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## Aerodynamic Variables and Loads Estimation Using Bio-Inspired Distributed Sensing

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# Overview

## Introduction

Motivation

Research Problem

## Research at UoB

Current Research

Characterisation results

Aerodynamic Variables and Loads Estimation

## Concluding Remarks

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## Motivation: Why Bio-Inspired Distributed Sensing?

Amazing Kestrel!!!

Kestrel Hovering and Hunting in Cornwall

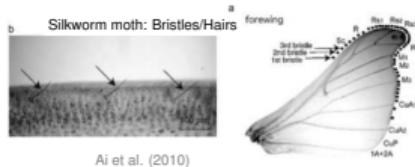
Paul Dinning, 2015

<https://www.youtube.com/watch?v=7j60sP7zL6w>

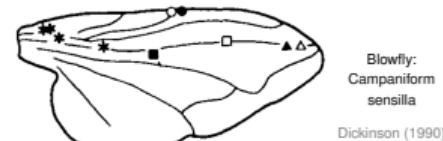
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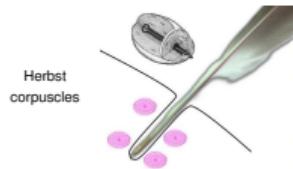
### Flow Sensors



### Force Sensors



## Birds



## Bats

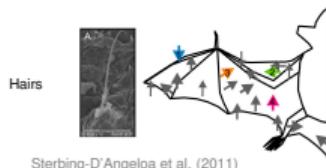
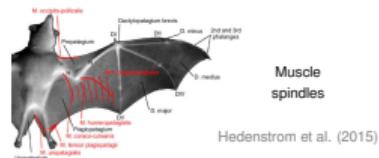


Figure: Biological sensory systems



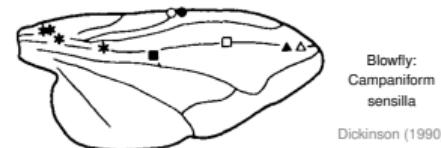
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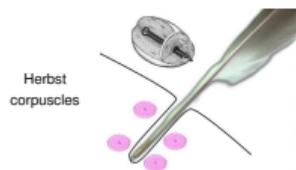
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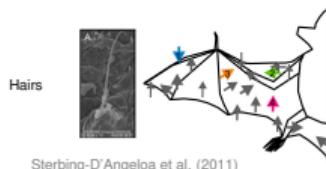
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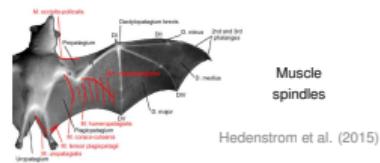
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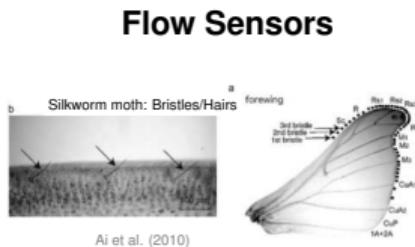


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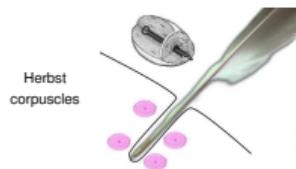


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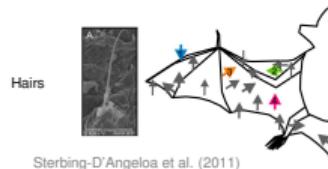
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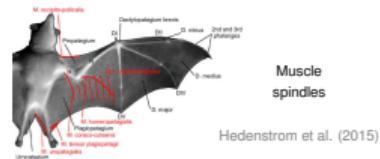
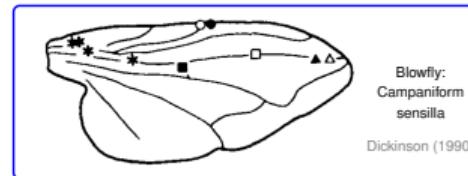
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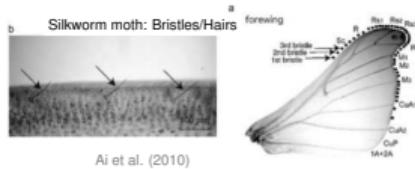


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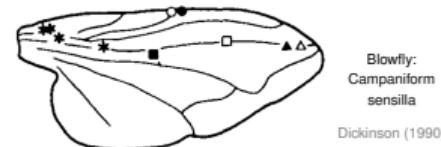
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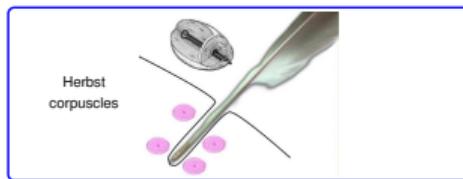
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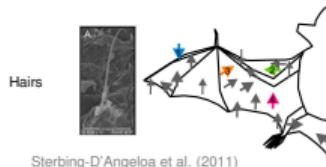
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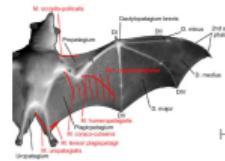
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## Muscle spindles



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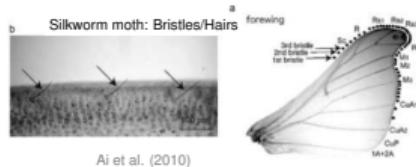


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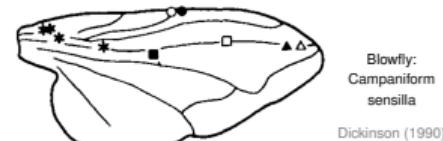
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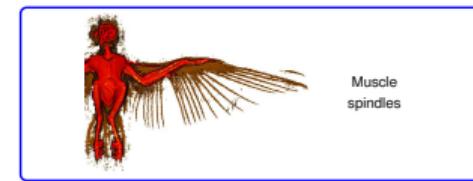
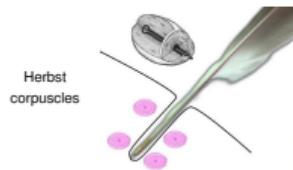
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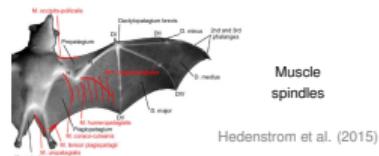
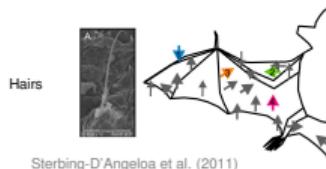
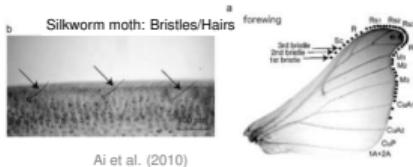


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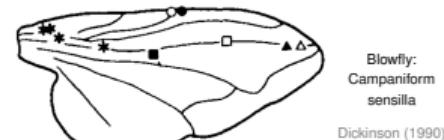
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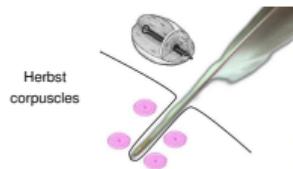
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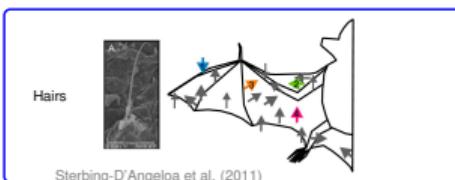
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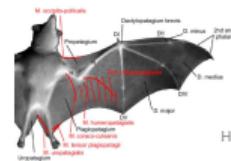
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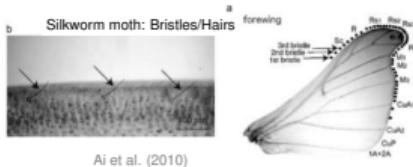
Hedenstrom et al. (2015)

Figure: Biological sensory systems

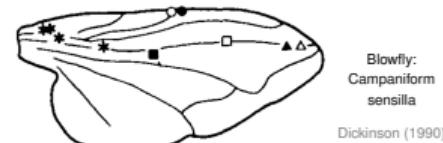
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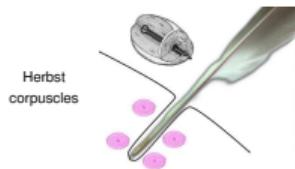
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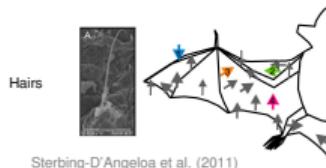
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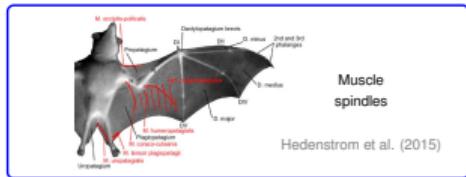


## Figure: Biological sensory systems

### Muscle spindle



## Muscle spindles



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## Motivation: Why Bio-Inspired Distributed Sensing?

- ❖ Current UAV autopilot technologies
  
- ❖ Challenges
  
- ❖ Potential use of force and flow information

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## Motivation: Why Bio-Inspired Distributed Sensing?

❖ Current UAV autopilot technologies

- Inertial
- Single point air speed
- GPS
- Vision

❖ Challenges

❖ Potential use of force and flow information

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## Motivation: Why Bio-Inspired Distributed Sensing?

❖ Current UAV autopilot technologies

- Intrinsic nonlinear dynamics
- Classic control strategies limitations
- Limitations of inertial controls

❖ Challenges

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## Motivation: Why Bio-Inspired Distributed Sensing?

### ❖ Current UAV autopilot technologies

- Availability of aerodynamic variables
  - Improved flight dynamics model
  - Stall detection

### ❖ Challenges

- Earlier gust detection
  - Gust rejection/alleviation
- Localised information
  - Localised control
  - Load tailoring

### ❖ Potential use of force and flow information

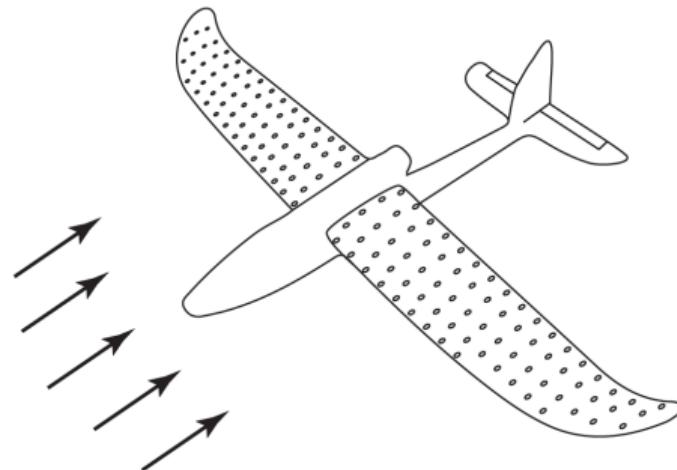
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## Research Problem

Use force and flow sensing to improve performance of UAVs flight control systems.

