PATH Progress on Truck Platoons and Bus Steering Guidance

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Outline

- **Truck Platoon Progress – emphasis on longitudinal control**
  - **Basic assumptions**
  - **Experimental results**
  - **Lessons learned**
- **Transit Bus Steering automation**
  - **Basic assumptions**
  - **Experimental results**
- **Further development needed**

Truck Platoons - Underlying Assumptions

- **Full automation of truck driving, without driver intervention**
  - **Avoid ambiguities about driver responsibility**
  - **Avoid driver errors**
  - **Ensure consistent vehicle behavior**
- **Automated driving on dedicated, physically protected lane(s)**
  - **Avoid hazards created by manual drivers**
  - **Ensure all vehicles behave consistently and predictably**
  - **Smooth traffic flow, at high capacity**
  - **Enable very short spacings to save energy**
- **Vehicle-Vehicle communication for cooperation**

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Cummins
C-Celect+
Engine ECU
Vehicle-to-Vehicle Communication System
WABCO "Euro" EBS
Accelerometer and
Gyroscope
Steering Actuator
PATH
Lidar and Radar Sensors
PC104 Control Computer
Magnetometer Sensor Array Bar

Accurate Longitudinal Control Results

- **Truck following speed profile command**
  - **Speed errors less than 0.5 m/s**
  - **Position errors generally less than 1 m**
- **Robust to loading variations**
- **Experimental verification:**
  - **Accurate longitudinal control of truck platoons, coordinated via 802.11 and 5.9 GHz DSRC wireless**
  - **Integrated control of WABCO EBS, compression brake and transmission retarder**
  - **Direct measurements of fuel and emissions**
  - **Smooth manual/automatic/manual transitions**
  - **Limited fault detection and identification**

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2-Truck Platoon Tests (3, 4 and 6 m gaps)

Aerodynamics of Class-8 Tractor-Trailer Trucks

- **PATH research led by Prof. Fred Browand, USC**
- **Scale-model tests in wind tunnel, then full-scale tests on track, directly measuring fuel use**
- **Measuring effects on aerodynamic drag of:**
  - **Separation between trucks (primary purpose)**
  - **Cross-wind components**
  - **Tractor-trailer spacing**
- **Strong effects seen on separation between trucks and on shape of front of truck**

