Pickup Truck Aerodynamics
A PIV Study

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Project Objectives

- To measure the mean and unsteady surface pressure distribution on a generic pickup truck geometry.
- To measure the unsteady flow field in the near wake of a generic pickup truck geometry using PIV.
- To provide a better understanding of the steady and unsteady forces on pickup trucks in order to achieve large drag reduction and reduced unsteady forces through small geometry modifications.

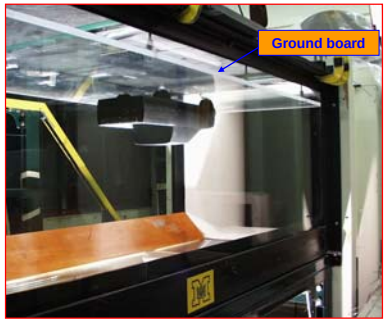
Outline

- Flow facility and Pickup Truck Model
- Pressure Measurement Instrumentation
- PIV Measurements Instrumentation
- Mean Pressure Results
- Unsteady Pressure Results
- Free stream and ground board boundary layer PIV measurements
- Pickup Truck PIV Measurements
- Summary and Plans

Flow Facility

- 60 x 60 *cm* open return, suction type wind tunnel
- Pickup truck model provided by GM R&D
- Ground board mounted on top side of tunnel
- Actual wind tunnel cross section 60 x 50 *cm*
- Model mounted 380 *mm* from ground board leading edge
- Tests conducted at 18, 25 and 30 *m/s* free stream velocity.
- Reynolds numbers based on model height are 1.7×10^5, 2.4×10^5, and 2.9×10^5 respectively.

Wind Tunnel Facility



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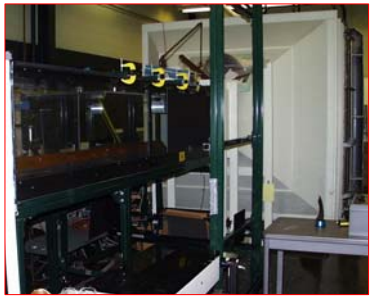
Particle Image Velocimetry System
Laser Sheet Illumination

- Image acquisition using two Nd-YAG lasers
- The duration of each laser light pulse is 6 ns
- The time between exposures was optimized to achieve low measurement noise

PIV Laser Setup for V Planes



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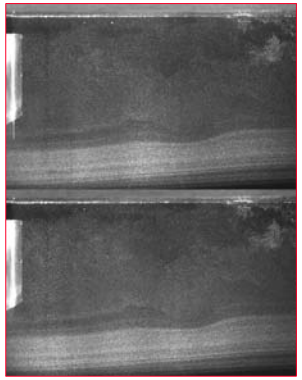
Particle Image Velocimetry System
Image Acquisition

- High resolution digital camera (1280 x 1024 pixels)
- High sensitivity cooled CCD sensor (12 bit digitization depth)
- Typical PIV image shown (not of the pickup truck flow)
- Top part of the picture shows the first image
- Bottom part of the picture shows the second image obtained 20 μm later



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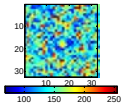
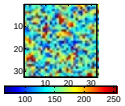
Particle Image Velocimetry System
Image Processing

- New image shift cross correlation technique has been developed.
  - First image shown on the left, shifted secon image shown on the right.
  - Cross correlation shown in bottom contour plot.
- Interrogation window was optimized for each flow condition.
- Typical search window (shown in green on the cross correlation plot.
- Location of the maximum gives the particle displacement.
- Data validation tests:
  - Maximum cross correlation inside search window.
  - Maximum greater than threshold value dynamically determined based on noise level.

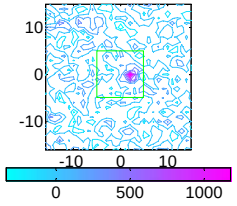
First Image



Second Image



Cross Correlation Contour Plot



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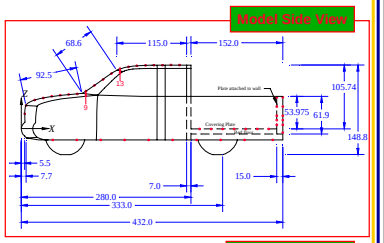
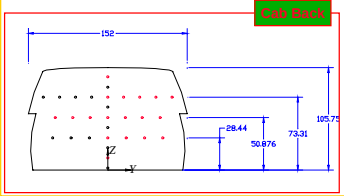
Mean Pressure Measurements

- Mean pressure measurements conducted using a 30-tube oil manometer rake.
- Pressure lines are embedded in the model and routed through orifices in the wheels to minimize flow interference.
- Up to 36 manometer rake readings were recorded optically and averaged to obtain the mean pressure.
- The measurement uncertainty is less 0.3% of the dynamic pressure.
- The locations of pressure taps are shown in the drawings.

