# Update on Juncture Flow PIV

## Results & Future Plans

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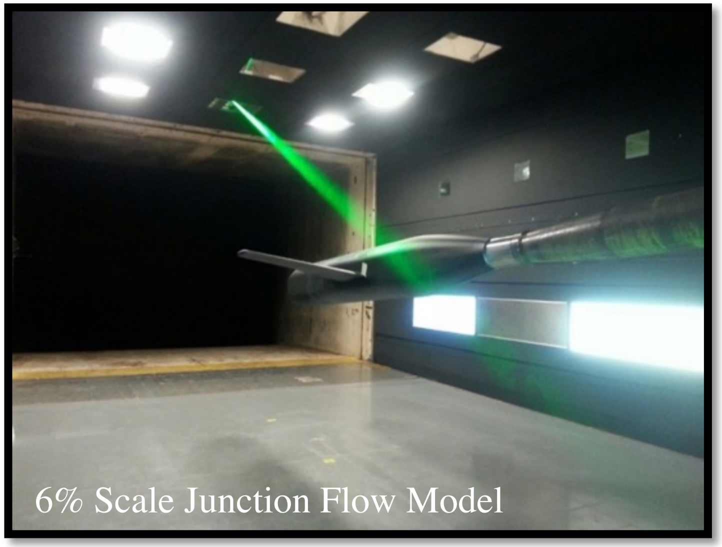
# Introduction

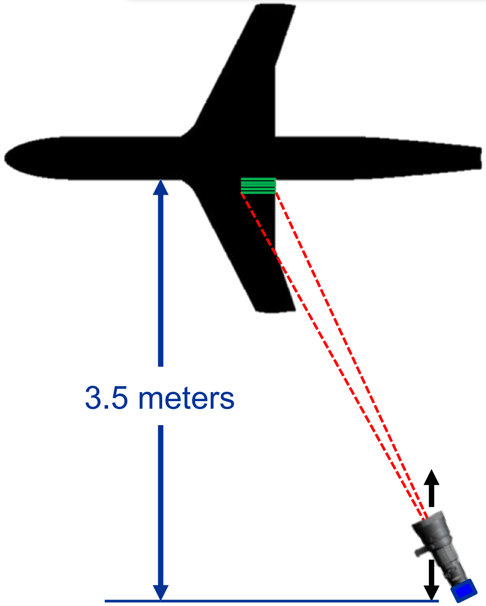
- Benchmark-quality data of the off-body flow in the wing-fuselage junction is needed for continued assessment and validation of turbulence models, flow solvers, and numerical methods.
- A myriad of measurement techniques are being used to characterize the flow in this region and develop a comprehensive picture of the separation process.
- In this experiment, Particle Image Velocimetry (PIV) is being used as a complimentary technique to LDV.
  - PIV is a proven, effective tool for investigating complex flows and providing both quantitative information and qualitative details.
  - Provides data and insight into the instantaneous and mean characteristics of the flow field over a larger spatial area.
  - Provides additional guidance for selecting LDV measurement locations.

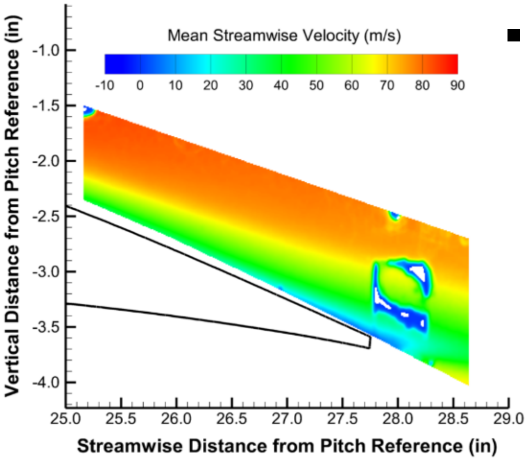
# Objectives

- Develop and implement an embedded PIV system to obtain off-body measurements in the wing-fuselage junction of the Juncture Flow Model near the wing trailing edge.
- Identify potential risks and problems to be addressed before applying the system in subsequent tests.

# First Version – 2D

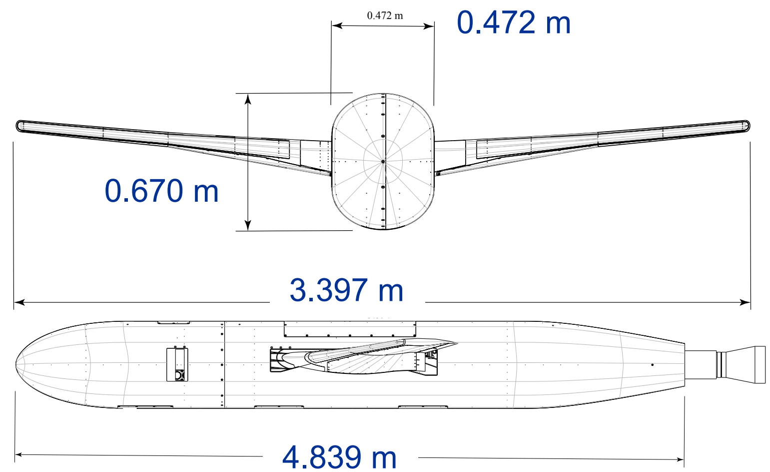


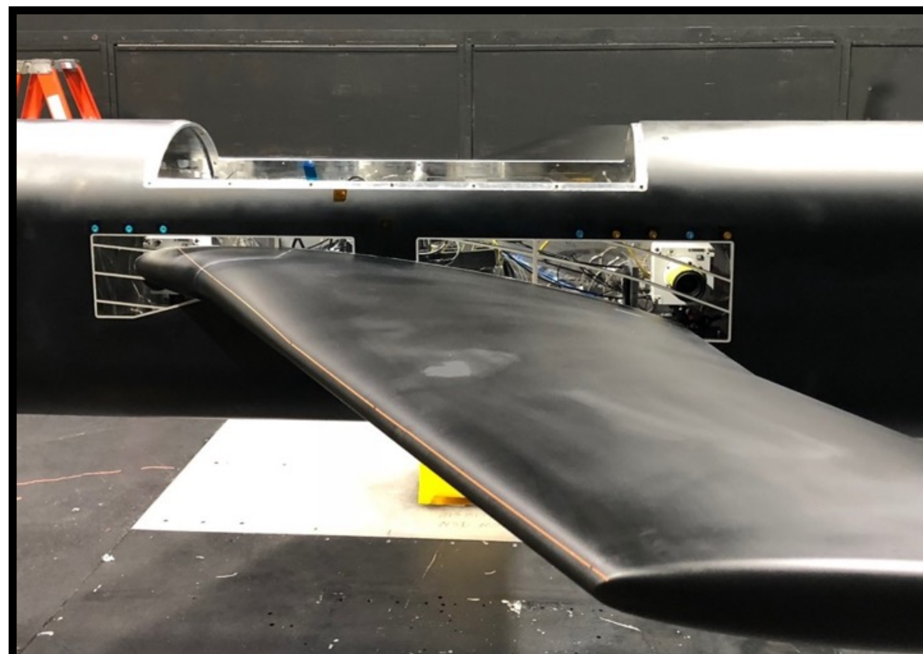




- Configuration
  - Focused on the wing-fuselage junction at the trailing edge.
  - 5 megapixel sCMOS camera mounted in tunnel wall.
  - 340 mJoule Nd-Yag laser
  - Light sheet projected through ceiling window.
  - Traverse system used to acquired data at several spanwise locations.
- Efficient operation - 1000 images acquired and stored in 3-5 minutes.
- Issues
  1. Field of view dependent on optical access into the test section.
  2. Different system configuration and calibrated required for each angle of attack.
  3. Slight model motion can cause inaccuracies in measurement location.
  4. Difficult to acquire data in model coordinate system.

