Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment

Phase One Final Report Summary

Presentation Overview

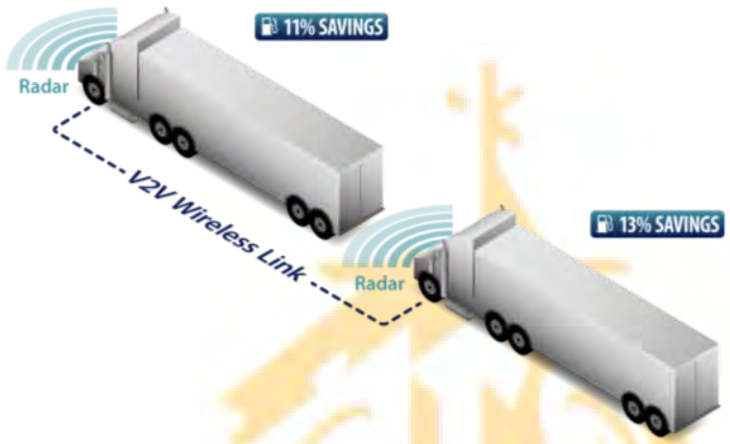
- Team Overview
- Driver Assistive Truck Platooning (DATP) Overview
  - Research Objectives
  - New Knowledge Expected
  - Key Questions
- Concept of Operations
- System Requirements
- Results of DATP Analyses
  - Business Case Evaluation
  - Vehicle Preparations and Sensor Research
  - Wireless Communications
  - Inter-Vehicle Aerodynamics Research
  - Finding Linking Partners
  - Traffic Flow and Mobility Impacts
  - Safety and Human-Machine Interface
- Phase II Plans
- Conclusion

Team Overview

- Auburn
  - Mechanical Engineering (David Bevly, Project PI)
  - Industrial and Systems Engineering (Richard Sesek and Chase Murray)
  - Aerospace Engineering (Joshua Batterson)
  - Computer Science (Alvin Lim)
  - Civil Engineering (Rod Turochy)
  - Consultant: Richard Bishop
- Peloton
  - Josh Switkes, Steve Boyd, engineering staff
- ATRI
  - Dan Murray
- Meritor-Wabco
  - Alan Korn
- Peterbilt
  - Bill Kahn

DATP Overview

- Driver Assistive Truck Platooning (DATP)
  - adaptation Cooperative Adaptive Cruise Control (CACC) for two-truck pairing
- CACC builds on Adaptive Cruise Control (ACC)
- Data exchange between trucks allows for close following
  - resulting in significant fuel economy benefits
- Technology basis: V2V communications, forward sensing (radar), positioning, actuation, and human-machine interface
- Driver roles:
  - Lead driver: normal driving
  - Following driver: steering (automatic longitudinal control)



Research Objectives

- Define a commercially viable DATP system
  - technically viable
  - operationally viable for commercial fleet operations
- Assess DATP by implementing a prototype system that meets the user needs and can have maximum positive impact on freight efficiency and mobility.
- Transition research results to industry

New knowledge expected

- Business case evaluation based on stakeholder input and analysis
- Better V2V understanding on heavy vehicles in particular
- Definitive assessment of fuel economy benefits in realistic trucking environment
- Improved simulation models incorporating vehicle dynamics and aerodynamics
- Development of algorithms to support linking process
- Assessment of traffic impacts
- User assessments to guide system developers
- State DOT level assessment

Key Questions

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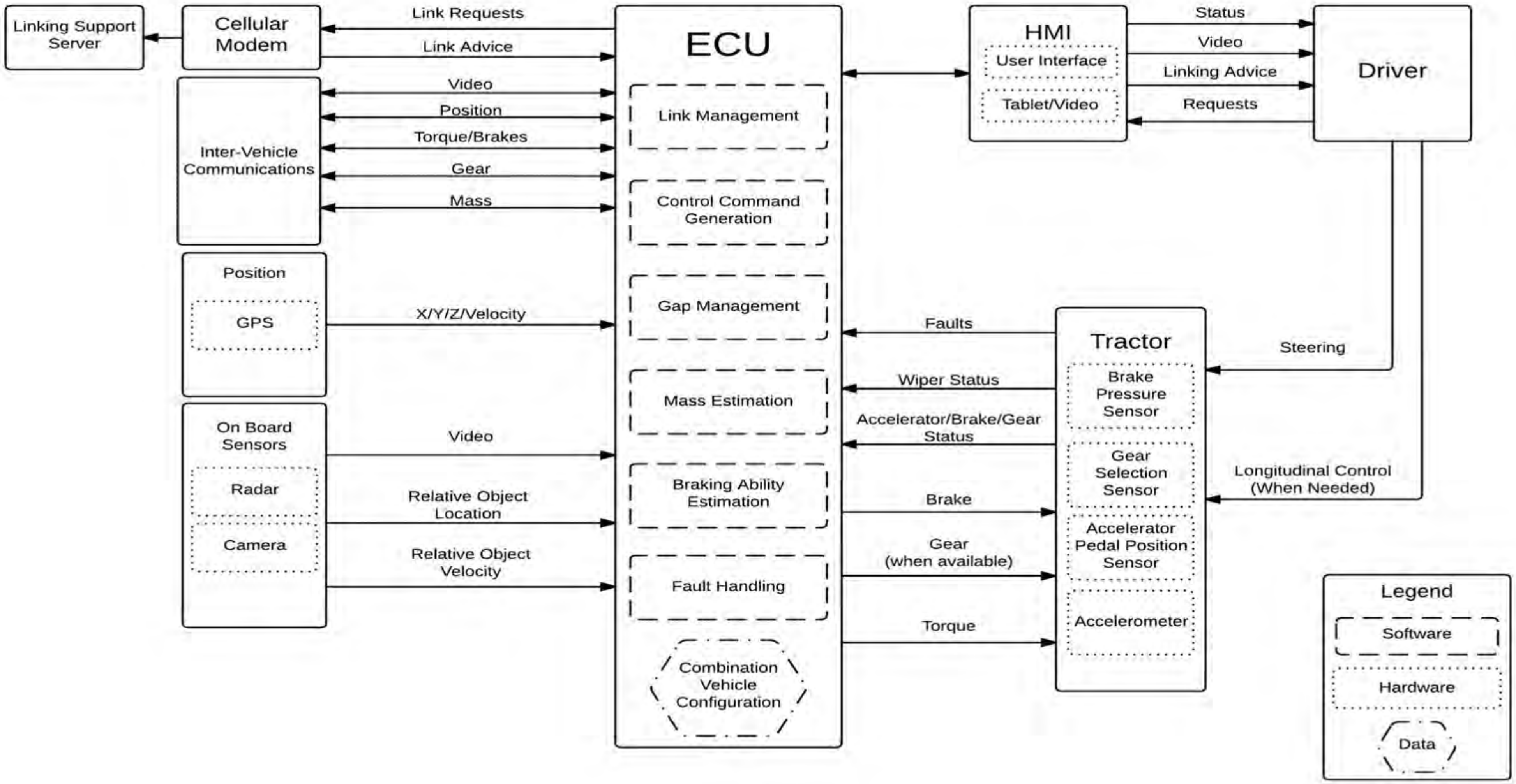
- DATP is a major step for fleet operators: depending on data from another vehicle for the safety of "my" vehicle.
- How can my driver efficiently find another equipped vehicle? How do I know the other vehicle is trustworthy?
- What factors are important to driver understanding and acceptance of the system? What is the best way to introduce drivers to this system? Can drivers use the system effectively and safely?
- How does the system react to passenger car cut-ins and other anomalies?
- How does surrounding traffic interact with the linked trucks?
- What fuel savings are achievable in the real world with real traffic?
- Is commercially available ACC readily adaptable to DATP?
- What operating strategies are best suited to use of DATP?
- How do the most promising operating strategies affect traffic flow, particularly in dense freight corridors?
- What is the effect of DATP on safety performance? Will the system introduce new safety risks, or be limited due to safety factors?
- How will the system adapt to varying braking capability, engine power, and load?
- What technological and institutional enablers are necessary to allow DATP to be commercially established in North America?

DATP Concept of Operations and System Requirements Document

- ConOps section addresses:
  - operational needs
  - user-oriented operations
  - the system approach
  - the operational environment
  - the support environment
  - operational scenarios
- Systems Requirements section provides high-level system requirements in the following major sections:
  - Driver Role
  - On-Board System
  - Inter-vehicle Communications

DATP Requirements Doc: Data Flow Diagram



DATP & Passenger Car Cut-Ins: Nothing New?

- Passenger vehicles cutting-in between closely spaced trucks are a common and dangerous scenario on the road.
- DATP builds on radar-based Adaptive Cruise Control (ACC) and collision mitigation systems (CMS) which aggressively brake in an impending crash situation.
  - in use by the trucking industry for several years
  - ACC/CMS systems assist the truck driver in braking as quickly as possible if necessary to respond to a cut-in vehicle
- Due to the laws of physics, not all collisions can be avoided but these systems can at least reduce the energy in an unavoidable crash.
- The potential for a near-crash or crash due to passenger vehicle cut-ins does not change with DATP
- However, the potential of cut-ins may be somewhat reduced due to the closer spacing between trucks.
- Future: when all cars have V2V, response to the cut-in can potentially occur even earlier.
- System requirements document defined a “safe” system, whether ACC, CMS, or DATP, as:
  - one which responds to a developing crash situation as quickly as possible (and significantly faster than a human driver could) to either avoid the crash or slow the vehicle speed to reduce the energy in a crash.