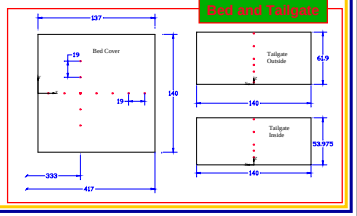
Model Side View



Cab Back



Bed and Tailgate

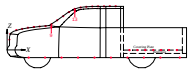


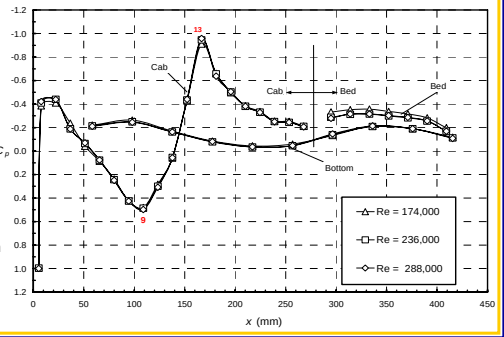
Mean Pressure Measurements

Horizontal Surfaces

Centerline Pressure Distribution

- The red numbers show reference points in the drawing and graph.
- Red circles show the locations of pressure taps.
- The cab pressure distribution has maximum suction near the front of the roof and over pressure at the lower corner of the windshield.
- The pressure distribution on the bottom surface shows variations that can be attributed to the narrowing of the flow path at the wheels.
- The bed pressure distribution shows some Reynolds number dependence for Reynolds number less than 2.4×10^5.

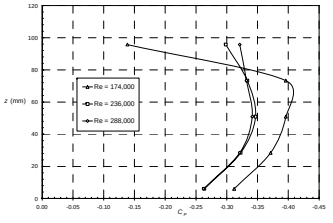


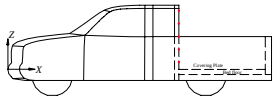


Mean Pressure Distribution – Vertical Walls

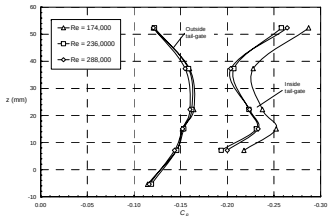
Cab Back and Tailgate

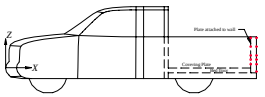
Cab Back





Tailgate

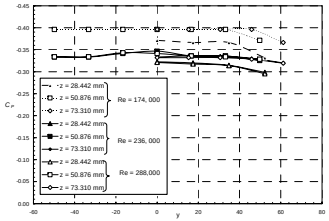




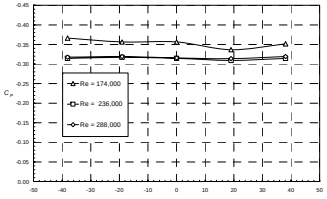
Mean Pressure Distribution

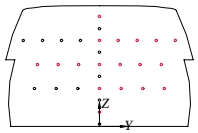
y-variation of mean pressure in the back of the cab and the bed

Cab Back

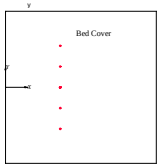


Bed





Flow direction



Summary Mean Pressure Measurements

- The mean pressure on the cab, bed, tailgate and bottom surfaces has been measured at three flow conditions.
- The mean pressure distributions on the cab front surface, bottom surface and external surface of the tailgate are independent of Reynolds number.
- The mean pressure distribution on the cab back surface, bed surface and tailgate internal surface show a slight dependence on Reynolds number below 2.4×10^5.
- The surface pressure distributions on the cab front surfaces, truck bottom surface and tailgate external surface are consistent with expected trends.
- On the bed surface the pressure increases slightly with downstream distance.
- On the inside surface of the tailgate the pressure shows large variations decreasing near the top edge.
- On the back side of the cab the minimum pressure is found at the center.