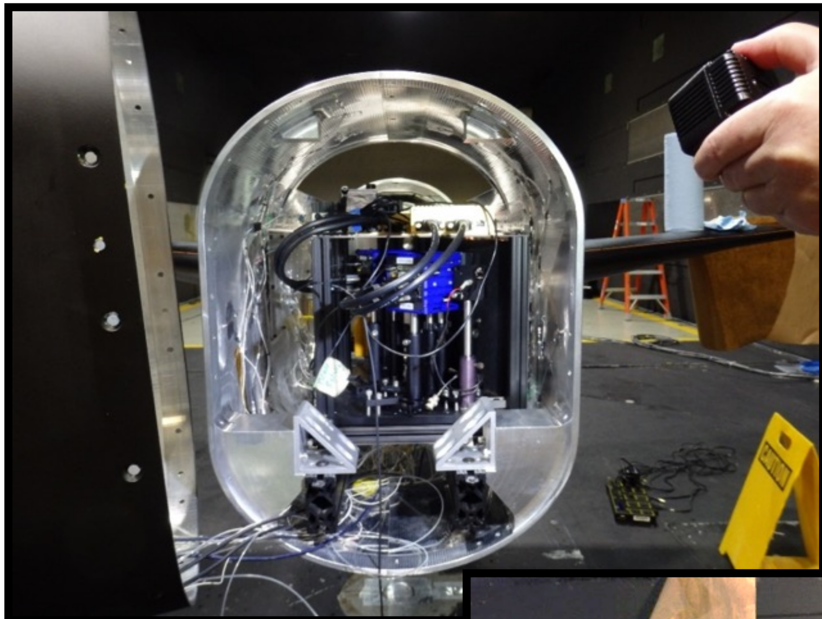
# 8% Scale Junction Model

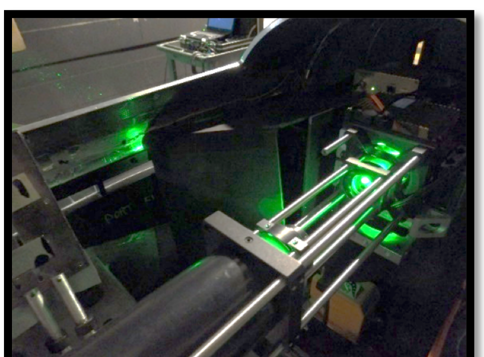



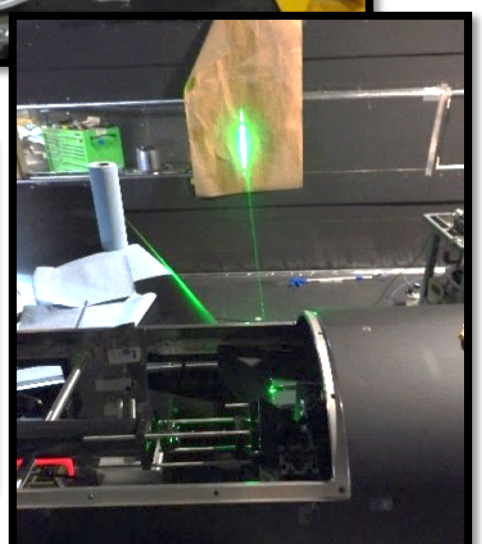



**Opportunity!!!**

# Second Version - Stereo

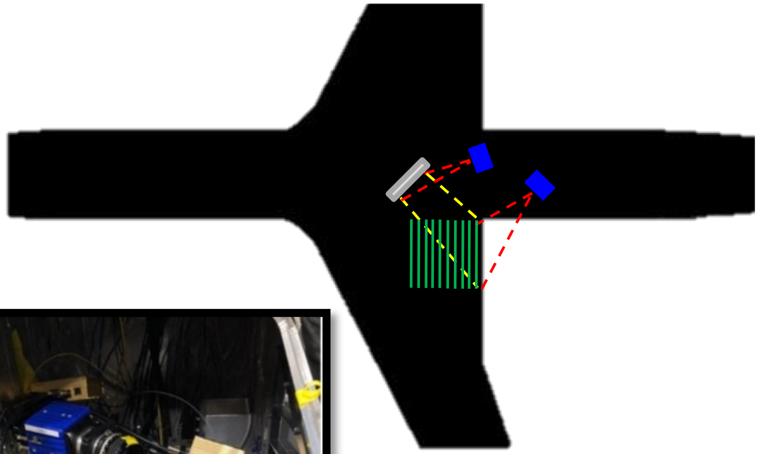


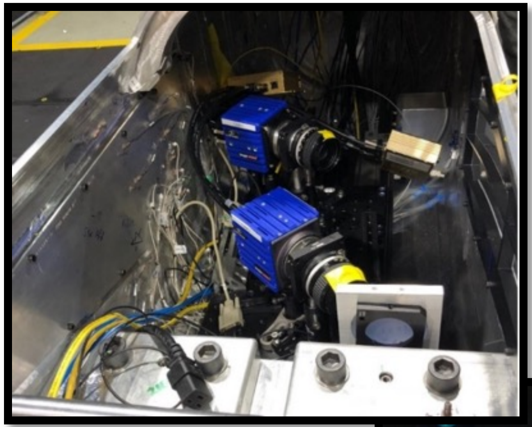


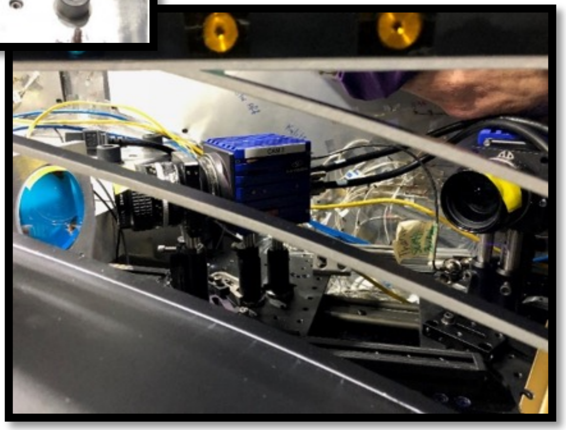


- Configuration
  - Measurements near wing leading edge (without the horn).
  - Two, 5 Megapixel sCMOS cameras mounted in the fuselage at a fixed location (*no traversing capability*)
  - Laser head and lightsheet optics mounted inside model and light sheet projected through model window.
- Significant improvement in efficiency
  - FOV set and calibration performed external to model.
  - Data can be acquired at any angle of attack.

# Third Version – Stereo

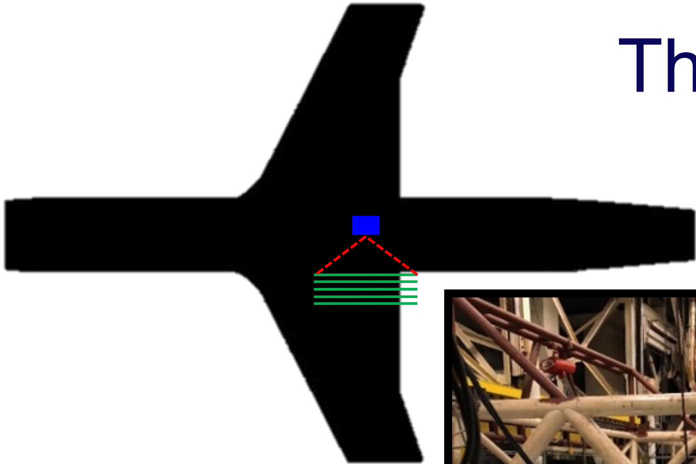




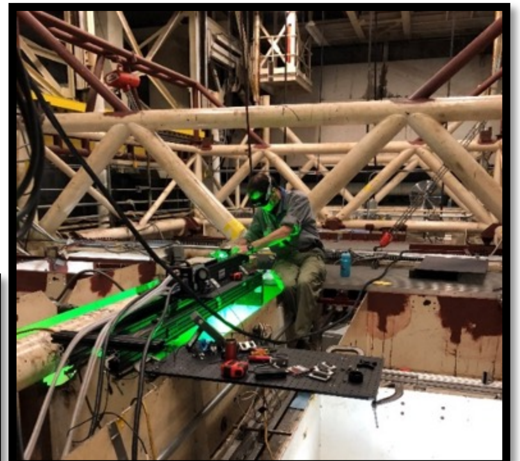


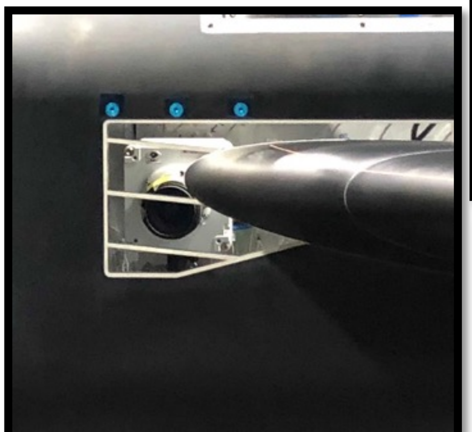
- Configuration
  - Measurements in wing junction near trailing edge (with horn).
  - Two sCMOS cameras mounted in model on translation stage
  - Mirror used to increase angle between cameras
  - 340 mJ Nd-Yag laser
  - Light sheet projected through window in tunnel ceiling
- Data acquired in spanwise planes at five longitudinal locations
  - α = -2.5 degrees
  - 3 velocity components
  - Sample Rate = 15 Hz
- Limitations
  - Flare from the wing surface obliterated the signal in the downstream camera so no useable data was obtained.
  - Location of windows in tunnel ceiling did not permit the lightsheet to be projected normal to the chord for α > 4 degrees.

# Third Version – 2D



- Configuration
  - Measurements in wing junction near trailing edge (with horn).
  - Two 4 megapixel, high-speed cameras mounted on translation stages inside model.
  - 40 mJoule, Nd-YLF laser mounted on the tunnel ceiling and light sheet projected through ceiling window.



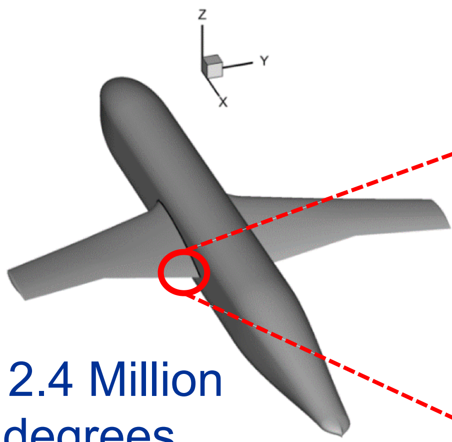


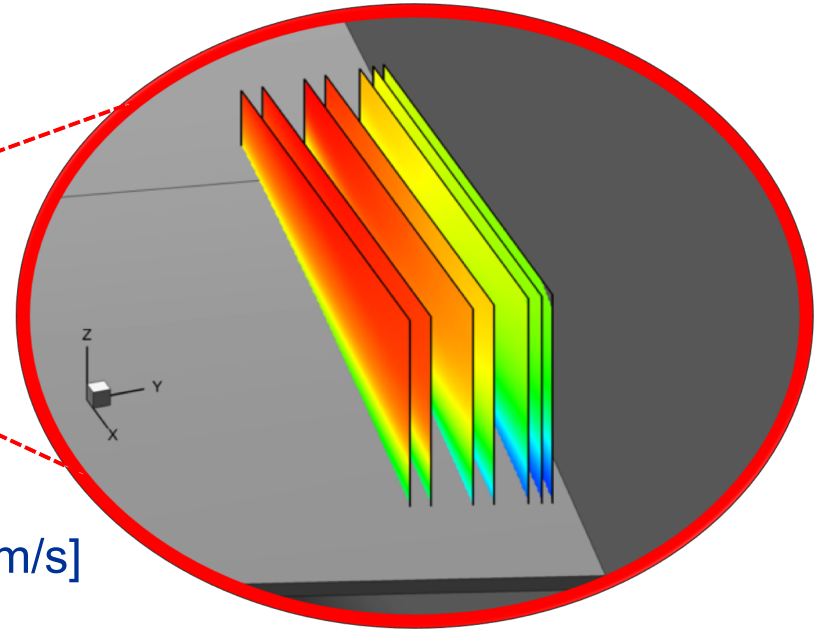
Forward Camera

Rear Camera

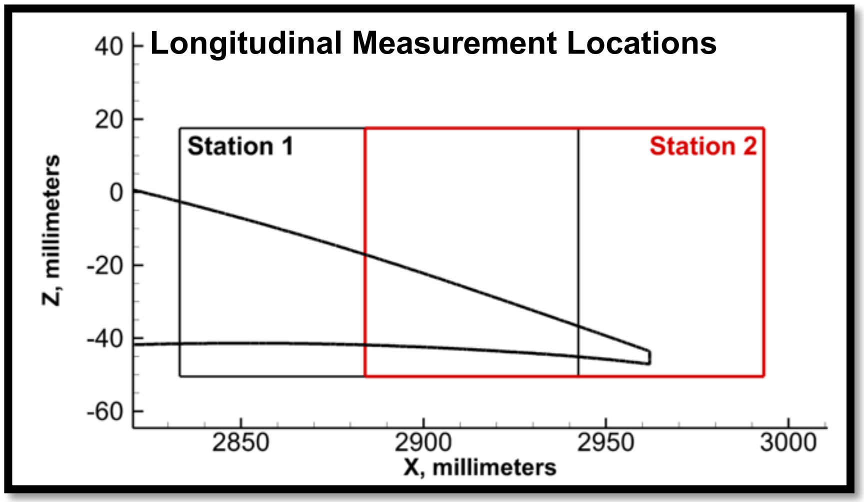
| System and Processing Parameters | |
|---|---|
| **Lens Focal Length** | 50 mm |
| **Working Distance** | 227.5 mm |
| **Field of View** | 109.2 mm by 68.0 mm |
| **Image Acquisition Rate** | 742 Hz |
| **Interrogation Window** | 32 pixel by 32 pixel (1.37 mm by 1.37 mm) |
| **Overlap** | 50% |
| **Vector Spacing** | 0.69 mm |

# Measurement Conditions and Locations




- Reynolds Number: 2.4 Million
- Incidence Angle: 5 degrees
- 0.175 ≤ Mach ≤ 0.205 [nom. 0.189]
- 58.07 m/s ≤ $U_\infty$ ≤ 71.99 m/s [nom. 64.27 m/s]

