Overview of Heavy Duty Truck Testing With Comparisons Between Rolling Road/Non-Rolling Road Tunnel Testing and SAE Type II

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Industry Introduction

- The cost of Fuel will continue to rise as the world burns up the natural resource called oil
- Increased Fuel Economy concern growing in Industry and Government
- Current aerodynamic Governmental approval methods are outdated
- Attempted correlation between more accurate testing methods in comparison to current Government sanctioned methods is required
- Wind Tunnel testing offers this opportunity.

Testing Method Introduction

- Rolling Road Wind Tunnel Testing of Heavy Trucks began in 1987 with Sardou in France

- Sardou showed high speed moving ground planes must be used for truck development

- Sardou found it was impossible to find any kind of correlation between stationary and moving ground results

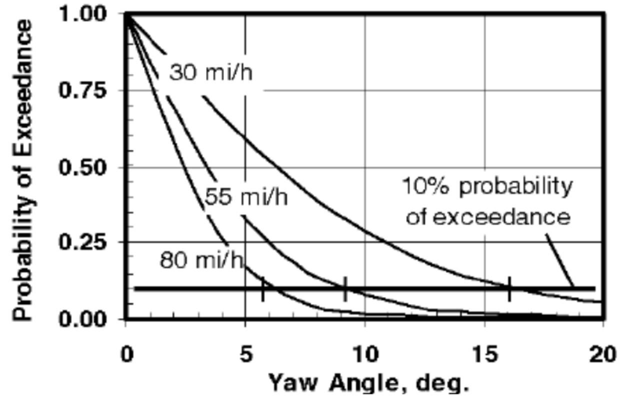
  - Passenger cars generally show a reduction in Cd with a moving road

  - Heavy trucks show an increase in Cd with a moving road

Initial Correlation Issues

- **Wind Average Drag:**
  - ✓ Widely accepted as the method for reporting wind tunnel results (note SAEJ1252)
- **Converting Drag to Fuel Economy:**
  - ✓ Several methods that are not well established
- **Full Scale Ambient Conditions:**
  - ✓ No rigidity in maintaining ambient conditions across test facilities

Wind Averaged Drag



- Graph shows probability of yaw angle versus speed for a heavy truck on the highway (Ref. Cooper)

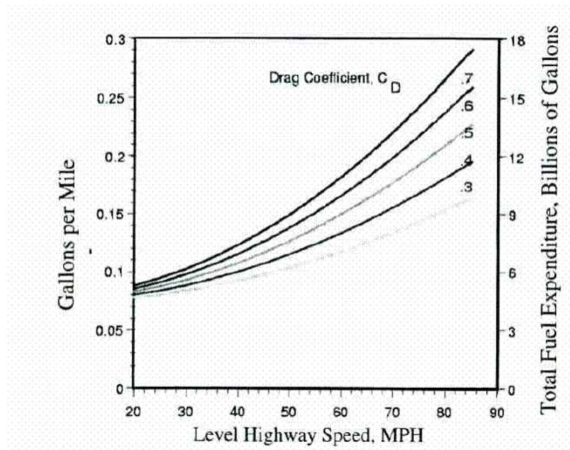
- Based on this graph and SAE J1252, wind averaged drag calculation assumes wind direction is distributed around 360 degrees

- It is very likely that SAE Type II tests have wind coming from only a single direction or at most a single quadrant

  ✓ Unfortunately, this is not measured as standard for the SAE Type II

Converting Drag to Fuel Economy

Vehicle Speed (mph)	Aerodynamic Drag Reduction to Increase Fuel Economy 1%
60	2%
40	3%
20	6%



- LHS table shows that to increase fuel economy by 1% you must reduce aerodynamic drag by 2% (Ref Wood)
    - ✓ A commonly used rule of thumb
- RHS graph illustrates a more defined aerodynamic drag versus fuel economy relationship (Ref McCallen)
    - ✓ ARC uses McCallen's relationship

SAE Type II Ambient Conditions

- **Inconsistent reporting of ambient conditions:**
  - ✓ One test dynamic pressures, another humidity
- **Drastic differences between baseline and test runs:**
  - ✓ One test showed an 8% difference in dynamic pressure
- **Wide variances in final fuel economy figures:**
  - ✓ One skirt manufacturer had 3.8% and 7.3% fuel economy gains
- **Accuracy is +/- 1% under ideal conditions.**