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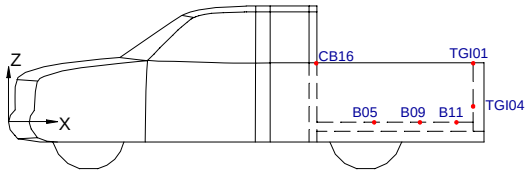
Unsteady Pressure Measurements

- Validyne P305D pressure transducer installed inside the model.
- Tektronix AM402 instrumentation amplifier
- National Instruments PCI-6023E Data acquisition board
- Sample frequency 250 *Hz*
- Sample duration 400 *s.*
- Frequency range DC to 100 Hz.
- Digitization resolution <0.04 *Pa*
- Unsteady pressure measurements conducted at six pressure ports in the bed: CB16, B05, B09, B11, TGI01 and TGI04



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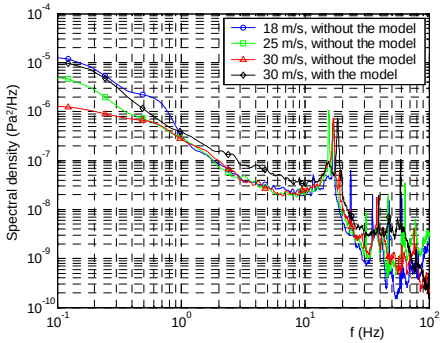
Unsteady Pressure Measurements

Free Stream Total Pressure Spectrum

- Very small amplitude pressure fluctuation.
- RMS value of pressure coefficient fluctuation less the 0.15%.
- Broad spectral peak at low frequency due to unsteadiness of the circulatory flow in the lab (open return wind tunnel).
- Narrow spectral peaks at 100-200 Hz due to electrical noise from the tunnel motor.



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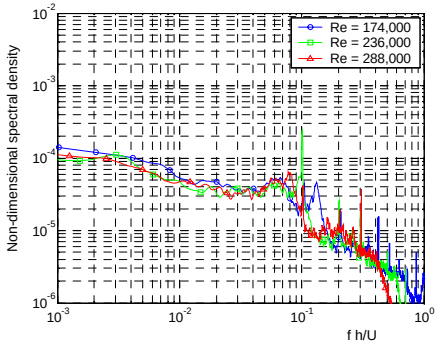
Unsteady Pressure Measurements

Pressure Port CB16

- Very low amplitude fluctuations. RMS values of pressure coefficient fluctuation ~0.004.
- Flow-induced spectral peaks at fh/U ~ 0.07 have smaller amplitude than noise peaks.



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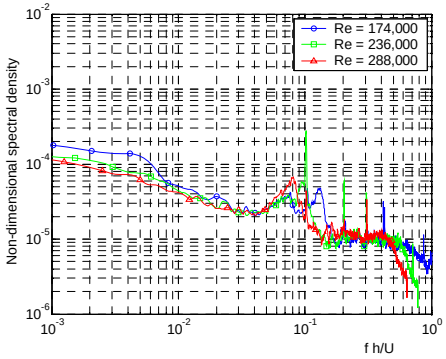
Unsteady Pressure Measurements

Pressure Port B05

- Very low amplitude fluctuations. RMS values of pressure coefficient fluctuation ~0.005.
- Flow-induced spectral peaks at fh/U ~ 0.07 have smaller amplitudes than noise peaks.
- At lowest Reynolds number a second flow-induced spectral peak found at fh/U ~ 1.1



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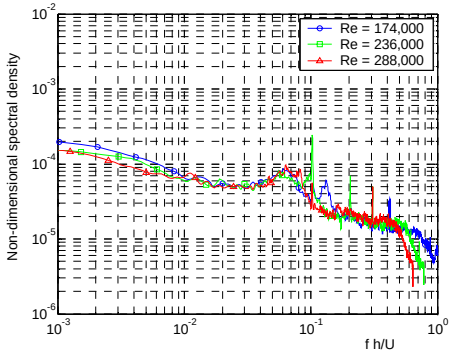
Unsteady Pressure Measurements