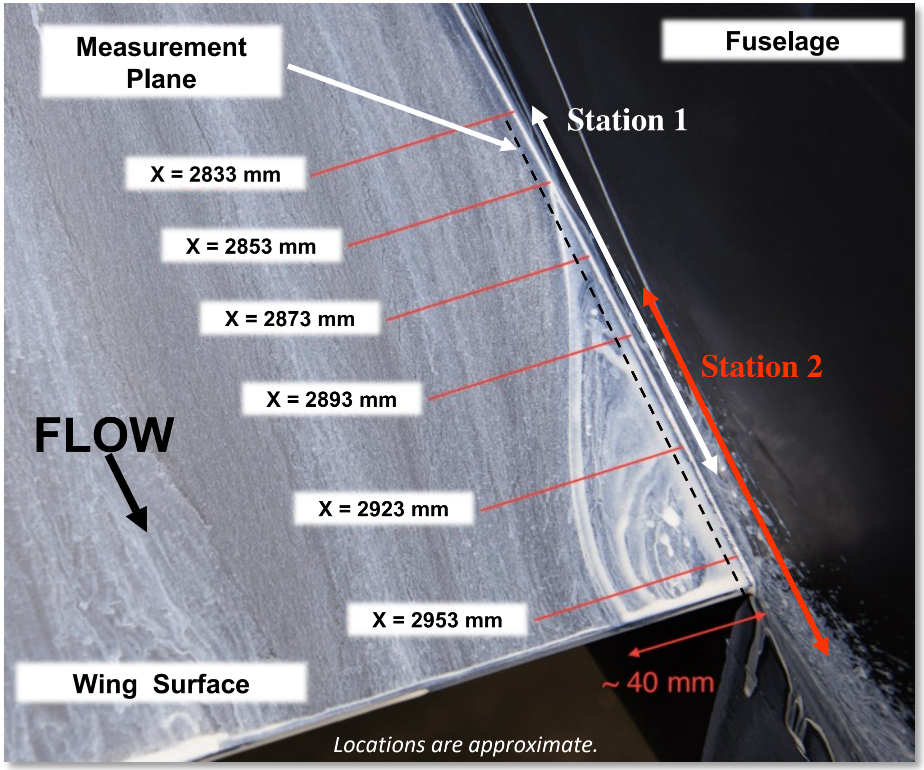


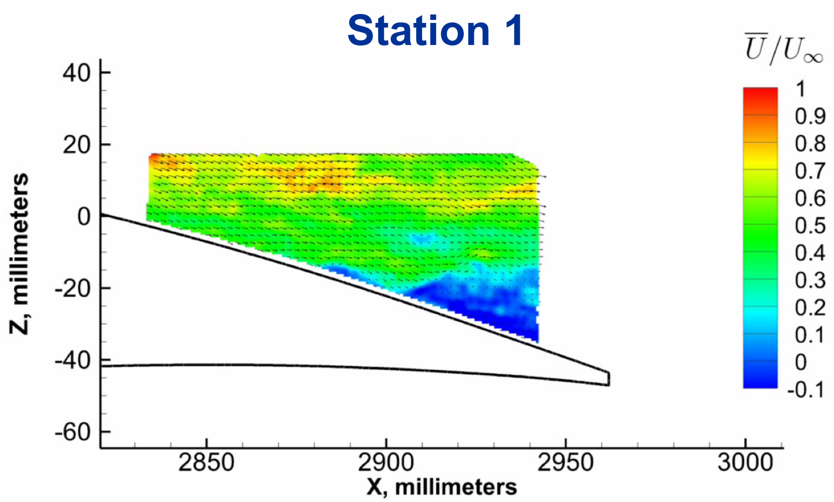

| Spanwise Plane | Y, mm | $Y-Y_o$, mm |
|---|---|---|
| 1 | -241.1 | -5.00 |
| 2 | -243.6 | -7.46 |
| 3 | -246.8 | -10.7 |
| 4 | -255.0 | -18.86 |
| 5 | -260.0 | -23.86 |
| 6 | -270.0 | -33.86 |
| 7 | -275.0 | -38.86 |

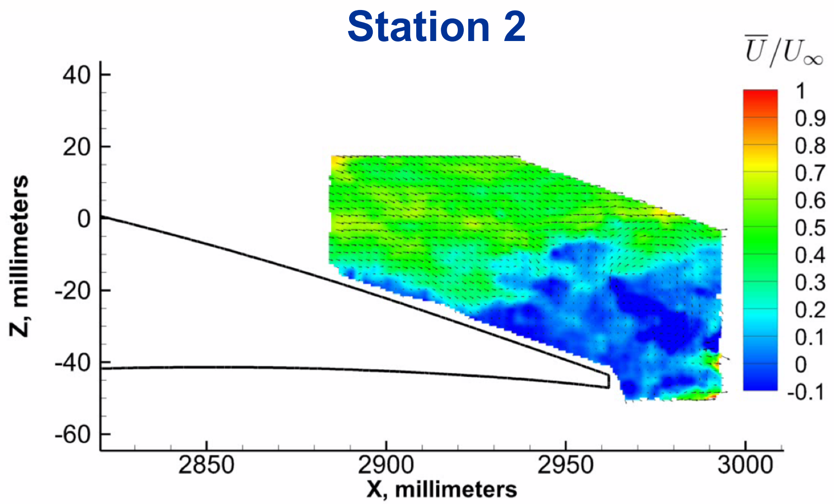
# Results

- Instantaneous Flow Field
- Mean Flow Field
- Comparisons with CFD (*Preliminary*)
- Comparisons with LDV (*Preliminary*)

# Instantaneous Flow (Y = -241.1 mm)

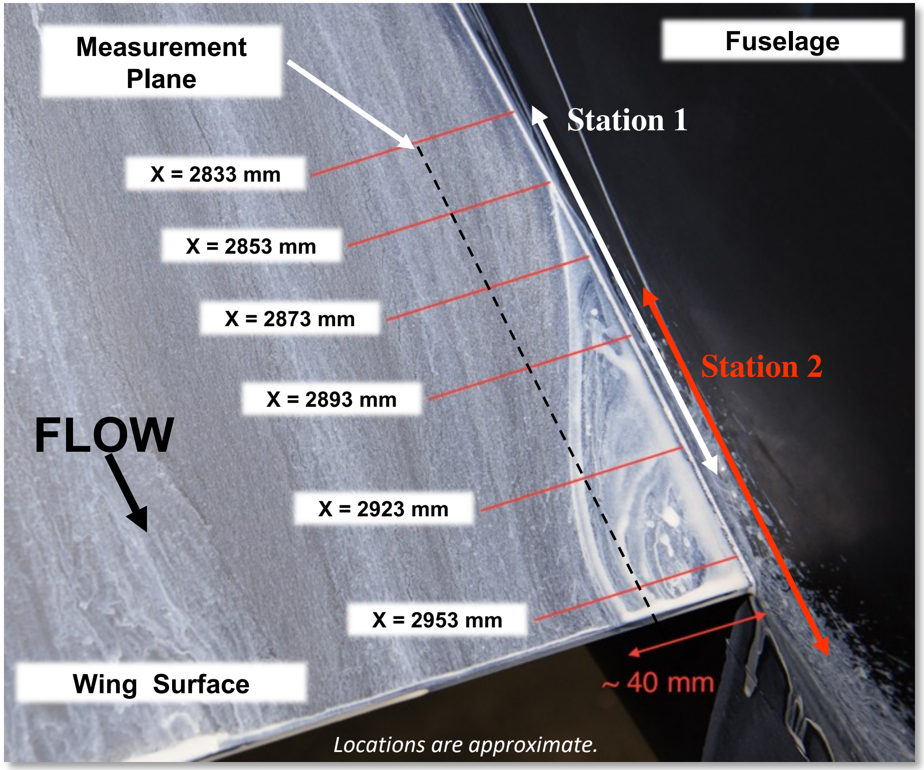


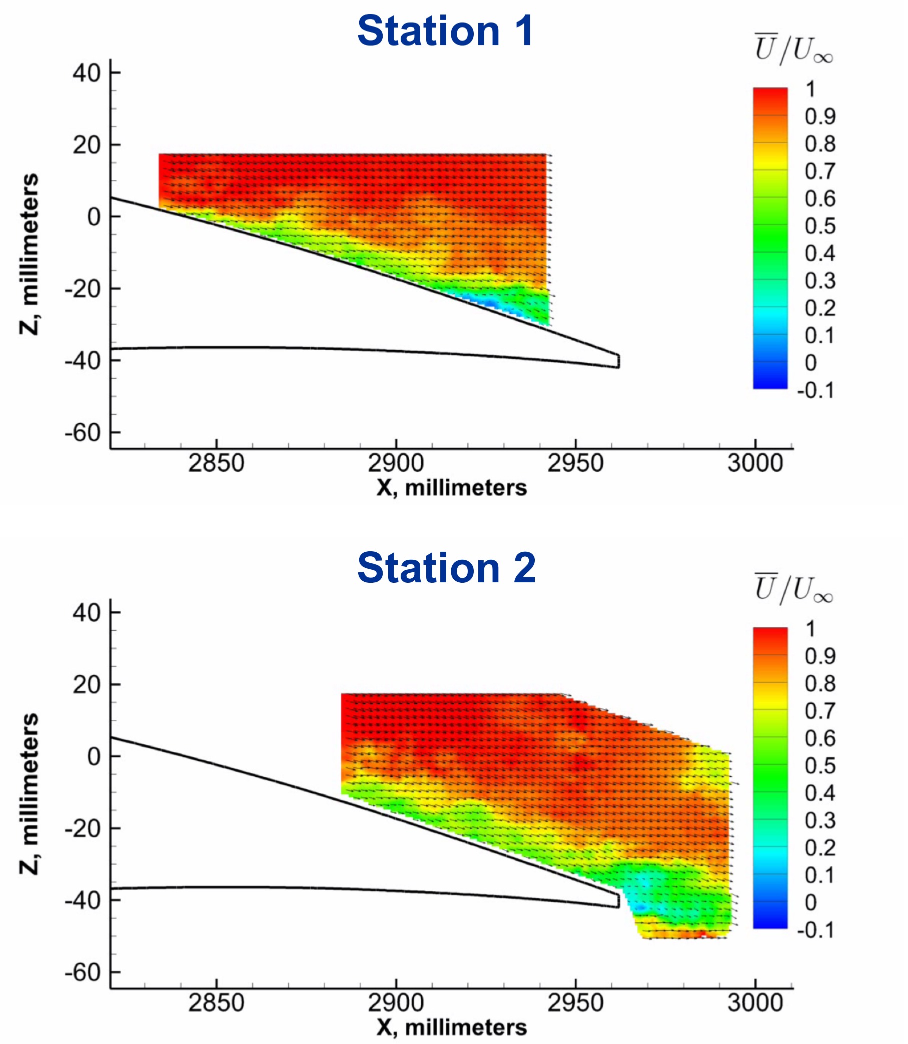




- Flow is highly unsteady
- Interaction between wing and fuselage boundary layers.
- Evidence of turbulent structures in fuselage boundary layer.