Business Case Evaluation

- Trucking industry is large and complex
- More than 10 billion tons of freight moved every year
- ATRI conducted survey soliciting both carrier and driver cost and benefit expectations
  - 109 respondents
  - Overall Response Demographic
    - 38% of responses were owner-operator/independent contractors
    - 40% of responses were company drivers
    - 22% of responses were fleet management
- Industry Sectors
  - Truckload Operations (TL)
    - Largest percentage of TL trip mileage occurs on highways and interstates
    - DATP attractiveness high
  - Less-than-truckload Operations (LTL)
    - LTL vehicles are slightly older on average than TL
    - DATP systems could be slower to adapt

Business Case Evaluation

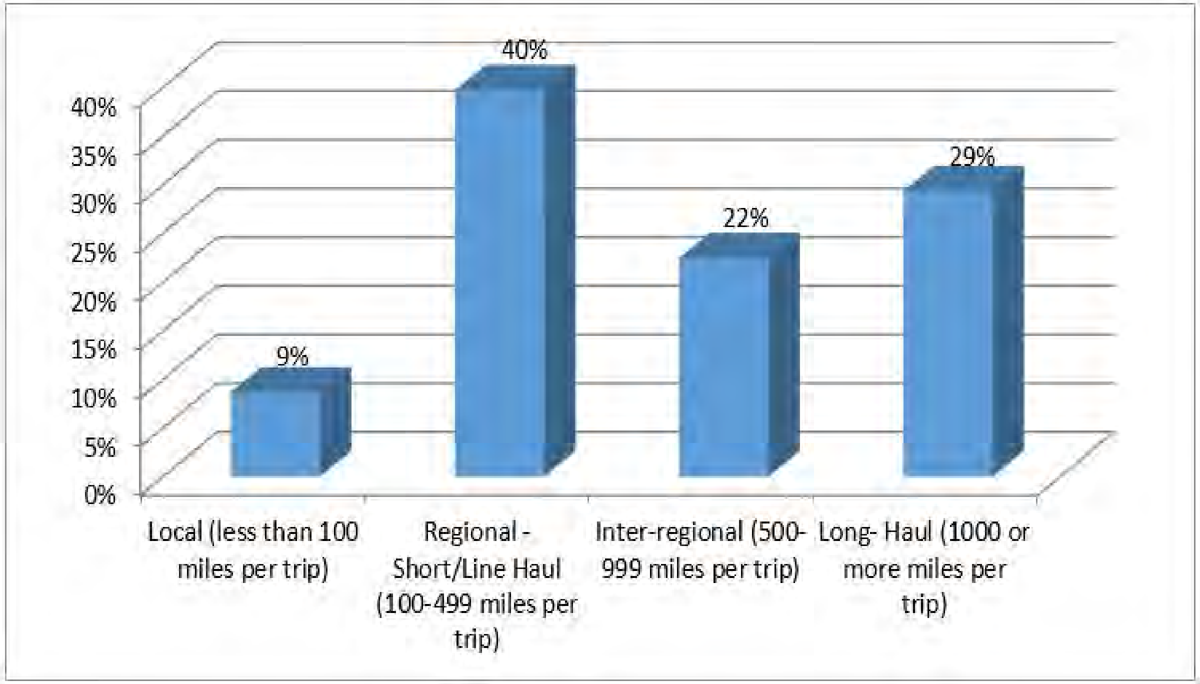
- For-Hire vs Private Fleet Operations
  - Both business models would likely weigh DATP in similar fashion even though they are different in structure
  - Private fleets have indicated the possibility of platooning after seeing the possible fuel economy benefits
- Commodity Types
  - All commodity types will benefit if fuel savings are as envisioned

Business Case Evaluation

- Finding Platoon Partners
  - all respondent groups favored platooning within their own company (or with other owner-operators)
  - many respondents favored platooning with fleets/trucks with whom they had previously platooned
  - truck location within platoon: who’s the referee?
    - rear truck gains greater fuel economy benefits than the lead truck
    - operational approaches to this will be further investigated in Phase II

Business Case Evaluation

- DATP Operating Environments
  - Survey: 65% of respondents operated primarily on limited access highways
  - DATP operations favorable here
  - DATP may need to adjust operating parameters in areas with:
    - Steep road grades
    - Traffic speed
    - Extensive merging
    - Work zones
    - Tight curves
- Truck Trip Lengths
  - Longer trip lengths likely to generate greater ROI
  - 54% of carriers and drivers had an average trip length of less than 500 miles
  - 46% were over 500 miles in average trip lengths
  - Analysis for break even points to be conducted in Phase II



Business Case Evaluation

- Industry Financial Expectations
  - ROI as important as the benefits generated by the technologies
  - Owner-Operators willingness to pay predicated on owning vs. leasing the technology

Fleet Size	WTP Install ($)	WTP Maintenance ($)	Break Even Period (months)
0-6	-	-	-
7-20	1000	1000	1
21-50	750	400	18
51-500	1120	422	10.8
501-1000	-	-	-
1001-5000	2000	250	36
5001+	1000	250	36

Average WTP per Truck (Install)
$1,511.11
Average WTP per Truck per Year (Operation)
$497.00

Business Case Evaluation

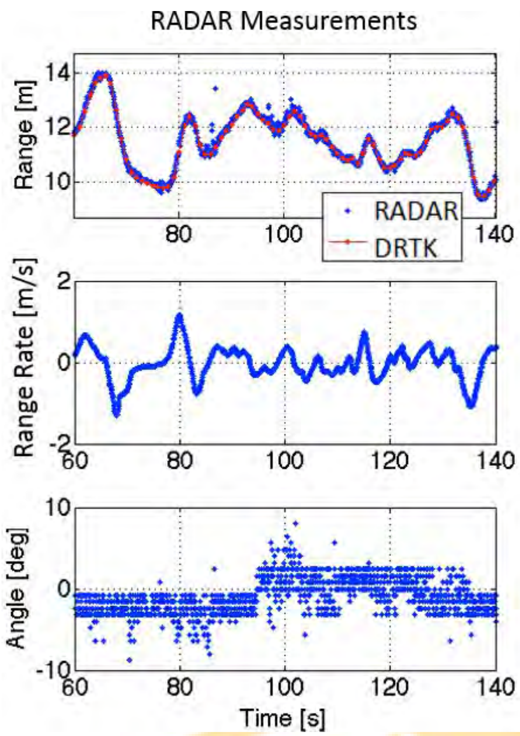
- Routes
  - for respondents, 68% to 71% of the trips are on the same routes
  - allows for more advance planning of potential DATP interactions
- Driver perceptions
  - fleet managers:
    - 54% -- DATP would have a "very positive," "somewhat positive," or no impact on driver retention.
    - 39% -- drivers are very likely, likely, or moderately likely to use a DATP system
  - owner-operators: responses for driver retention and usage on opposite end of the scale

Business Case Evaluation

- Conclusions
  - Legitimate targets
    - Larger for-hire over-the-road TL and LTL line-haul fleets and private fleets
  - These targets have the financial capabilities, risk tolerance, trip lengths, and lane corridor densities necessary for DATP operations
  - Research needs to validate the roadway types, driving conditions, and truck networks that favor DATP operations
  - Data generated from this research must be clear, accurate, and disseminated to the key target markets

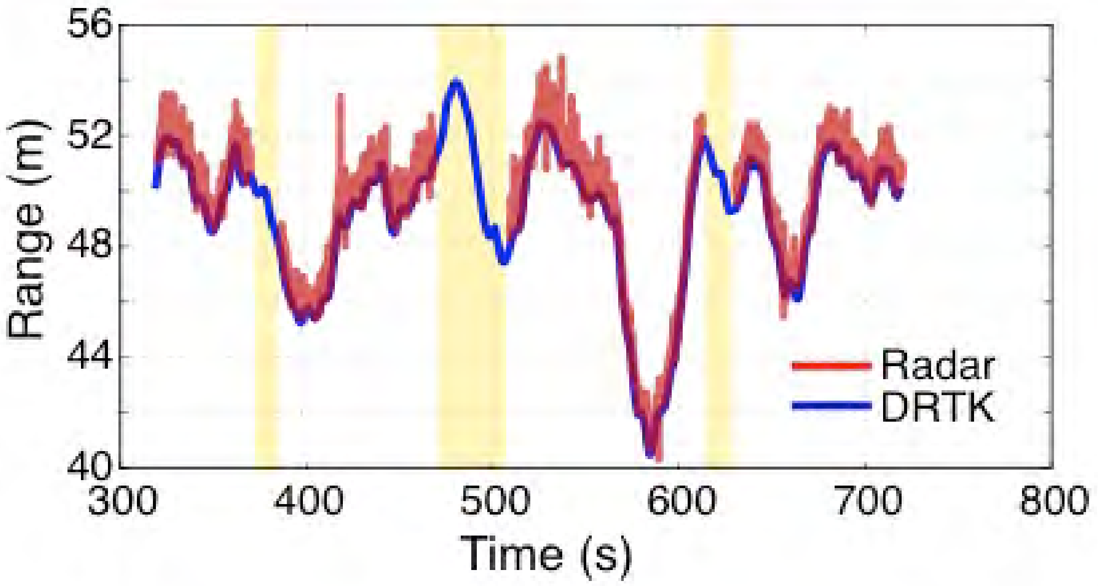
Vehicle Preparations and Sensor Research

