Heavy Truck Rollover Characterization: New-Generation Single Tires vs. Standard Duals

H. E. (Bill) Knee, Gary Capps and Oscar Franzese
Center for Transportation Analysis
Oak Ridge National Laboratory

Paul Pollock and Daniel Coleman
Dana Corporation

Ibrahim Janajreh, Steven Haas and Norman Frey
Michelin Americas
Research and Development Corporation

E. Harry Law and Eric Johnson
Clemson University

Joe Petrolino and David Rice
National Transportation Research Center, Inc.

2005 International Truck & Bus Safety & Security Symposium November 14-16, 2005

Sponsorship

- **Research Sponsored by a Grant from the Federal Highway Administration (FHWA) to the National Transportation Research Center, Inc. (NTRCI) to conduct laboratory-to-roadside Heavy Vehicle Safety Research.**

- **Heavy Vehicle Safety Research Program initiated in 2002.**
  - **Finite-Element Vehicle-Infrastructure Crash Modeling**
  - **Evacuation Modeling With an Emphasis on Truck Traffic**
  - **Brake Module Enhancement of TruckSim**
  - **Brake Material Characterization (Rust, Humidity, Torque)**
  - **Aftermarket Brake Lining Characterization**
  - **Long-Phosphoring Paint Pigments for Enhanced Conspicuity of Highways and Trucks**
  - **Pulsed UV-Headlights**
  - **Prototype Multi-Plate Performance-Based Brake Tester**
  - **Wireless Brake and Safety System Monitoring and Reporting**
  - **Truck Rollover Characterization**
  - **Correlation of OE and Aftermarket Brake Performance in Laboratory, Test-Track and Field-Testing (NHTSA).**

Approach

- **Instrument a class-8 tractor-trailer with various vehicle dynamics sensors – 79Klbs GVWR. Use of tractor-trailer donated by Dana Corp.**
- **Tilt-table test for static rollover characterization (at UMTRI).**
- **Rollover catalytic maneuvers engaged in at TRC with a professional driver.**
- **Collect vehicle dynamics data for series of tests using combinations of:**
  - **standard duals,**
  - **new-generation singles, and**
  - **wider-slider suspensions on the trailer.**

1999 Peterbilt 379

2004 Wabash dry freight van trailer

Phased Approach

- **Phase 1: Baseline Data Collection - dual tires on the tractor drive axles and trailer axles.**
  - **Selected maneuvers derived from vehicle dynamics sources including ISO standards, SAE papers, etc.**
  - **Maneuvers selected:**
    - **Swept-Sine,**
    - **Evasive Lane Change,**
    - **Constant Radius 150 ft.**
    - **Constant Radius 400 ft., and**
    - **Run-off-the-Road.**

- **Phase 2: Tractor/Box-Trailer Testing**
  - **combinations of new-generation single tires on the tractor and trailer**
  - **involved a van type trailer, with and without a wider-slider suspension.**
- **Phase 3: Tractor/Flatbed/Tanker Testing (FUTURE).**
- **Phase 4: Customized Tractor-Trailer with Low Rollover Propensity (FUTURE).**

Objective of the Research:

- **To form a baseline analysis of tractor/trailer rollover characteristics for further comparative studies**

- **To do a preliminary analysis of the impact of replacing standard duals with next generation single radials.**

