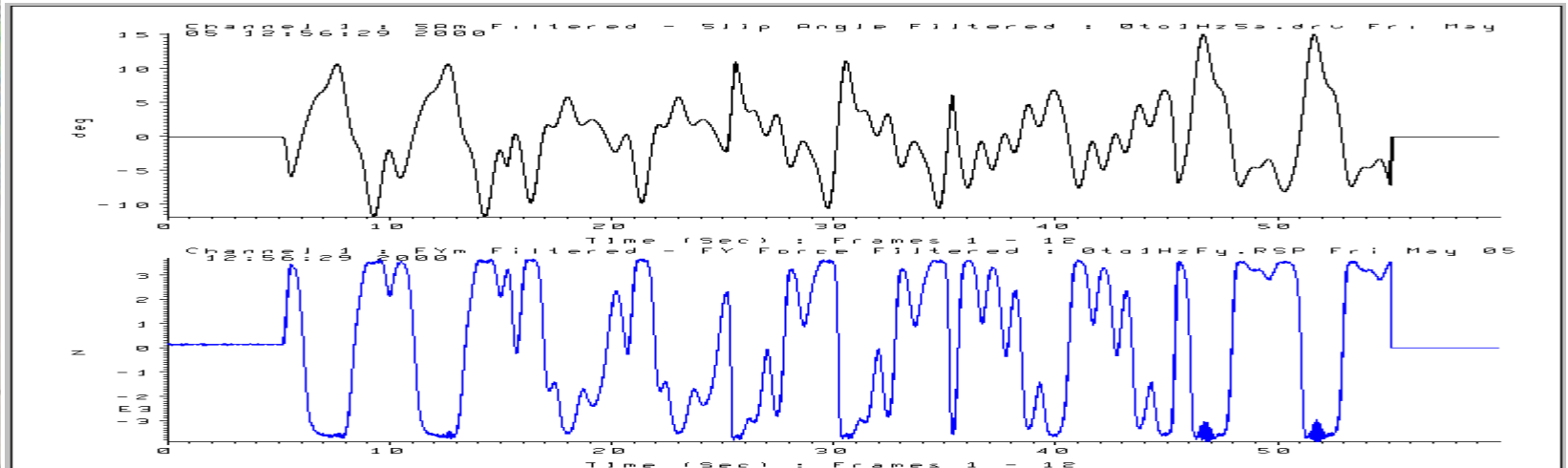
(Values held constant during test)

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- Loaded Radius: 303 mm, (about 4500 N)
- Speed: 50 kph (7 rev / sec)
- Output filters: 20 Hz lowpass, Butterworth

