Lateral Offset and Its Potential Effects on Platooning

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Topics Covered

- Introduction & Motivation
- Meshing and Simulation Methodology
- Simplified Car Body
  - Two body
- Single Heavy Vehicle
  - Baseline model
- Multiple Heavy Vehicle
  - Two vehicle
- Previous Results
- Lateral Offset
- Conclusions
Motivation: Improved Fuel Economy

• 2012 Transportation industry:
  ▫ $1.33 Trillion
  ▫ 8.5% national GDP
  ▫ Extremely competitive

• Crude oil is a finite commodity
  ▫ Highly variable market

• Improved fuel economy
  ▫ Allows marketplace advantage
  ▫ Complies with DOT / EPA regulations [2]

• If the FedEx fleet (25,000 tractors) improved gas mileage by 1% it would generate $20 million USD savings per year
**Motivation**

- Previously unfeasible due to human physiological limitations
  - Driver reaction time
  - Limited visibility
  - 80,000 lb loaded trailer requires ≈ 400-500 ft stopping distance
- Cooperative Adaptive Cruise Control (CACC) removes barriers
  - Offers longitudinal vehicle automation via throttle / braking control
  - Driver still controls lateral movement (steering)
- Research system being tested by Auburn-led FHWA project team
  - Grant awarded as part of the Exploratory Advanced Research Program under the Federal Highway Administration
  - Private sector team members providing trucks and research version of DATP platooning system
  - Partners include: Auburn University, Peloton Technology, Meritor Wabco, Peterbilt, and the American Transportation Research Institute
Motivation

• Why CFD studies?
  ▫ Physical testing prohibitively expensive
    • Wind Tunnel testing requires large, expensive models to eliminate wall-effects
    • Direct observation of coefficient of drag requires large number of expensive sensors and testing facilities
  ▫ Flexibility – Multiple scenarios
    • 2-4 Truck platoons, multiple geometries, various offsets, etc.
CACC

- Sensor and display package installed on existing tractor
- Automatically monitors and adjusts distance between vehicles via Dedicated Short Range Communication
- System recognition and response time orders of magnitude lower than human senses

Figure 1. Heavy Vehicle Platoon [1]
Driver-Assistive Truck Platooning (DATP)

- **Platooning**
  - A group of two or more aligned vehicles in a leader-follower configuration
  - Utilizes fuzed GPS-Radar for range measurement, DSRC for V2V communications
- Takes advantage of a phenomenon referred to as “drafting”

Figure 2: Auburn Peterbilt 579’s in Platoon
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Simplified Car Body

- First vehicle modeled, colloquially known as “Ahmed body,” after 1984 wind tunnel test [3]
- Designed to represent a simplified, generic bluff body
- $0^\circ$ rear slant used to more closely represent tractor-trailer
- Used as validation case for one and two body simulations

Figure 3. Ahmed body reference dimensions [6]

Figure 4. Ahmed Body Isometric View
Turbulence Modeling

- Turbulence is a phenomenon that occurs every day on a variety of scales
- Difficult to model
  - Irregular and chaotic in nature
  - Highly nonlinear
  - Adds several variables to the Navier-Stokes equations
- Two models considered herein:
  - Realizable $k-\varepsilon$
  - Detached Eddy Simulation
Turbulence Modeling Flaws

- RKE cannot return to laminar flow once turbulent
- Does not terminate wake
- Poor prediction at large distances
- LES Based models more accurate
- RKE still valid from 0-300ft
- Indicates RKE performs poorly in low TKE situations
- Consistent with knowledge about RKE

Figure 13. Two vehicle 1000 ft spacing: RKE (top) vs. DES (bottom)
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Mesh Size Variation

- Asymptotically approaches wind tunnel data
- Highly nonlinear error reduction
- Mesh size largely dependent on local refinement
  - 1mm reduction in body surface element resulted in 1.1M more elements
Simulation vs. Wind Tunnel

