# Development of Multi-axle Semitrailers in Ontario

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# Ontario in North America

# Trucking in Ontario

- 38% of Canada's population live in Ontario
- 50% of truck trips in Canada travel in Ontario
- One third of large trucks are from another jurisdiction
- 3.5 million trucks cross the Ontario - US border per year, or one every 9 seconds

# Advent of Multi-axle Semitrailers

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# Ontario Bridge Formula, 1970

- Reflected the actual capacity of bridges
- Became the axle and gross weight regulation
- Increased weight from 33,000 to 63,500 kg
- Intended to make Ontario more competitive
- No restrictions on
  - Configuration
  - Number, type or location of axles

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# What was Expected ………

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# What Emerged .........





Lots of liftable axles !

# Metrication, 1978

- The bridge formula was quickly found too complicated to enforce
- A legislated tolerance was added to allowable axle weights
- New tables for allowable gross weight rounded bridge formula values up
- Weights increased 5-8%
- No configuration controls, though the tables implicitly encouraged B-trains over A-trains

# 48 ft Semitrailers, 1984

- Adopted by US in 1982
- Ontario matched this in 1984, to allow free movement of tandem semitrailers across the border
- The extra length allowed one more axle on a semitrailer

# More New Configurations ……

For Ontario





For Ontario into Michigan

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# National Harmonization

# National Initiative

- Diverse increases in weight by provinces
- Provincial Committee on Vehicle Weights and Dimensions formed, 1975
- Bridge studies led to road and bridge improvements, 1975-85
- CCMTA/RTAC Vehicle Weights and Dimensions Study, 1984-86
- National Memorandum of Understanding on Vehicle Weights and Dimensions, 1988

# Ontario Response, 1989

- Public pressure prevented increases in semitrailer and double trailer length
- Industry pressure prevented phase out of liftable axles
- M.o.U. configurations were accommodated at existing lengths
- Ontario became a barrier

