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Integration of Active Morphing Technology With Smart Morphing Wing Concept for Simultaneous In-Flight Performance Optimisation, Load Alleviation and Flight Dynamic Control (PPT)

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Integration of Active Morphing Technology With Smart Morphing Wing Concept for Simultaneous In-Flight Performance Optimisation, Load Alleviation and Flight Dynamic Control

Tigran Mkhoyan,Vincent Stuber, Nakash Nazeer, Roeland De Breuker Roger Groves, Pim Groen, Sybrand van der Zwaag, Jurij Sodja, Xuerui Wang

SMARTX-ALPHA

TUDelft

Aeroelastic Structures

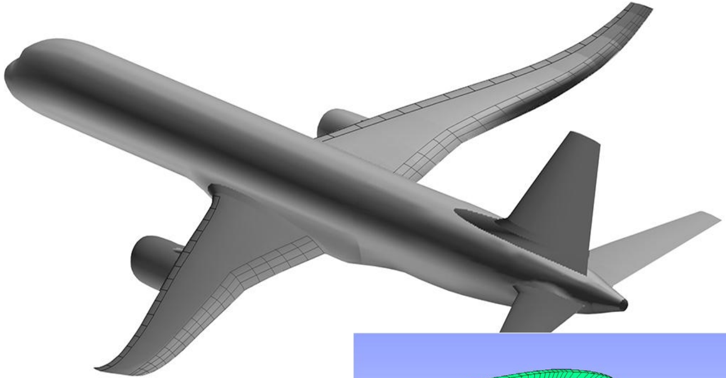
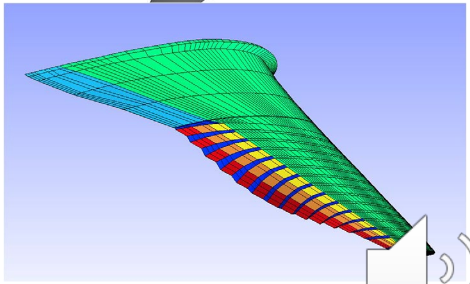
Introduction

Trend towards flexible configurations:

Adaptive Compliant Trailing Edge

(source: NASA)

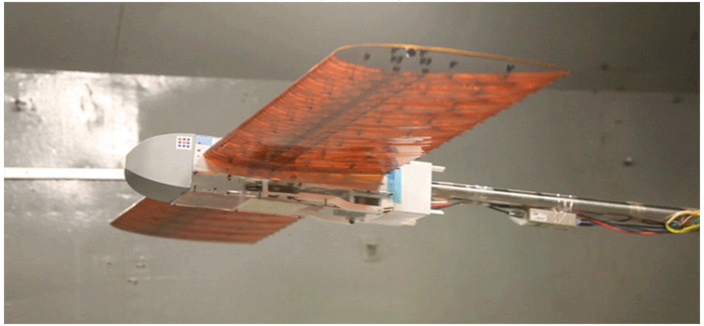
Variable camber continuous trailing edge flap flap

(source: NASA)

Applications: slender flexible (morphing) aircraft

Cellular morphing wing



(source: NASA/MIT)

HALE solar power aircraft

(source: NASA)

Facebook drone aquila

(source: Facebook)

SmartX : SmartX-Alpha

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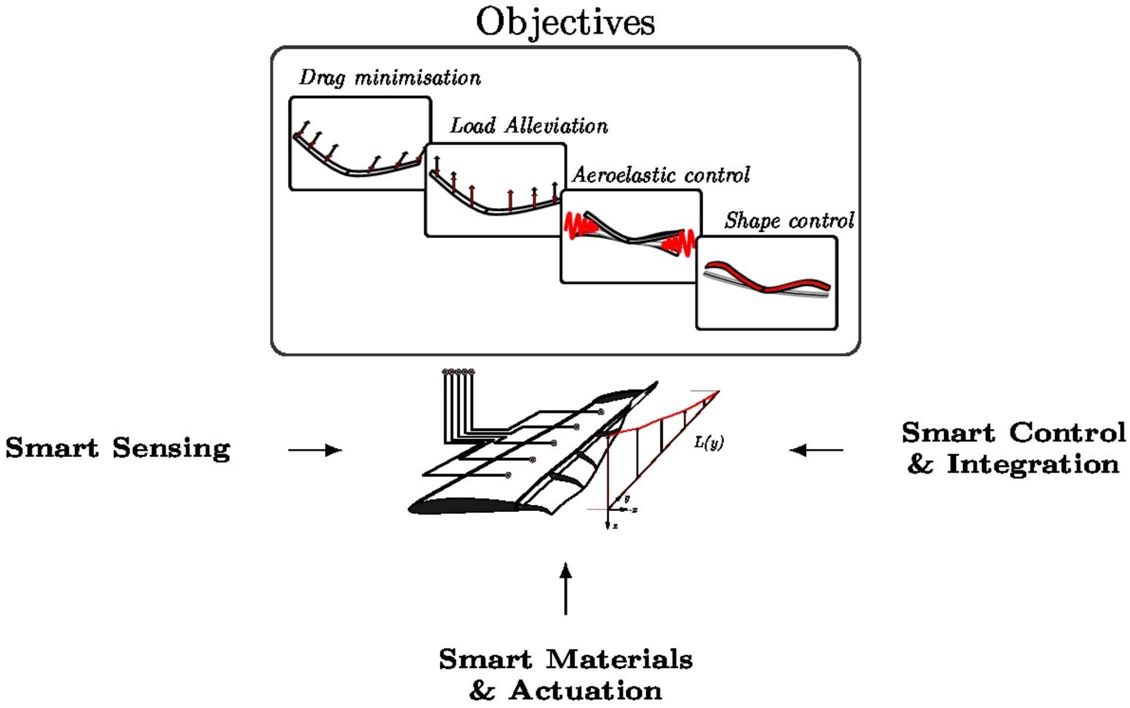
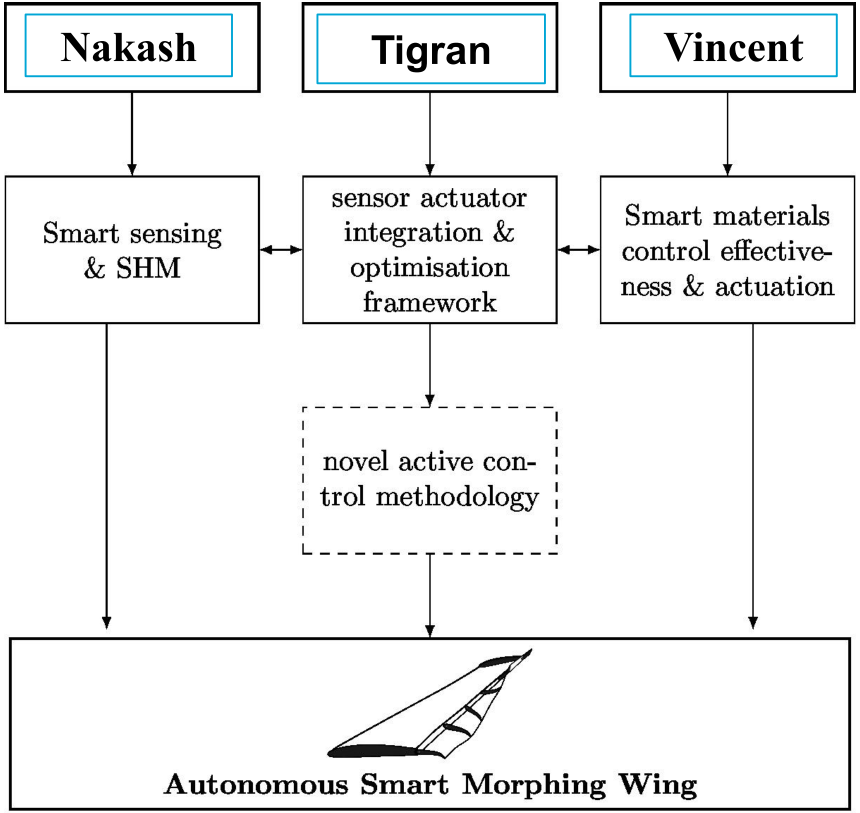
Goal: the Smart Morphing Wing

How can we use multidisciplinary integration of novel control laws, sensing methods, and actuation mechanism for real-time, in-flight, multi-objective optimisation of actively morphing wing?