- Radar – fundamental sensor for range determination
- GPS provides a secondary measurement
  - Fusing the two measurements together would improve the system robustness in terms of positioning immensely
- Assessment of Radar performance while tracking a leading vehicle
- Dynamic Real Time Kinematic (DRTK) GPS used as reference (cm level relative position)
  - DRTK is a differential GPS method for determining range between two mobile receivers



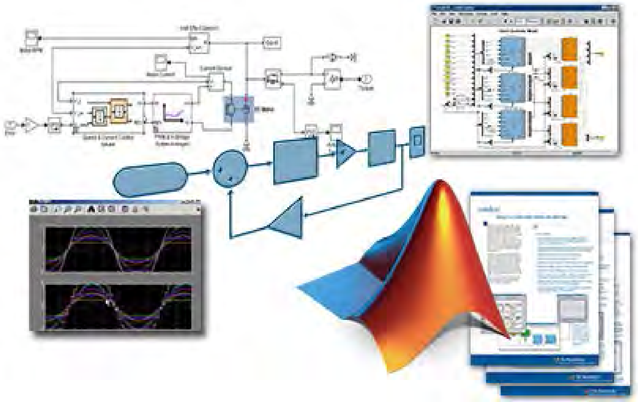
Vehicle Preparations and Sensor Research

- DRTK GPS vs. Radar Test
  - Conducted at NCAT track (1.7 mi. oval)
  - Radar noisier than DRTK
  - Bias on radar vs. DRTK
  - Radar showed dropout around turns
  - DRTK maintained through turns
- Radar Mitigation Areas:
  - Sharp turns
  - Areas of large undulation
- GPS Mitigation Areas:
  - Urban canyons (cities with tall buildings)
  - Heavy foliage
  - Tunnels



Vehicle Preparations and Sensor Research

- Vehicle Simulation
  - adaptation of modeling previously done for a truck system supplier
  - Objective
    - Simulate accurate vehicle fuel consumption at all points during a run when a time, velocity, and road grade profile are given
    - Study how different road profiles affect fuel efficiency of a heavy truck platoon
  - Phase I Work
    - Changing the air drag coefficient to compare fuel consumption on different road and speed profiles for the truck platooning
    - Testing different speed profiles will reveal the effectiveness of truck platooning in non-interstate applications



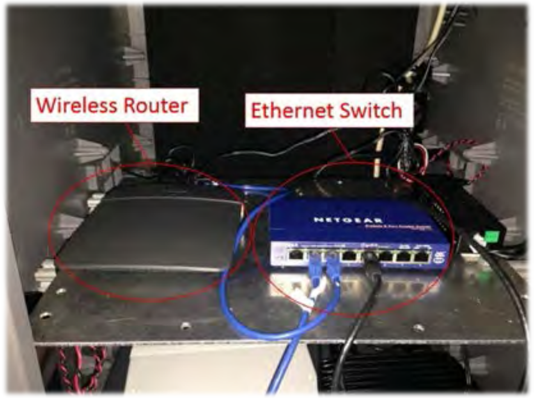
- Vehicle Delivery
  - Two Peterbilt 579's delivered to Auburn University during Phase I
  - Extensive collaboration between project partners in order to optimize the project
    - Different braking systems

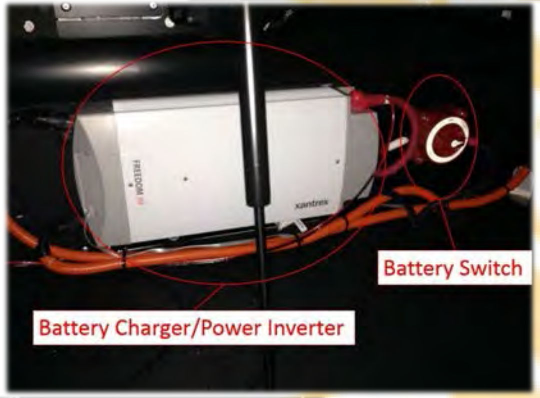
Vehicle Preparations and Sensor Research

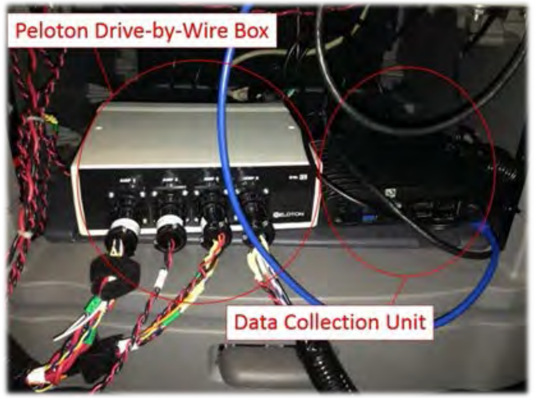
- Phase II Plans
  - Task 2.1: System Prep
    - Acquire necessary equipment for platooning system
    - Install all equipment onto the two Peterbilt 579's
    - Run initial tests to validate system functionality
  - Task 2.2: Data Collection
    - Document outlining testing plans
    - Driver response sheet
    - On-track and off-track testing

Vehicle Preparations and Sensor Research

- Phase II Work
  - System Prep
  - Equipment purchased and installed







Wireless Communications

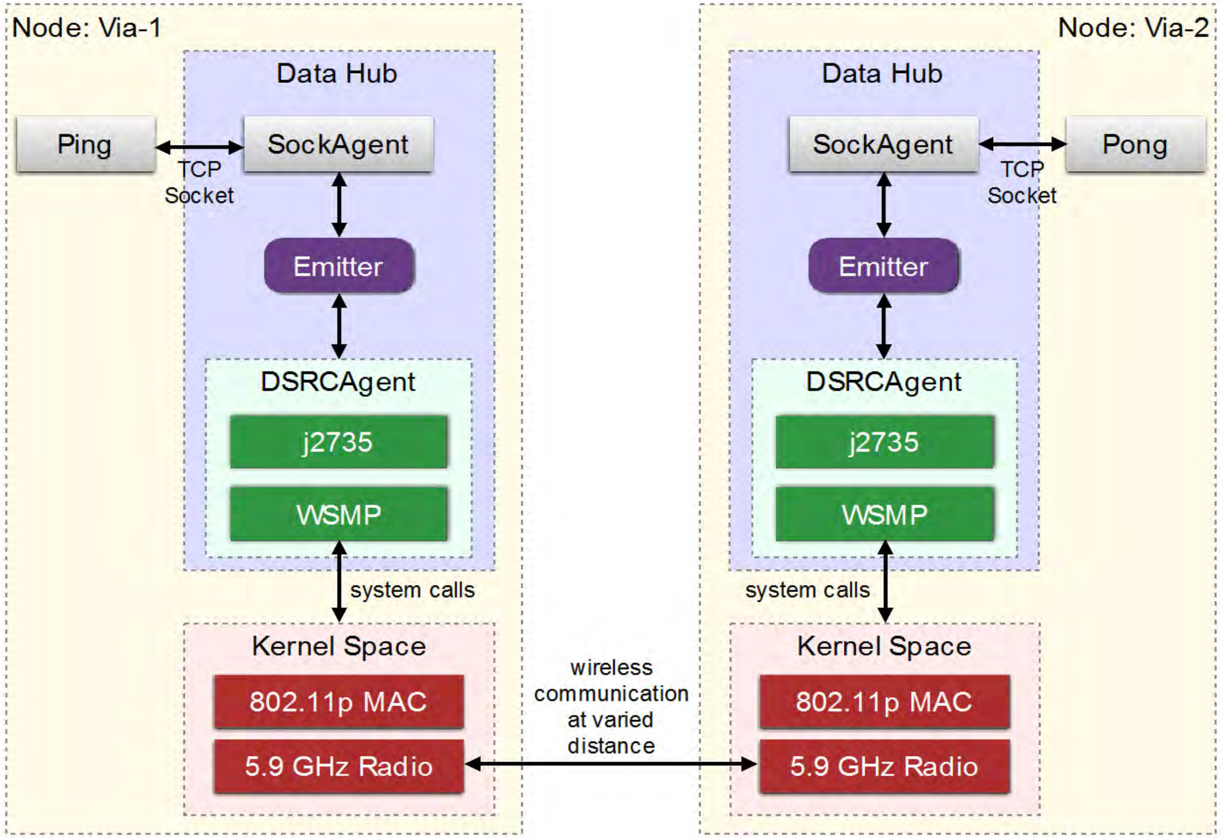
- Vehicle to Vehicle (V2V) Overview
  - V2V Technology: DSRC
  - DSRC mostly finalized, but software is not available in public domain
  - Team's implementation
    - Takes into consideration of IEEE and SAE standards
  - Data hub
  - Tests

Wireless Communications

- DSRC Implementation
  - IEEE 802.11p
    - Physical Layer, Unex card (done)
      - 5.9 GHz; 10 MHz channels
    - MAC Layer – Outside Context of Basic Service Set (BSS) (partial)
      - Remove association; wildcard BSSID
- Wave Short Message Protocol (WSM done)
  - Minimum header for multiplexing
- DSRC Message Dictionary SAE j2735 (done)
  - Transpile ASN.1 -> C

