

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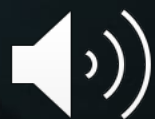
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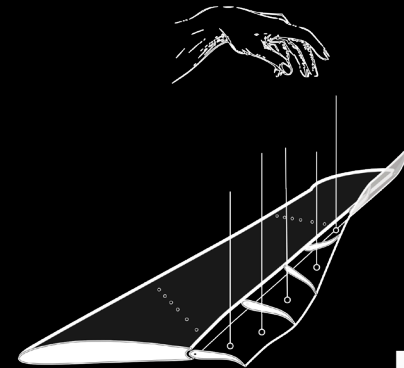
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# Integration of Active Morphing Technology With Smart Morphing Wing Concept for Simultaneous In-Flight Performance Optimisation, Load Alleviation and Flight Dynamic Control

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



# Aeroelastic Structures



# Introduction

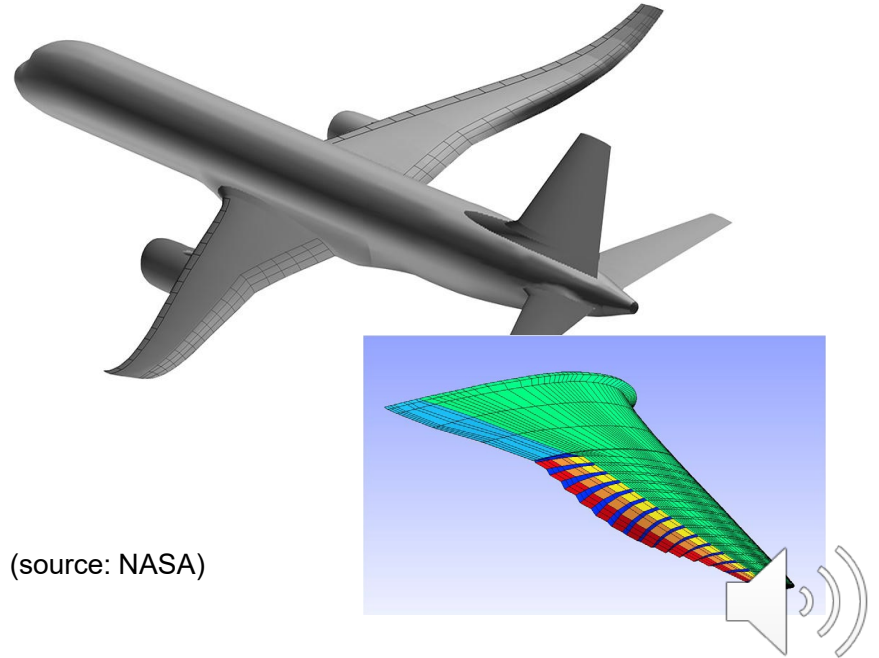
Trend towards flexible configurations:

**Adaptive Compliant Trailing Edge**



(source: NASA)

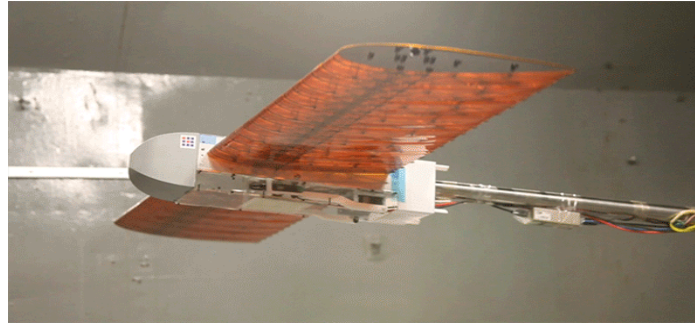
**Variable camber continuous trailing edge flap flap**



(source: NASA)

# Applications: slender flexible (morphing) aircraft

**Cellular morphing wing**



(source: NASA/MIT)

**HALE solar power aircraft**



(source: NASA)

**Facebook drone aquila**



(source: Facebook)

