Experimentalist View: Data Processing Methods and Lessons

A.Prof Nick Lawson

Department of Aerospace, School of Aerospace, Mechanical and Mechatronic Engineering

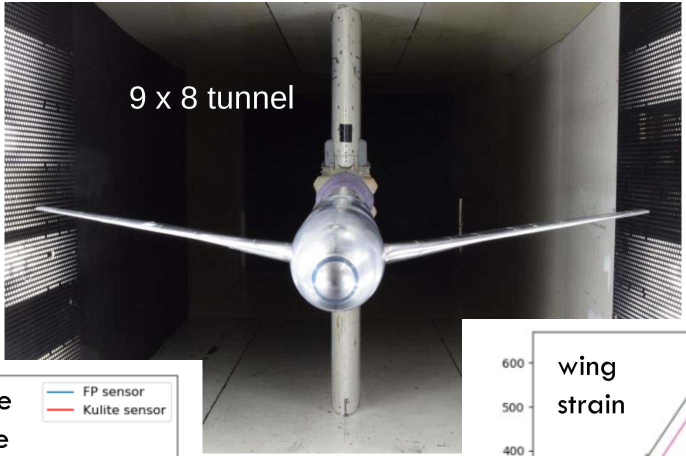
THE UNIVERSITY OF SYDNEY

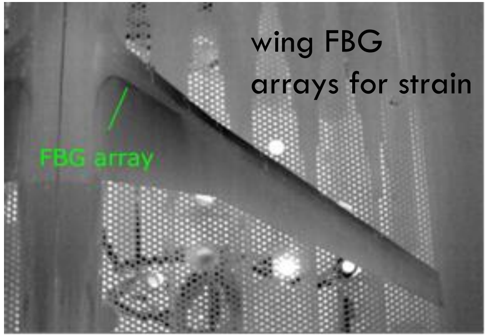
Contents

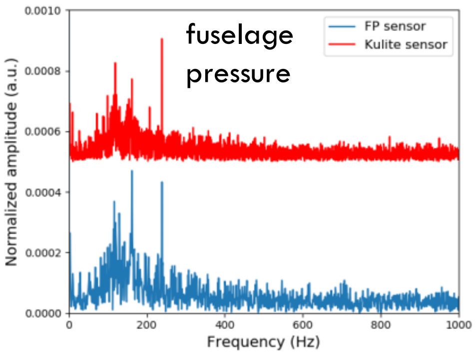
Research Background

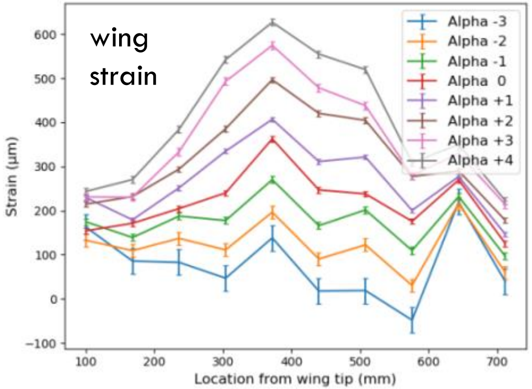
Fibre optic pressure and strain sensing in a transonic wind tunnel M0.82

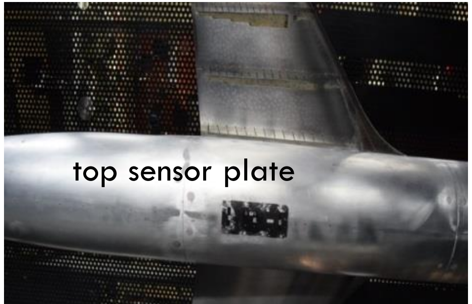
Wind tunnel trials ARA Bedford September 2019

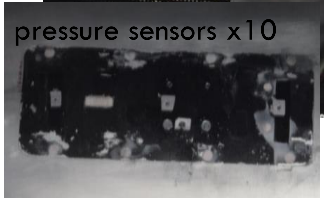








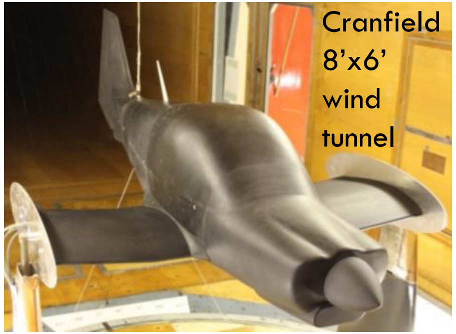




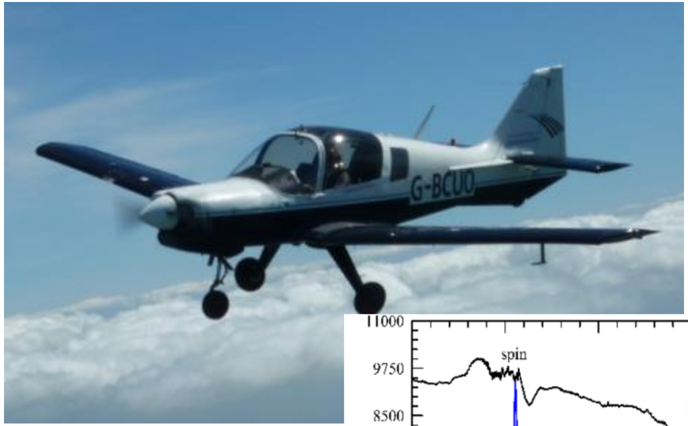
Research Background

Fibre optic pressure and strain sensing on an aircraft wing in-flight

Collaboration between Cranfield and 11 European partners

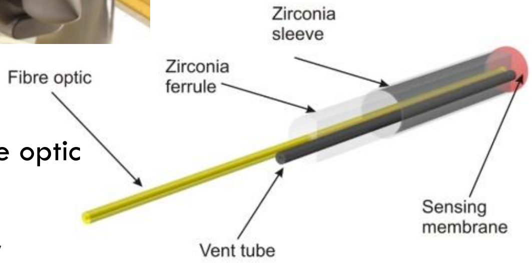


Cranfield 8'x6' wind tunnel

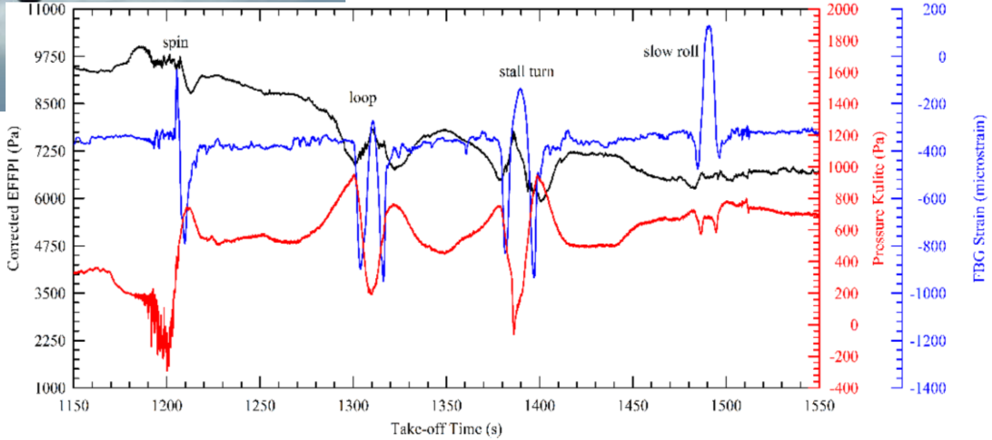


Bulldog flying testbed

Fabry Perot fibre optic pressure sensor



The University of Sydney



SEVENTH FRAMEWORK PROGRAMME

AIM²

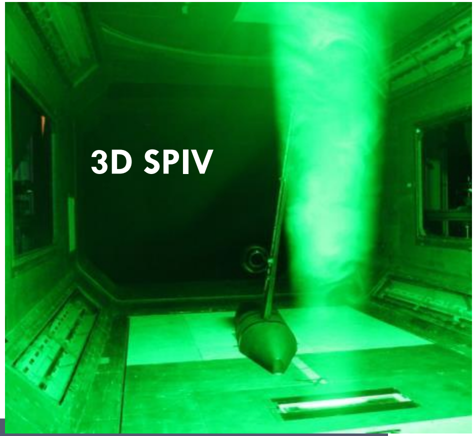
Advanced In-Flight Measurement Techniques 2

