

MORSE MEASUREMENTS LLC

MAXIMIZING SUSPENSION PERFORMANCE



Dialing In Dynamics: K&C Testing Insights

Introduction to Morse Measurements

- ***Facility Opened in 2005 in Salisbury, NC***
- ***Operates a Suspension Parameter Measurement Machine (SPMM 4000) produced by Anthony Best Dynamics, UK***
- ***Over 20 years experience testing race cars***



Introduction to Morse Measurements

- ***The SPMM and other commercially available K&C rigs were made to test production cars***
- ***Morse Measurements developed racecar testing on the K&C rig***
 - ***Chassis Mounting***
 - ***Wheel Measurement Fixture Mounting***
 - ***Test Protocols***
 - ***Work Platforms***
 - ***Real-time test results***
 - ***Live graph while test is running***



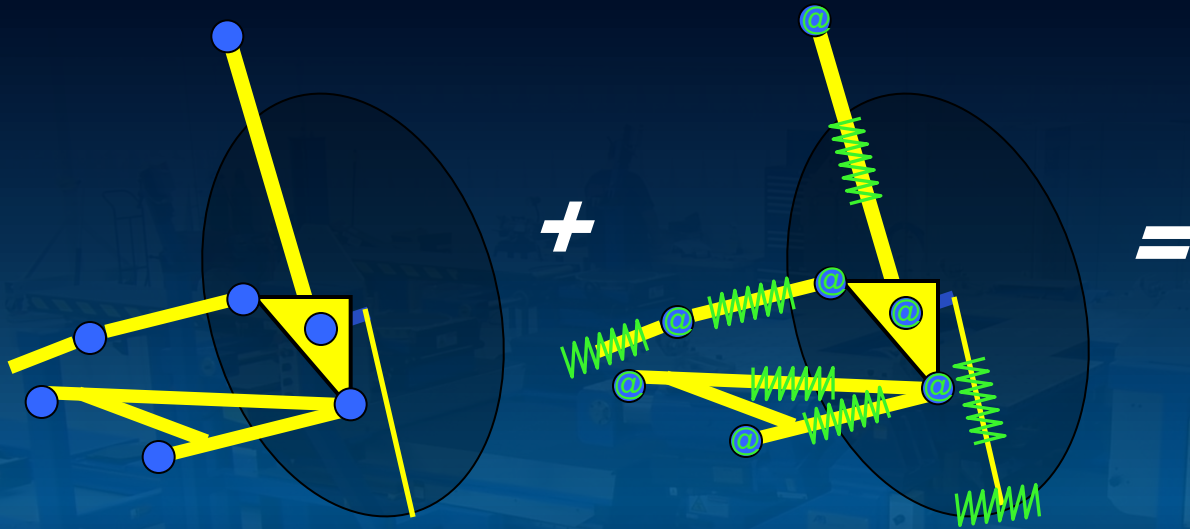
Introduction to Morse Measurements

• Tests cars across all the major professional race series:

- NASCAR: Cup, Xfinity, Truck***
- Indy Car***
- IMSA: Prototype, GT3, GT4***
- SRO: GT3, GT4***
- Trans Am***
- Super Modified***
- Late Model***
- And Much More!***



What is K&C?

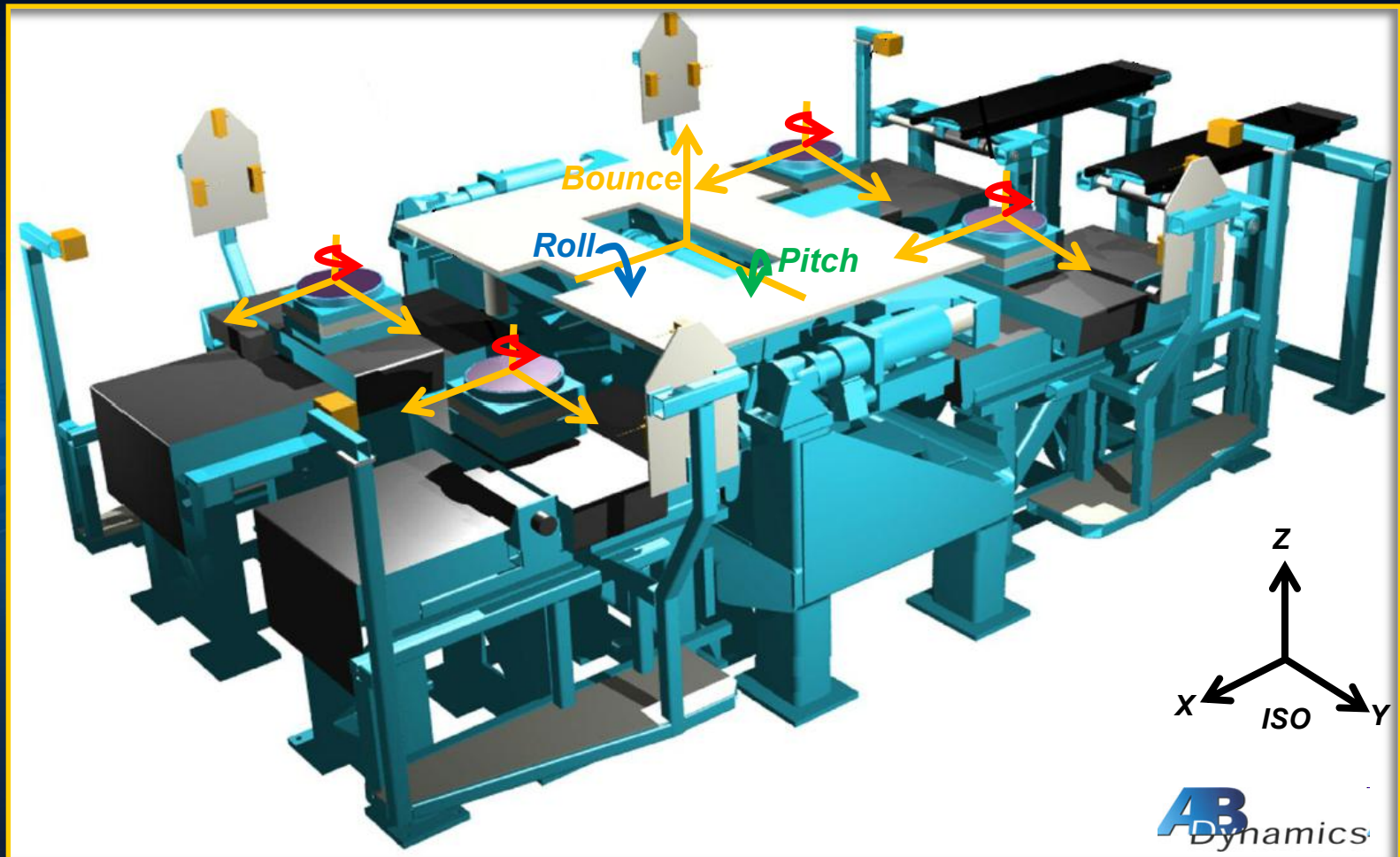


&

KINEMATICS = Suspension Geometry

COMPLIANCE = Suspension Stiffness

Tour of the Rig



Applications

What Makes K&C Testing Unique?

- ***Applies realistic cornering, braking, and tractive loads at the tire contacts***
- ***Measures the response of the suspension***
 - ***Toe, Camber orientation under load***
 - ***Vertical loading at each corner***
 - ***Suspension friction and binding under load***
 - ***Wheel rates under load***
 - ***Anti-dive, anti-squat, roll centers***

Applications

How Can K&C Help Racers?

- > Understand suspension setups and changes objectively***
- > Use track time to tune the car, not to figure out what the suspension adjustments do***
- > This allows you to go fast at the track, much faster!***

Applications

Advantages of K&C Testing Over Track Testing For Understanding Suspension Setups:

- Objective, highly repeatable measurements on-rig***
- No variation due to temperature, tire wear, changing track conditions, etc.***
- Have detailed metrics to compare between setups, not just lap times and driver feedback***
- Make changes and see the results in minutes***

Applications

Typical Applications of K&C Testing for Racers:

- Find problems in the suspension – many customers have a specific handling problem and want to understand it***
- Compare two chassis – why don't they respond to changes the same / why do they need different setups?***
- Understand the suspension and setup options before going to the track – use track time to tune the car for the track***
- Build a better simulation model – can use in the driving simulator***

Applications

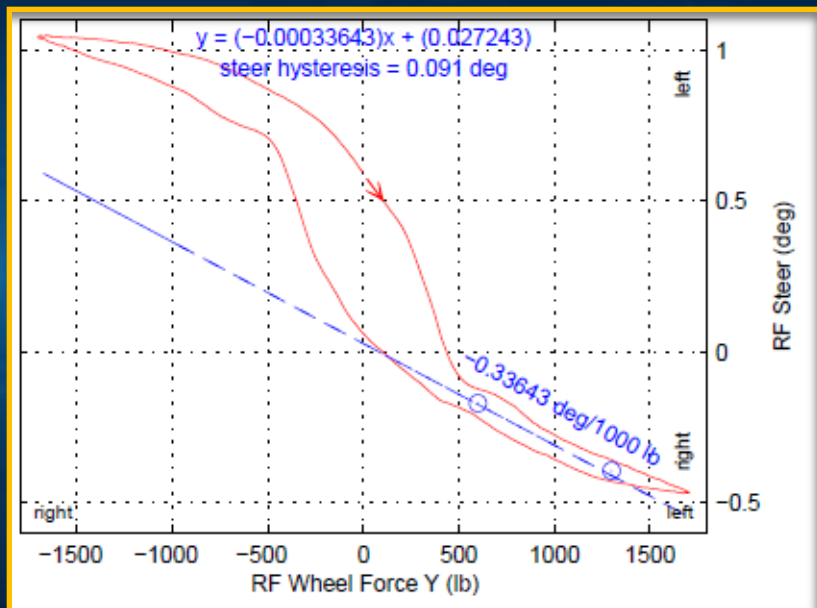
K&C Test Demo

> Lateral Force Test

- Chassis held fixed (aero loaded)***
- Lateral force applied at tire contacts***
- Lateral load based on lateral G experienced on-track***
- Results:***
 - Camber Compliance***
 - Steer Compliance***
 - Force-based roll centers***