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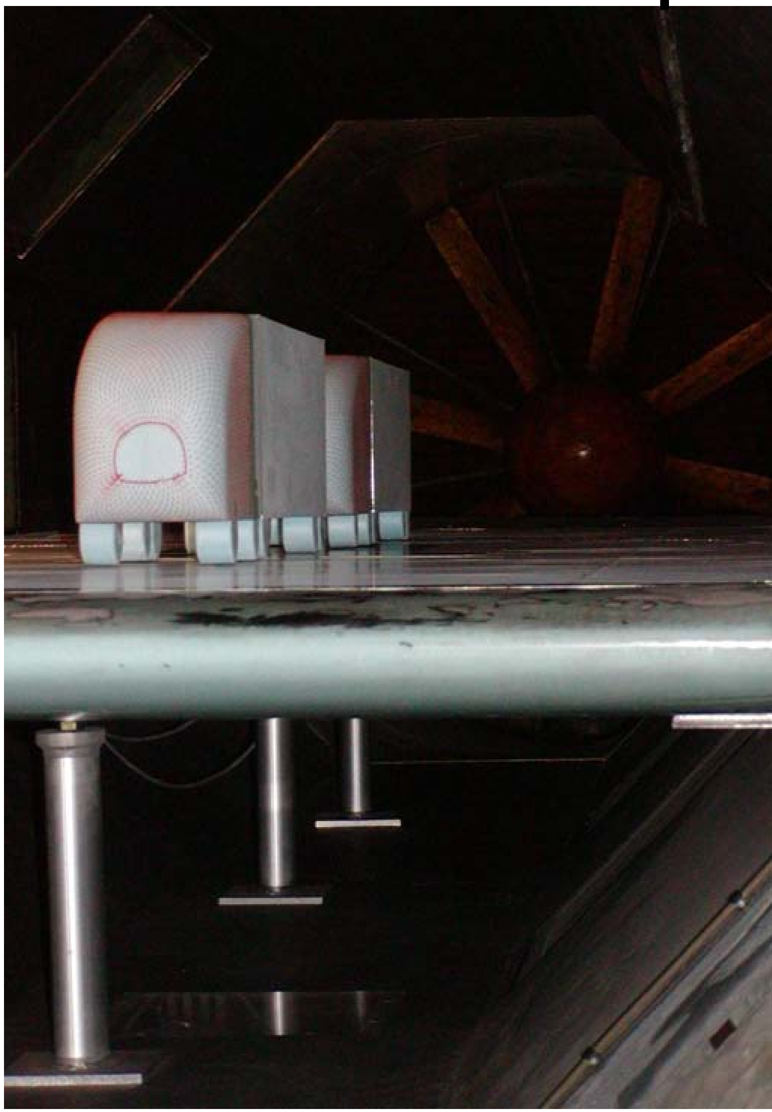
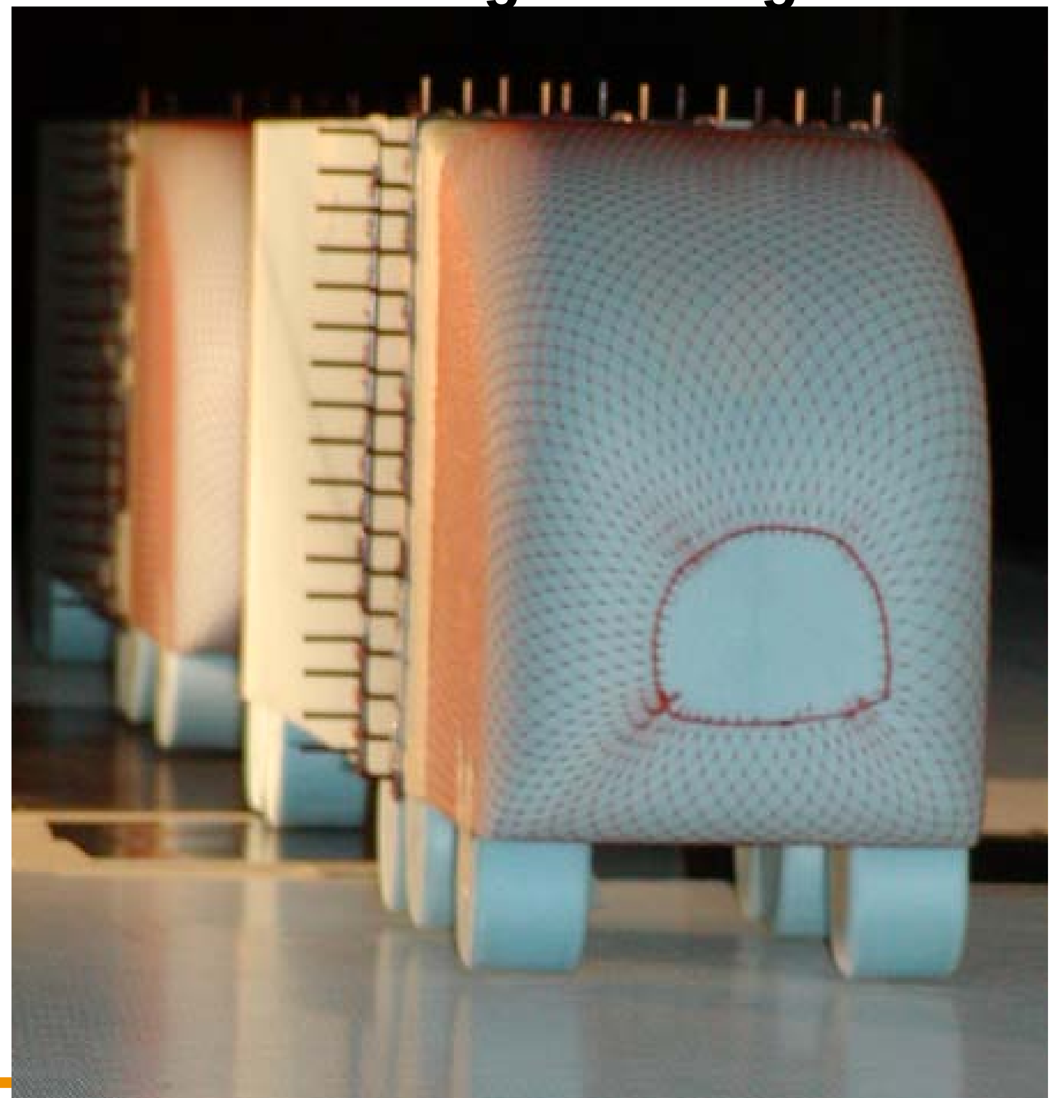
Wind-Tunnel Truck Models

