



# Experimental Results



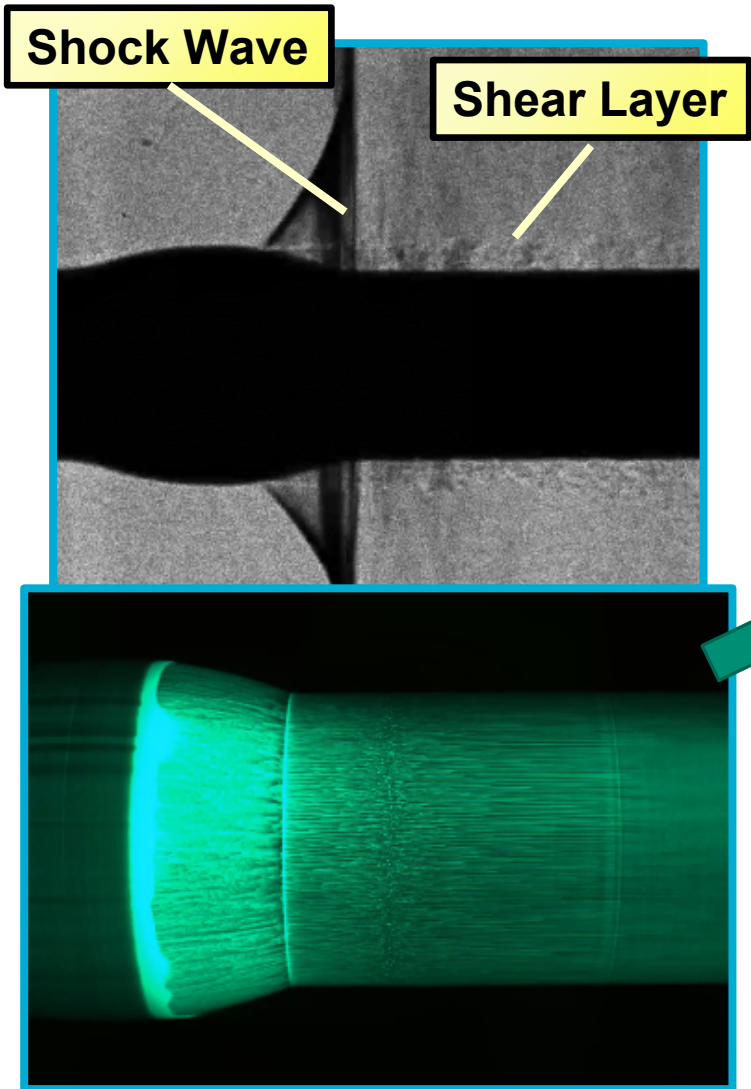
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## Kyle Lynch

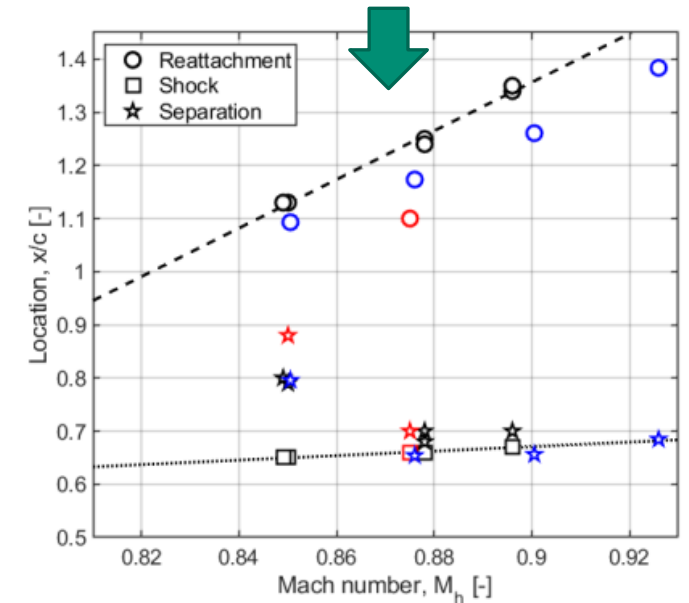
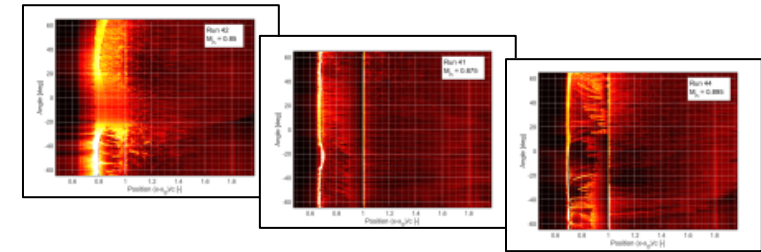
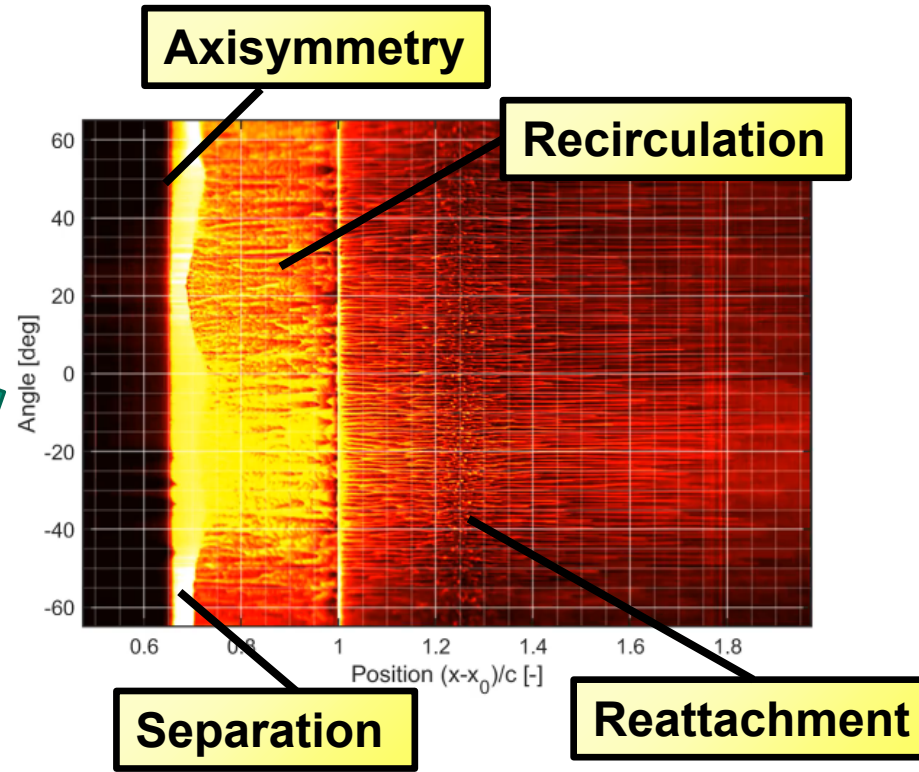
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# Surface Flow Topology