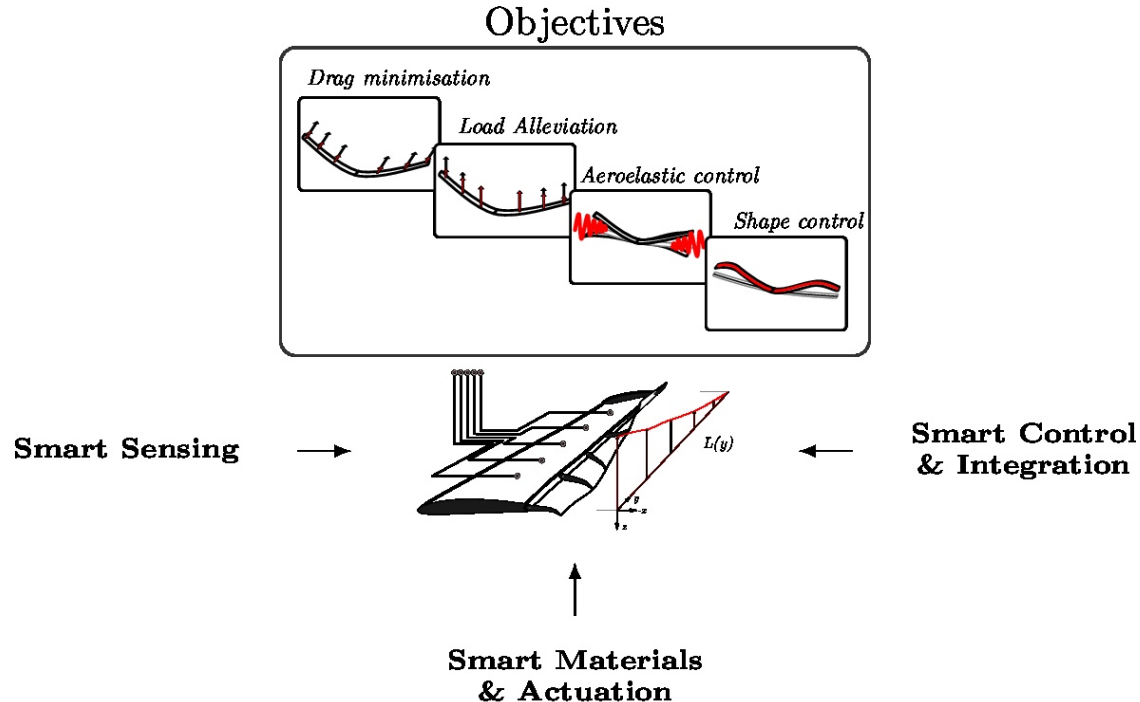


# SmartX : SmartX-Alpha



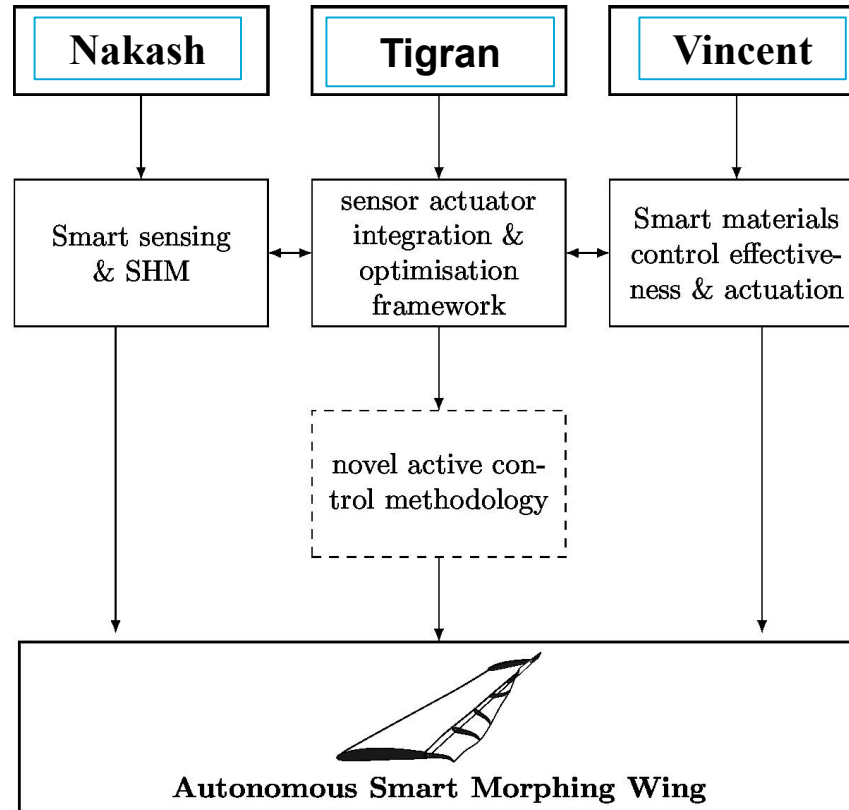
# Goal: the Smart Morphing Wing

*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?*



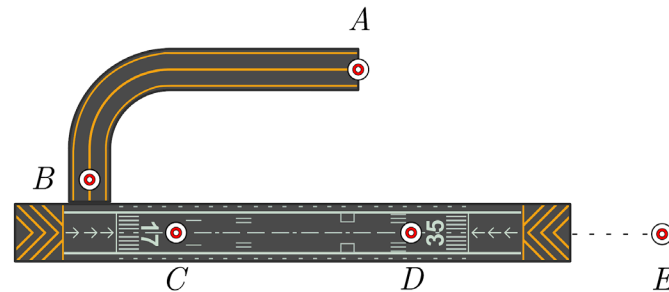
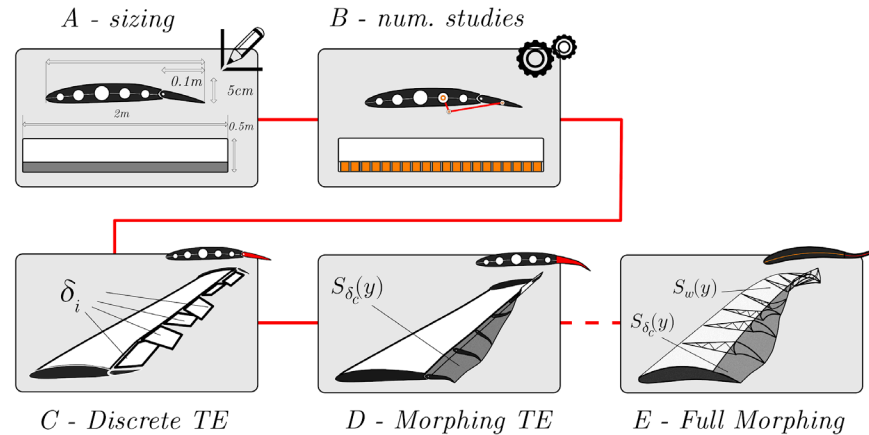