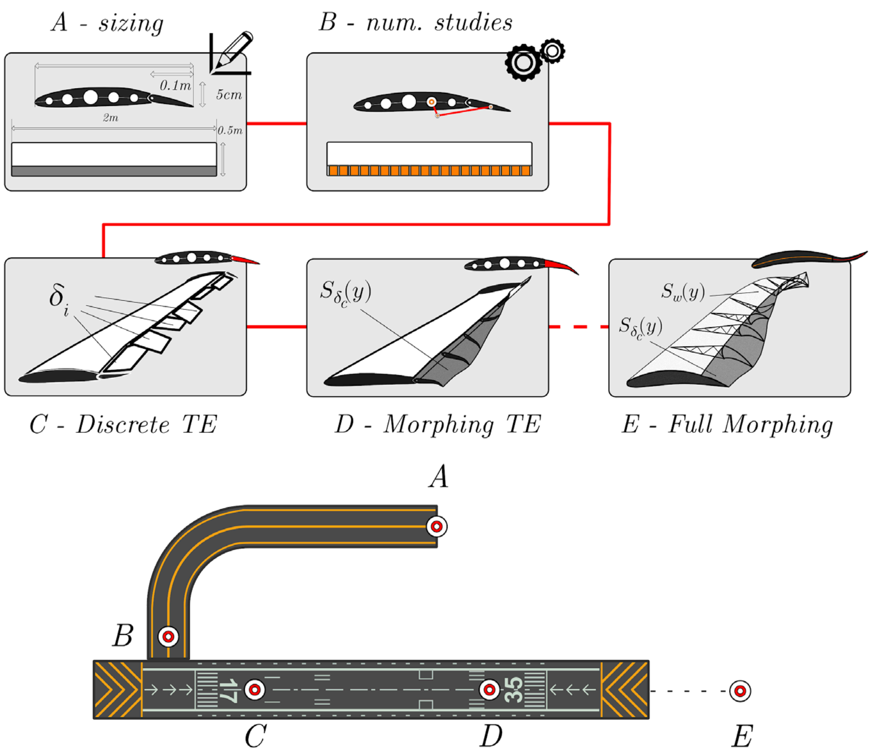


Smart-X: multidisciplinary collaboration

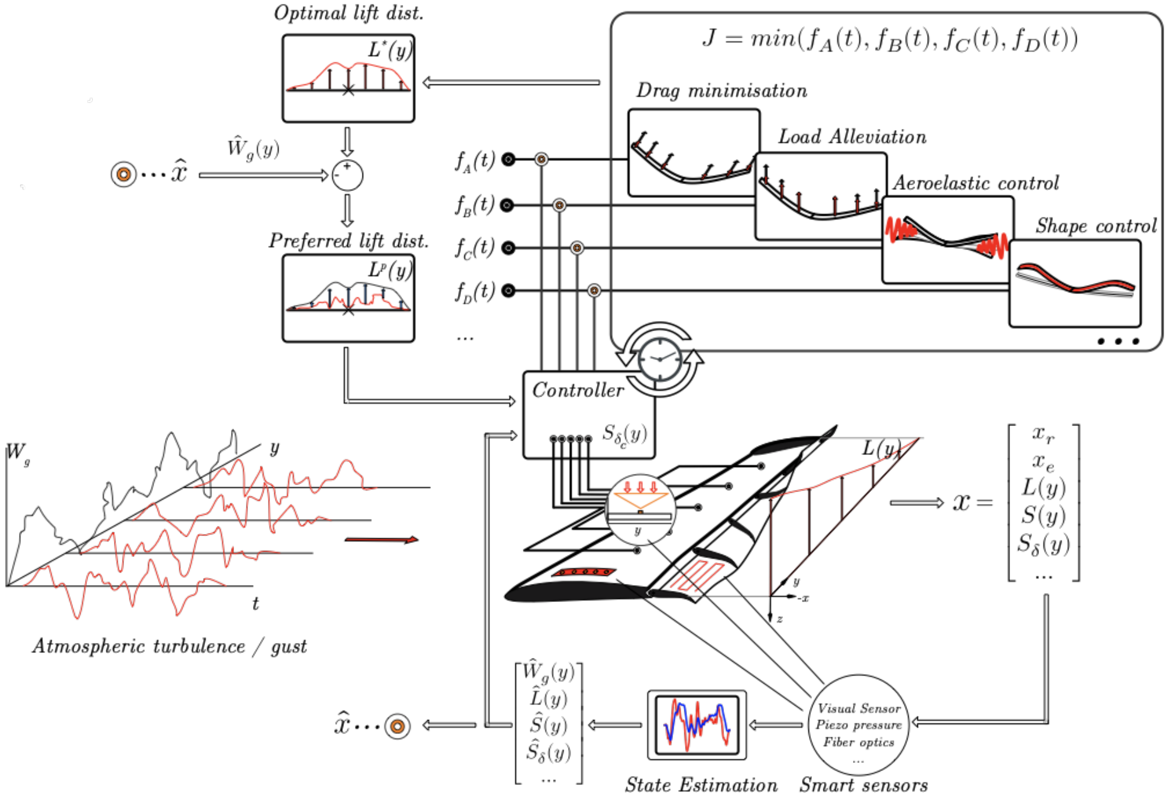


Smart-X rationale

Real-time multi-objective performance optimisation

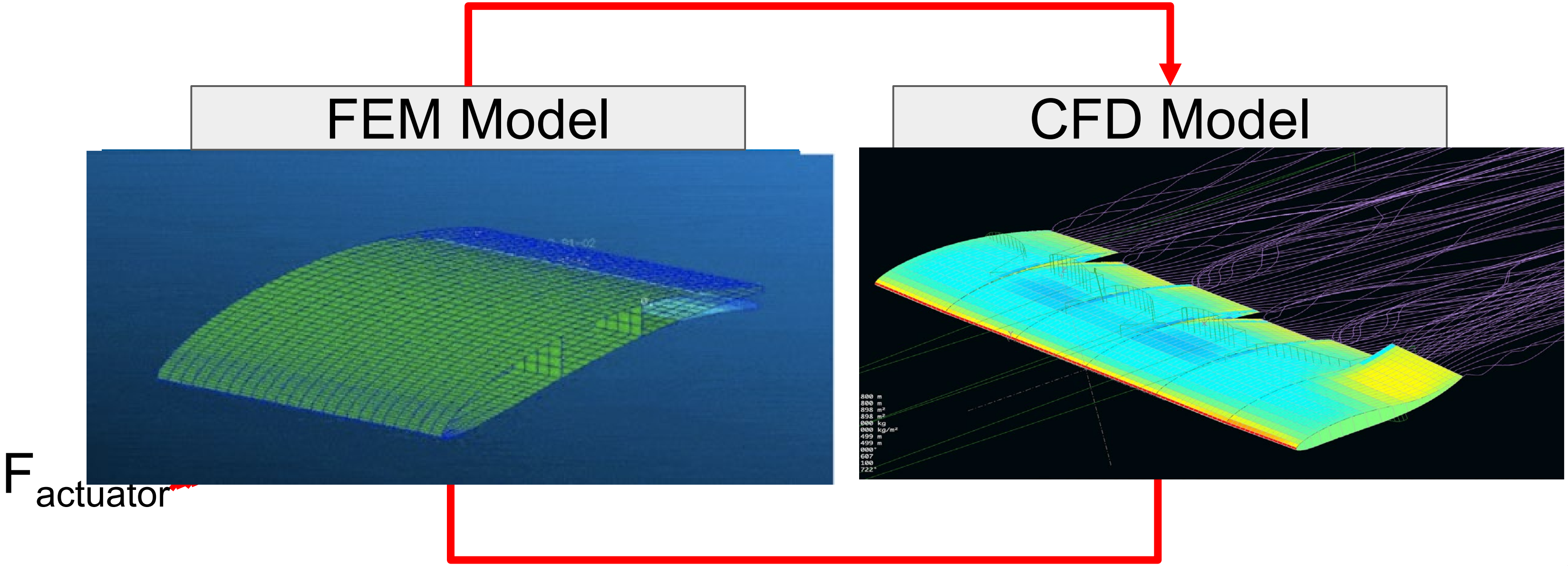