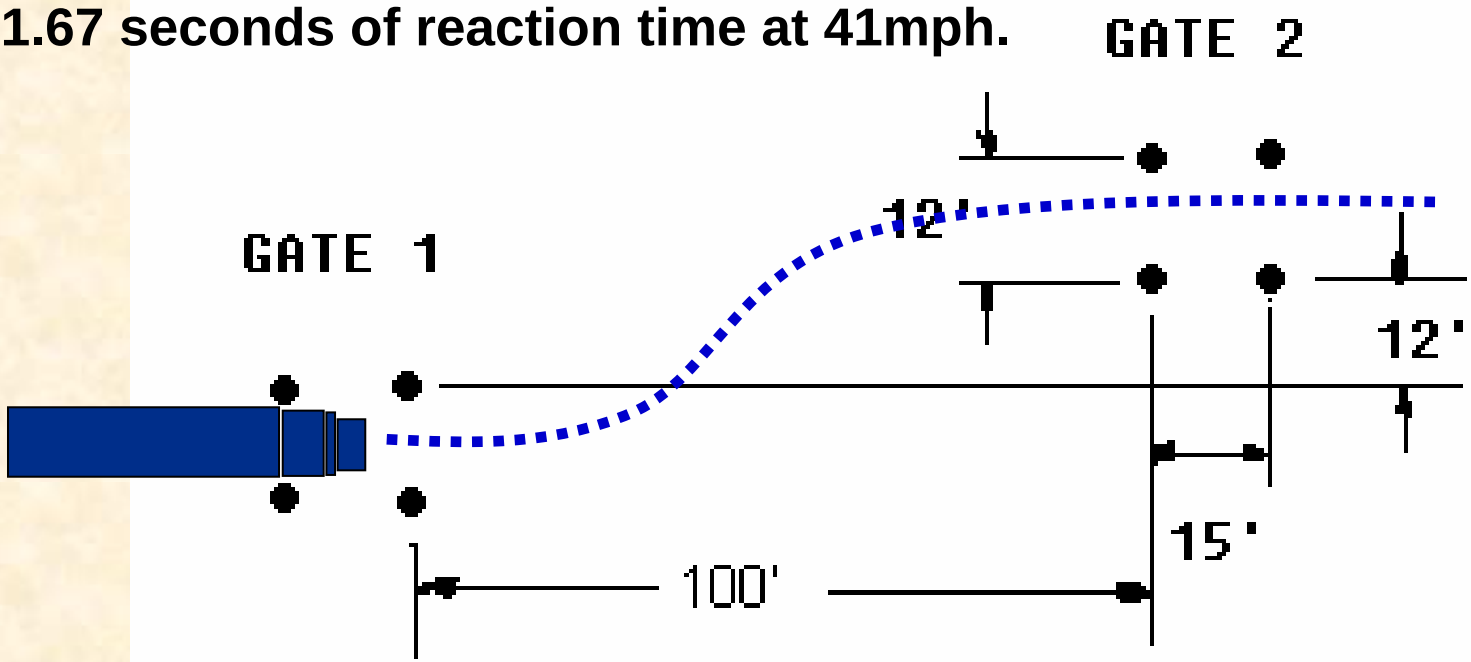
Vehicle Tire Configurations for Phase 1 and Phase 2 Testing

Test Series	Phase	Tractor	Trailer Suspension Type	
			Standard (48 in Box Width)	Wider-Slider (54 in Box Width)
1*	Phase 1	dual	dual	*not used*
2	Phase 2	new-generation single	dual	*not used*
3*	Phase 2	new-generation single	new-generation single	*not used*
4	Phase 2	dual	new-generation single	*not used*
5*	Phase 2	new-generation single	*not used*	new-generation single
6	Phase 2	dual	*not used*	new-generation single