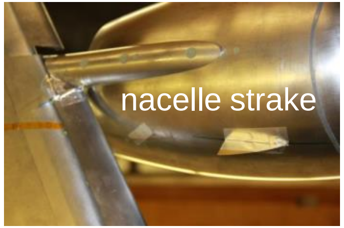
Cranfield University

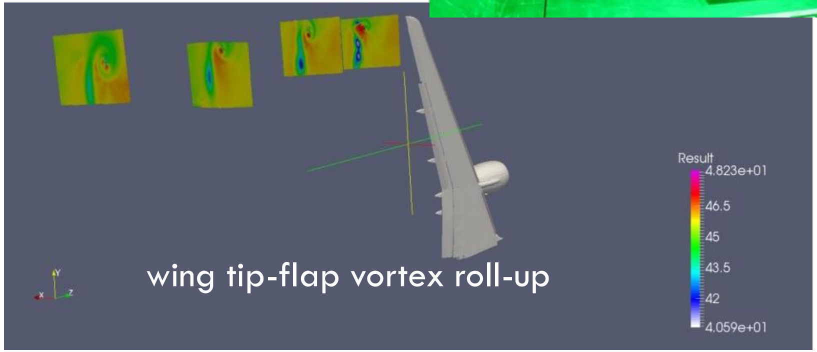
Research Background

30 years of laser flow measurement (PhD – PIV)

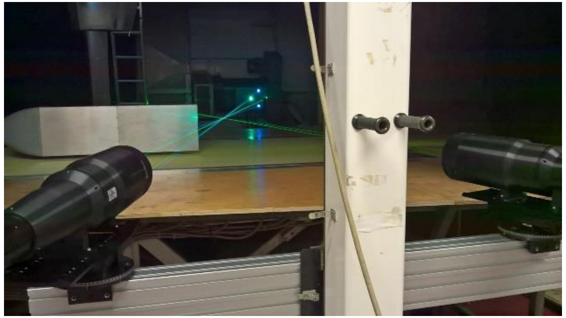
high lift wing flap nacelle vortex formation: Airbus ATI project



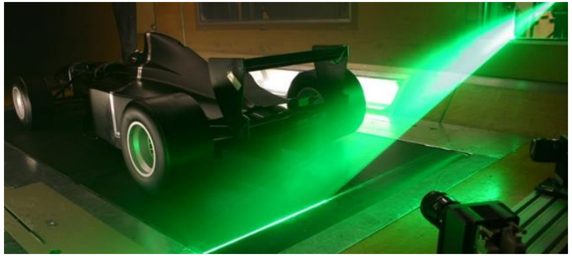




other laser projects



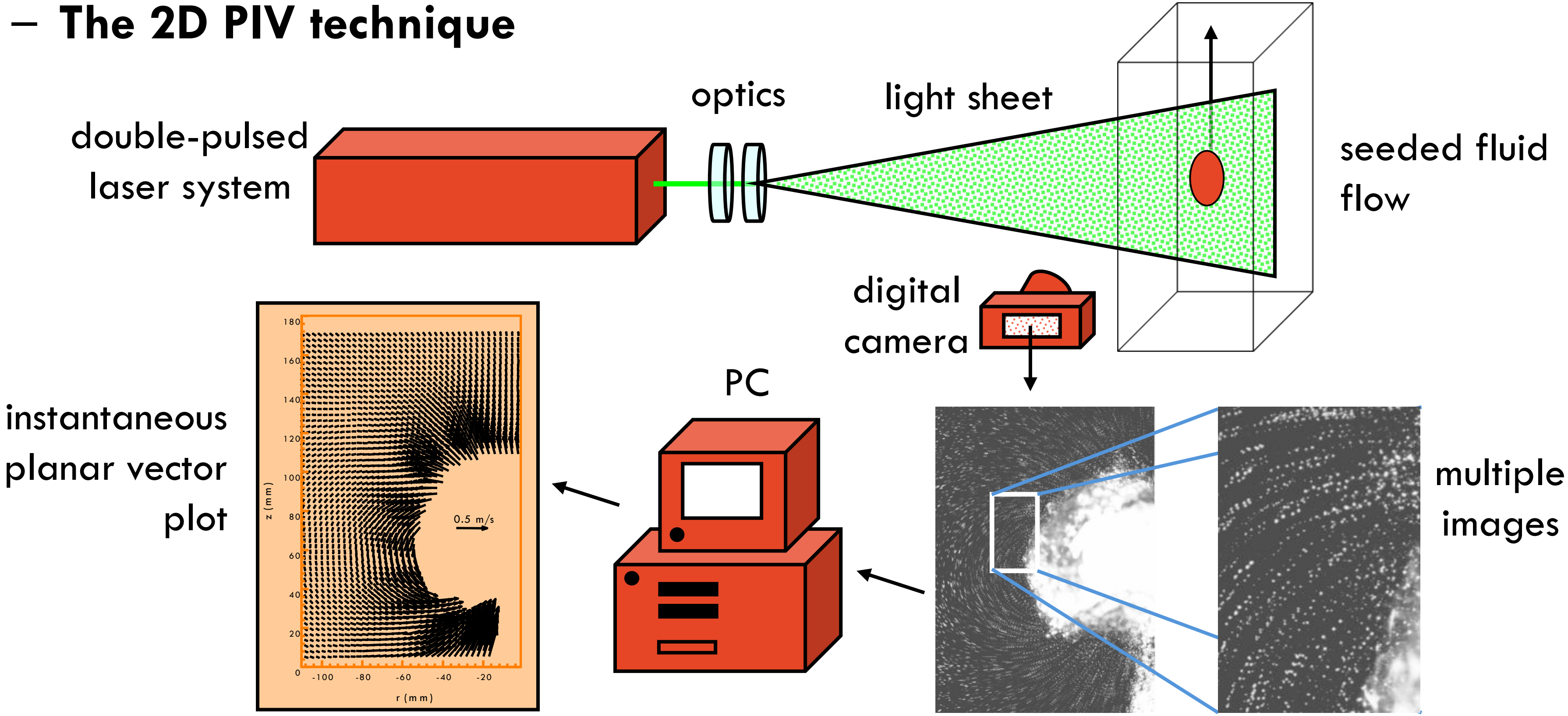
3D LDA underbody car diffuser studies (internal PhD)



PIV automotive wake studies

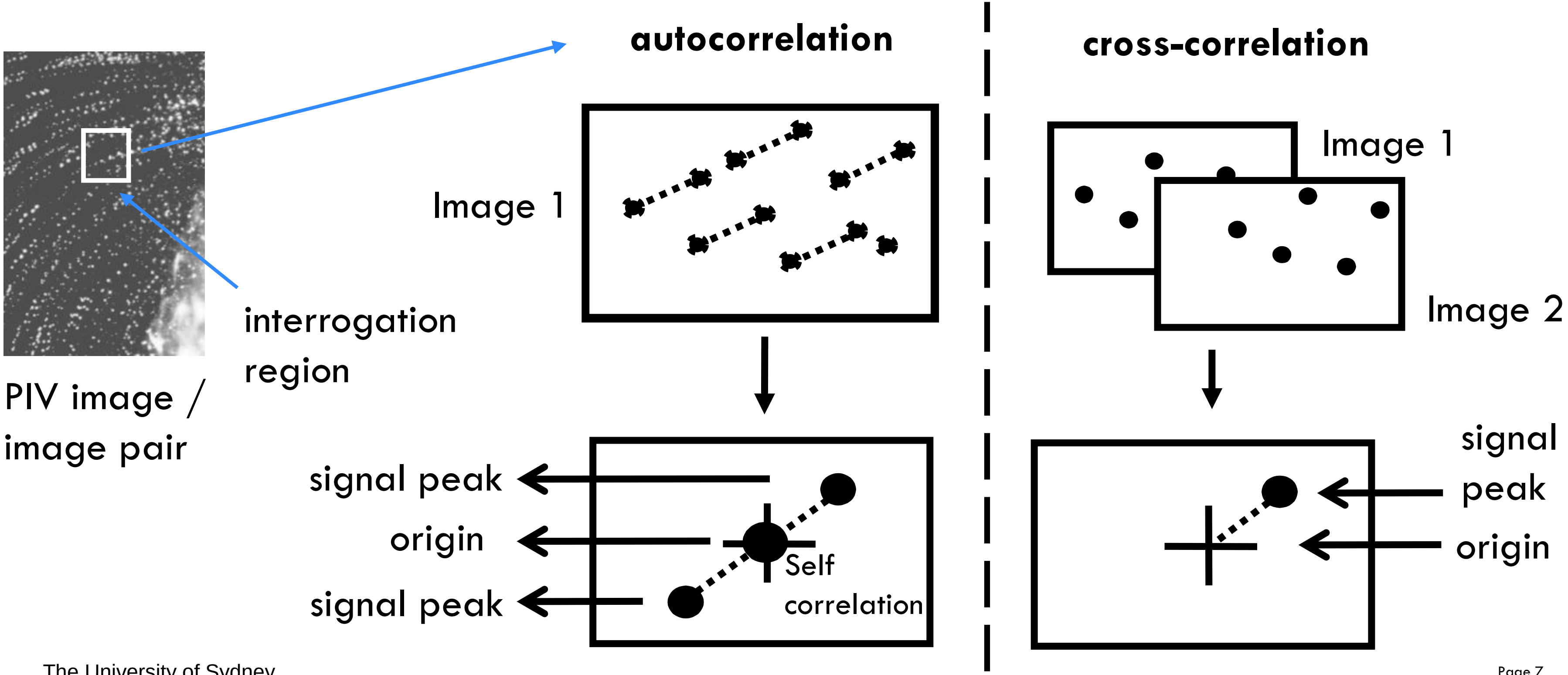
Experimental Challenge 1 – Data Noise Background