To achieve this we aim to:

- ❖ Develop distributed sensing system for UAV
- ❖ Integrate with conventional flight control system
- ❖ Measure response to gusts/turbulence
- ❖ Develop flight control systems



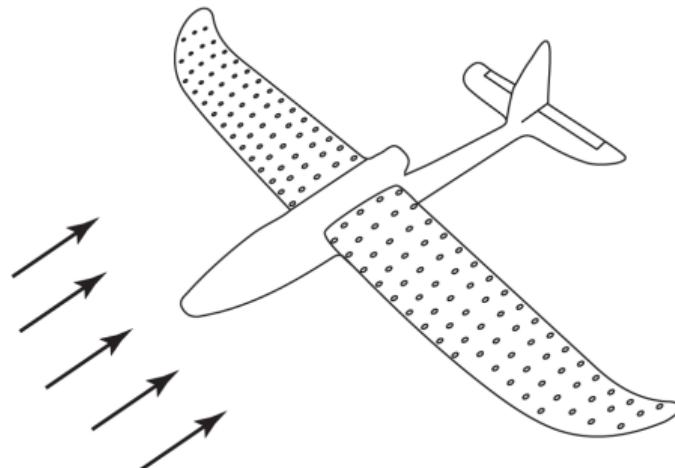
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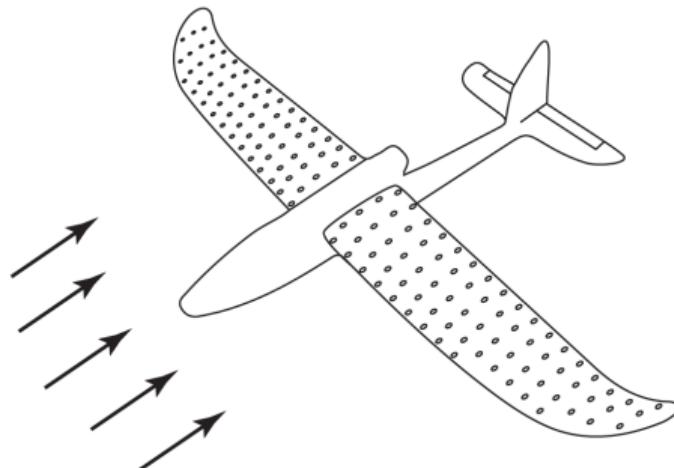
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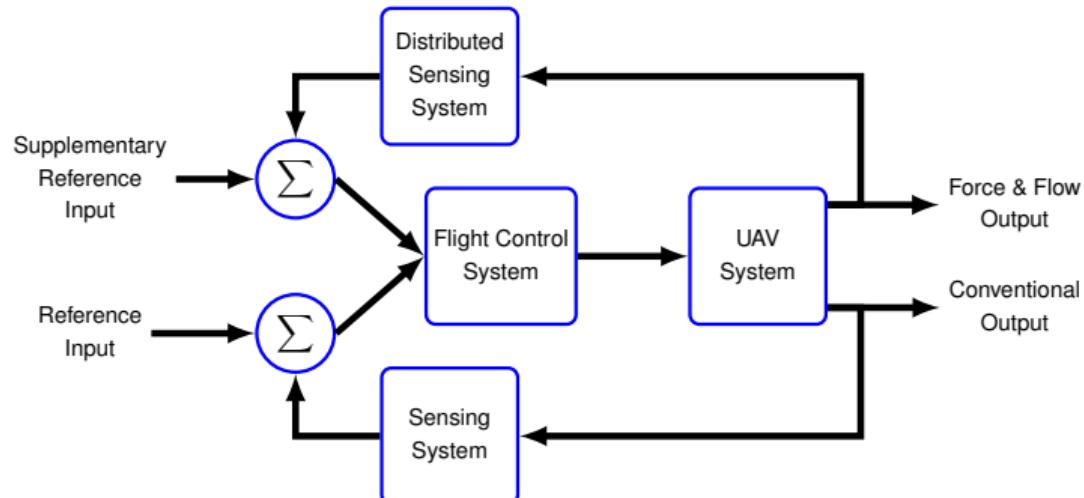


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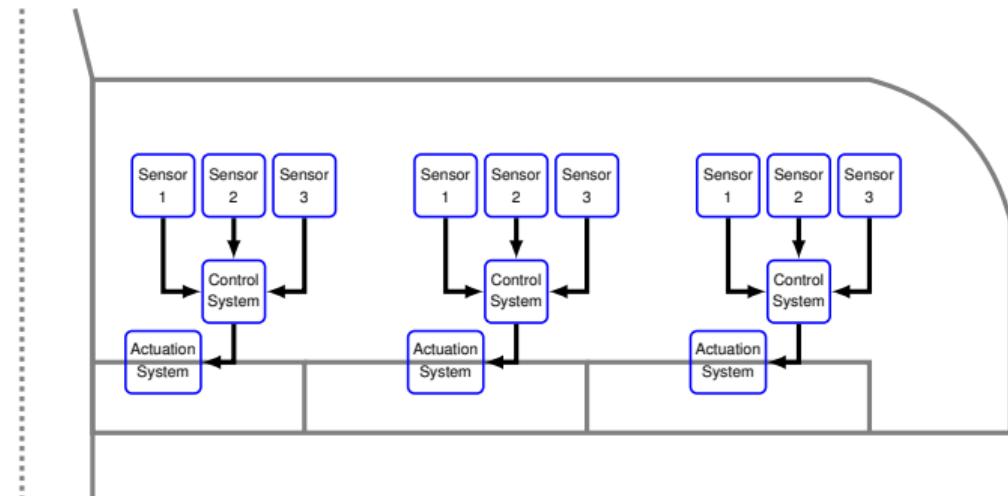
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## Previous Research at UoB

What did we learn?

- ❖ Strain & pressure signal show
- Good performance
- Robustness to sensor noise
- Good performance
- ❖ Similar performance to IMU-based control
- Good performance
- Robustness to sensor noise
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- ❖ Information not available using IMU

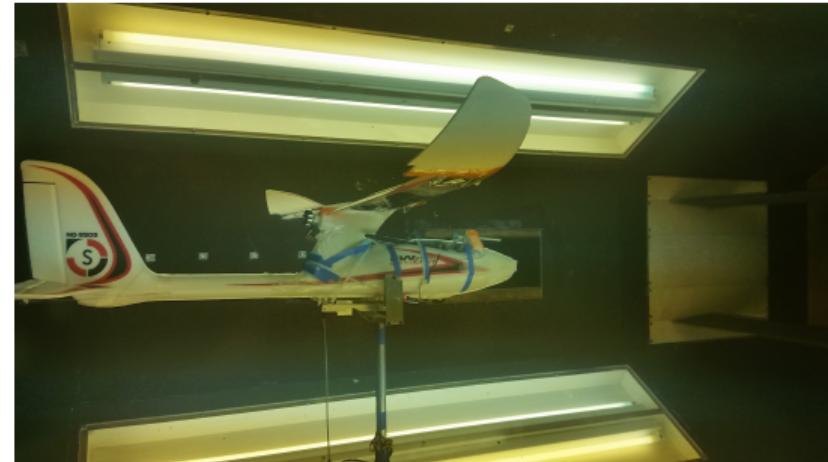


Figure: Strain sensing platform

## Previous Research at UoB

What did we learn?

- ❖ Strain & pressure signal show
  - Linear response with AoA
  - Stall markers
- ❖ Similar performance to IMU-based control
  - Strain → roll control
  - Pressure → pitch control
- ❖ Information not available using IMU
  - AoA, stall, roll acceleration, non-linear lift

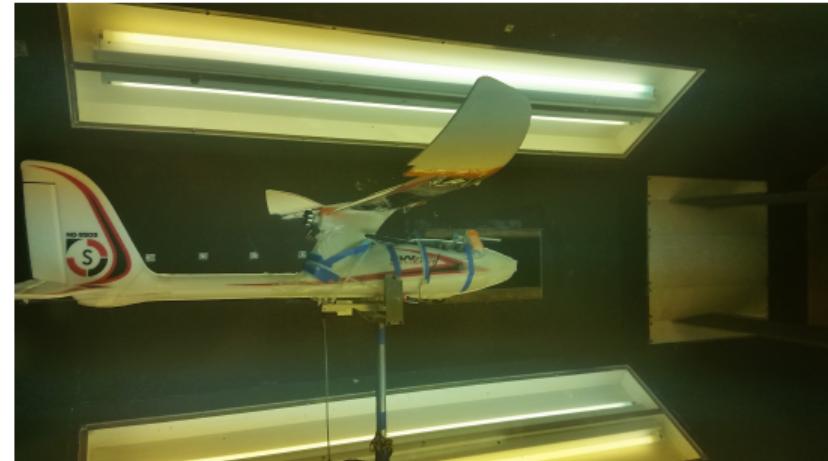


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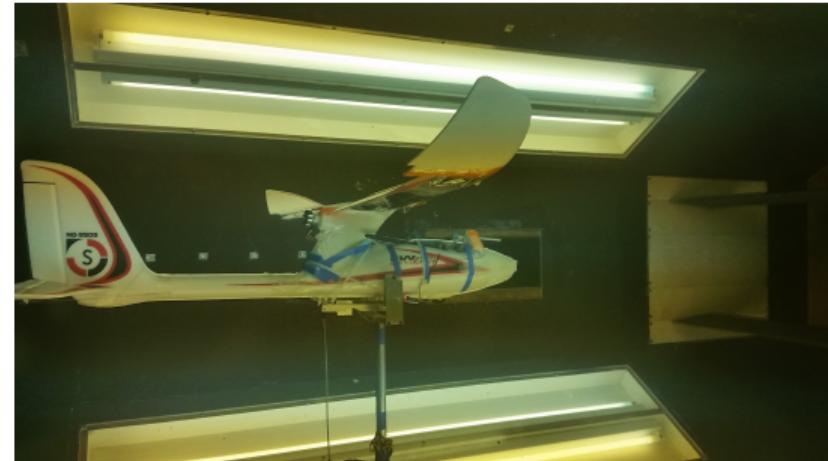


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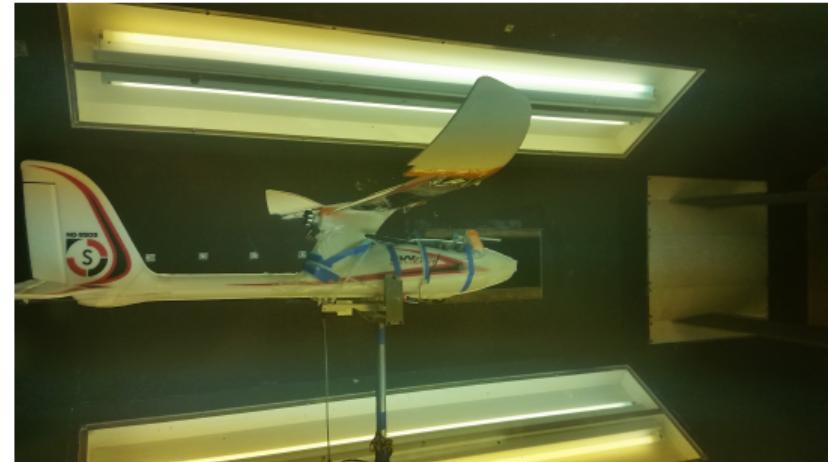


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Wing model instrumentation:

- ☛ Chord-wise array of 30 pressure ports in two sections
  - ☛ Span-wise array with 16 strain gauges
  - ☛ Servo actuated control surfaces
  - ☛ MCU-based data acquisition system using, sampling 200 Hz
  - ☛ 1-DOF pitch motion servo-driven system for automated motion
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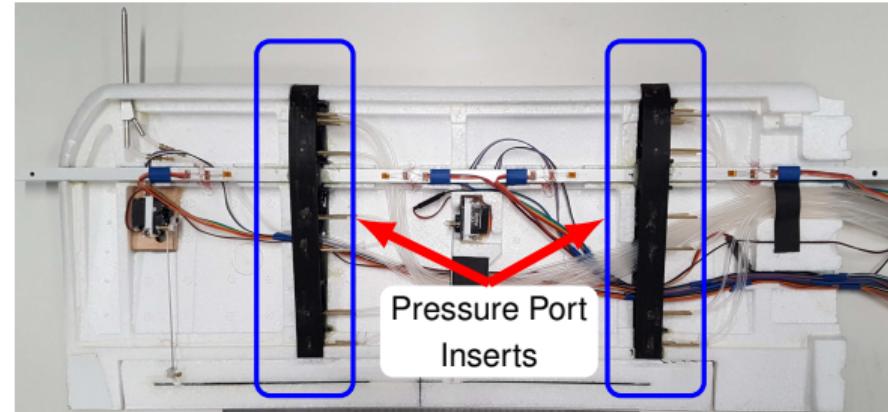