Indicates Tilt-Table Test Performed on This Configuration

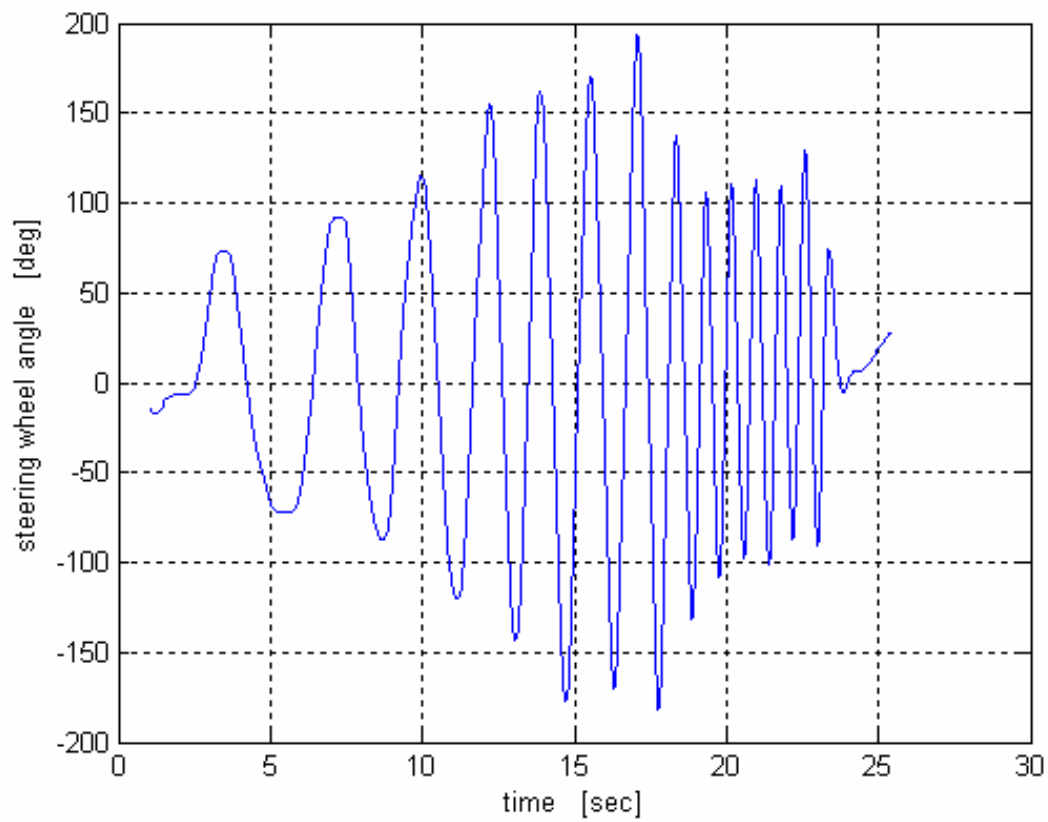
Evasive Maneuver

- **Determine a vehicle's transient response when subjected to a sudden lane change.**
- **Initial run = 41 mph.**
- **Subsequent runs; speed increased by 2mph until wheel lift-off.**
- **1.67 seconds of reaction time at 41mph.**



Swept Sine Maneuver

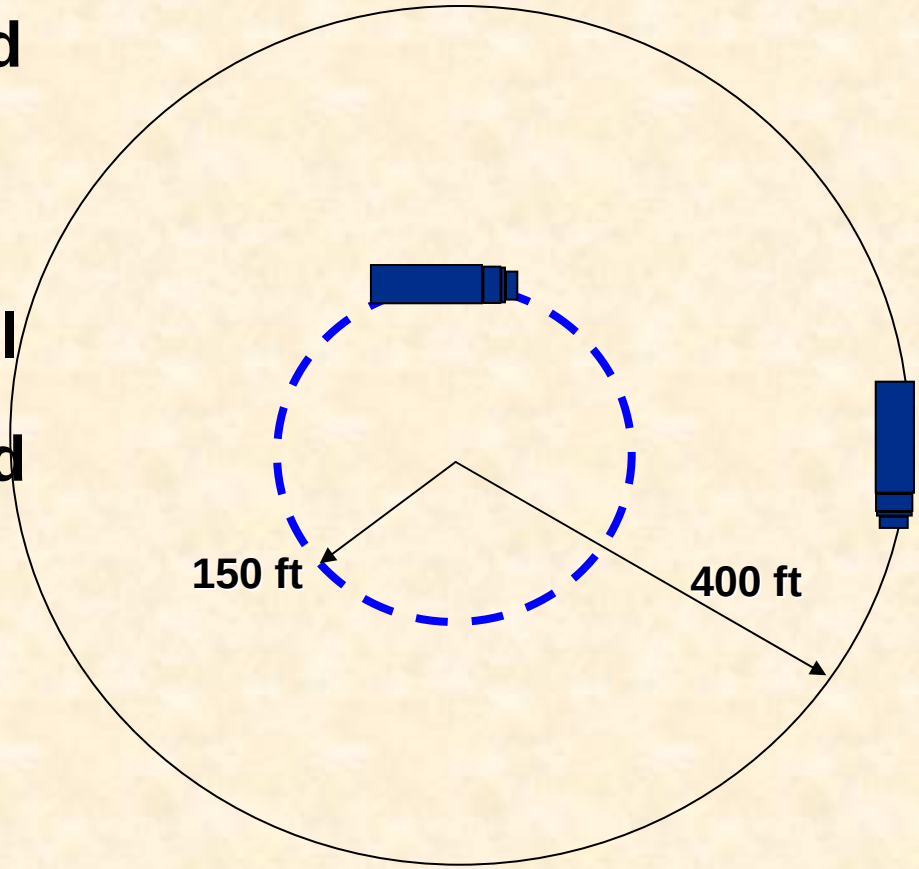
- **Provides information related to the vehicle's frequency response.**
- **Maintain a constant speed of 50 mph throughout the maneuver.**
- **Begin with a sinusoidal steering rate of 0.2 Hz.**
- **Steady increase in sinusoidal steering.**
- **Initial steering direction should remain consistent.**
- **Approximately 25 sec in duration with at least 0.5 sec straight line at the beginning.**



