
Bio-Inspired Distributed Sensing for Improved Flight Control

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Overview

Introduction

Motivation

Research Problem

Research at UoB

Previous Research

Current Research

Concluding Remarks

2018-05-03

└ Overview

1. First I will introduce the motivation behind our research.
2. Then, I will briefly describe the research problem that we have set.
3. Next, I will present examples of past and current research carried out at UoB.
4. I will end this talk with some concluding remarks.

Motivation: Why Bio-Inspired Distributed Sensing?

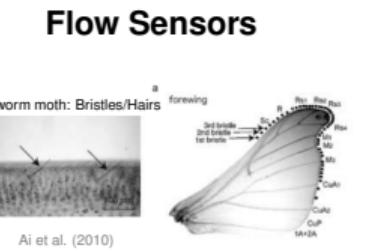
Amazing Kestrel!!!

Kestrel Hovering and Hunting in Cornwall
Paul Dinning, 2015

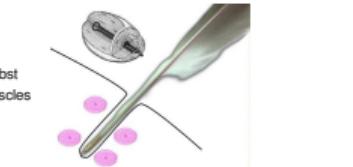
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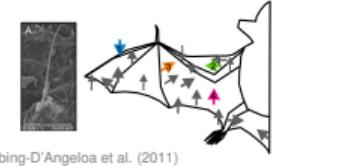
Insects



Birds

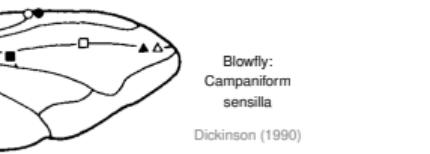


Bats



Unit 1: Biological sensory systems

Distance Sensors



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Inspired Distributed Sensing

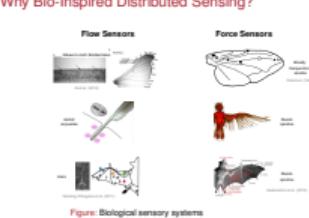
Introduction

- Motivation

Motivation: Why Bio-Inspired Distributed Sensing?

- Insect sensory systems include inertial, visual airflow and wing load sensing.
 - Insect flow sensing: For instance, in the silkworm moth, bristles along the wing provide information about wing beat frequency
 - Insect force sensing: In the blowfly the campaniform sensilla operate as load sensors
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 - Bat force sensing: Muscle spindles

Section: What Are Ingested Distributed Sessions?



Motivation: Why Bio-Inspired Distributed Sensing?

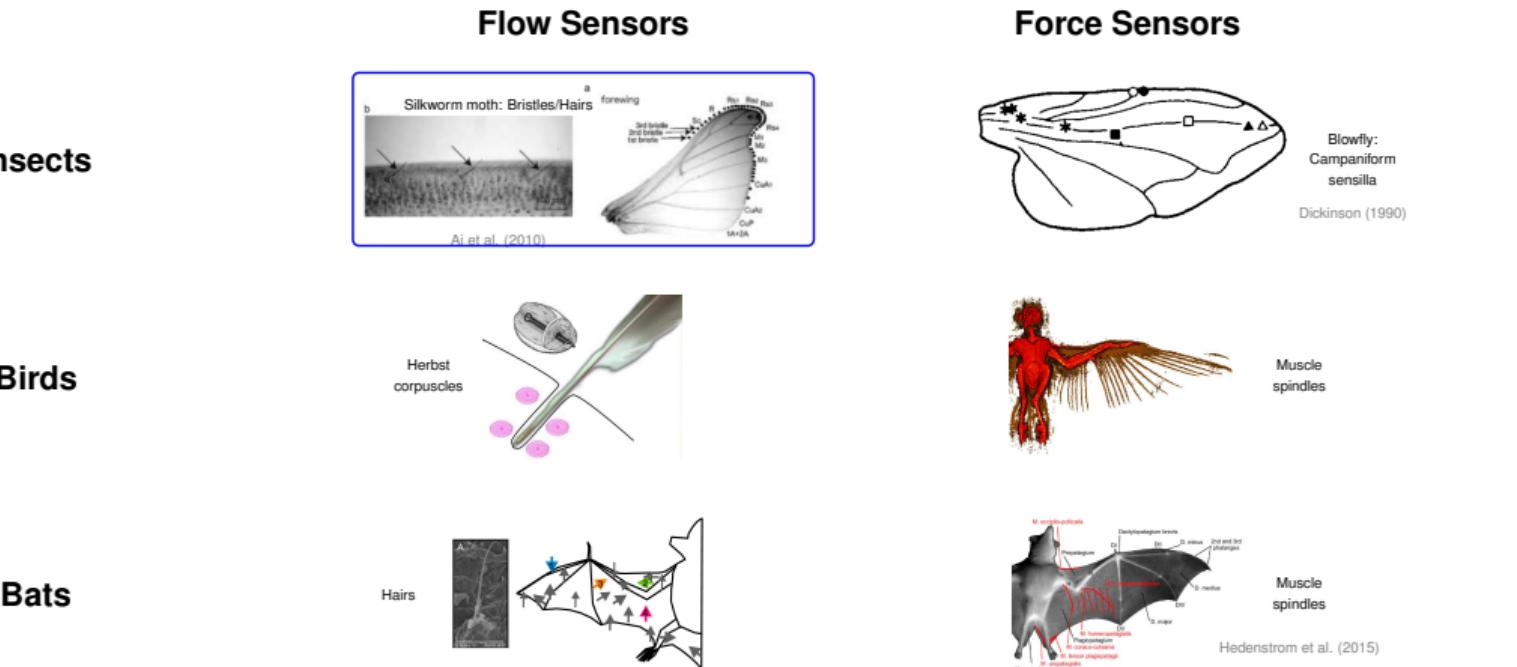
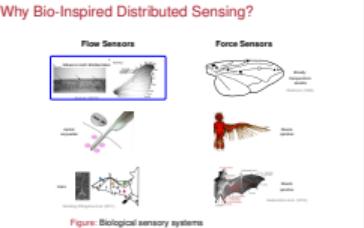
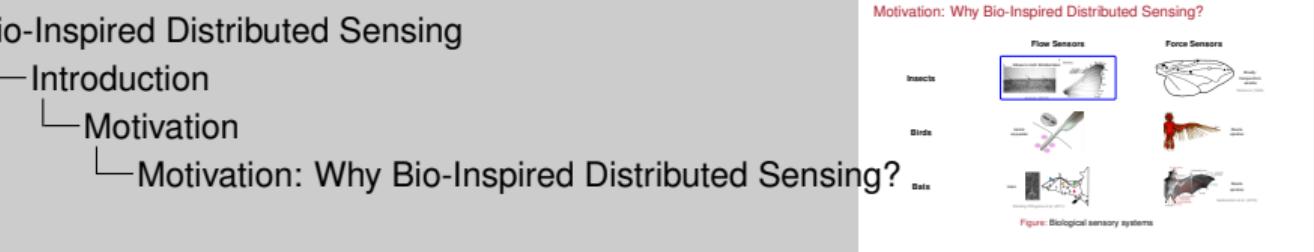
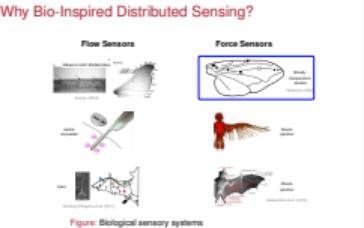
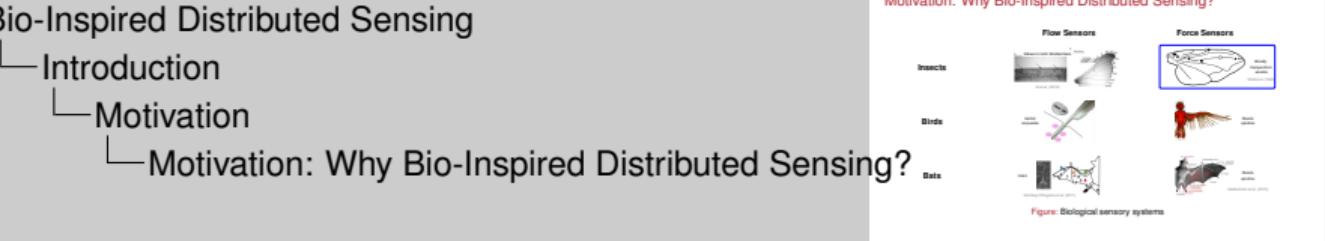
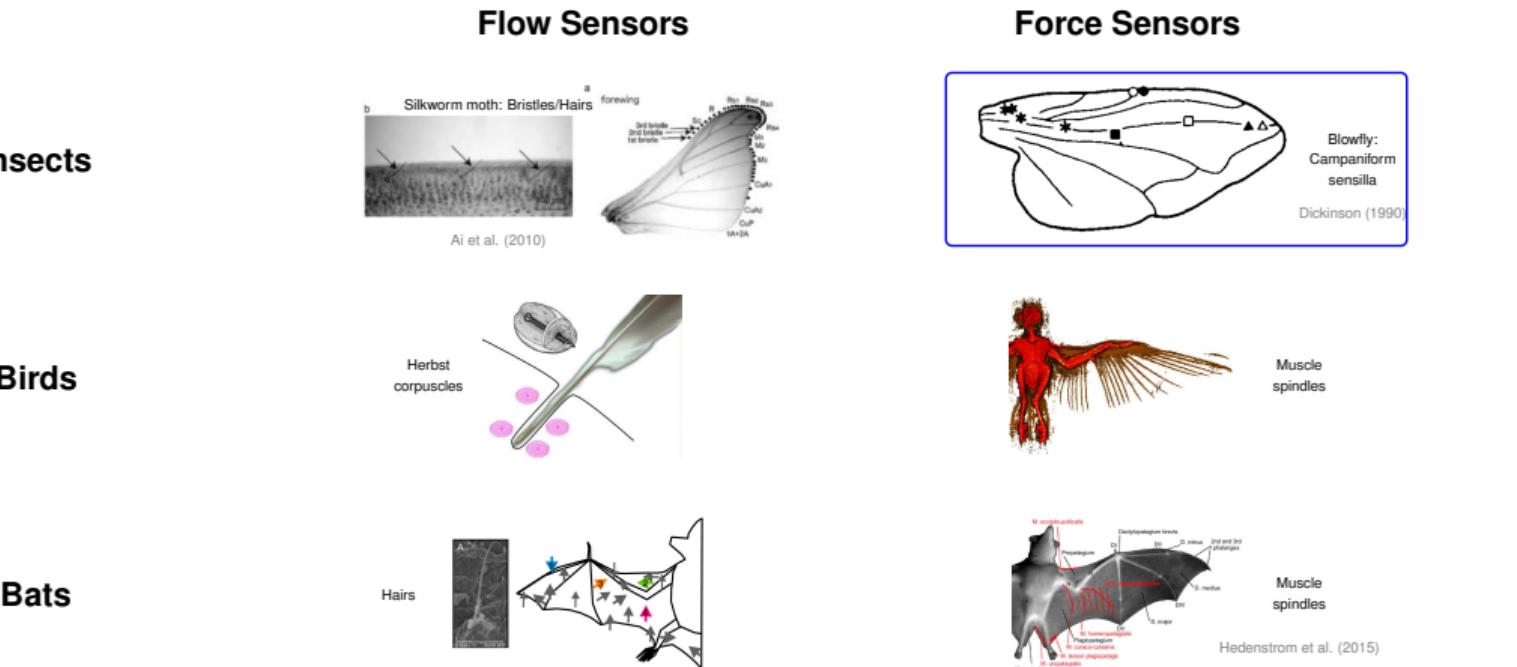