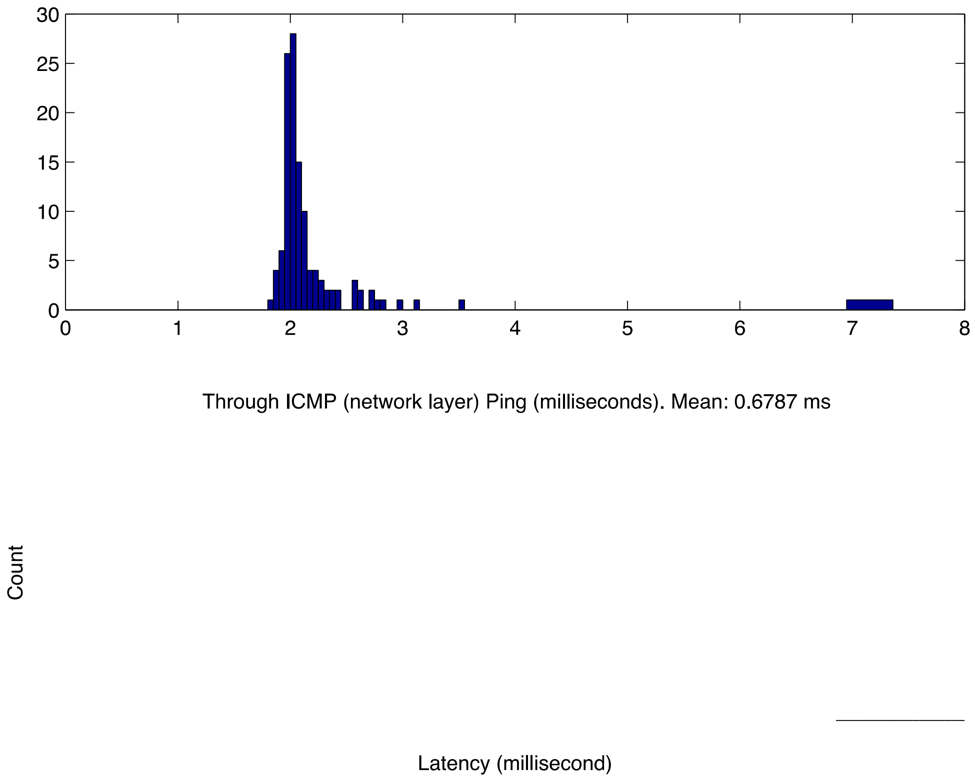
Wireless Communications

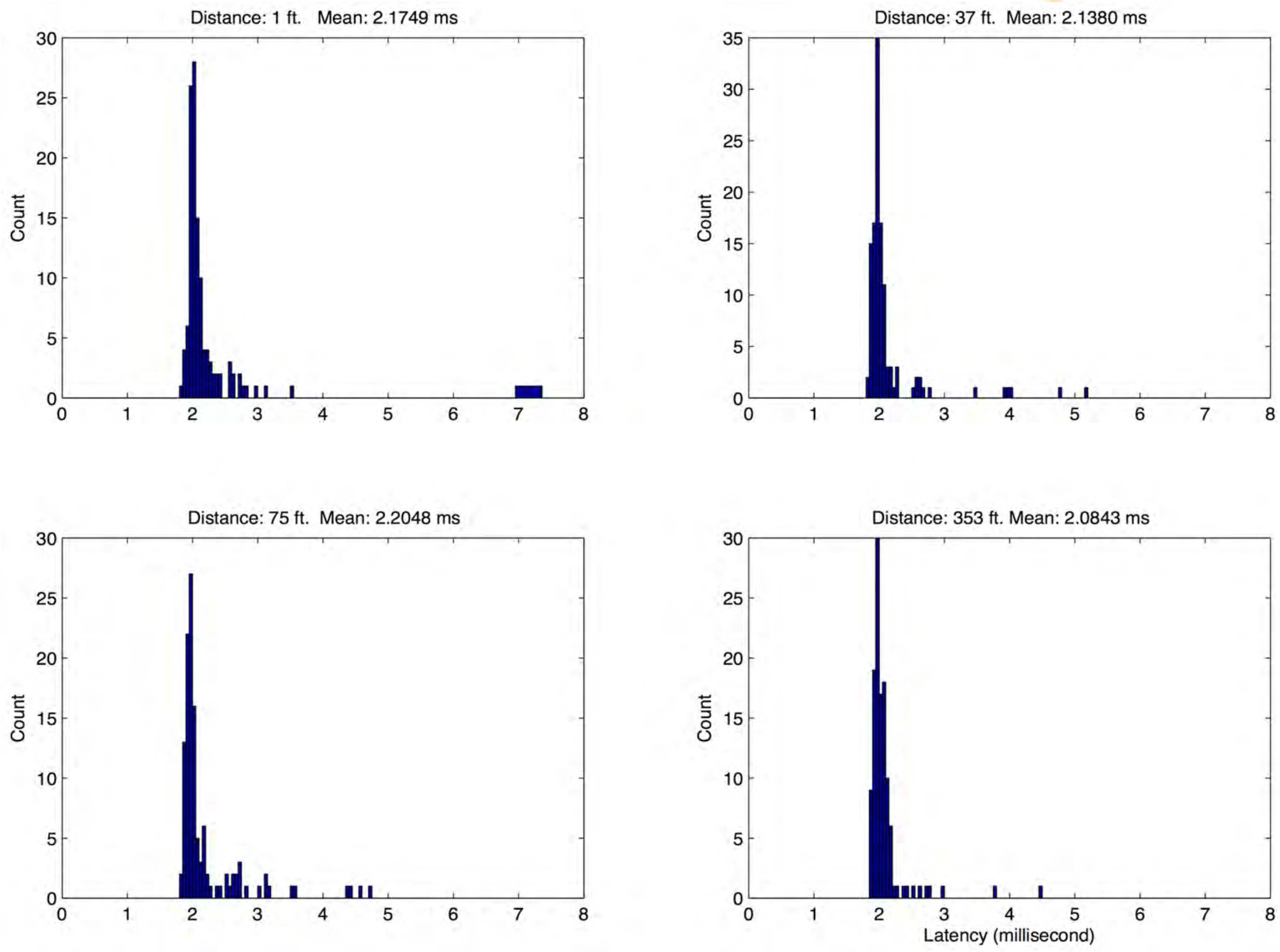
- Data Hub
  - Motivations
    - Heterogeneous Subsystems
    - Complex Data Streams
    - Different Trade-offs
  - Implementation
    - Publish-Subscribe Paradigm
    - Different Agents for Performance or Ease of Development
    - Highly Concurrent
- DSRC with Data Hub Testing



Wireless Communications

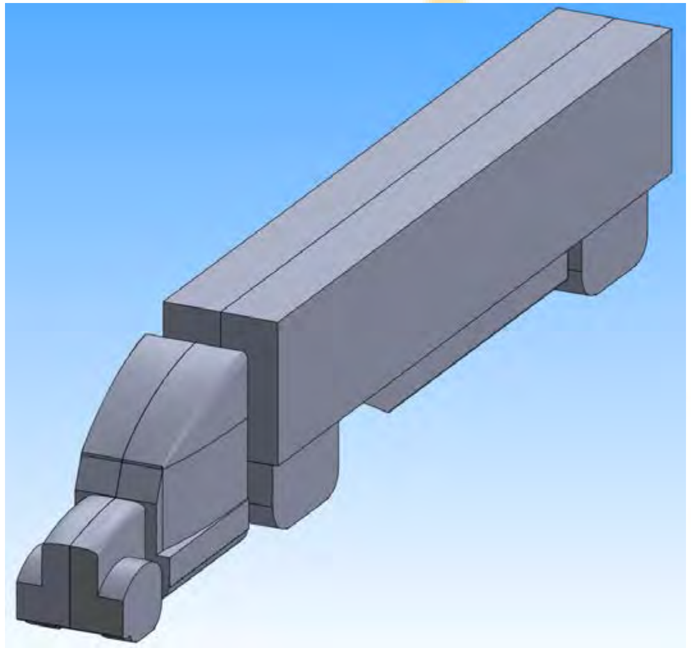
- Network layer ping vs. Through data hub test
- Network layer ping vs. Through data hub test: Distance Varied

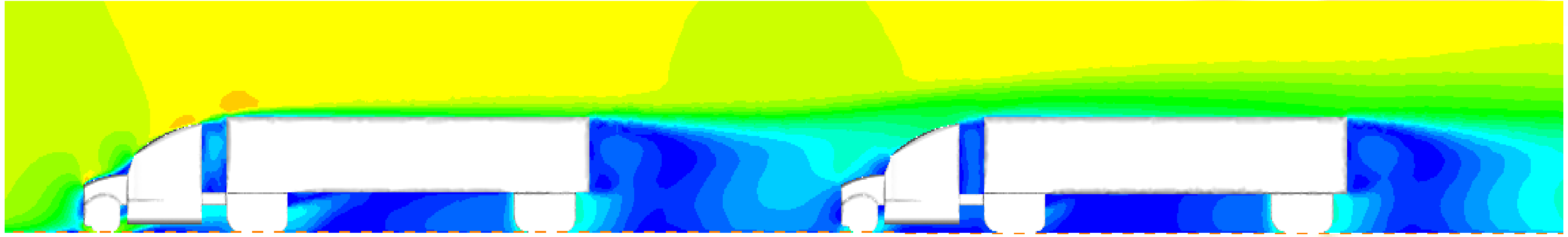




Inter-Vehicle Aerodynamics Research

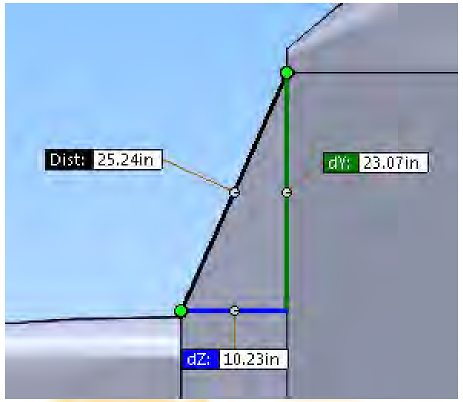
- Aerodynamic Force Model
  - Developing drag vs. spacing trend
  - From drag savings determine fuel savings
  - Aerodynamic drag is the #1 contribution to fuel consumption at highway speed (scales with speed squared)
- Motivation
  - Produce and validate a model reduces need for road testing
  - Can predict fuel savings for separation lengths that are not tested
  - Limited existing computational work
    - Manual platooning unsafe and often illegal – "Tailgating"
- Computational Fluid Dynamics (CFD)
  - Modeling fluid flow
  - Governed by Navier-Stokes equations
    - No analytic solution
    - Discretely and numerically solved