- **The 2D PIV technique**



Experimental Challenge 1 – Data Noise Background

– PIV data processing

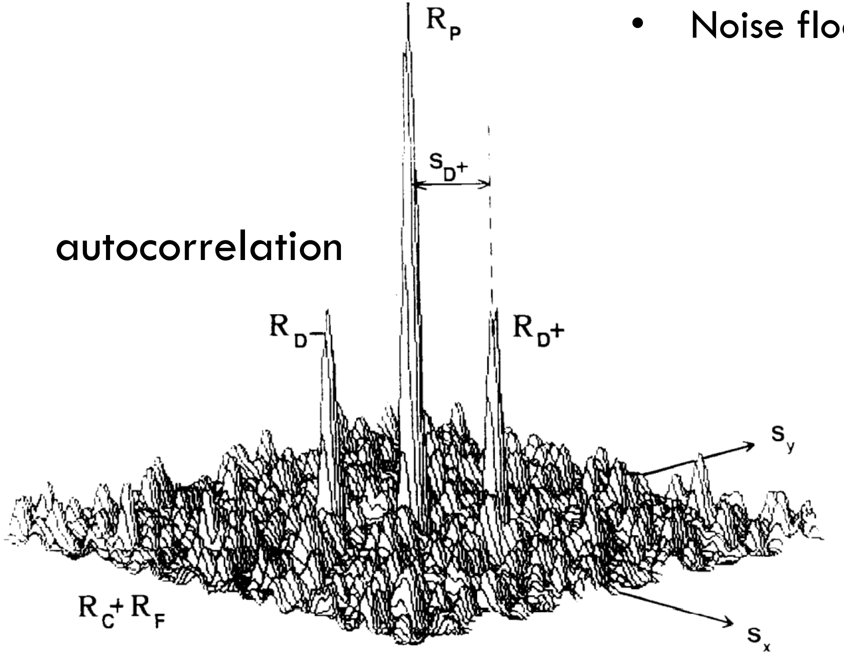


Experimental Challenge 1 – Data Noise Background

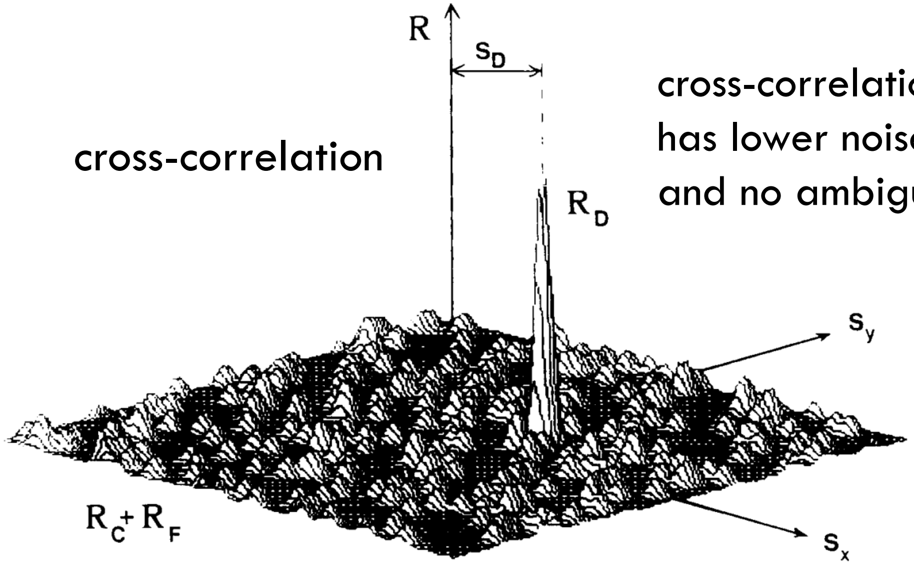
– Spatial Correlation

- Signal peak height directly dependent on particle image pairs N_p
- Noise peaks dependent on inter-particle correlations
- Noise floor average dependent on detector noise correlation

autocorrelation



cross-correlation

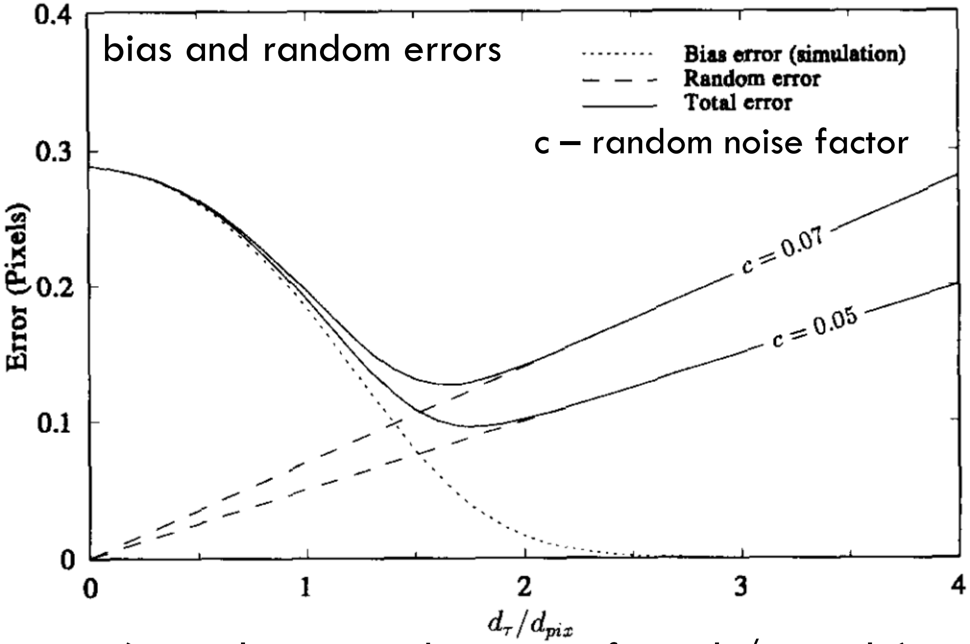


cross-correlation has lower noise and no ambiguity

Figures from: Keane R. D., Adrian R. J., *Meas. Sci. Technol.* 1 p1202-1215 (1990), Keane R.D., Adrian R.J., *J. Appl. Sci. Res.* 49 p191-215 (1992)

Experimental Challenge 1 – Data Noise Dilemmas

– Spatial Correlation Errors



(particle image dia – no. of pixels/particle)

- Correlation bias error depends on:
  - Particle image diameter
  - Sub-pixel peak fitting method (centroid or curve fit)
  - Velocity gradient

Larger particle image diameters improve bias error and peak fit accuracy

- Correlation random error depends on:
  - Particle image diameter
  - Correlation method (auto or cross)
  - Velocity gradients
  - Detector noise (CCD or CMOS)

Larger particle image diameters increase random error. Optimum ~2 pixels

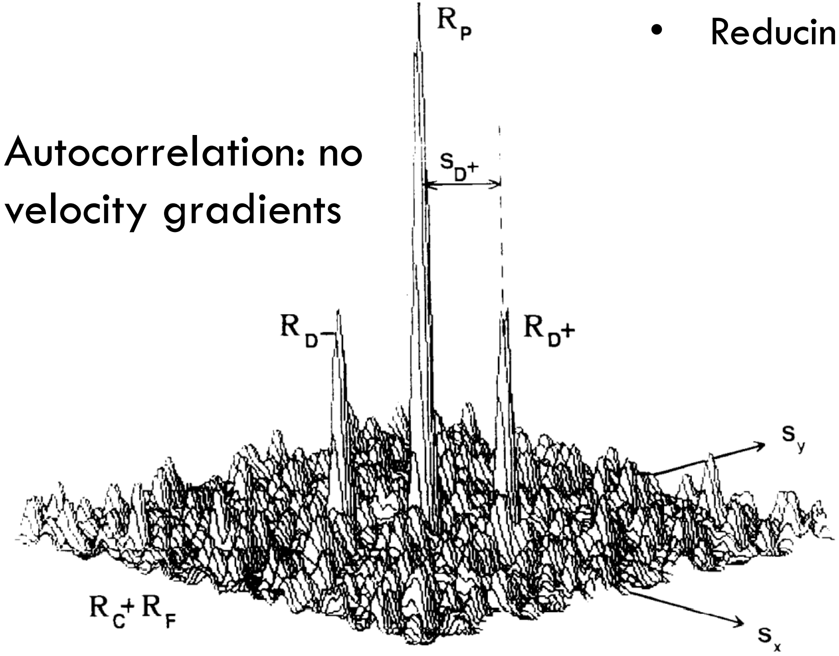
Figures from: Prasad A.K., Adrian R.J., Landreth C.C., Offutt P.W., *Exp. in Fluids 13*, p105-116, (1992)

