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Feasibility of Retroreflective Particle Image Velocimetry for Flow Measurement Around a Thick Aerofoil with a Gurney Flap

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1. Introduction & Background

Particle Image Velocimetry (PIV) is the conventional technique for full-field flow measurement. The flow is seeded with tracer particles, illuminated by a laser sheet, and the velocity is derived from cross-correlation of image pairs.

Limitations near solid surfaces:

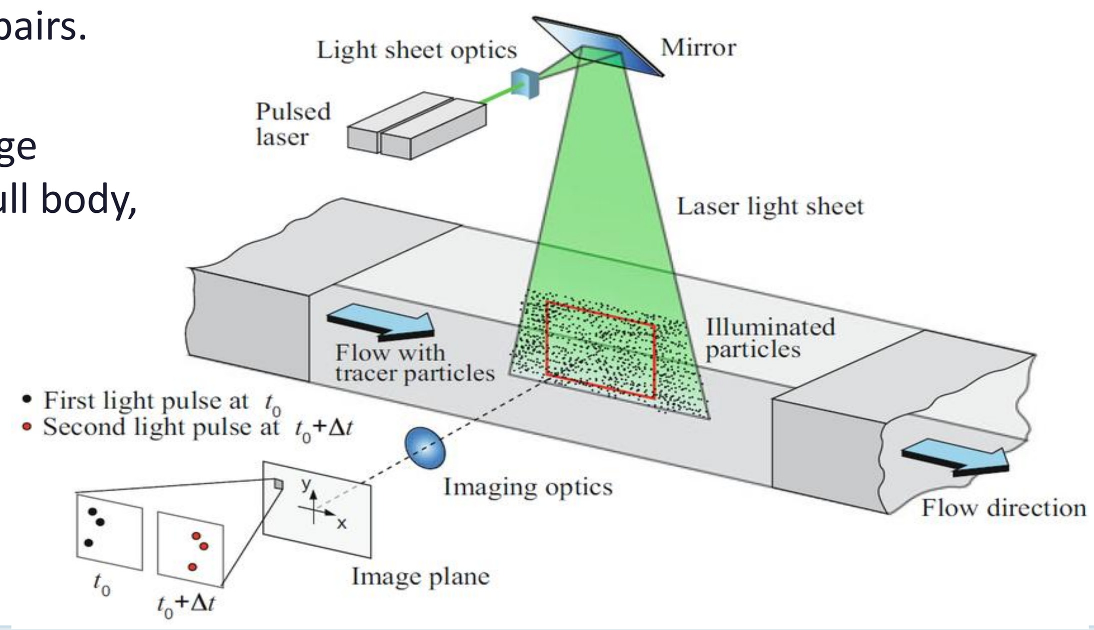
- Optical glare and reflections from the body surface
- Shadowing restricts near-wall optical access
- Cannot view the flow on both sides simultaneously

Retroreflective shadowgraphy:

- LED + retroreflective screen image particles as **dark silhouettes** – full body, shadow-free, no laser

Why a Gurney flap?