# Smart-X: multidisciplinary collaboration

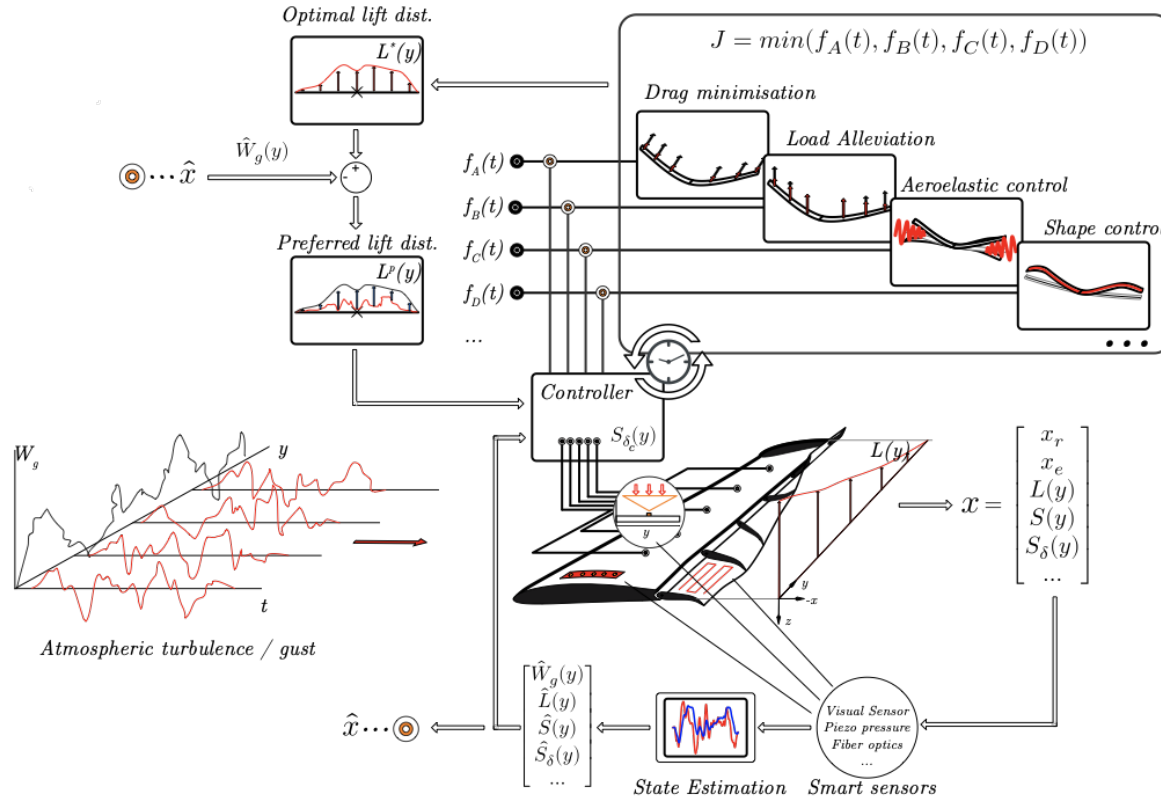


# Smart-X rationale

## Real-time multi-objective performance optimisation



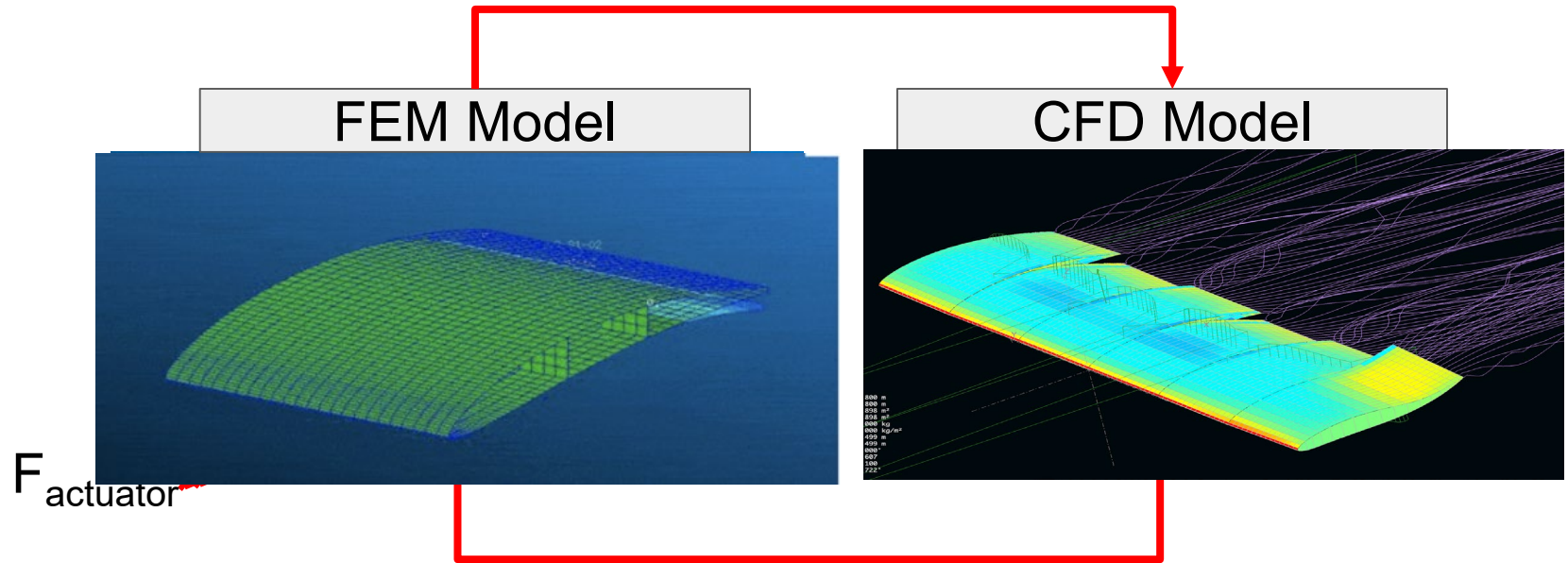
# Real-time multi-objective performance optimisation