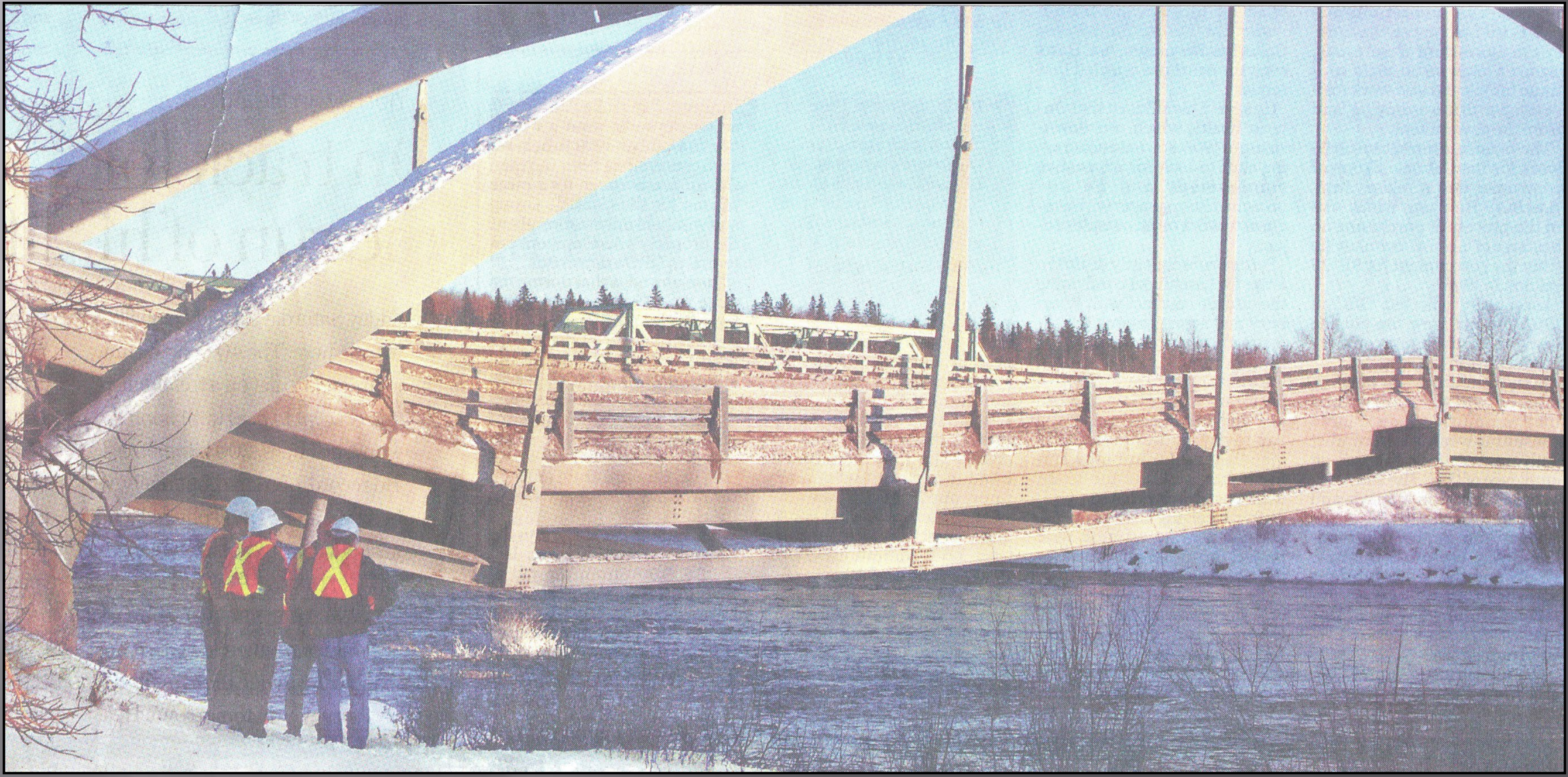
# 53 ft Semitrailers

- Standard in the US by the early 1990's
- More pressure on Ontario
- Adopted in 1994, with 25 m (82 ft) doubles
- Detailed configuration specifications per the M.o.U.

# Eastern Provinces Harmonization

- Agreed to eliminate liftable axles, 1995
- Scuttled by industry in Ontario
- Other five provinces proceeded
- Led to infrastructure and freight studies
- Interpretation of the infrastructure study showed trucks with liftable axles were costing Ontario $300 million (Cdn) per year in highway maintenance and rehabilitation

# Increasing Rate of Bridge Failure



# Reform of Weights and Dimensions

# Scope

- Regulation of legal trucks
- Pilot programs introduced
- Permits introduced for operation of special truck configurations

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# Reform for Legal Vehicles

- Phase 1, effective 1 January 2001
  - Defined "Safe, Productive and Infrastructure-friendly" (SPIF) trailers
  - Introduced self-steer tri-axle and self-steer quad
  - Reduced the allowable gross weight of tri-axle semitrailers from 2006
- Phase 2 , effective 1 July 2002
  - Required dump semitrailers built after 2002 to meet SPIF standards

# SPIF - Safe Productive Infrastructure-Friendly


Self-steer tri-axle


Self-steer quad

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# Reform for Legal Vehicles

- Phase 3, 2006
  - Other multi-axle semitrailers with liftable axles
  - Doubles
- Phase 4, 2011
  - Straight trucks
  - Truck-trailer combinations
  - Everything else

# Phase 3 Scope

- Assessment by computer simulation of the dynamic performance of:
  - Existing multi-axle semitrailers
  - Candidate SPIF multi-axle semitrailers
- Test two 5-axle semitrailer configurations
- Doubles already  addressed by M.o.U.

# Ontario Configurations for Operation in Ontario


# Ontario Configurations for Operation into Michigan


# Michigan Configurations that Operate into Ontario

27 Others (9%)


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# Simulation Methodology

- Yaw/roll program
  - Compute responses to a standardized input
  - Compute performance measures
  - Compare these to performance standards
- Performance measures
  - Static roll threshold, high-speed offtracking
  - Load transfer ratio, transient offtracking
  - Low-speed offtracking, rear outswing, friction demand, lateral friction utilization, maximum self-steer angle