Experimental Challenge 1 – Data Noise Sensitivities

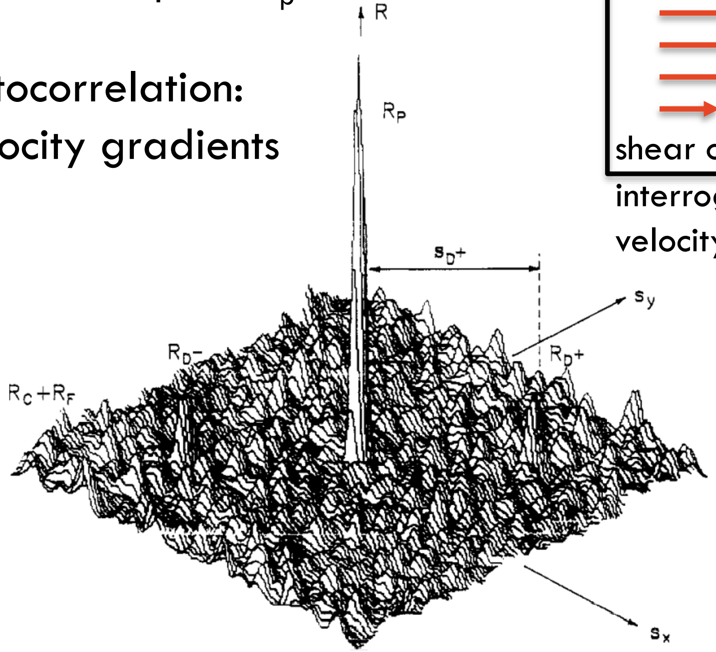
– Spatial Correlation

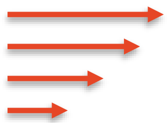
- Velocity gradients degrade signal peak quality
- Use of smaller interrogation regions or smaller Δt reduces
- Reducing Δt reduces pairs N_p

Autocorrelation: no velocity gradients



Autocorrelation: velocity gradients



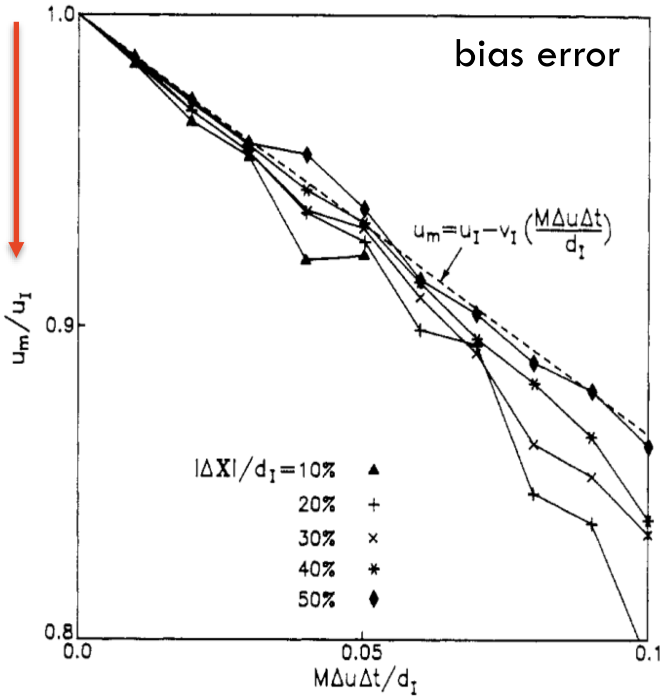


shear or vortex interrogation region velocity gradient

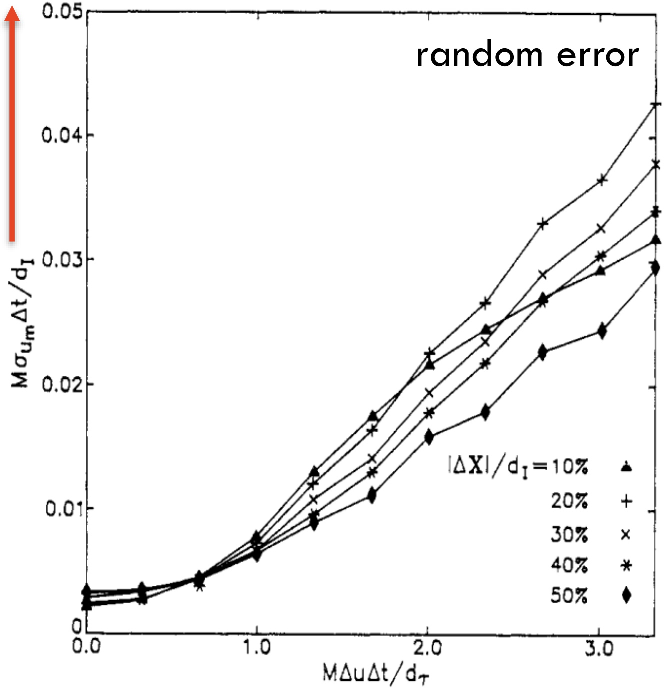
Figures from: Keane R. D., Adrian R. J., *Meas. Sci. Technol.* 1 p1202-1215 (1990), Keane R.D., Adrian R.J., *J. Appl. Sci. Res.* 49 p191-215 (1992)

Experimental Challenge 1 – Data Noise Sensitivities

increasing bias error



increasing random error



increasing velocity gradient

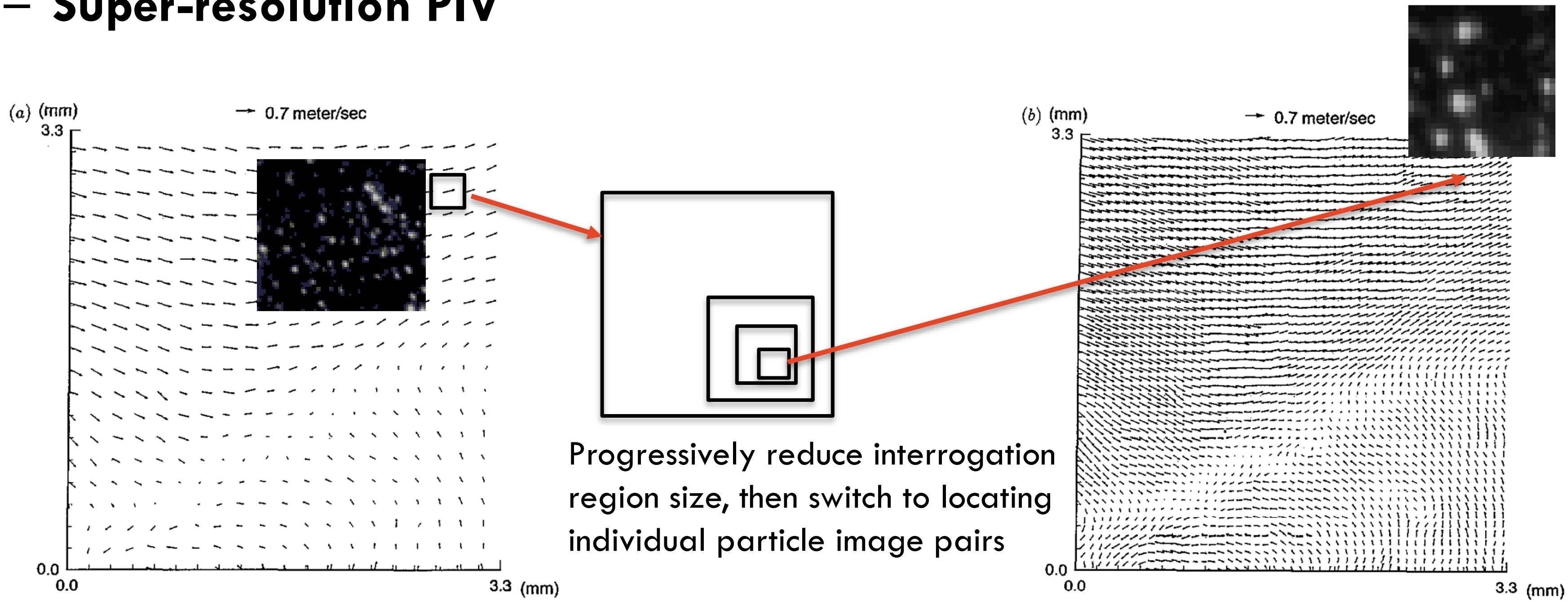
Increasing velocity gradients:

- increase bias error (peak splintering)
- increasing random error (peak height degradation / widening)

Figures from: Keane R. D., Adrian R. J., *Meas. Sci. Technol.* 1 p1202-1215 (1990)

Experimental Challenge 1 – Maximum Data Output

– Super-resolution PIV

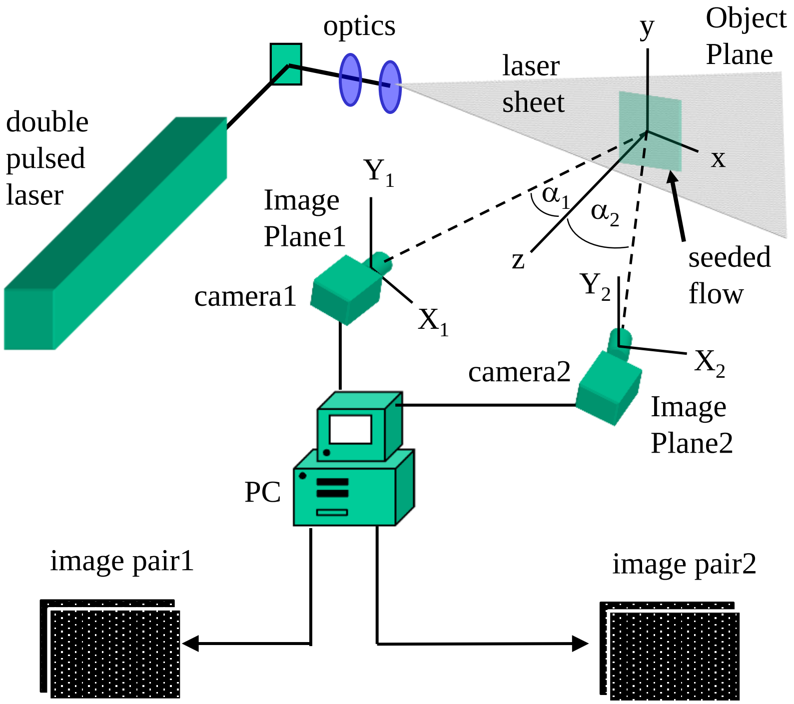


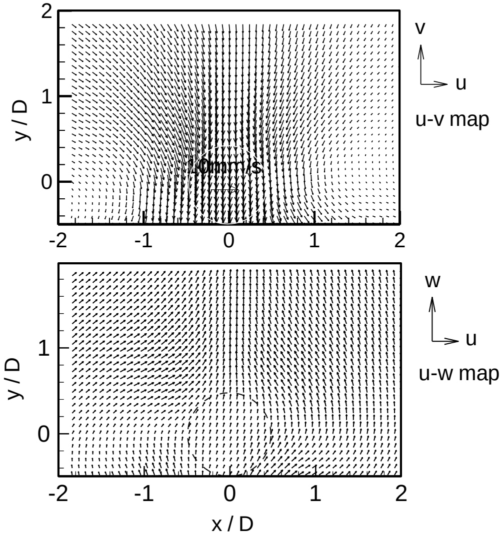
super-resolution method eliminates velocity gradient effect, bias and random errors, however, remain

Vector maps from: Keane R. D., Adrian R. J., Zhang Y., *Meas. Sci. Technol.* 6 p754-768 (1995)

Experimental Challenge 1 – Other PIV Methods

– Stereoscopic PIV



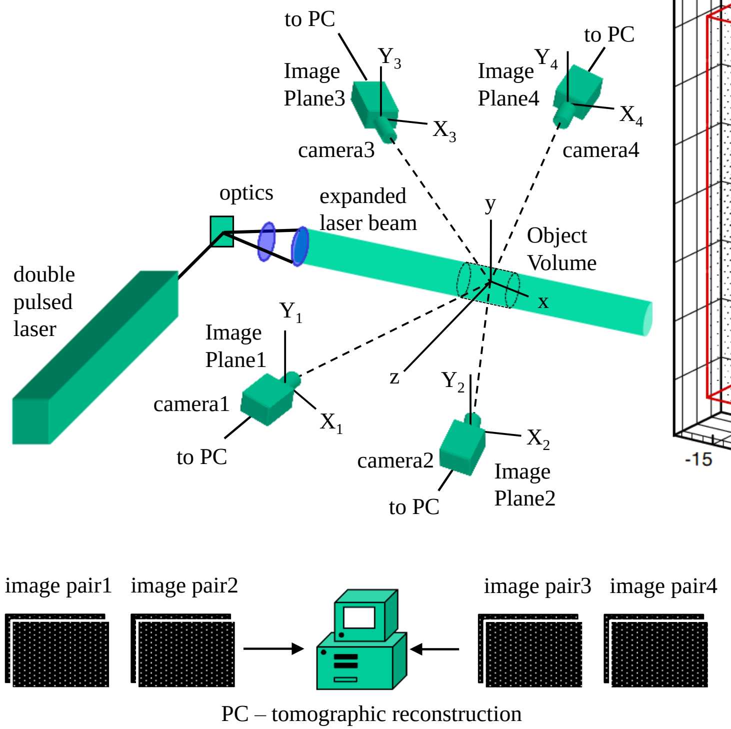


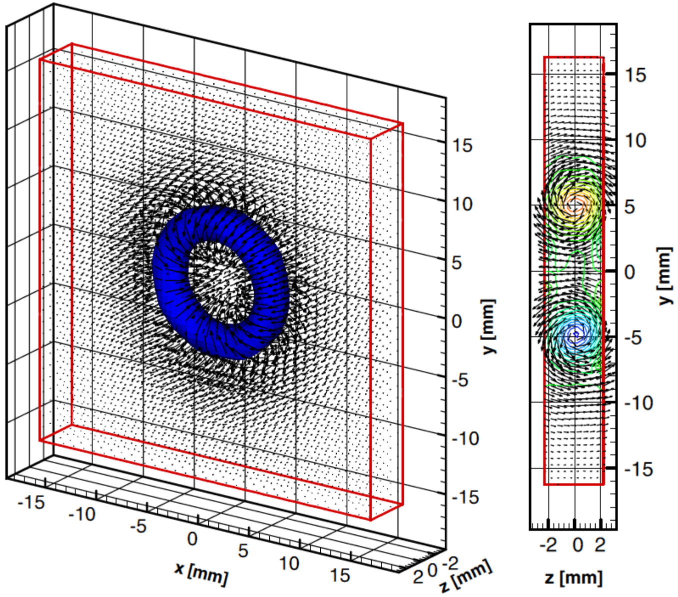
Stereoscopic PIV provides in-plane u-v-w components:

- Calibration errors (image alignment & dewarping)
- Random and bias errors similar to 2D PIV
- Imaging optics characteristic less critical

Experimental Challenge 1 – Other PIV Methods

– Tomographic PIV





Elsinga et al, *Exp. in Fluids* 41: 933 – 947 (2006)

Tomographic PIV provides full volume u-v-w components:

- Calibration errors (multiple image alignment & cameras)
- Random and bias errors from 'voxel' location
- Ghost errors when N_p too high