Pressure Port B09

- Very low amplitude fluctuations. RMS values of pressure coefficient fluctuation ~0.0055 - 0.006.
- Flow-induced spectral peaks at fh/U ~ 0.07 have smaller amplitude than noise peaks.
- At lowest Reynolds number a second flow-induced spectral peak found at fh/U ~ 1.1



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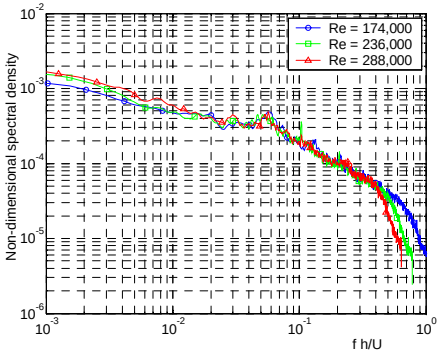
Unsteady Pressure Measurements

Pressure Port B11

- RMS values of pressure coefficient fluctuation ~0.0121 -0.0127.
- Spectral density well above noise levels.
- Good collapse of data at various Reynolds numbers
- Spectral density at low frequency increased by an order of magnitude compared to upstream pressure ports (CB16,B05,B09)
- Flow-induced spectral peaks at fh/U ~ 0.06.
- Flow-induced pectral peak at fh/U ~ 1.1 for lowest Reynolds number is very weak.



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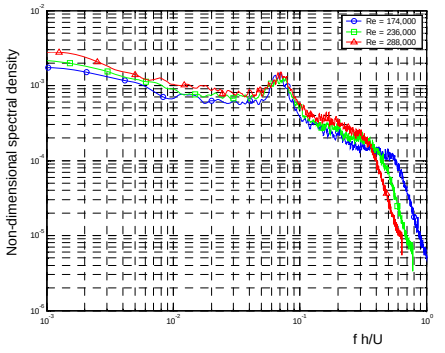
Unsteady Pressure Measurements

Pressure Port TGI01

- RMS values of pressure coefficient fluctuation ~0.0184 -0.0193.
- Spectral density well above noise levels at all frequencies.
- Good collapse of data at various Reynolds numbers
- Spectral density at low frequency increased by an order of magnitude compared to upstream pressure ports (CB16,B05,B09)
- Broad flow-induced spectral peak observed at fh/U ~ 0.07.
- Flow-induced spectral peak at fh/U ~ 1.1 for lowest Reynolds number not observed.



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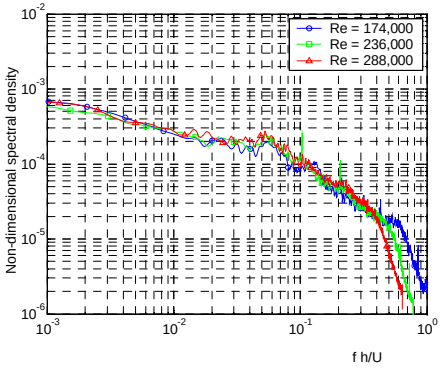
Unsteady Pressure Measurements

Pressure Port TGI04

- RMS values of pressure coefficient fluctuation ~0.0085.
- Good collapse of data at various Reynolds numbers
- Spectral density at low frequency increased compared to upstream pressure ports (CB16,B05,B09)
- Broad flow-induced spectral peak found at fh/U ~ 0.06.
- Flow-induced spectral peak at fh/U ~ 1.1 for lowest Reynolds number is observed but is very weak.



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Summary Unsteady Pressure Measurements

- RMS amplitude of pressure coefficient fluctuations at the forward part of the bed behind the cab are very small less than 0.0065.
- RMS amplitude of pressure coefficient fluctuations at the back of the bed and the tailgate are significantly larger in the range 0.008 to 0.019. The larger values are found at the edge of the tailgate
- Spectra at all locations and Reynolds numbers show large values of the spectral density a very low frequency suggesting an unexpected sensitivity of the pickup truck flow field to very small amplitude fluctuations in the free stream.
- Spectra measured on the tailgate show a flow-induced spectral peak at f h/U = 0.07 . This spectral peak appears to be associated with unsteady separation of the flow at the tailgate edge.