- Small trailing-edge tab → more camber & circulation; thickens wake



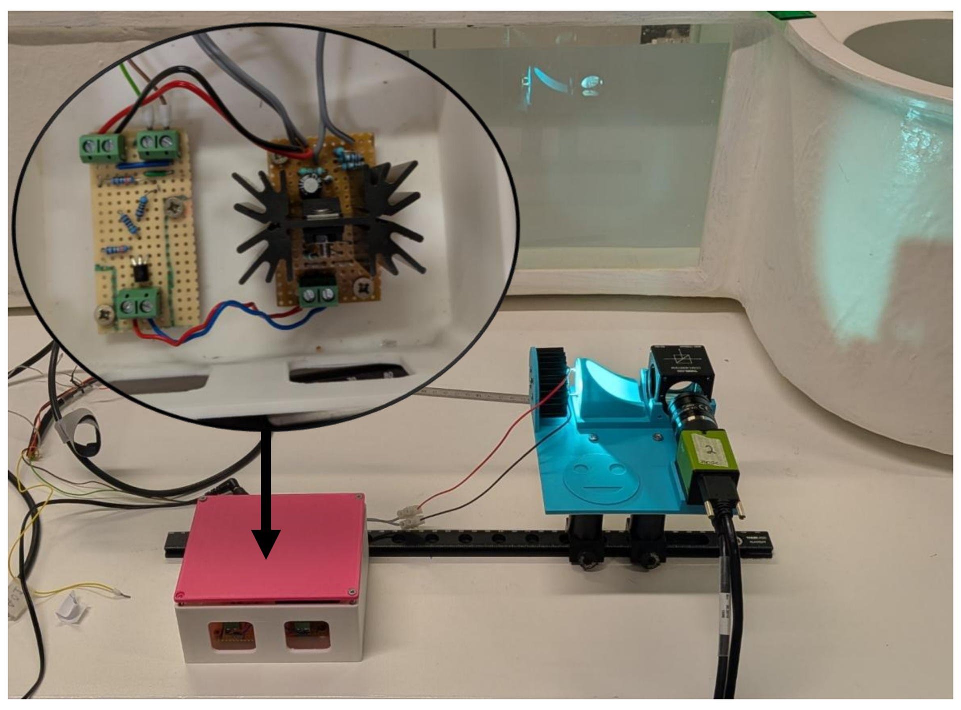
2. Aims & Objectives

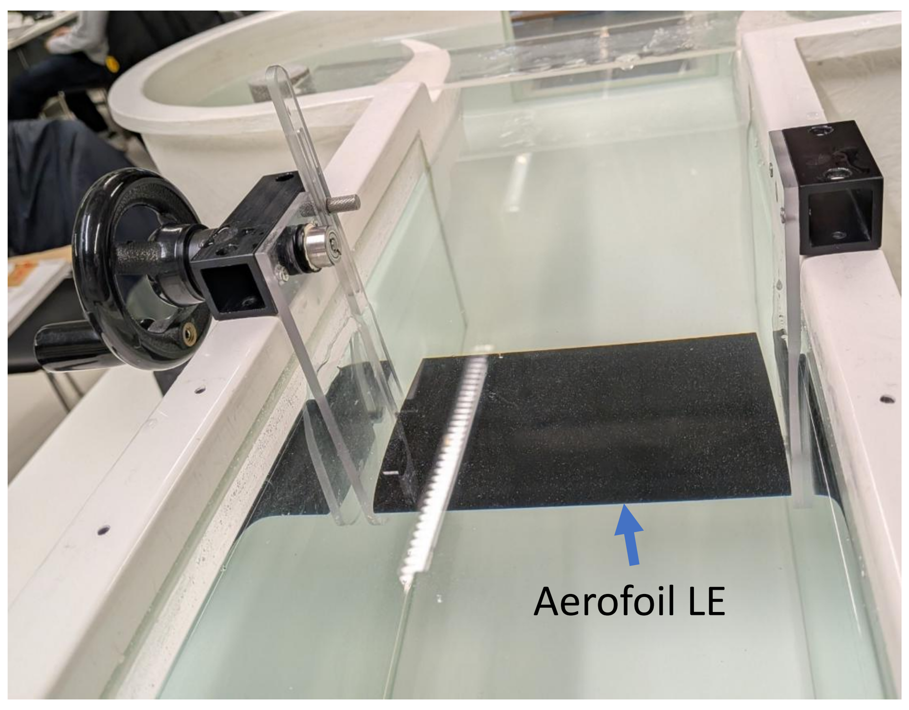
AIM: Develop and assess ***retroreflective*** *particle image velocimetry for* ***full-field flow measurement*** *around a NACA 0020 aerofoil with a Gurney flap in a water tunnel.*

- Design a retroreflective optical setup and mount an aerofoil in a water tunnel
- Develop an image pre-processing pipeline suitable for PIV analysis
- Conduct a systematic study across 5 angles of attack × 5 flow speeds
- Obtain velocity, vorticity and RMS fluctuation fields via PIV
- **Compare** and **validate** results with conventional laser-sheet PIV and published literature

3. Methodology

Experimental Setup

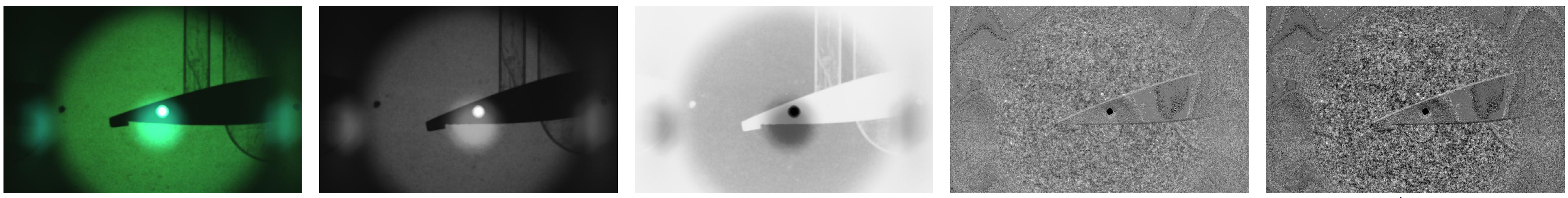




Parameter	Value
Water Tunnel	7”x10” test section
Aerofoil	NACA 0020
Background	ORALITE 5710
Camera	JAI GO-2400C-USB, 1920x1200 px, 12 mm lens
Chord (c)	111 mm
Gurney flap	~3% chord
Spatial calibration	10.38 px/mm
Image pairs / runs	200
Interrogation window	128 → 16 px
Angles of attack tested	−6°, 0°, 4°, 8°, 12°
Reynolds number range	7800 → 16800