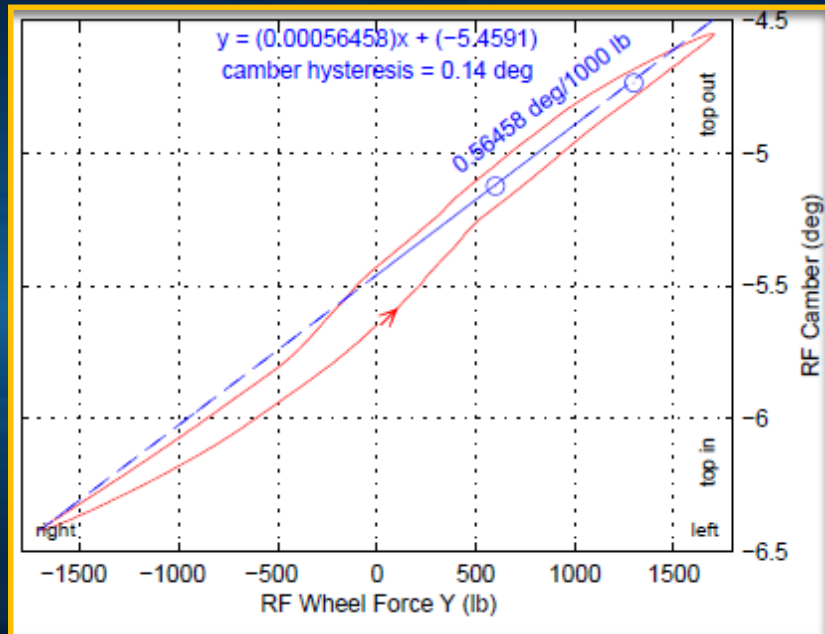
Compliance: Lateral Tests

Steer Compliance



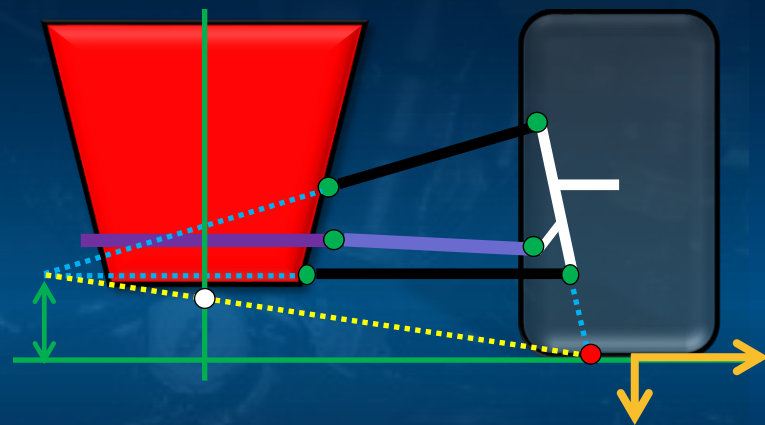
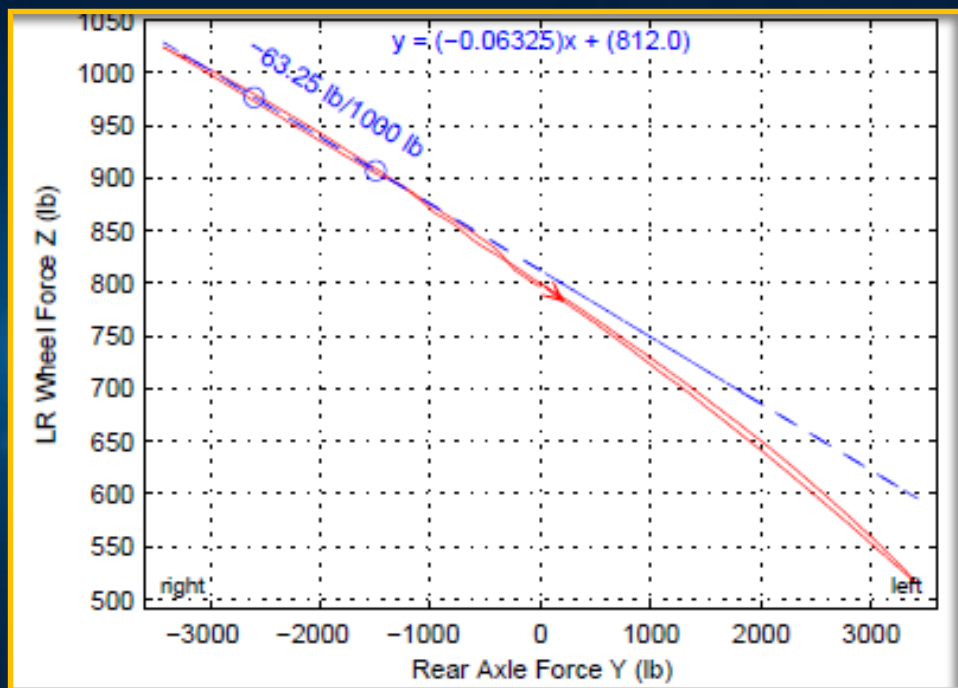
Compliance: Lateral Tests

Camber Compliance



Compliance: Lateral Tests

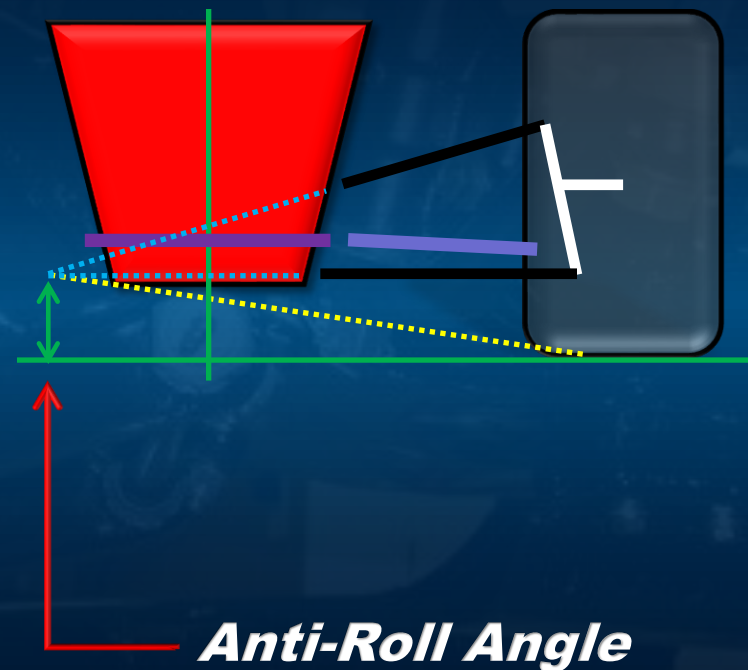
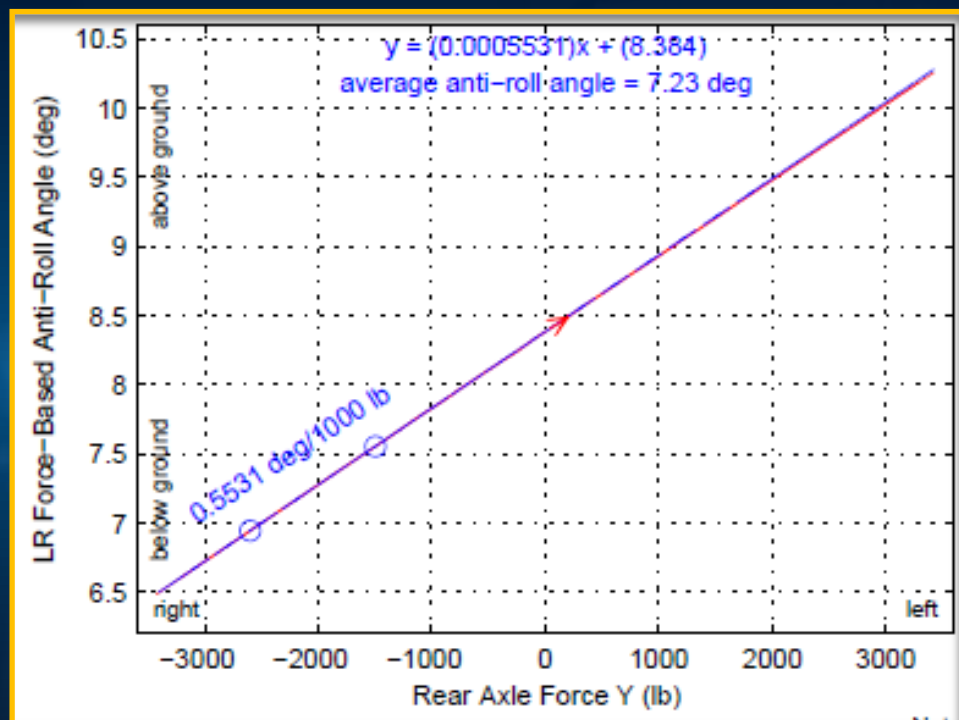
Lateral Jacking Force