Description of ARC Test Facility

- Scale Model Rolling Road Wind Tunnel
- 6 component load cell balance mounted inside the model
- Balance cradle mounts to strut that mounts to a steel platform
- The steel platform is attached to vibration pads 8 feet into ground
- Model wheels are attached and run on the rolling road
- Rolling road surface roughness matches average US highway/road
- Belt and wind speed are matched to +/- 0.01 m/s
- Turbulence intensity is 0.24%
- Flow angularity is 0.24 degrees
- Boundary Layer is 99.8% FS at 1.0mm off belt at model center

Description of ARC Test Facility Cont.

- Vehicle Model Motion System is mounted inside model
  - ✓ VMMS allows automated pitch, roll, yaw, heave and front wheel steer
- Multi-Port suction system throughout platen to maintain road flatness
- A pneumatic tensioning system is used to eliminate belt edge curl
- Intercooled platen due to heat generation from belt
- A static electricity discharge system eliminates electricity before reaching model
- A three stage boundary layer removal system utilizing suction is in place

Test Procedure – Pretest & Warm Up

- Balance and laser systems are warmed up a minimum of 4 hours prior to test
- Tunnel and data acquisition systems are run for a minimum of 30 minutes prior to test
- The model is inspected for general health following the warm up run
- The tunnel and road system are inspected following the warm up run
- The yaw, heave, roll and pitch positions are all measured and maintained

Test Procedure – General

- Each test series begins with a static weight tare of the model
- Next, a rolling wheel tare is measured for each yaw angle (at test speed)
- The yaw sweep for each run was (0, 9, 6, 3, 0, -3, -6, -9, 0) degrees
- The three 0 deg yaws are used to check "first to last" match and run consistency
- Following the rolling tares, a data run is taken for the full yaw sweep
- All tests are run at a constant dynamic at 50 m/s
- After the data is collected, the tunnel is shut down and a change is made
- Following the model change and/or inspection the general process is repeated

Data Reduction Tools

- AEROTECH 6 component load cell balance: 3 forces and 3 moments
- PSI modules: 124 static pressures recorded
- PI Mistral system: Tunnel parameters recorded
- PI AERO: Displays the raw and reduced data in Excel
- Excel: Summarizes data into a reporting format

Data Reduction Practice

- Measured C_d for yaw angle used to calculate C_{dw} from 22.3 m/s (50 mph) through 33.5 m/s (75 mph)
- Each C_{dw} compared to baseline and a percentage change is calculated
- McCallen's relationship convert s C_{dw} into percentage savings of fuel