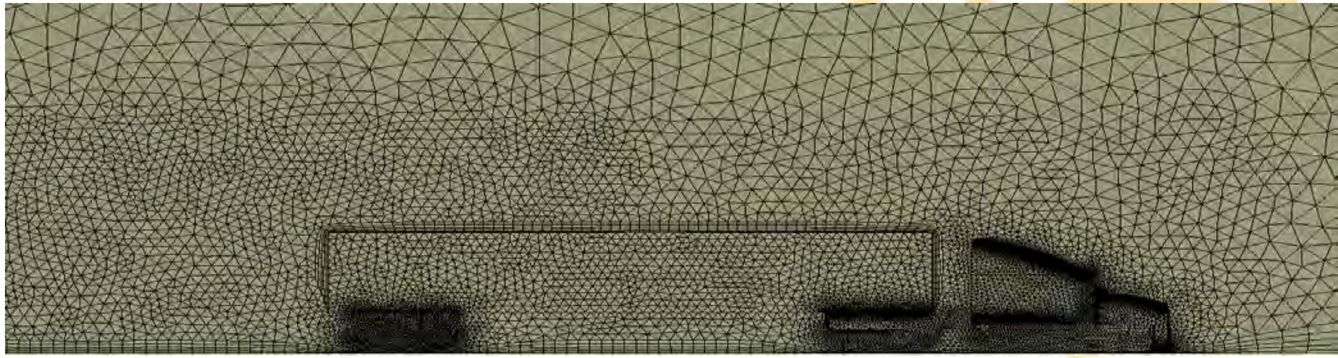




Inter-Vehicle Aerodynamics Research

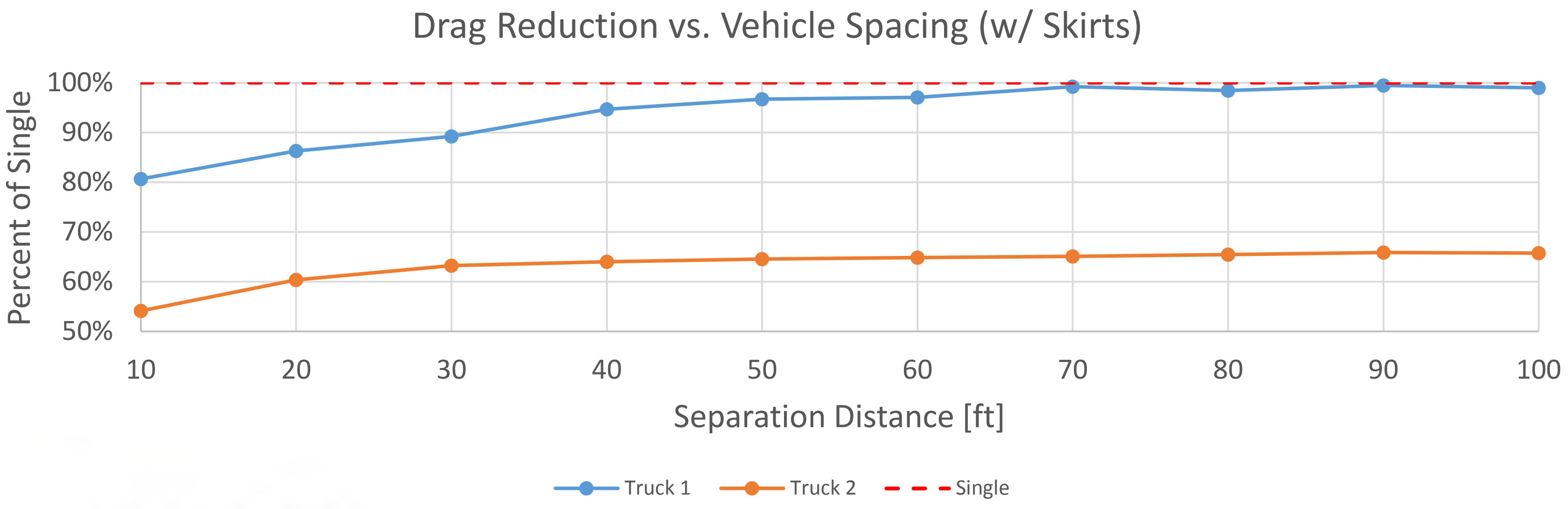
- Meshing
  - Discretizing volume around geometry to numerically solve Navier-Stokes equations
- Simplified geometry
  - Representative of aerodynamic profile
  - Does not capture unnecessary features such as side mirror, grill, etc. (do not affect drag significantly)
- Large disparity in length scales makes mesh refinement an iterative process
  - Smaller Features require finer mesh, but elements grow very rapidly
  - Ahmed body: change from 10mm to 8mm face size on body results in approx. 2m more grid points
- 3 million elements per single truck, medium-coarse grid
- Limited to ~8 million (RAM available)





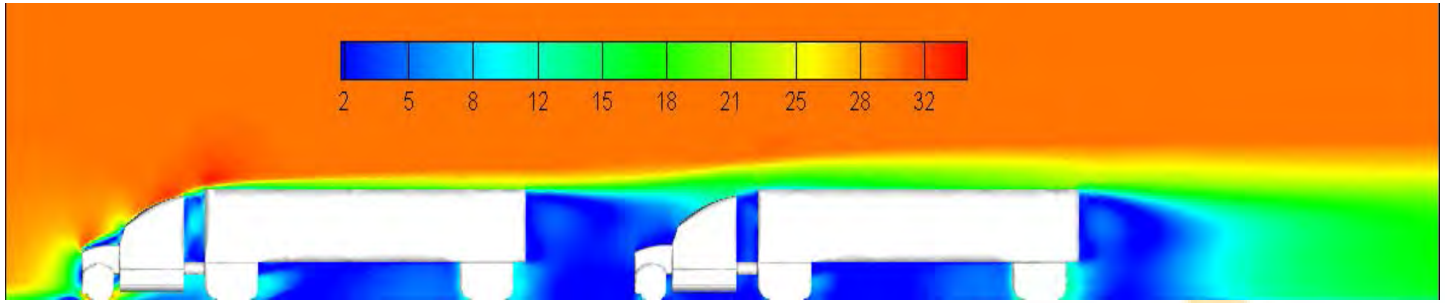
Inter-Vehicle Aerodynamics Research

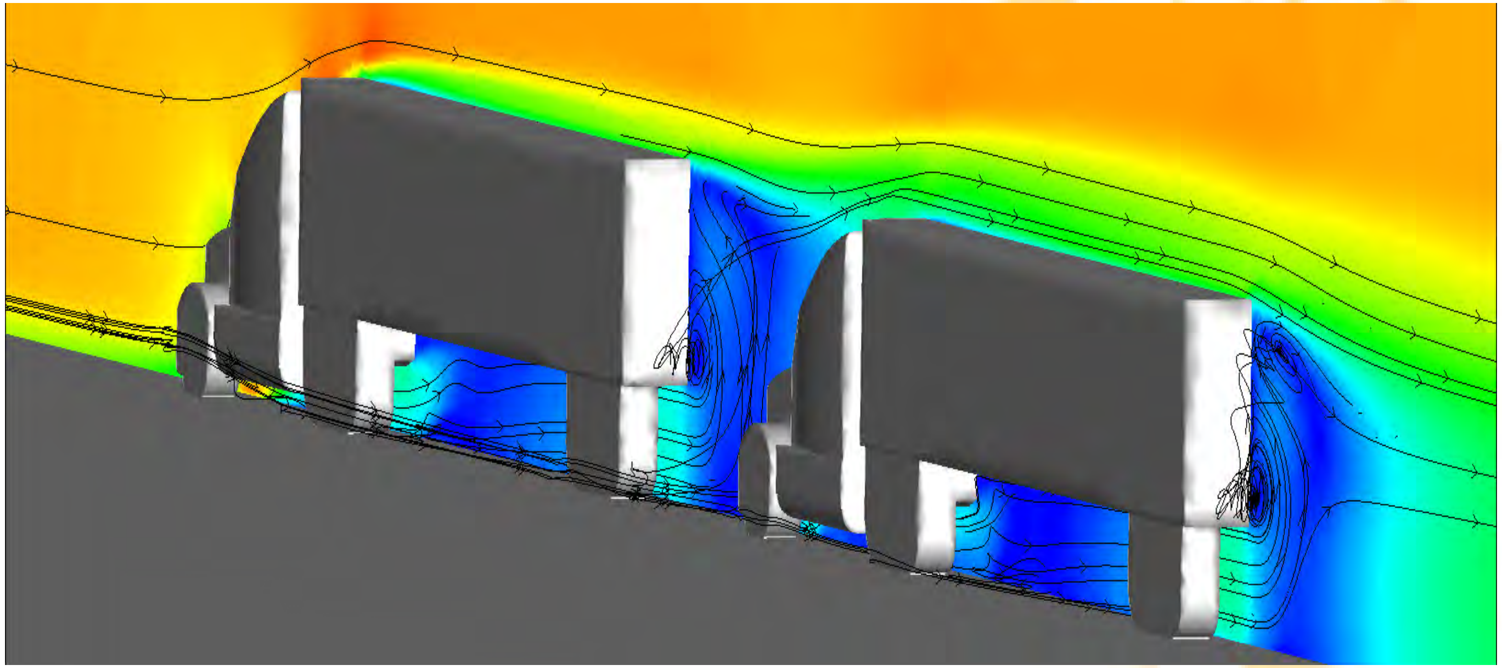
- Drag Trends
  - Truck 1 asymptotes at approximately 1 vehicle length, sees significant reduction beginning at approximately 0.5 vehicle lengths
  - Rear Truck still sees significant drag reduction at large distances
  - Rule of Thumb: At highway speed, 0.5% fuel savings for every 1% drag reduction