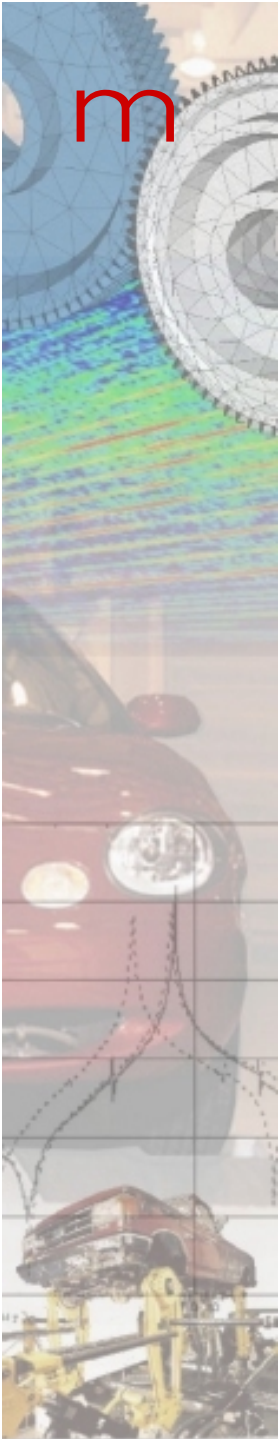




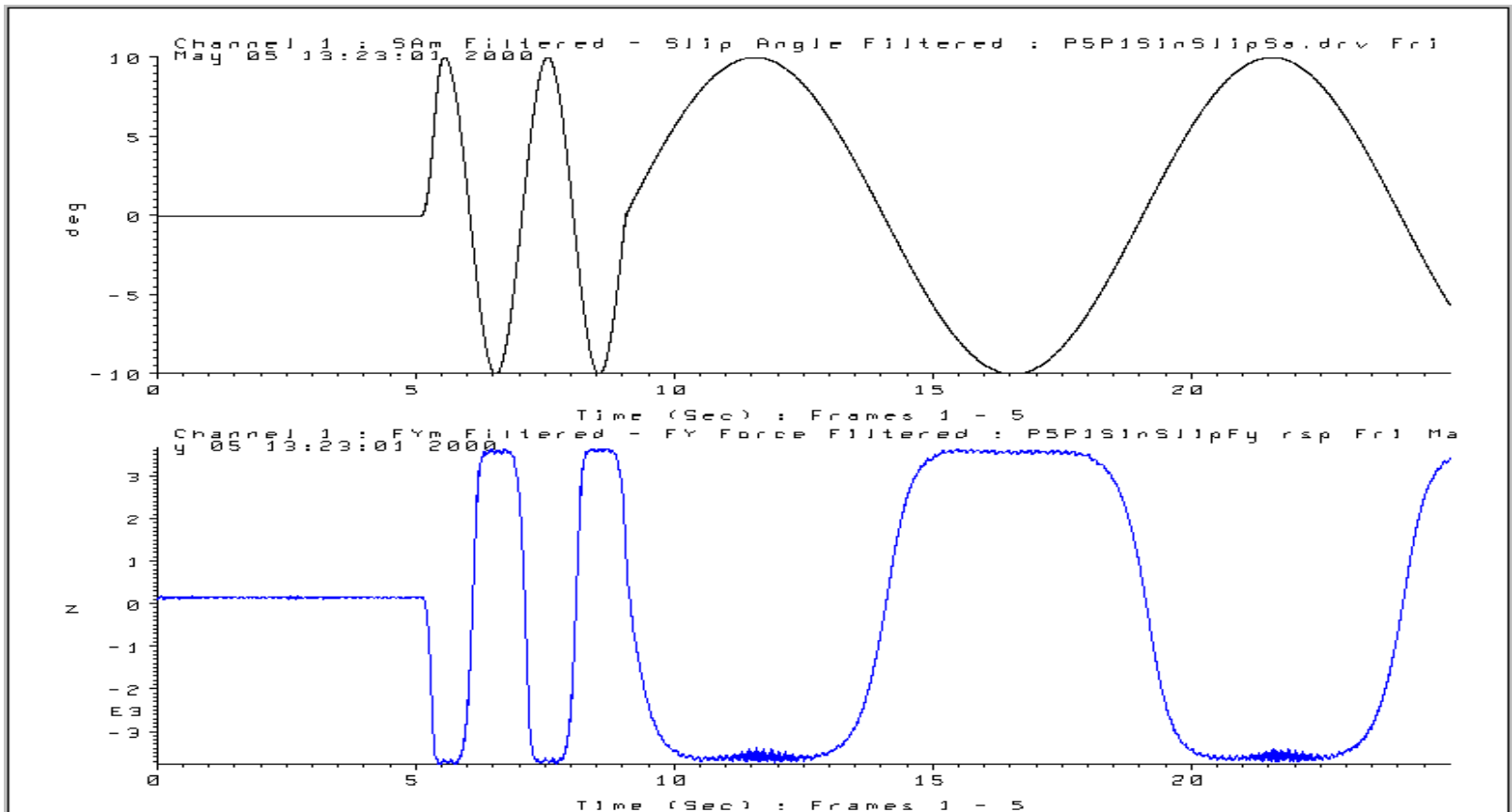
File 1: Training Excitation and Response



Note:
Fy constants at high Slip angle.
Fy vibration at high Slip angles, about (35 hz)