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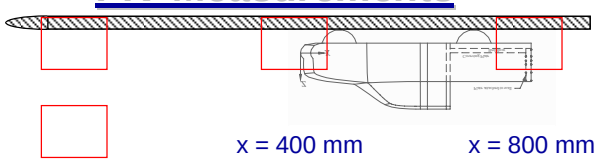
Ground Board Boundary Layer PIV Measurements



x = 100 mm x = 400 mm x = 800 mm

- All measurements conducted without the pickup truck model installed. Model shown in graph for reference.
- Ground board boundary layer measurements conducted at three locations x = 100, 400 and 800 *mm* from leading edge, and three speeds 17, 21 and 28 *m/s*.

x (*mm*)	100	400	800
Image magnification (*px/mm*)	46.9	32.0	28.7
Interrogation window (*px*)	128×16	128×16	128×16
Interrogation window (*mm*)	2.7×0.34	4.0×0.50	4.46×0.56
Field of view (*mm*)	26×22	39×32	43×36

- PIV image processing parameters shown in the table.
- Free stream PIV measurements at x =100 *mm*
- Measured free stream turbulence intensity 0.24%

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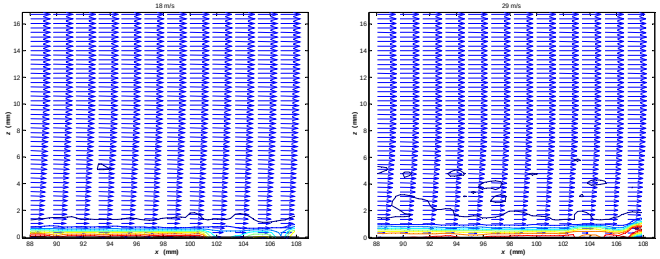
Ground Board Boundary Layer Measurements

x = 100 mm



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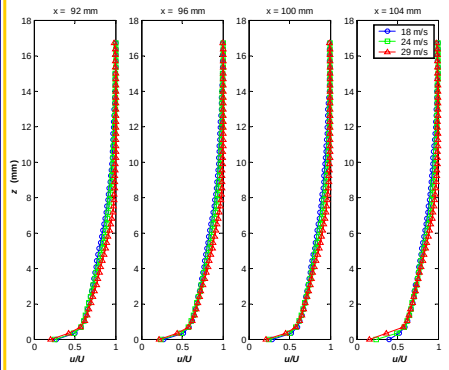
Ground Board Boundary Layer Measurements (x = 100 mm)



- Turbulent boundary layer
- Boundary layer velocity thickness in the range ~11 *mm* at low speed to ~8.5 *mm* at the high speed

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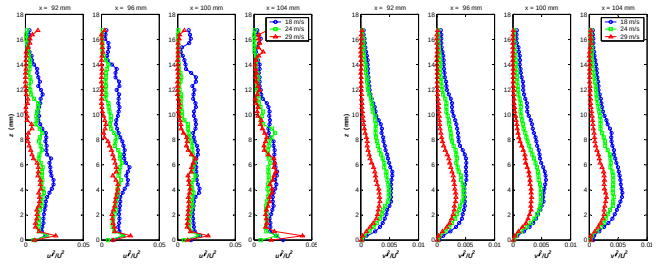
Ground Board Boundary Layer Measurements (x = 100 mm)



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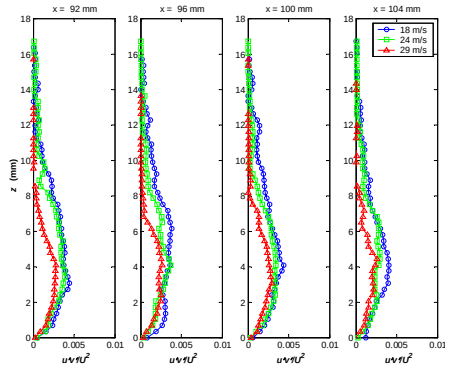
Ground Board Boundary Layer Measurements (x = 100 mm)