Example of Swept Sine Steering Wheel Input

Steady State Constant Radius Turn - 150 ft Radius and 400 ft Radius

- **Determine the maximum lateral acceleration that could be achieved by a vehicle under steady state cornering conditions.**
- **Negotiate a circular path until the maximum achievable steady state speed is attained and hold for at least one complete lap.**
- **Vehicle speed was increased at a linear rate of 2.5 mph every 15 sec.**
- **The test was repeated in the opposite direction (CCW).**



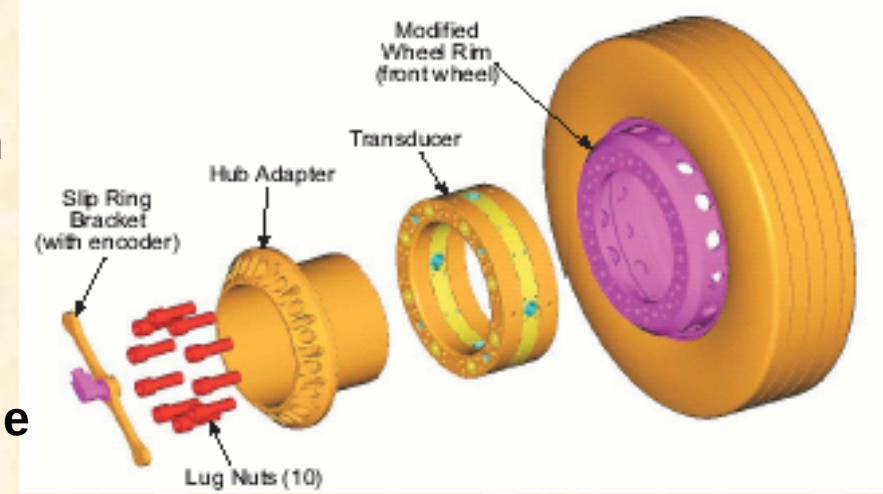
Straight-Line Road Edge Rollover - Step Function

- **to evaluate whether a rollover occurs when the driver simply goes over the edge of the road and encounters a step function between the pavement and the shoulder.**
- **to look at overcorrection effects relative to bringing the vehicle back to the roadway.**
- **travel at a constant speed of 35 mph for 800 ft.**
- **allow the vehicle to drift left at a defined yaw angle until the left tires crossed the road edge.**
- **Subsequently, engage in an aggressive right steer over-correction to direct the vehicle back onto the pavement.**

Major Instrumentation

(most equipment donated by Dana Corp, Michelin and NTRCI)

- **The high-tech instrumentation selected by the research partners offered unique insight into the rollover characteristics of the test vehicles.**
- **Datron DLS optical speed sensor.**
- **Watson DMS-E604 (to dynamically measure lateral acceleration, roll angle, and angular rates.**
- **Oxford RT3100 measured similar parameters at the trailer CG.**
- **PCB accelerometers to assess the lateral accelerations at the rear drive and rear trailer axles.**
- **A SEA steering controller was used to perform robotic steer maneuvers**
- **A fifth wheel load transducer (leased from UMTRI)**
- **String potentiometers were located on the both sides of the vehicle to determine the roll angle between the axles and the sprung mass.**
- **MTS-SWIFT 50T wheel force transducers were installed at the right rear drive axle and right rear trailer axle wheels. Use donated by Dana Corp.**