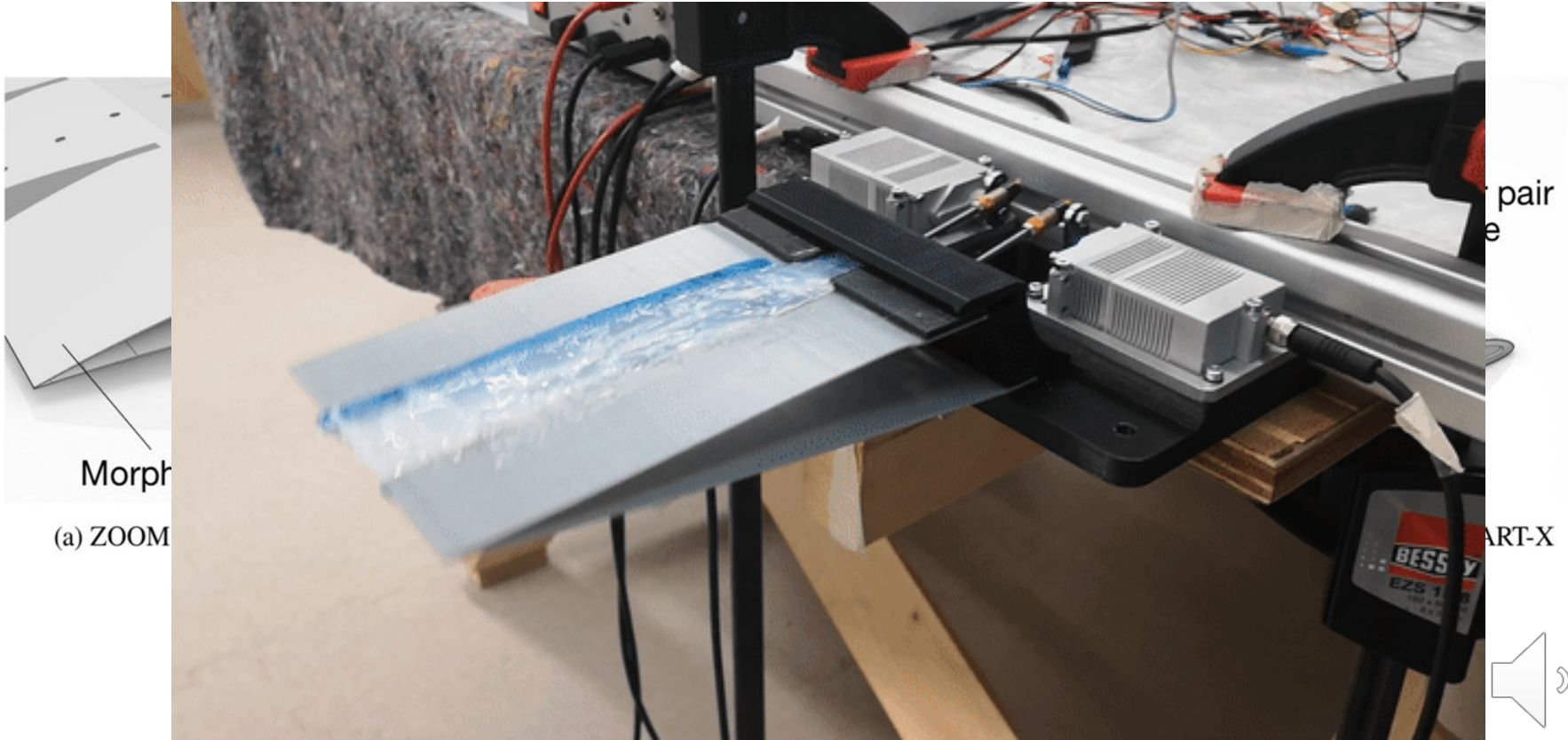
# Morphing Design



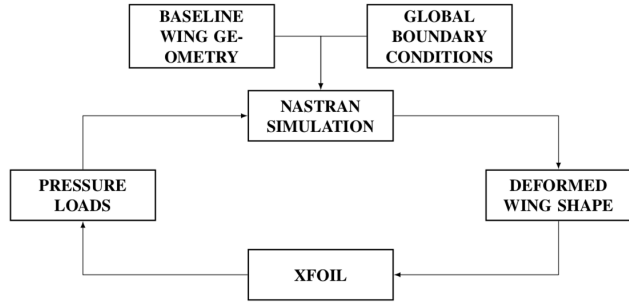
# FSI FRAMEWORK



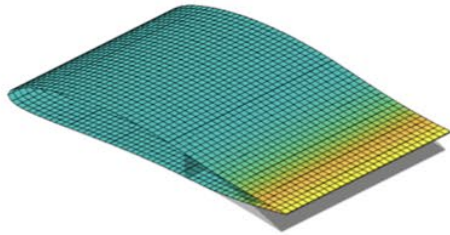
# Distributed TRIC concept with spanwise continuity



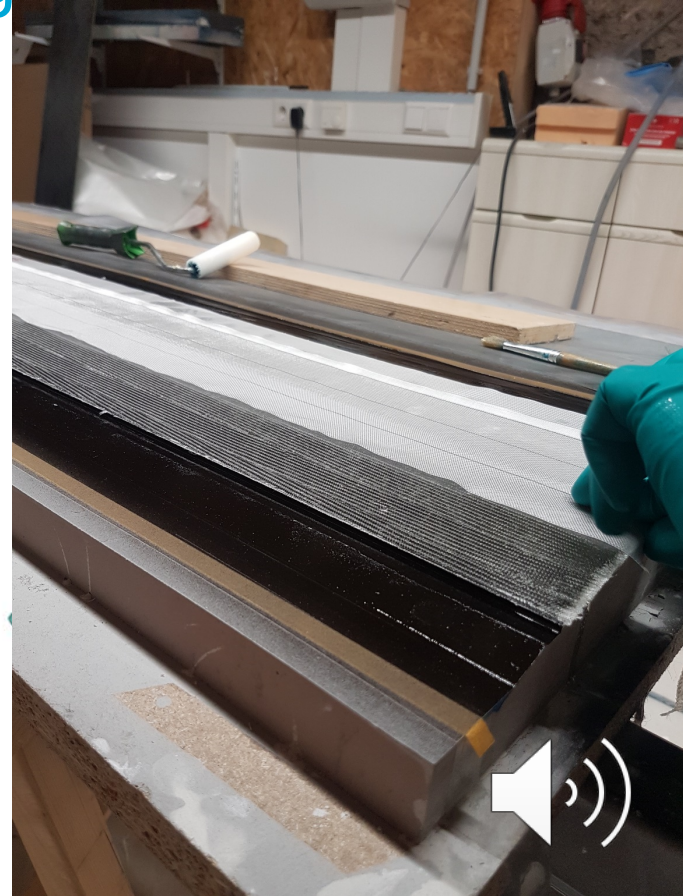
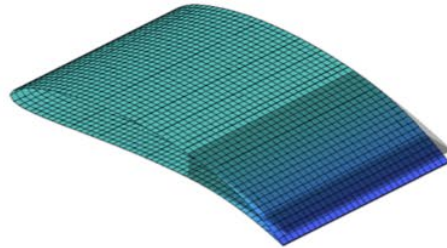
# Laminate design with ply dropping