Two preliminary studies: material selection - ORALITE 5710 chosen over 3M 7610, and pre-processing workflow optimisation to maximise particle visibility.

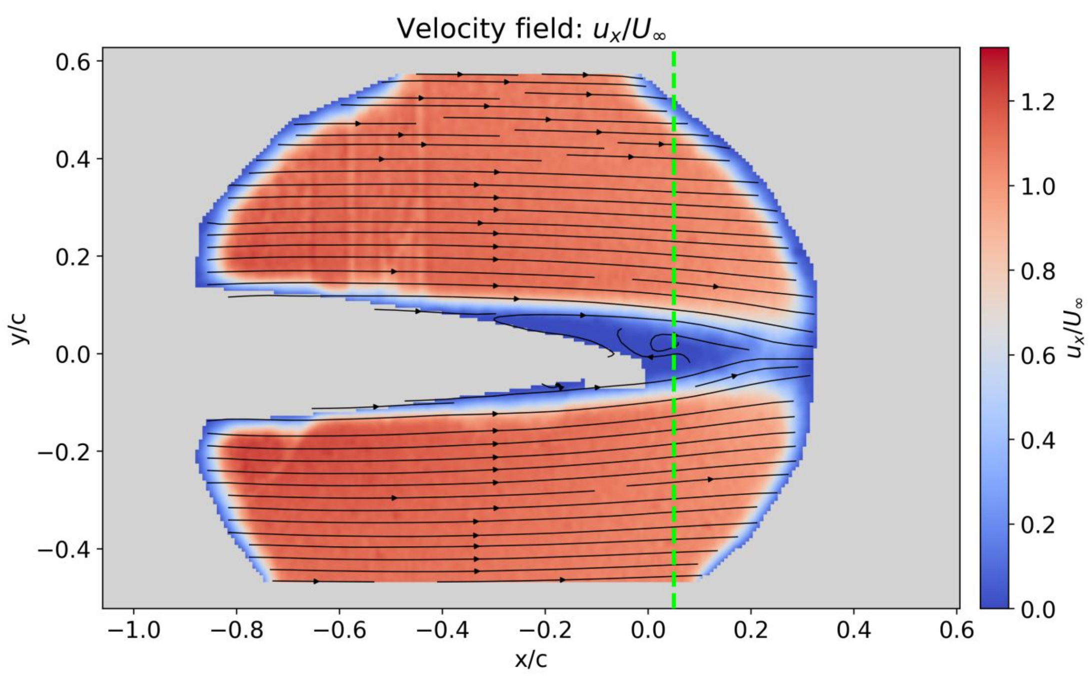
Processing Workflow



PIVTOOLS (Python) — multi-pass FFT cross-correlation, 128→16 px interrogation windows, masking, sub-pixel refinement. **200 image pairs per runs** → ensemble-averaged/instantaneous velocity fields.