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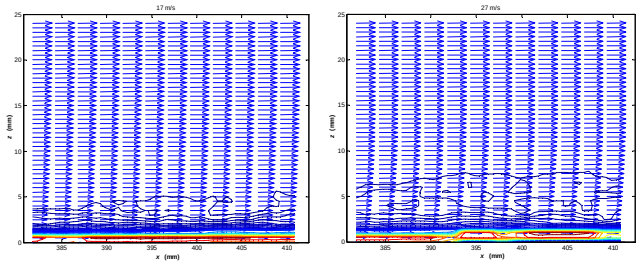
Ground Board Boundary Layer Measurements

x = 400 mm



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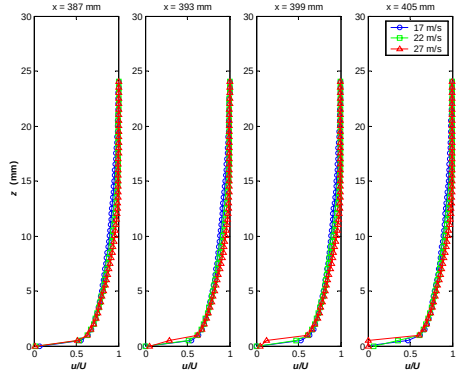
Ground Board Boundary Layer Measurements (x = 400 mm)



- Turbulent boundary layer
- Boundary layer velocity thickness in the range ~16 *mm* at low speed to ~11 *mm* at the high speed

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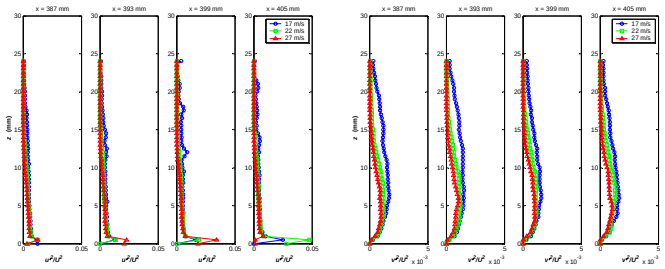
Ground Board Boundary Layer Measurements (x = 400 mm)



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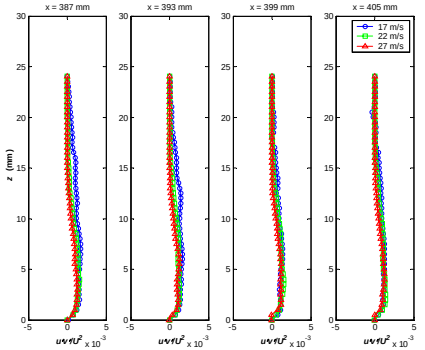
Ground Board Boundary Layer Measurements (x = 400 mm)



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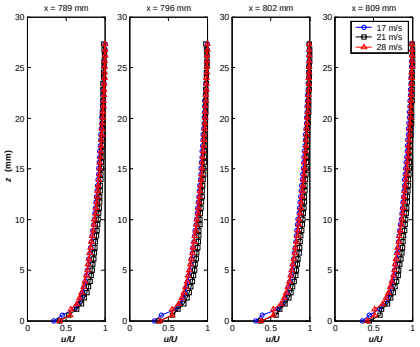
Ground Board Boundary Layer Measurements (x = 400 mm)



- Turbulent boundary layer
- Boundary layer velocity thickness in the range ~18 *mm* at low speed to ~15 *mm* at the high speed

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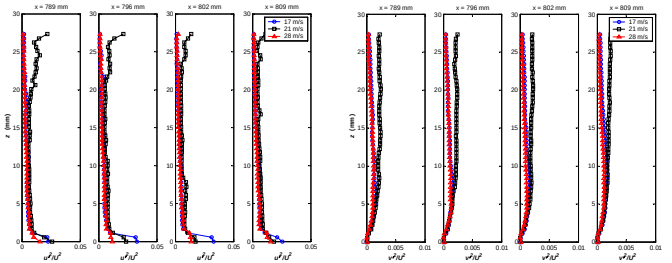
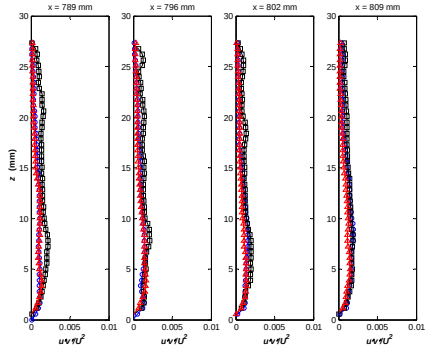
Ground Board Boundary Layer Measurements (x = 400 mm)