## Fluorescent oil defines shock, separation, and reattachment locations



- Photogrammetry 'unwraps' images onto calibrated grid
- Manual identification of topology features
- Runs at different Mach establish topology trends

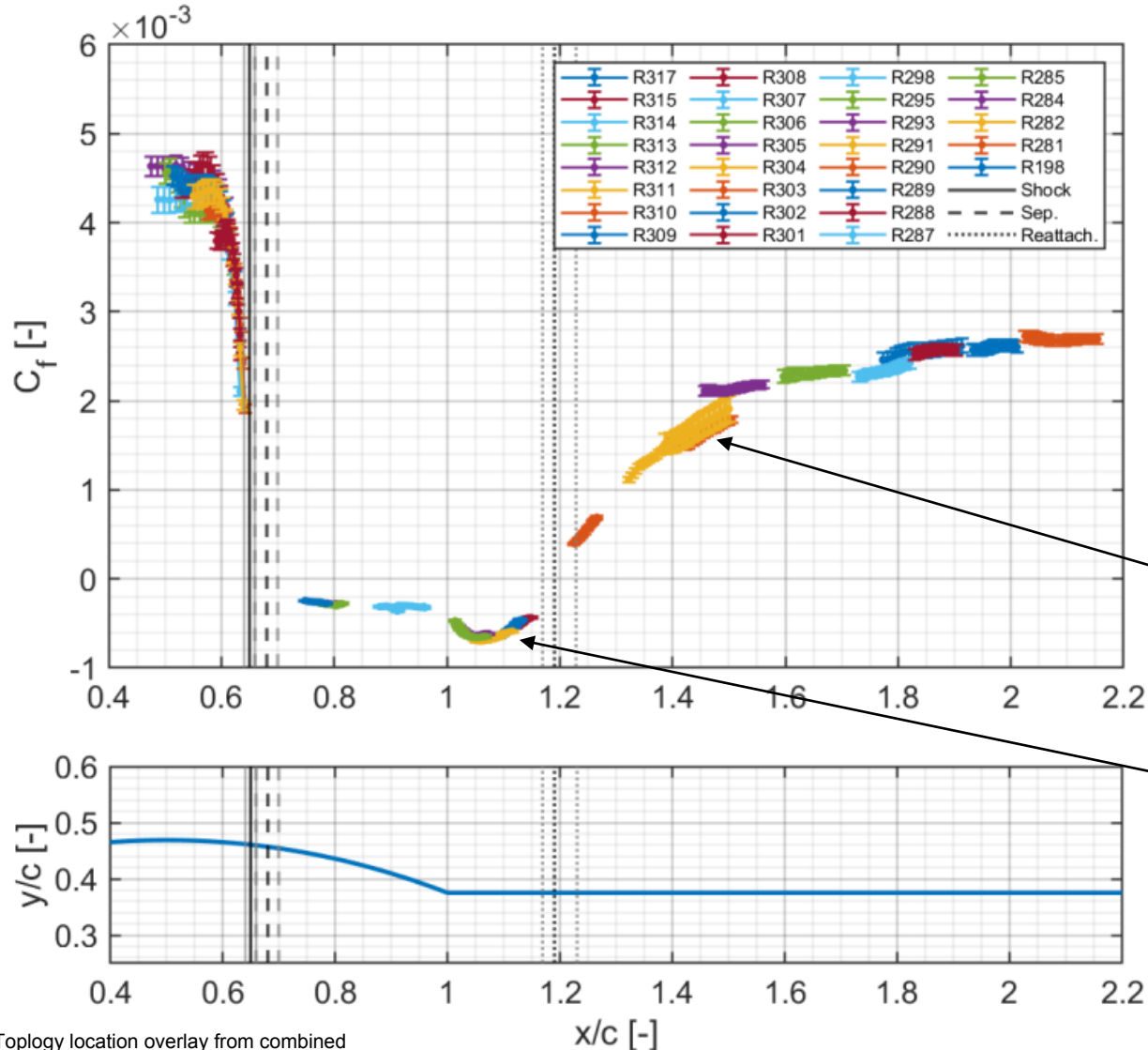


- At  $M=0.875$ , the shock and separation locations are nearly identical. However, different for  $M < 0.875$

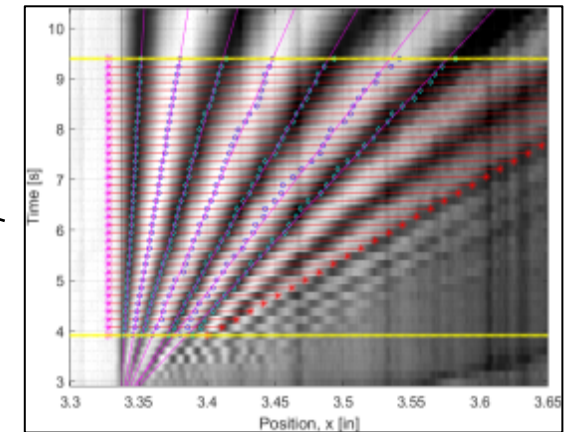
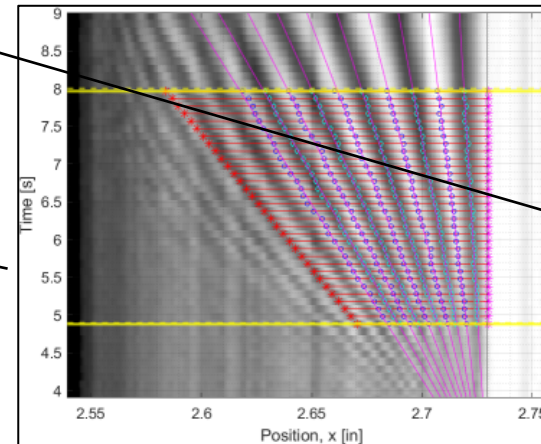