Real-time multi-objective performance optimisation

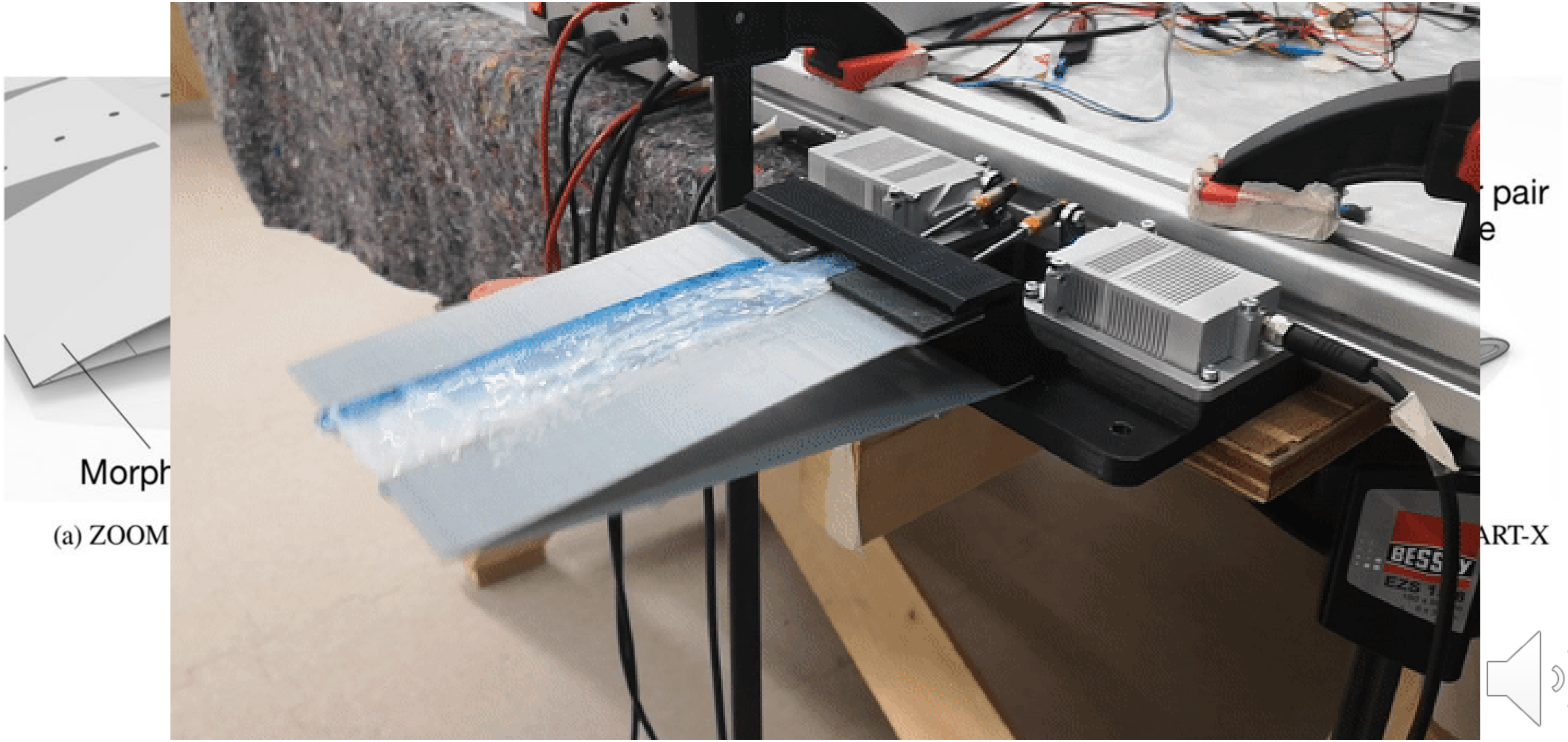


Morphing Design

FSI FRAMEWORK

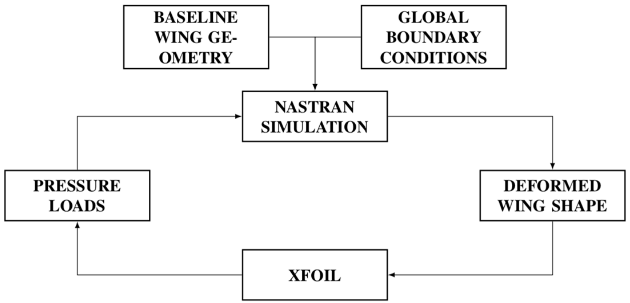


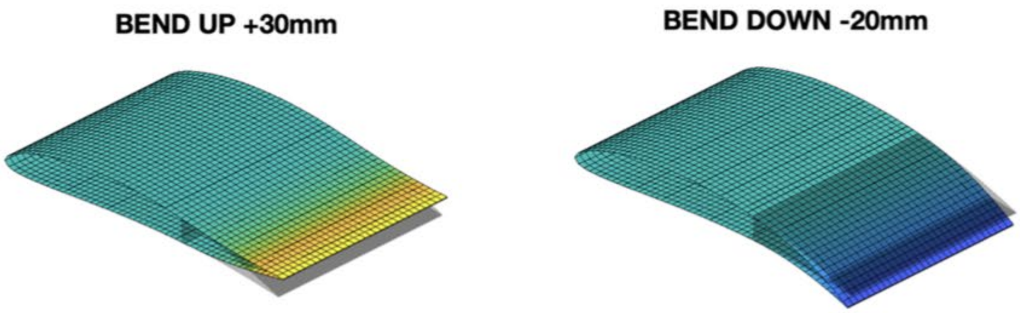
Distributed TRIC concept with spanwise continuity