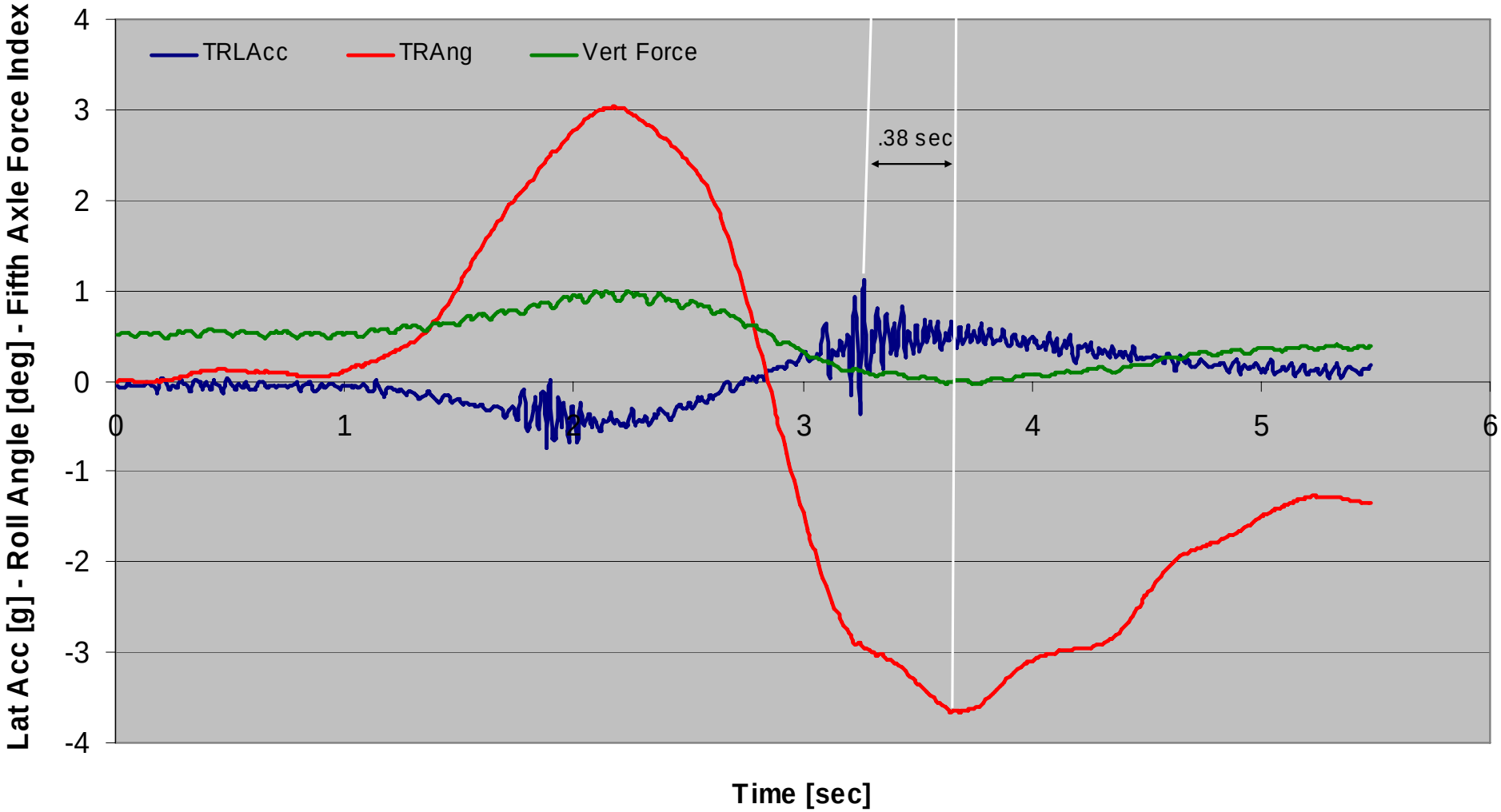
Data Collected

- **1.2Gbytes**
- **45 channels**

- **Vehicle Speed**
- **Lateral Acceleration**
- **Roll Angle**
- **Roll/Pitch/Yaw Rates**
- **X-Acceleration**
- **Longitudinal, Lateral and Vertical Forces**
- **Slip Angle**
- **Overturning Moment**
- **Driving/Braking Moment**
- **Steering Moment**
- **Wheel Angle**
- **Steering Wheel Position**
- **Wheel Lift-Off (axles 3, 4 and 5)**

Evasive Maneuver Discussion - Good Run

(maximum lateral acceleration, lift-off, maximum roll angle)



Sample Results – Evasive Maneuver

- ***Roll Stability Index: Maximum Roll Angle per Maximum Lateral Acceleration***

Series	Roll Stability Index [deg/g]		Percent Difference
	Mean	Std Dev	
1. All Duals	-5.073	0.783	---
2. Tractor – Singles Trailer - Duals	-4.008	1.058	21.01
3. Tractor – Singles Trailer – Singles	-3.791	0.807	25.28
4. Tractor – Duals Trailer – Singles	-4.399	0.940	13.28
5. Tractor – Singles Trailer – Singles Wider-Slider	-3.809	0.658	24.93
6. Tractor – Duals Trailer – Singles Wider Slider	-2.755	0.323	45.70