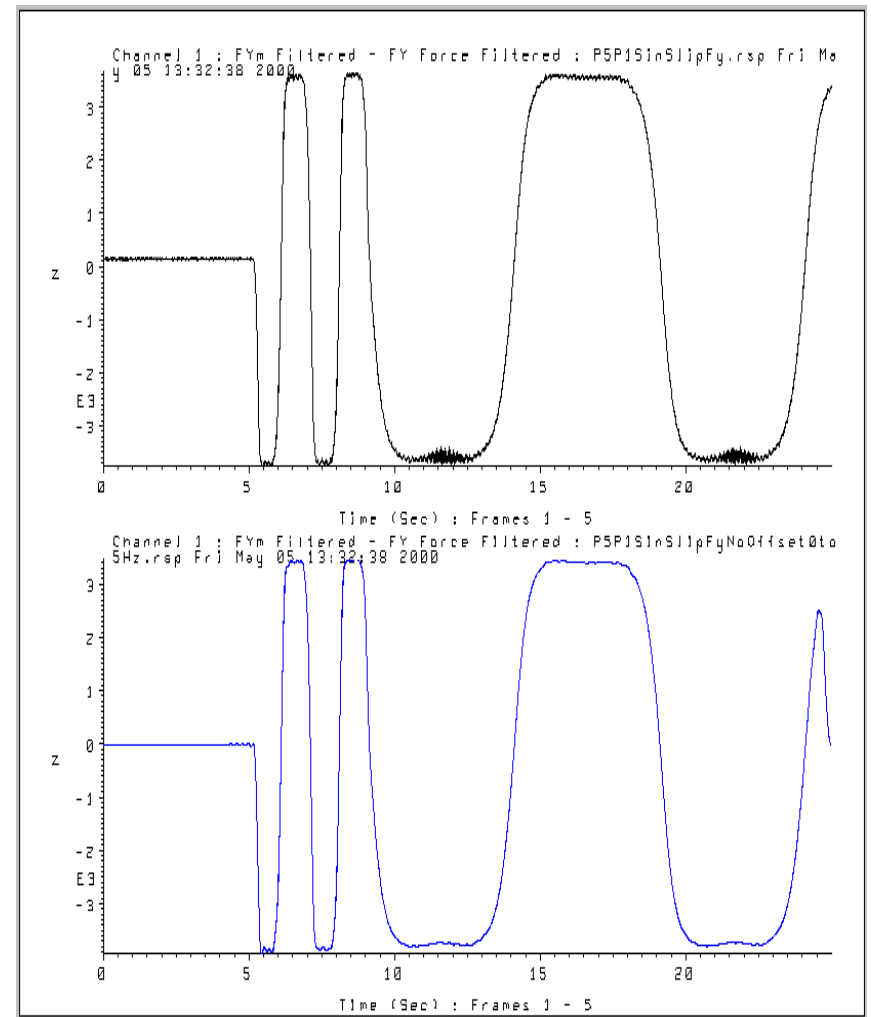