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# Dynamic Performance of Existing Configurations

| Config | Lift Axles | SRT (g) | HSOT (m) | LTR | TOT (m) | LSOT (m) | RO (m) | FD |
|---|---|---|---|---|---|---|---|---|
| | | >0.4 | <0.46 | <0.6 | <0.8 | <5.6 | <0.2 | <0.1 |
| 12S113 | Down | 0.39 | 0.53 | 0.60 | 0.81 | 4.00 | 0.10 | 0.68 |
| 12S113 | Up | 0.36 | 0.64 | 0.57 | 0.76 | 5.16 | 0.03 | 0.14 |
| 12S131 | Down | 0.39 | 0.56 | 0.58 | 0.79 | 4.00 | 0.09 | 0.61 |
| 12S131 | Up | 0.33 | 0.61 | 0.70 | 0.91 | 4.18 | 0.25 | 0.11 |
| 12S114 | Down | 0.43 | 0.48 | 0.59 | 0.78 | | | High |
| 12S114 | Up | 0.38 | 0.57 | 0.54 | 0.69 | 4.98 | 0.06 | 0.07 |
| 12S141 | Down | 0.43 | 0.51 | 0.61 | 0.86 | | | High |
| 12S141 | Up | 0.37 | 0.55 | 0.67 | 0.86 | 4.06 | 0.24 | 0.10 |

# Candidate Configurations

- Based on existing trailer configurations
- A self-steer axle replaced a rigid liftable axle
- Axle weights were equalized
- Axle spacings and spreads were adjusted to:
  - Satisfy the bridge formula
  - Balance the vehicle
  - Retain current gross weight
- Self-steer axles with:
  - Low, medium, or high centring force, or locked
  - Single or dual tires

# Candidate Configurations

- Configurations for operation in Ontario
  - 12S131
  - 12S113
  - 13S13
- Configurations for operation into Michigan
  - 12S141
  - 12S114

# Dynamic Performance of Candidate Configurations

| Config | SRT (g) | HSOT (m) | LTR | TOT (m) | LSOT (m) | RO (m) | FD | LFU | MSS (deg) |
|---|---|---|---|---|---|---|---|---|---|
| | >0.4 | <0.46 | <0.6 | <0.8 | <5.6 | <0.2 | <0.1 | <0.8 | <20 |
| 12S113 | 0.43 | 0.54 | 0.54 | 0.72 | 5.07 | 0.04 | 0.23 | 0.58 | 19.6 |
| 12S131 | 0.43 | 0.53 | 0.57 | 0.75 | 3.98 | 0.17 | 0.22 | 0.54 | 17.6 |
| 12S114 | 0.43 | 0.47 | 0.54 | 0.68 | 5.02 | 0.04 | 0.24 | 0.54 | 22.5 |
| 12S141 | 0.42 | 0.49 | 0.59 | 0.77 | 3.44 | 0.31 | 0.29 | 0.53 | 19.8 |
| 13S13 | 0.41 | 0.49 | 0.52 | 0.64 | 5.15 | 0.04 | 0.12 | 0.79 | 17.1 |

# Preferred Configuration for 12S113 and 12S114

- Self-steer axles:
  - Need low centring force
  - As close as possible to each other
  - As close as possible to the fixed axles
  - Need at least 25 deg of steer
  - Do not need to be locked at high speed

# Preferred Configuration for 12S131 and 12S141

- Fixed axles moved rearward between self-steer axles
- Self-steer axles need:
  - Low centring force
  - At least 25 deg of steer
- Rear self-steer axle should be locked at high speed, and should lock and unlock automatically with speed

# Issues for Test Program

- Validity of the warrant for the friction demand performance measure?
- Actual high-speed offtracking?
- Self-steer capability?
- Need to lock self-steer axles at high speed?
- Can self-steer axles introduce hazards not found on existing trucks?
- Can we trust the computer simulation?