Figure: Biological sensory systems



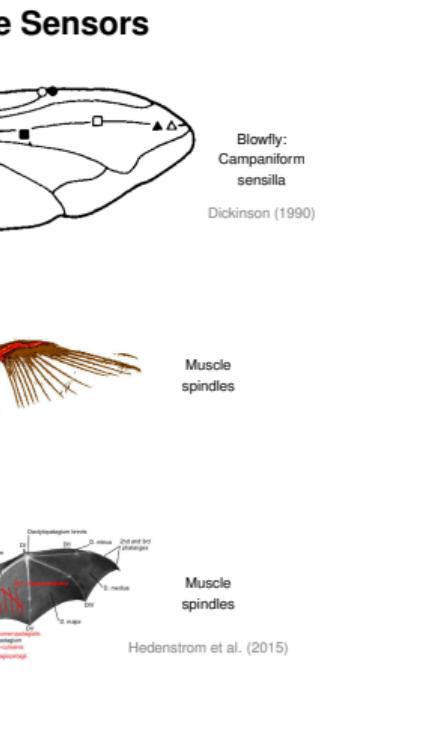
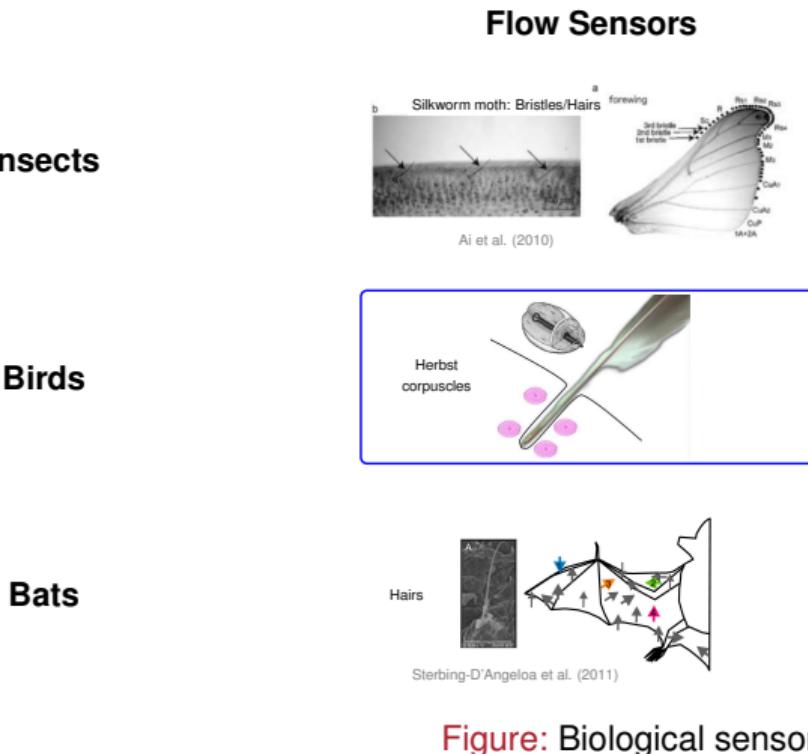
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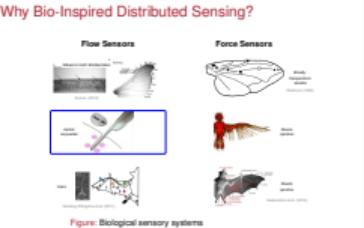
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2018-05-03

Bio-Inspired Distributed Sensing

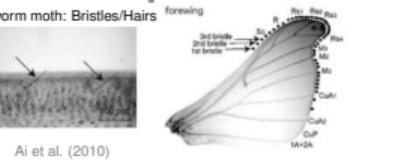
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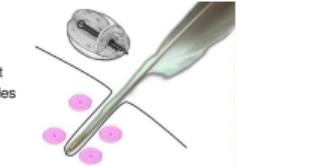
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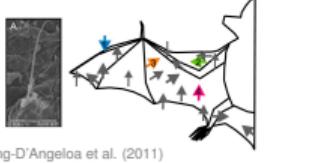


Birds



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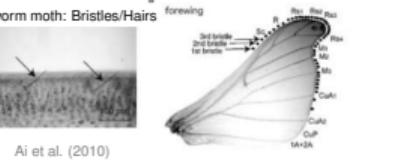
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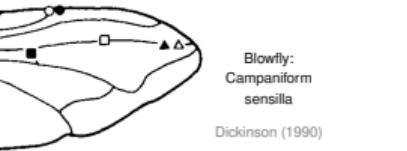
ing-D'Angelo et al. (2011)

Unit 1: Biological sensory systems

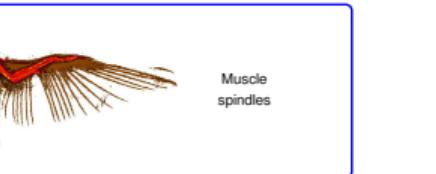
Sensors



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Bio-Inspired Distributed Sensing

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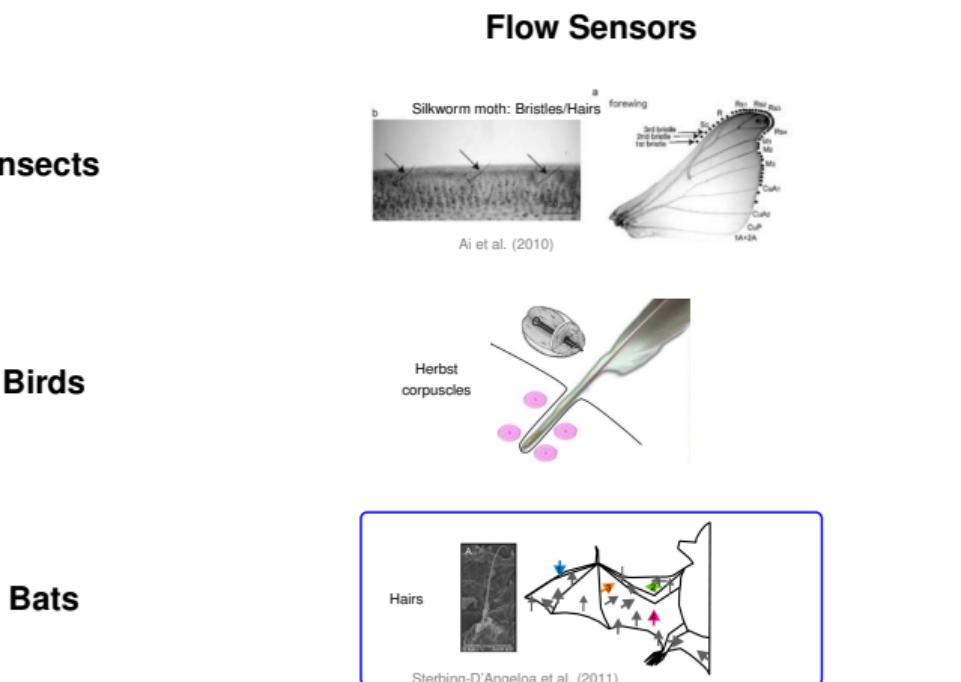
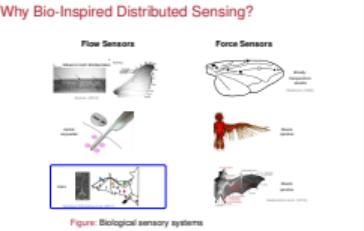
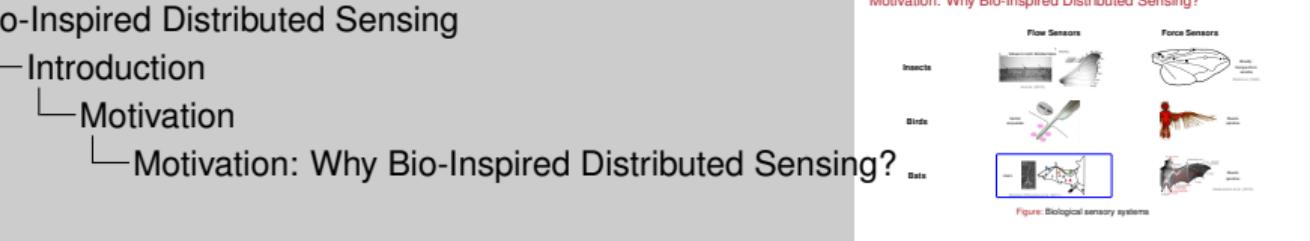


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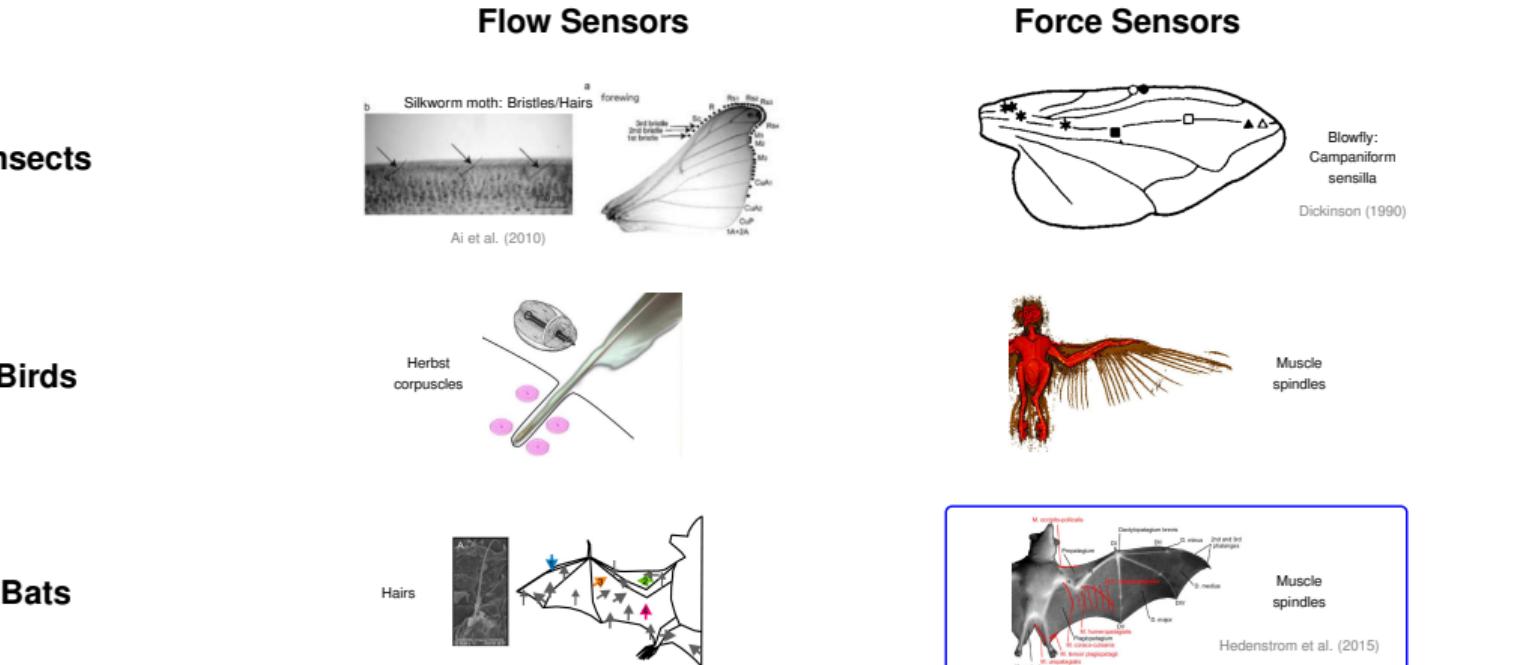
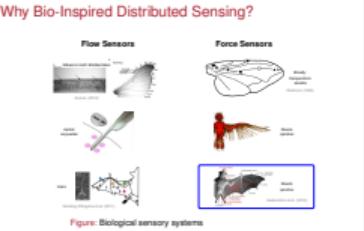
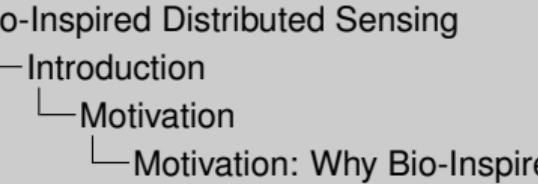


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Motivation: Why Bio-Inspired Distributed Sensing?

❖ Current UAV autopilot technologies

❖ Challenges

❖ Potential use of force and flow information

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

Motivation: Why Bio-Inspired Distributed Sensing?

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

Motivation: Why Bio-Inspired Distributed Sensing?

❖ Current UAV autopilot technologies

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

❖ Challenges

❖ Potential use of force and flow information

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- ❖ Current UAV autopilot technologies
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Motivation: Why Bio-Inspired Distributed Sensing?