# Instantaneous Flow (Y = -270.0 mm)



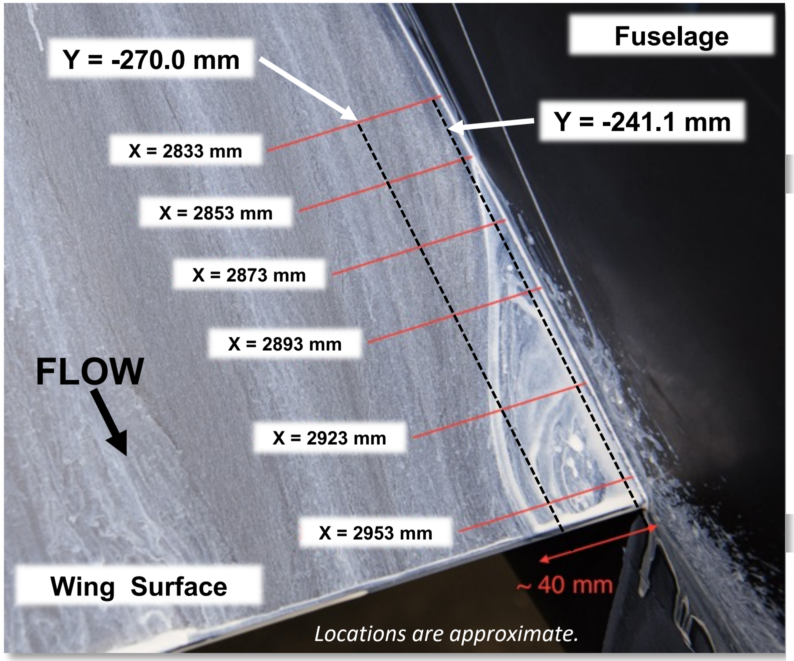



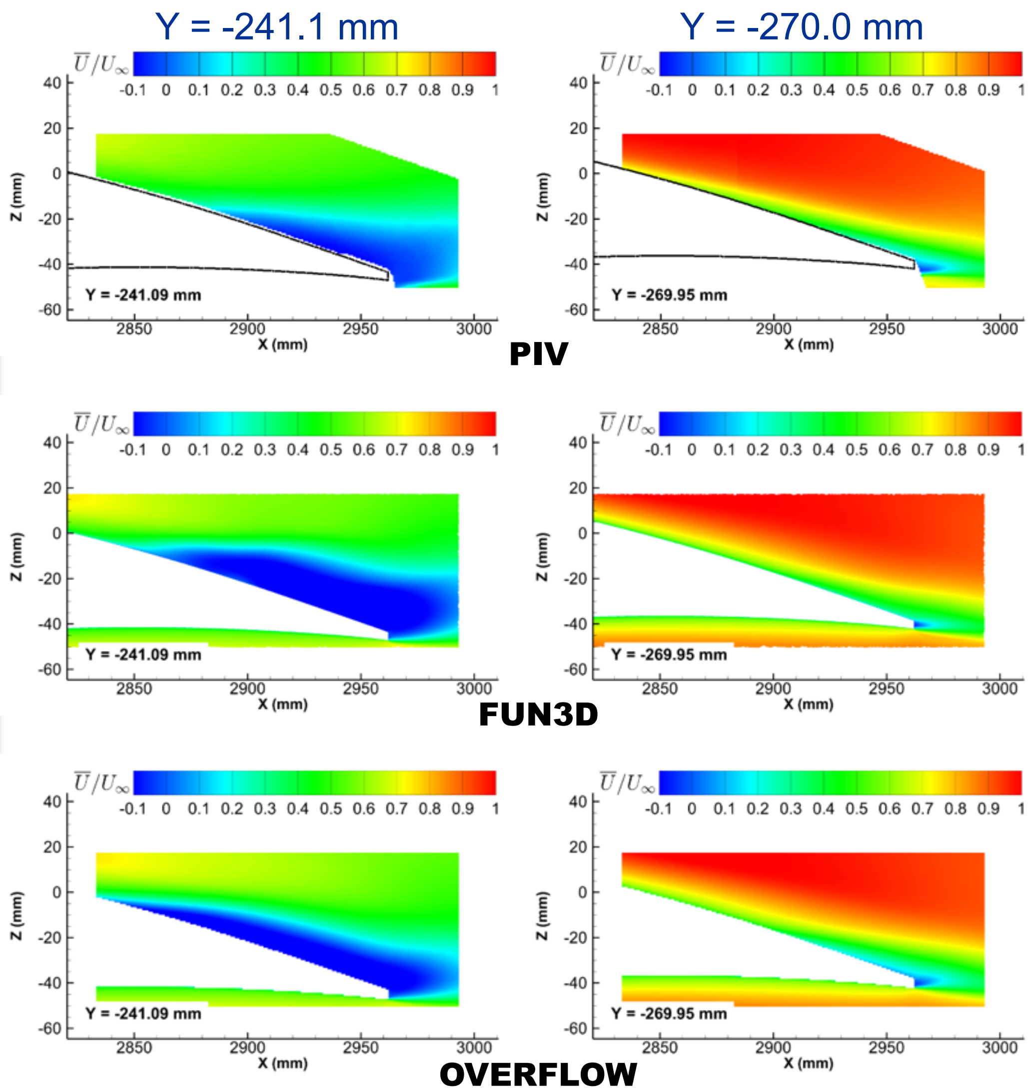

- Flow is unsteady.
- Outside of the fuselage boundary layer.
- Low velocity fluid concentrated near wing trailing edge.

# PIV-CFD Comparison: Parameters

| Parameter | Fun3D | Overflow 2.2N |
|---|---|---|
| Grid | Fine | Fine |
| Turbulence Model | SA-RC-QCR2000 | SA-RC-QCR2013 |
| Conditions | Free Air | In Tunnel |
| Number of Unknowns/Grid Points | 161 Million | 173 Million |
| Publications | AIAA-2019-0079 | AIAA-2019-0080 |

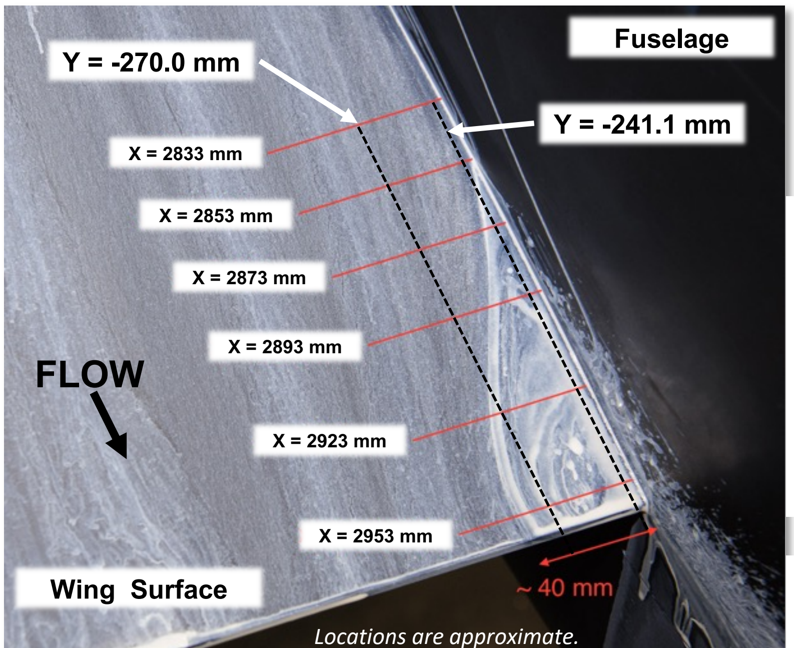
# PIV-CFD Comparison: Longitudinal Velocity

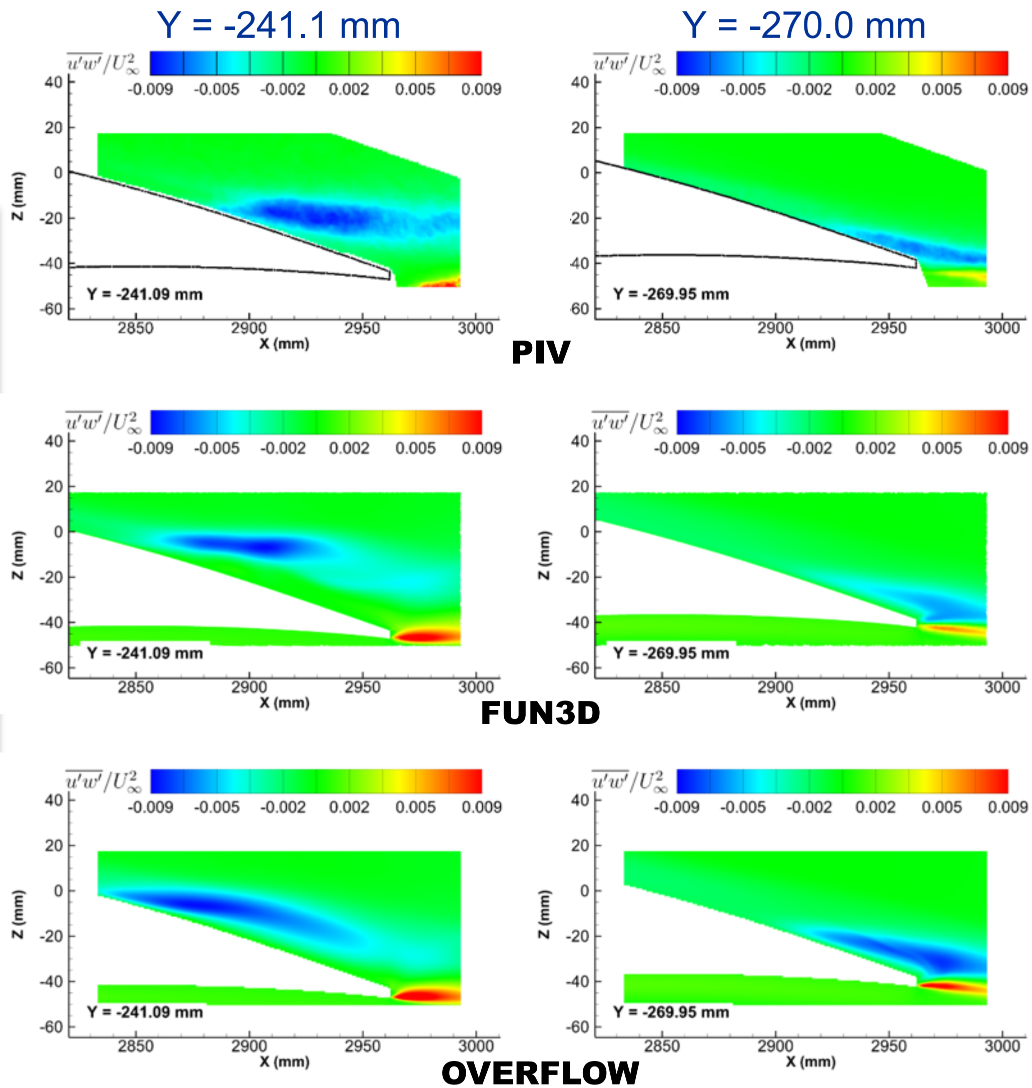



- CFD predicts separation further upstream, resulting in a larger region of separated flow.
- Agreement between PIV and CFD is better outboard.