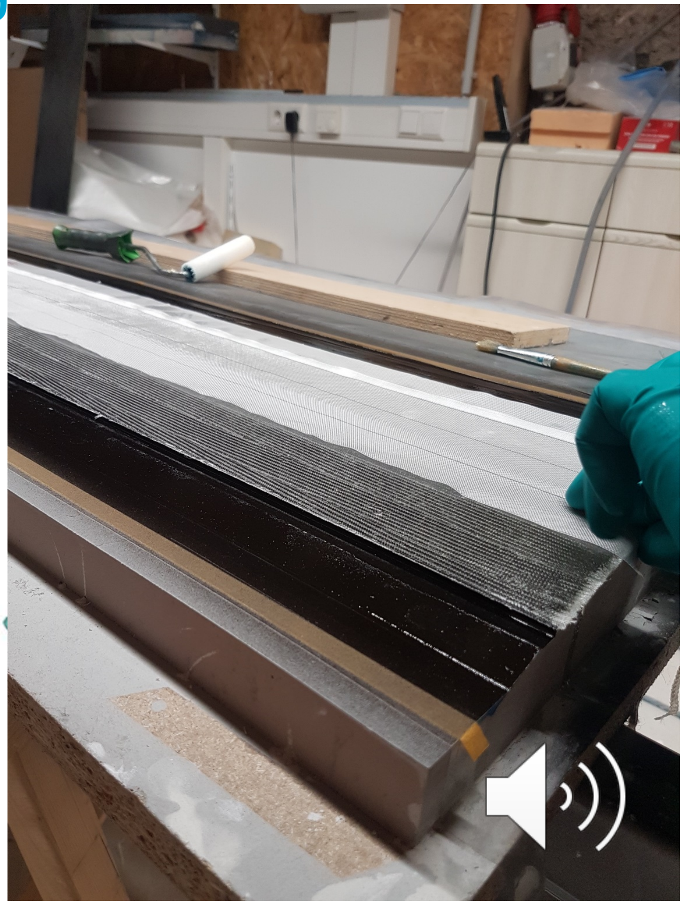


(a) ZOOM ... ART-X

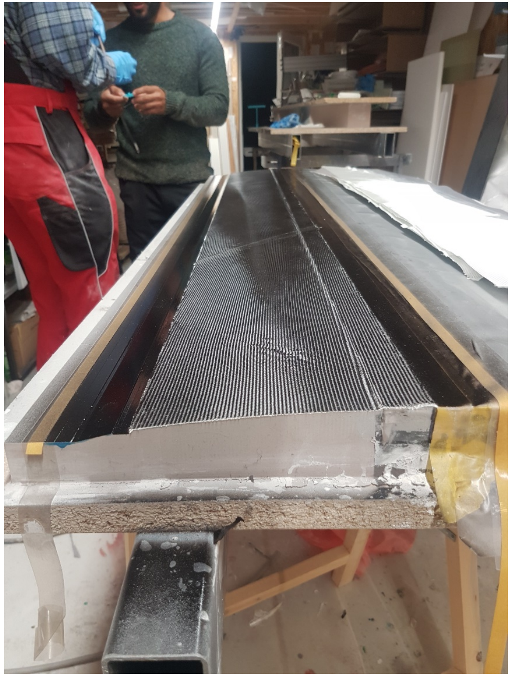
Laminate design with ply dropping







Manufacturing process



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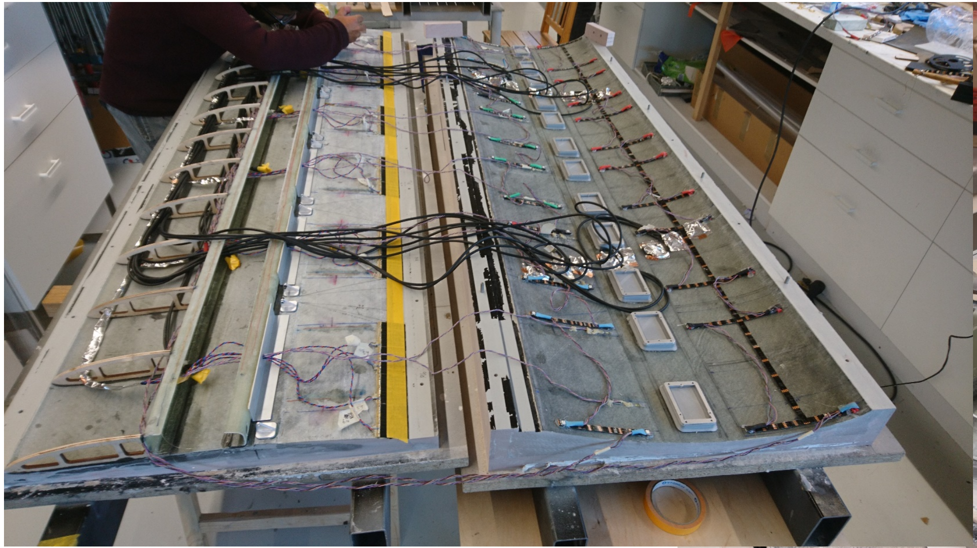
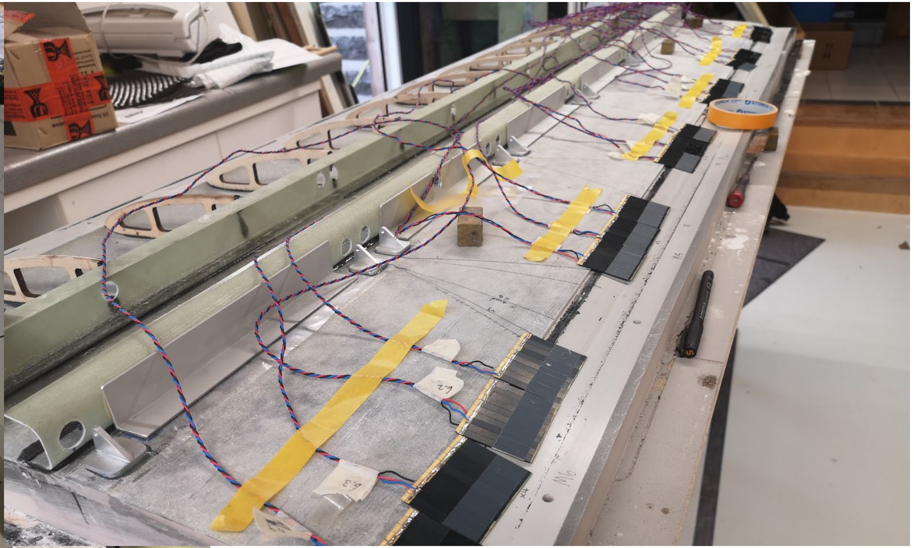
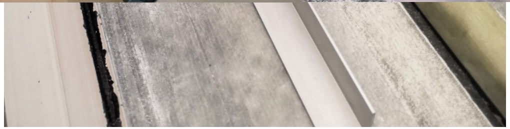
Manufacturing process



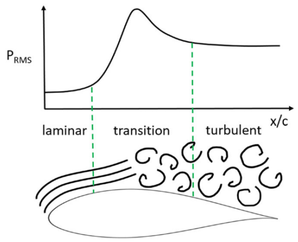




Piezoelectric Stall Sensor and Actuator

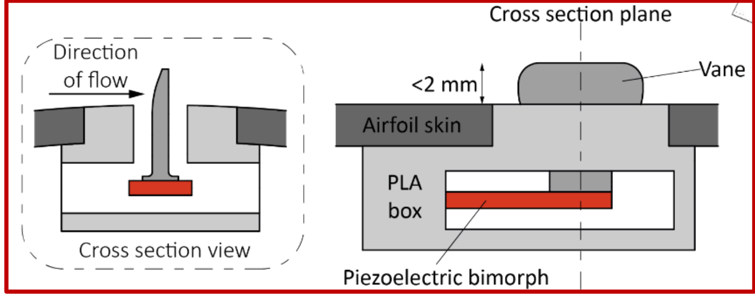
Piezoelectric Flow Sensors

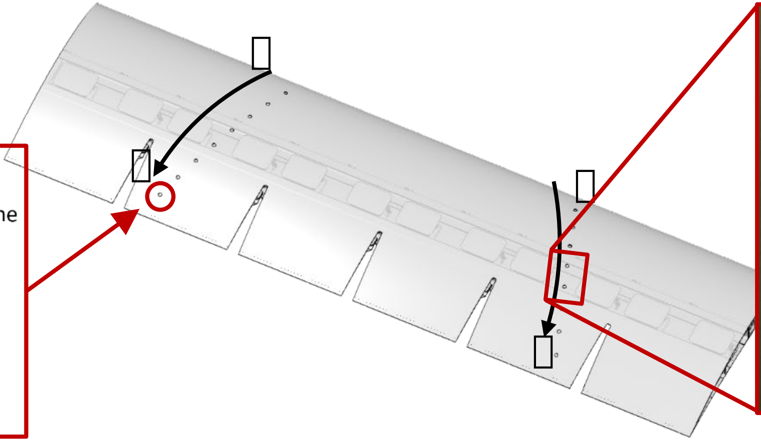
Sensors directly measure oscillations in the boundary layer