❖ Current UAV autopilot technologies

- Availability of aerodynamic variables
 - Improved flight dynamics model
 - Stall detection
- Earlier gust detection
 - Gust rejection/alleviation
- Localised information
 - Localised control
 - Load tailoring

❖ Challenges

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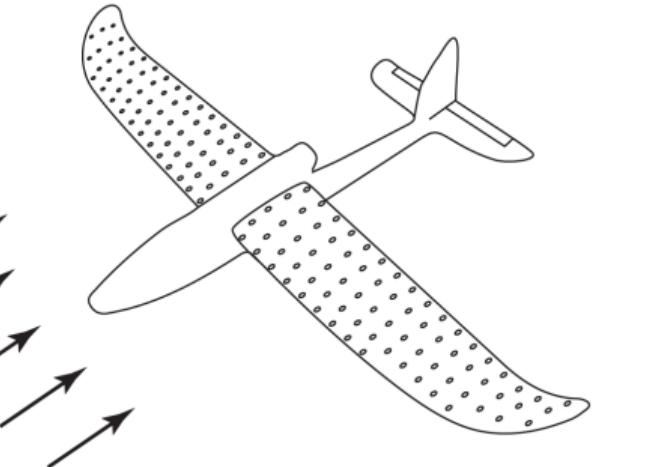
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Research Problem

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

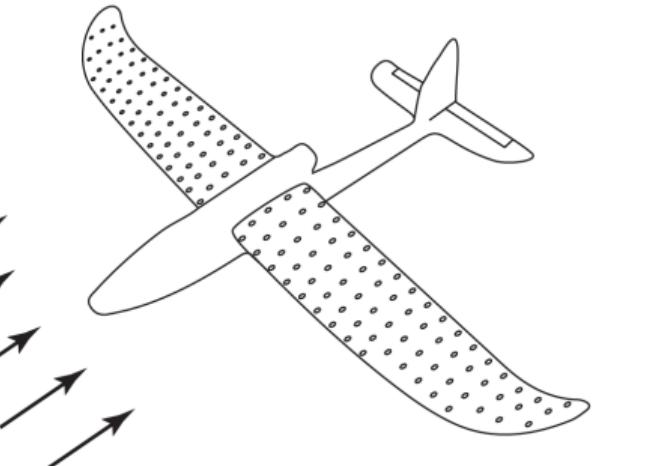


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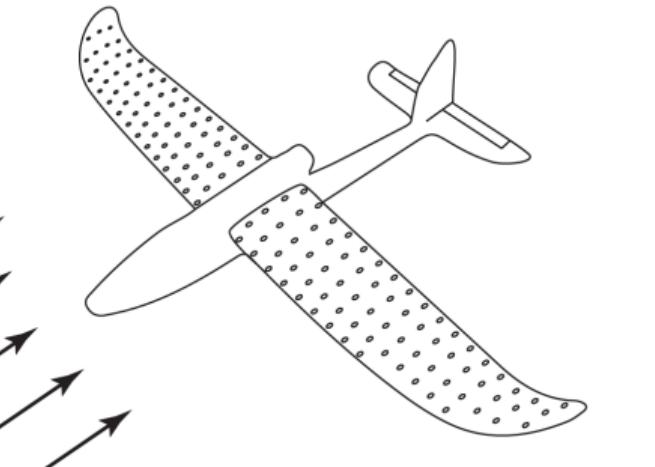


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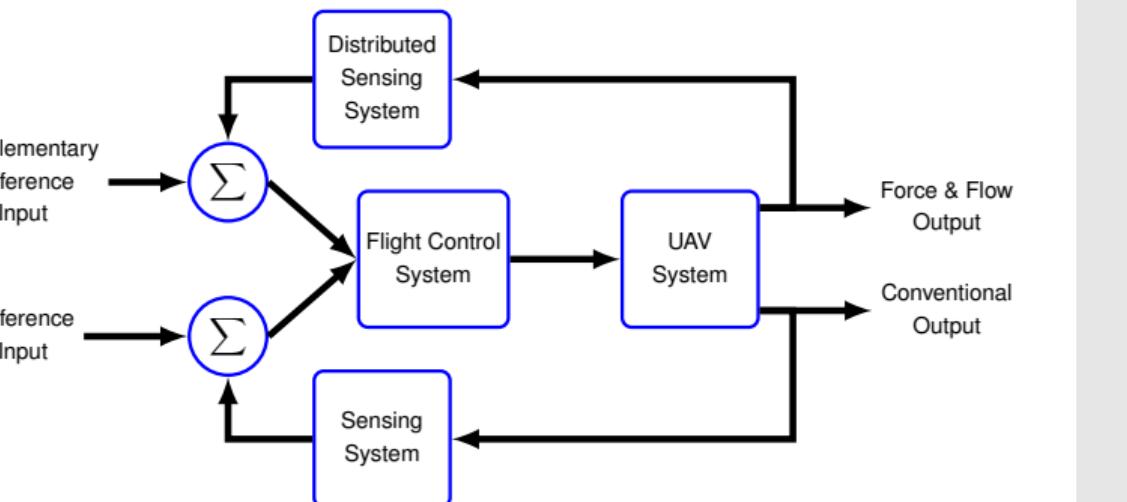


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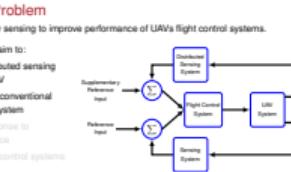
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Bio-Inspired Distributed Sensing

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- Research Problem
- Research Problem



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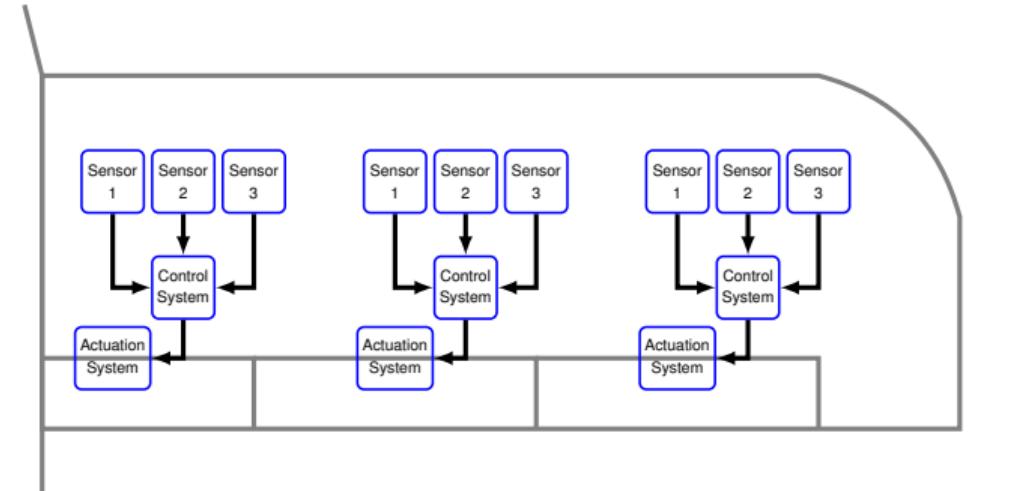
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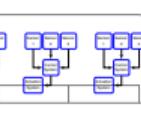


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Previous Research at UoB: Strain sensing

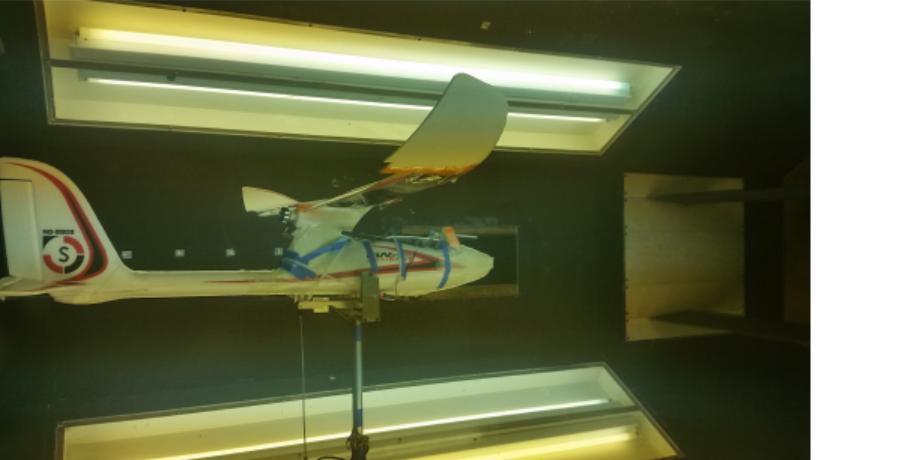


Figure: Strain sensing platform

Bio-Inspired Distributed Sensing
Thursday, May 3

- ❖ 12 full-bridge strain gauges and amplifiers distributed along spar of wing
- ❖ Wind tunnel characterisation

Bio-Inspired Distributed Sensing

└ Research at UoB
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Strain sensing platform

Previous Research at UoB: Strain sensing

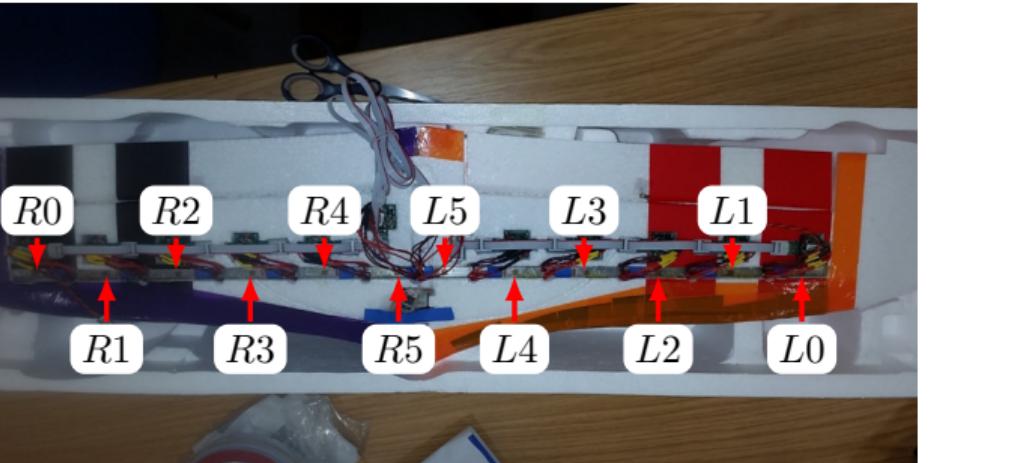
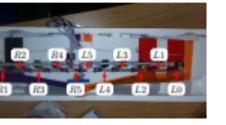


Figure: Strain sensing platform instrumentation



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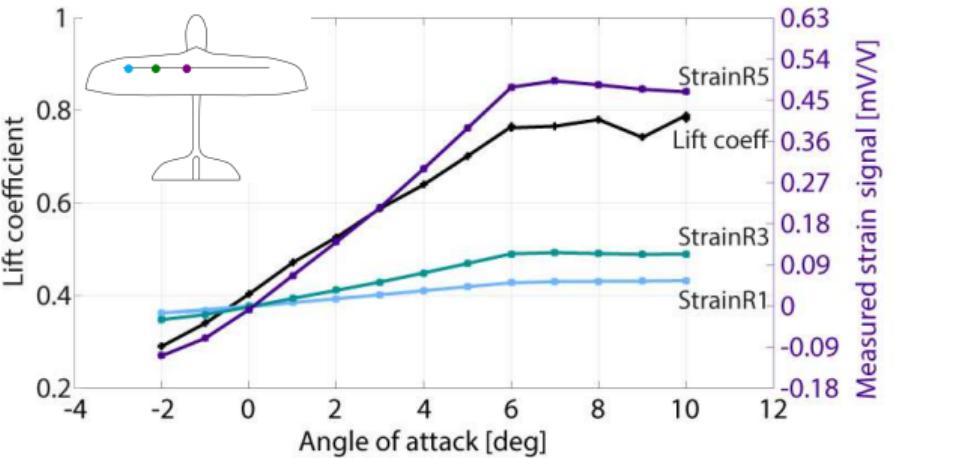
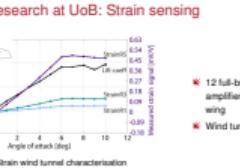
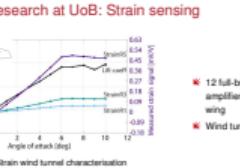
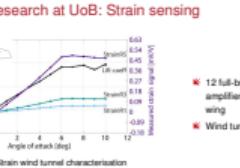


Figure: Strain wind tunnel characterisation



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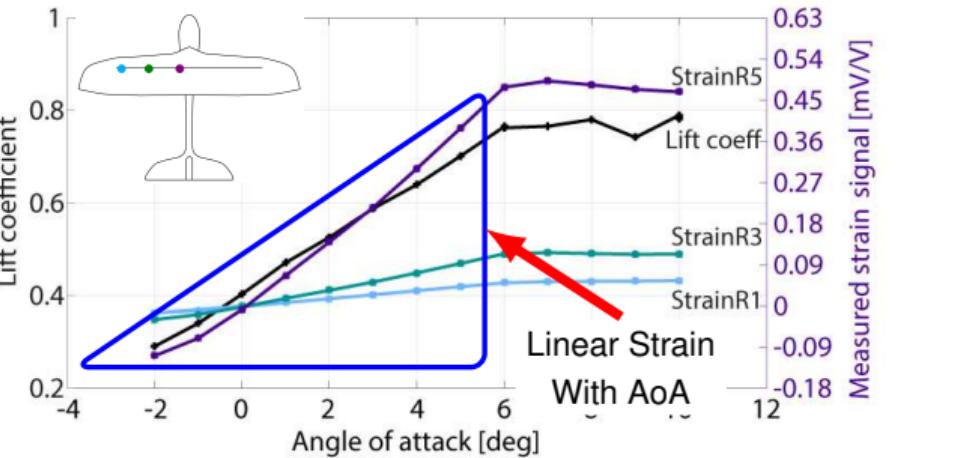