# Configuration 12S113


5,452 kg 18,125 kg 15,176 kg 22,900 kg

- Gross weight 61,653 kg
- Single tires on self-steer axles
- 28 deg self-steer

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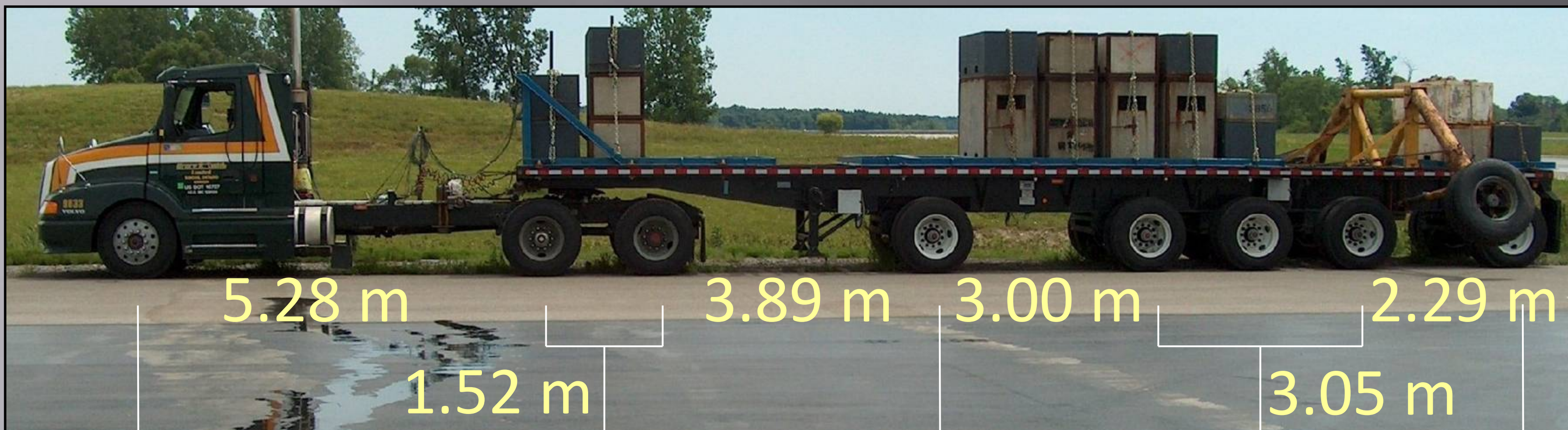
# Configuration 12S131