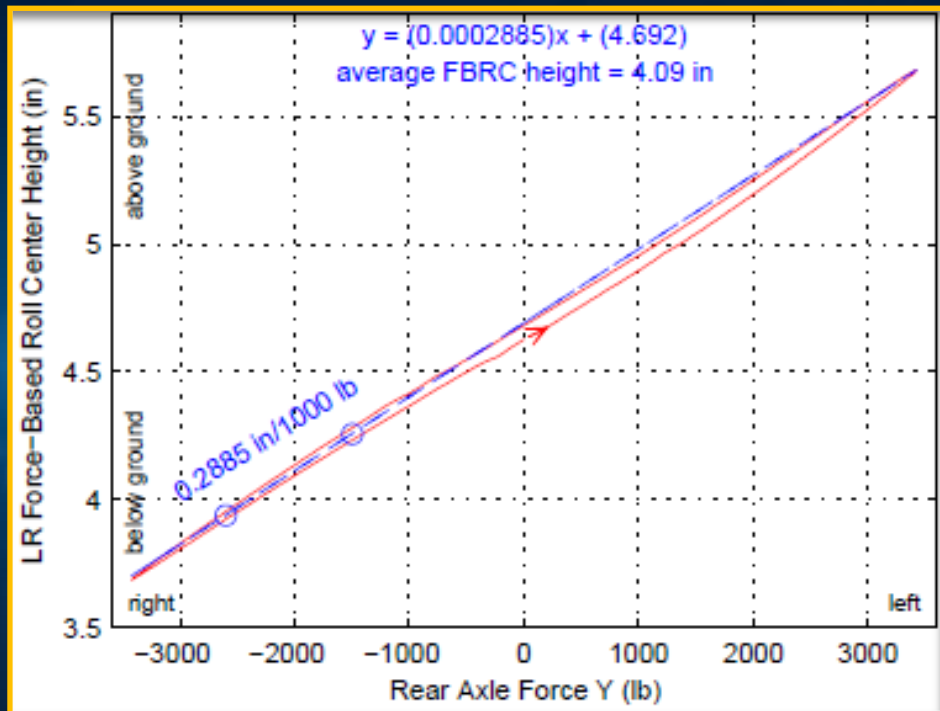
Jacking Force

Compliance: Lateral Tests

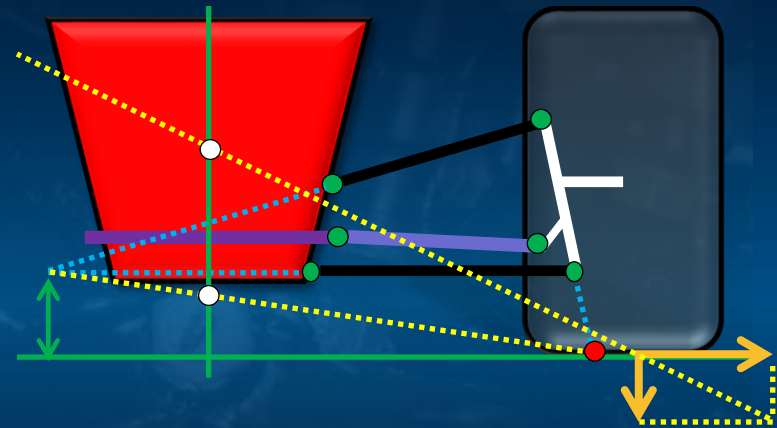
Force Based Anti-Roll Angle



Compliance: Lateral Tests



Force Based Roll Center Height



Taken from the tire COP

Applications

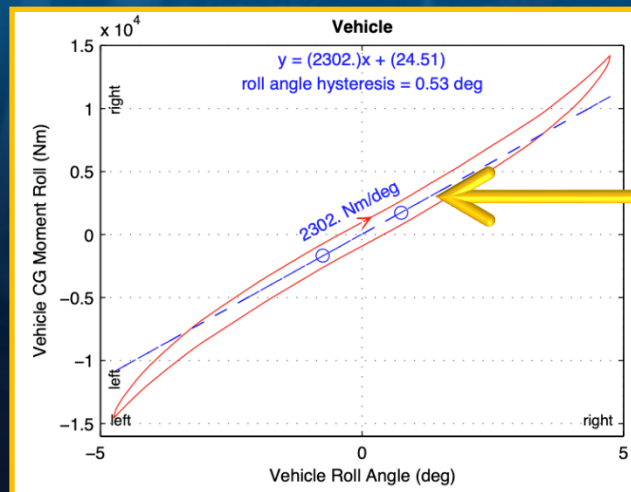
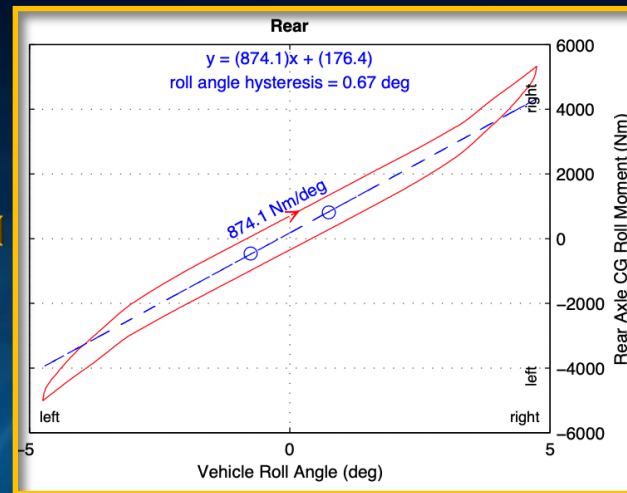
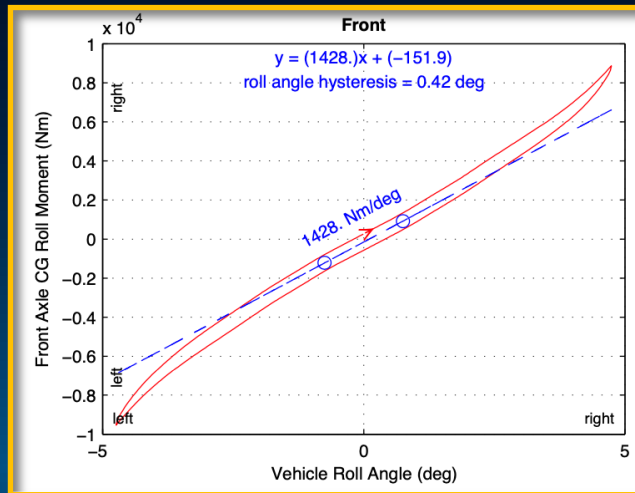
K&C Test Demo

> Roll Test

- ***Can be Fixed Axis or Natural Axis***
 - ***Fixed rolls about an axis in the ground plane***
 - ***Natural maintains constant axle loads***
- ***Zero scrub force maintained at tire contacts***
- ***Results:***
 - ***Roll Stiffness and Roll Stiffness Distribution***
 - ***Roll Steer***
 - ***Camber Recovery in Roll***
 - ***Anti-Roll Bar Contribution to Roll Stiffness***

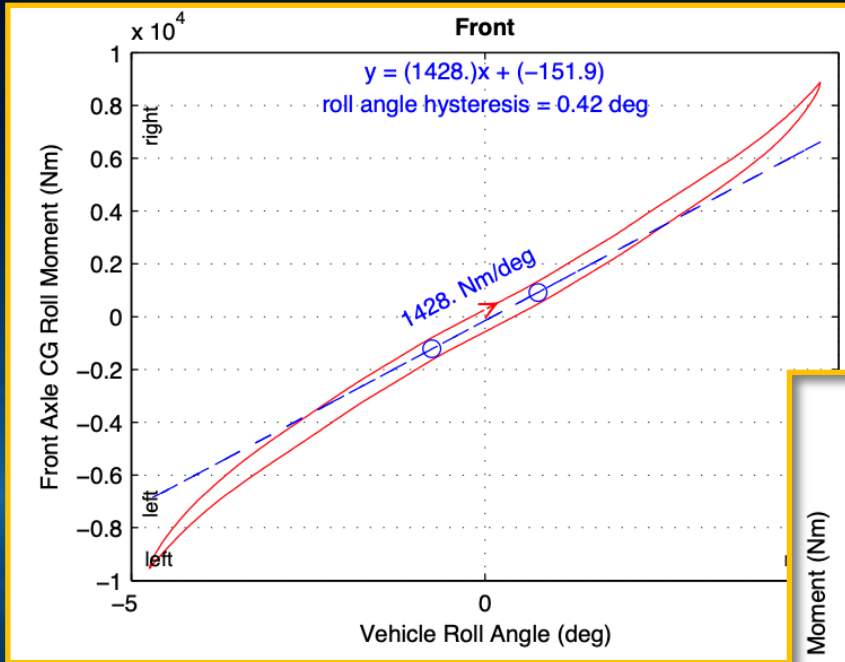
Kinematics: Roll Test

Total Roll Stiffness



Linear Spring Rate Region (Curve Fit). This slope is total roll stiffness.