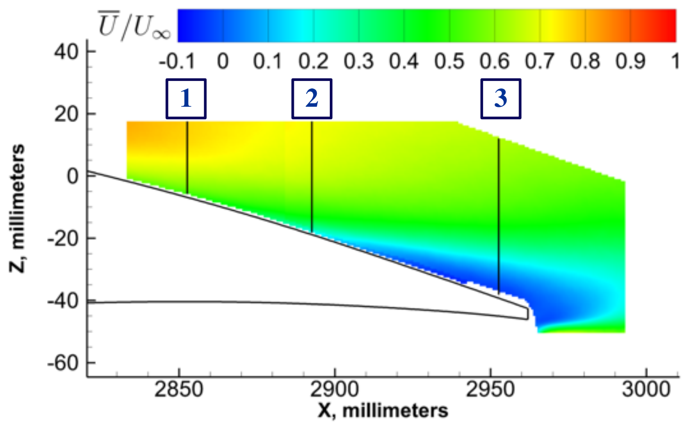
# PIV-CFD Comparison: Reynolds Shear Stress



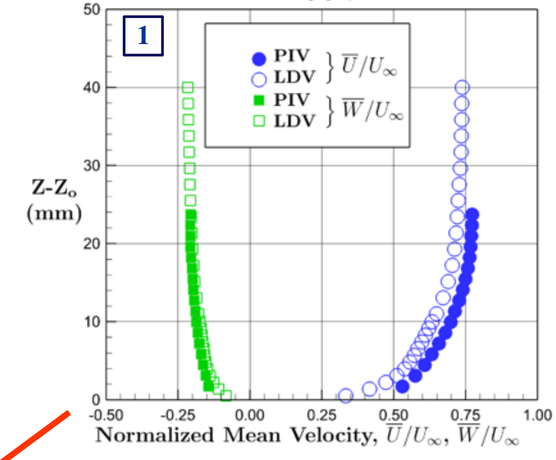



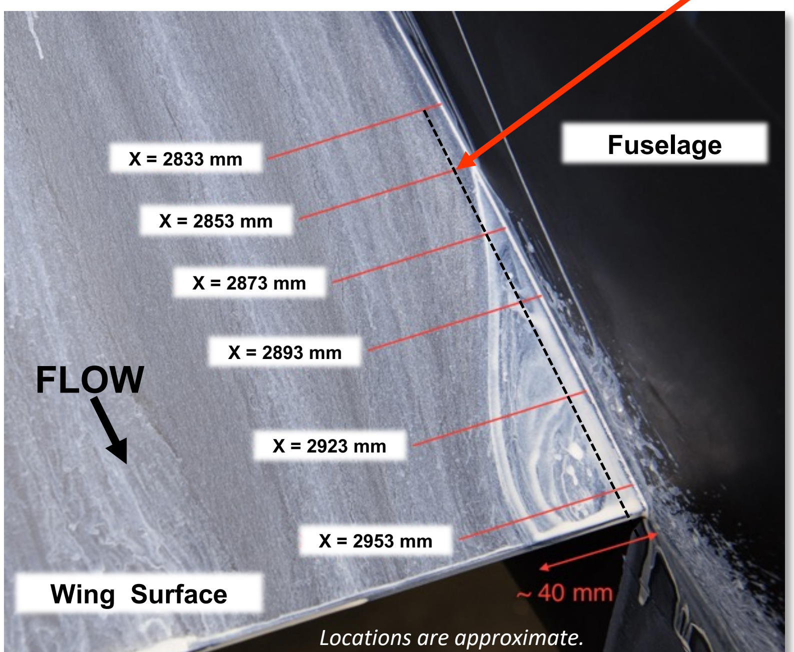

- Close to the fuselage, CFD shows maximum shear stress region farther away from wing.
- Agreement is better at Y = -270.0 mm but CFD does not predict region of high shear stress close to the wing surface.

# PIV-LDV Comparison: *Mean Velocity*



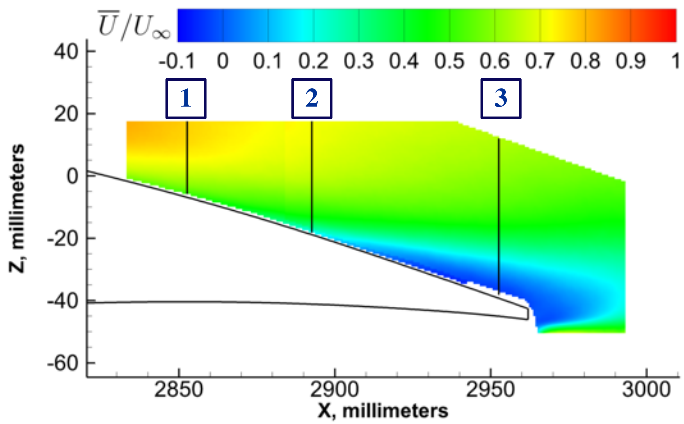

X = 2853 mm




PIV: Y = -246.8 mm
LDV: Y = -246.1 mm

# PIV-LDV Comparison: *Mean Velocity*

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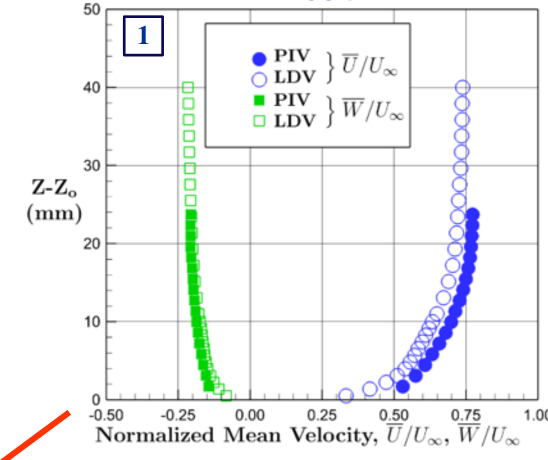
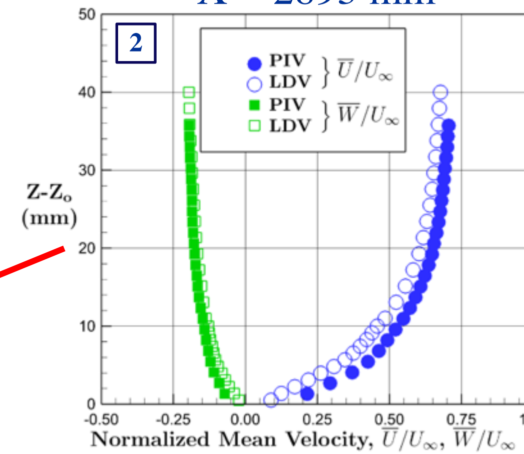
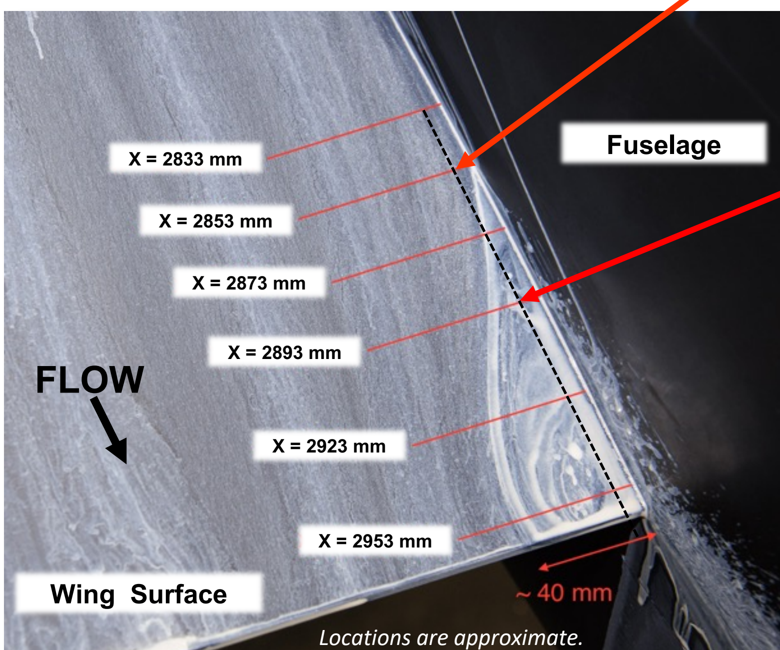



X = 2893 mm




PIV: Y = -246.8 mm
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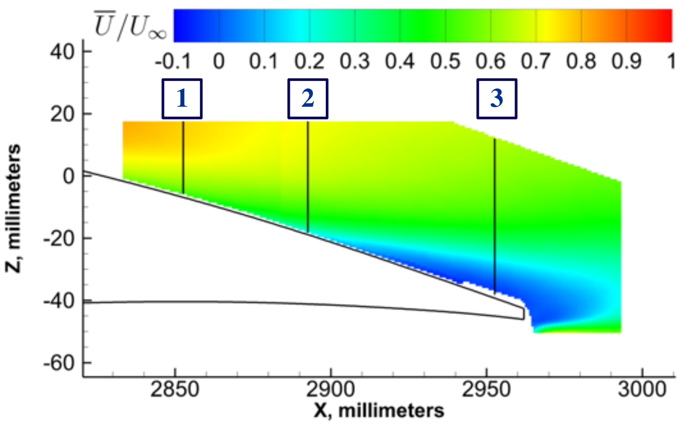
# PIV-LDV Comparison: *Mean Velocity*

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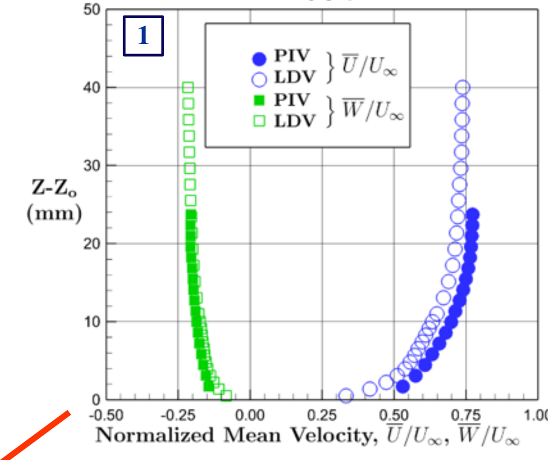


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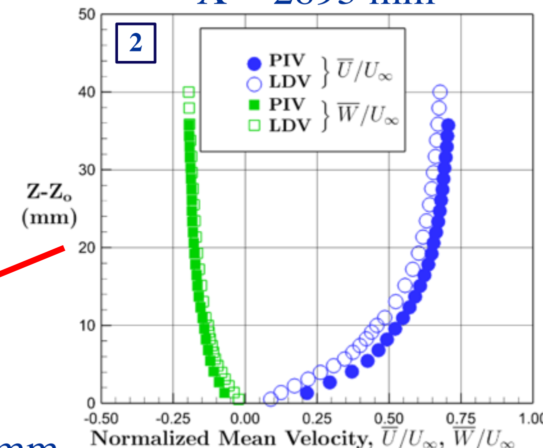