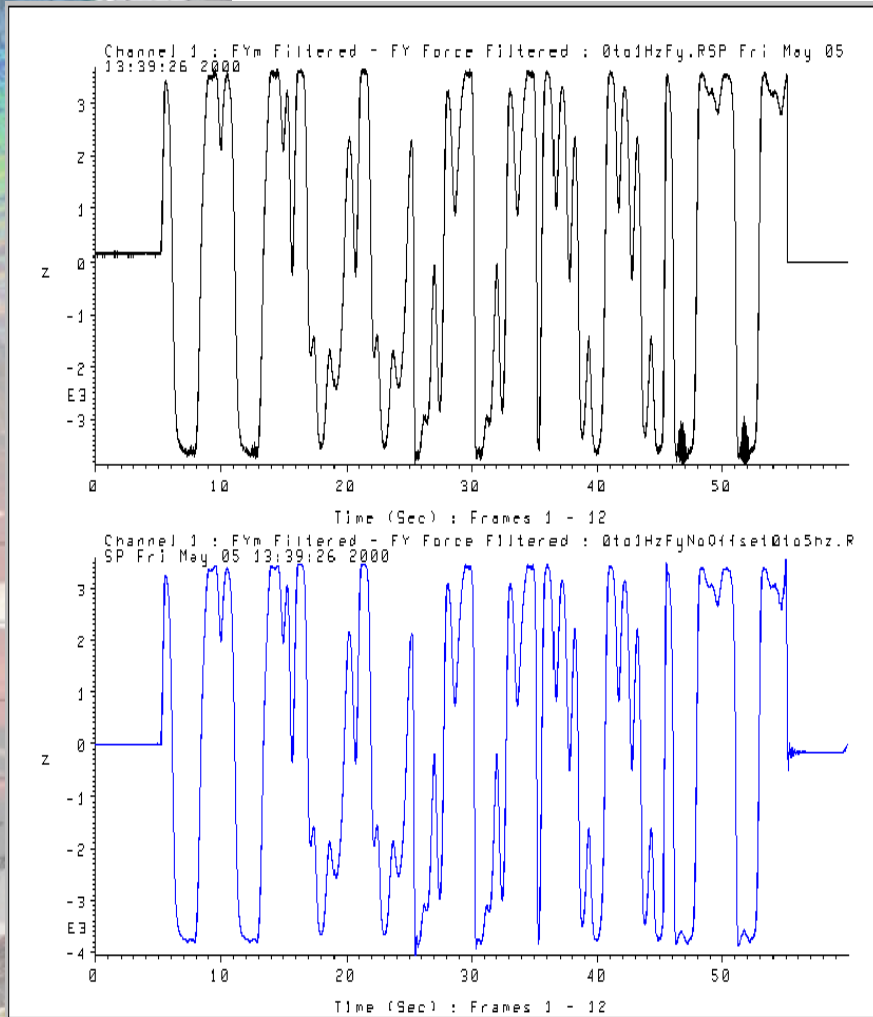