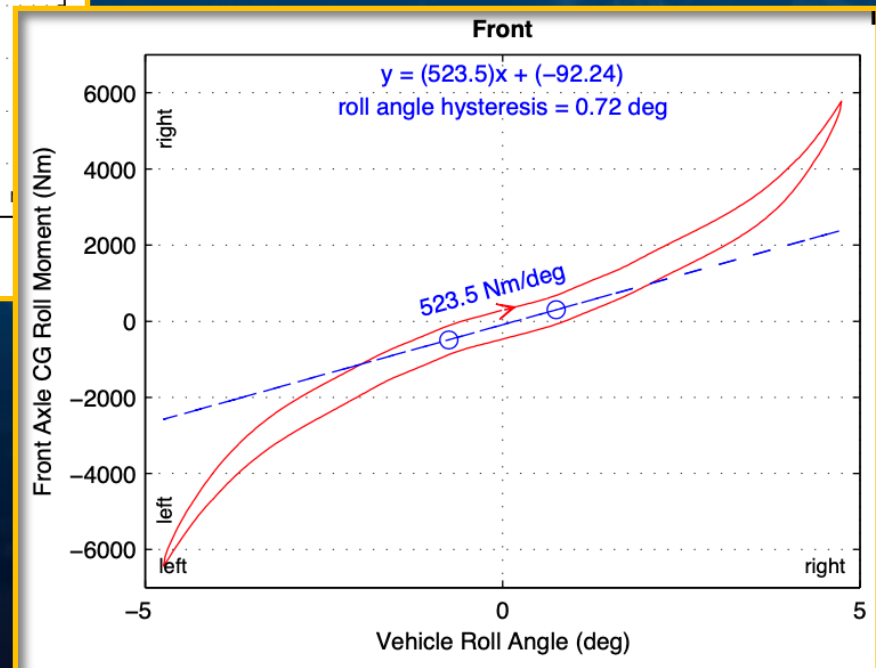
Kinematics: Roll Test



***As installed ARB
contributions can
be determined***

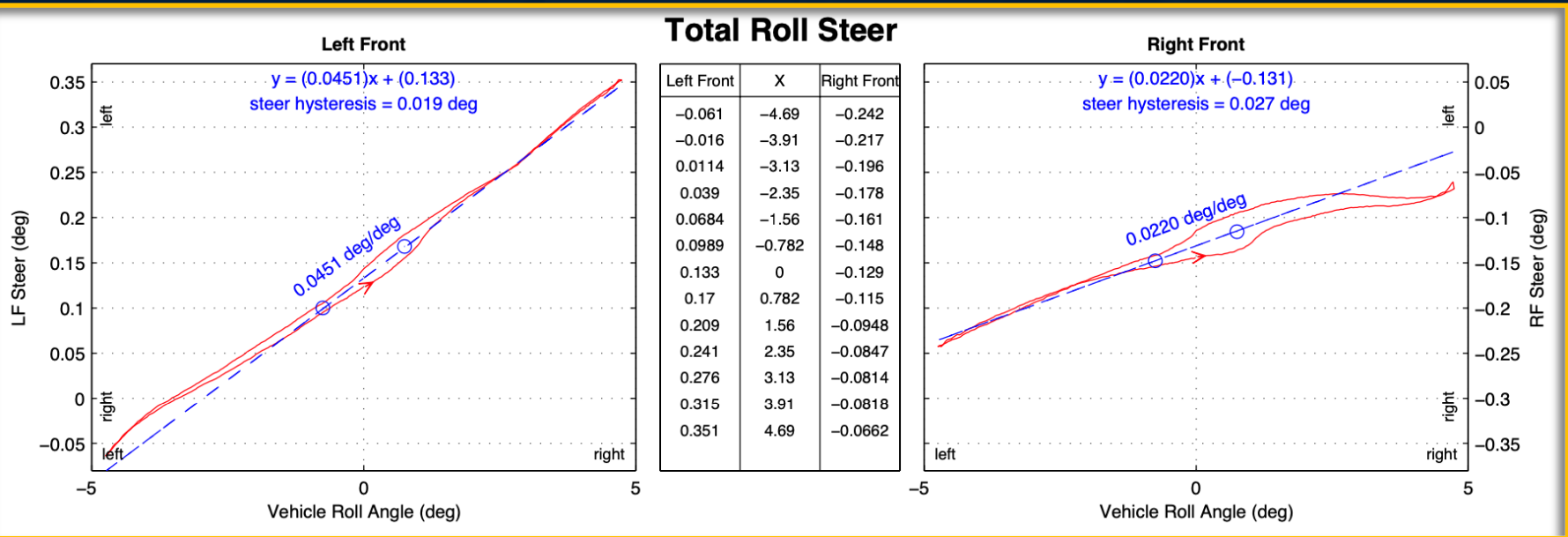
Total Roll Stiffness w/ ARB's

w/o ARB's



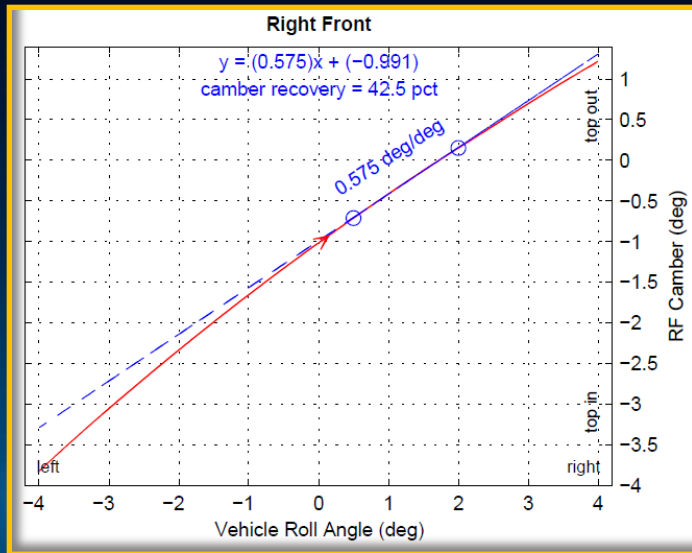
Kinematics: Roll Test

Total Roll Steer

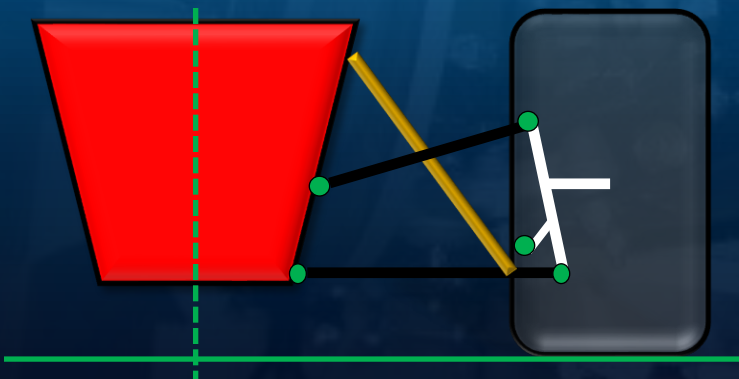
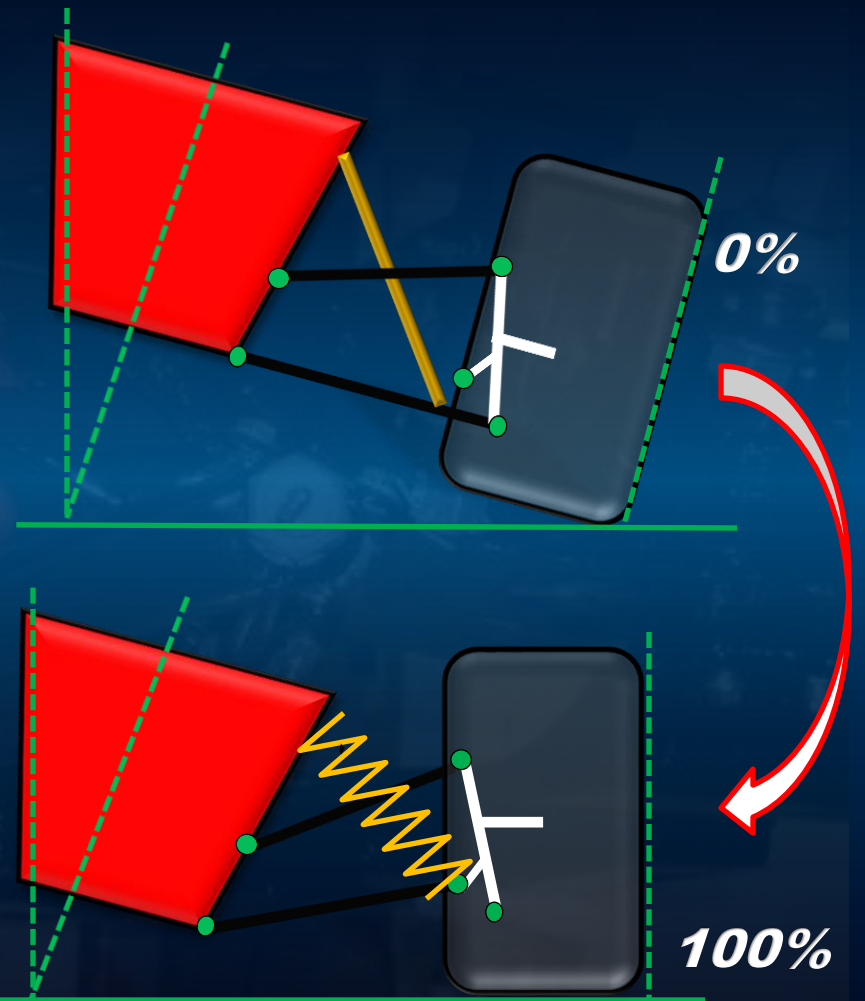