Experimental Challenge 2 – Data Processing

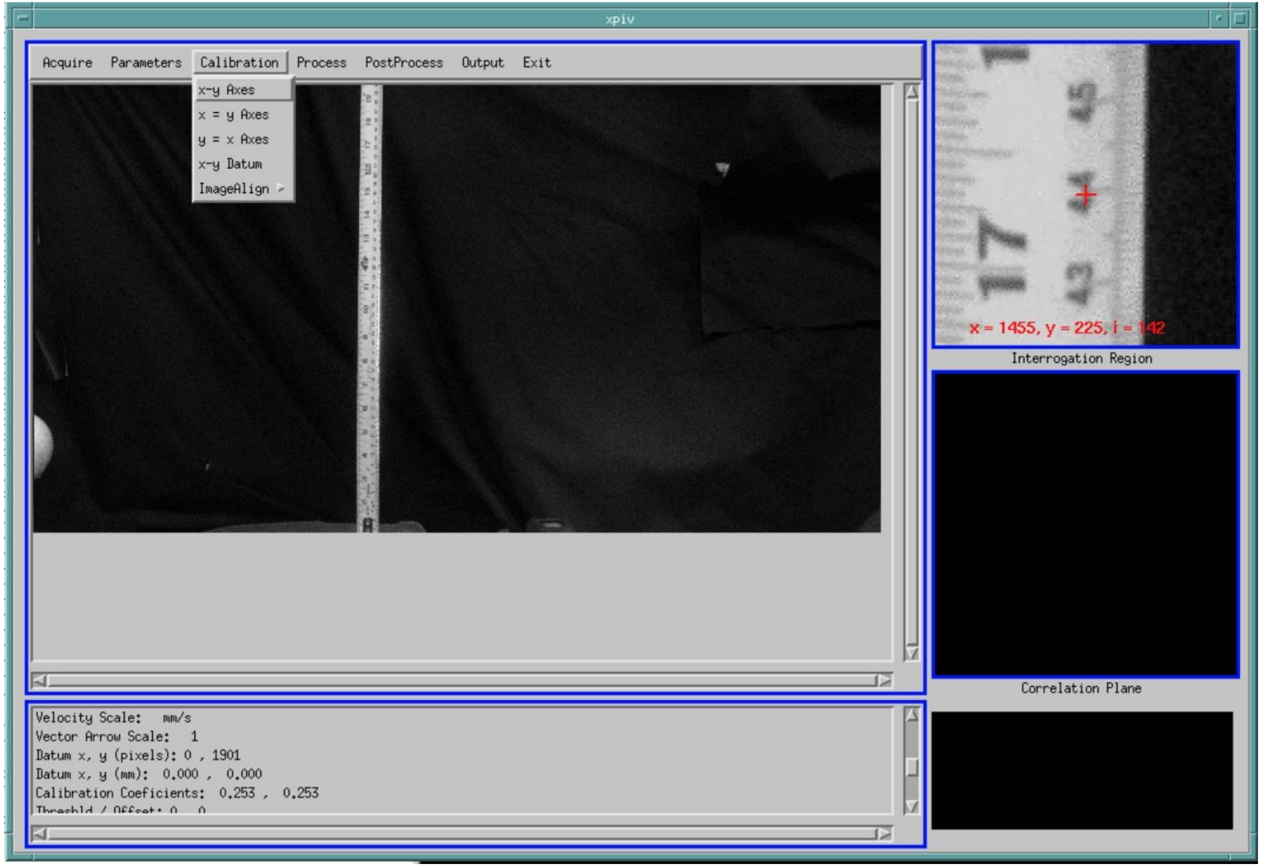
– Data processing interface

- PIV set-up and data processing still requires judgement and experience:
  - Seeding density and laser settings (Δt and N_p)
  - Camera positioning and focussing
  - Data processing algorithm choice /settings
  - Post processing methods

- Interface between the user and the data is critical to make initial/final choices:
  - Calibration and selection of interrogation region size
  - Viewing correlation plane during processing
  - Post-processing: automated and manual methods

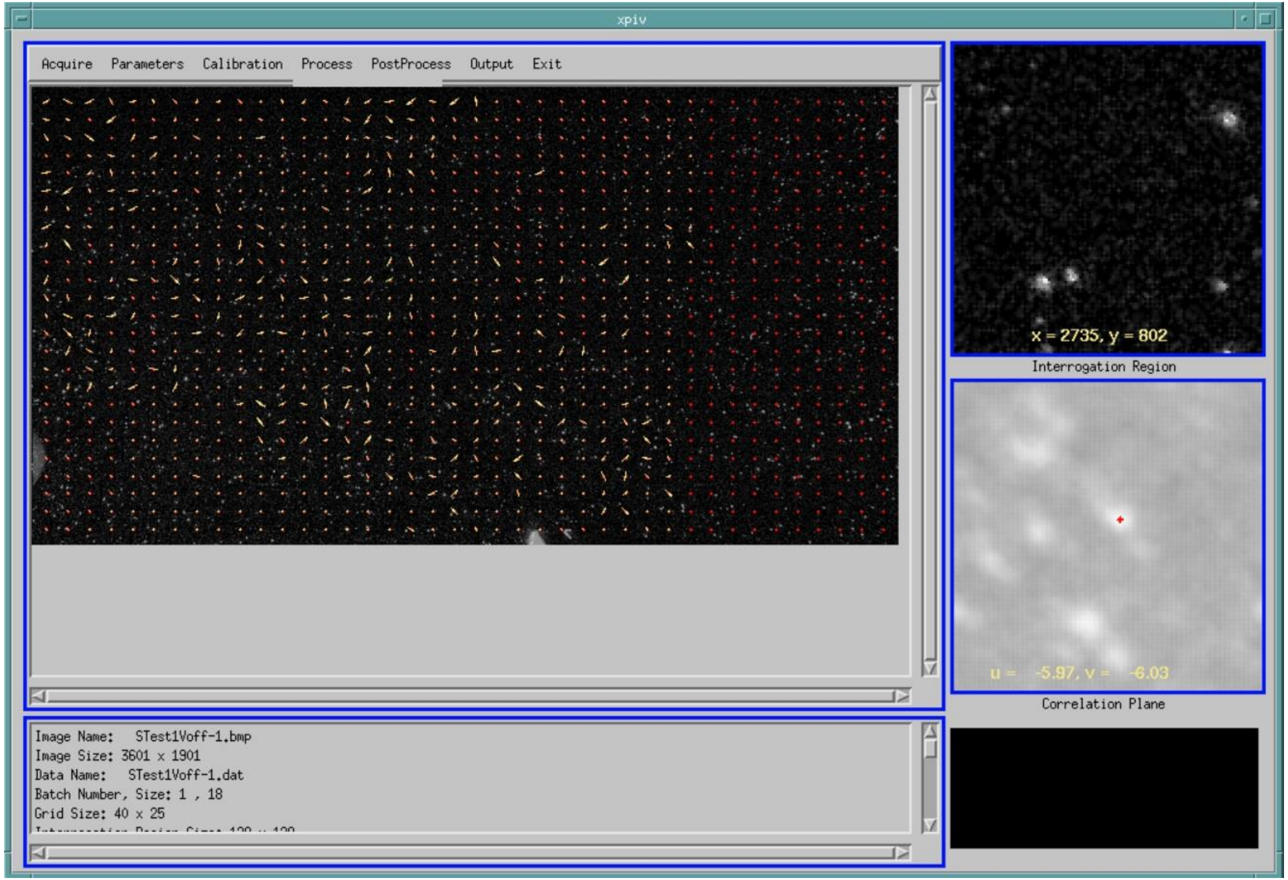
Commercial off-the-shelf systems, highly mature, but bespoke systems are still used and developed by research groups (DLR, TU Delft, Uni of Illinois).

Experimental Challenge 2 – Data Processing



- Software 'xpiv' developed during post-doc 25 years ago in C-code
- Unix / Linux Interface through X-Windows due to processing speed requirement
- Still compatible from old Sun workstations to current Linux HPCs
- Requires Motif Windows Manager, MobaXterm or Xming / putty shell windows interface into HPC
- Full calibration / correlation processing / post-processing software suite

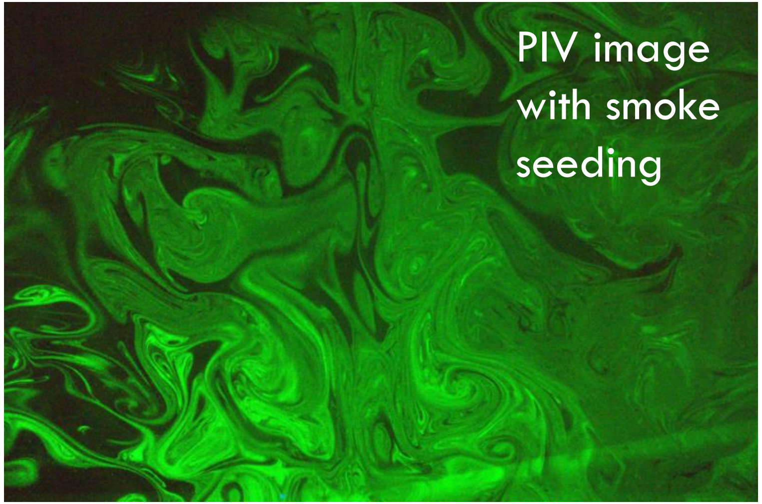
Experimental Challenge 2 – Data Processing