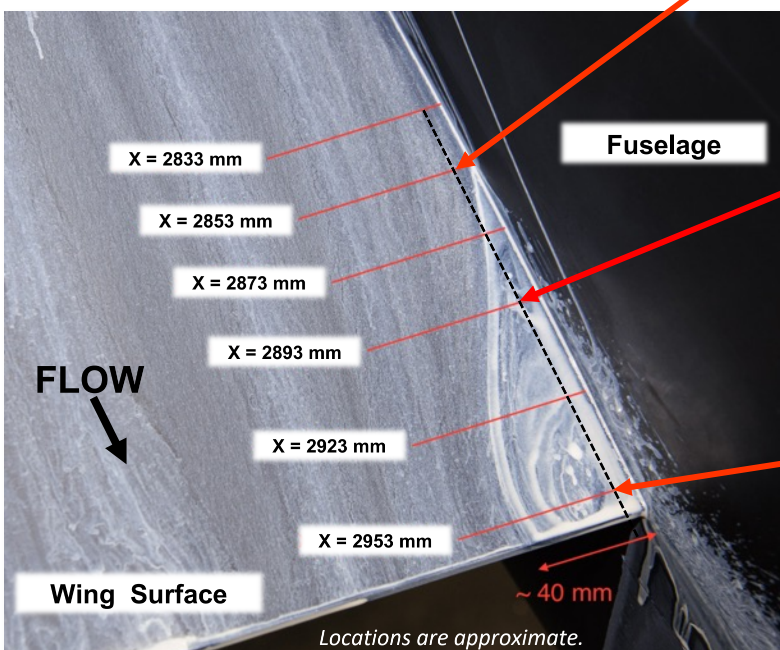


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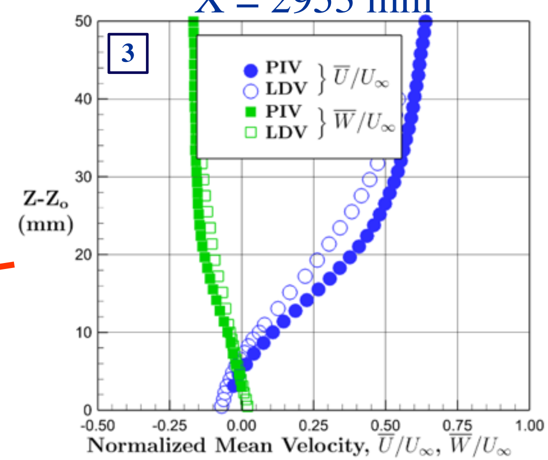


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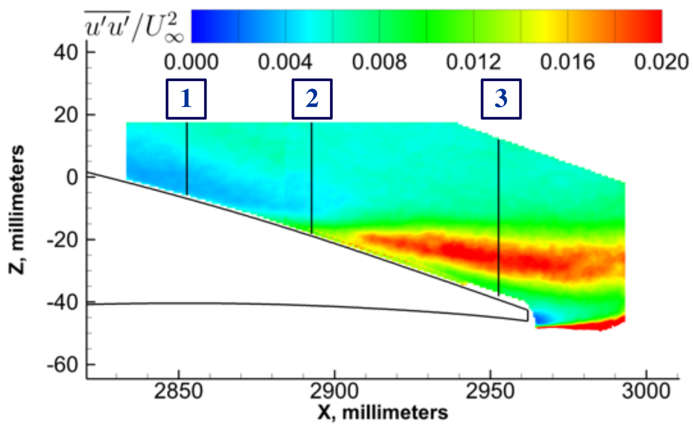
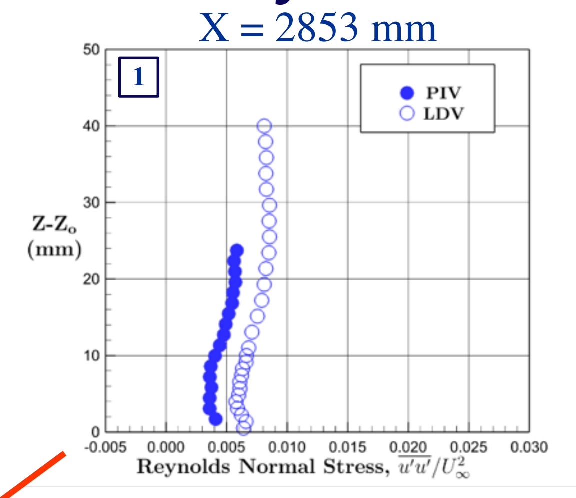
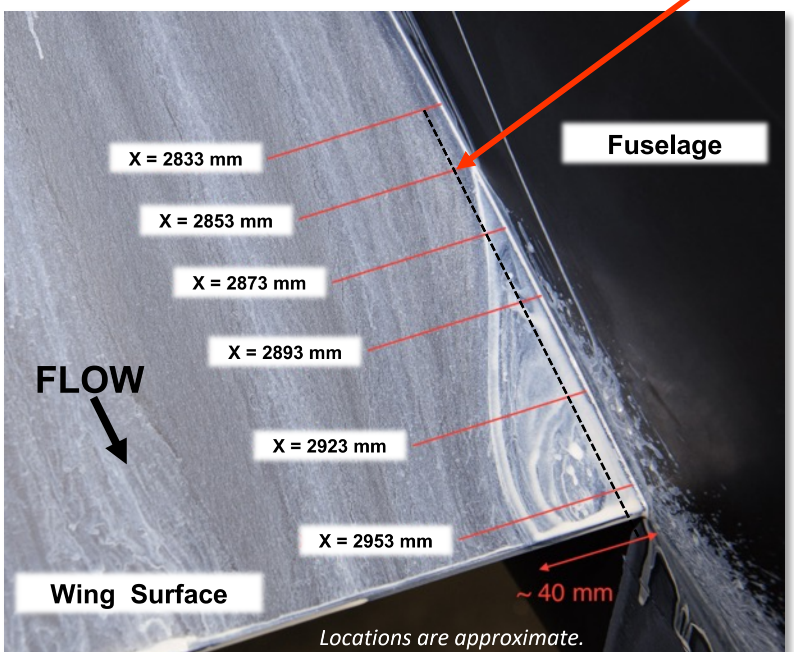
LDV: Y = -246.1 mm

# PIV-LDV Comparison: *Reynolds Normal Stress*

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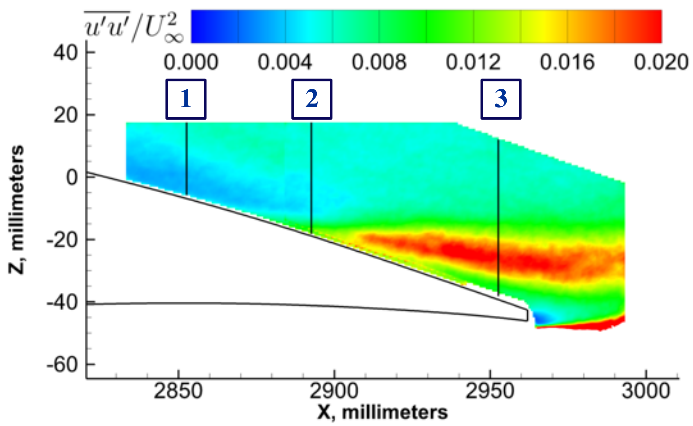


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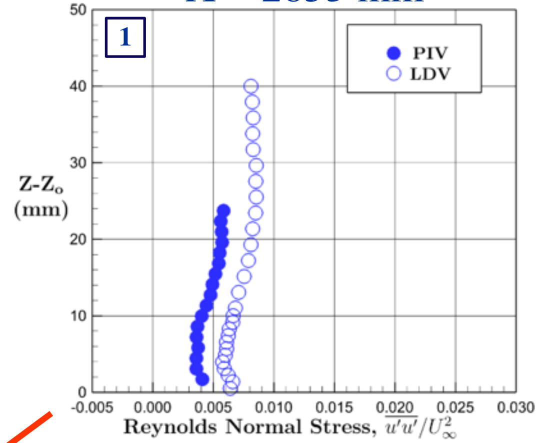


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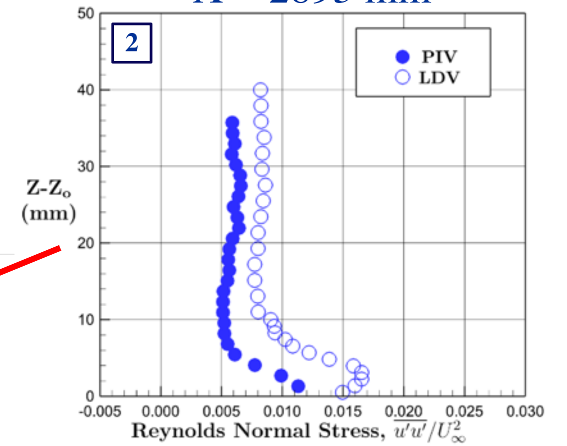


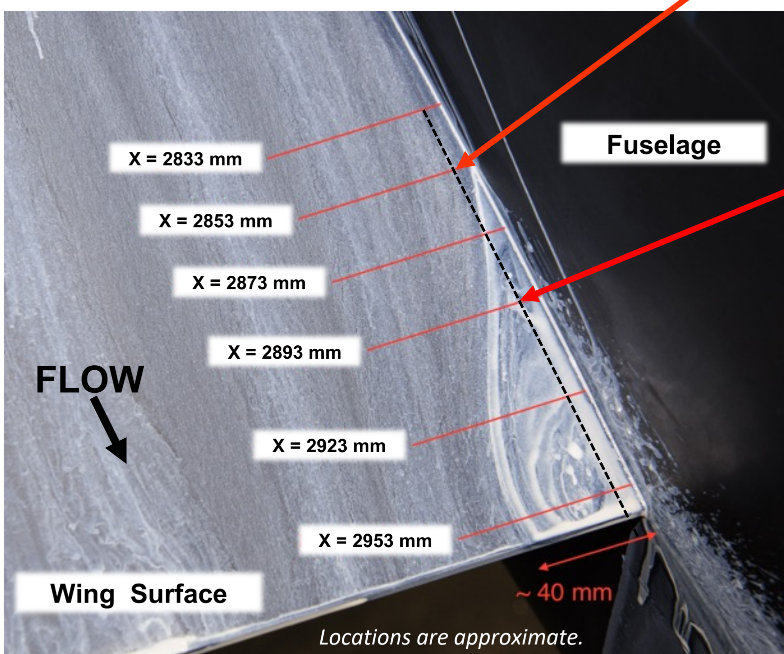


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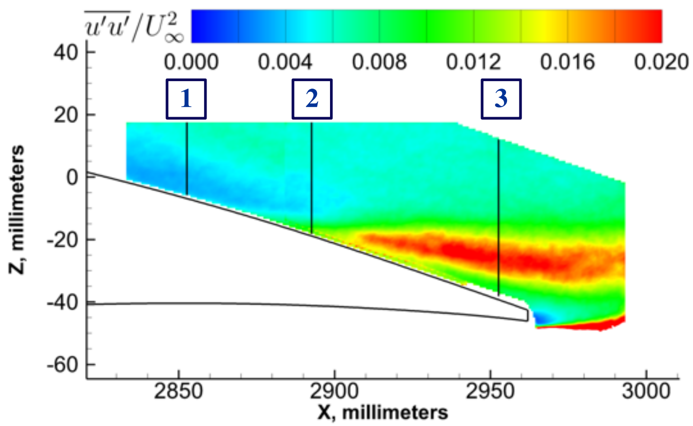