• Black points in this figure denote our measurements. Colored points are historical.



## Oil-film interferometry (OFI) defines surface shear stress



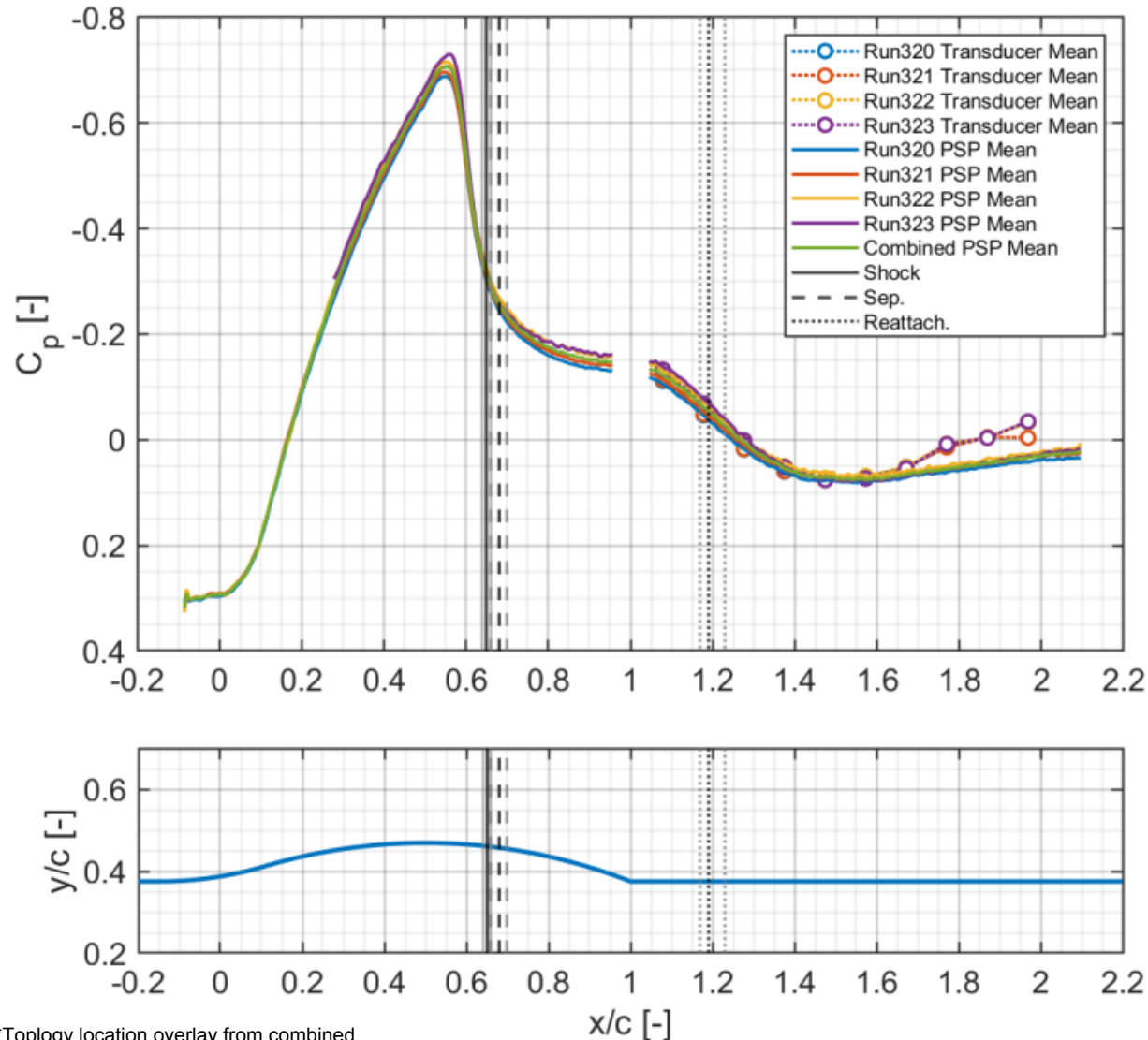
- OFI requires oil to be applied in small patches along the model. To create an entire curve, multiple runs are performed.
- Photogrammetry ‘unwraps’ images and determines light incidence angle\*
- Multi-image analysis used to mitigate effect of tunnel startup transient on result†
- Separation and reattachment estimated from bracketing of zero crossing