Evasive Maneuver - *continued*

- **A Trailer Roll Gradient Analysis, Series 5 (rather than series 6) resulted in less roll per unit g than the other series.**
- **Fifth Wheel Roll Moment Sensitivity Analysis, ……series 5 gave the best overall performance in terms of roll moment generation,**
  - **followed somewhat closely by series 6.**
  - **similar results were obtained in analyses of understeer gradient and lateral acceleration.**

Constant Radius – 150 ft

Series	RS [deg/g]	Percent Difference
1. All Duals	-6.981	---
2. Tractor – Singles Trailer - Duals	-5.229	25.09
3. Tractor – Singles Trailer - Singles	-5.591	19.91
4. Tractor – Duals Trailer – Singles	-7.588	-8.70
5. Tractor – Singles Trailer – Singles Wider-Slider	-4.792	31.35
6. Tractor – Duals Trailer – Singles Wider Slider	-2.908	58.34

Conclusions for Evasive and Constant Radius Maneuvers

- **Test results indicated that Series 2 to 6 consistently performed better (except for one case, i.e., Series 4, constant radius test) than the series 1 (standard layout)**
- **Results also indicated that Series 5 and 6 were the best performers of all of the six series analyzed.**
- **Use of wider-sliders for the trailer, improved stability and increased the effective stiffness of the trailer.**

Swept-Sine Maneuver

- **Six frequency response functions (FRFs) to study the frequency range of each of the six test series.**
- **The swept sine test was used, to calculate FRFs for**
  - **yaw rate-to-steering wheel angle (related to the driver's visual perception during the maneuver), and**
  - **lateral acceleration-to-steering wheel angle (related to feedback cues the driver receives from the vehicle).**

- **Results: In general, differences between the test series were small with the exception of the wider-slider configuration (the estimated trailer roll gain was noticeably lower with the wider-slider configuration).**

Overall Conclusions

- **This project has contributed to the understanding of the roll stability and roll characteristics of tractor-trailers engaged in severe driving maneuvers using both standard dual tires and new-generation single tires; and utilizing wider-slider suspensions.**
- **Results suggest that real and significant improvements in roll stability for tractor-trailers are possible via tire and suspension improvements.**
- **The data collected and analyses performed in this project suggests that the performance of new-generation single tires resulted in improved roll stability over the performance of standard dual tires. Wider-slider suspensions added even better roll performance.**

Recommendations

- ***Even small advances in vehicle stability can reduce truck rollover propensity and consequently contribute to the reduction of the heavy truck rollover accident rate.***

- ***Opportunities for increased roll stability:***
  - **Increase track width,**
  - **Decrease payload CG height,**
  - **Decrease tire compliance to limit the lateral translation of the CG,**
  - **Eliminate fifth wheel and spring lash, which appear as free play in the rolling motion,**
  - **Minimize the angular or roll clearance of the roll bump stops for the tractor axles,**
  - **Maximize the roll bump stop clearance for the trailer axles,**
  - **Increase drive axle suspension roll stiffness,**

Recommendations - continued

- ***Opportunities for increased roll stability - continued:***
  - **Reduce lateral compliance (deflection) of the suspension,**
  - **Increase front axle suspension roll stiffness while considering ride quality trade-offs,**
  - **Increase the stiffness of the truck frame allowing the driver to better sense roll motions,**
  - **Raise the suspension roll axis to reduce body roll angle,**
  - **Distribute load among suspensions in proportion to the distribution of roll stiffness,**
  - **Reduce lateral beaming of the vehicle frame,**
  - **Ensure cargo is placed on-center to control lateral displacement of CG, and**
  - **Reduce torsional compliance of the vehicle frame, particularly flat-bed trailers.**

Future Directions

- **Prior proprietary testing of new-generation single tires conducted on vehicles using axles, frames, and suspensions optimized to the dual tire configuration.**
- **Integration of new-generation single tires, wider axles, associated suspensions, wider frames and torsionally optimized frame-rails to get……**
- **…..a vehicle that takes better advantage of the new-generation single tire's stability and space-saving footprint.**
- **Repeat Phases 1 & 2 for a flatbed trailer, a tanker trailer with new-generation single tires and dual tires (Phase 3).**
- **Measure torsional stiffness for all platforms.**
- **Phase 4: develop a modified class-8 tractor with widened frame rails and axles, along with a redesigned suspension and new-generation single tires.**