- Trend captured
- Validates simulation increase prediction
- Difference due to rear slant variation (25°)
  - Shows tighter wake increases rear body drag
  - Analogous to aerotail on a trailer

Figure 7. Two Ahmed CFD vs. Wind Tunnel [8]
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Single Vehicle Simulations

- Performed to gain a baseline drag force
- Allowed detailed surface analysis to determine primary contributing drag surfaces
- 53 ft trailer simulated – Industry Standard

Figure 8. P579 [4]
Peterbilt 579 CAD Model

- Peterbilt 379 simplified CAD modified to create Peterbilt 579 model
  - Sloped hood
  - Aerodynamic fairing
- Primary test model
  - For future comparison to experimental data

Figure 9. P579 CAD

Figure 10. P579 Surface Mesh
Workaround Features

- Due to complex nature of tractor geometry additional modifications were required
- Nonphysical regions that cannot be discretized exist in mesh
  - Sharp curves that meet with near tangent surfaces
  - Meshing algorithm attempts to create a volume mesh on a point, results in error
- Example
  - Intersection of wheel curve and flat ground
  - Add 1” buffer region so there is a finite end to air region

![Figure 11. Workaround feature example](image)
Two Vehicle

- Primary focus of study
  - Developed drag vs. vehicle spacing trend
- Peterbilt 579 geometry
- Simulated at many distances
  - Small separation: < 100 ft between vehicles
  - Large separation: > 100 ft between vehicles

Figure 12. Two vehicle velocity profile, top to bottom: 10 ft, 36 ft, 90 ft spacing
Two Vehicle Simulation Results

• **Important Takeaways**
  - Drag reduction monotonically improves as separation distance diminishes
  - Drag reduction corresponds to fuel-consumption
  - Rear truck sees benefit even at relatively high distances
  - Front truck benefit diminishes rapidly

![Figure 14. Two vehicle drag vs spacing](image-url)
Previous Experimental Results

- PATH Project – Wind Tunnel Results

Figure 15: Path Project Wind Tunnel Results [5]

- Follows similar overall trend to simulated data
Energy ITS Results

- Energy ITS – Fuel Economy Results

![Graph](Image)

- Similar Results – Laterally Controlled

![Graph](Image)
NREL Results

- National Renewable Energy Laboratory – Fuel Economy Results

- Drastically different trend than simulated data
  - Engine fan duty-cycle much higher at close separation distances
Possible explanations

• Engine Temperatures
  ▫ As separation distance diminishes, less convective heat transfer for rear truck engine

• Controller Dither
  ▫ As spacing diminishes, more aggressive controller behavior

• Previously non-captured aerodynamic effects
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Lateral Offset – Potential Culprit

• Previous testing indicates most likely explanation is an aerodynamic effect
• Lateral offset – More likely to occur at close following distances
  ▫ Vortex shedding off front truck coupled with lack of visual cues to center the rear truck
• Second set of simulations conducted to investigate
Laterally Offset Platooning

- Lateral offset negatively effects the drag reduction on rear truck
  - No longer drafting optimally
  - Asymmetrical pressure distribution
- More pronounced at smaller spacings

Figure 22: Pressure Contour on the Front Surface of the Rear Truck with Outline of Front Truck
Lateral Offset Simulation Results

Figure 23: CFD Results including 2 ft. Lateral Offset
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Conclusions

• New trend matches experimental data more closely
  ▫ Lateral offset most likely to occur at close spacings
  ▫ Largest difference between ideal and offset drag reduction also at close distances

• Verification of lateral offset during testing in progress
Implications

• Lateral control a potential way to improve efficacy of DATP systems
  ▫ Despite this, DATP still provides large benefit to fuel consumption without lateral control ~10%
• Implies optimal spacing of platoon is non-uniform
• Further research shows that offset platoons vary even more drastically with ambient conditions
  ▫ Cross-winds and other potential phenomena affect offset platoons differently from controlled platoons
Questions
References