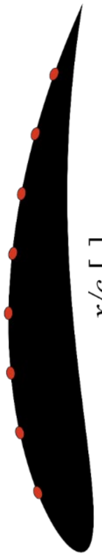
Özçakmak

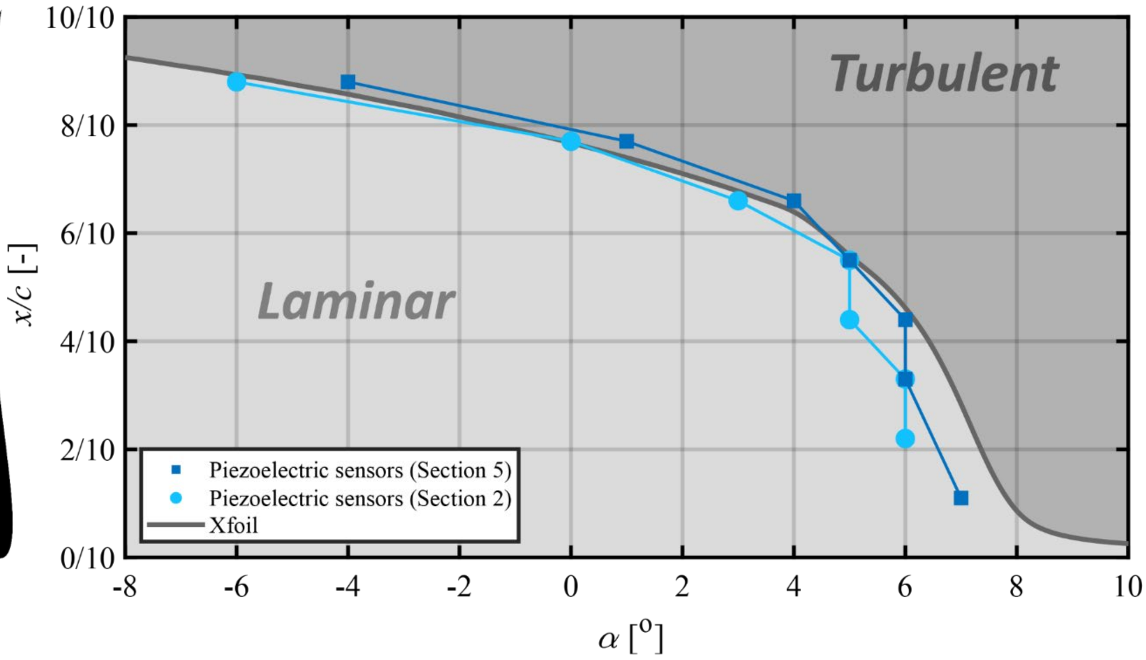
FIGURE 7 Chordwise pressure fluctuation changes during laminar to turbulent boundary layer transition [Colour figure can be viewed at wileyonlinelibrary.com]

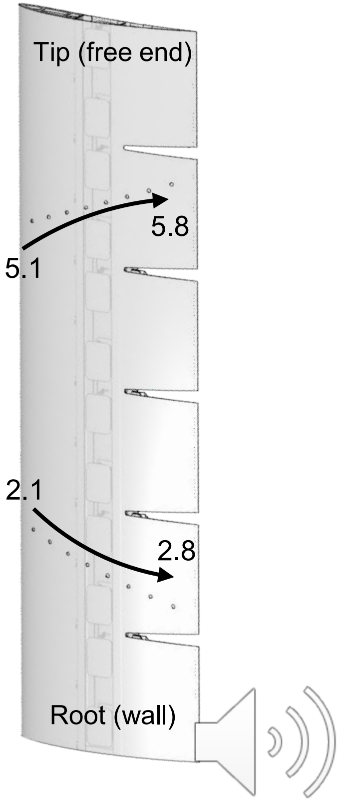




Locating Transition (not-morphing)







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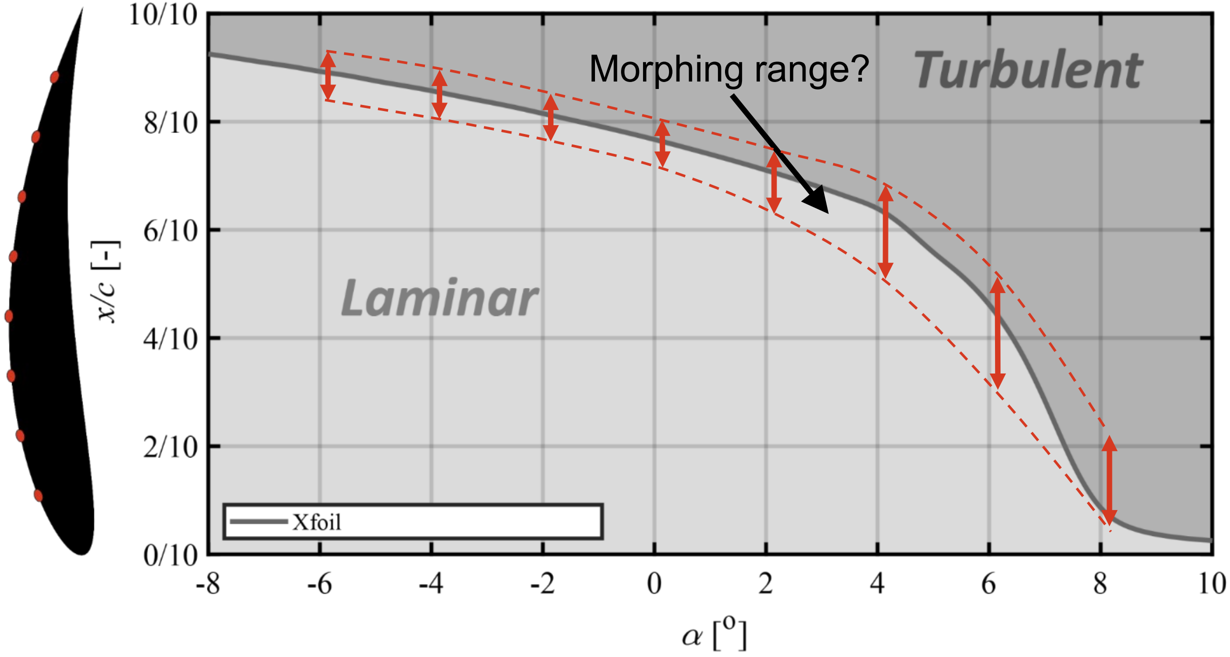
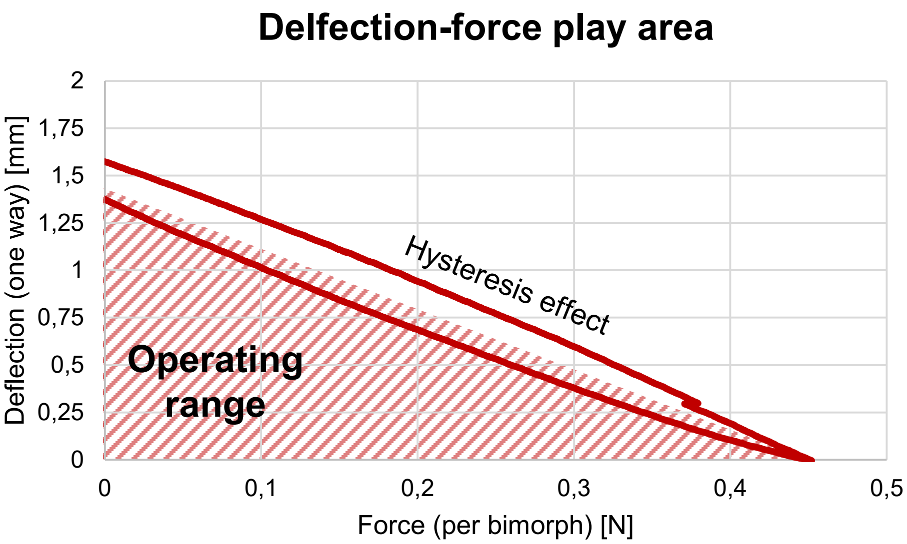
Locating Transition (morphing?)