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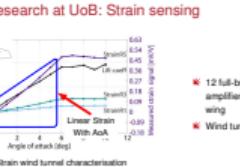


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Wind tunnel characterisation

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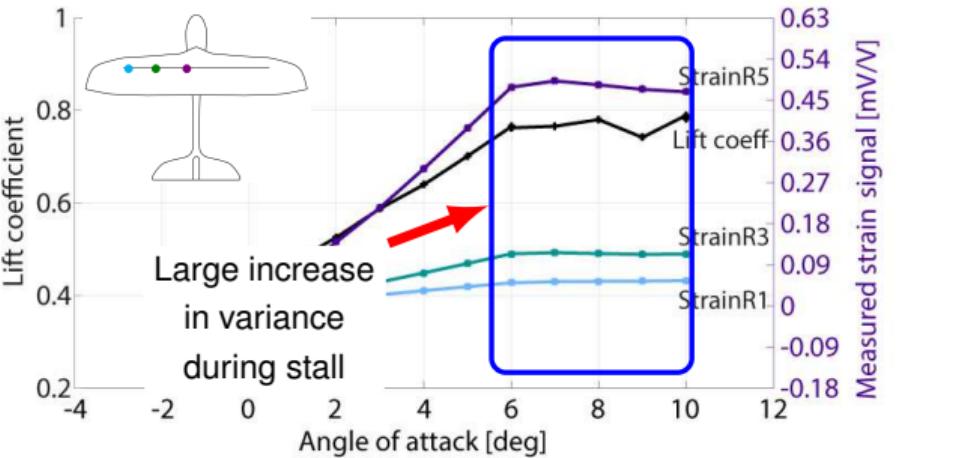
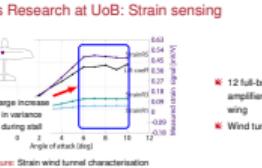


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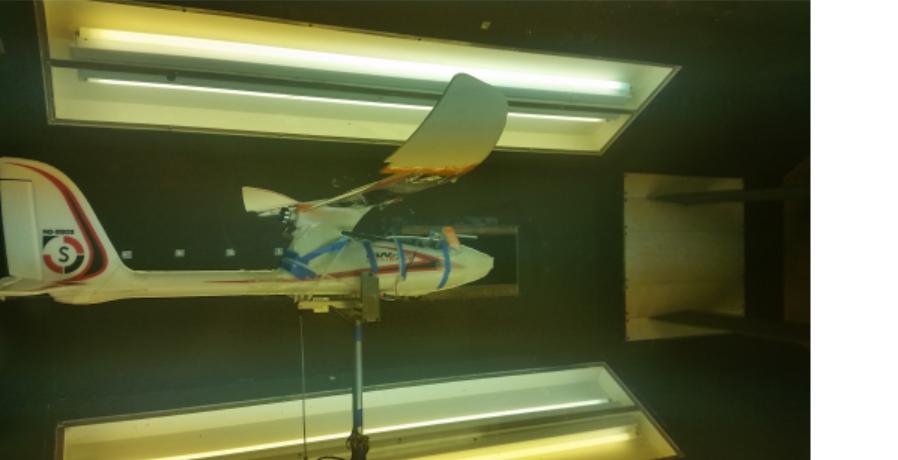


Figure: Strain sensing platform

- ❖ Response to controlled gusts
- ❖ Open loop free flight
- ❖ Closed loop free flight
- ❖ Outdoor flight testing

Bio-Inspired Distributed Sensing
Thursday, May 3

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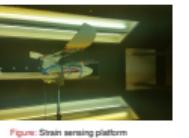


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1. Click on 'Response to controlled gusts' to show gust video:

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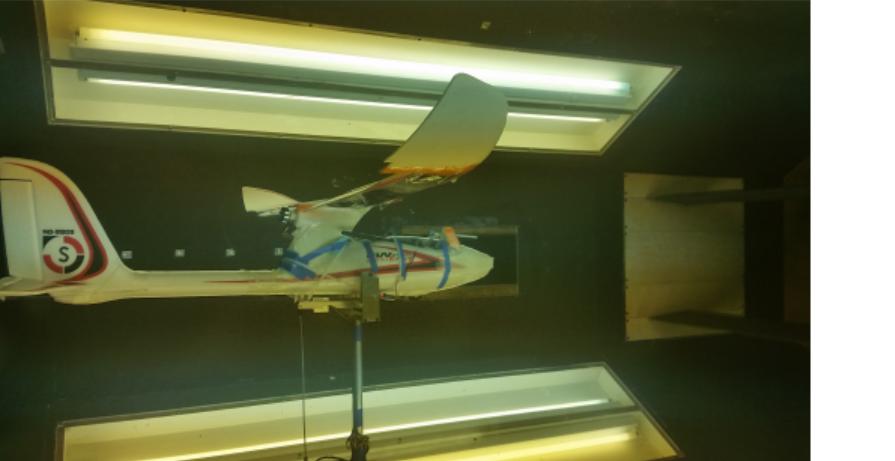


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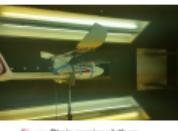
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- ❖ Closed loop free flight
- ❖ Outdoor flight testing

1. Click on 'Open loop free flight' to show open-loop video

Previous Research at UoB: Strain sensing

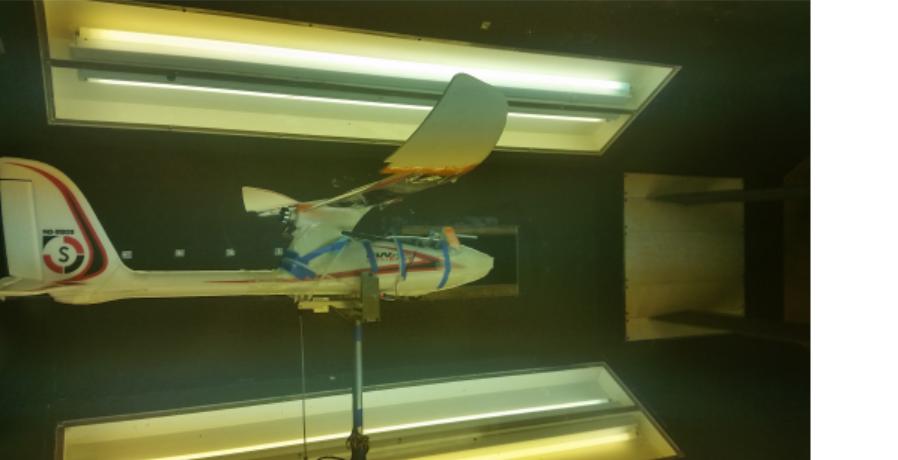


Figure: Strain sensing platform

Bio-Inspired Distributed Sensing
Thursday, May 3

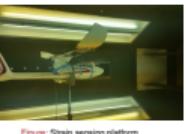
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Bio-Inspired Distributed Sensing

- └ Research at UoB
- └ Previous Research
 - └ Previous Research at UoB: Strain sensing

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Previous Research at UoB: Strain sensing



- ❖ Response to controlled gusts
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1. Click on 'Closed loop free flight' to show closed-loop video

Previous Research at UoB: Strain sensing

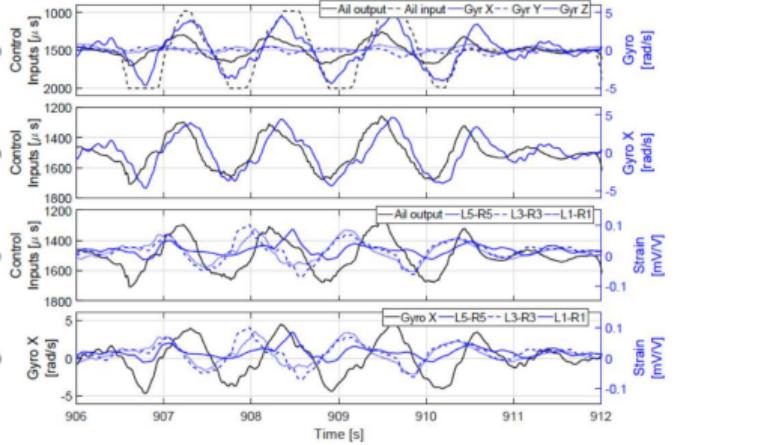
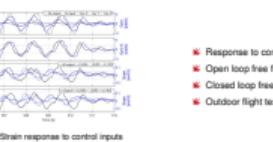


Figure: Strain response to control inputs

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Previous Research at UoB: Strain sensing



1. Outdoor flight graph

Previous Research at UoB: Strain sensing

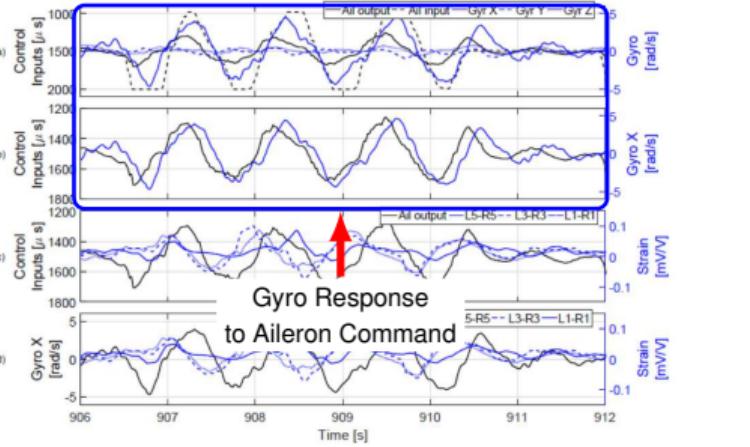


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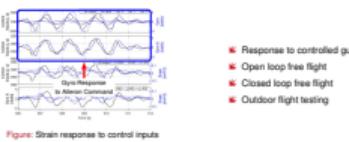
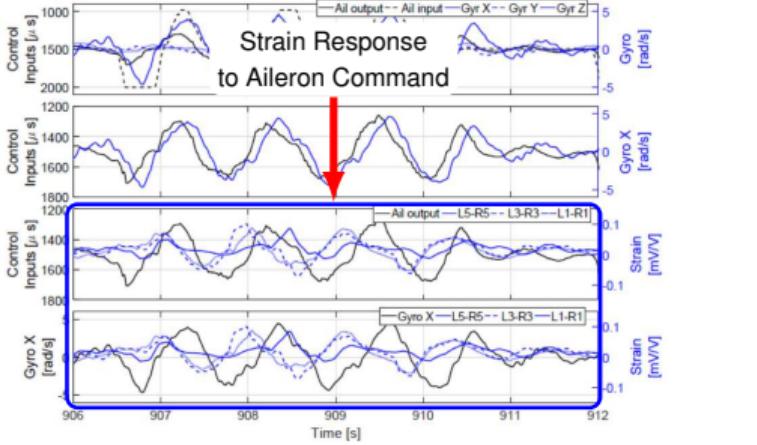


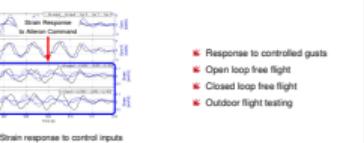
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Previous Research at UoB: Pressure sensing



Figure: Pressure sensing platform

Bio-Inspired Distributed Sensing
Thursday, May 3

- ❖ 3-D printed insert on starboard wing
- ❖ Static-pressure ports distributed along wing-chord
- ❖ Wind tunnel characterisation
- ❖ Closed loop 1DOF WT testing
- ❖ Outdoor flight testing

Bio-Inspired Distributed Sensing

└ Research at UoB
└ Previous Research
└ Previous Research at UoB: Pressure sensing

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Previous Research at UoB: Pressure sensing



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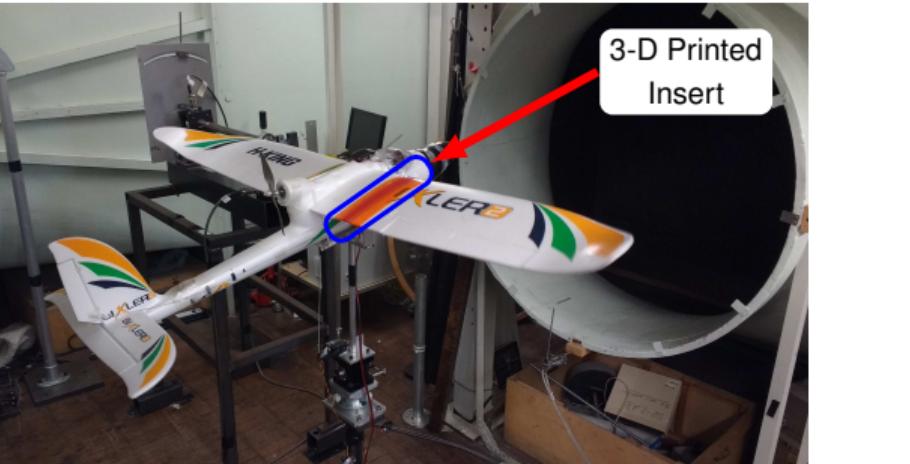
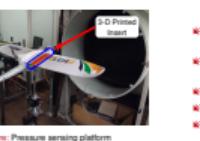