File 2: Training Excitation and Response



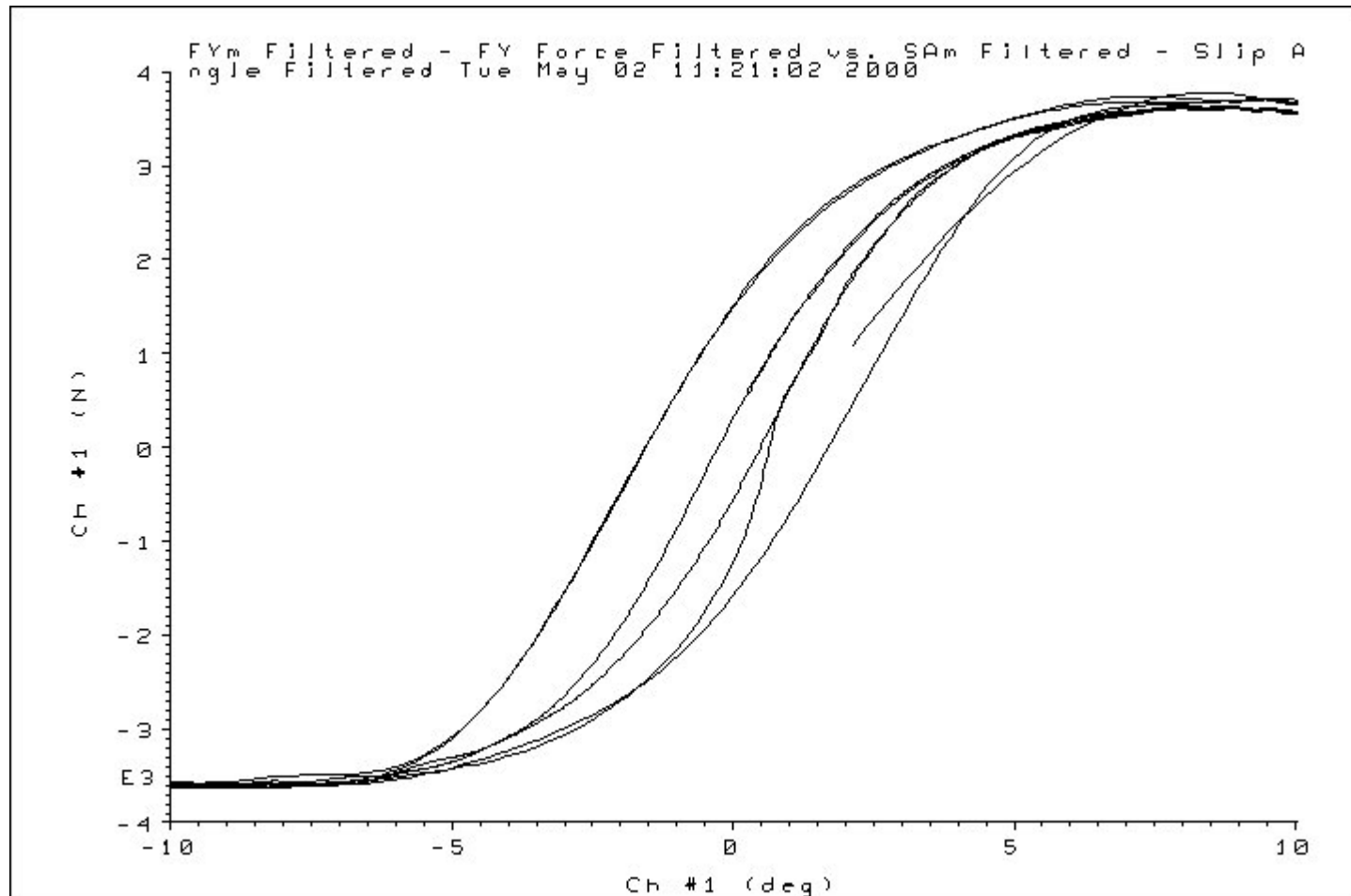


Need to remove 36 hz vibration model will try to fit it.