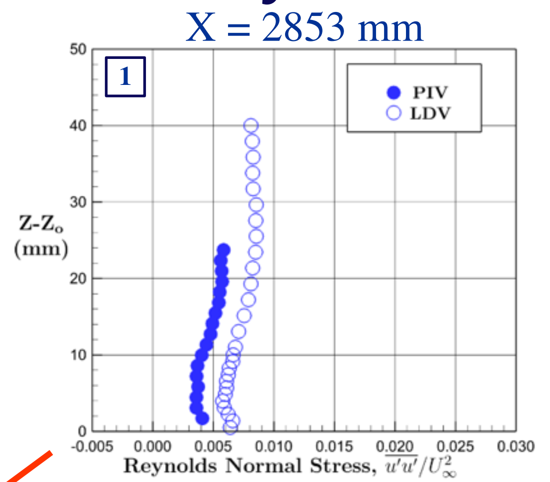


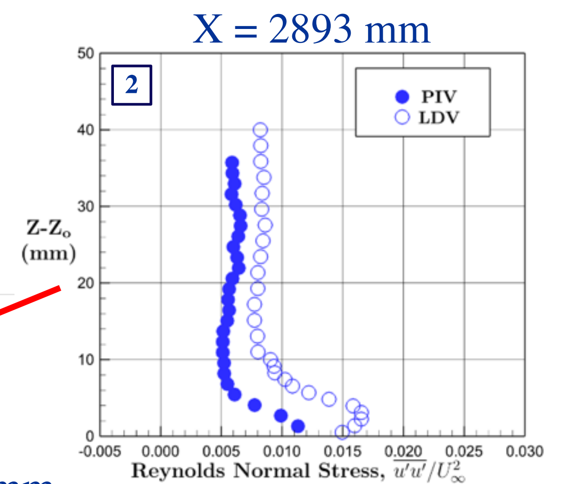


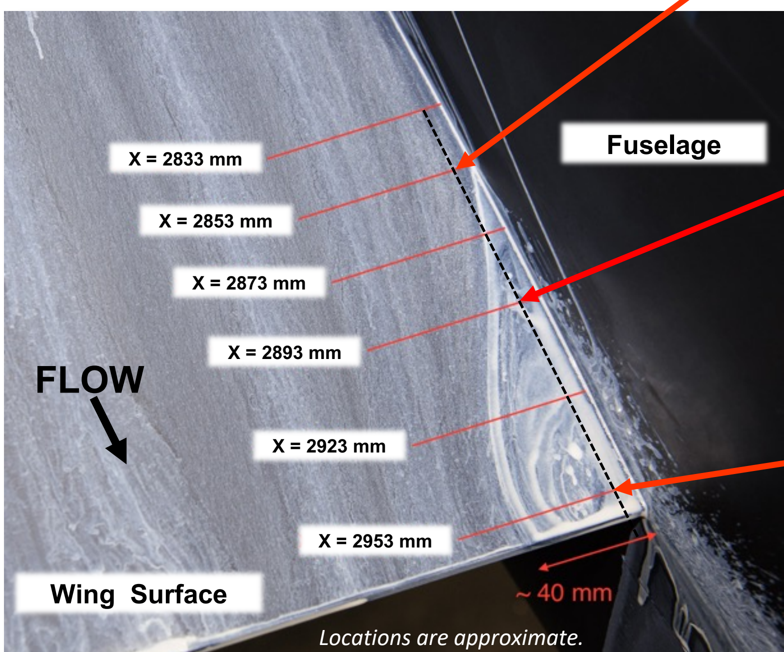


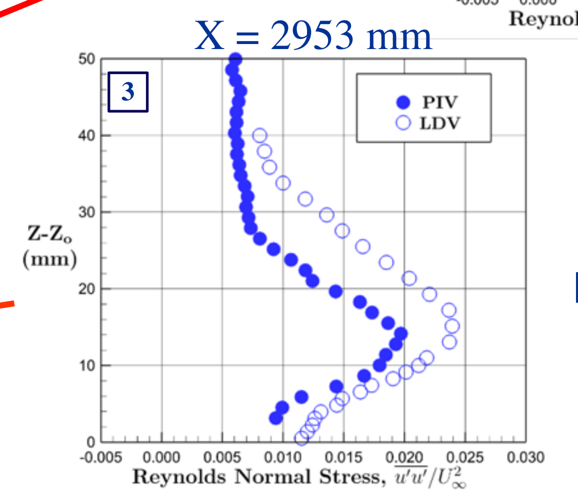


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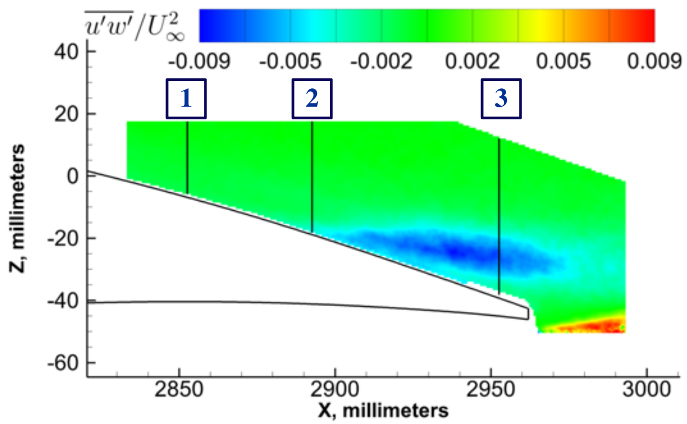
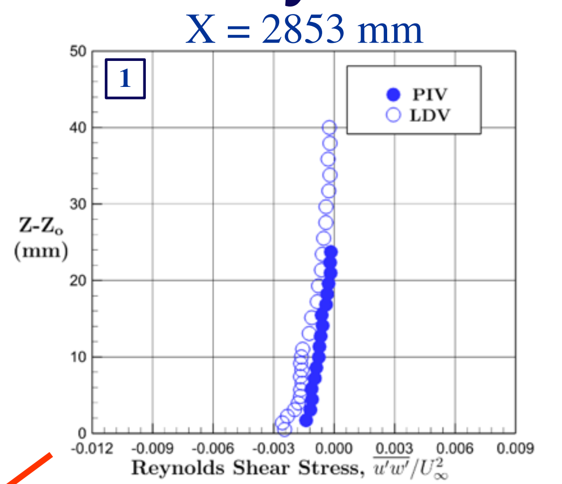
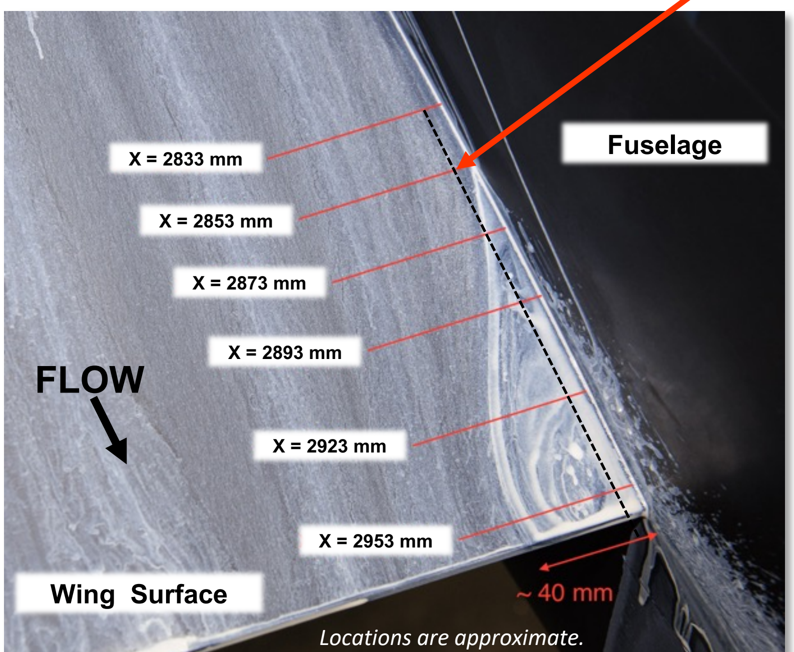
# PIV-LDV Comparison: *Reynolds Shear Stress*

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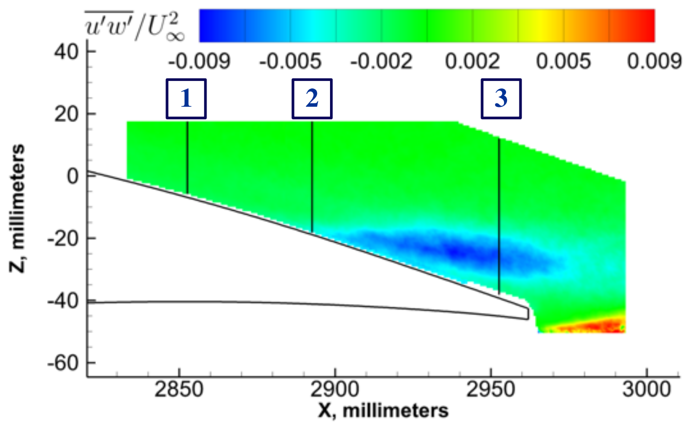