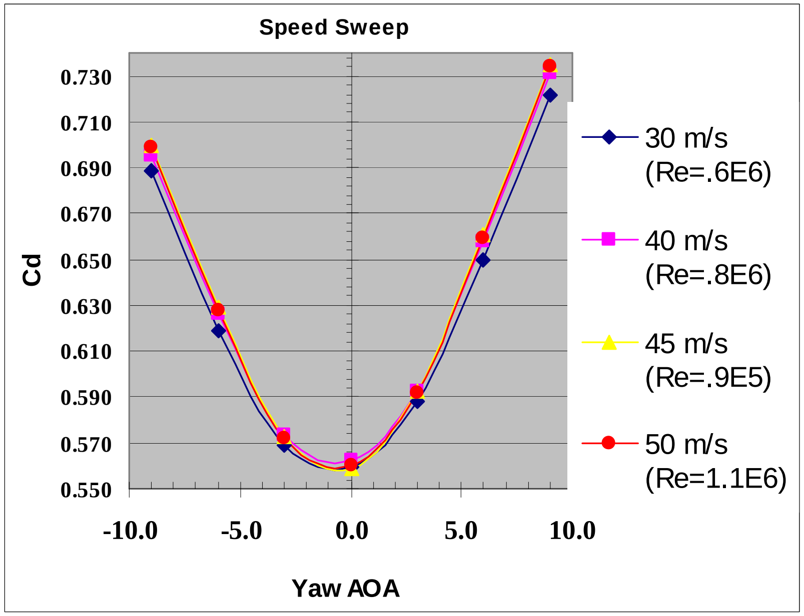
Re Number

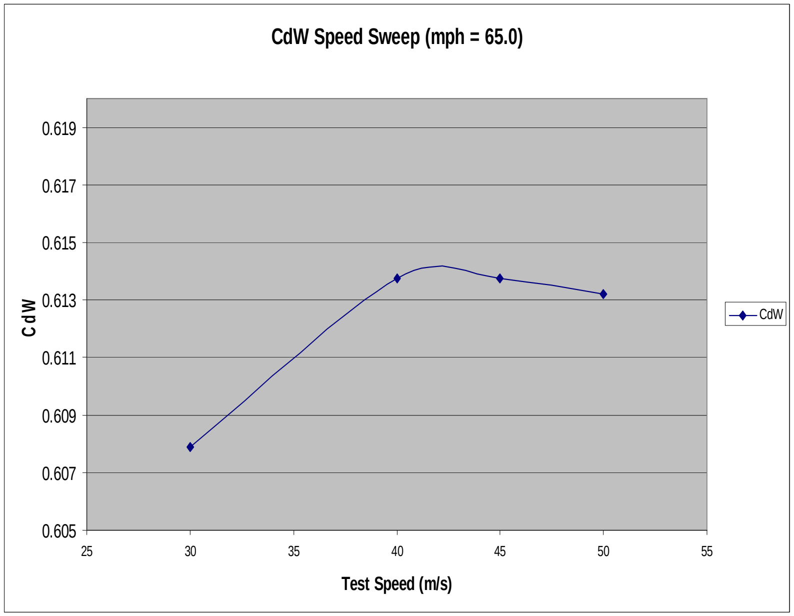
- **SAE J1252** states **Re = 0.7E6** is sufficient for a 1/8 scale model

- **Storms** shows a **Re = 1.1E6** showed little change in the wind averaged drag numbers compared to testing at Re = 7.0E6

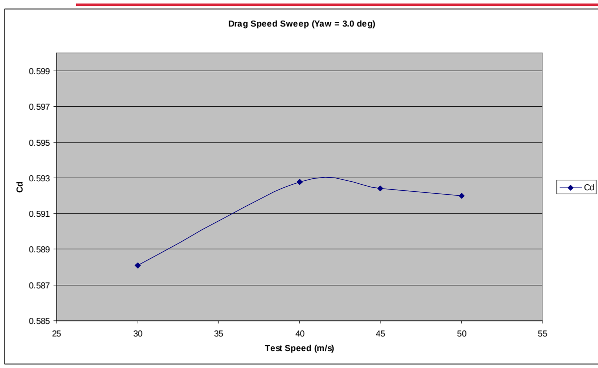
- **ARC** tests at 50 m/s, constant dynamic, using a detailed 1/8 scale model which is a **Re = 1.1E6** using the model's width as a characteristic length