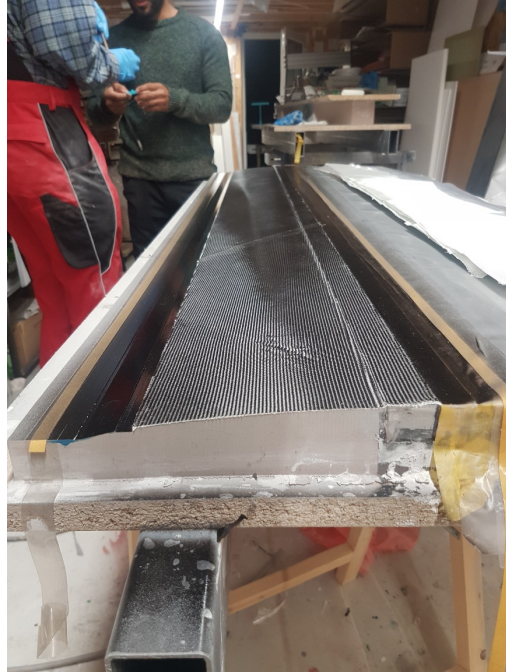
**BEND UP +30mm**



**BEND DOWN -20mm**

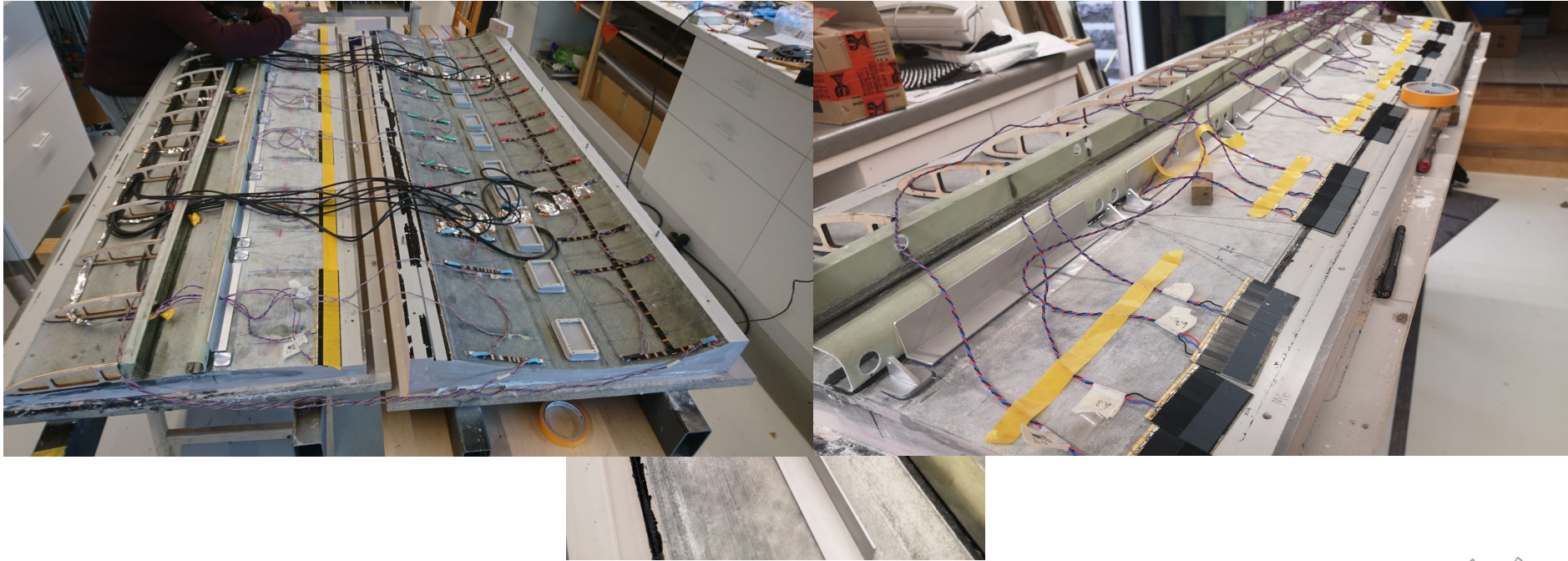


# Manufacturing process





# Manufacturing process

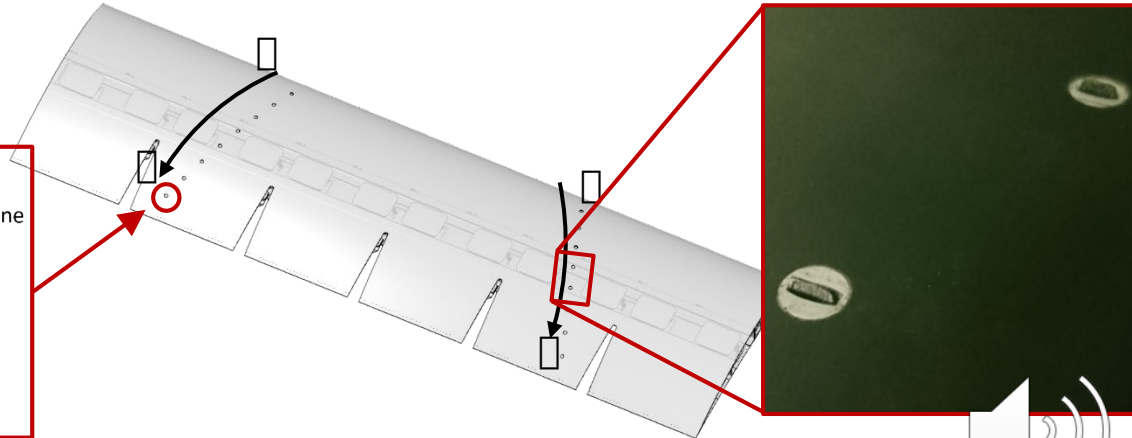
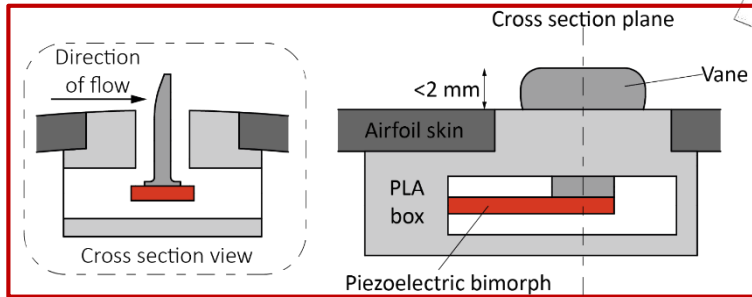
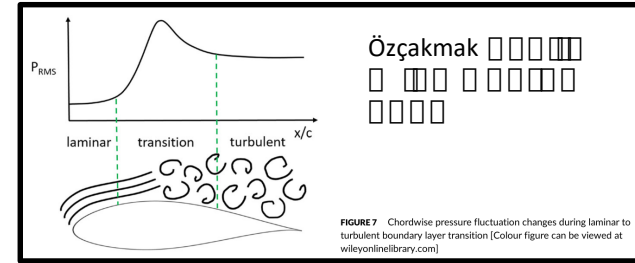


# Piezoelectric Stall Sensor and Actuator

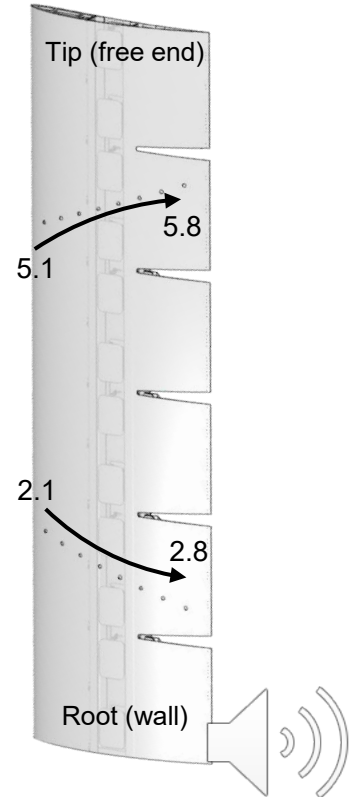
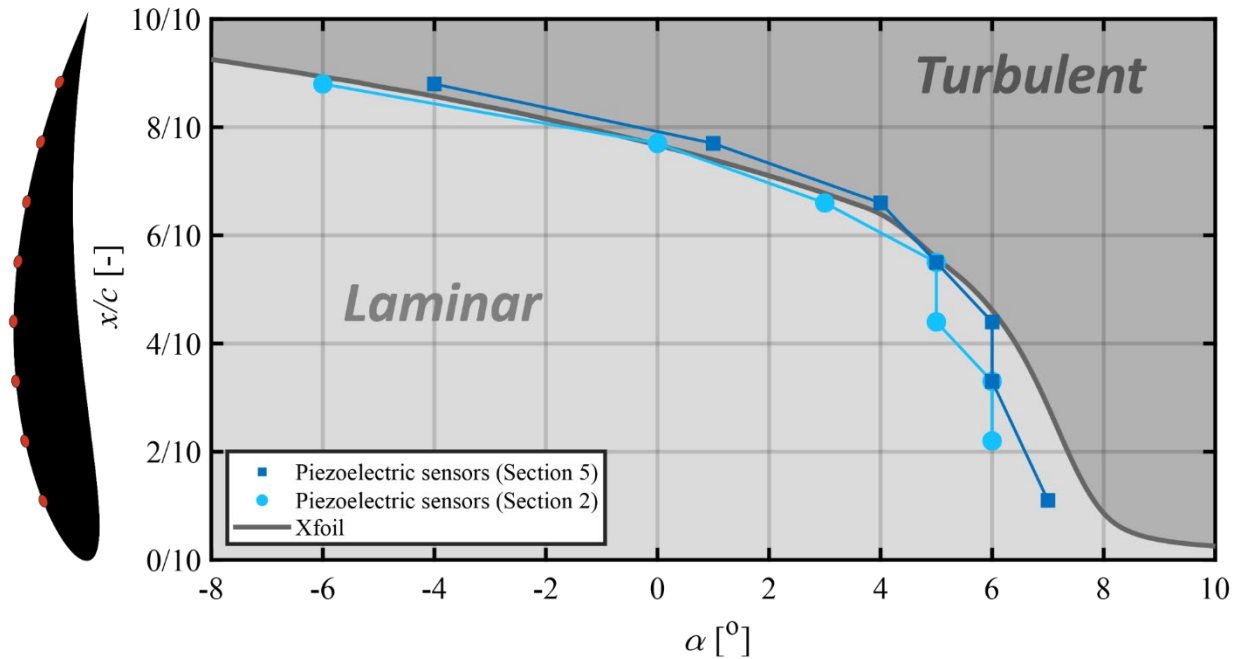