Inter-Vehicle Aerodynamics Research

- Flow profile: 18ft Separation
  - No side skirt for visibility
  - Flow in ahead of Vehicle 1 is unchanged
    - “Wall of Air”
  - Vehicle 2 encounters very turbulent “broken” air
    - Non-uniform
    - Undirected
  - Wake behind Vehicle 2 is unaffected
    - Near identical vorticity profile to single vehicle
    - Lower magnitude due to lower overall velocity
  - Upper vortex behind Vehicle 1 is unable to form, resulting in lower pressure drag on the vehicle rear





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Inter-Vehicle Aerodynamics Research

- Conclusions
  - Lead vehicle sees no benefit unless rear vehicle is close enough to interfere with wake (40 ft or less)
    - The only effect Vehicle 2 can have on Vehicle 1 is via wake interaction
    - Remainder of drag profile is unchanged (identical to single body)
  - Follow vehicle drag reduction at large distances
    - Flow disturbance from front truck propagates far down field
    - Mean flow is still much lower velocity than freestream

Finding Linking Partners

- Goal
  - Use data collected by ATRI to identify what platooning opportunities there are
    - actual timing, routes for all movements by specific fleets over 300 mile section of interstate
  - An optimization approach was used to analyze the data
  - For Phase I, equal fuel economy benefits on all trucks assumed (to be refined in Phase II)
- Metrics of Interest
  - Percent trucks that join a platoon
  - Number of platoons formed
  - Number of trucks that were time delayed due to platooning operations
  - Number of platoon formation operations (number of times vehicles adjusted speed to join a platoon)
  - Maximum platoon size at any given time
  - Time lost for trucks that platoon
  - Distance traveled in platoon by individual trucks
  - Percent distance traveled in platoon versus on the road
  - Savings earned
- "Adjustment Speeds" defined
  - a truck ahead of a potential partner slows, or the upstream truck accelerates, in order for them to meet.
  - fuel usage penalties incorporated into overall fuel benefits/disbenefits

Finding Linking Partners

- Findings / Conclusions
  - Platoon formation of 30-45% in one dataset
    - trucks remaining platooned between 55-75% of the 300 mile road segment
  - Most intuition was confirmed regarding trends and how parameter changes influence the results
  - Key result is that percent savings seems to only be influenced by air drag and road saturation (how many trucks are on the road)
  - All other parameters seem to have no impact:
    - Lead truck adjustment speed (magnitude of deceleration of lead truck to form a platoon)
    - Trail truck adjustment speed (magnitude of acceleration of trail truck to form a platoon)
    - Maximum allowable platoon size.
- Overall results very promising for commercial fleet operations

Finding Linking Partners

- Plans for Phase II
  - Constrain time lost to a reasonable limit
  - Consider additional visuals
  - Continue improving the data analysis script
    - Make the analysis faster
    - Automate figure generation
    - Automate reporting
  - Use artificial braking scores to determine truck position based on brake quality
  - Extend analysis of the ATRI-provided truck data for additional highway corridors

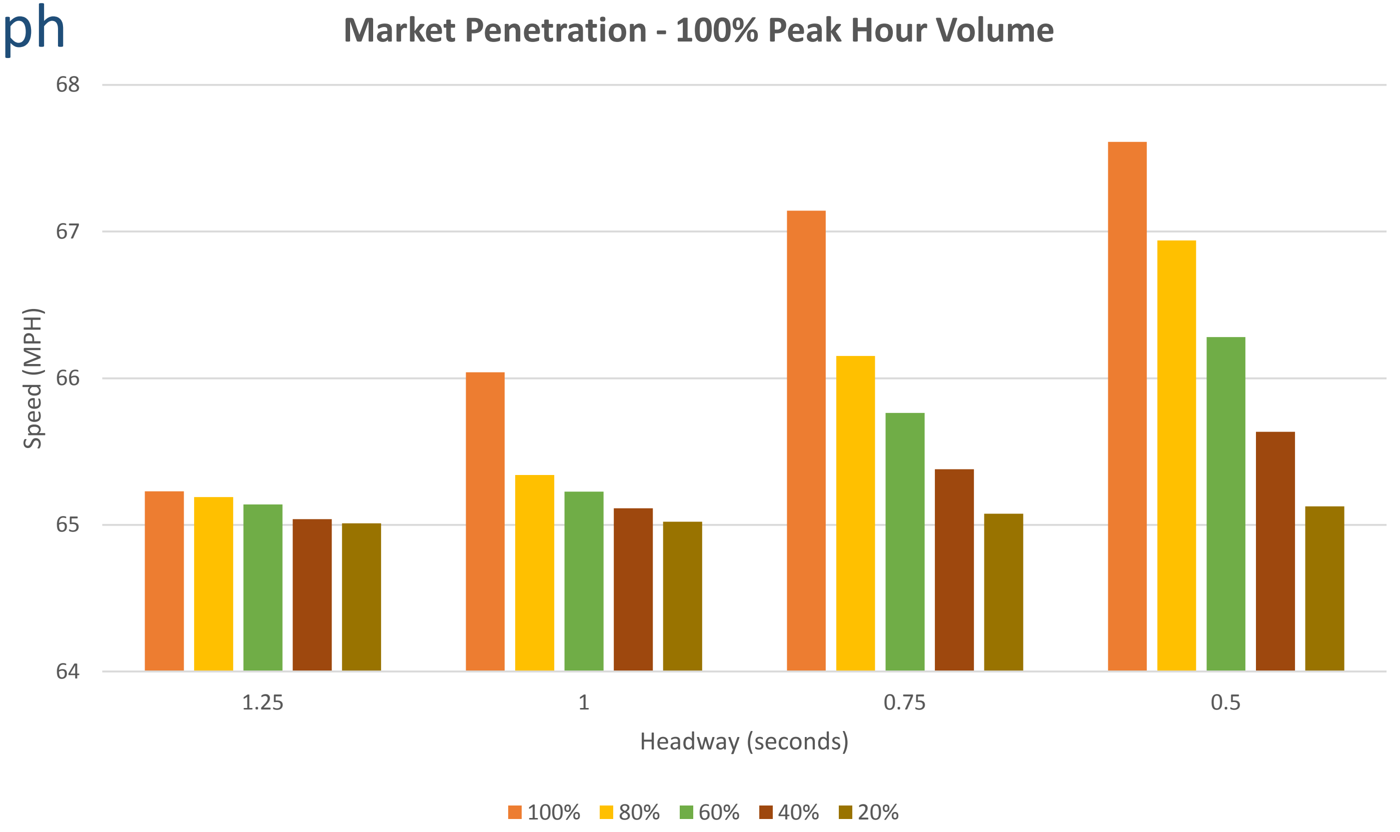
Traffic Flow and Mobility Impacts

- Approach
  - Use of microscopic traffic simulator CORSIM to examine DATP effect on traffic efficiency
  - Simulation Area: I-85 in Auburn, AL from beyond exit 57 to exit 62
    - Section includes three exits
  - Three parameters are varied through 63 simulation cases
    - Headway: 1.25s, 1.00s, 0.75s, 0.50s
      - Non-advanced technology vehicles headway distribution centered at 1.50s
    - Market Penetration: 20%, 40%, 60%, 80%, 100%
    - Traffic Volume: Peak Hour Volume (PHV), 115% PHV, 130%
      - Three baseline cases correspond to traffic volume
  - Did not examine entry /exit effects in this phase

Traffic Flow and Mobility Impacts

- Results
  - All headway and market penetration combinations at present peak hour volume
    - Average Speed Results
    - Baseline average speed: 65.02 mph

Baseline Model Results		
Traffic Volume	Travel Delay (sec)	Average Speed (mi/h)
PHV	19.11	65.02
115% PHV	46.68	65.11
130% PHV	69.08	65.07



Traffic Flow and Mobility Impacts

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- Conclusions
  - DATP caused no delays compared to existing conditions
  - At baseline Peak Hour Volume significant improvement in flow begins at 60% penetration (gaps of 1.25 seconds)
  - Higher traffic flow lead to greater benefit
  - 20% penetration rate only beneficial with very small spacing
  - Reduction in driver decisions should lead to a decrease in incidents on the roadway
- Future work
  - Three vehicle platoons
  - Investigating traffic flow effects on different highway types
  - Restricted lane platooning
  - Examine entry /exit effects

Safety and Human-Machine Interface

- Dissertation by Assad Alam (KTH Royal Institute of Technology)
  - 3 dependent variables
    - Braking ability for both trucks
    - System delay (transmission/computation)
    - Current velocities
  - Perfect case (Safe distance = 4ft)
    - Follower has better brakes
    - No system delay
    - 55mph
  - Conservative case (Safe distance = 50ft)
    - Follower has 20% worse brakes
    - System delay of 0.5s
    - 55mph
- Our case
  - System delay ~0.05s
  - Follower always has better or equivalent brakes
  - 64mph

Safety and Human-Machine Interface

- Review of Peloton Technology
  - User-comfort discussion w/ Auburn NCAT drivers
  - Monitors- location in cab, warning signals, text size/color, brightness/glare
    - Map features (zoom, goal-location view, etc)
  - Hard stops – location, size, color, shape, texture
  - Inter-vehicle hazard detection system
    - Cut-ins

- Lane-departure technology
  - Meritor-Wabco – increased warnings due to platooning?