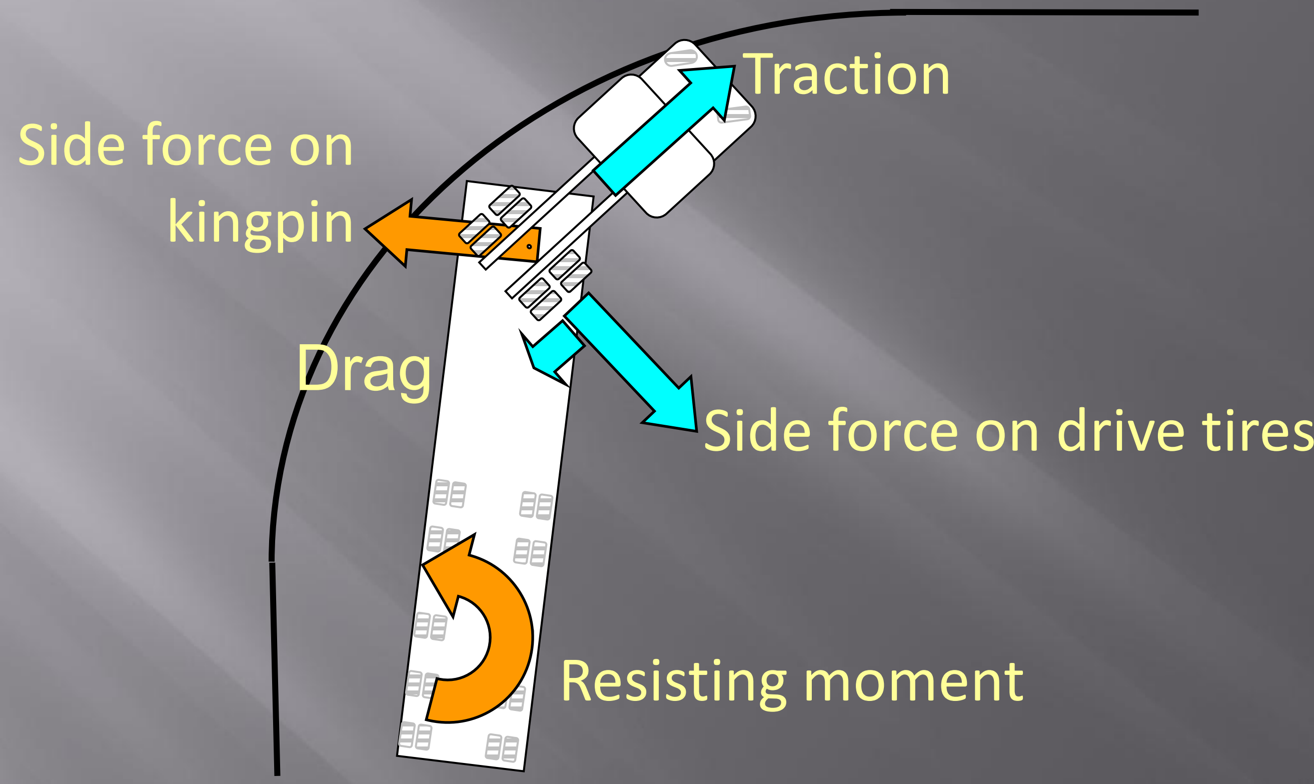

5,447 kg 17,998 kg 7,692 kg 22,666 kg 7,692 kg

- Gross weight 61,494 kg
- Dual tires on self-steer axles
- Nominal 20 deg self-steer, actually 18 deg

# Test Program

- Low-speed turns on a low-friction surface
- Low-speed turns on real streets
- 0.2 g turn on 30.5 m radius
- 0.2 g high-speed turn
- SAE J2179 lane changes
- SAE J2179 lane changes at twice amplitude
- Provoked steer inputs to self-steer axles

# Friction Demand




Friction demand = $\frac{\text{Side force on drive tires}}{\text{Vertical load on drive tires}}$