# Piezoelectric Flow Sensors

Sensors directly measure oscillations in the boundary layer

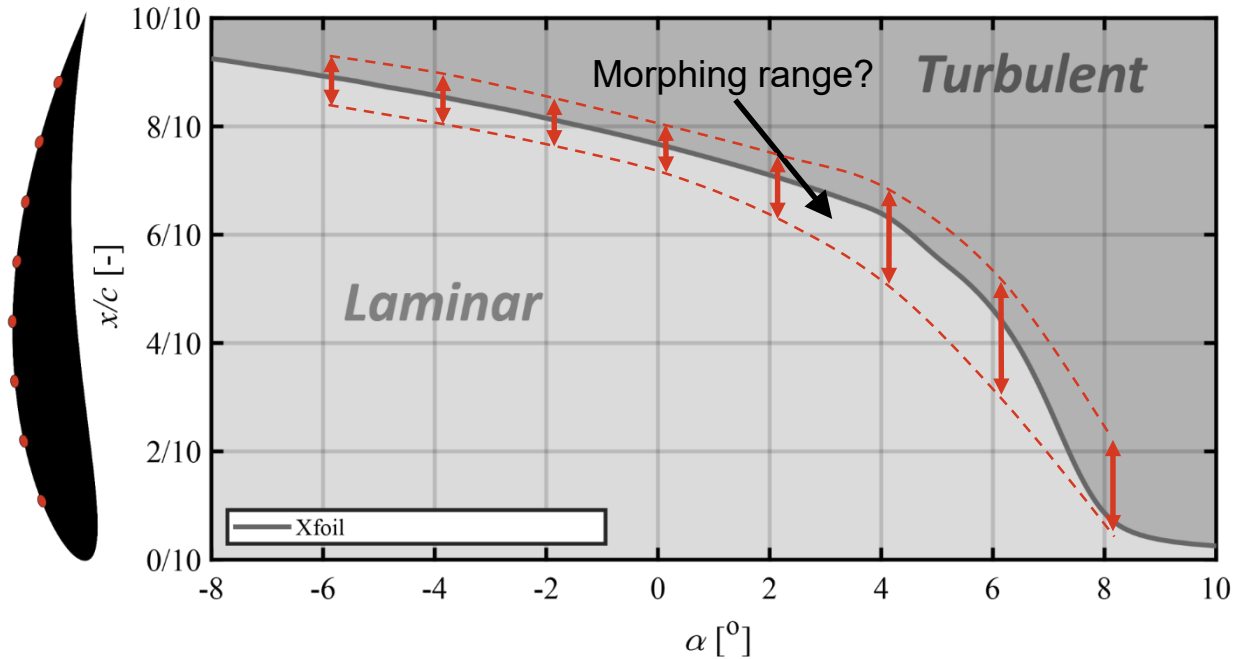


# Locating Transition (not-morphing)



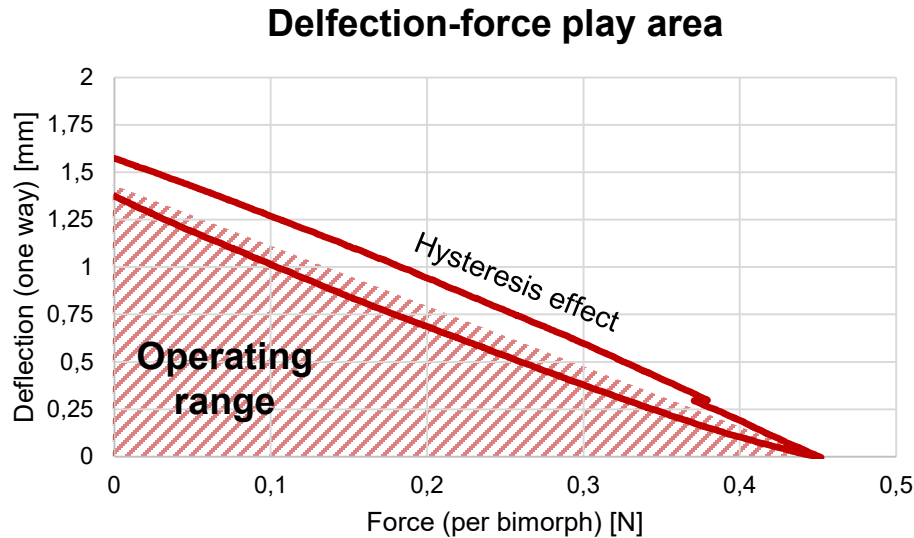
# Locating Transition (morphing?)

How will morphing affect the location of transition?