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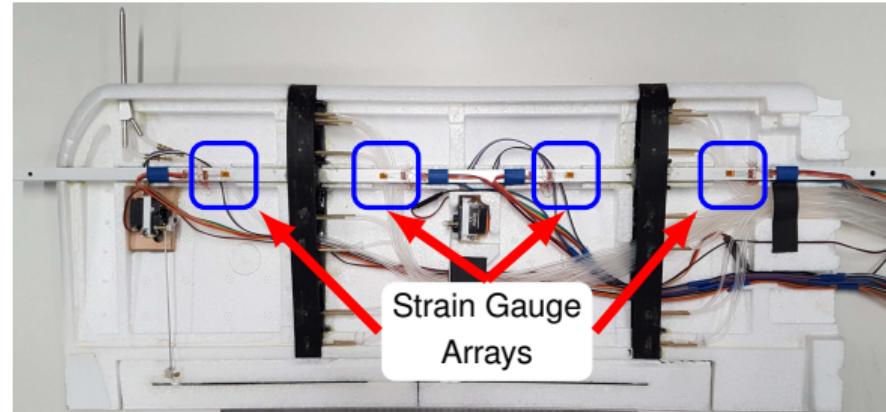


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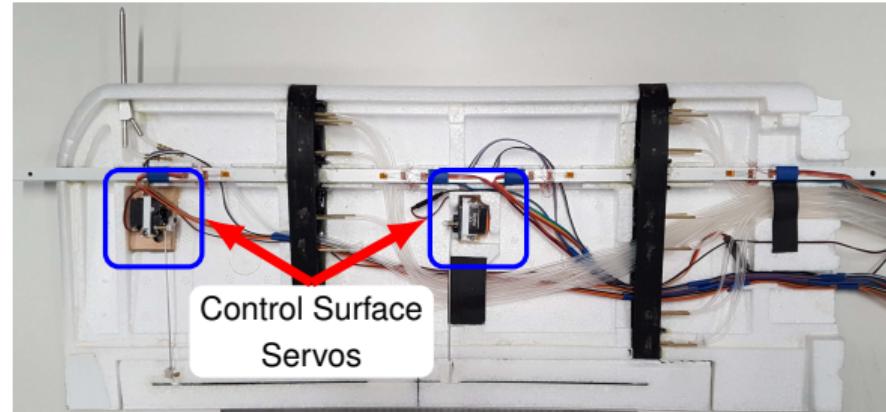


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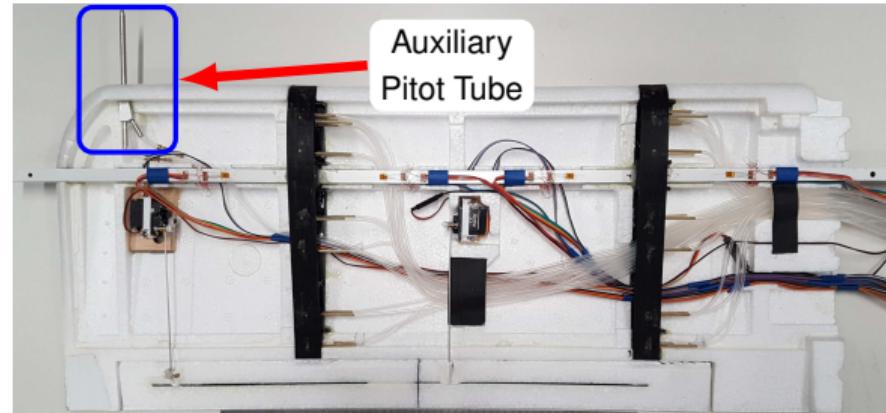


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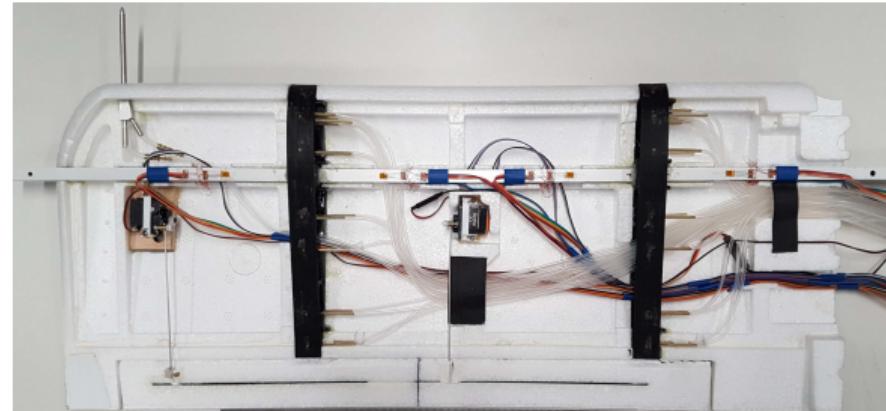


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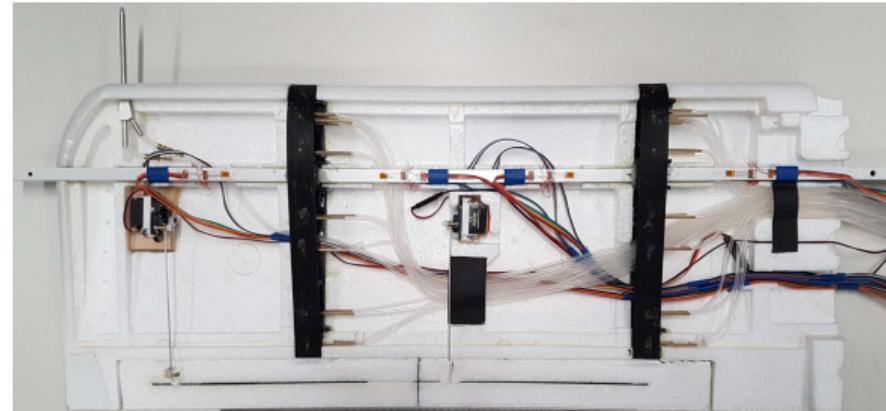
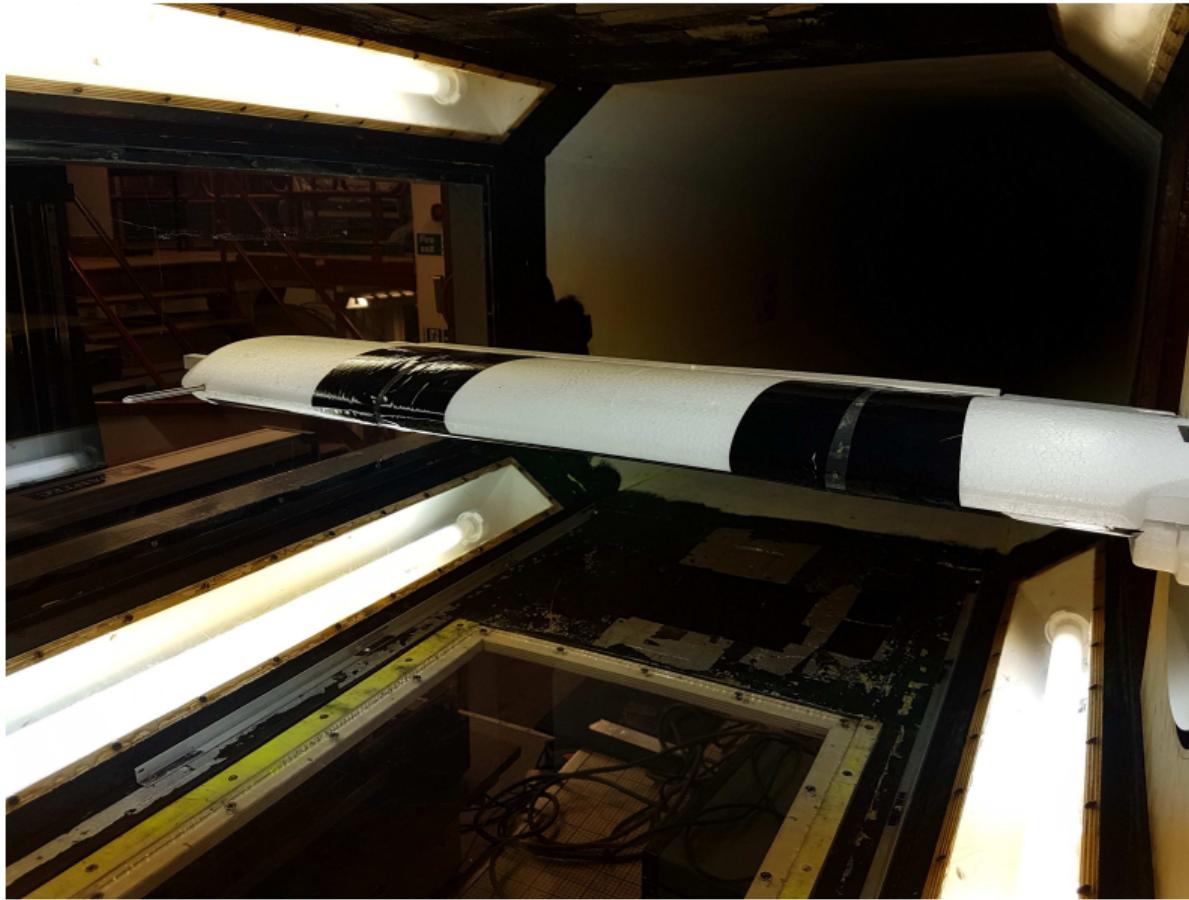


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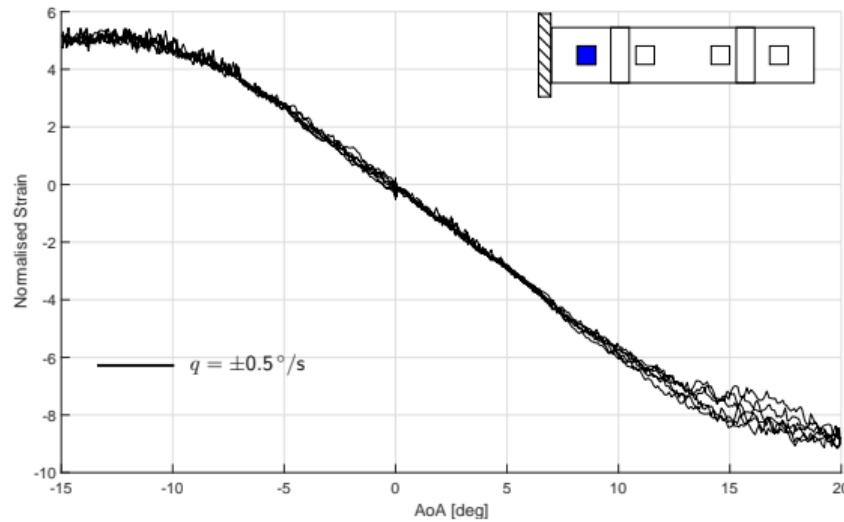


Figure: Strain response for various  $q$  values

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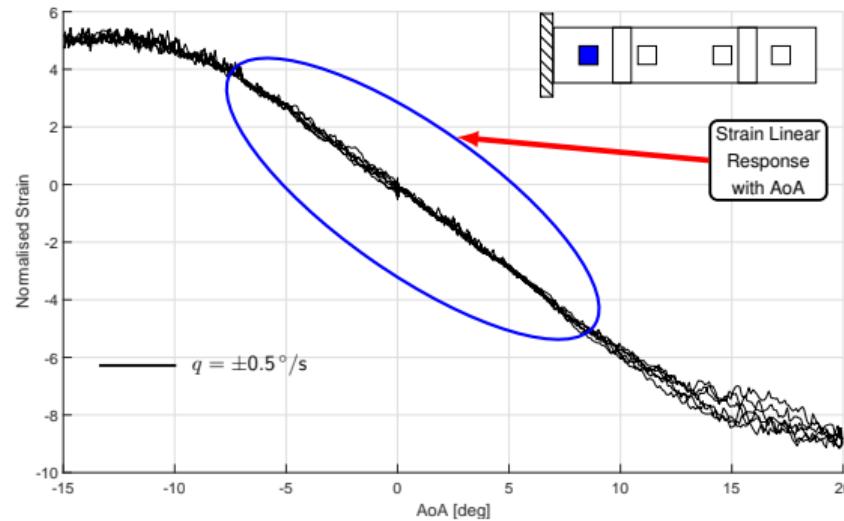