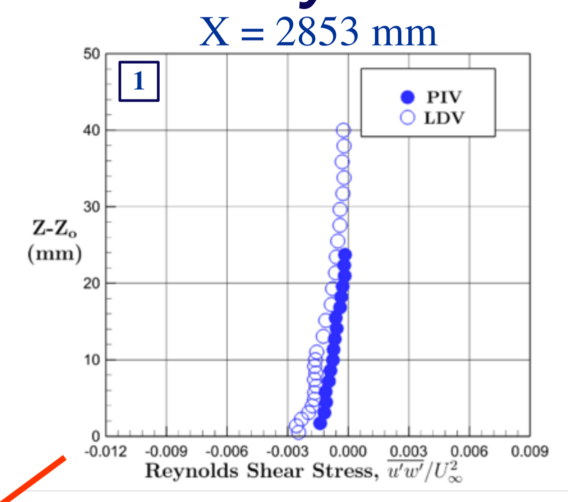


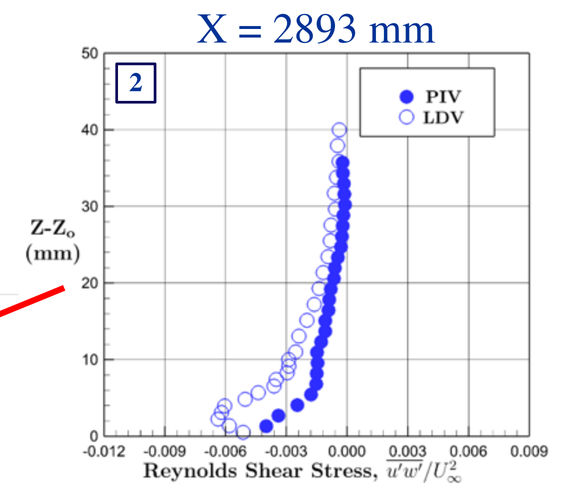


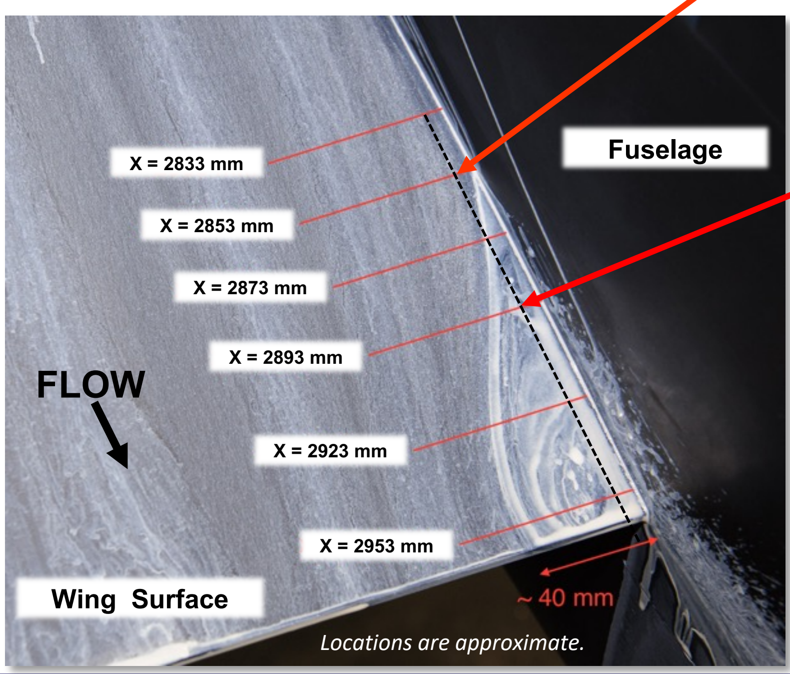


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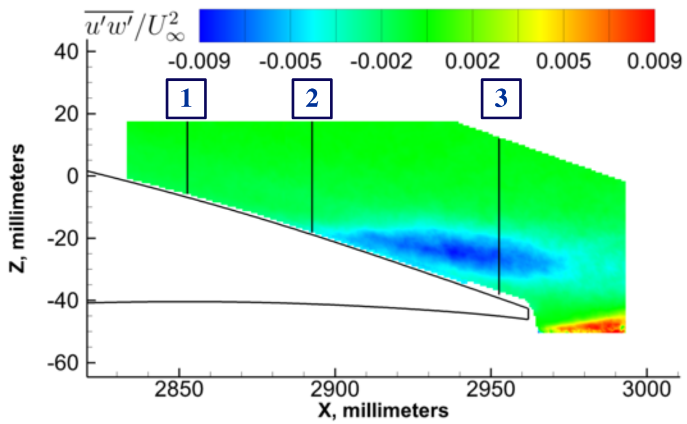
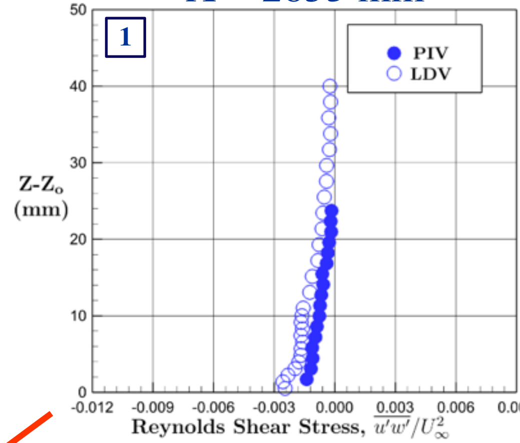
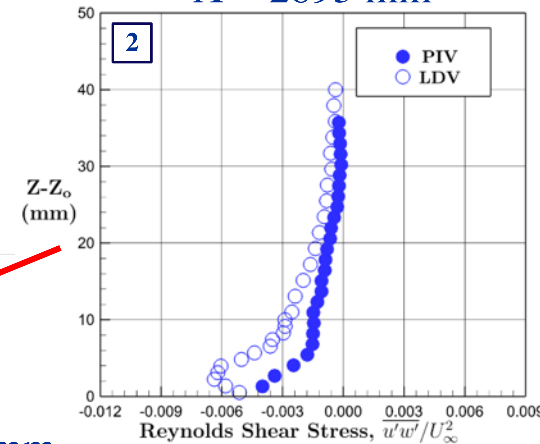
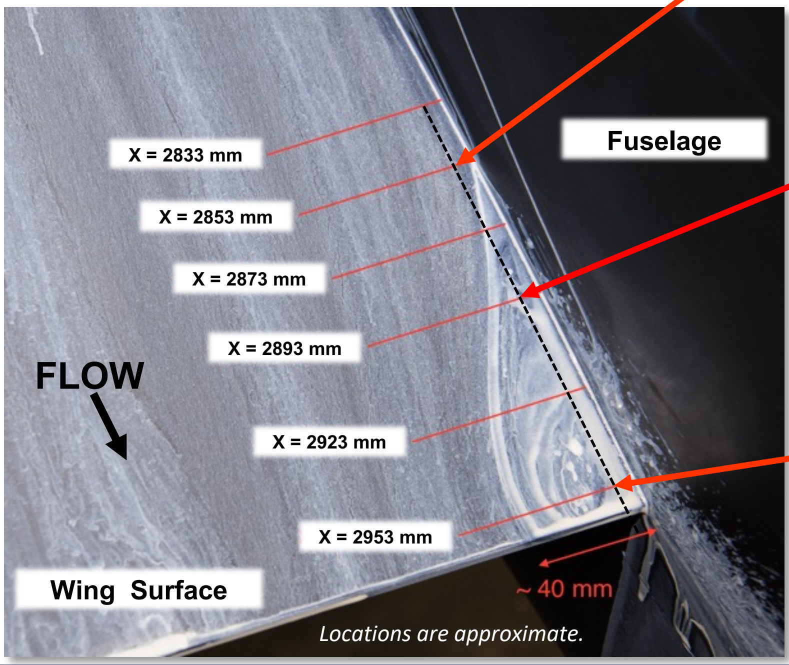
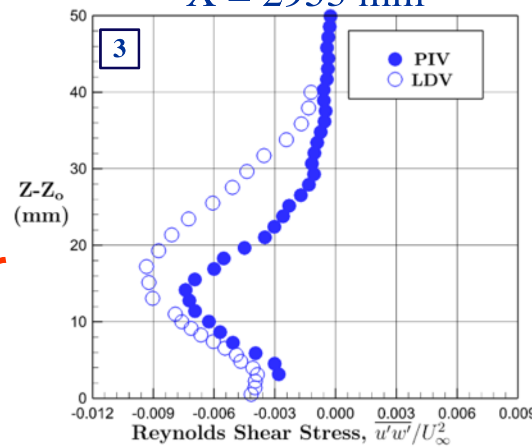


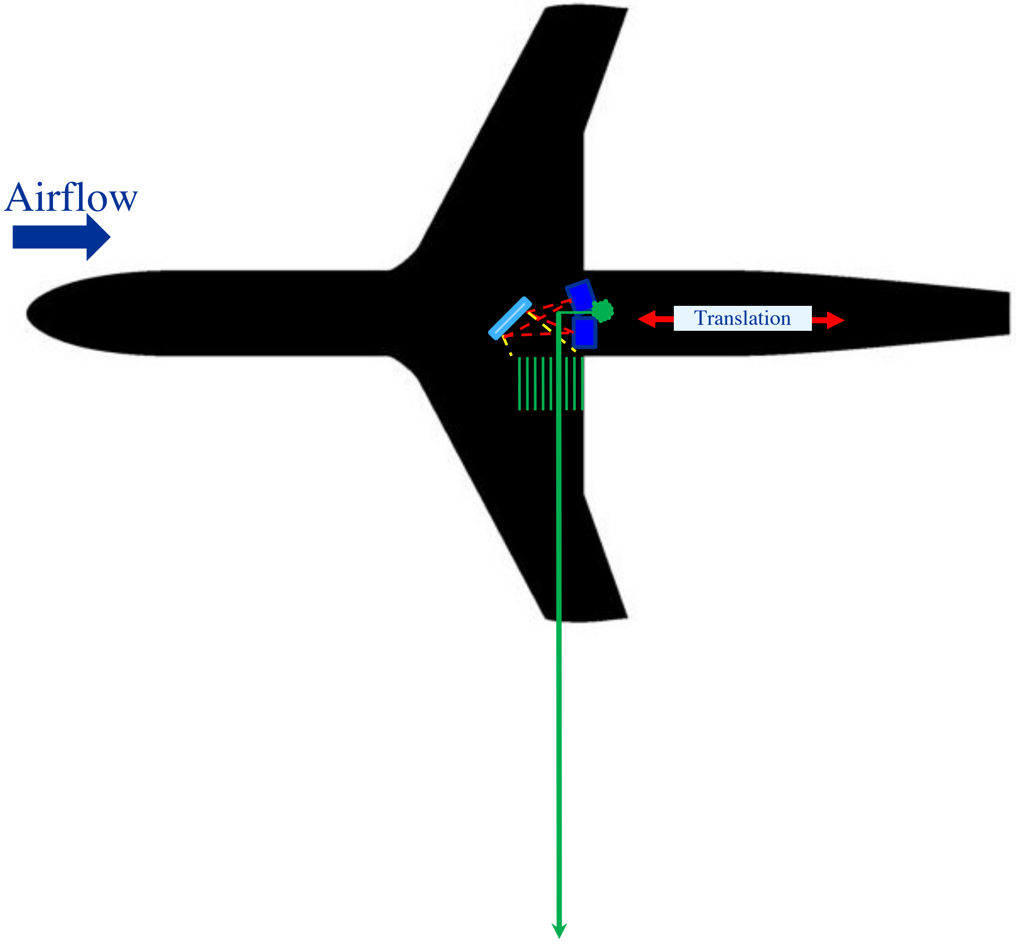

PIV: Y = -246.8 mm
LDV: Y = -246.1 mm

# Summary

- The embedded PIV system proved to be quite capable of capturing unique details of the flow separation.
- Notable gains in efficiency with regard to installation, image acquisition, and test operations.
- The PIV data show reasonably good agreement with the computational results and measurements made using the embedded LDV system.
- This effort also resulted in several firsts…
  - First use of an embedded PIV system at NASA Langley
  - First use of a high-speed PIV system in the 14- by 22-Foot Subsonic Tunnel

# Future Plans

- Acquire data in closely spaced, spanwise planes using SPIV.
- Evaluate the use of fiber optics to project the laser light sheet over the wing from inside the model.
- Use a second SPIV system to acquire data over a smaller FOV to improve resolution.



# QUESTIONS