# Piezoelectric Actuators

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



# Fibre optics

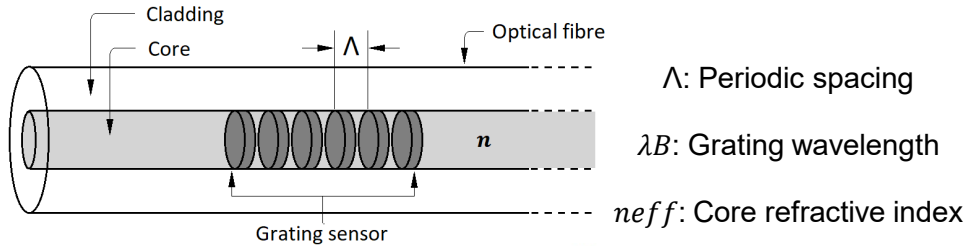
## Shape sensing



# Methodology

## Bragg grating (FBG)

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



$\Lambda$ : Periodic spacing

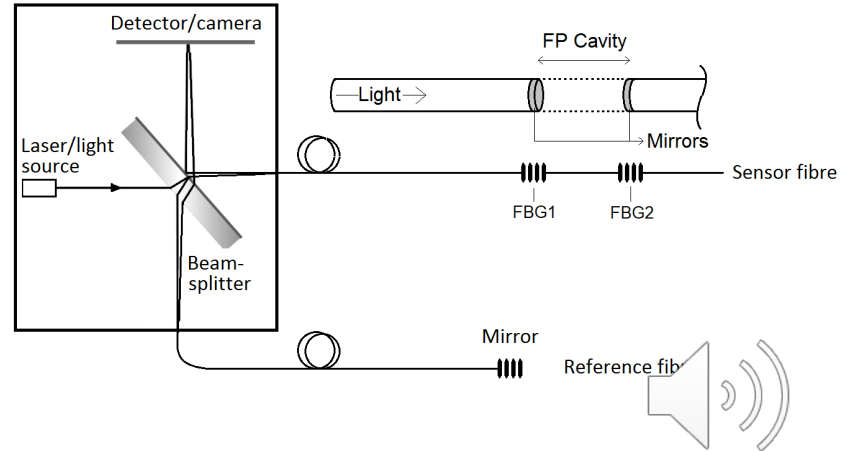
$\lambda_B$ : Grating wavelength

$n_{eff}$ : Core refractive index



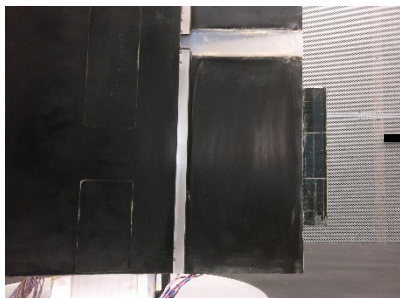
## Fabry-Pérot (FP)

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

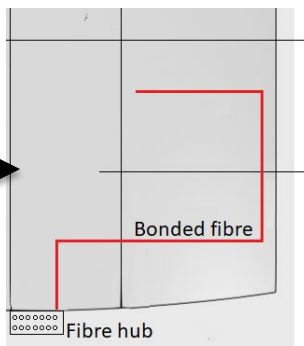




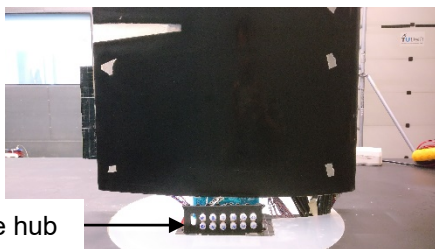
# Setup



Lower-surface

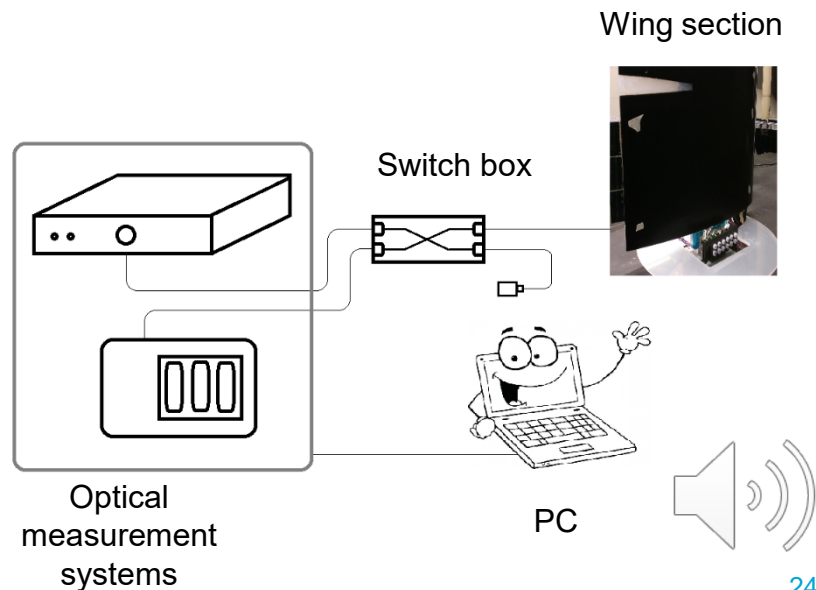


14 sensing fibres  
2 fibres per morphing section  
2 fibres in spanwise direction