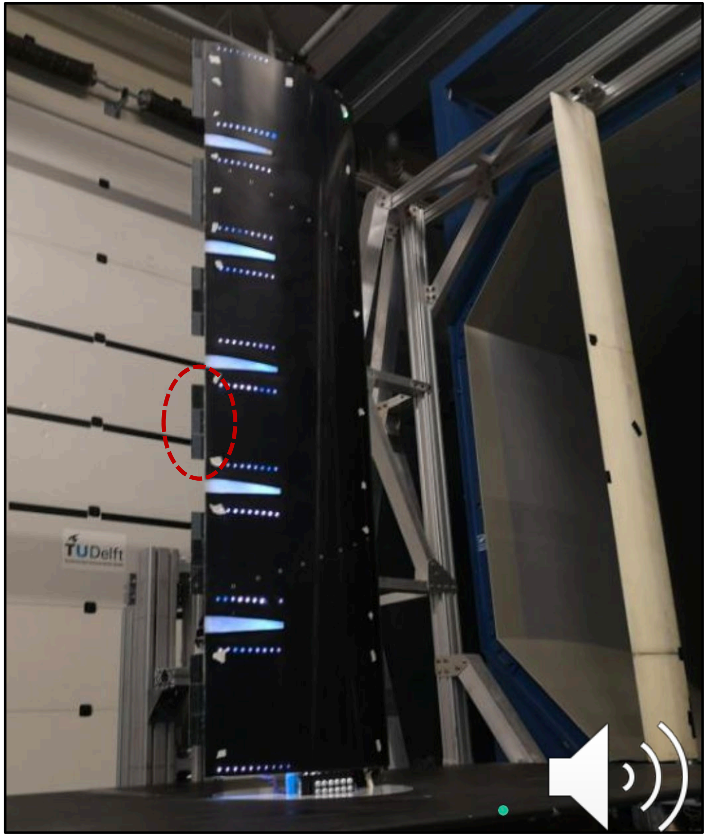
How will morphing affect the location of transition?



Piezoelectric Actuators

- Little space required
- Fast response (capped at 25 Hz)
- Small deflections (couple of mm)





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Fibre optics
Shape sensing

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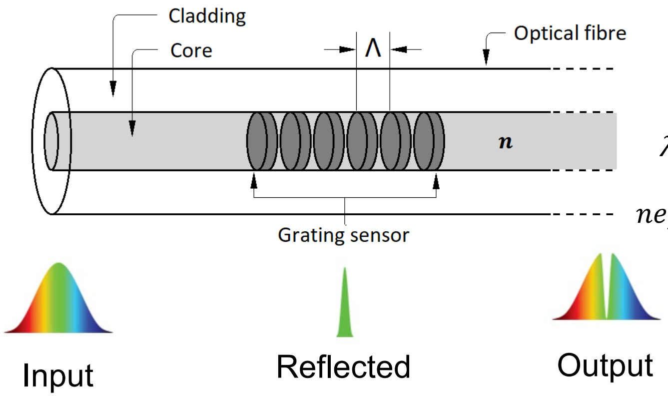
Methodology

Bragg grating (FBG)

$$\lambda_B = 2n_{eff}\Lambda$$



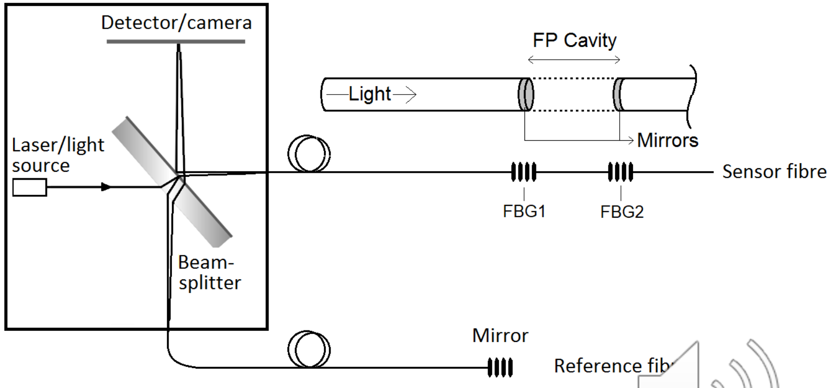
Λ: Periodic spacing

λB: Grating wavelength

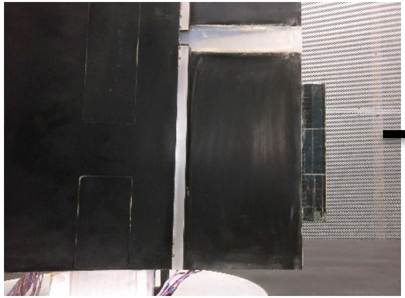
$neff$: Core refractive index

Fabry-Pérot (FP)

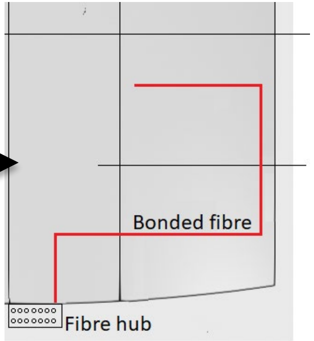
$$\Delta\varepsilon = \frac{\Delta\lambda_{BS}}{(1-\rho_a)\lambda_B} \qquad \varepsilon = \frac{\Delta d}{L}$$