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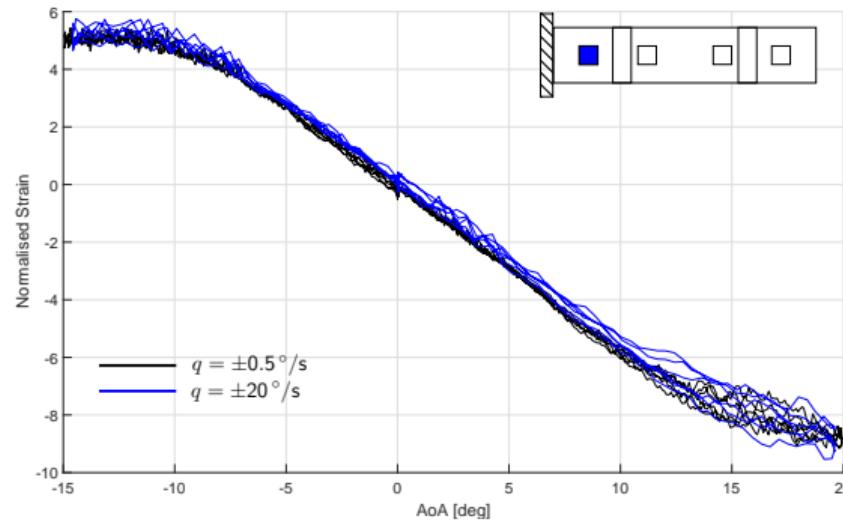


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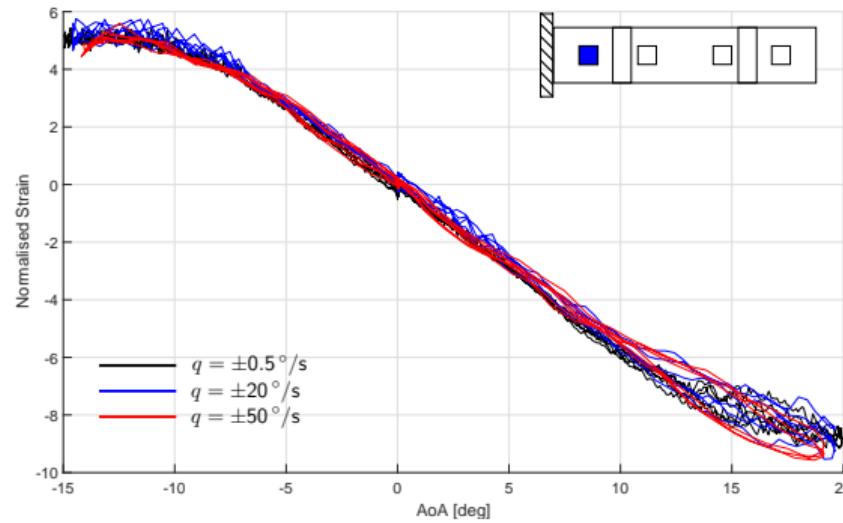


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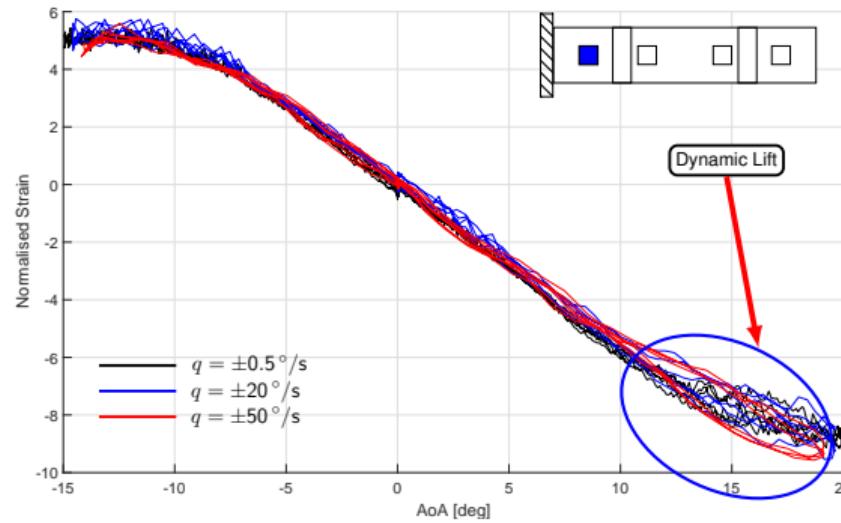


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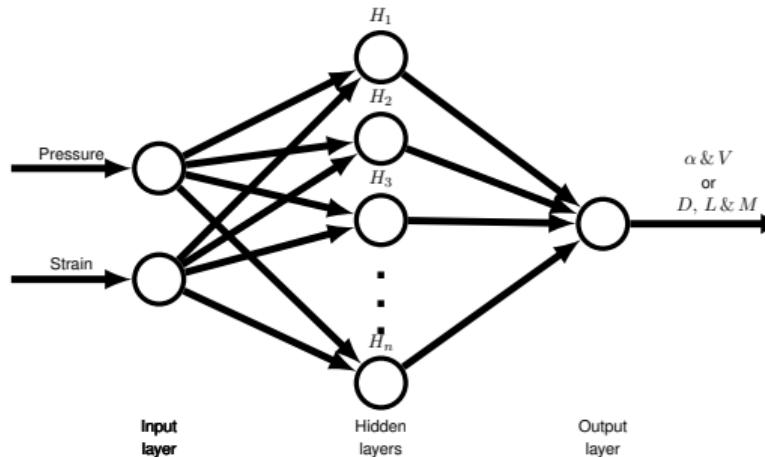
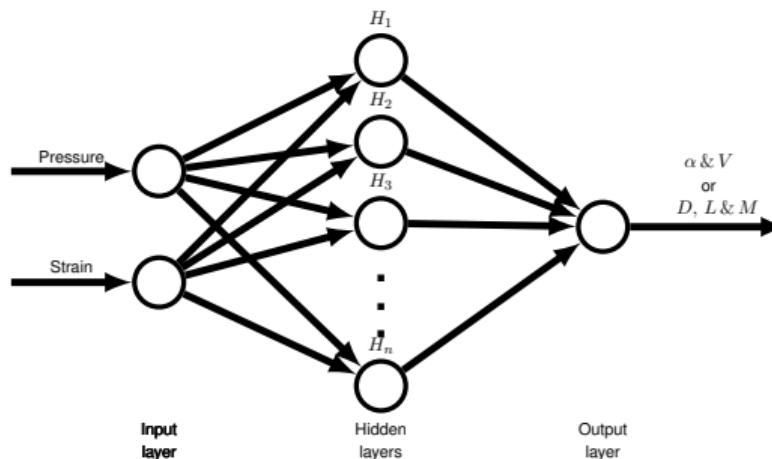


Figure: General structure of ANN used for estimation

❖ Use strain and pressure signals to estimate

- AoA, airspeed
- Aerodynamic loads

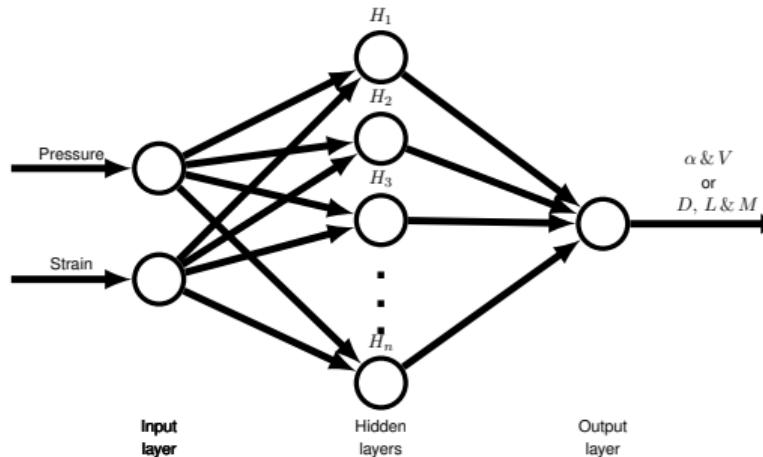
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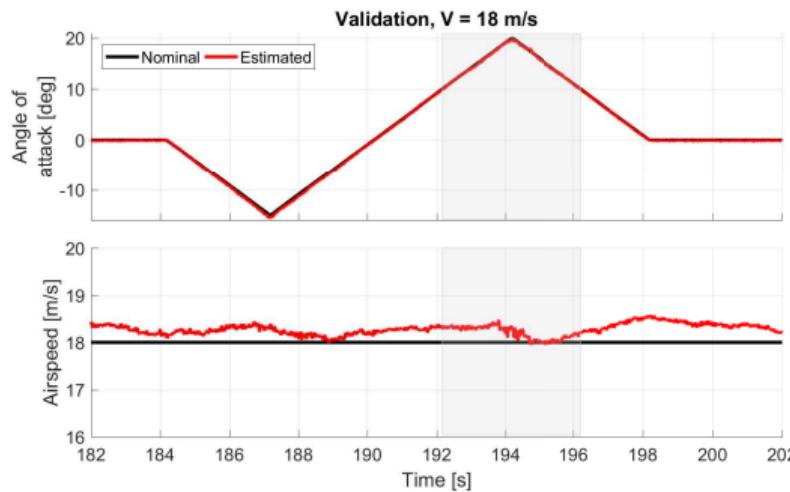


Figure: AoA & airspeed estimation

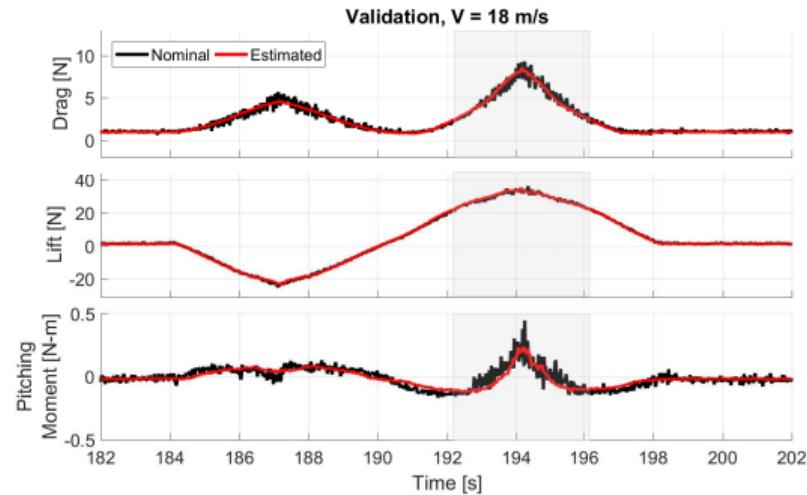


Figure: Aerodynamic loads estimation

## Concluding Remarks

❖ Current ANN is able to accurately predict:

• the presence of a target animal in a field

❖ Future directions:

• the development of a distributed sensing system to monitor multiple fields simultaneously  
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❖ Questions remain:

• how to deal with false positives and false negatives  
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## Concluding Remarks

- ☛ Current ANN is able to accurately predict:
  - ▶  $\alpha, V, D, L$  and  $M$ , even in the stall region
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  - ▶ pressure + strain + inertial ANN-based estimators to improve flight control performance
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# Thank you

We would like to thank Dr Kieran Wood and Dr Tom Richardson for their involvement in the  
pressure sensing project.