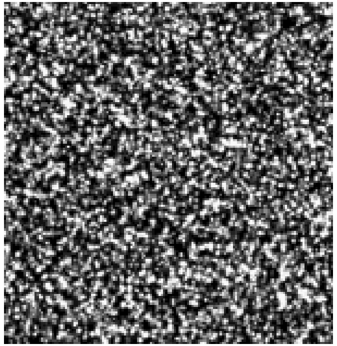


- Viewing and interrogation window for set-up and vector inspection
- Live correlation window for correlation set-up
- Autocorrelation and several cross-correlation algorithms
- Includes correlation averaging for low seeding density
- Peak fitting choices
- Post-processing vector validation and smoothing
- Batch processing and data output for movies or other data formats
- In constant development

Experimental Challenge 1 – Data Processing

– Use of bespoke software for challenging data format

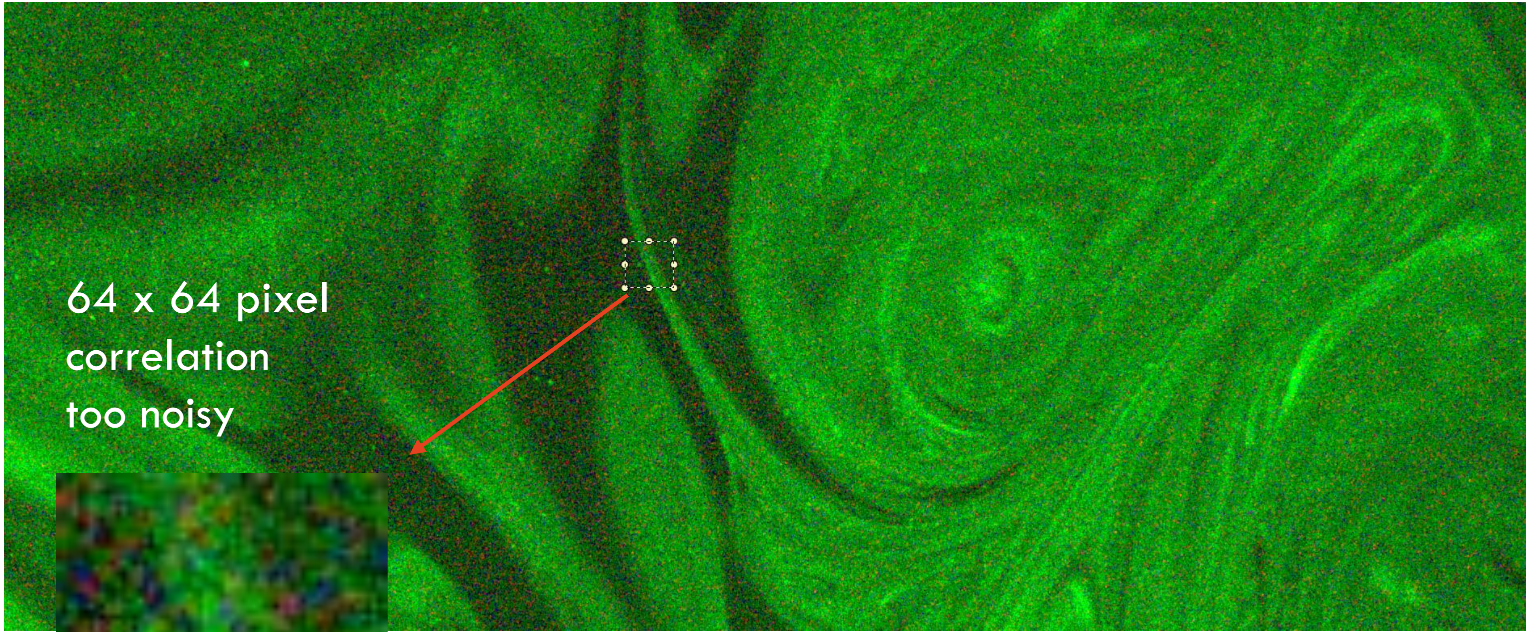


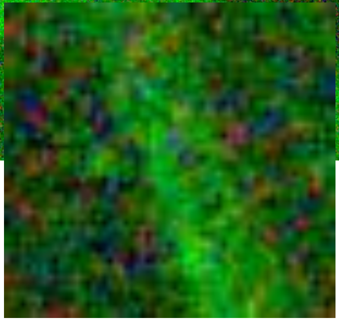


Example of 'classic' PIV image

'Classic' PIV images not possible with smoke which was the only effective seeding in large areas and which formed convecting large 'spatial patterns'

Experimental Challenge 1 – Data Processing





COTS software typically stops at interrogation region size

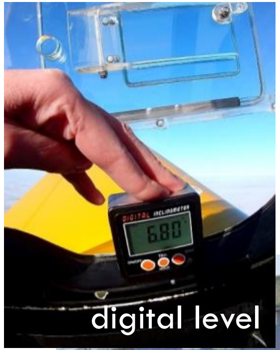
128 x 128

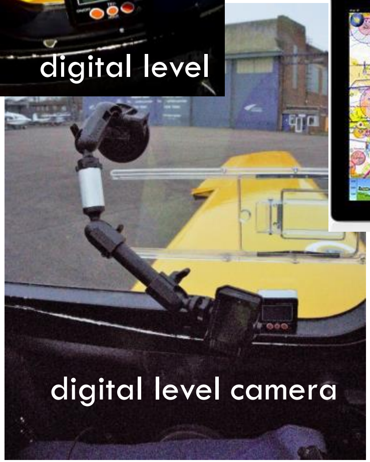
Non-standard PIV data processing methods with large interrogation windows (512 x 512 pixels) and correlation averaging methods

In-Flight Data Example

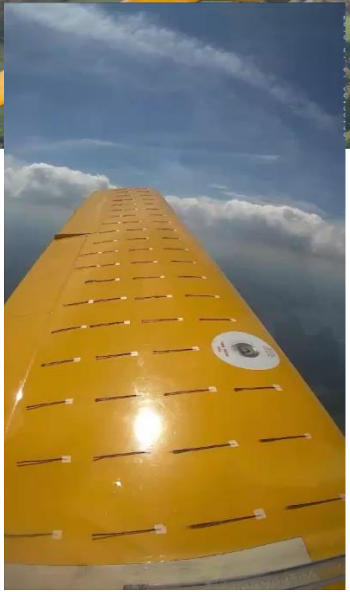
Stall Buffet Modelling & Measurement of a Slingsby Aircraft

Method 1 – iPad-Level-Altimeter





iPad ground speed (1Hz)