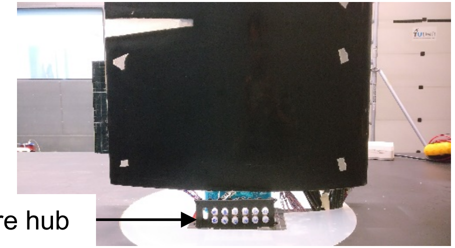
Setup



Lower-surface

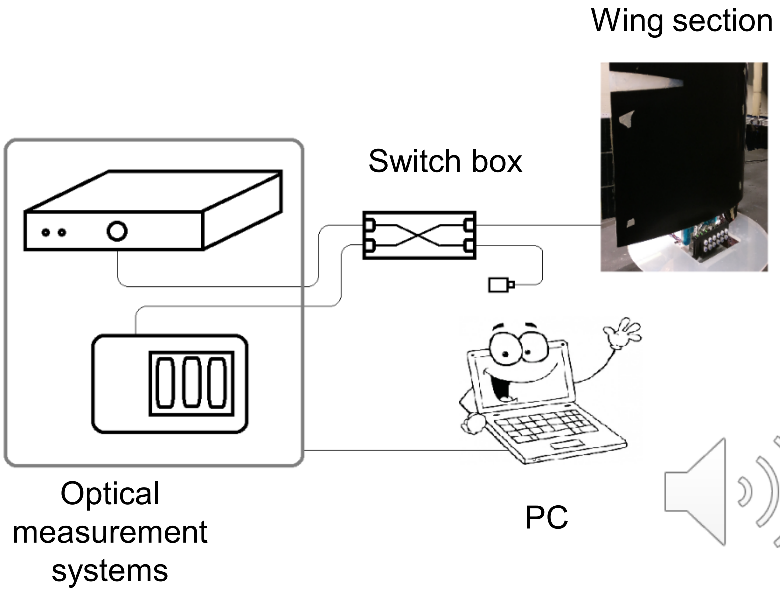


Fibre hub



Upper-surface

14 sensing fibres
2 fibres per morphing section
2 fibres in spanwise direction



Deflection estimation

Measured vs estimated values in mm for bend up, bend down and twist configuration *

Bend up

Measured	Estimated
2	2,1
6	1,93
9	8,48

Bend down

Measured	Estimated
5	3,16
10	11,58
15	13,31

Twist - right tip

Measured	Estimated
2	0.66
4	5.18
6	5,98

Twist - left tip

Measured	Estimated
2	1.25
4	4.65
6	5.97

- Average error of 1.3 mm for bend up & down with a maximum error of -4 mm
- Average error of -0.05 mm for twist with a maximum error of -1.34 mm

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* *'Multi-modal fibre optic shape sensing for the SmartX morphing wing demonstrator'*
- Nakash Nazeer, ASME 2020 SMASIS

Morphing Control and Real-time Visual Tracking

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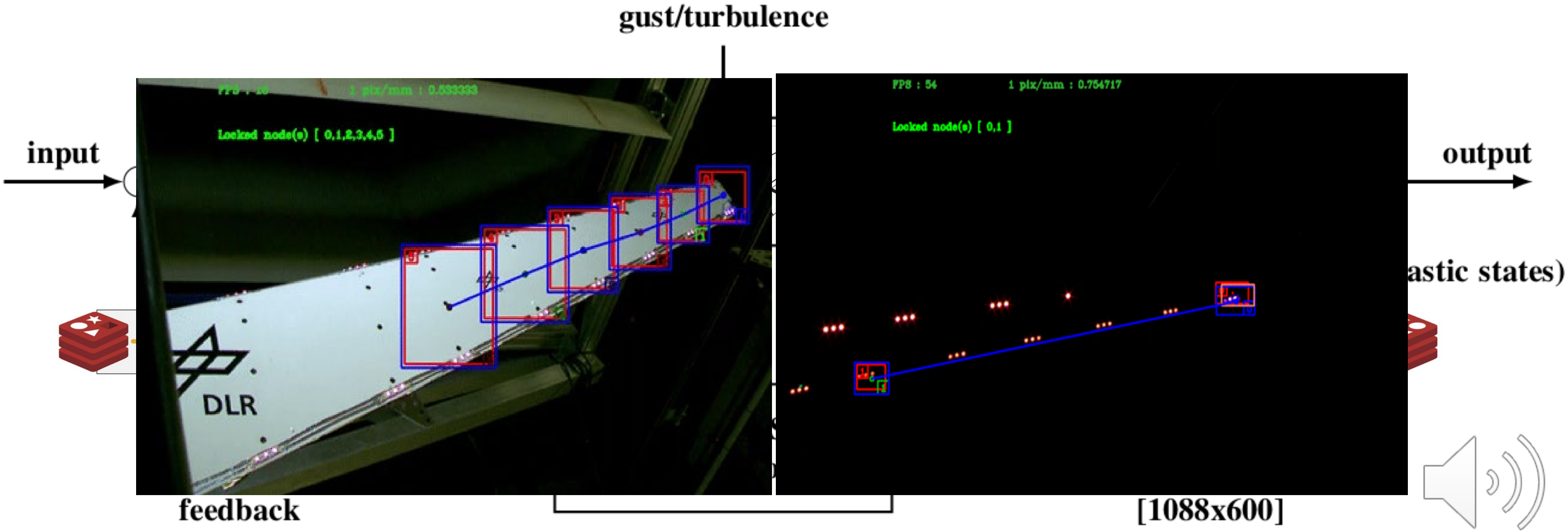
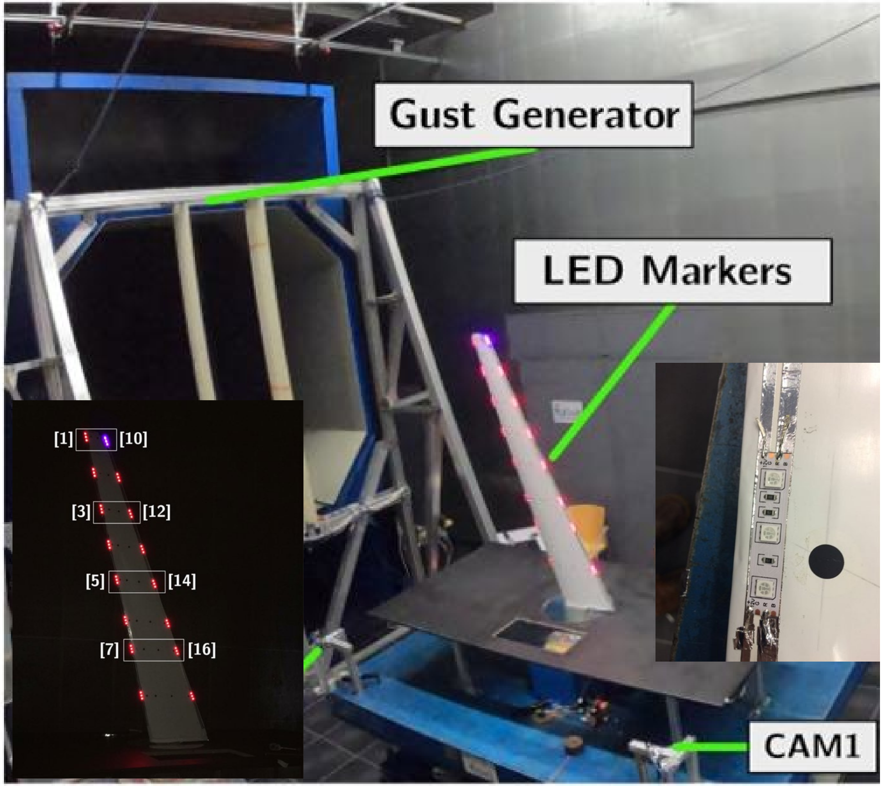
Visual tracking for control feedback

- Novel tracking methods (KCF-AEKF)
- Unsupervised clustering methods



Visual tracking for control feedback



Control Methods

Linear quadratic Gaussian (LQG) control

- Classical Model-based control
- Requires Kaman filter for state observation

Incremental control

- Novel sensor-based control
- Replaces a part of model information by senso
- Enhanced robustness against model uncertain disturbances