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under the European Unions Horizon 2020 research and innovation programme  
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European Research Council  
Established by the European Commission

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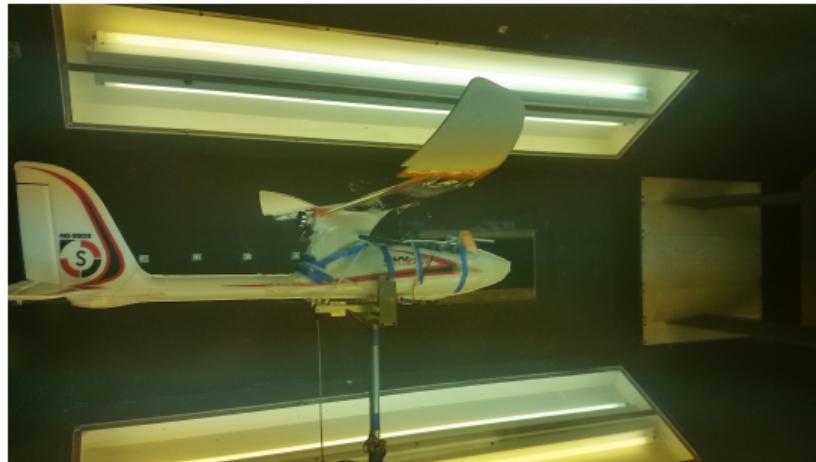


Figure: Strain sensing platform

- ❖ Implement closed loop roll control using strain sensing
- ❖ 12 full-bridge strain gauges and amplifiers distributed along spar of wing
- ❖ Wind tunnel characterisation

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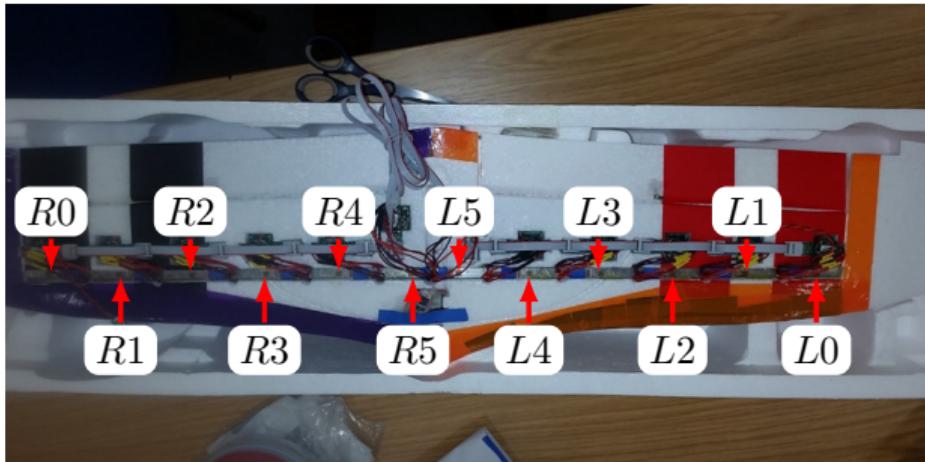


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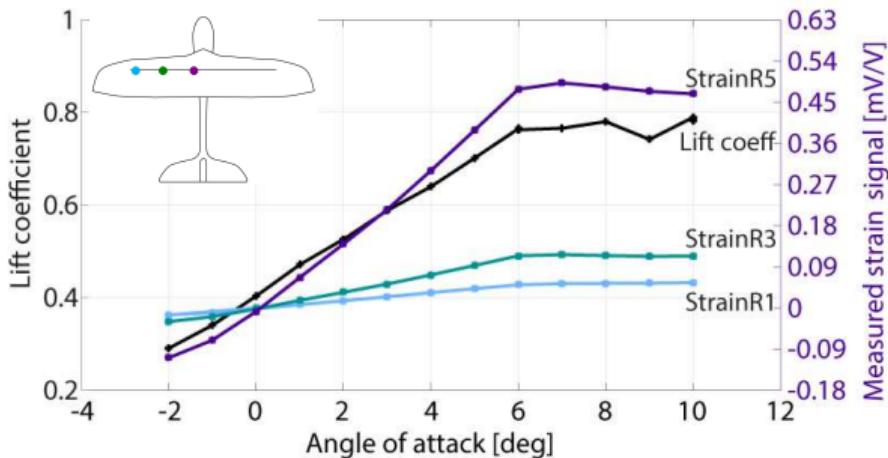


Figure: Strain wind tunnel characterisation

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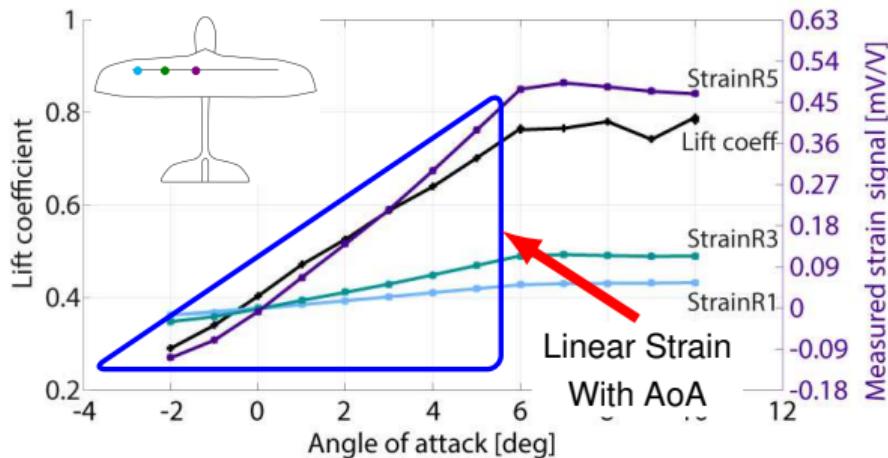


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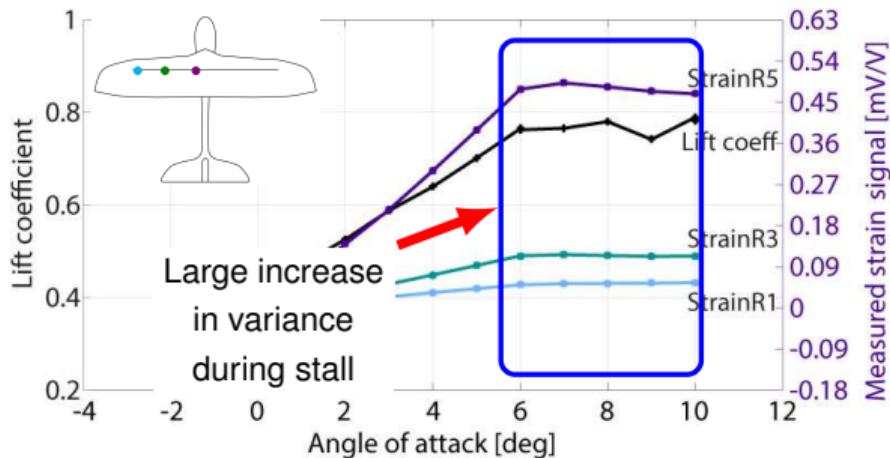


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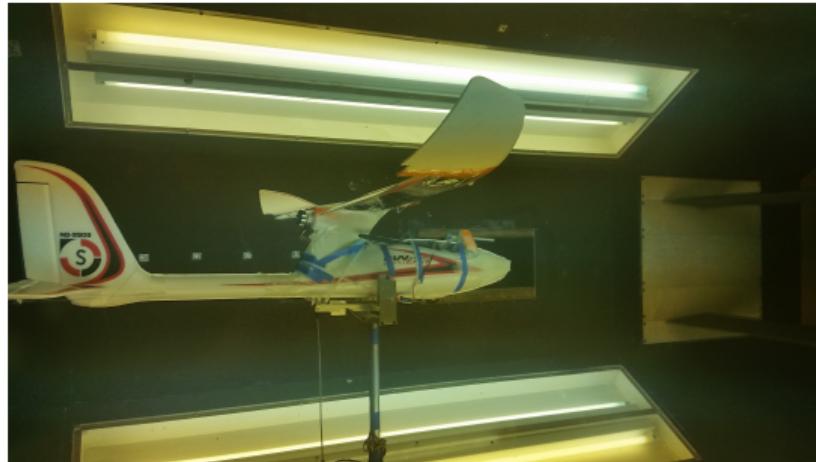


Figure: Strain sensing platform

- ❖ Response to controlled gusts
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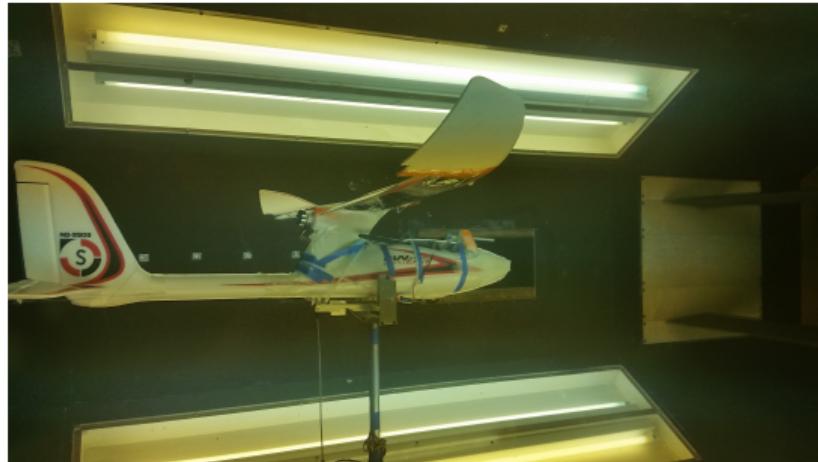
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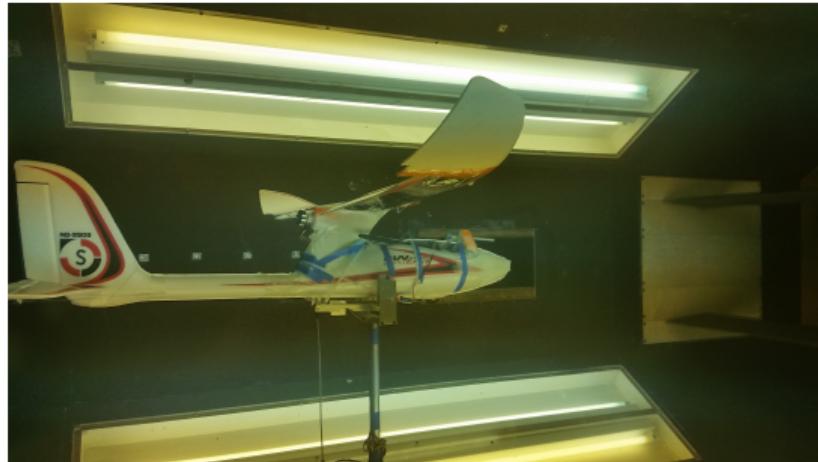
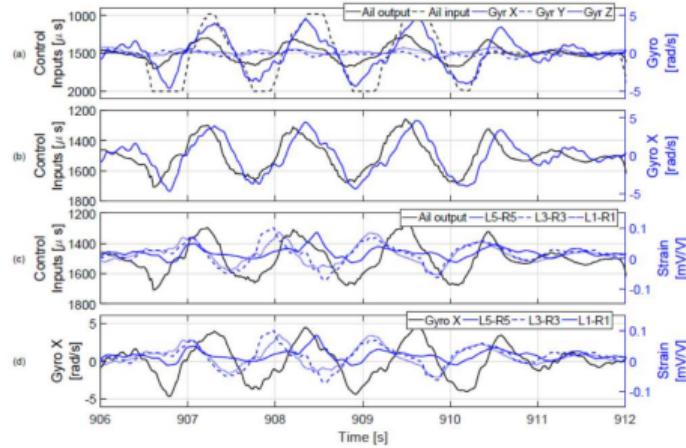