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Previous Research at UoB: Pressure sensing

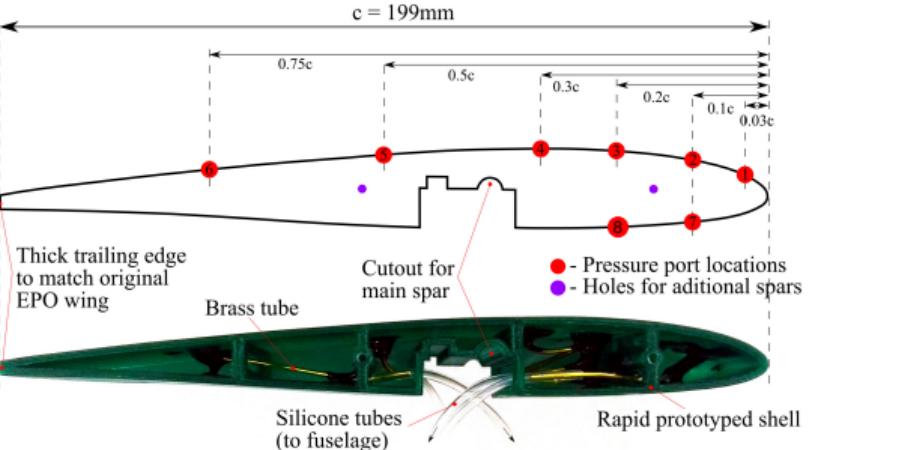


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Bio-Inspired Distributed Sensing
Thursday, May 3

Bio-Inspired Distributed Sensing

Research at UoB

Previous Research

Previous Research at UoB: Pressure sensing

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Previous Research at UoB: Pressure sensing



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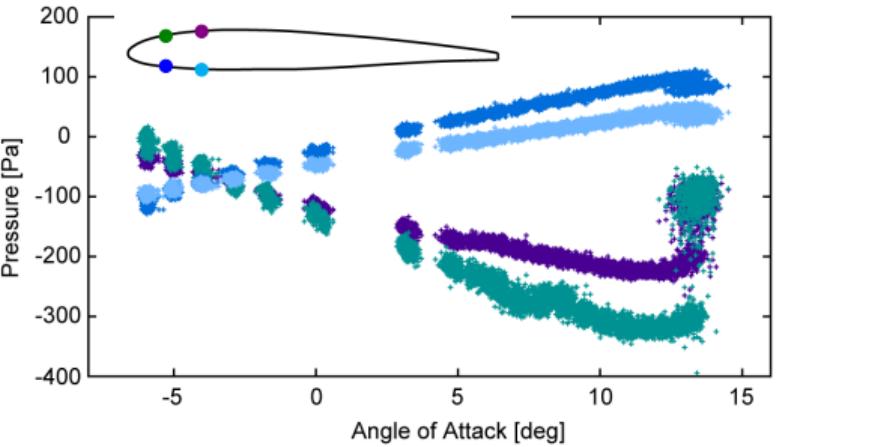


Figure: Pressure wind tunnel characterisation

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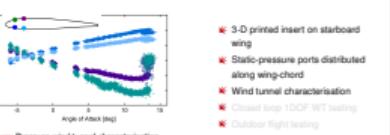


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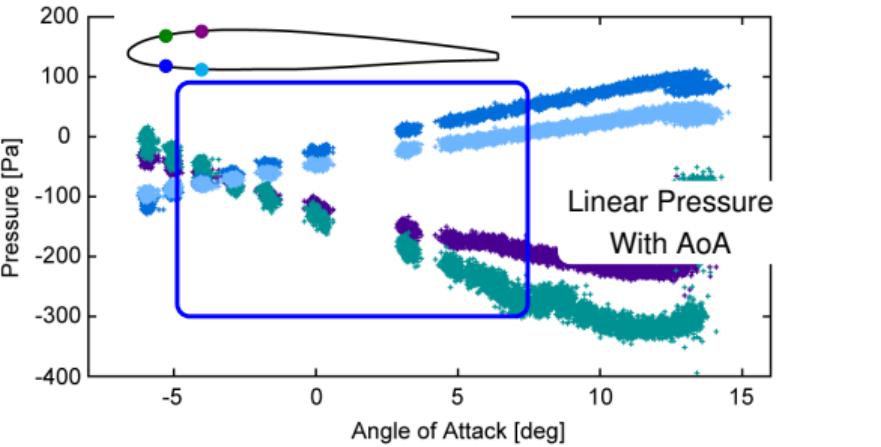
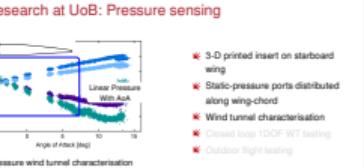


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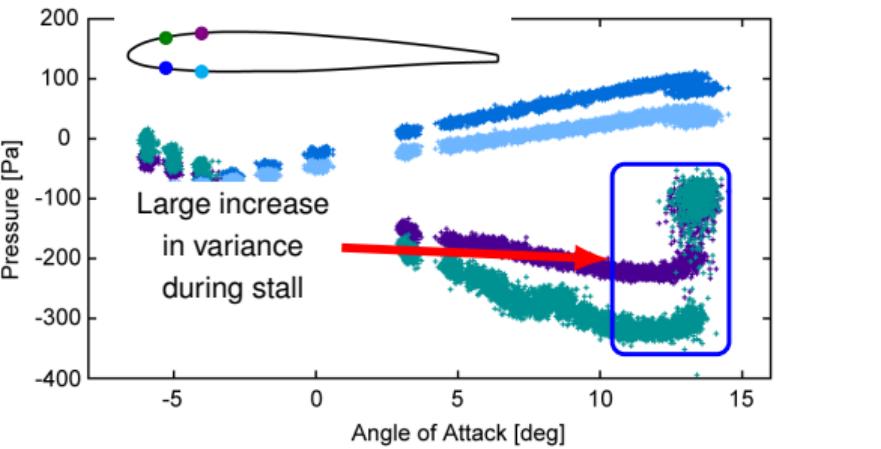
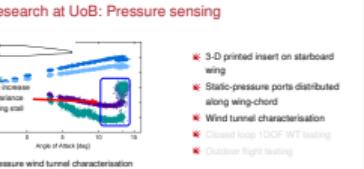


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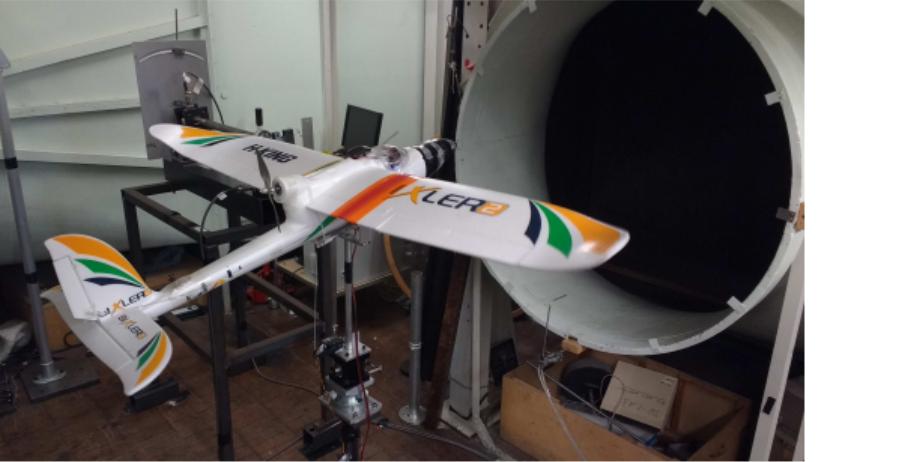


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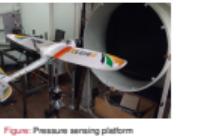


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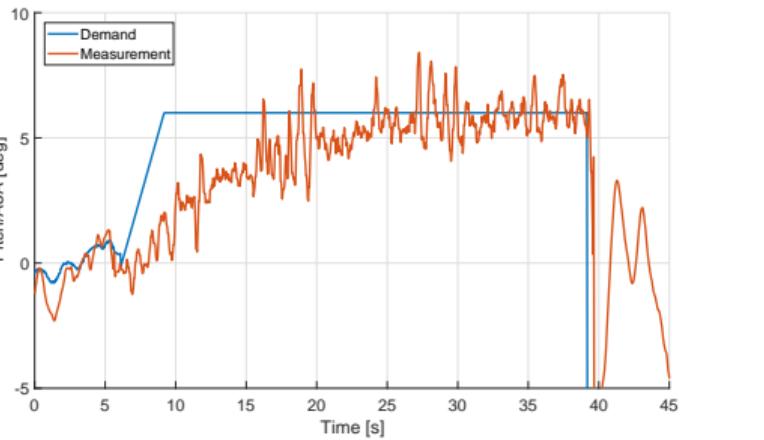
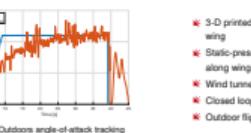


Figure: Outdoors angle-of-attack tracking

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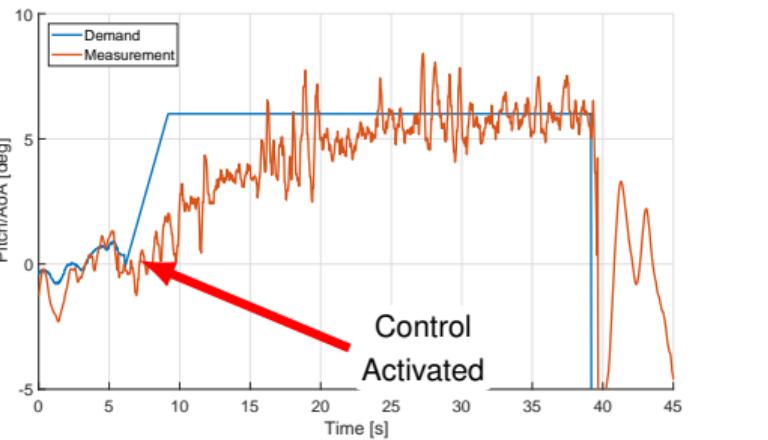
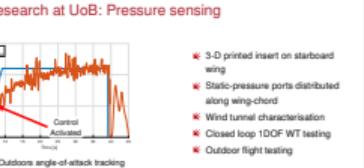


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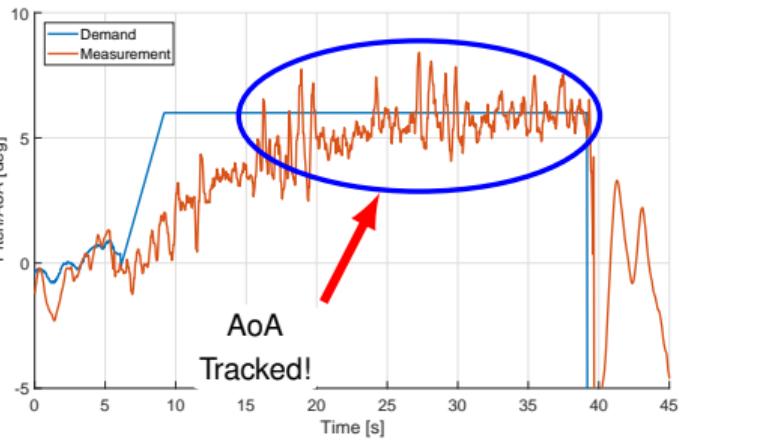


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Thursday, May 3

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Bio-Inspired Distributed Sensing

Research at UoB
Previous Research
Previous Research at UoB: Pressure sensing

2018-05-03

Previous Research at UoB: Pressure sensing



Previous Research at UoB

What did we learn?