- *Magnitude and direction*
- *Left to Right Asymmetry*

Kinematics: Roll Test



Camber Recovery



Applications

K&C Test Demo

> Cornering Simulation

- Simulate steady-state cornering event***
- Apply roll moment to chassis + lateral load at tire contacts***
- Optionally include aero loading, driver steer input, tire pneumatic trail***
- Test typically run to lateral G loading experienced on-track***

Applications

K&C Test Demo

> Cornering Simulation

- ***Results:***

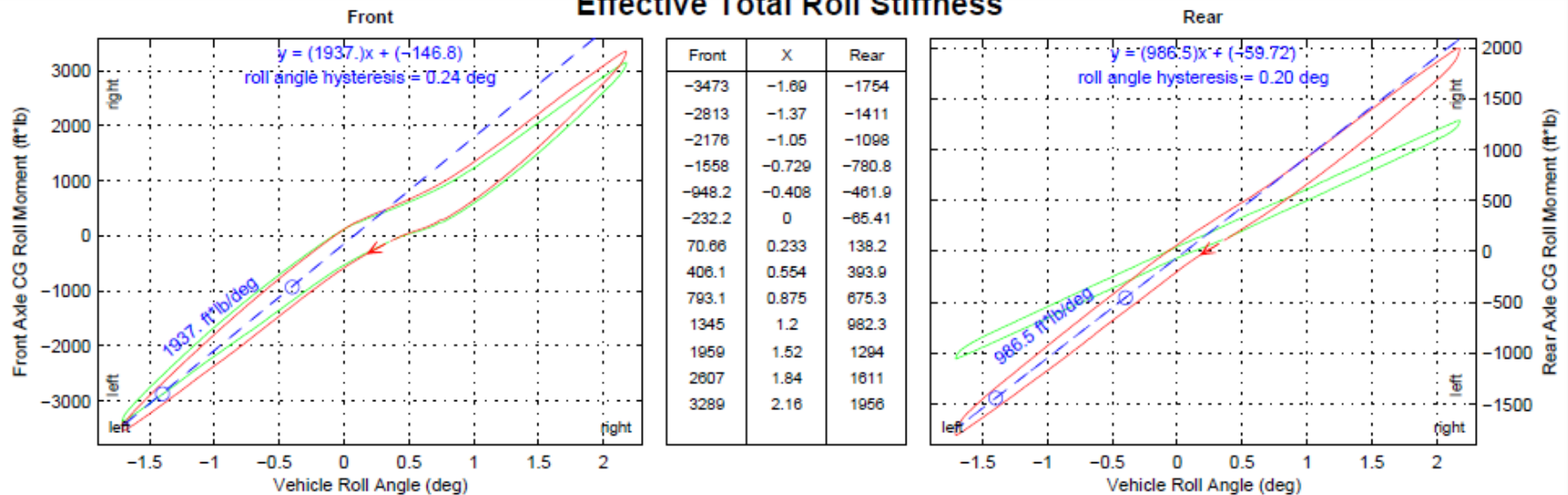
- ***Wheel orientation under load (Steer, Camber)***
- ***Lateral Weight Transfer Components***
 - ***Elastic Weight Transfer (springs and bars)***
 - ***Geometric Weight Transfer (directly through links, due to jacking forces / roll center heights)***
- ***Suspension friction under load***
- ***Binding under load***

Simulation: Cornering

Roll Stiffness

- *Comparing cornering sim with and without lateral forces*

Effective Total Roll Stiffness

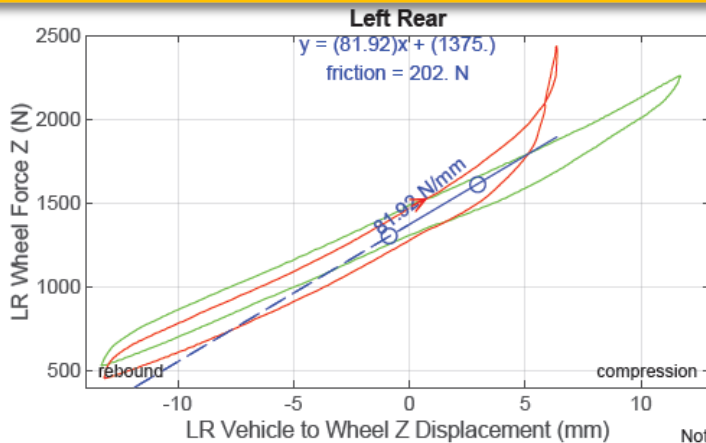


Cornering Sim w/ Forces
Cornering Sim w/o Forces

Simulation: Cornering

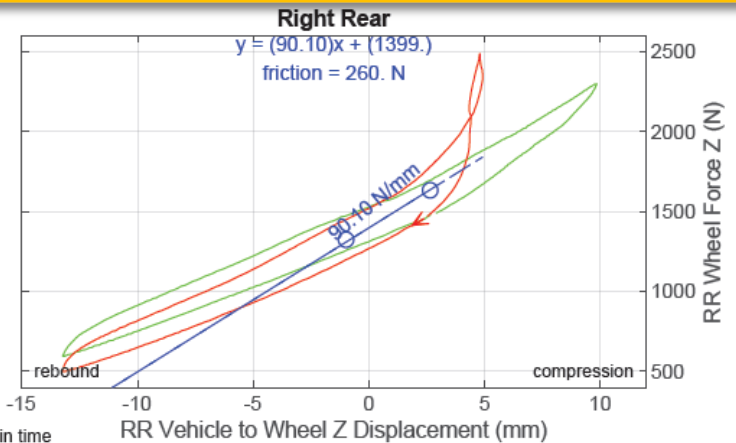
Wheel Rates

- This example illustrates binding under load



Left Rear	X	Right Rear
460	-13.2	510
610.9	-11.5	647.4
702.4	-9.91	739.9
798	-8.29	833.4
898.2	-6.67	929.3
999.8	-5.05	1032
1109	-3.44	1146
1231	-1.82	1264
1377	0	1394
1481	1.42	1506
1621	3.04	1688
1814	4.66	2288
2307	6.28	