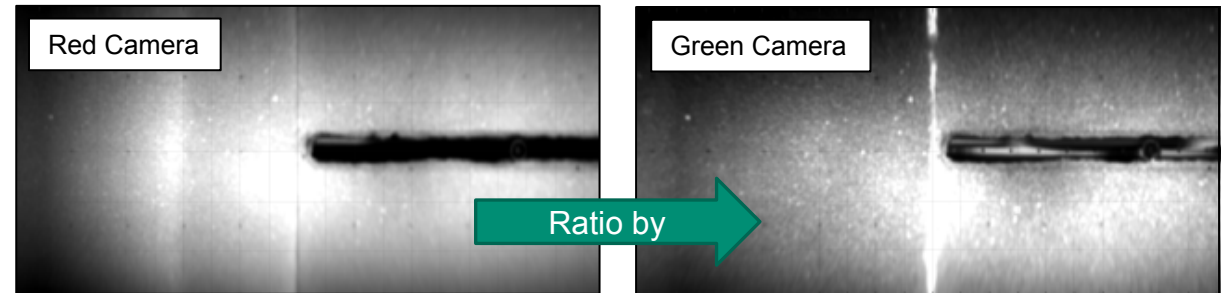
\*Naughton and Liu (2007) Photogrammetry in Oil-Film Interferometry. *AIAA J*

†Naughton and Hind (2007) Multi-image oil-film interferometry skin friction measurements. *Meas Sci Technol*