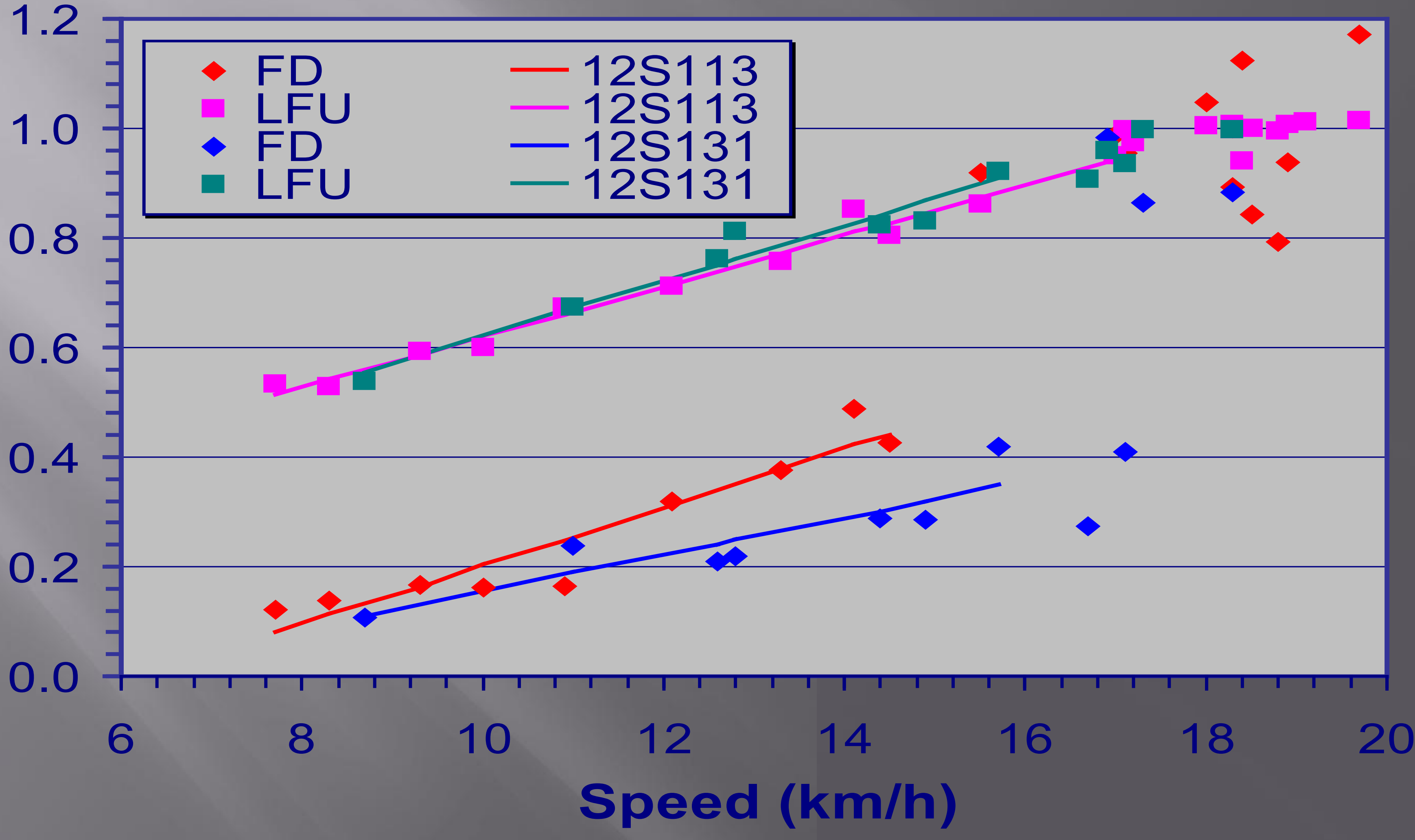
# Friction Demand

- High friction demand might lead to a jackknife in a low-speed turn
- Performance standard was set at 0.1
- Previous tests could not provoke a jackknife
- Tridems operate at 0.12 to 0.20, self-steer quads up to 0.25
- These trucks do not seem to jackknife
- Candidate trucks had higher friction demand

# Friction Demand Test

- Low-speed turns on a low-friction surface
- Friction demand set by adjusting the centring force or locking the self-steer axles
- Driver, data, and simulations all agreed that low self-steer axle centring force was best
- Both configurations jackknifed or ploughed out, but at speeds far higher than any driver would consider for a turn in such a truck

# Friction Demand and LFU from Simulations of Test Runs



# Friction Demand

- Friction demand depends on the self-steer axle settings, turn radius, and speed
- Carriers adjust self-steer axles for low friction demand to reduce tire wear
- Drivers choose a turn radius and speed that allows an easy (low friction demand) turn
- The friction demand performance measure did not appear strongly related to safety