Note: Red arrows indicate direction of test in time

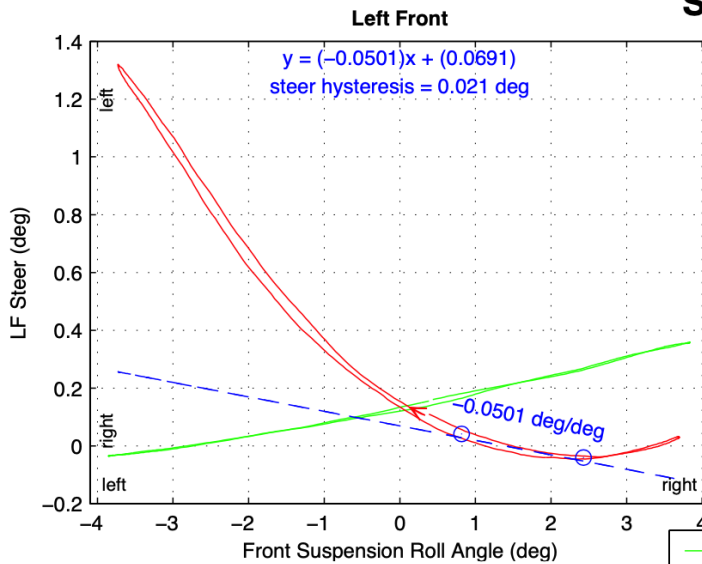


Cornering Sim w/ Forces
Cornering Sim w/o Forces

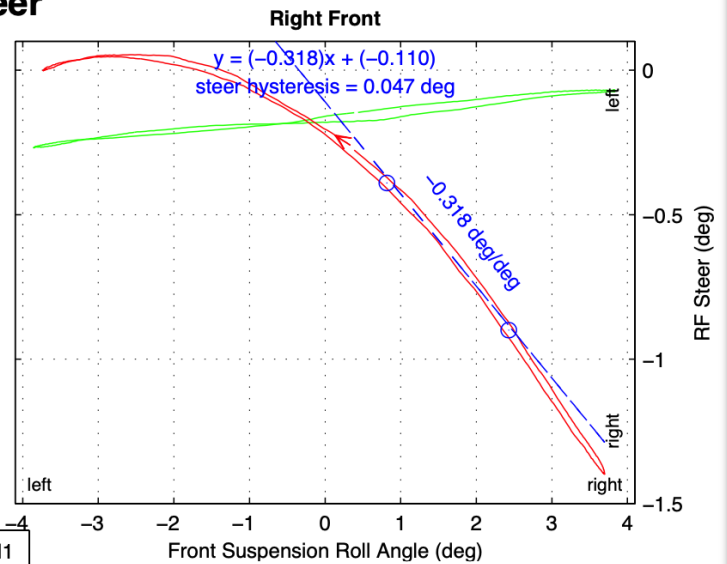
Simulation: Cornering

Roll Steer

Suspension Roll Steer



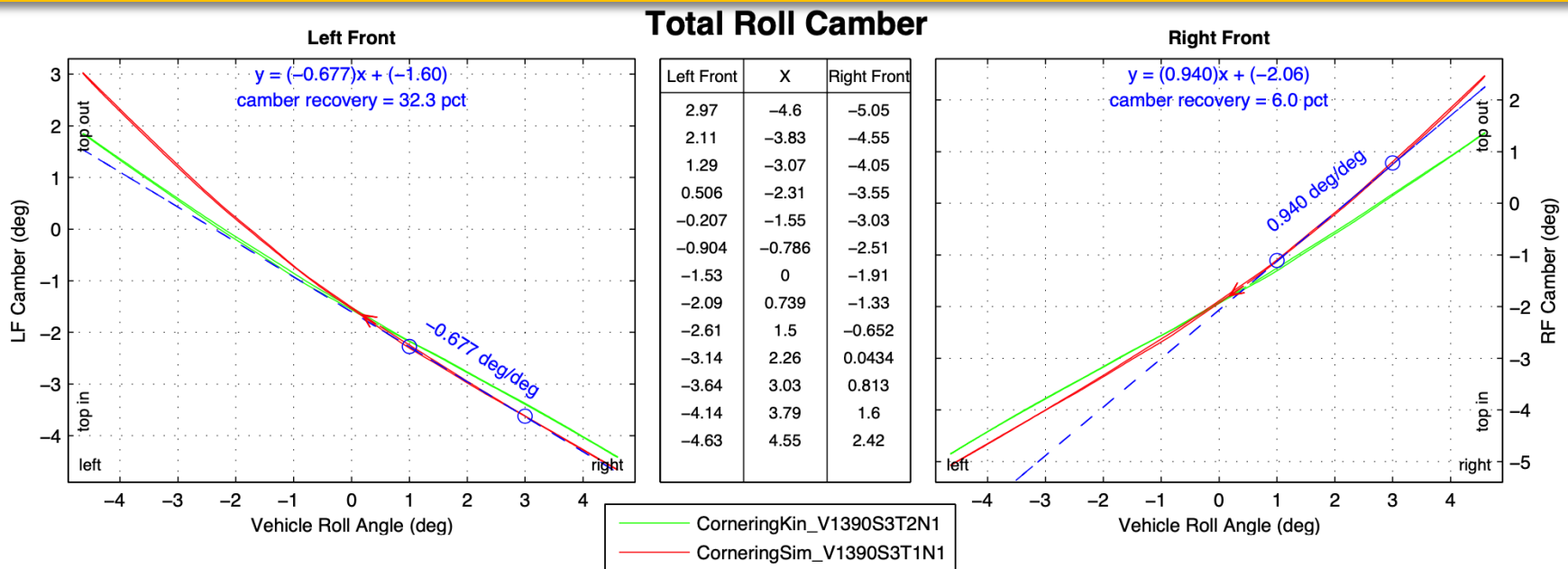
Left Front	X	Right Front
1.3	-3.69	0.00525
1.07	-3.08	0.0451
0.828	-2.47	0.0465
0.6	-1.85	0.0231
0.415	-1.24	-0.0255
0.26	-0.628	-0.111
0.144	0	-0.213
0.0649	0.597	-0.34
0.00691	1.21	-0.491
-0.0286	1.82	-0.682
-0.0404	2.44	-0.904
-0.0213	3.05	-1.14
0.0265	3.66	-1.38



Cornering Sim w/ Forces
Cornering Sim w/o Forces

Simulation: Cornering

Camber Compliance



Cornering Sim w/ Forces
Cornering Sim w/o Forces

Simulation: Cornering

Morse Measurements Reporting



Simulation Tests

1/10/2024
CorneringSim_V1390S3T1N1

Cornering Simulation, +/-0.80g Summary page 1

Effective Total Roll Stiffness

Front: 1636. Nm/deg
Rear: 1189. Nm/deg
Vehicle: 2717. Nm/deg

Jacking Force Contribution to Total Roll Stiffness

Front: 56.86 Nm/deg
Rear: 410.8 Nm/deg
Vehicle: 487.8 Nm/deg

Effective Suspension Roll Stiffness

Front: 2038. Nm/deg
Rear: 1356. Nm/deg
Vehicle: 3196. Nm/deg

Jacking Force Contribution to Suspension Roll Stiffness

Front: 129.0 Nm/deg
Rear: 498.2 Nm/deg
Vehicle: 608.7 Nm/deg

Effective Wheel Rates in Roll

68.45 N/mm	139.6 N/mm
61.35 N/mm	61.84 N/mm

Jacking Force Contribution to Wheel Rates in Roll

3.911 N/mm	10.06 N/mm
22.58 N/mm	22.29 N/mm

Simulation: Cornering

Morse Measurements Reporting

Lateral Weight Transfer

Front: 6175. N/g
Rear: 4515. N/g
Vehicle: 1.043e+04 N/g

Front Weight Transfer Components

Elastic: 6086. N/g
Geometric: 88.37 N/g
Total: 6175. N/g

Front Percentages

Elastic: 98.6 pct
Geometric: 1.4 pct
Total: 100.0 pct

Rear Weight Transfer Components

Elastic: 3003. N/g
Geometric: 1513. N/g
Total: 4515. N/g

Rear Percentages

Elastic: 66.5 pct
Geometric: 33.5 pct
Total: 100.0 pct

Applications

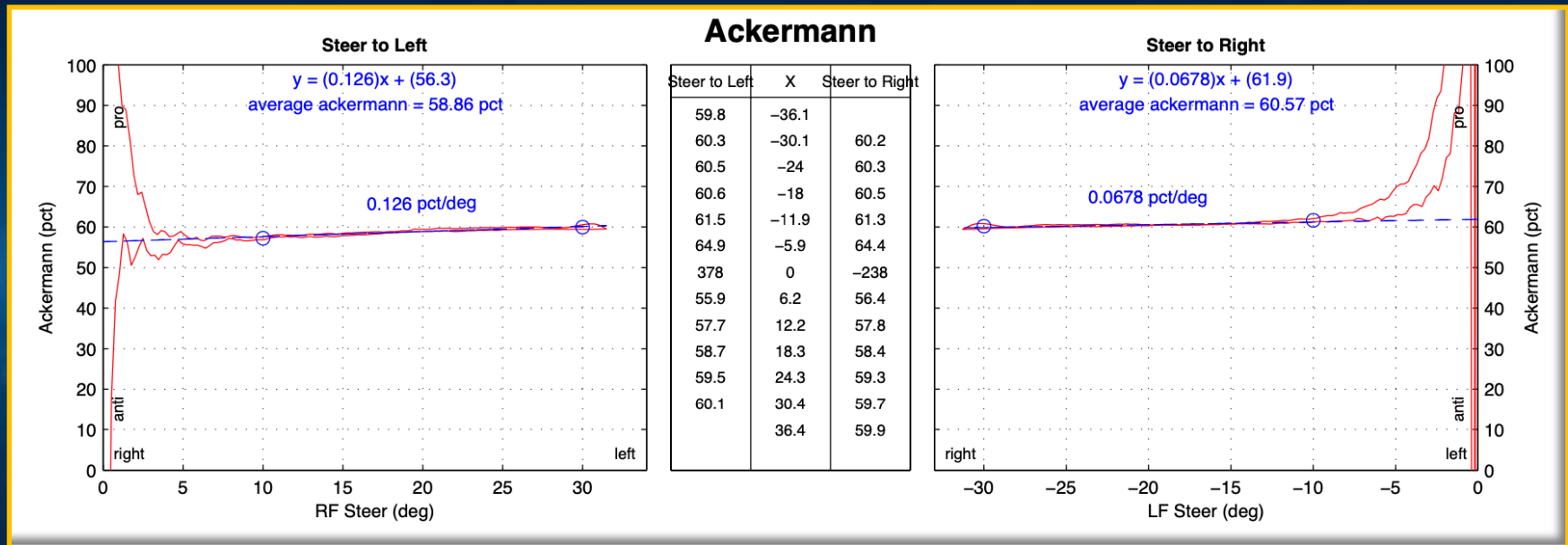
K&C Test Demo

> Steering Geometry Test

- Chassis held fixed (aero loaded)***
- Robot sweeps through a range of steer***
- Zero scrub force maintained***
- Wheel motion measured***
- Results:***
 - Ackermann***
 - Instantaneous Steering Ratio***
 - Steering Geometry (Caster, Scrub Radius, Mechanical Trail, etc)***