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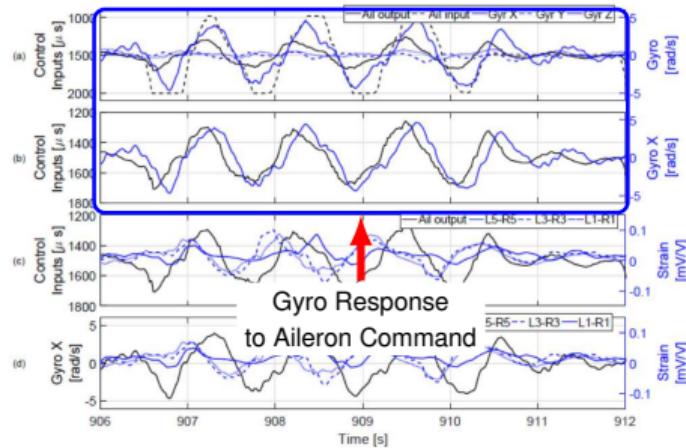
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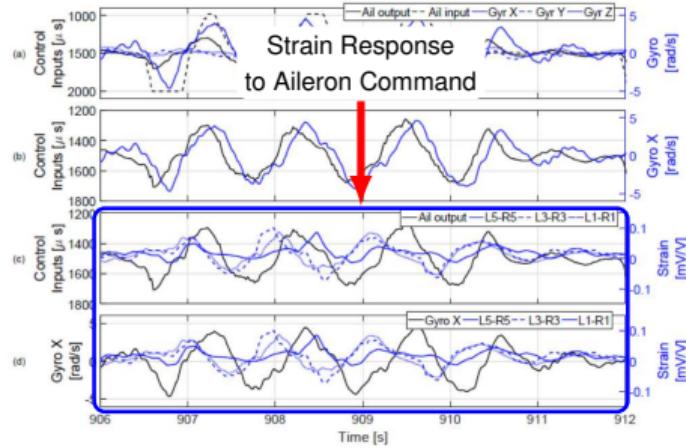
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## Previous Research at UoB: Pressure sensing



Figure: Pressure sensing platform

- ❖ Implement closed loop pitch control using pressure sensing
- ❖ 3-D printed insert on starboard wing
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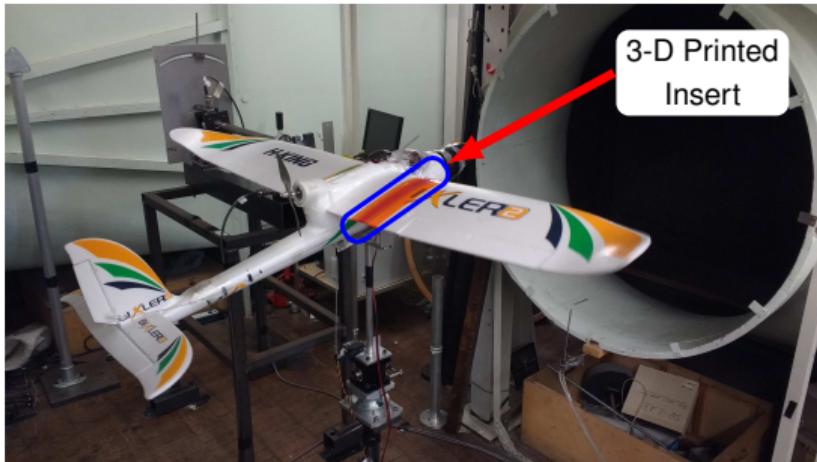


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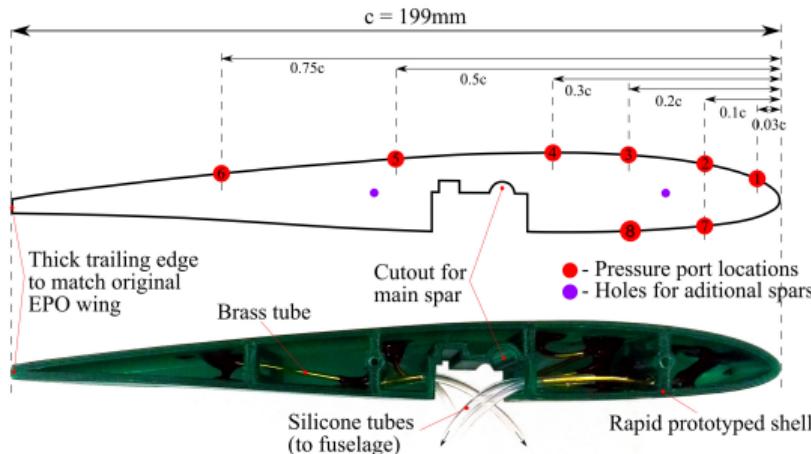


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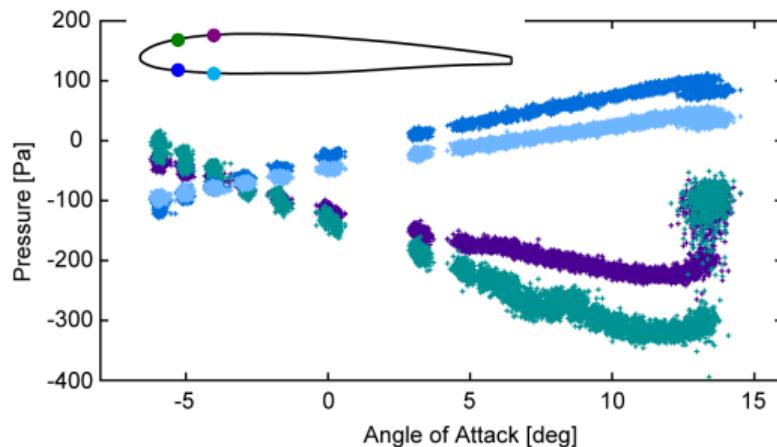


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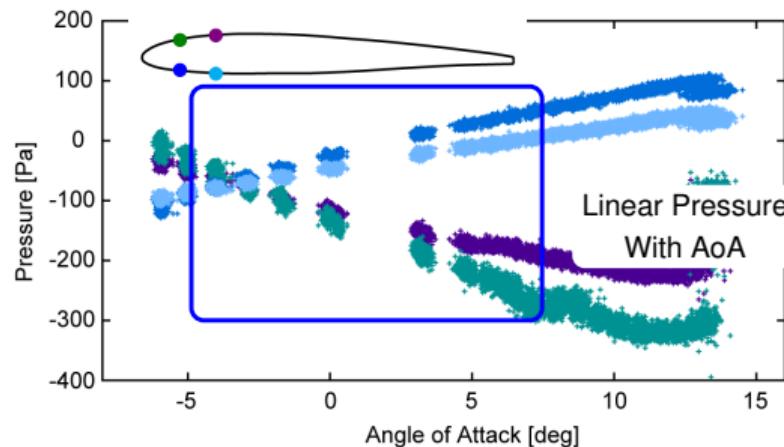


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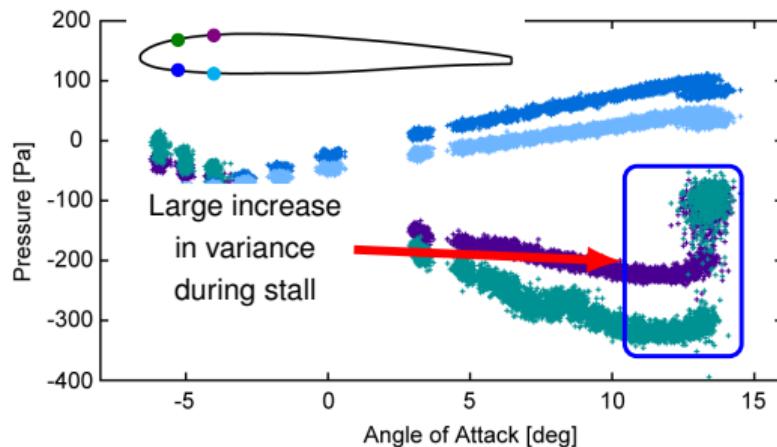


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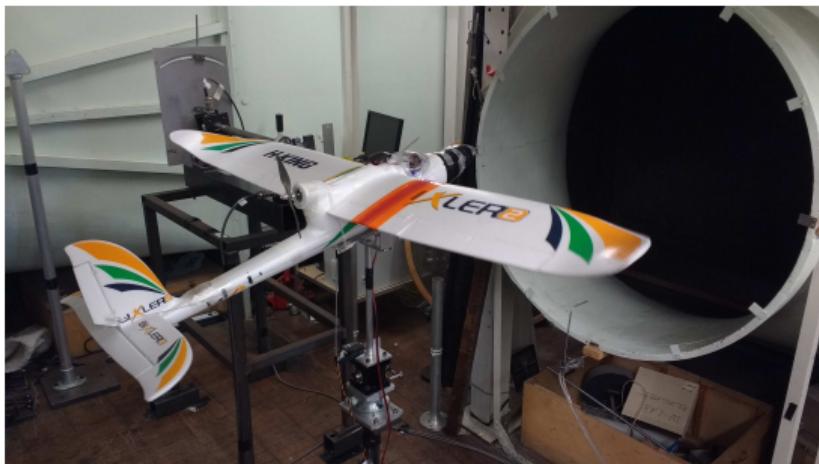


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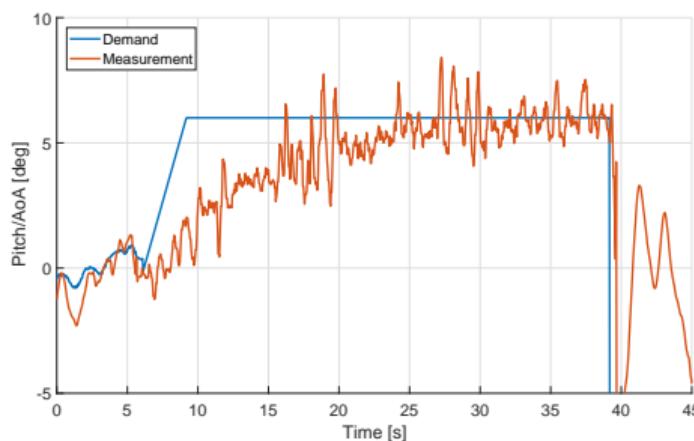


Figure: Outdoors angle-of-attack tracking

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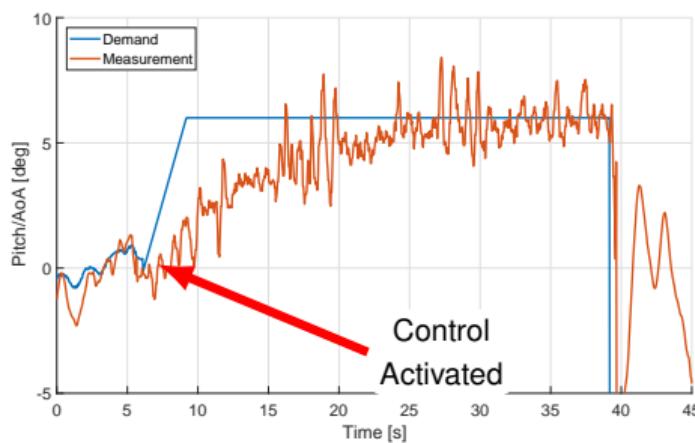


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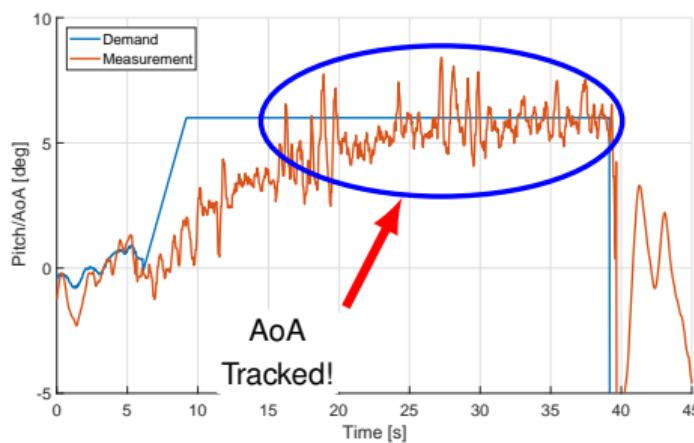