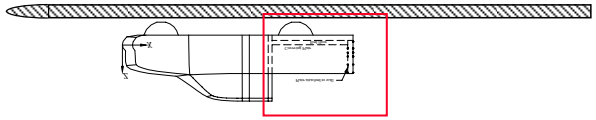
Ground Board Boundary Layer Measurements (x = 400 mm)



Summary Ground Board Boundary Layer Measurements

- Data acquisition completed.
- Preliminary analysis of the data revealed no unexpected results.
- Turbulent boundary layer at the three locations and at the three speeds tested.
- Boundary velocity thickness range from ~1.5*cm* at the front bumper to ~1.7 *cm* at the tailgate.
- Turbulence data obtained but are still being analyzed.

Pickup Truck PIV Measurements

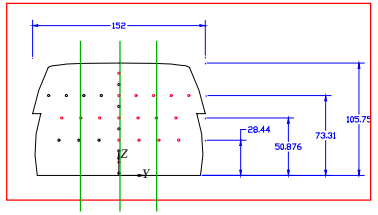


- Pickup truck measurements conducted on six planes and three speeds ~17, ~21 and ~28 *m/s.*
- Image magnification: 4 *px/mm*.
- Field of view: 310×256 *mm*.
- Interrogation window: 16×16 *mm* (64×64 *px*).

Pickup Truck PIV Measurements

Vertical Planes

- Three vertical planes documented:
  - Symmetry plane
  - y = 33.21 *mm*
  - y = - 33.21 *mm*
- Measurement inside and outside bed.
- Field of view:
  - x - 300 to 500 *mm*
  - y - 0 to 150 *mm*

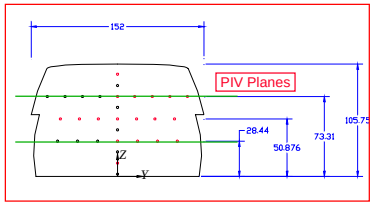


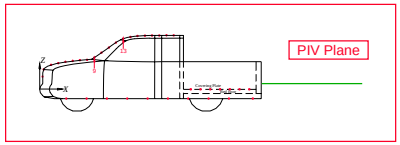
PIV Planes

Pickup Truck PIV Measurements

Horizontal Planes

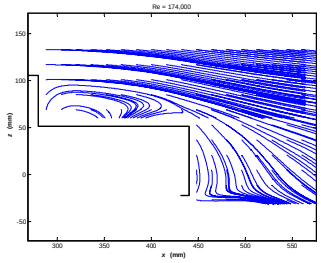
- Three horizontal planes tested:
  - z = 73.31 *mm* above bed
  - z = 28.44 *mm* inside bed
  - z = 15.08 *mm* behind tailgate
- Field of view:
  - x - 300 to 500 *mm*
  - y - 75 to -75 *mm*

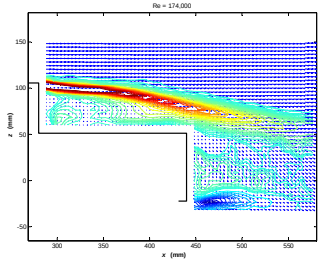




Pickup Truck PIV Measurements Symmetry Plane

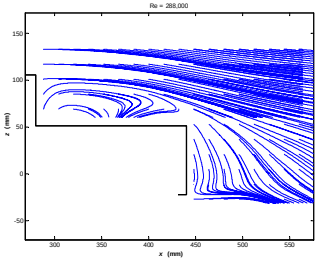
U = 18 *m/s*

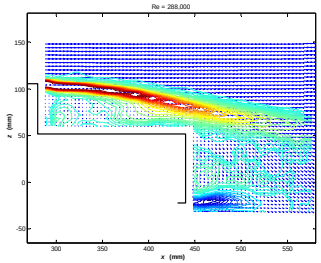




Pickup Truck PIV Measurements Symmetry Plane

U = 30 *m/s*

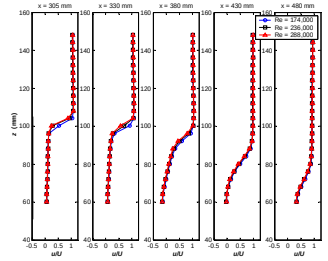




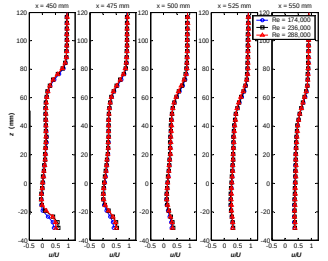
Pickup Truck PIV Measurements Symmetry Plane