- ❖ Strain & pressure signal show
- Force and pressure information
- Force and pressure information
- Force and pressure information
- ❖ Similar performance to IMU-based control
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- ❖ Information not available using IMU
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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
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 - AoA, stall, roll acceleration, non-linear lift

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Current Research at UoB

Research focuses on:

- ❖ Pressure and strain sensing experimental platform
- ❖ Calibration & characterisation experiments
- ❖ Closed loop control algorithms

Divided into two phases:

- ❖ Phase 1: Wind tunnel experiments
- ❖ Phase 2: Outdoor flights experiments

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Current Research at UoB

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 100 Hz
- ❖ 1-DOF pitch motion servo-driven system for automated motion

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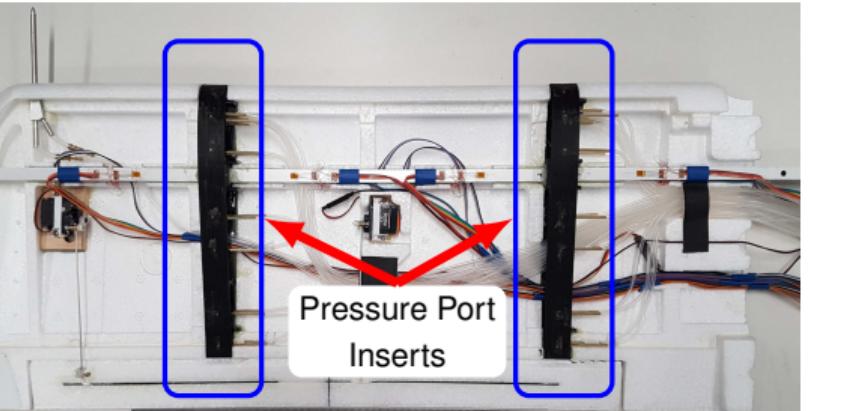


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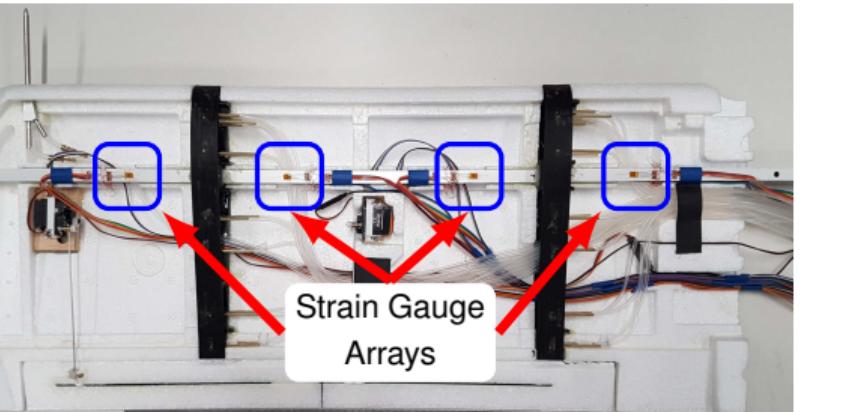


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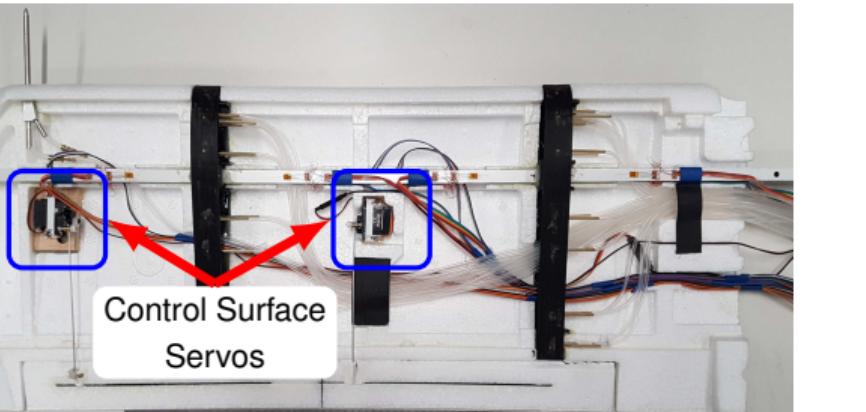


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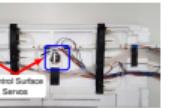


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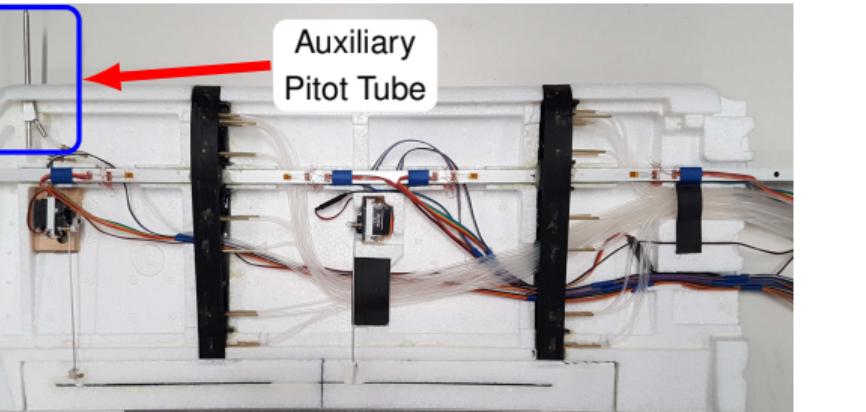


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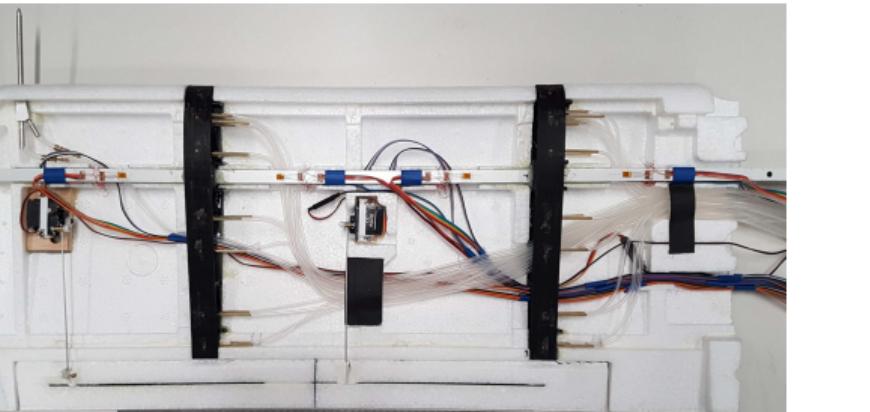


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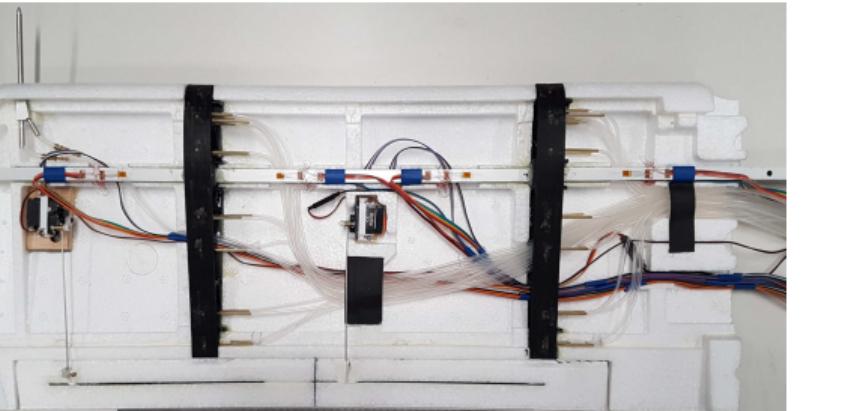


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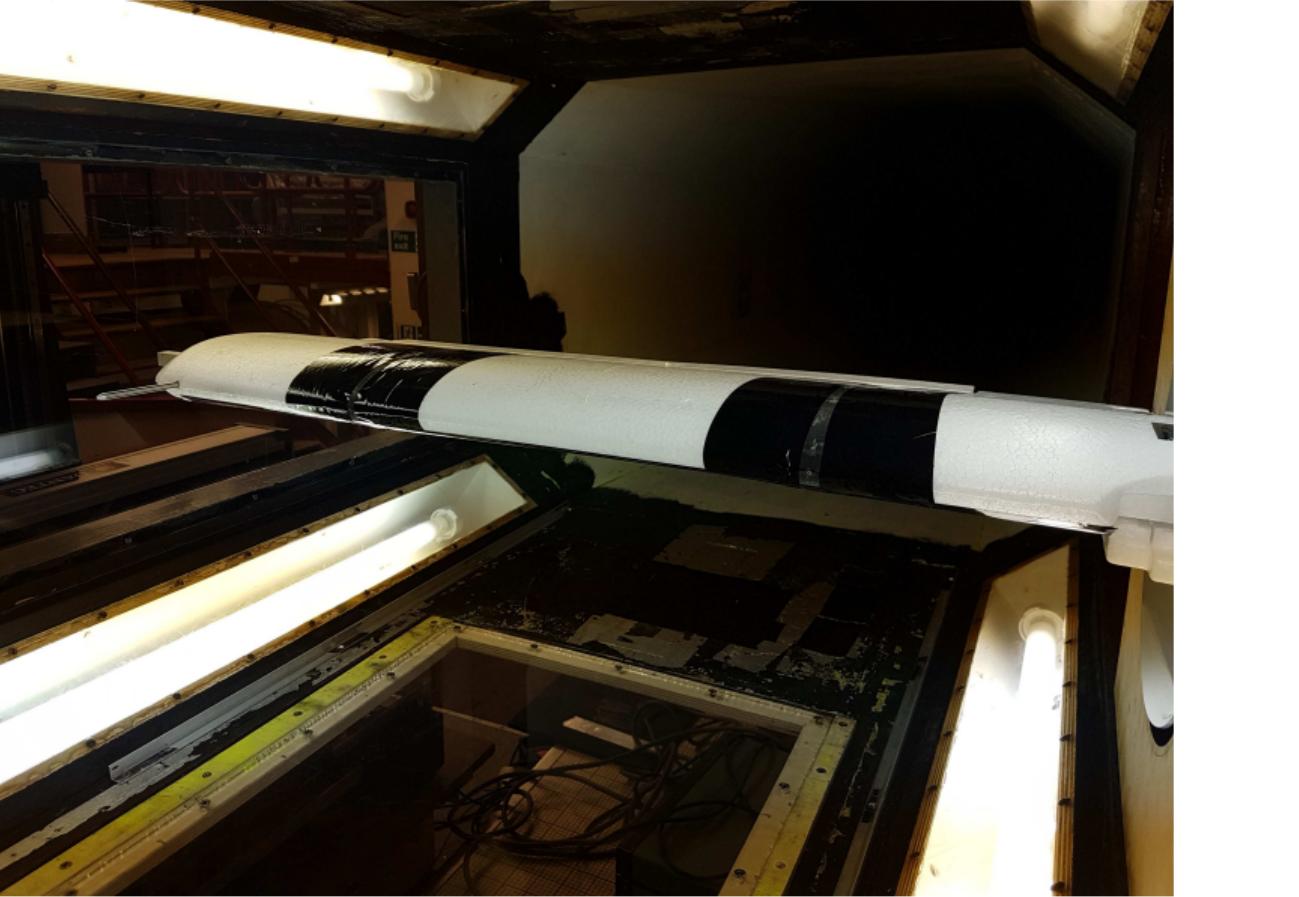
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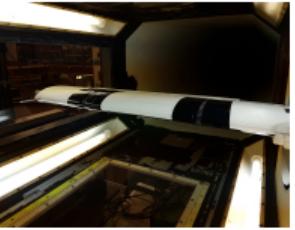


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└ Research at UoB
 └ Current Research

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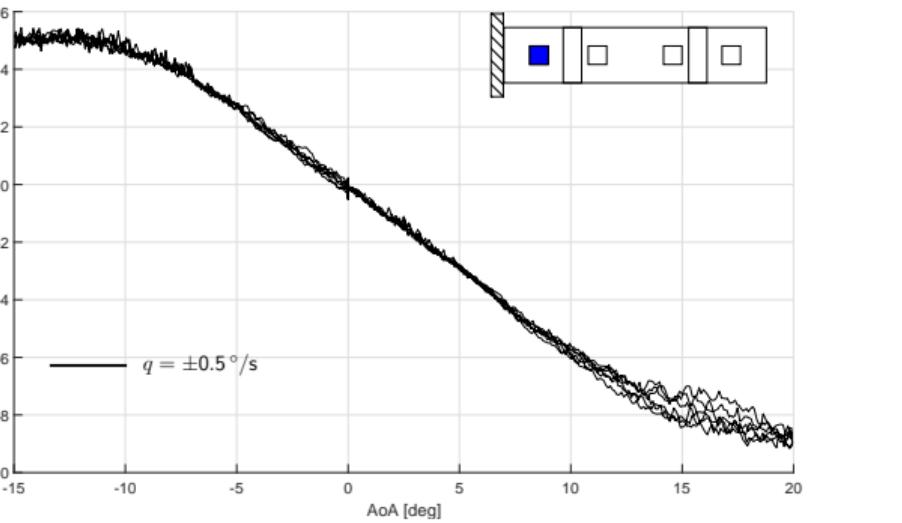
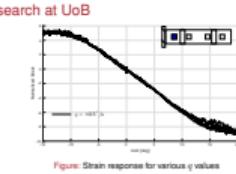