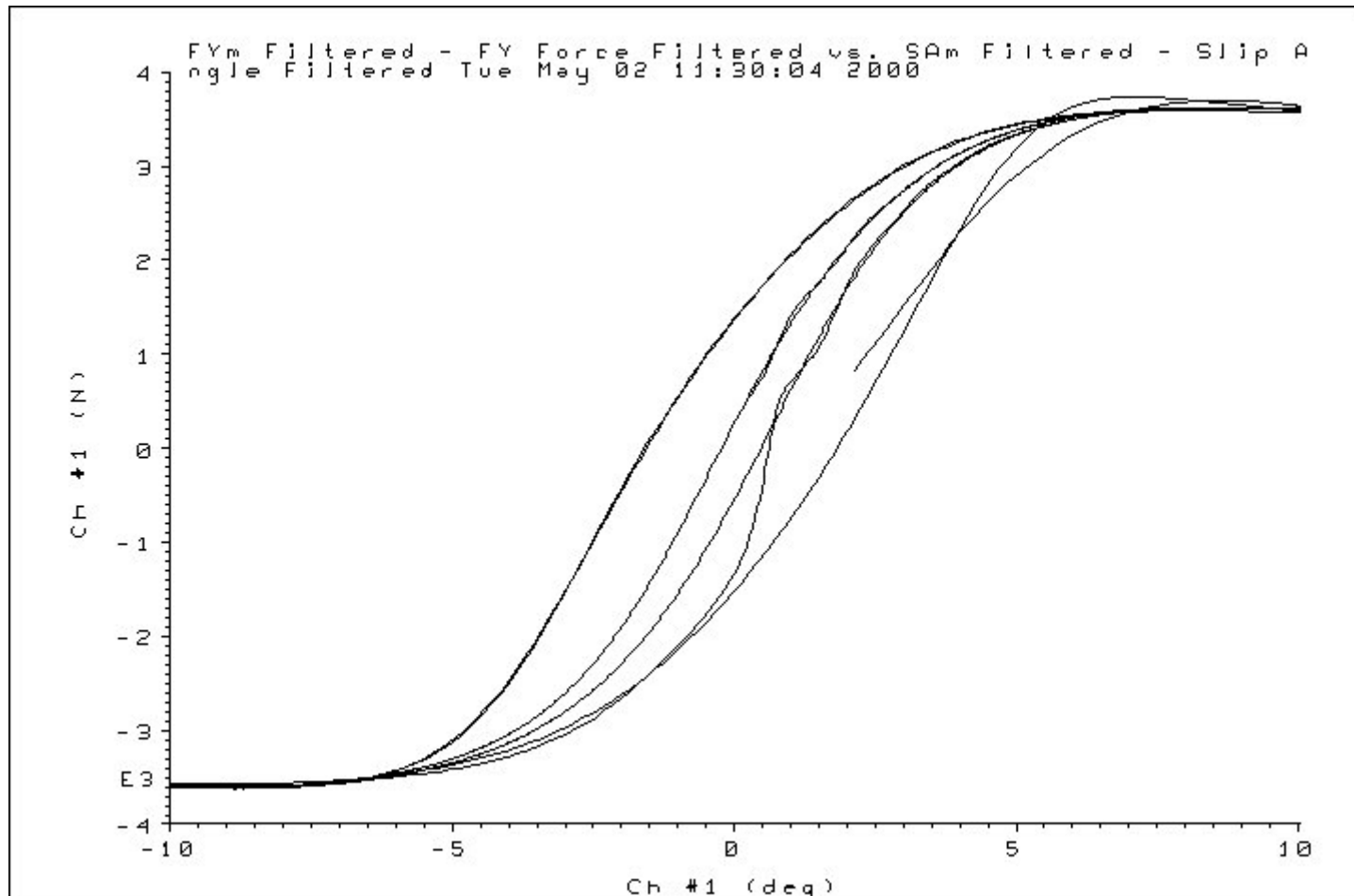


Measured Sa vs Fy



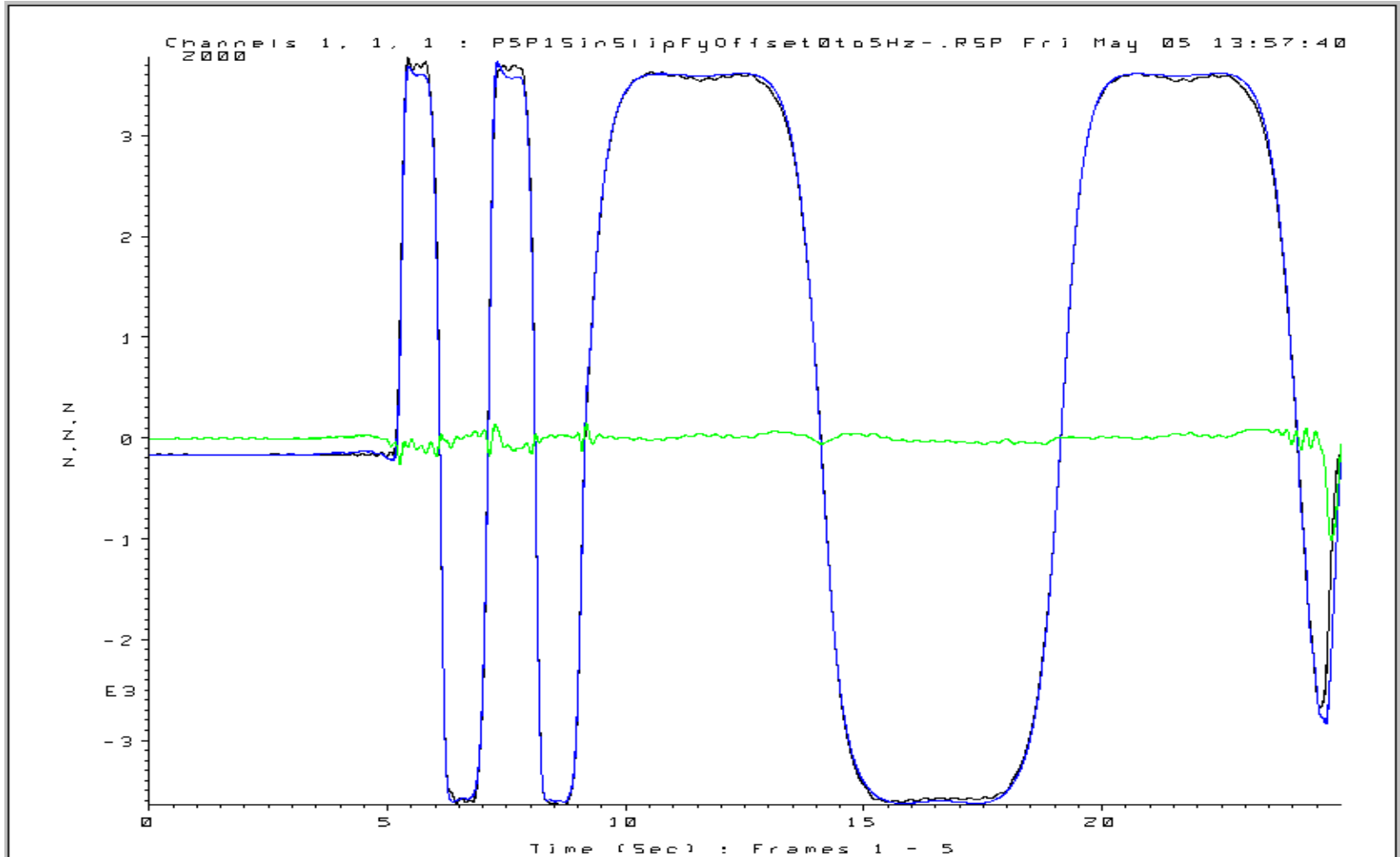


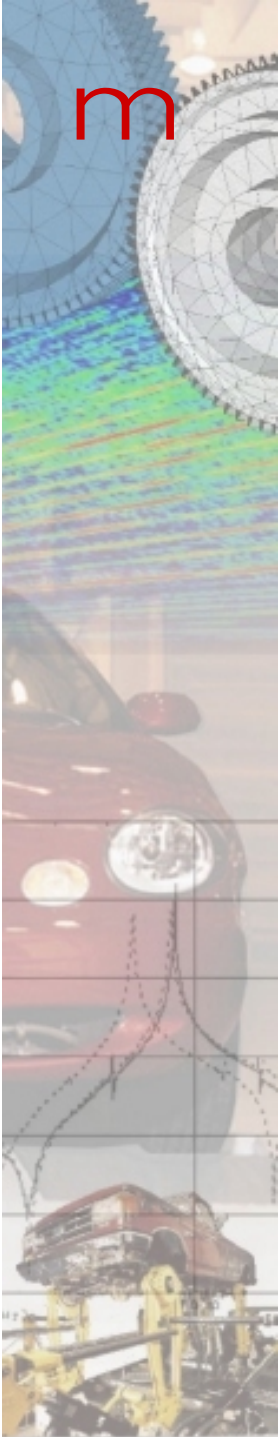
Model Prediction Sa vs Fy





Measured and Modeled Comparison





Case 2: SISO, Conclusions

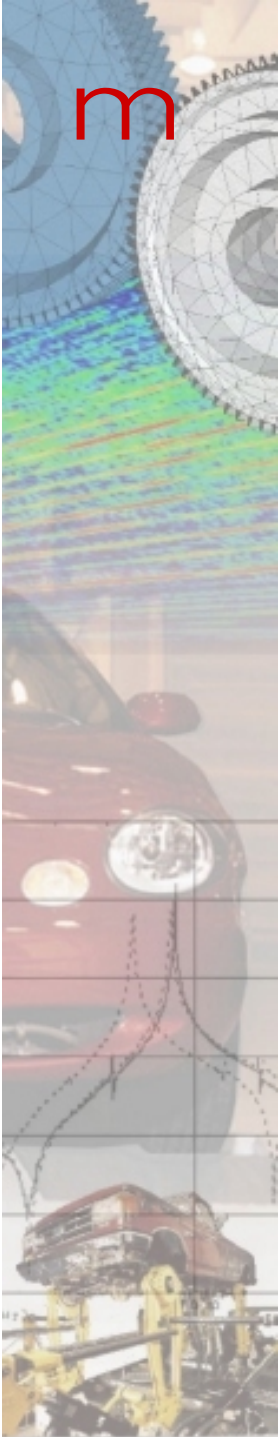
- Can create model with random data and use model with very non-linear data.