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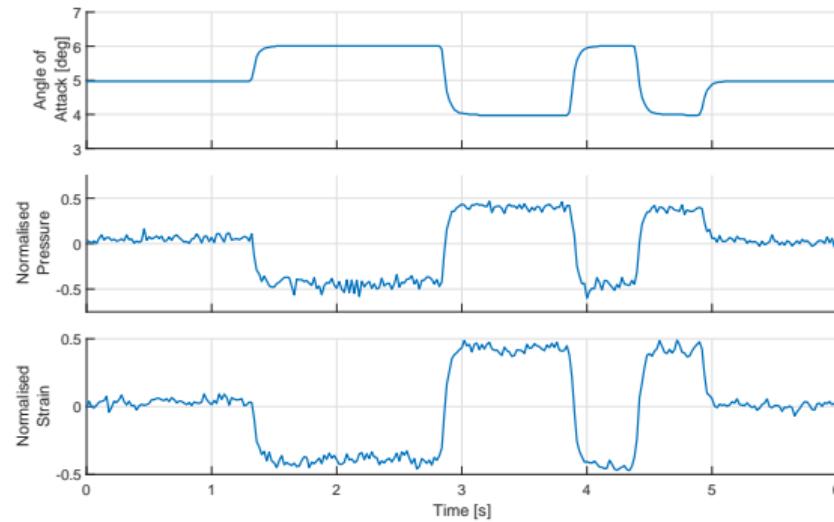


Figure: Pressure & strain response to dynamic input

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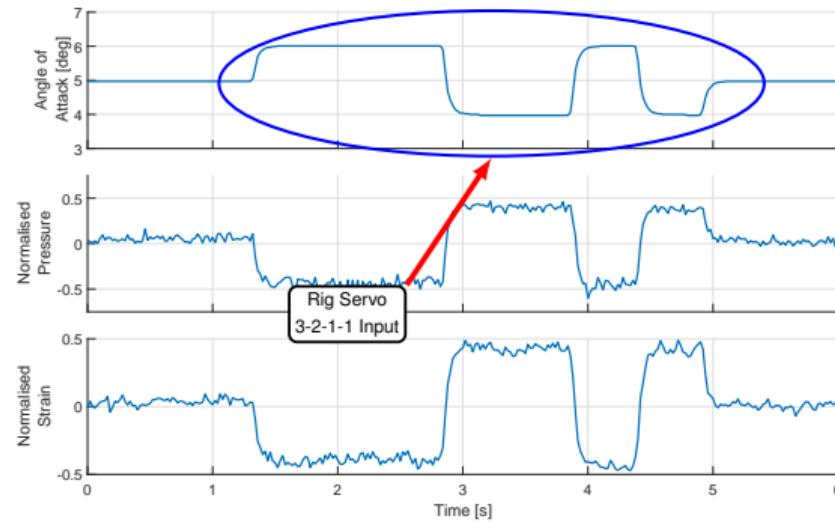


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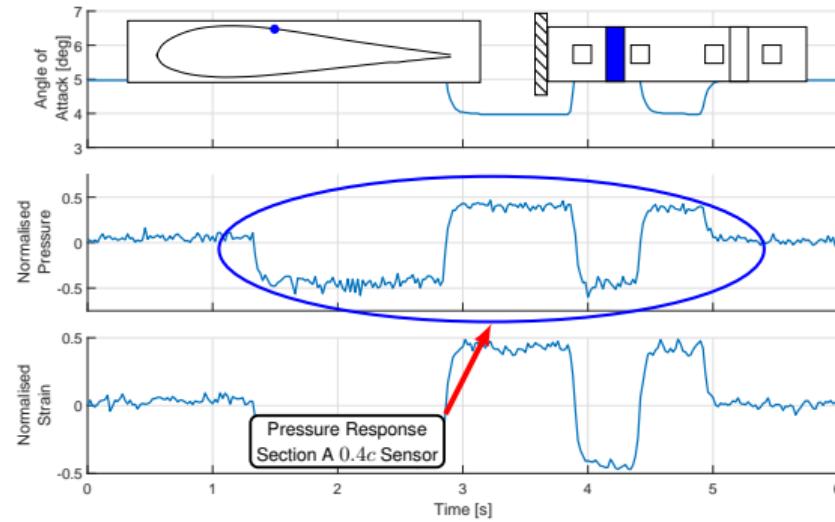


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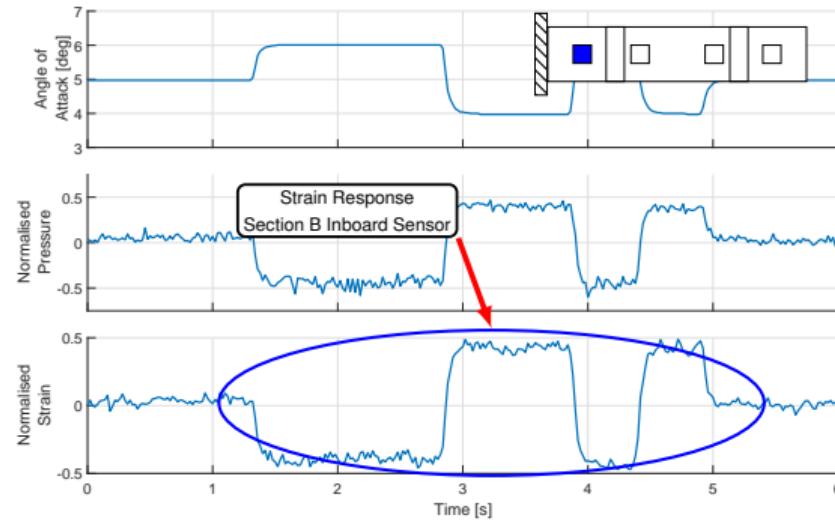


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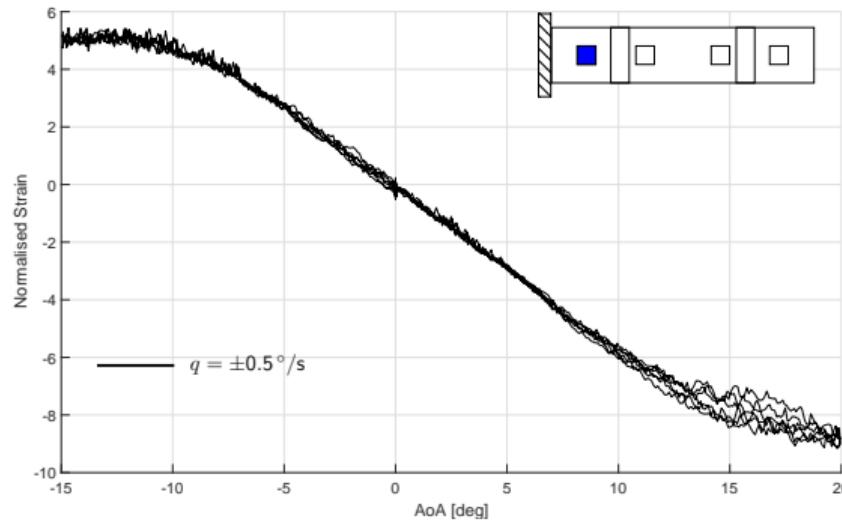


Figure: Strain response for various  $q$  values

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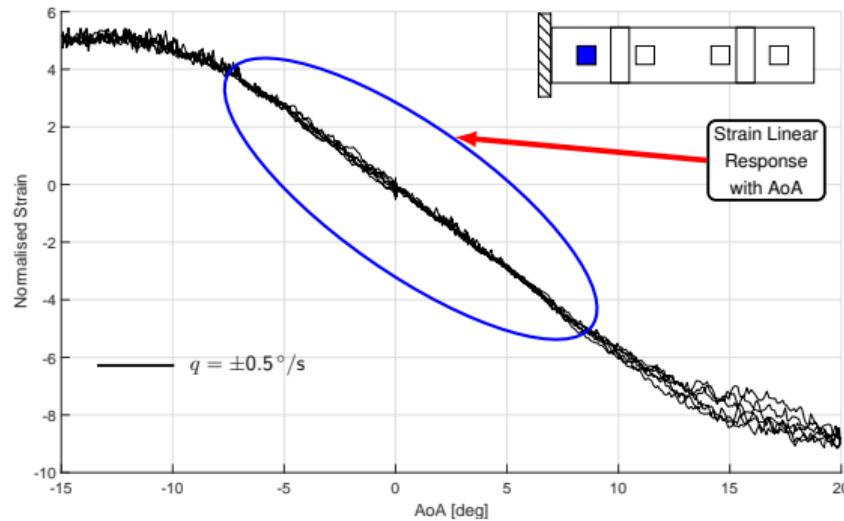


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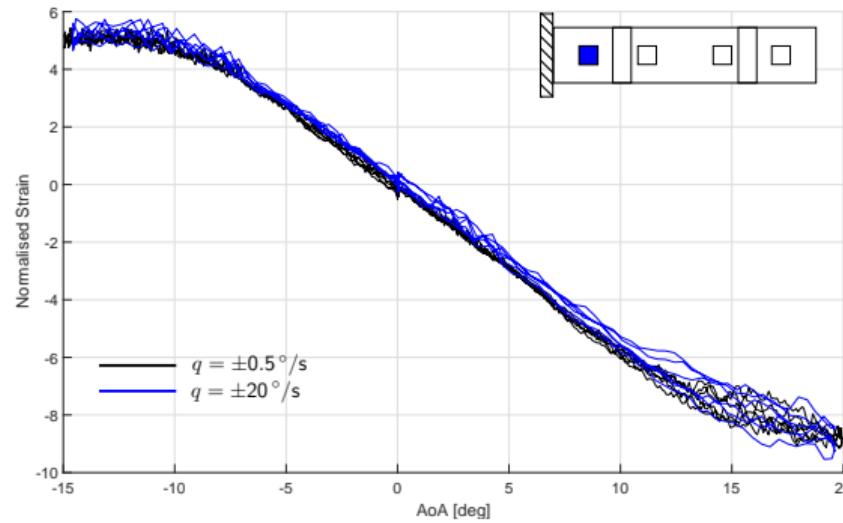


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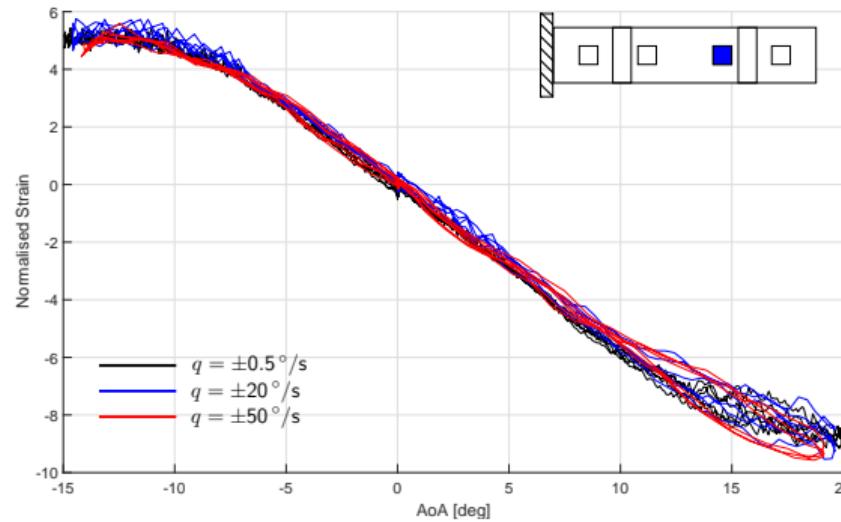


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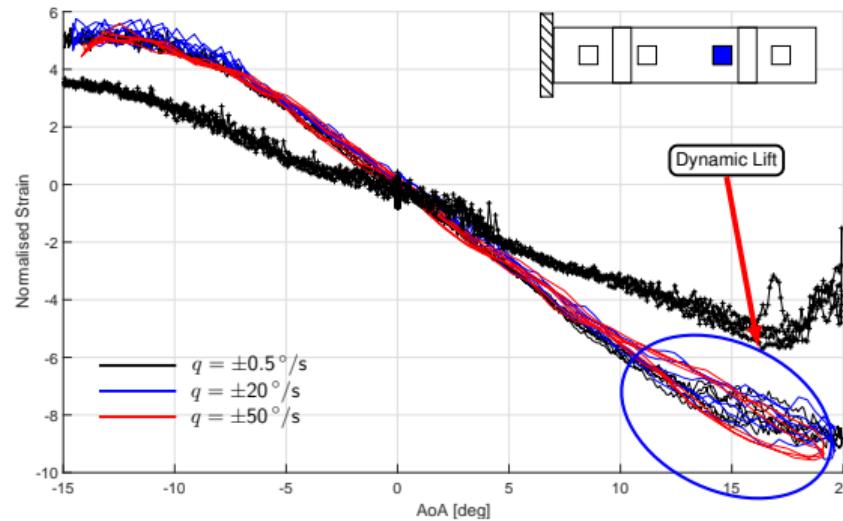