4. Representative Flow Fields

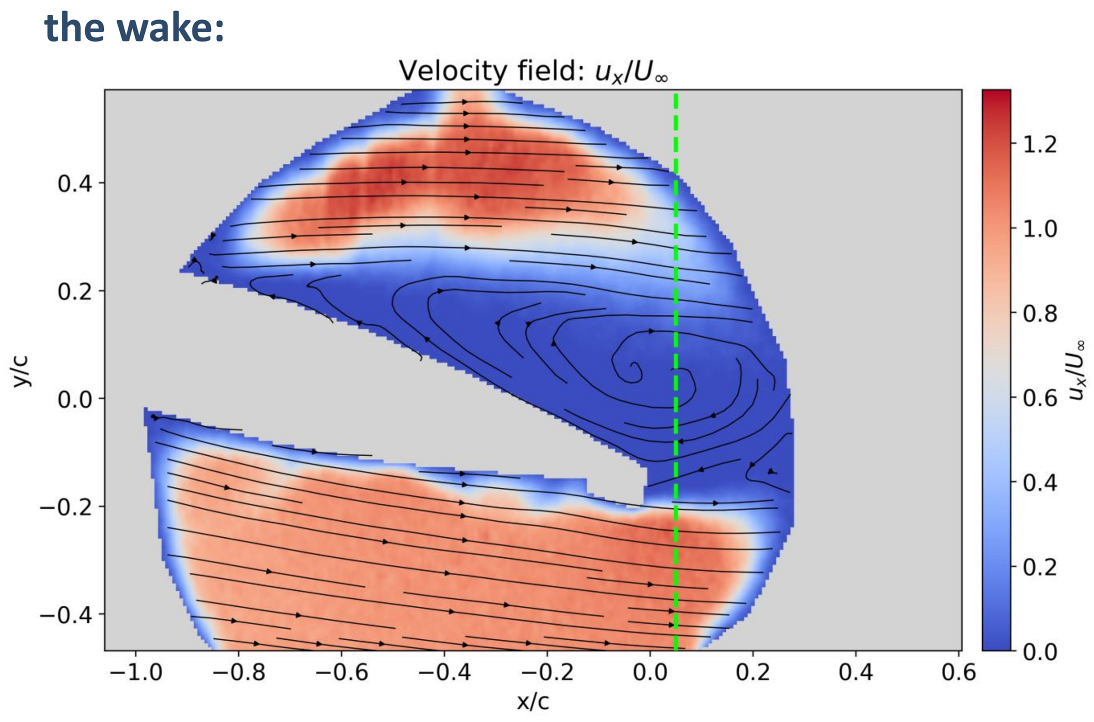
Mean streamwise velocity (ux) at 0° AoA, Re ≈ 1.08×10⁴:



Uniform freestream transitions to a distinct boundary layer and velocity deficit in the near wake downstream of the trailing edge.
Gurney flap produces a persistent wake deficit even at 0°, expected for a symmetric aerofoil with a trailing-edge device.

5. Effect of Angle of Attack

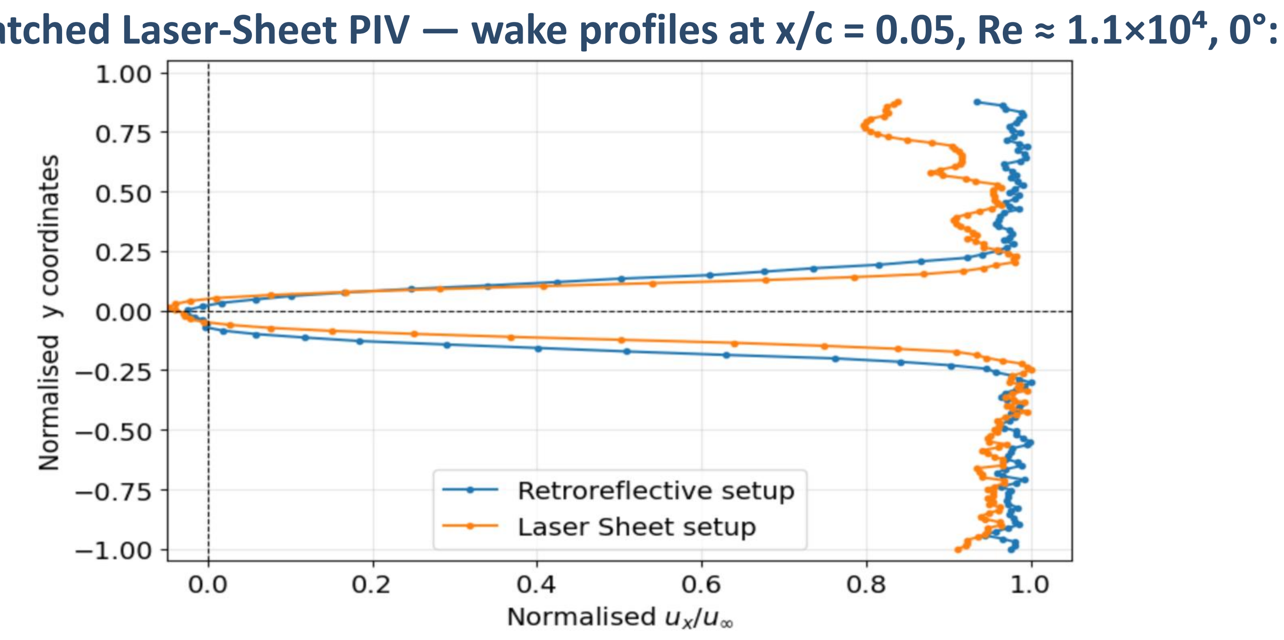
Increasing AoA progressively broadens and displaces the wake:



0° AoA: Compact, near-symmetric wake. Gurney flap introduces local trailing-edge deficit.
12° AoA: Substantially wider, asymmetrically displaced wake. Regions of near-zero / reversed flow (ux) indicate upper-surface separation, consistent with low-Reynolds-number laminar separation.