Safety and Human-Machine Interface

- Phase II Plans
  - Hands-on review of Peloton technology
    - Propose redesign solutions if necessary
    - Review Peloton's training of the drivers
  - Safe distance validation – test track
    - Brake tests
    - System delay tests
  - Inter-platoon hazard (cut-in)
    - User-comfort with current warning signals/automatic deceleration

Phase II Status / Plans

- System Preparation
  - Essential platooning equipment:
    - Radar
    - GPS antennas and receivers
    - Video Camera
    - DSRC Radios/Antennas
    - Data Acquisition Unit
    - Tablets for HMI
    - Power Inverter/Charger
  - All equipment purchased and installed onto the Peterbilt 579’s
  - All equipment must be fastened down in a safe and secure manner
  - External equipment fixed to body of trucks must abide by federal highway laws and regulations

Phase II Plans

- Initial Testing
  - Brake and throttle command must be tested on individual trucks first
  - DSRC must be tested in separate lane test
  - Once DSRC is validated, initial on-track testing begins
  - NCAT track to be undergoing road work and maintenance beginning April 2015 (only one lane available during this time)
  - Testing has been broken down into the following buckets:
    1. One Truck/No Trailer
    2. One Truck/With Trailer
    3. Two Trucks/No Trailers/No Platooning
    4. Two Trucks/With Trailer/No Platooning/On-Track
    5. Two Trucks/With Trailer/No Platooning/Off-Track
    6. Two Trucks/With Trailer/Platooning/On-Track
    7. Two Trucks/With Trailer/Platooning/Off-Track
  - This is to make testing as efficient as possible and reduce testing hours
  - System tested and validated on NCAT test track and ready for highway runs
- Demonstrations: planning underway based on funding modification (added $105k for 2 shows)
- On Road Testing: AL DOT approval already granted for on-road testing
- Next possible control: lateral control

Planned Highway Testing Hours

- ALDOT has approved highway testing for the project
- At least 4 different following distances to be tested:
  - 10m
  - 15m
  - 20m
  - 50m
- Target Speed: 64mph
- Distance: 40 – 50 miles (I-85 b/t Montgomery and GA State Line)
- Sequence:
  - Warm up → Baseline (min. 3 runs) → Tests (min. 3 runs)
  - To be repeated for each following distance
- Highway testing planned to start in Summer 2015
- Candidate demonstration locations:
  - TMC Fall Meeting (Orlando)
  - SAE Commercial Vehicle Show (Chicago) or AV Summit (Florida)

Planned Highway Testing Hours

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- Warm-up:
  - Run trucks independently for system and tire warm-up
- Baseline:
  - Run test route independently to achieve a **t/c ratio** (fuel used by test vehicle/fuel used by control vehicle) to within **2%** of each other on 3 consecutive runs
  - 4 to 5 runs maximum
  - 50 mi. runs @ 64 mph = **46 min. 52.5 sec. for one run**
- Testing:
  - Run test route with control truck (by itself) and the two test vehicles (in platoon) to achieve a t/c ratio to within 2% of each other on 3 consecutive runs
  - 4 to 5 runs maximum
- Breaks:
  - Have to be < 20 min. between warm-up/baseline/tests and between each run
  - **If > 20 min. warm-up must be run again**
  - Used for weighing and switching fuel tanks

Planned Highway Testing Hours

Following Distance	Warm-up	Baseline	Testing	Breaks (total)	Totals	Planned
10m	1 hr.	~47 min. per run	~47 min. per run	~200 min.	~12 hr. 10 min.	13 hr.
15m	1 hr.	~47 min. per run	~47 min. per run	~200 min.	~12 hr. 10 min.	13 hr.
20m	1 hr.	~47 min. per run	~47 min. per run	~200 min.	~12 hr. 10 min.	13 hr.
50m	1 hr.	~47 min. per run	~47 min. per run	~200 min.	~12 hr. 10 min.	13 hr.

- Note: each test costs approximately $5K

Discussion: Additional Potential Testing Options

- Areas of potential research:
  - Following distance
    - Specific regions of interest
  - Number of vehicles in platoon
    - Greater than 2-truck platoons
  - Trailer configurations
    - Aero-tails, double pups, etc.
  - Lateral Steering Study
- These potential areas of research would require additional funding
  - Simulation evaluations would be cost efficient

Other Platoon Configurations: Following Distance

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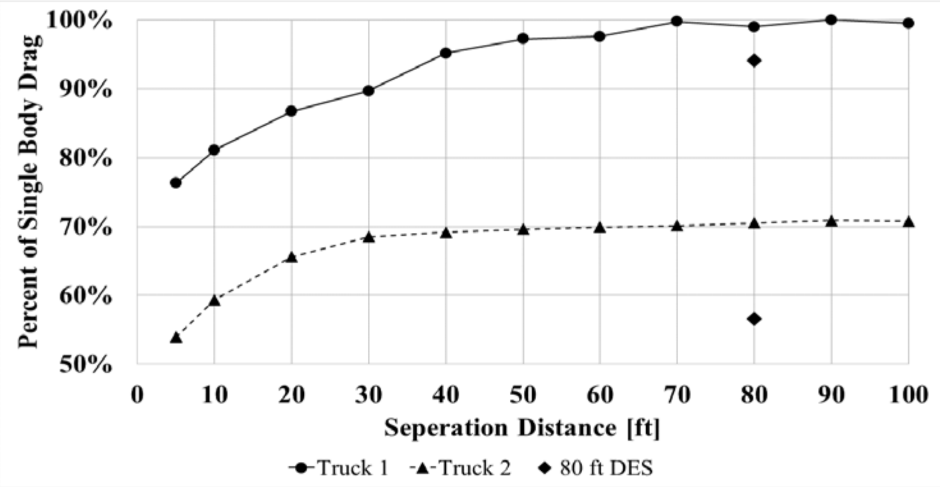
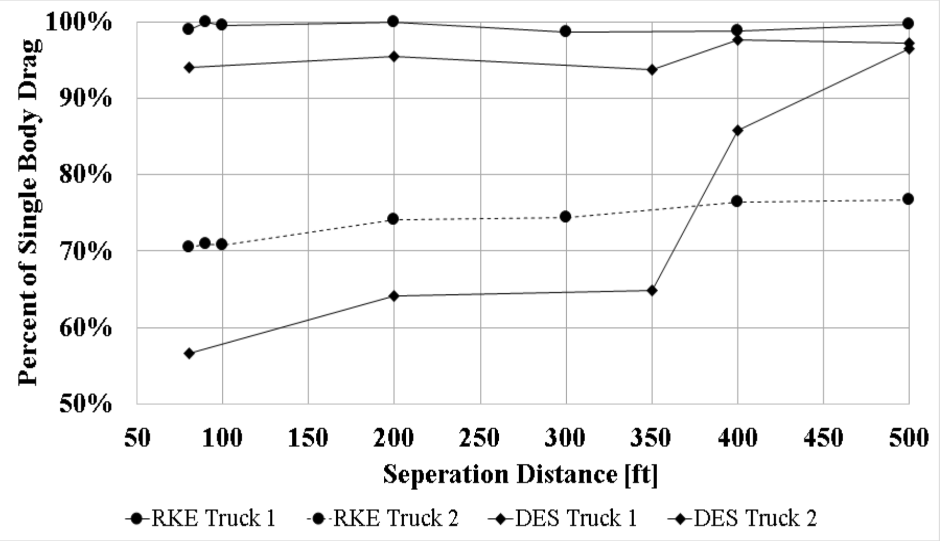
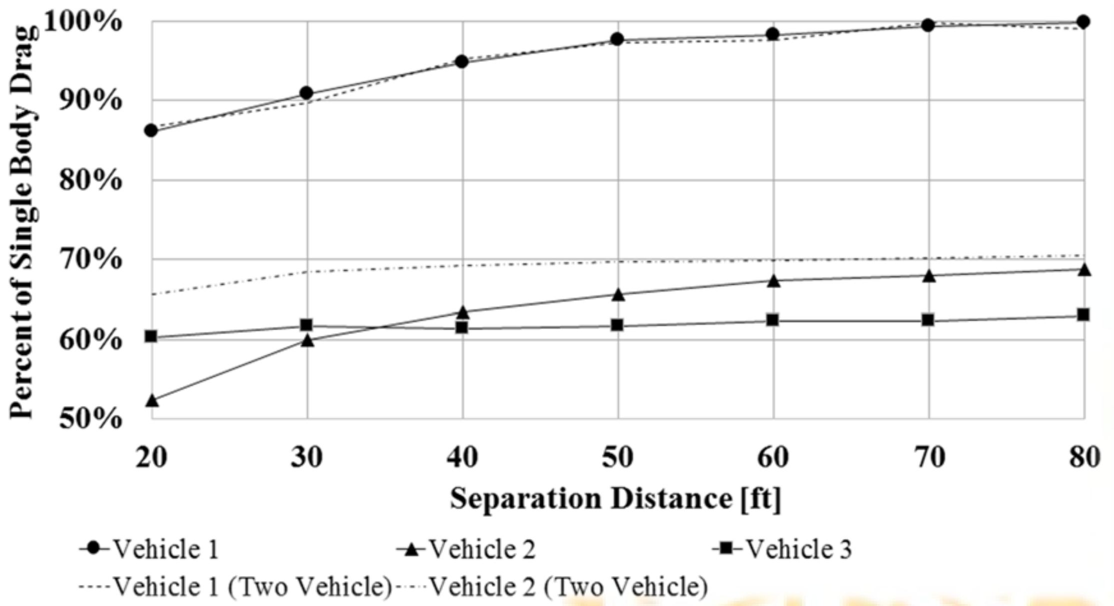
- Transitional areas could benefit from finer distance following testing
  - Aero models show a trend or no change
  - Would like to be able to validate this simulation
- Close Following Distance:
  - Following distance < 10m (< 30ft) (1 or 2 tests)
- Medium Following Distance:
  - 10m (30ft) < following distance < 30m (90ft) (2 or 3 tests)
- Long Following Distance:
  - Following distance > 20m (60ft) (2 or 3 tests)
- Other configurations besides following distance:
  - Double pups trailers
  - Trailers with aero tails
  - Three truck platoons