## Pressure-sensitive Paint (PSP) and transducers define surface pressure



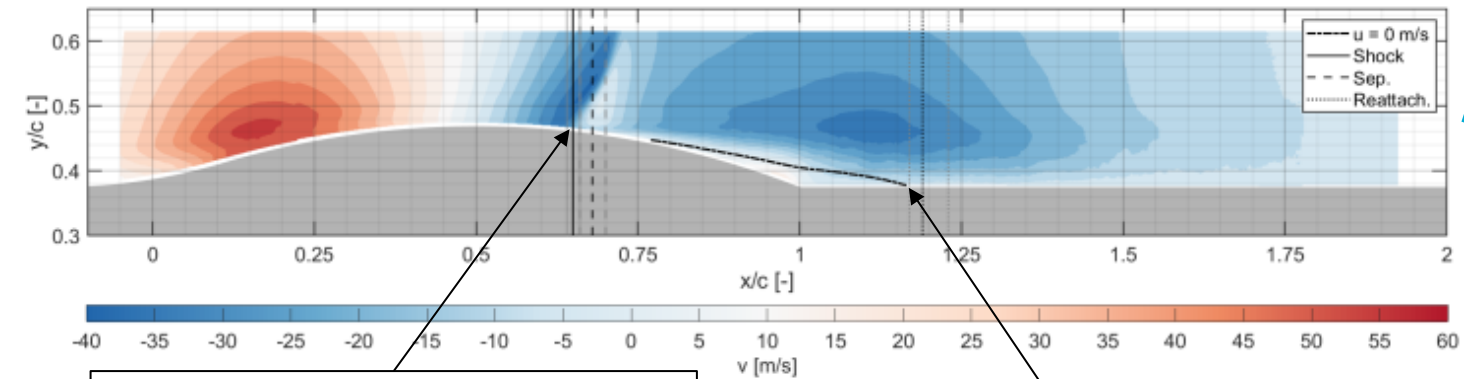
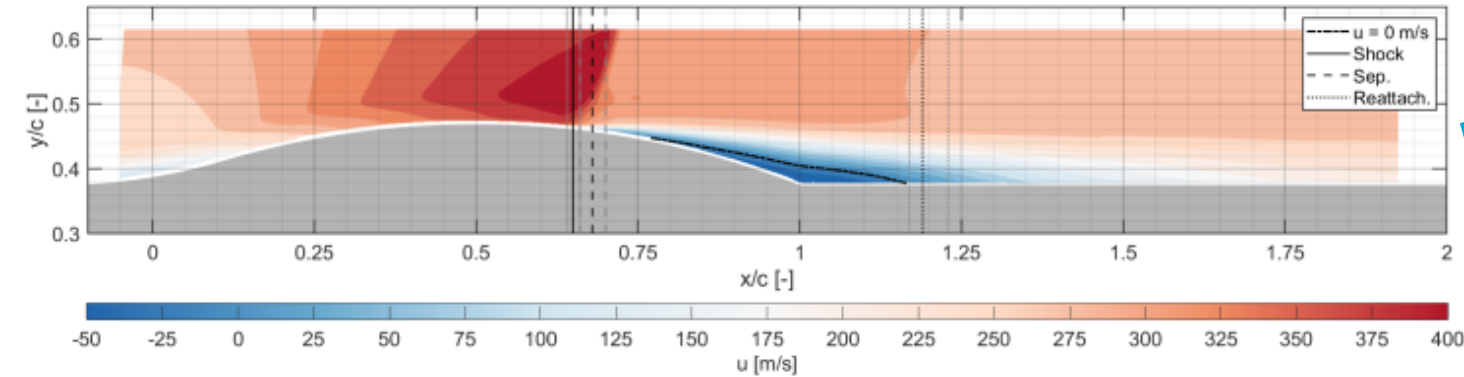
- Two-camera, two-color PSP used to account for temperature sensitivity of paint
- Red cam: pres./temp., Green cam, temp. only
- Photogrammetry 'unwraps' images allowing the cameras to be ratio'ed, to data



- No fluctuating surface pressure because fluctuation magnitude was too low to measure effectively.
- Still working to resolve downstream discrepancy with pressure sensors.

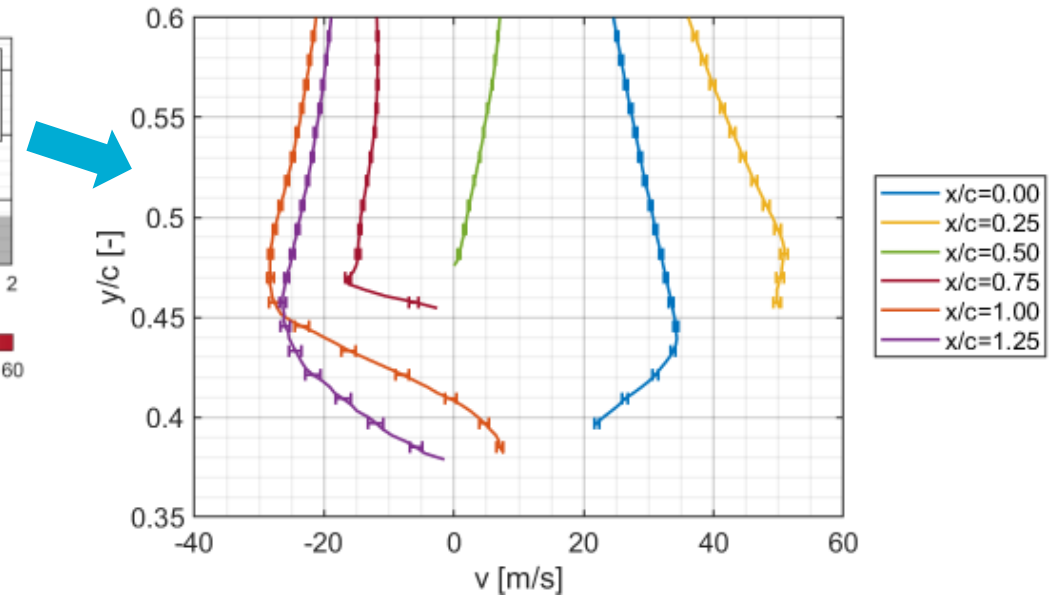
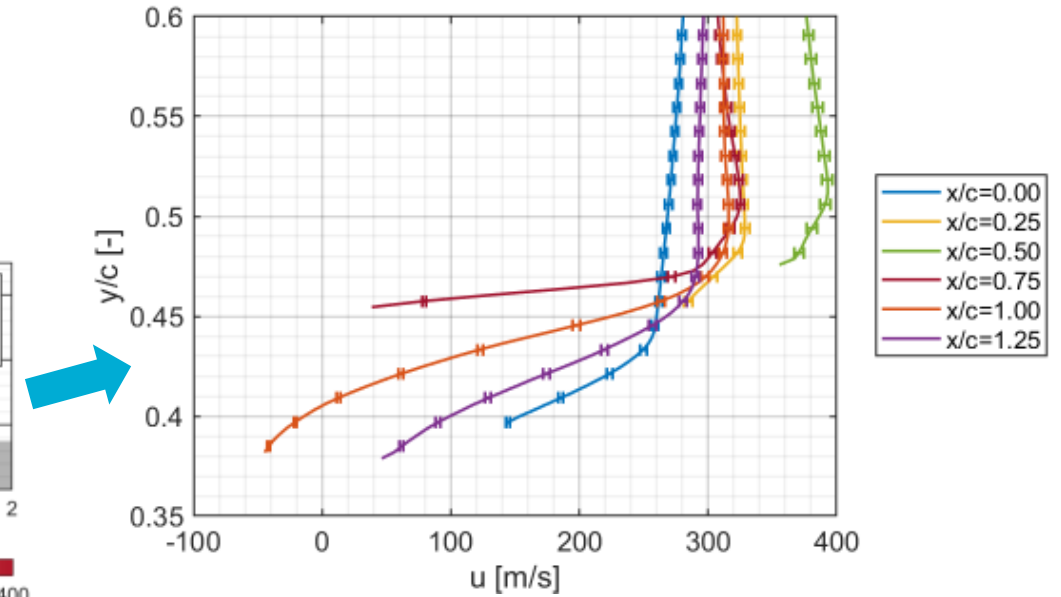
# Mean Velocity Fields from PIV