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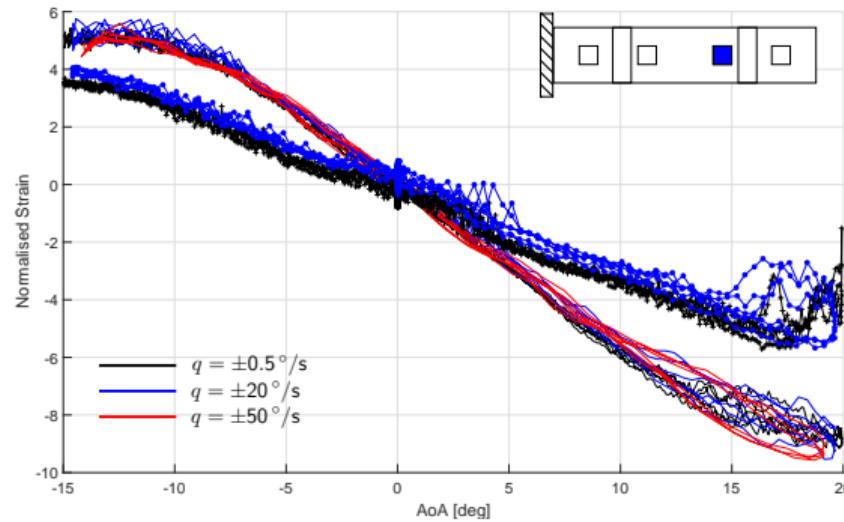


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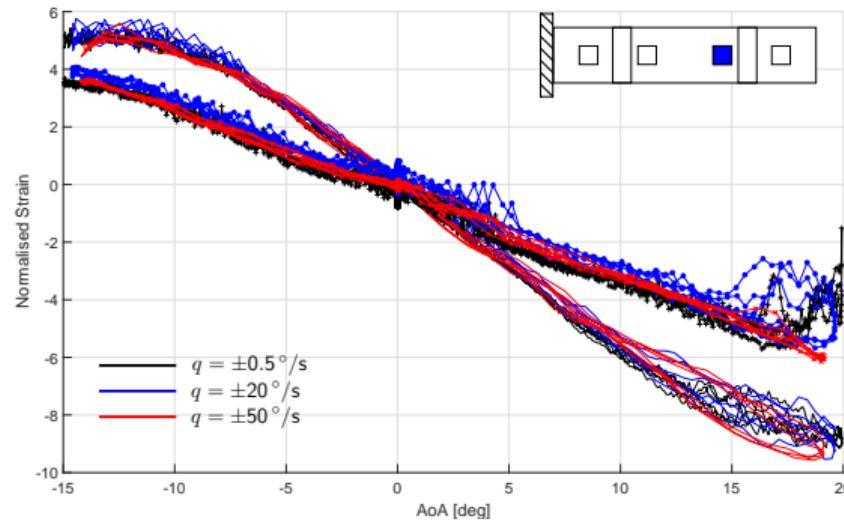


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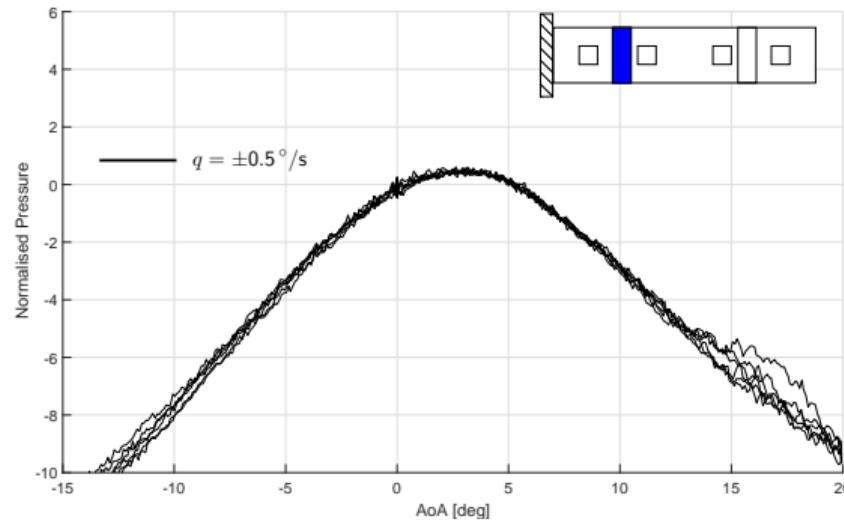


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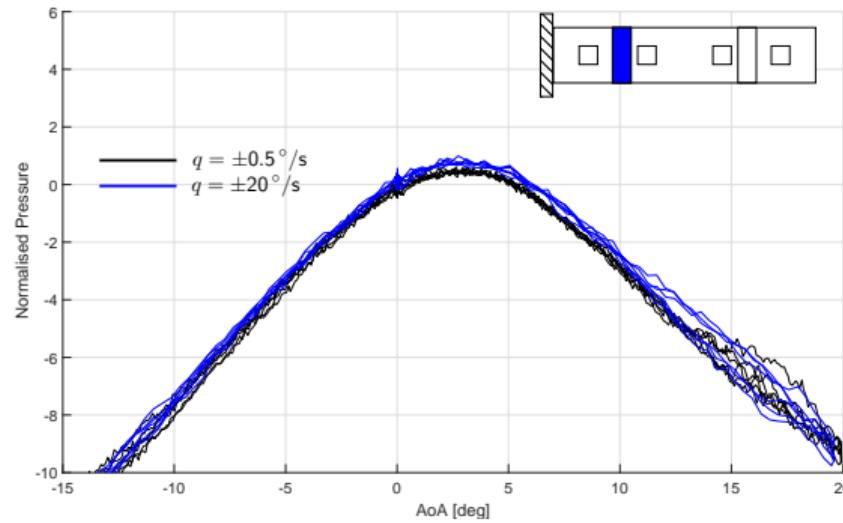


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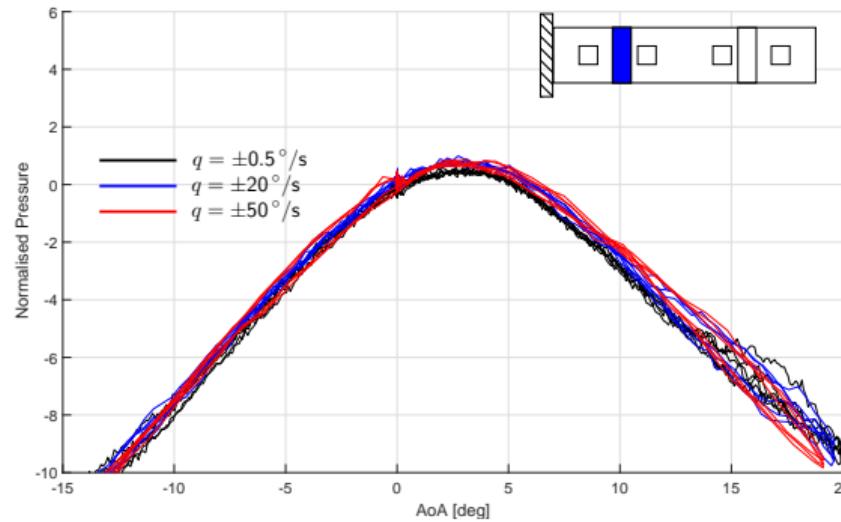


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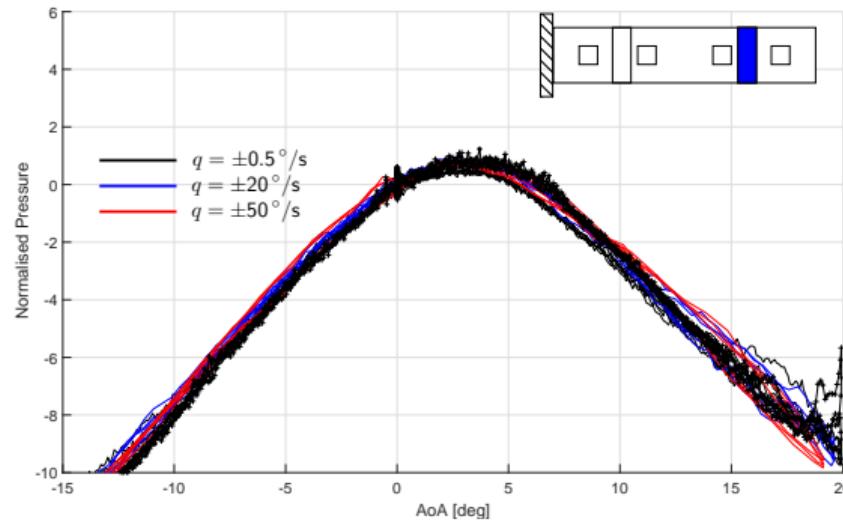


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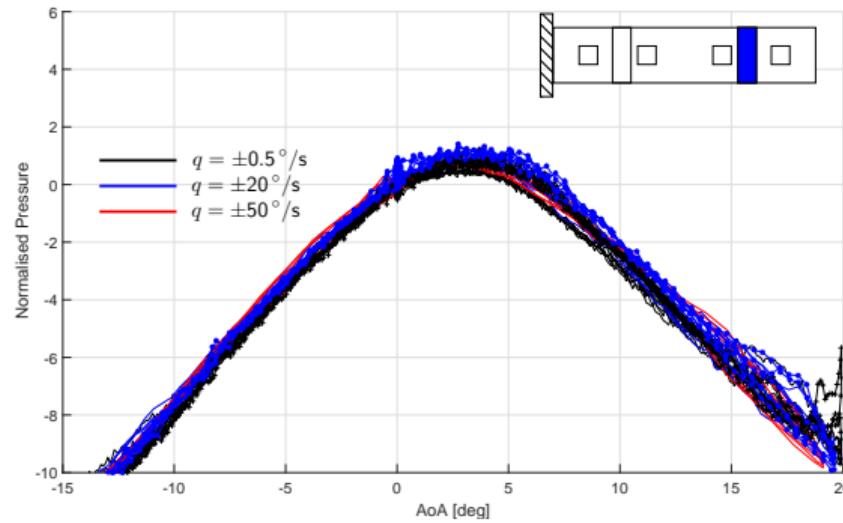


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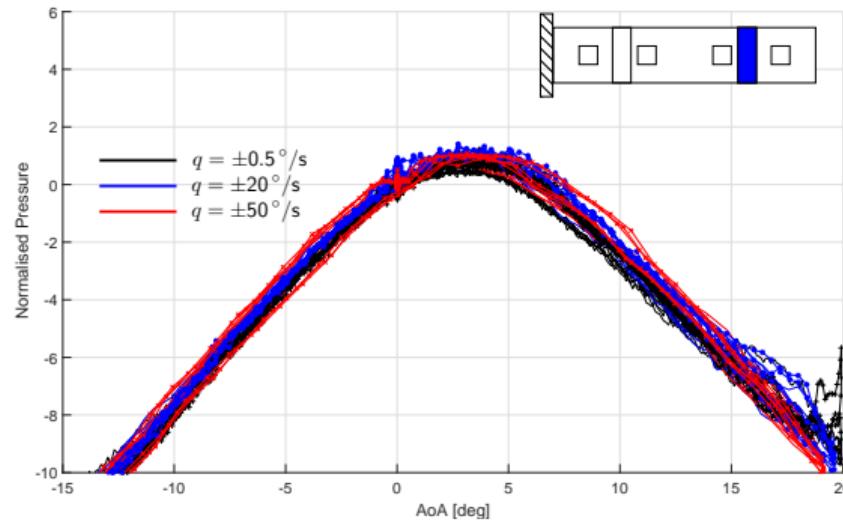


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