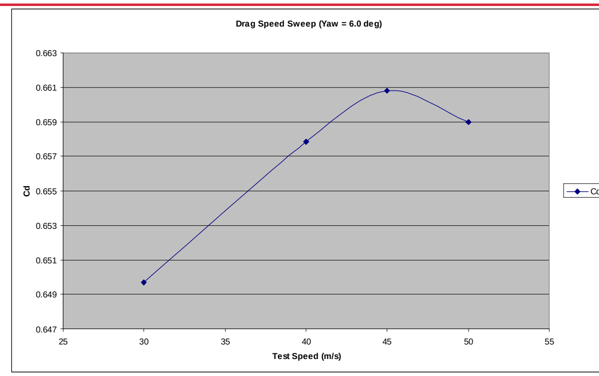
ARC Speed Sweep

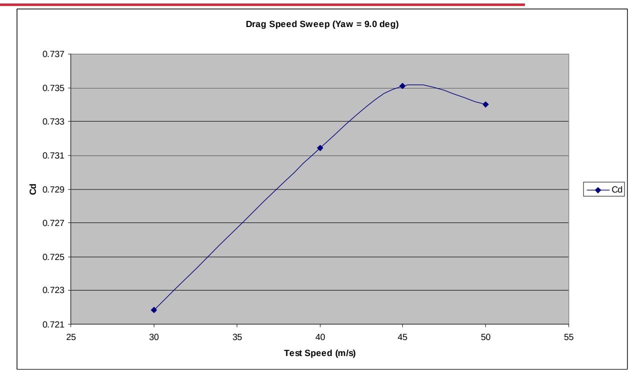


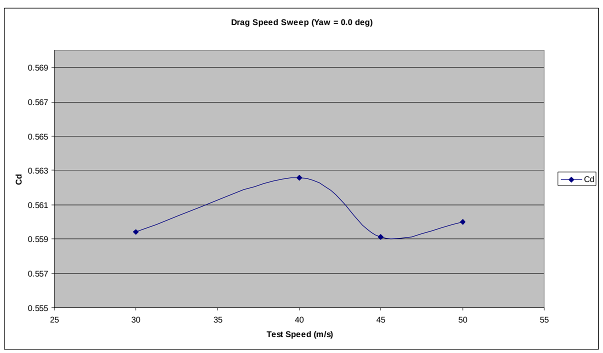


Yaw Dependent Reynolds Effects

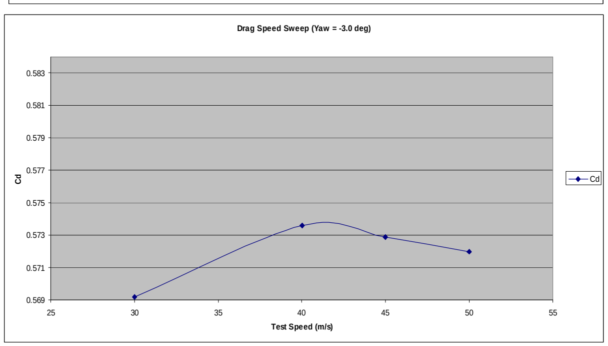


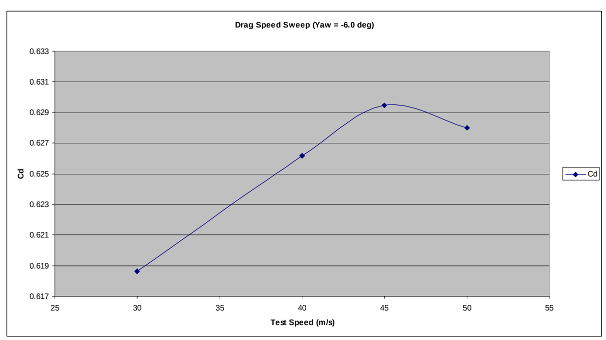


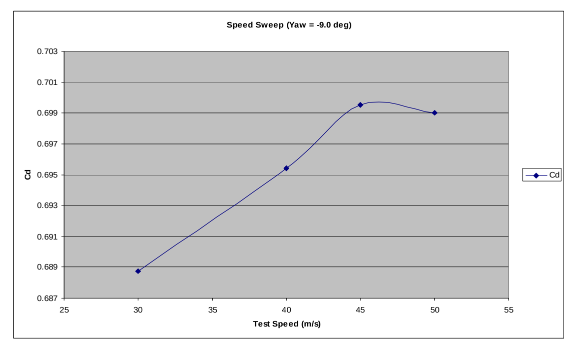




Re is yaw angle dependent!







Description of Test Vehicle

- An 1/8 scale Navistar Prostar sleeper tractor was used in combination with an 1/8 scale 53′ Wabash trailer
  - ✓ Tractor data came from scanning a full scale tractor
  - ✓ Trailer data was provided directly by Wabash
- Articulating Suspension
- 124 pressure taps
- Internal flow modeling through grill, radiator and into engine bay
- Trailer bogey was adjustable for multiple positions

Pictures of Test Vehicle

ARC
AUTO RESEARCH CENTER

Configuration of Test Vehicle

TRUCK SPECIFICATION

- 2008 International Pro-Star Sleeper Premium 6x4
- 270″ Wheelbase
- Full Height Roof Fairing
- Vertical Exhaust
- Full Aero Side Mirrors
- Hood Mounted Mirrors
- Full Length Fuel Tank Covers
- Full Length Fuel Tank Skirts
- Factory Cab Extenders

TRAILER SPECIFICATION

- 2008 Wabash 53′ Dura Plate Dry Van
- 102″ Wide
- Swing Doors
- 36″ King Pin
- Hendrickson Air Ride Suspension
- 13.6′ Height with 1″ Taper
- Sliding Bogey Set to California Position