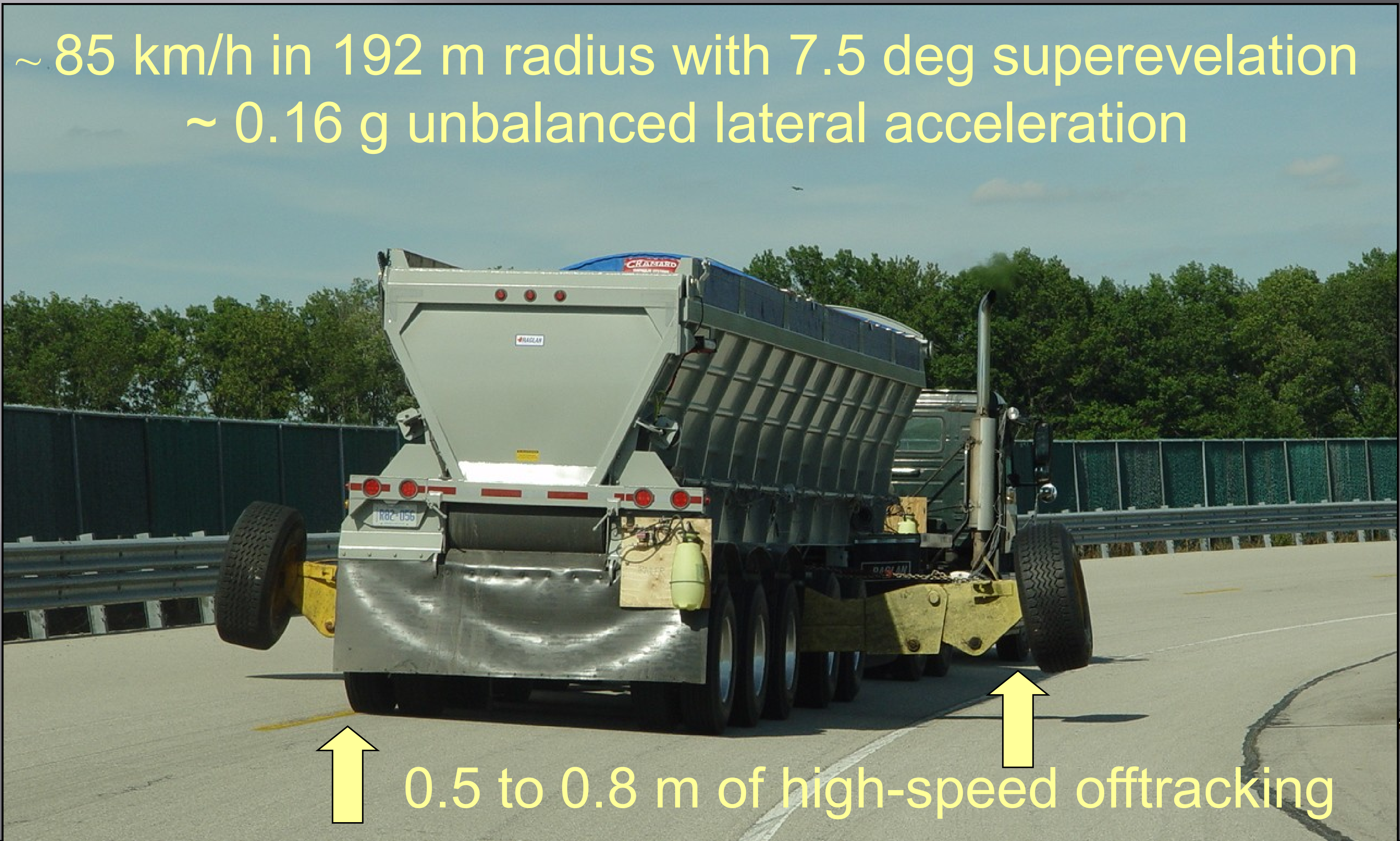
# Self-steer Capability

- Drove around interior roads at test site
- Configuration 12S113 had 28 deg of self-steer
  - Plenty
- Configuration 12S131 had only 18 deg of self-steer
  - Marginal
  - More would reduce the risk of bottoming

# Actual High-speed Offtracking

- Warrant for performance standard is a curb strike, possibly causing a tripped rollover
- Performance standard of 0.46m leaves 0.08 m clearance for a vehicle is centred in its lane
- Test in 0.2 g turns showed:
  - Inward offtracking at 27.5 km/h in a 30 m radius
  - Outward offtracking at 80 km/h in a 250 m radius
- High-speed offtracking was typical for self-steer quads

# Actual High-speed Offtracking



# Actual High-speed Offtracking

- No outward offtracking at speeds typical on urban roads, which have curbs
- High-speed offtracking appears critical on roads with a speed limit of 80 km/h, which typically do not have curbs
- It is not significant on freeways, which have a design speed of 120 km/h or more

# The Need to Lock Self-steer Axles at High Speed

- Lock allowed about 1 deg of free play
- Locking both self-steer axles of 113 trailer, or front axle of 131 trailer, had no evident effect
- Locking rear self-steer axle of 131 trailer moderated both high-speed and transient offtracking
- A tight lock would be more effective

# Potential Hazards of Self-steer Axles

- Braked wheels on one side of self-steer axles to provoke self-steer, then ran off road
- Ran one wheel over speed bump
- Experienced lock-up and hard-over of both self-steering axles of 113 trailer during test
  - No problem for driver to maintain control
  - A 2S/1M ABS mitigates this risk
- Shimmy, if kingpin inclination not controlled

# The Fidelity of the Computer Simulation

- Measured steer angle and speed from test fed as inputs into simulation
- Simulation responses reflected:
  - Both gross and small steer inputs seen in test
  - Changes in test vehicle parameters
  - Differences between test vehicles

# Implementation

- All candidate configurations were defined in regulation, effective 1 January 2006
  - Self-steer angle based on offset from fixed axles
  - ABS on all axles
  - Split braking system
- Weight reductions for non-SPIF semitrailers built after 2005
- Weight reductions for all non-SPIF semitrailers from 2016

# Thank you for your attention!

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