- 2-D planar PIV, 7 fields-of-view with 3500 snapshots each
- Fields-of-view stitched together to create panorama
- Uncertainty propagated from cross-correlation algorithm and camera magnification error.

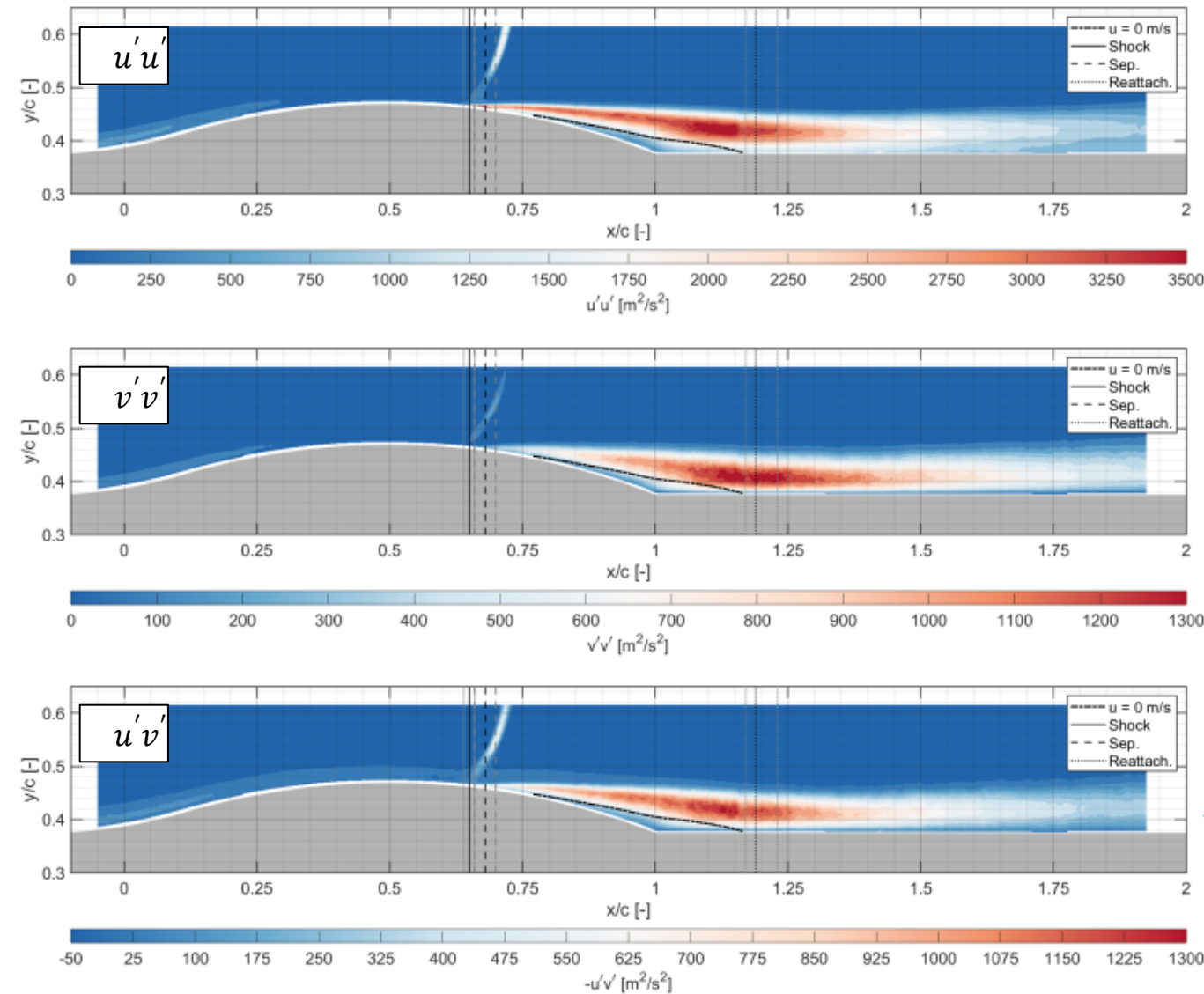


Shock location from PIV  
determined by contour inspection

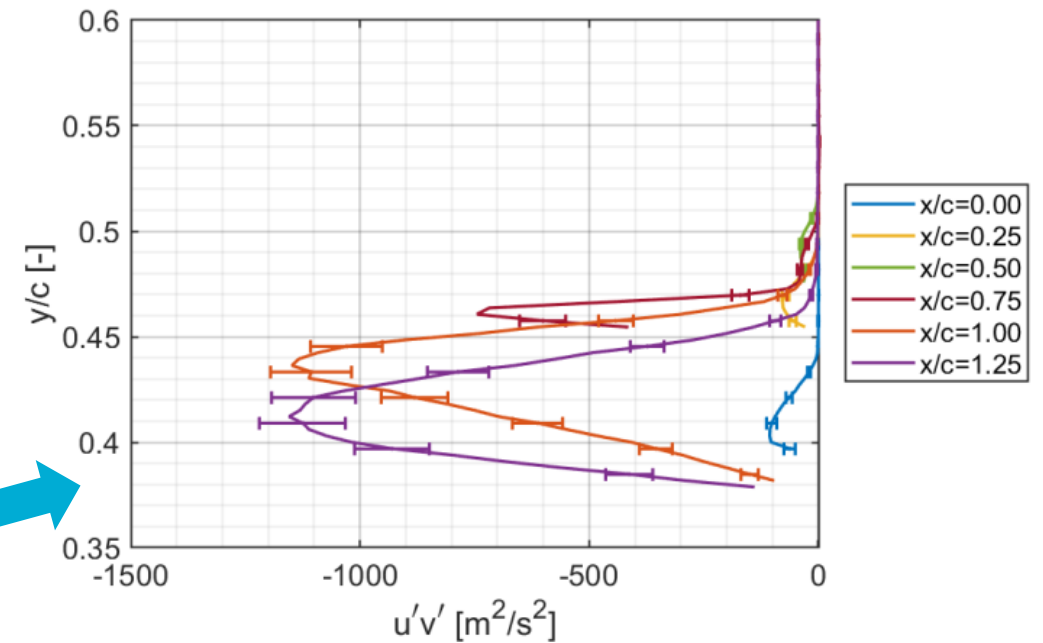
Intersection of  $U=0$   
with wall defines  
reattachment



# Reynolds Stresses from PIV



- Fluctuating statistics from 3500 snapshots at each field-of-view.