Configurations Tested

- **Ridge Corp 32″ Greenwing Trailer Skirt**
- **Ridge Corp 36″ Greenwing Trailer Skirt**
- **Ridge Corp 36″ Greenwing Trailer Skirt integral struts**
- **Wabash Trailer Skirt**

Results – Road On/Road Off

Wind Averaged Drag Coefficient at 60 mph			
	Road On	Road off	% Difference
Baseline A	0.623	0.615	1.28%
Configuration 1	0.563	0.554	1.60%
Configuration 2	0.557	0.545	2.15%
Configuration 3	0.554	0.542	2.17%
Baseline B	0.683	0.661	3.22%
Configuration 4	0.620	0.595	4.03%

- Road on results in more drag (not simply a small offset)
- Change to baseline B:
  - ✓ 9″ Tractor/Trailer gap increase
  - ✓ Mud flaps moved to trailer's bumper

Results – Road On/Road Off

Wind Averaged Drag Coefficient at 60 mph			% Difference to baseline	
	Road On	Road off	Road On	Road Off
Baseline A	0.623	0.615		
Configuration 1	0.563	0.554	-9.63%	-9.92%
Configuration 2	0.557	0.545	-10.59%	-11.38%
Configuration 3	0.554	0.542	-11.08%	-11.87%
Baseline B	0.683	0.661		
Configuration 4	0.620	0.595	-9.22%	-9.98%

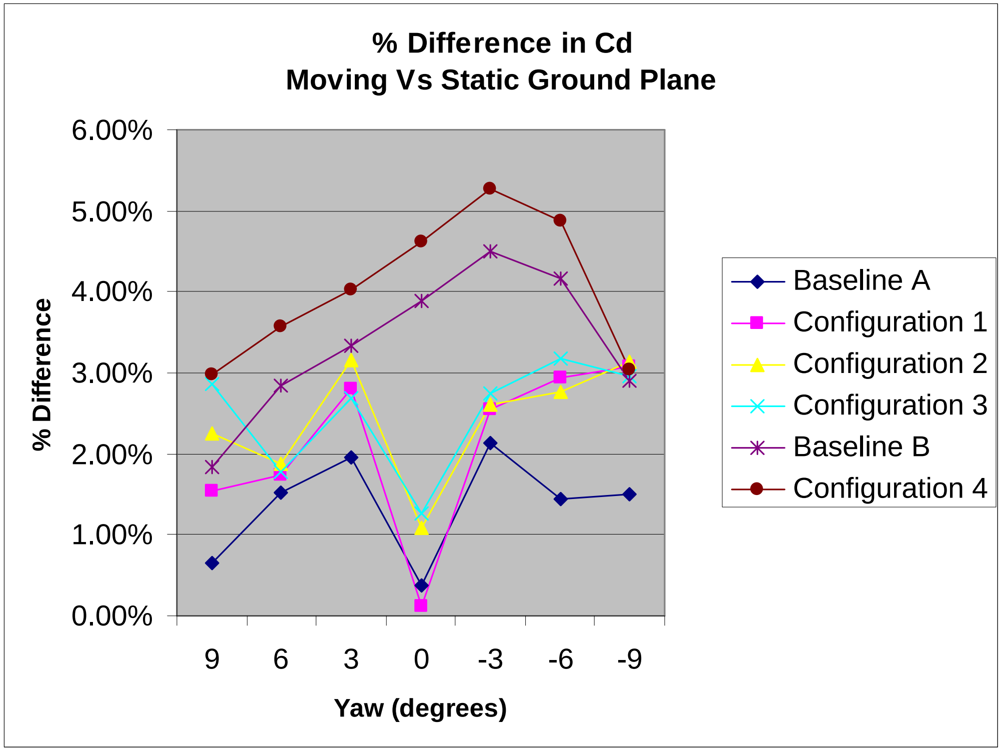
- Road off shows larger difference to baselines
- Road off appears overly optimistic compared with road on results

Results – SAE Type II

Device Tested	SAE Type II	WT (rolling road)	WT (non-rolling road)
Configuration 1	4.0%	4.8%	4.97%
Configuration 2	5.2%	5.31%	5.69%
Configuration 3	5.1%	5.54%	5.94%
Configuration 4	5.6%	4.62%	4.99%