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Gust Load Alleviation

Gust generator

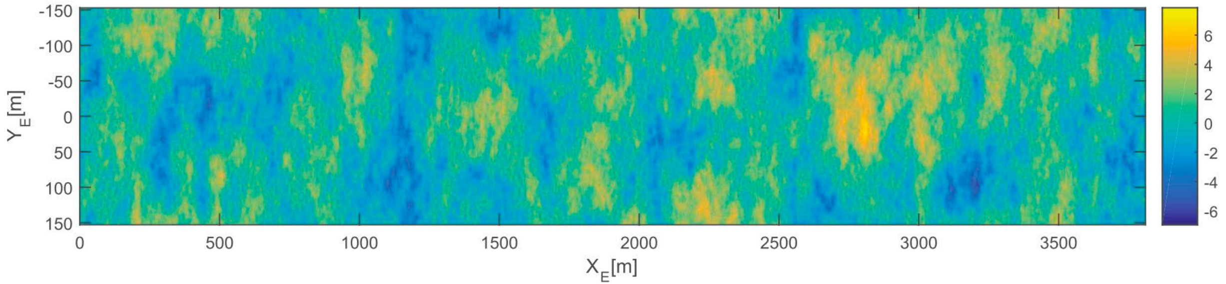

Figure 1. 2D von Kármán vertical turbulence field with $L_g = 762m, \sigma = 3m/s$.

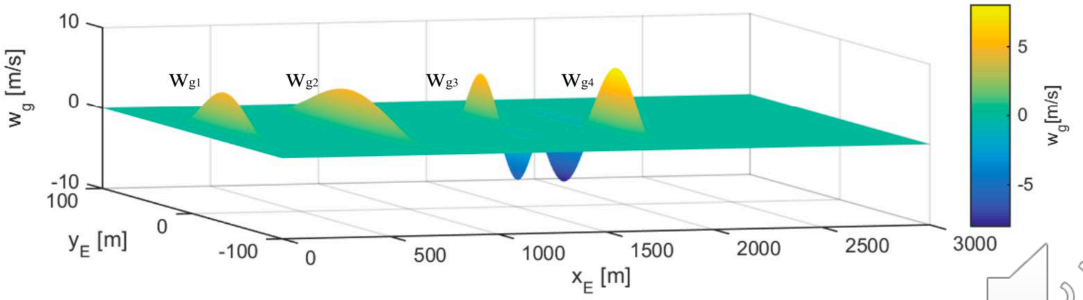

Figure 2. 2D "1-cos" vertical gust field.

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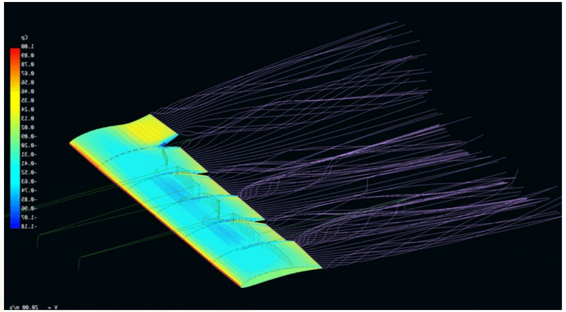
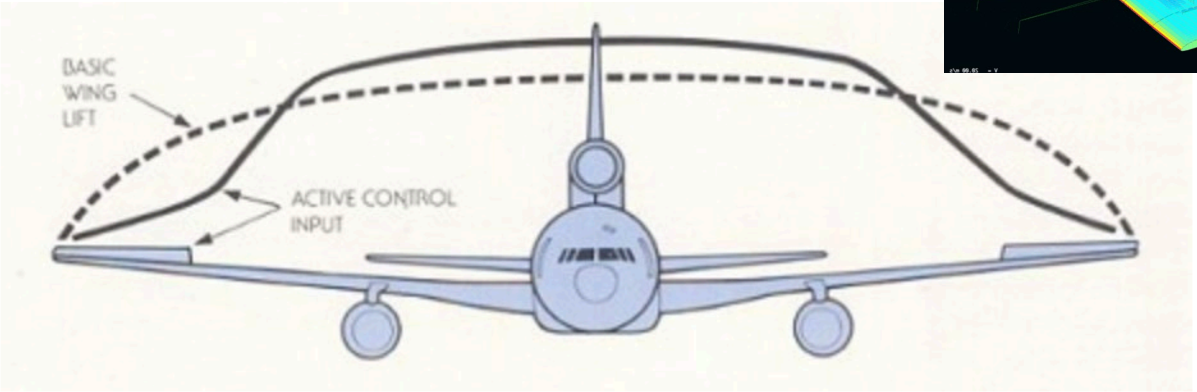
Maneuver Load Alleviation





Use distributed morphing modules to redistribute the lift in spanwise direction

Alleviate the loads during maneuvers

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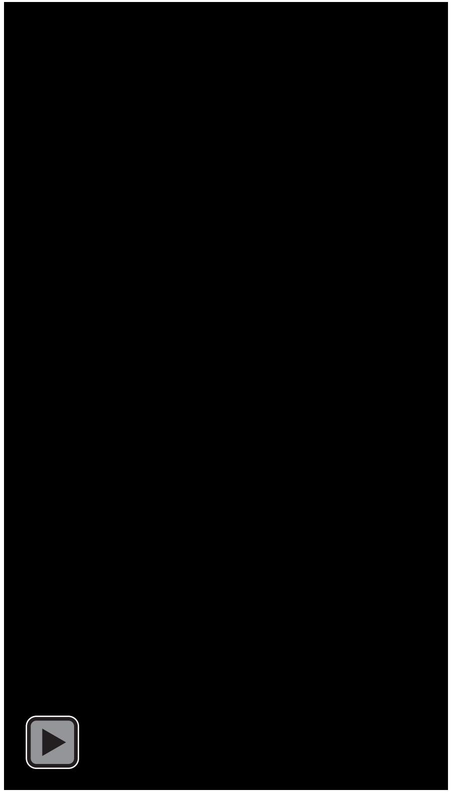
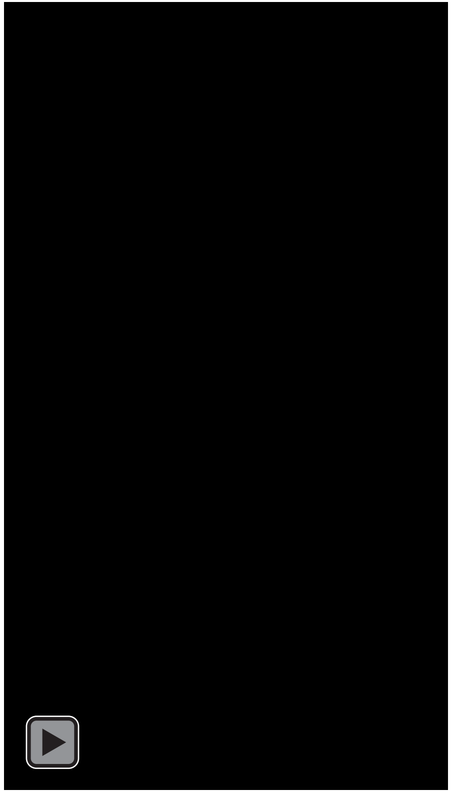
Conclusions

- Active morphing design with multidisciplinary state-of-the art technology development
- Morphing design is challenging in terms of design and manufacturing
- Piezo electric materials are suitable for novel sensor and actuator designs
- Fiber optic sensing methods for novel morphing structures
- Control and real-time feedback of morphing deflections is needed for morphing control

Future Work

Smart-X adaptive morphing control





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THANK YOU

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