Figure: Strain response for various q values



Current Research at UoB

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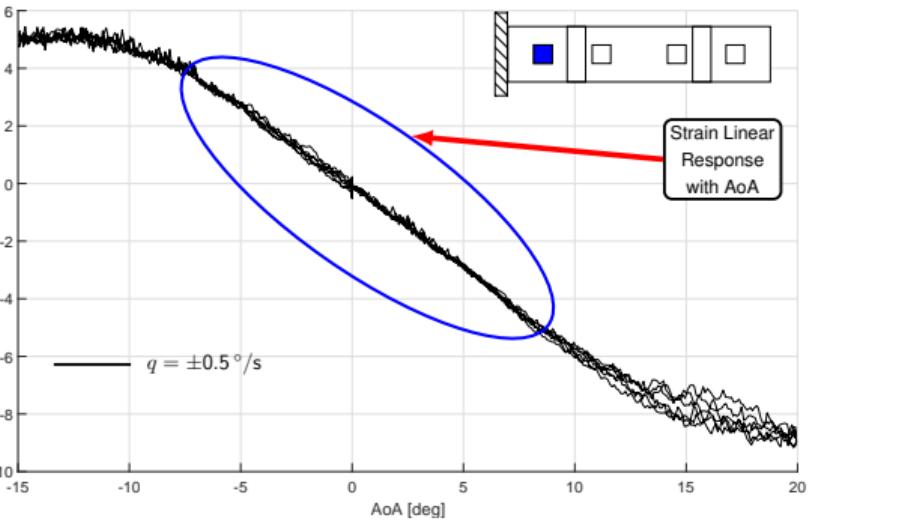


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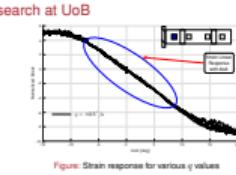


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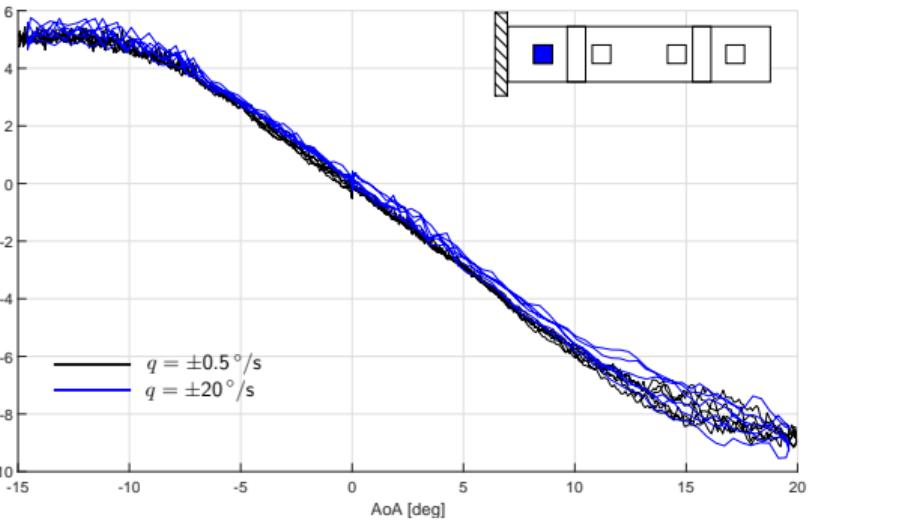
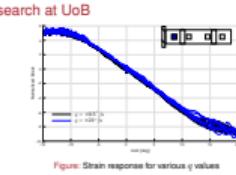


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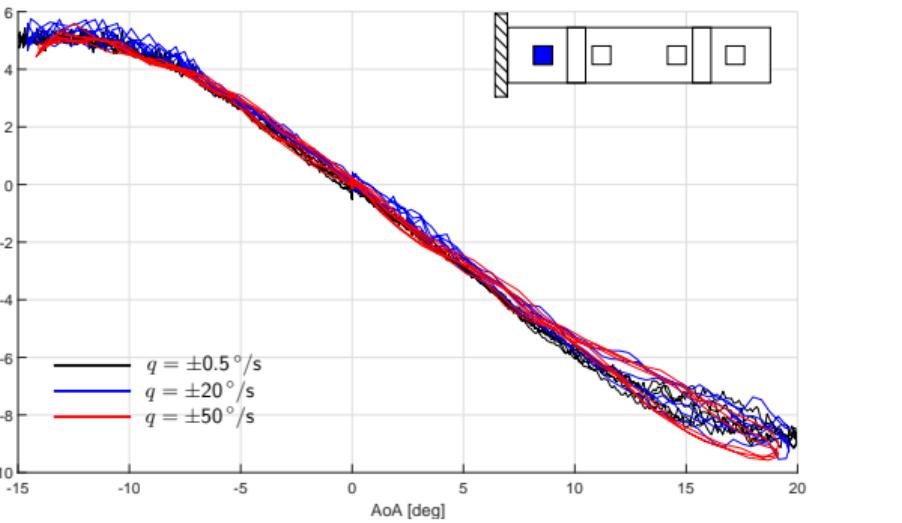


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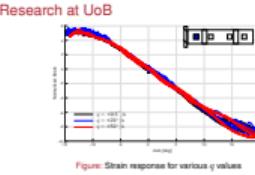


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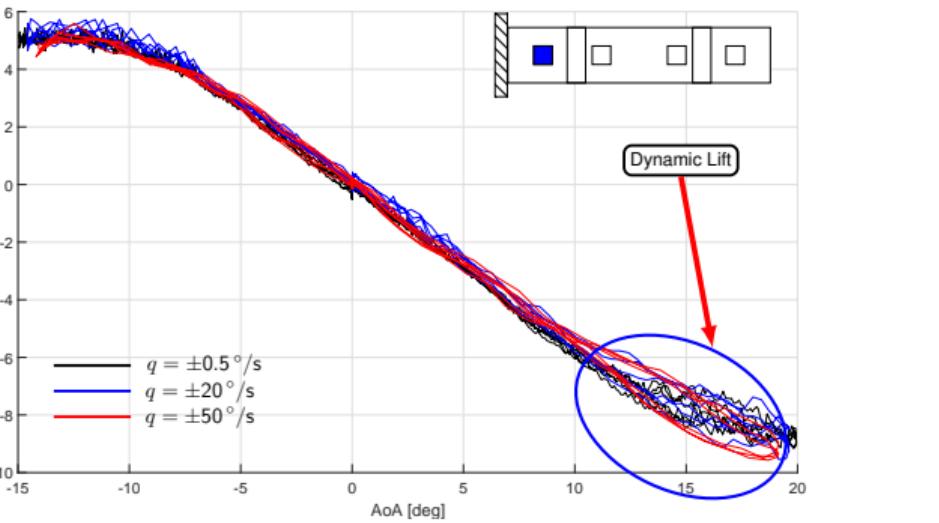
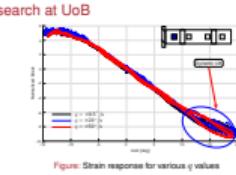


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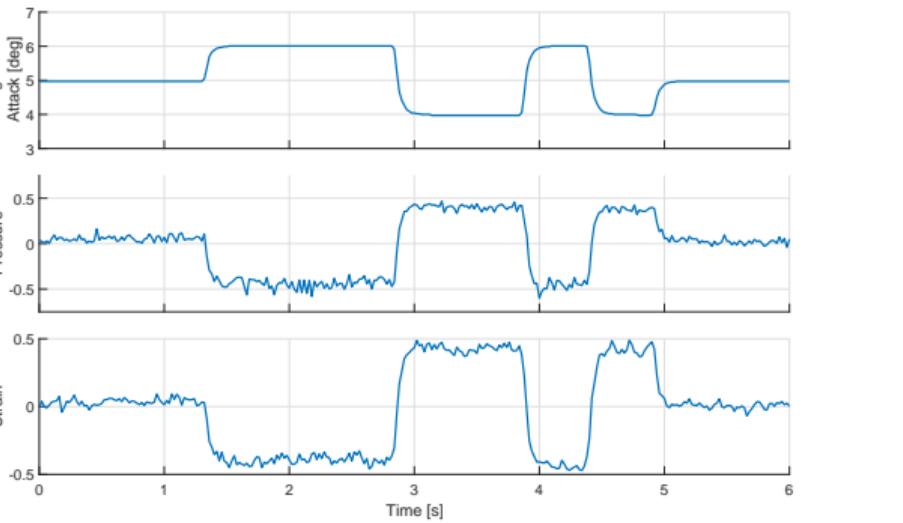
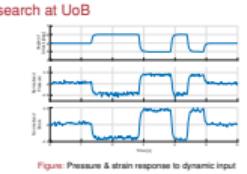


Figure: Pressure & strain response to dynamic input



Current Research at UoB

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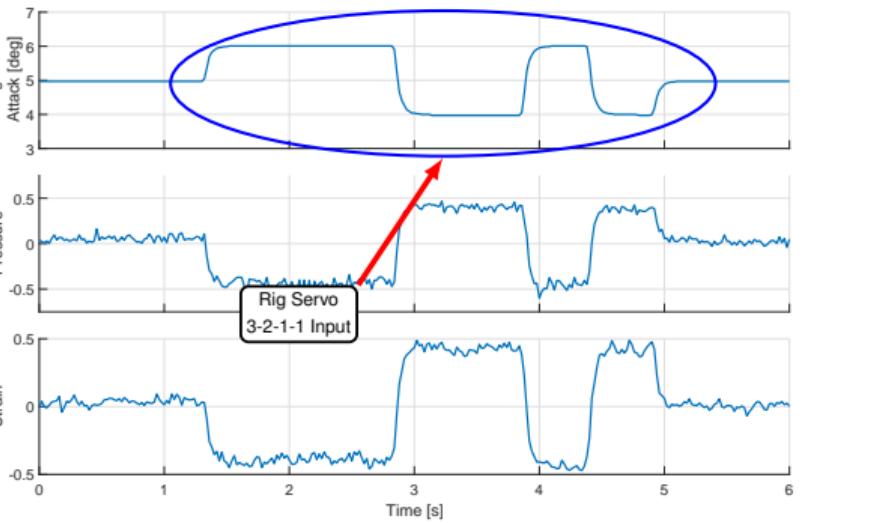
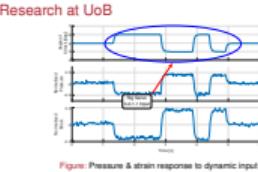


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2018-05-03



Current Research at UoB

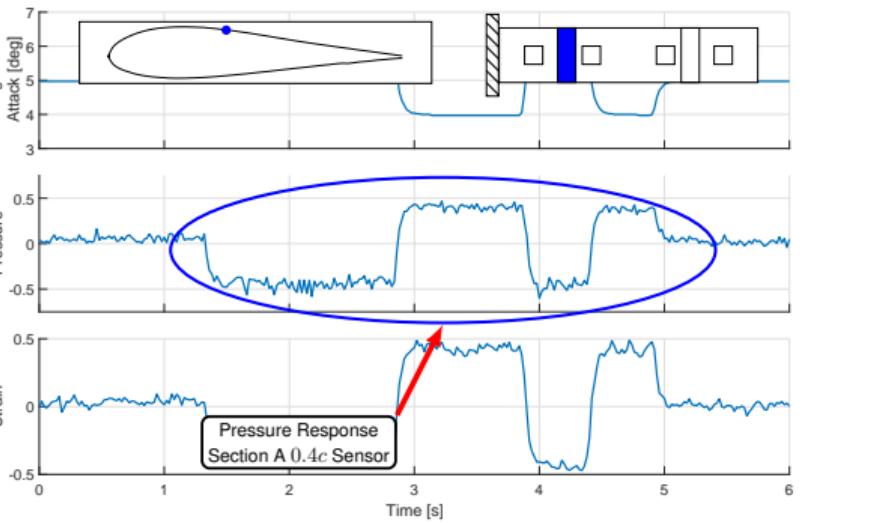
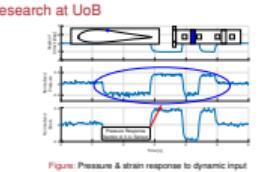