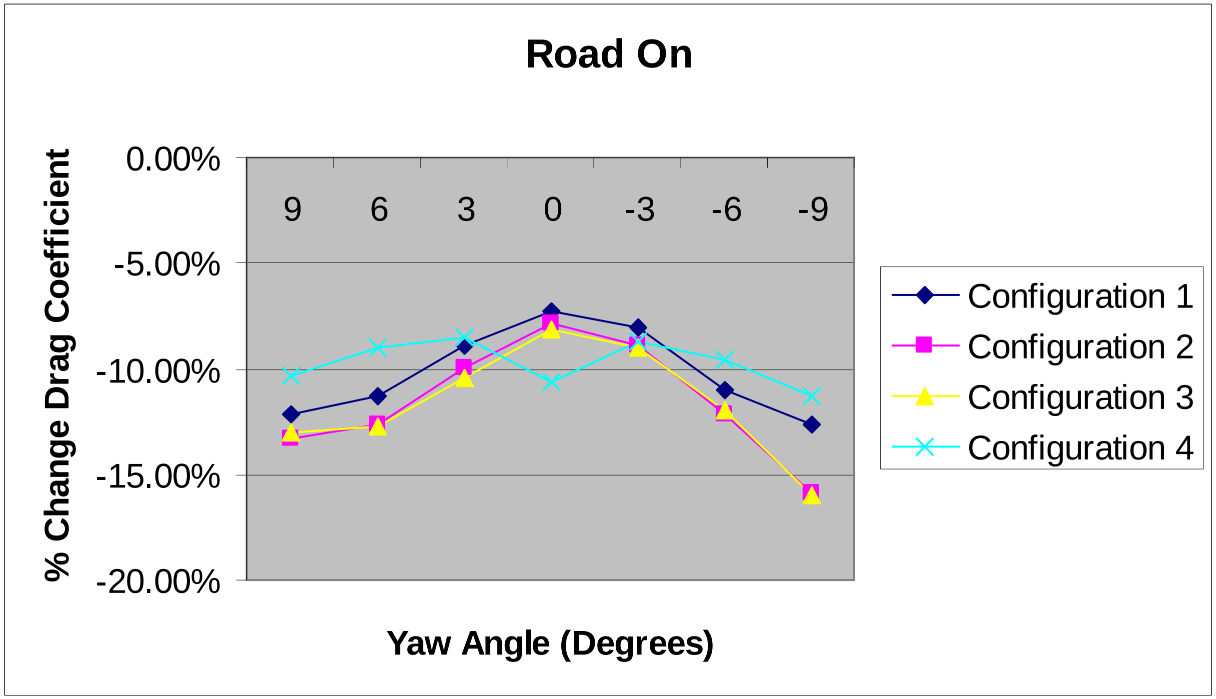
- Results are in directional agreement
- Road on & off over predict SAE Type II in 3 out of 4 cases

Results – Yaw Sweep Analysis



- Deltas vary throughout yaw range
- Baseline B shows a hysteresis effect where Baseline A does not

Results – Yaw Sweep Analysis



- Asymmetry in relation to yaw angle
- Wind averaged drag calculation assumes a somewhat evenly distributed wind direction around 360 degrees, these asymmetries could also be playing a role with making tunnel comparisons to SAE Type II testing difficult

Conclusions

- C_{dw} takes into account the average of all cross flows a tractor/trailer could see (over 360 degrees). Wind tunnel comparisons to SAE Type II testing can be skewed.
- The interaction between the tractor/trailer and the moving ground plane is complex. It must be independently tested for each case of interest.
- The static ground plane appears to overestimate aerodynamic improvements compared to the rolling road testing.
- With some baselines a hysteresis effect can be measured throughout the yaw range. Trailer skirts do not change this hysteresis effect, but simply offset it.
- Tractor/Trailer combinations have a Re dependency that is a function of yaw angle. This yaw angled Re dependency shows that simply listing one minimum Re to define the testing of Class 8 Trucks is not appropriate.

Future Work

- C_{dw} – Improve calculation to increase correlation opportunities
- Draw comparisons for other "Add-On" devices
- Use CFD to explore the localized flow around the yawed rolling wheels
- Understanding why some configurations have a hysteresis
- Re dependency study relating to model changes