- Uncertainty dominated by flow unsteadiness, minor contribution from measurement noise
- Peak Reynolds stresses occur around  $x/c = 1.125$ , upstream of reattachment

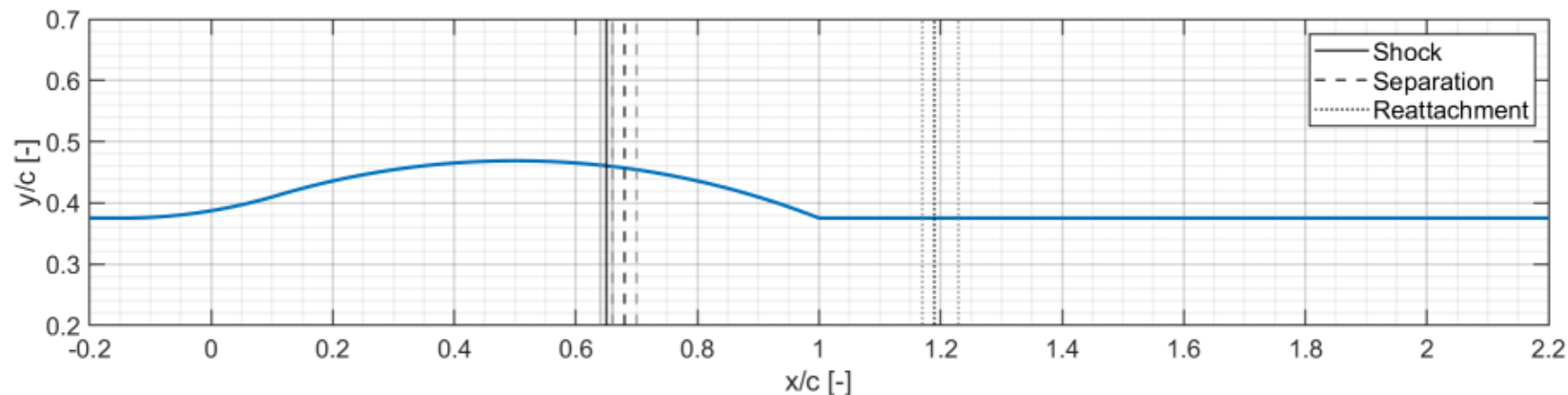




## Multiple measurements compiled to estimate topology

- We are using the oil visualization, OFI, and PIV to define the key topology locations
- The combined result has been shown as overlays in previous slides
- PSP suggests the shock around 0.6; we believe the PSP is not biased, but do not presently have a physical interpretation that is consistent with our other measurements.