- Model can reproduce the dynamic hysteresis characteristics of the tire.





Future Work

- Deal with tire eccentricity better
 - Subtract out eccentricity load as a function of rotational position.
 - Use eccentricity load as another input channel during model generation.
- Use Extrinsic conditions to handle different radial loads and speeds.
- Run tests on the more dynamic Flat-Trac



Static / Dynamic Flat-Trac[®] Comparison

Static

Loaded Radius - 74 mm/sec

Slip Angle - 25 deg/sec

Camber Angle - 1 deg/sec

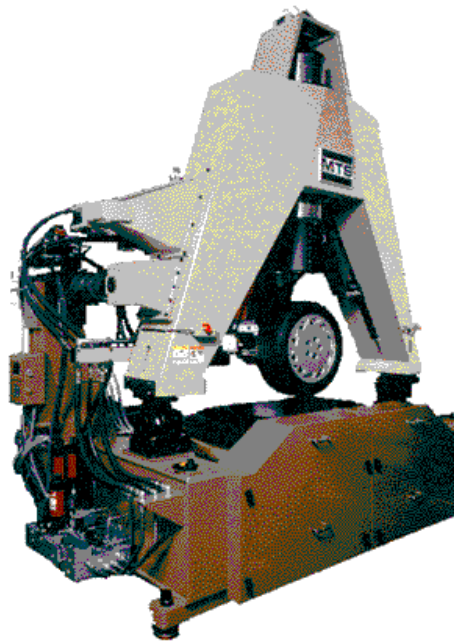
Dynamic

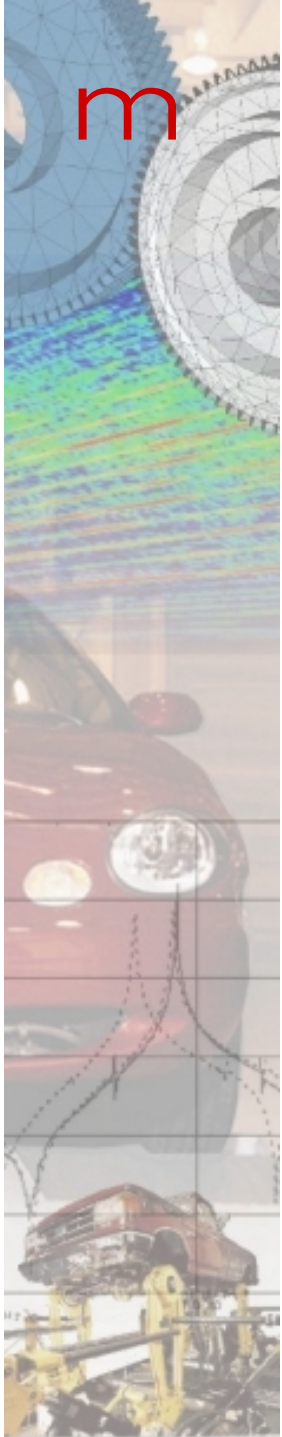
300 mm/sec

50 deg/sec

5 deg/sec

- Inertial Compensation
- Higher Bandwidth Load cells
- Accelerometer Stabilization





Large Camber Movement