- **Note blunt front comparable to cab-over-engine design tractor**





Contrast in Gaps for Truck Tractors

Cab-over-engine (European units could be only 2 m long)

Engine-forward with Sleeper cab – Typical in U.S.

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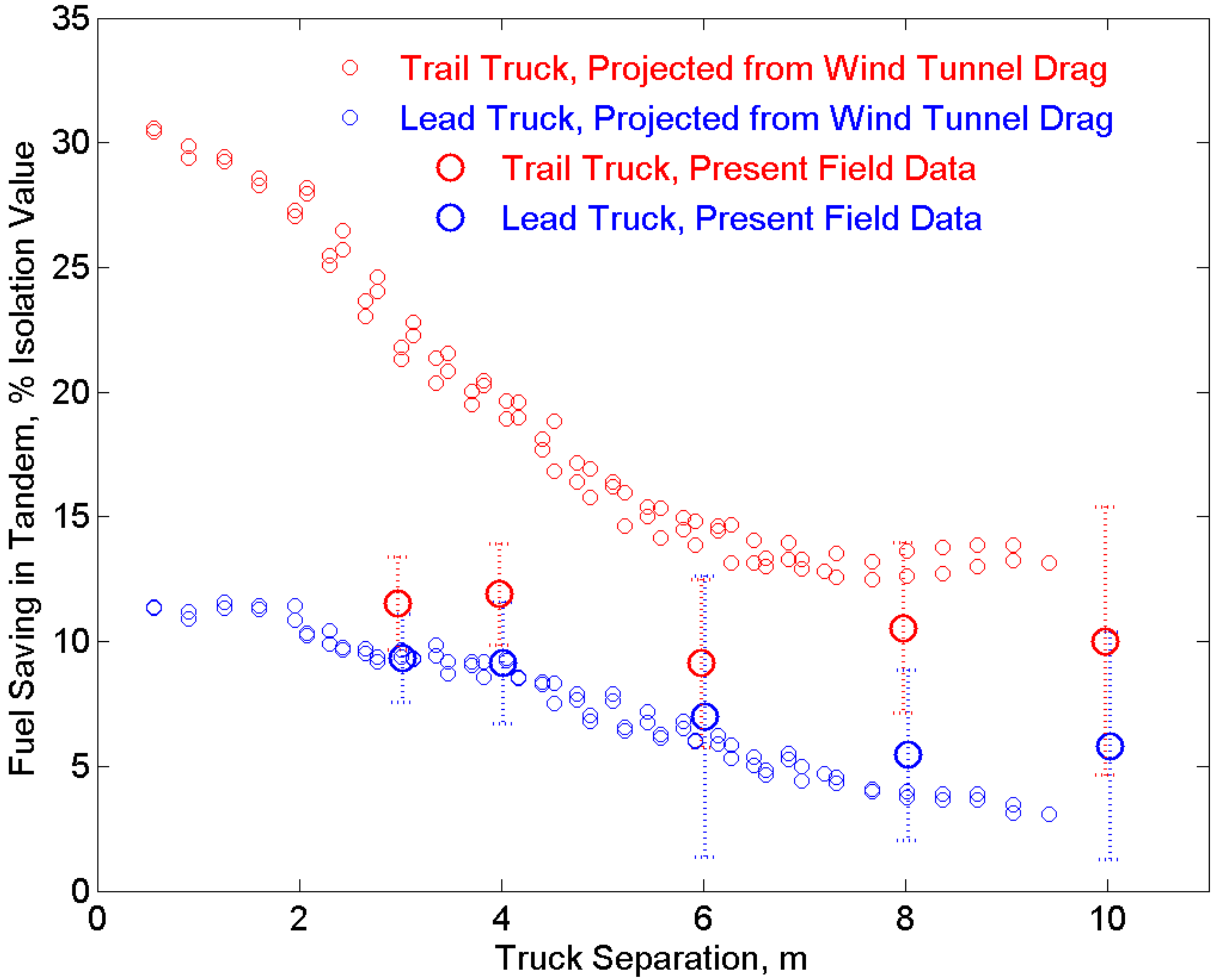
Comparison of Wind Tunnel and Direct Measurements of Fuel Saved