	Shock	Separation	Reattachment
Oil-Flow	0.66	0.68	1.23
OFI	0.66	0.69	1.18
PIV	0.65	0.68	1.17
<b>Combined</b>	<b>0.65 +/- 0.01</b>	<b>0.68 +/- 0.02</b>	<b>1.19 -0.02/+0.04</b>



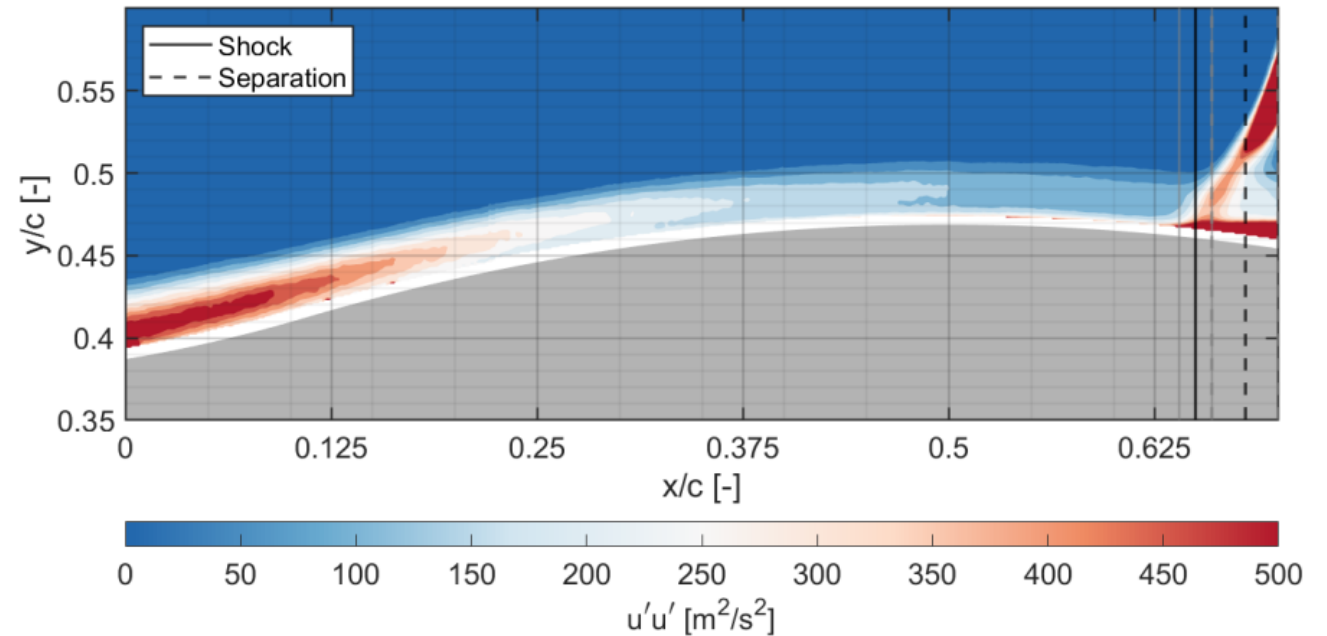
# What About the Possibility of Re-laminarization?

Launder's pressure gradient parameter:

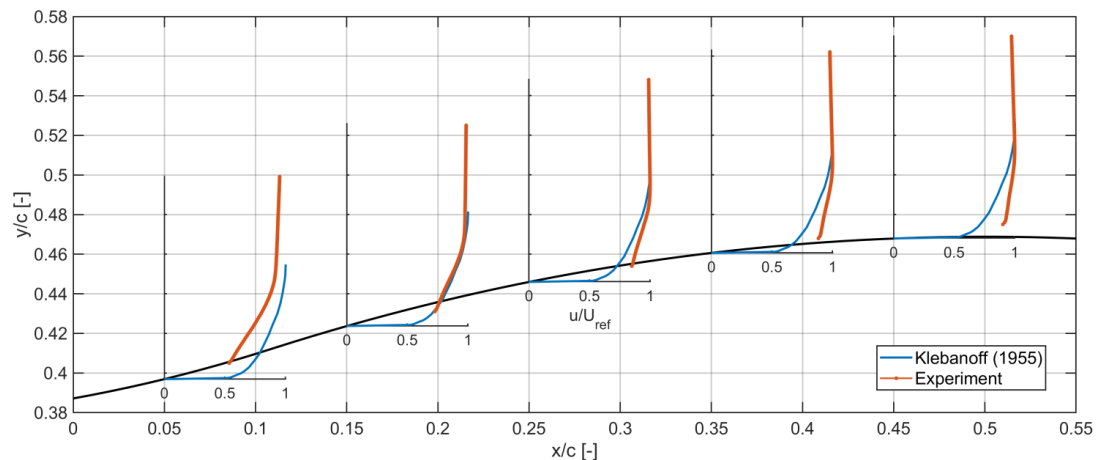
No  
Image

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Normalized mean velocity profiles



Profiles of  $u'u'$