Figure: Pressure & strain response to dynamic input



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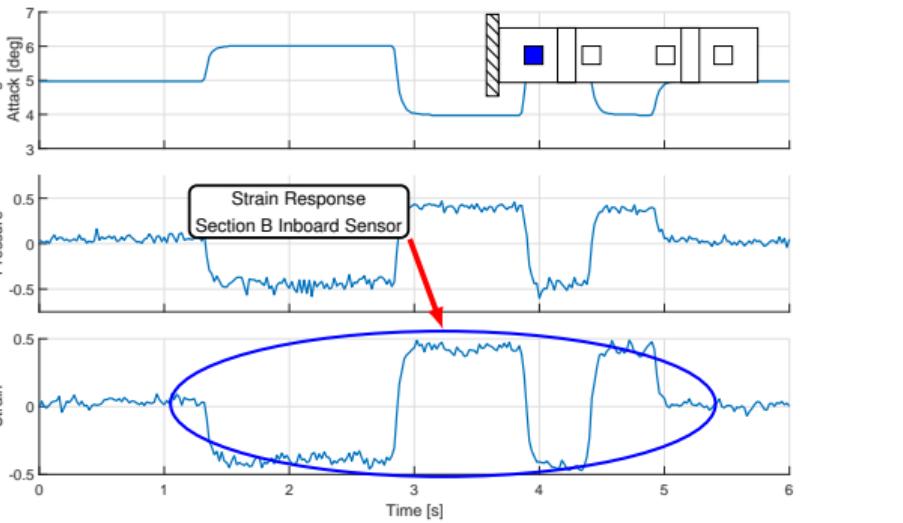
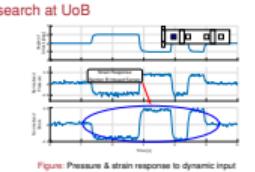


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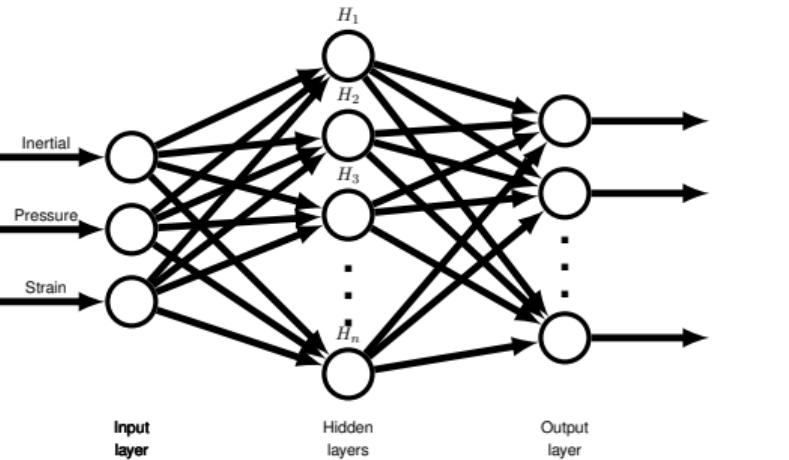


Figure: Possible UAV control strategies

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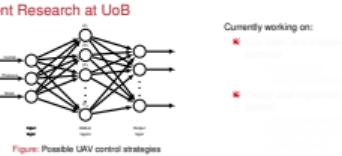
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- ❖ Design and implement closed loop control:

Bio-Inspired Distributed Sensing
Thursday, May 3

2018-05-03

Bio-Inspired Distributed Sensing

- Research at UoB
- Current Research
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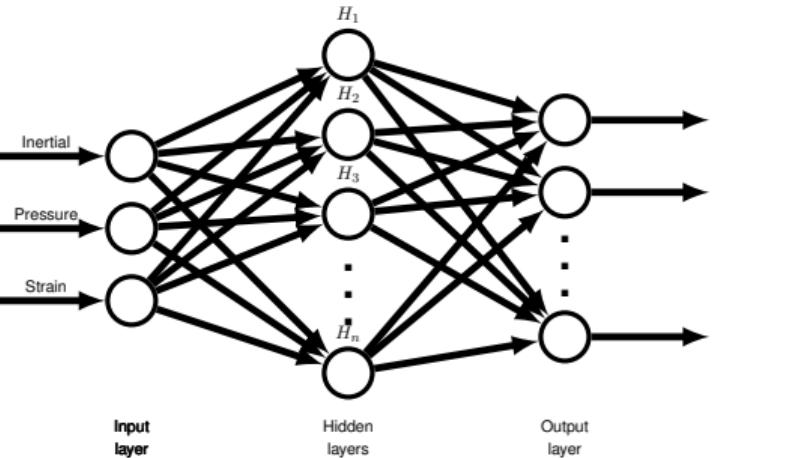


Figure: Possible UAV control strategies

Currently working on:

- ❖ Use strain and pressure signals to estimate
 - AoA, airspeed
 - Aerodynamic loads
- ❖ Design and implement closed loop control:
 - Classic control architecture
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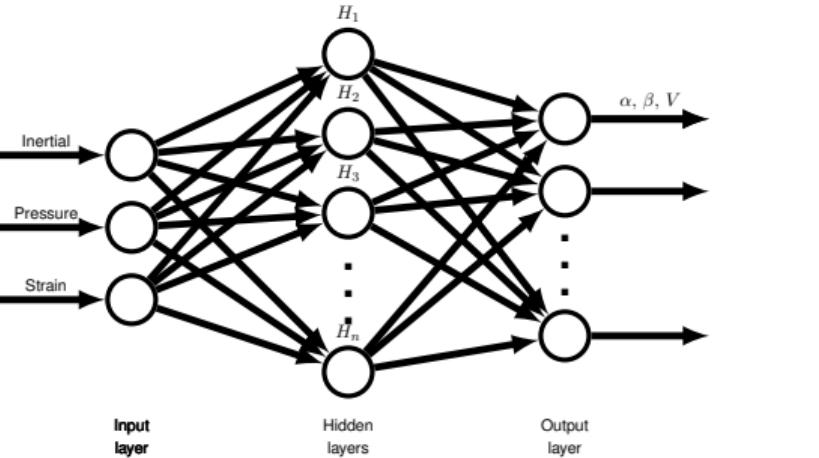
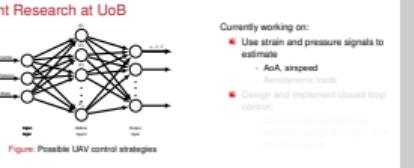


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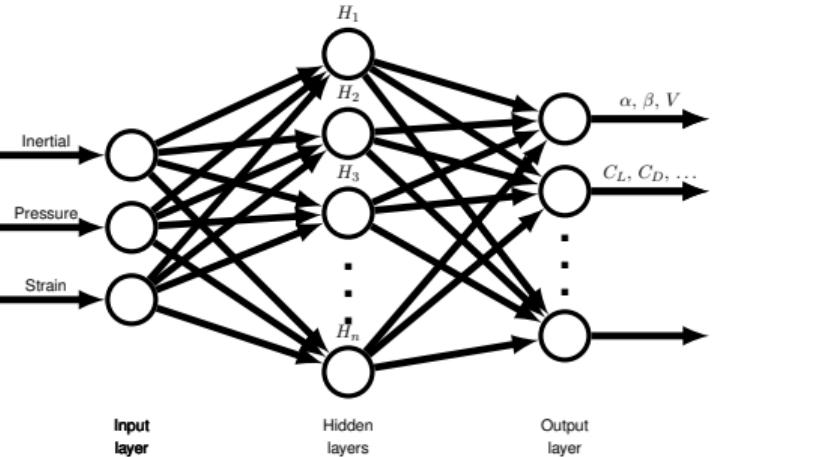


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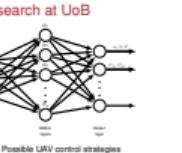
- └ Research at UoB
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Current Research at UoB

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Figure: Possible UAV control strategies



The diagram shows a complex neural network structure with multiple input nodes, several hidden layers, and a single output node. Arrows indicate connections between nodes across different layers. A legend on the right side defines symbols: a red star for 'Currently working on', a green checkmark for 'Use strain and pressure signals to estimate', a blue circle for 'AoA, airspeed', a red circle for 'Aerodynamic loads', and a red star for 'Design and implement closed loop control'.

Current Research at UoB

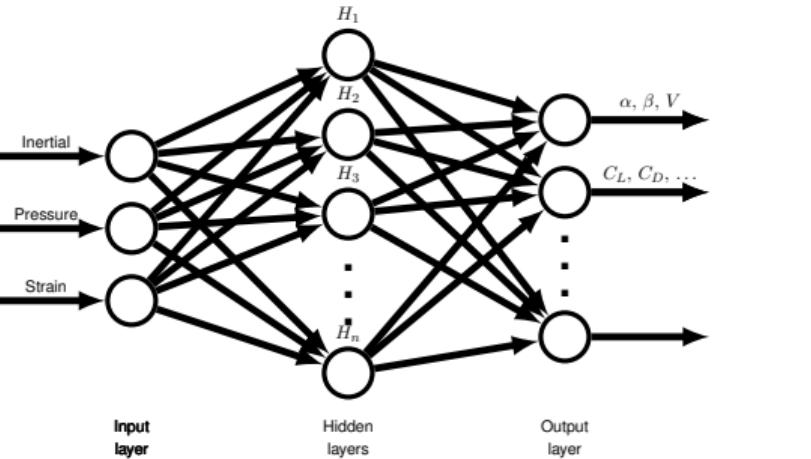


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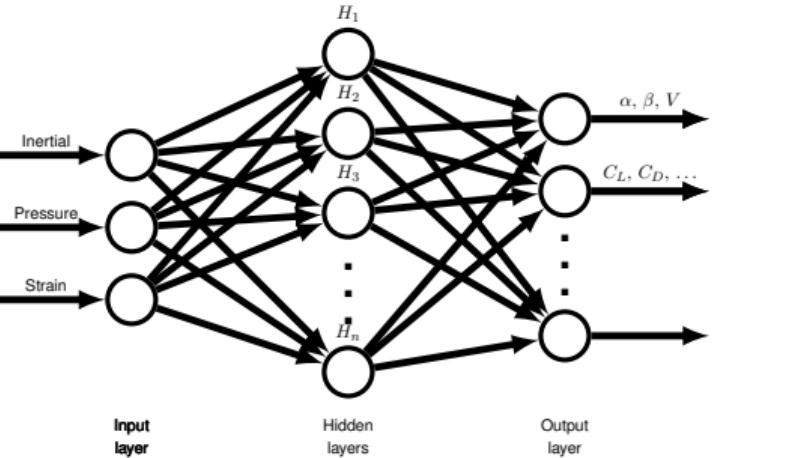


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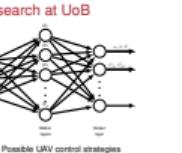
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Current Research at UoB



The diagram shows a network of sensors (represented by circles) distributed across a 3D volume. Sensors are located on a vertical axis (labeled 'Height') and a horizontal plane (labeled 'Azimuth'). They are interconnected by a mesh of lines representing communication links. A legend on the right specifies: 'Currently working on:' with two items, and 'Currently working on:' with three items.

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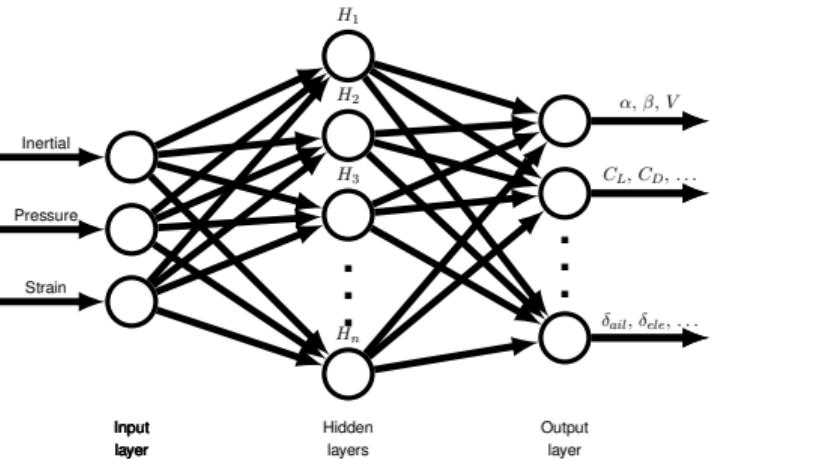
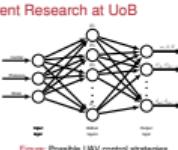


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Concluding Remarks

- 👉 Lots of information on pressure and strain data
- 👉 Challenges:
 - Designing sensors
 - Processing data
 - Power consumption
- 👉 Questions remain:
 - What is the best way to process data?
 - How can we reduce power consumption?

Concluding Remarks

- ☛ Lots of information on pressure and strain data
- ☛ Challenges:
 - Best way to use data?
 - Role of machine learning
- ☛ Questions remain:
 - Sensors location & number
 - Extra potential uses & benefits?

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Thank you

This project has received funding from the European Research Council (ERC)

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Established by the European Commission

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