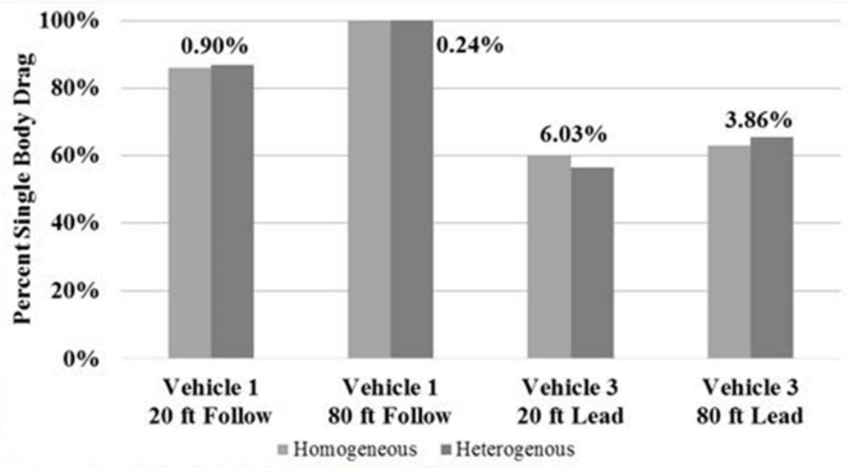


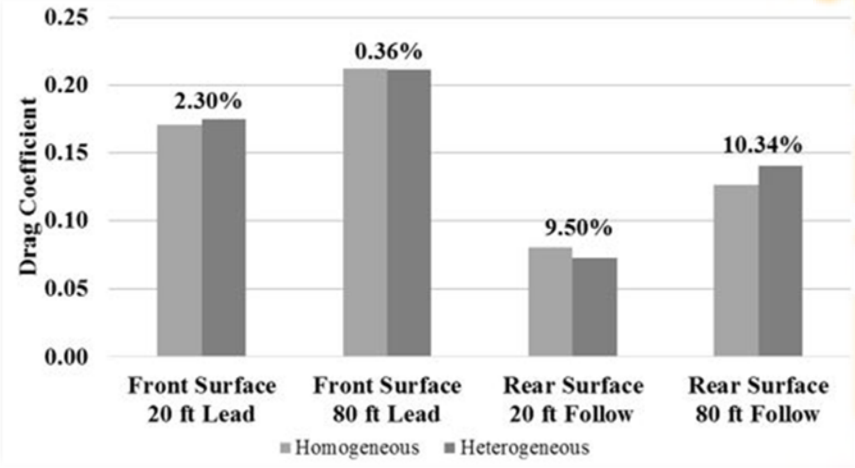


Other Platoon Configurations: Three Trucks

- Three truck platoons
  - Equidistant platoons
    - Vehicle 1 similar to two vehicle platoon
    - Vehicle 2 shows remarkable drag reduction between 20 to 40 feet following distance
    - Vehicle 3 shows a constant drag reduction
  - Non-equidistant platoons
    - Vehicle 1 shows no change (multi-vehicle platoons have no upstream effect beyond 2 vehicles)
    - Vehicle 3 shows change that is not negligible
    - Vehicle 2 shows ~10% difference







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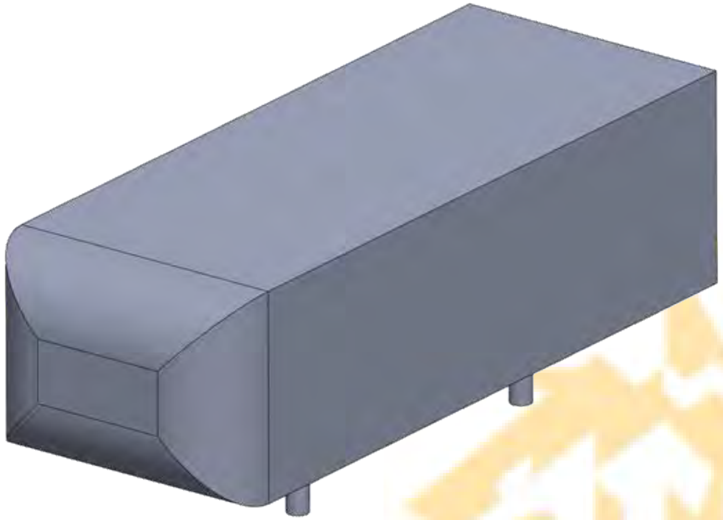
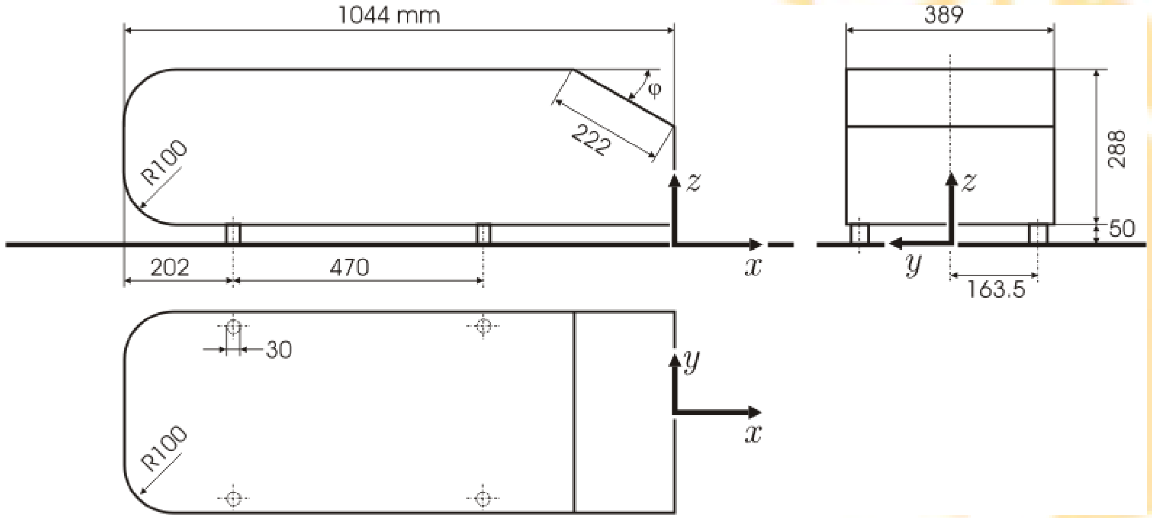
Other Platoon Configurations: Trailer Modifications

- First structure modeled: Ahmed body
  - Designed to represent a simplified, generic bluff body
  - 0° rear slant used to more closely represent tractor-trailer
- Can be changed to have an angle: representative of aero-tails
  - Potentially could cause adverse results
    - Simulation needs validation with highway tests
    - Need for an aero-tails configuration test
- Would also like to investigate the effects of running other tractor trailer combinations
  - Double-pups, tanker trucks, flat beds
  - Passenger Car Cut-ins
  - Simulation-only: approximately $50K - $100K





Benefits of Adding Lateral Control

- Assess driver effectiveness of longitudinal DATP enhanced with lateral control
  - Investigate safety and ergonomics
- Run long duration tests on NCAT test track
  - Modify trucks
  - Verify system
  - Develop human test plan
  - Conduct experiments/Gather data
  - Document results
- Potential start date: Spring 2016
- Approximately $600K - $1M

Conclusion

- Business case and technical analyses regarding DATP are promising regarding viability for commercial use
- Phase I deliverables
  - Concept of Operations and Requirements Document
  - Phase I Results Summary
- Phase II has begun in terms of vehicle preparation, initial system bring-up, and track testing
- Early planning for 2015 demonstrations underway