Mean velocity x-direction

Flow over the bed



Flow behind the tailgate



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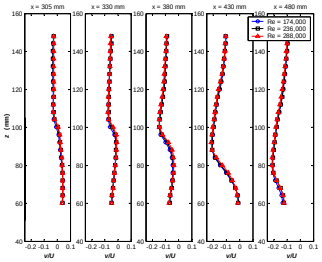
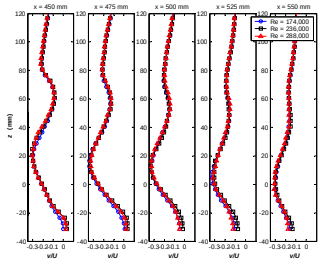
Pickup Truck PIV Measurements
Symmetry Plane

Mean velocity y-direction

Flow over the bed | Flow behind the tailgate





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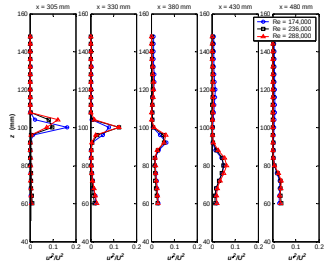
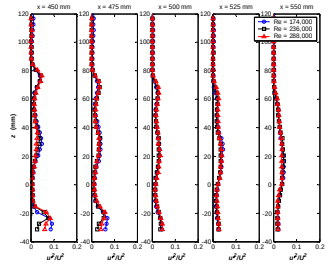
Pickup Truck PIV Measurements
Symmetry Plane

$\overline{u'^2}$ Reynolds Stress

Flow over the bed | Flow behind the tailgate





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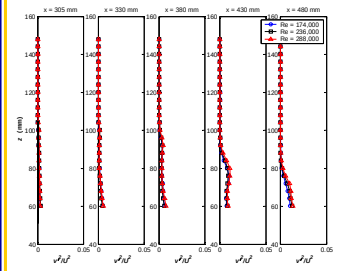
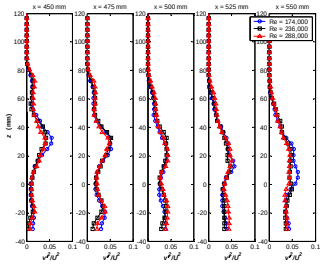
Pickup Truck PIV Measurements
Symmetry Plane

$\overline{v'^2}$ Reynolds Stress

Flow over the bed | Flow behind the tailgate





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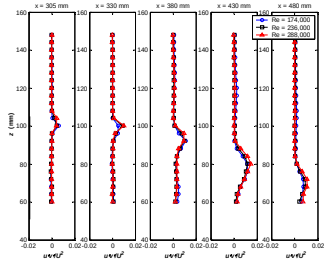
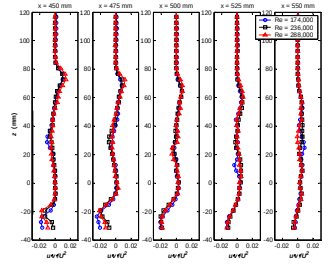
Pickup Truck PIV Measurements
Symmetry Plane

$\overline{u'v'}$ Reynolds Stress

Flow over the bed | Flow behind the tailgate





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Summary Pickup Truck PIV Measurements

- PIV velocity field measurements of pickup truck flow have been completed on the symmetry plane.
- Preliminary analysis of the data show a relatively quite region behind the cab and an unexpected flow behavior around the tailgate.
- There is no recirculation region behind the tailgate at the flow conditions tested.
- Turbulence data was obtained and is being analyzed.

Plans

- Complete PIV measurements at 2 more vertical planes and 3 horizontal planes.
- Continue PIV data.
- Synchronized PIV-unsteady pressure measurements (PIV on symmetry plane).
- Develop data processing.
- Prepare final report by 30 June 2002.