Kinematics: Steer Test

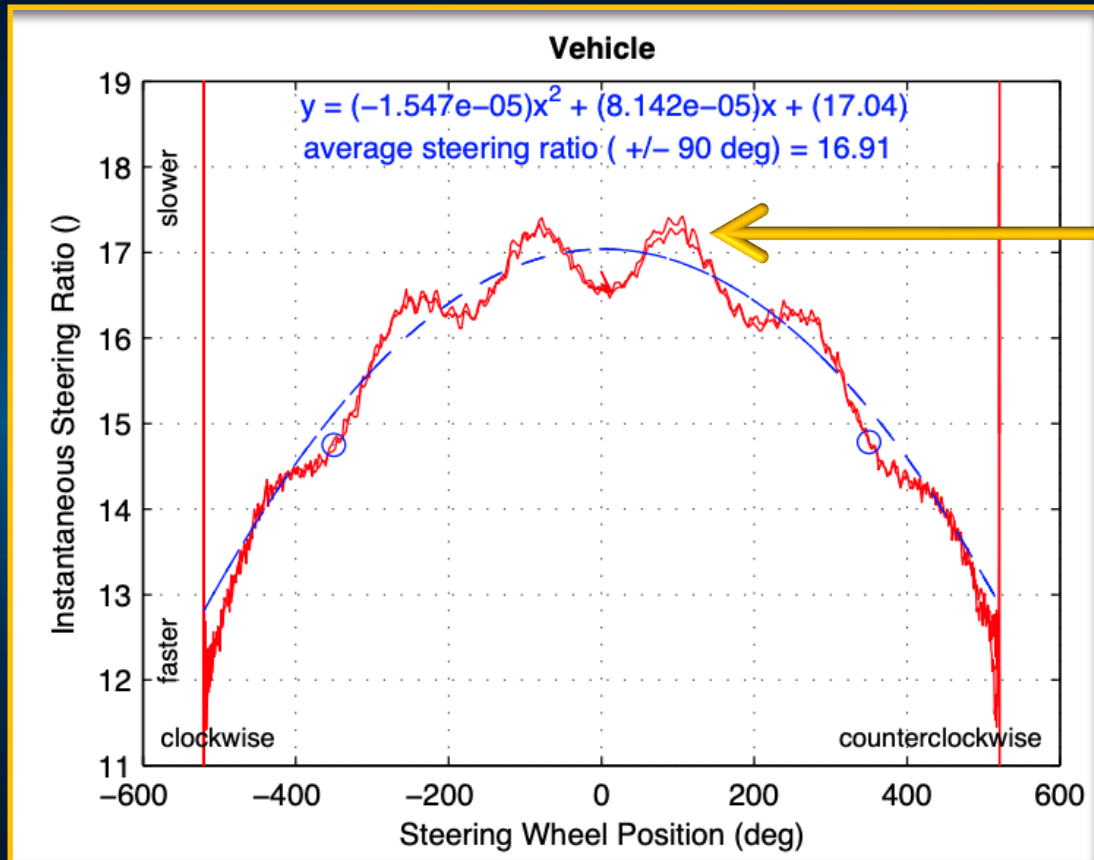
Ackermann



- **Magnitude, pro or anti**
- **Left to Right Asymmetry**

Kinematics: Steer Test

Instantaneous Steering Ratio



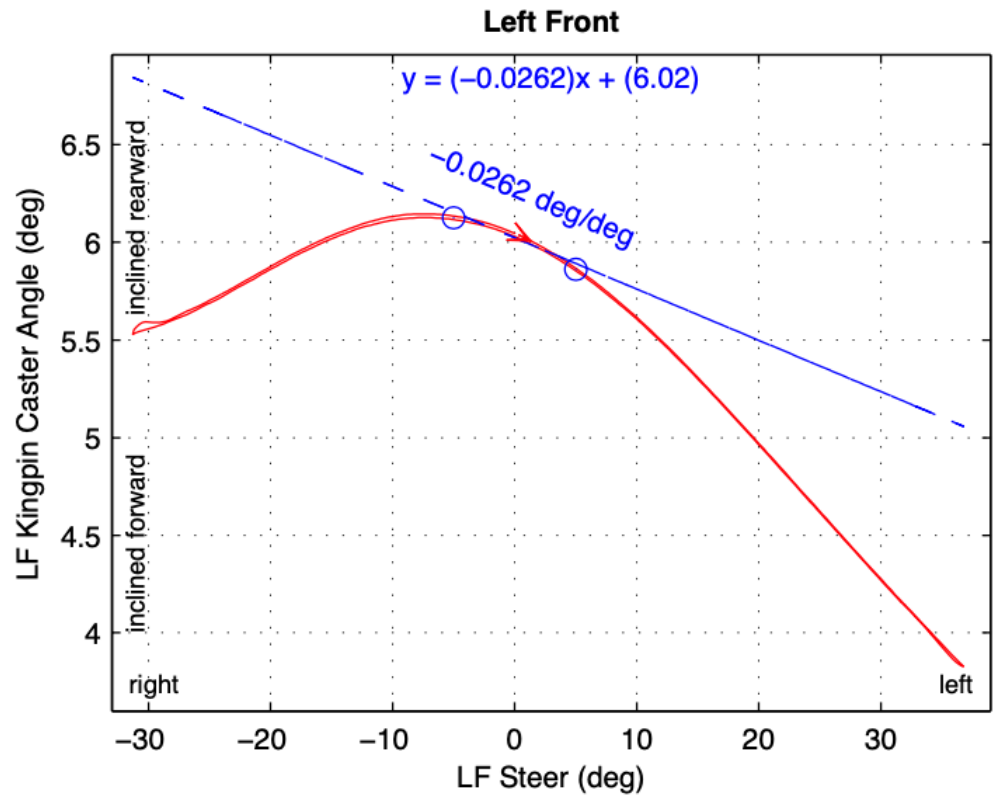
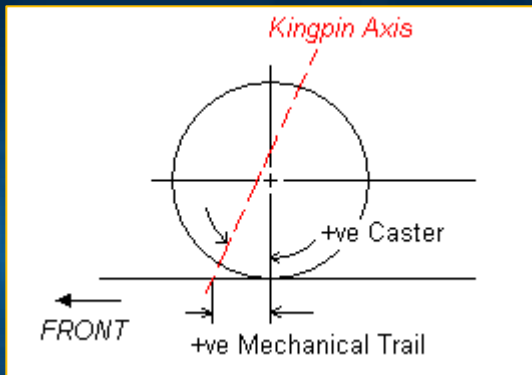
***U-Joint
clocking***

***Instantaneous Steer
Parameters:***

Peak Phase Shift: 3.8 deg
Trough Phase Shift: -92.1 deg
Average Peak to Peak: 0.6
Peak to Peak Percent: 3.8 pct

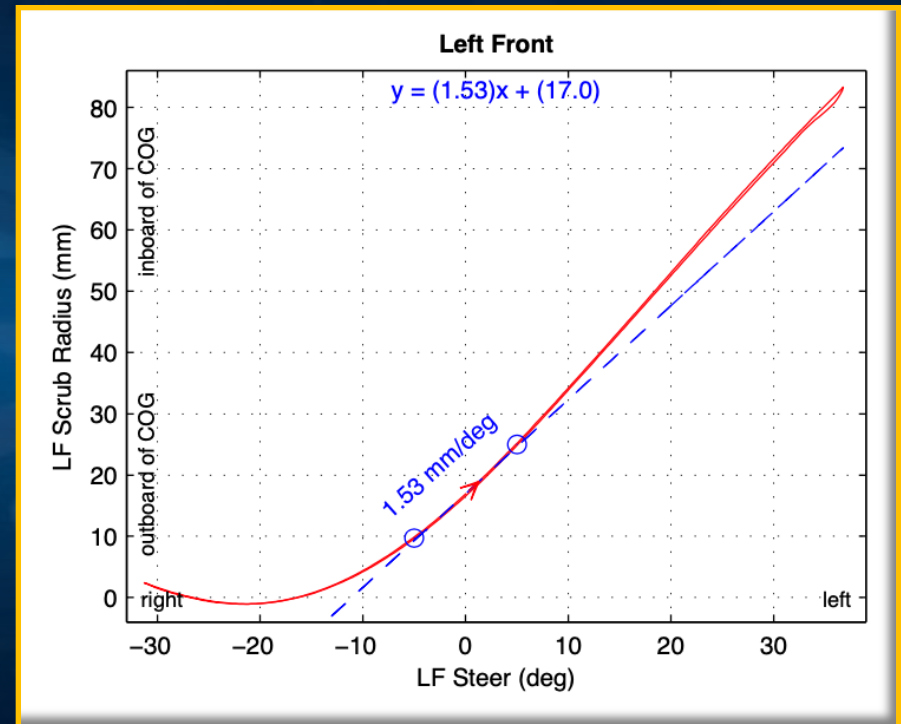
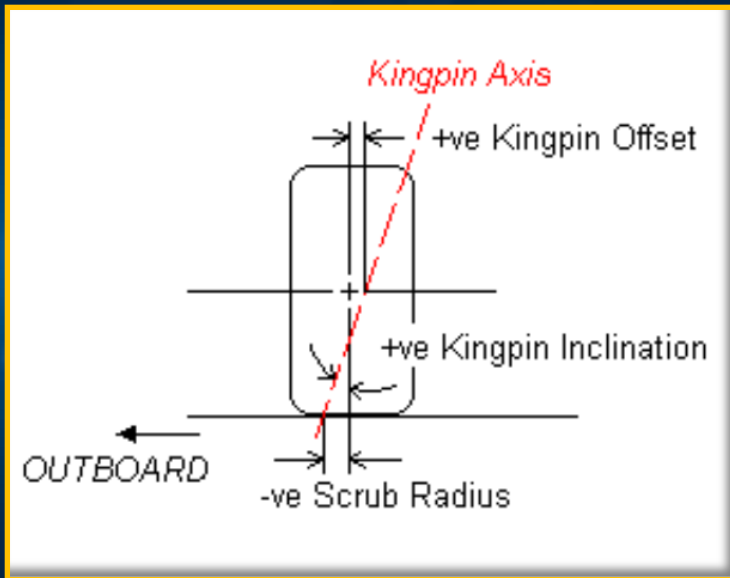
Kinematics: Steer Test

Kingpin Caster Angle



Kinematics: Steer Test

Scrub Radius



Applications

A race engineer's top 10 from a K&C test:

1. Where are the roll centers and how do they move under realistic corner loads? Not the kinematic roll centers but the forced based roll centers. Measured values, not calculated.
2. What is the tire spring rate and how does it change with tire pressure?
3. What is the rate of all my anti roll bars at the wheel? Not a theoretical rate, but a measured, as installed rate.
4. Do I have a problem with a part of the suspension or a bracket bending? Where is the bending taking place and what can I do to fix it?
5. When you load all the suspension arms, uprights, wheel, joints and brackets where are the wheels pointed under max load?
6. What is the anti-dive, anti-squat, and anti-lift when the car is loaded? How much effect do the adjustments have?
7. Is there some part of this spec car that I can't legally change that will dominate the set up choices? Is there a soft engine mounting or a weak bell housing that may make me look at the set up and adjustments differently?
8. What is the real motion ratio and how does it change with rocker position or wheel travel?
9. How much friction is there in the suspension and does it bind up under load?
10. What is the steering geometry, how much Ackermann do I have, is it pro or anti?