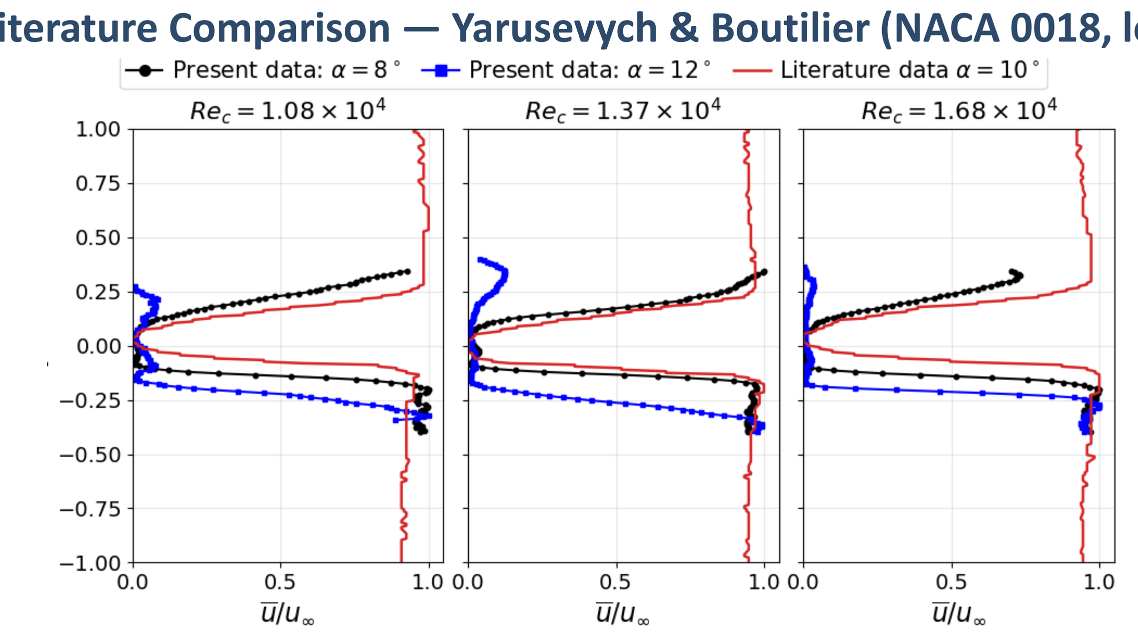
6. Validation & Comparison

Matched Laser-Sheet PIV — wake profiles at x/c = 0.05, Re ≈ 1.1×10⁴, 0°:



- Freestreams match **within 4%**
- Centreline velocity deficit within 0.3% and comparable wake half-width **within 8%**
- RMS profile difference 0.07 in $0.07u/U_\infty$.

Literature Comparison — Yarusevych & Boutilier (NACA 0018, low Re):



7. Conclusions

✓ Retroreflective PIV **successfully demonstrated** — all 25 test cases yielded physically plausible velocity fields.
✓ Full-body **shadow-free visualisation** achieved with LED illumination — a practical advantage over laser-sheet PIV.
✓ Wake broadening with angle of attack and Gurney flap influence captured consistently across all Reynolds numbers.
✓ Near-wake profiles broadly **consistent** with matched laser-sheet PIV and published NACA 0018 literature.
⚠ Quantitative accuracy limited by uncalibrated free-stream speed and restricted illuminated field of view (≤ 0.25 x/c downstream).
▶ Method is viable for *qualitative and semi-quantitative* aerodynamic assessment; further refinement needed for high-precision quantitative use.

8. Future Work

- Enlarge and homogenise the illuminated field of view to observe far-wake structure
- Introduce direct free-stream velocity calibration to remove main quantitative uncertainty
- Formal uncertainty quantification (Sciacchitano 2019 framework)
- Stereo / multi-camera extension for three-component velocity fields
- Wider comparison with laser-sheet PIV across full AoA and Re range

References: [1] Raffel et al., PIV: A Practical Guide, Springer 2018 | [2] Hargather & Settles, Applied Optics 48, 2009 | [3] Yarusevych & Boutilier, AIAA 2010 | [4] Wang, Li & Choi, Progress in Aerospace Sciences 44, 2008 | [5] Troolin, Longmire & Lai, Experiments in Fluids 41, 2006