Experimentalist View: Data Processing Methods and Lessons

A.Prof Nick Lawson
Department of Aerospace, School of Aerospace, Mechanical and Mechatronic Engineering
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Research Background

Fibre optic pressure and strain sensing in a transonic wind tunnel M0.82
Wind tunnel trials ARA Bedford September 2019

The University of Sydney
Research Background

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

Collaboration between Cranfield and 11 European partners

Bulldog flying testbed

Cranfield 8’x6’ wind tunnel

Fabry Perot fibre optic pressure sensor

The University of Sydney
Research Background

high lift wing flap nacelle vortex formation: Airbus ATI project

3D SPIV

aileron attachments

nacelle strake

wing tip-flap vortex roll-up

30 years of laser flow measurement (PhD – PIV)

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

double-pulsed laser system

optics

light sheet

seeded fluid flow

digital camera

instantaneous planar vector plot

PC

multiple images

The University of Sydney
Experimental Challenge 1 – Data Noise Background

- PIV data processing

**autocorrelation**

**cross-correlation**

PIV image / image pair

interrogation region

signal peak

signal peak

origin

Self correlation

signal peak

signal peak

origin

Image 1

Image 2

Image 1
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

Experimental Challenge 1 – Data Noise Dilemmas

- Spatial Correlation Errors

- 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

Experimental Challenge 1 – Data Noise Sensitivities

- Spatial Correlation

- Velocity gradients degrade signal peak quality
- Use of smaller interrogation regions or smaller $\Delta t$ reduces
- Reducing $\Delta t$ reduces pairs $N_p$

Autocorrelation: no velocity gradients

Autocorrelation: velocity gradients

Experimental Challenge 1 – Data Noise Sensitivities

Increasing velocity gradients:
- increase bias error (peak splintering)
- increasing random error (peak height degradation / widening)

Experimental Challenge 1 – Maximum Data Output

– Super-resolution PIV


Progressively reduce interrogation region size, then switch to locating individual particle image pairs.

super-resolution method eliminates velocity gradient effect, bias and random errors, however, remain
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
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 ($\Delta t$ 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 ‘xpv’ 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

‘Classic’ PIV images not possible with smoke which was the only effective seeding in large areas and which formed convecting large ‘spatial patterns’
Non-standard PIV data processing methods with large interrogation windows (512 x 512 pixels) and correlation averaging methods.

COTS software typically stops at interrogation region size 128 x 128.
In-Flight Data Example

Method 1 – iPad-Level-Altimeter

Method 2 – Pixhawk4 Inertial Unit

Stall Buffet Modelling & Measurement of a Slingsby Aircraft

- iPad
- Level
- Altimeter

- digital level
- iPad
- ground speed
  (1Hz)

- 250Hz accel’s
- 250Hz pitch attitude
- 5Hz GPS grd speed
- 5Hz GPS altitude

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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!AqvNv7Mai6RqhatzgheKAIgmdqvw?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
Questions?