Applications

Case Studies

> K&C Zines, in print only, for your analog summer!

- The Asymmetric Anti-Roll Bar***
- The Case of the Anti-Squat that Wasn't***
- The Stiff Anti-Roll Bar That Was Limp***
- The Strut that Wouldn't***

Post Test

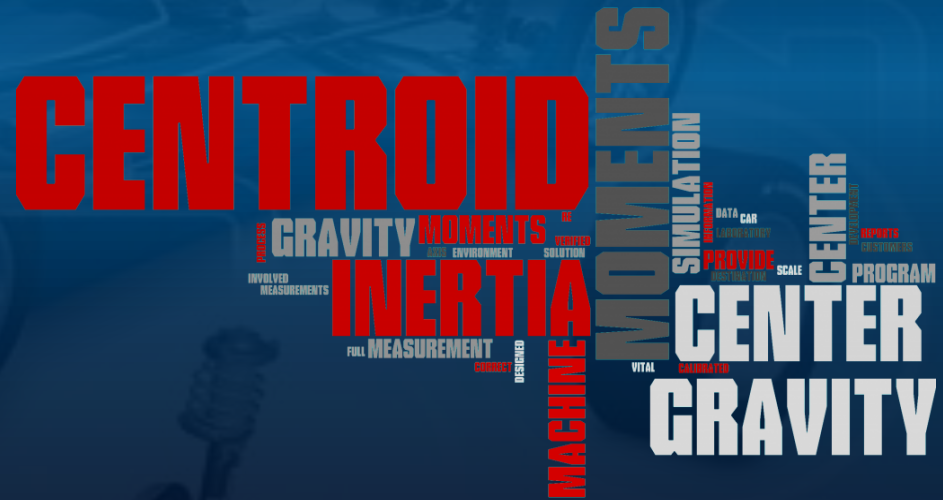
What happens after the K&C test?

- > Morse Measurements is available to answer questions and help with interpreting the data.***
- > Morse Measurements can provide an engineering summary report, highlighting important findings, getting you to “the answer” much faster.***
- > You go fast at the track, much faster!***

Additional Services

➤ CG and Inertia Measurements

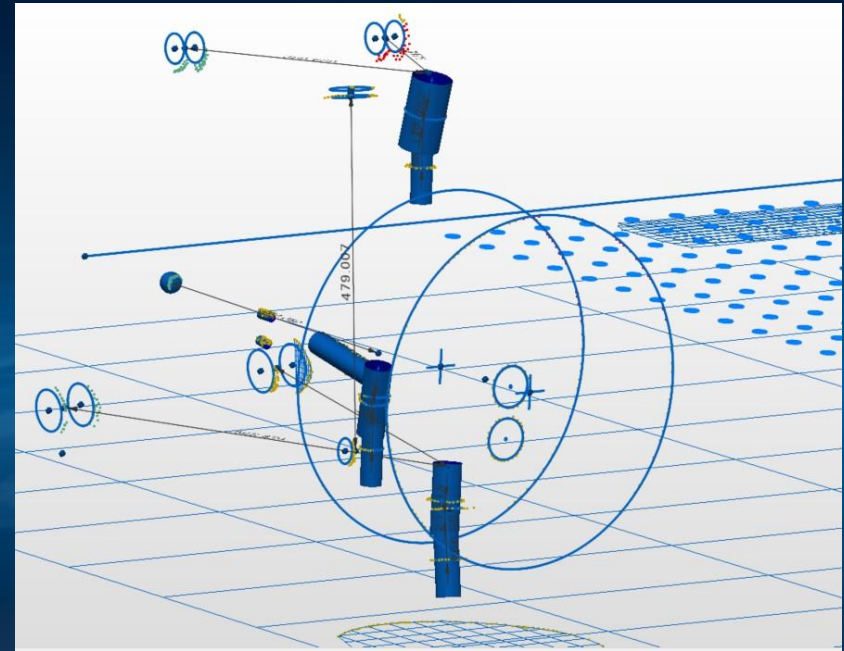
- In partnership with the Aerodyn Centroid facility***
- Full vehicle center of gravity location and principle mass moments of inertia.***

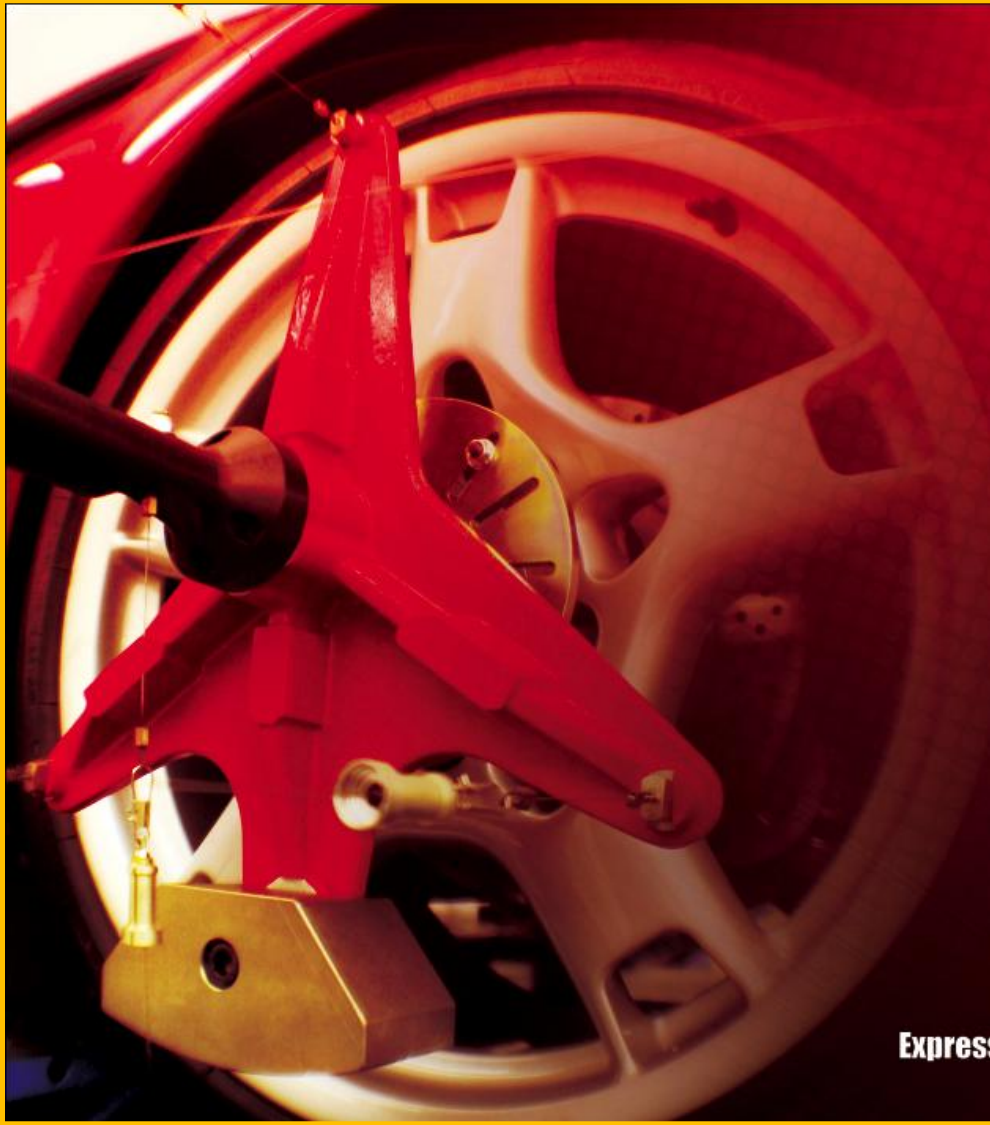


Additional Services

➤ CMM of Suspension Hard Points

- ***Provides (x,y,z) coordinates of all suspension hard points***
- ***Build/Verify kinematic model to compare to K&C data***
- ***Identify differences between chassis***
- ***Identify left-to-right asymmetries***
- ***Measurements with made with car in same position / configuration as K&C. Can directly compare to validate a kinematic model or identify unintended asymmetries***





MAXIMIZING SUSPENSION PERFORMANCE

with

Kinematics and Compliance (K&C) Testing

- Quickly capture all key suspension geometry and stiffness characteristics
- Gain competitive edge through exacting set-up
- Realize your mechanical grip potential

Flexible • Confidential • Fast

MORSE MEASUREMENTS
LLC

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