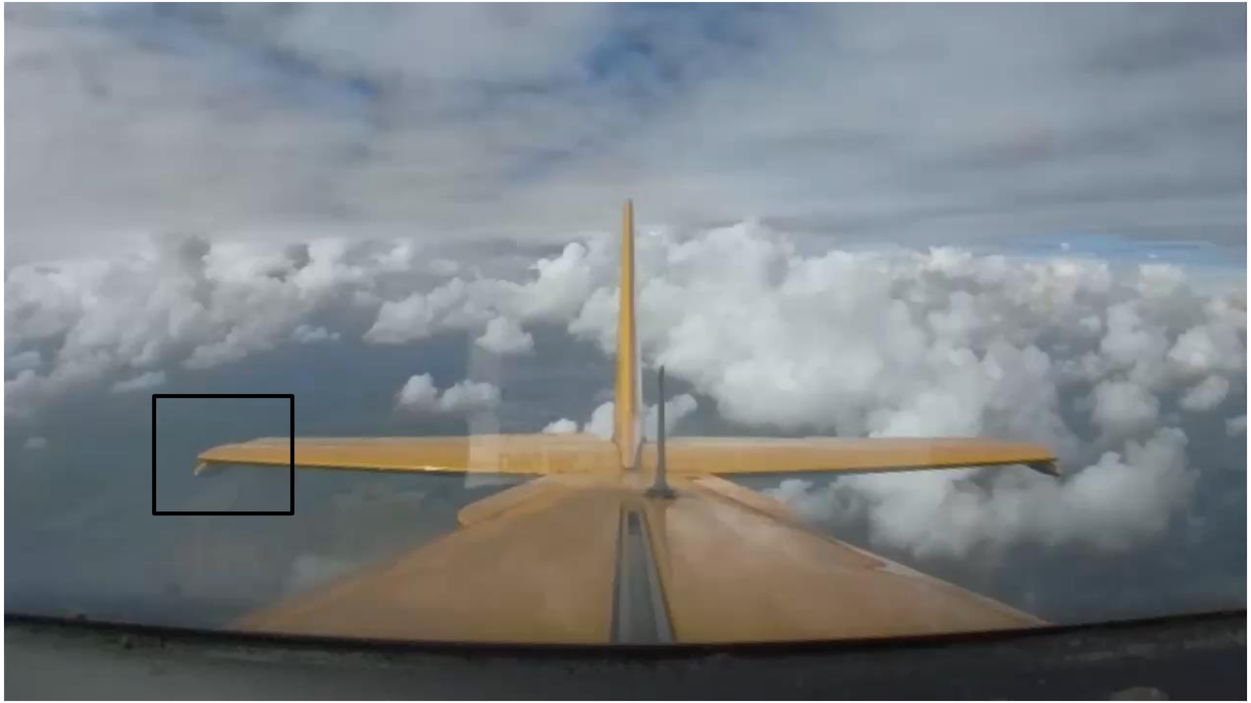
Method 2 – Pixhawk4 Inertial Unit

250Hz accel^{n}s
250Hz pitch attitude
5Hz GPS grd speed
5Hz GPS altitude

In-Flight Data Example

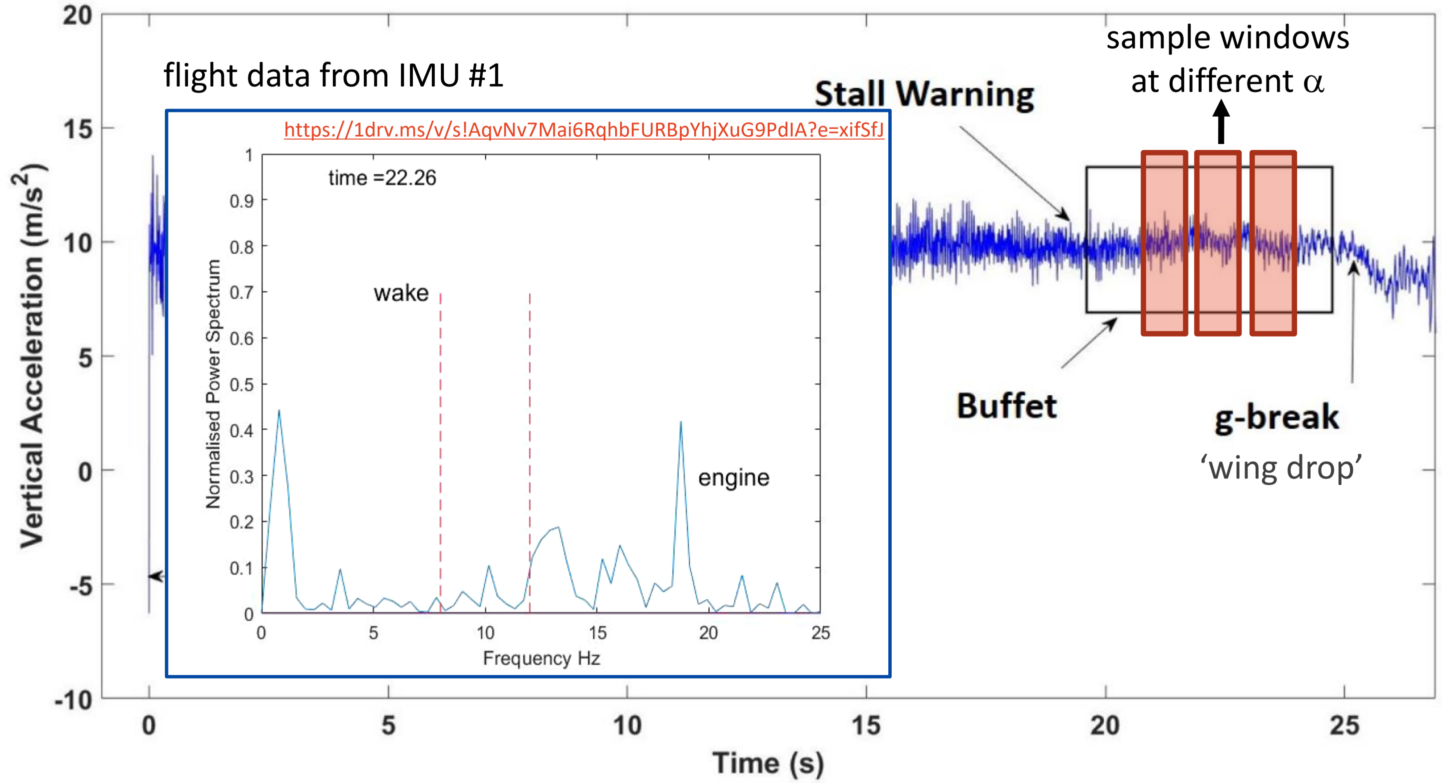
- **Flight test tailplane view during stall**

front view:
https://1drv.ms/v/s!AqvNv7Mai6Rqhat1RHb-AeOriCqNhg?e=2Yj2Jr
rear view:
https://1drv.ms/v/s!AqvNv7Mai6RqhatzgheKAiSgmdqvww?e=3ODRxW



rear view: progressive stall to heavy buffet and ‘wing drop’

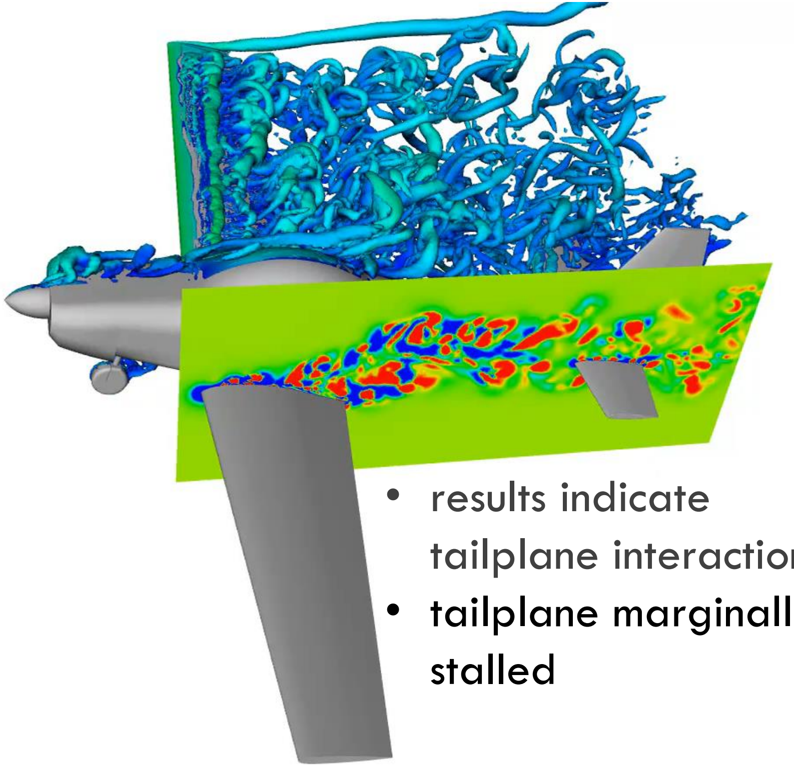
In-Flight Data Example



- Viewing data in an unsteady format can be critical to correct interpretation of a complex characteristic
- Multiple complex datasets
- How do we teach machines to do this?

Research Experience

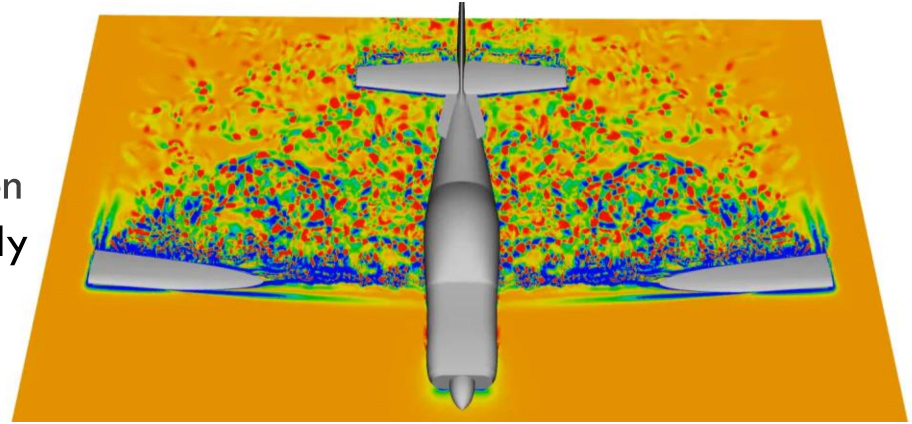
Integration and interpretation of experimental and numerical data sources is critical to physical understanding. How will machines do this?



- results indicate tailplane interaction
- tailplane marginally stalled

https://1drv.ms/v/s!AqvNv7Mai6Rqhat4dkV0vTgOxsjrPA?e=duKh6a

https://1drv.ms/v/s!AqvNv7Mai6Rqhat51vmhLbHs3FaA_Q?e=vYEn8H



Questions?