Three-Truck Automated Platoons

- Three-truck platoons could double the capacity of a dedicated truck lane, enabling dramatic cost savings in construction of high-capacity truck facilities
- Experimental implementation using 5.9 GHz DSRC for V2V communication in 2010-11, under FHWA Exploratory Advanced Research Program (EARP)
  - Gaps from 10 m to 4 m
  - Platoon join and split maneuvers
  - Variations in speed and road grade
  - Fuel consumption measurements

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Three-truck Automated Platoon (2010)

Three-Truck Platoon Experiments

- Longitudinal control was automated, but steering was still manual
- 8 km section of 2-lane highway, temporarily closed to public traffic for tests
- Direct fuel consumption measurements, with some limitations:
  - Lateral offsets to provide DSRC antenna line of sight guarantee
  - Some windy conditions added noise to drag measurements
  - Cruise speed of 90 km/h, at altitude of 1800 m

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Three-Truck Platoon Results

- **Accurate vehicle following – RMS gap variations of 0.22 m for second truck and 0.25 m for third truck**
- **Tentative energy savings results at 6 m gap because of experimental condition limitations:**
  - **First truck saved 4.3%**
  - **Second truck saved 10%**
  - **Third truck saved 13% - 14.5%**
- **Compensating for test altitude and speed, sea level driving at 115 km/h could produce 50% larger savings**
- **Aerodynamics and prior results indicate that second truck should have saved the most**

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Experimental Lessons Learned

- **Truck automation is significantly more difficult than automation of cars**
  - **Power limitations and slow responses**
- **Successful automatic steering and speed control have been demonstrated under a limited range of conditions**
- **Very close separations have been achieved between trucks on test track**
- **Fuel consumption savings are significant, but emissions effects are less certain**
- **More refinements and testing are needed**

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Transit Bus Steering Automation

- **Emphasis on steering automation for:**
  - **Precision docking at bus stations, so passengers can gain rail transit service quality**
  - **Safe and efficient operations in narrow rights of way (toll booth, busway in crowded urban environment)**
  - **Avoiding tire damage against curbs**
- **Future combination with longitudinal control to achieve full automation**
  - **Bus platoons, where needed for capacity**

High-Performance Steering Automation

- **Docking accuracy ~1 cm at bus station**
- **Enabling full-speed operations where drivers normally need to slow down (busway curves, narrow toll booth)**
- **Steering accuracy ~10 cm at cruising speed, enabling narrow busways in tightly constrained urban rights of way**

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Experiments in Bus Automation (2003)

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Real-World Implementations

- Steering automation of AC Transit Transbay buses on 6 km approach to San Mateo Bridge toll plaza – this year
- Steering automation of EmX BRT bus on busway in Eugene, OR (with precision docking) – this year
- Prototype tests with real-world impediments in San Leandro, CA (2008):

Further Development Needed

- Site-specific deployment case studies to provide bases for strong cost and benefit estimates (in diverse scenarios)
- Fault detection, identification and management technology (self-healing control systems)
- Fault-injection testing protocols to determine system robustness
- Software safety development and verification
- Driver interface/control transition testing by typical professional drivers
- Extensive testing to prove safety