Upper-surface

Fibre hub



# 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

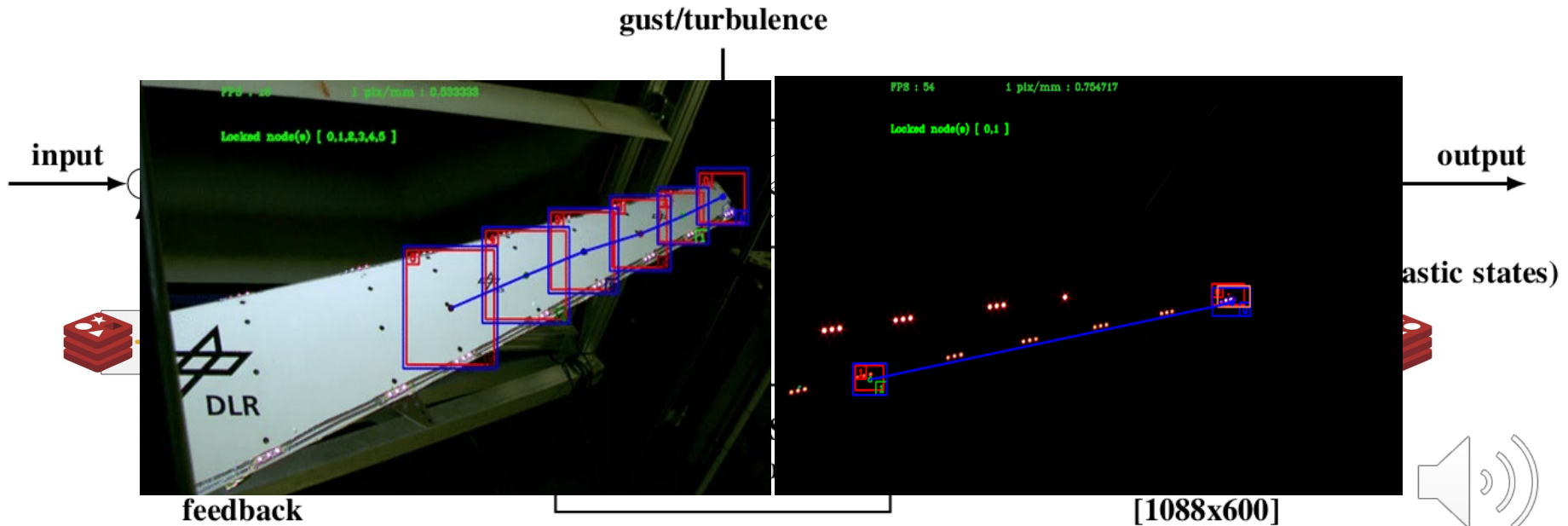


# Morphing Control and Real-time Visual Tracking

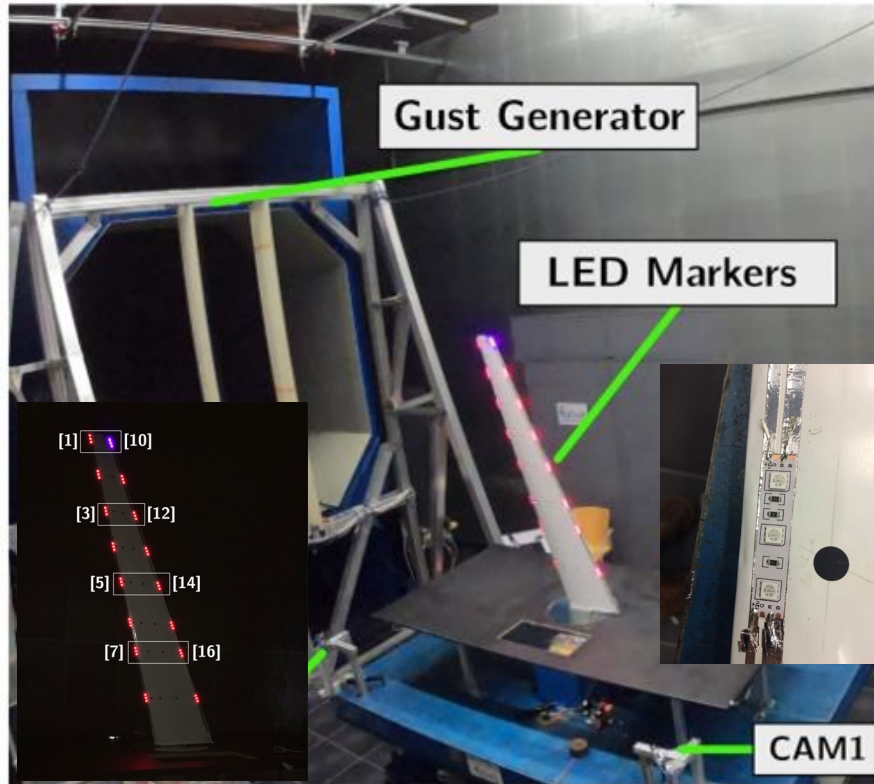


# Visual tracking for control feedback

- 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 sensor
- Enhanced robustness against model uncertainty and disturbances





# Gust Load Alleviation



Gust generator

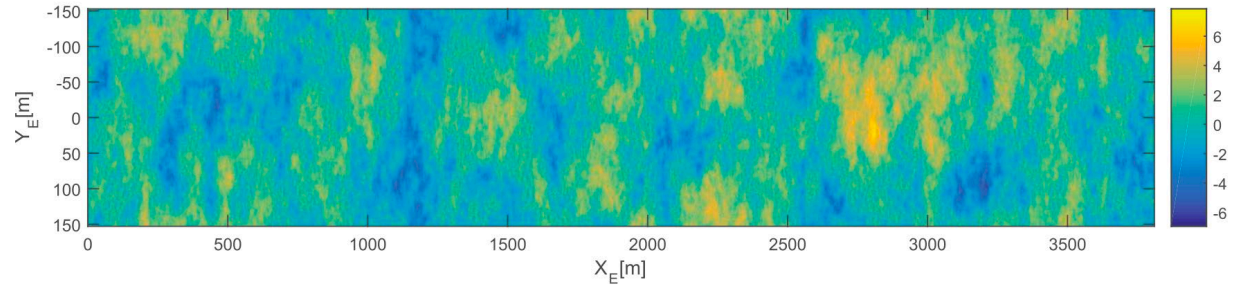


Figure 1. 2D von Kármán vertical turbulence field with  $L_g = 762\text{m}$ ,  $\sigma = 3\text{m/s}$ .

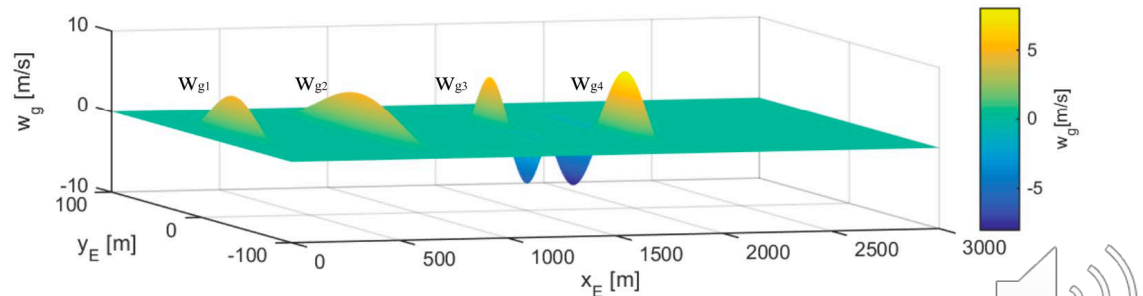
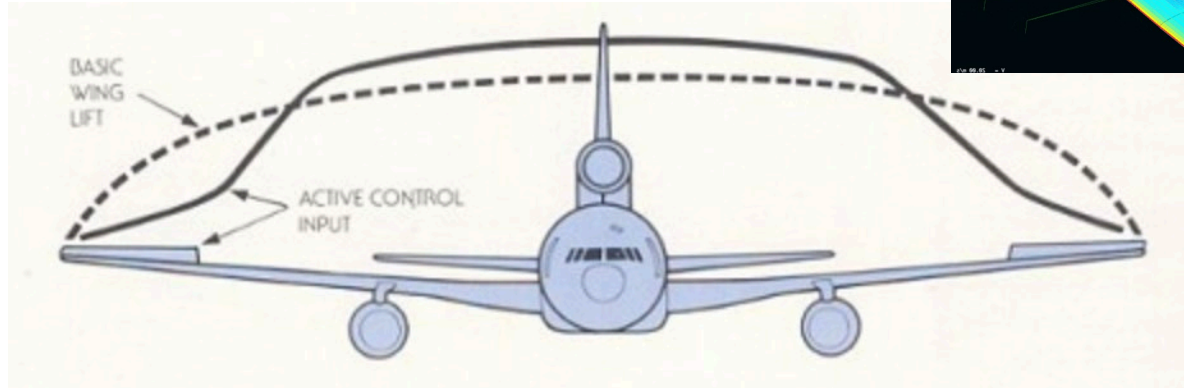
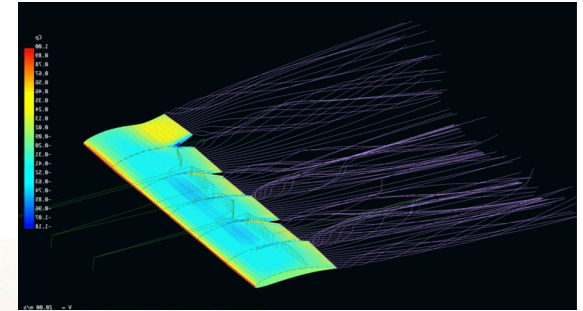


Figure 2. 2D "1-cos" vertical gust field.



# Maneuver Load Alleviation



Use distributed morphing modules to redistribute the lift in spanwise direction  
Alleviate the loads during maneuvers



# Conclusions

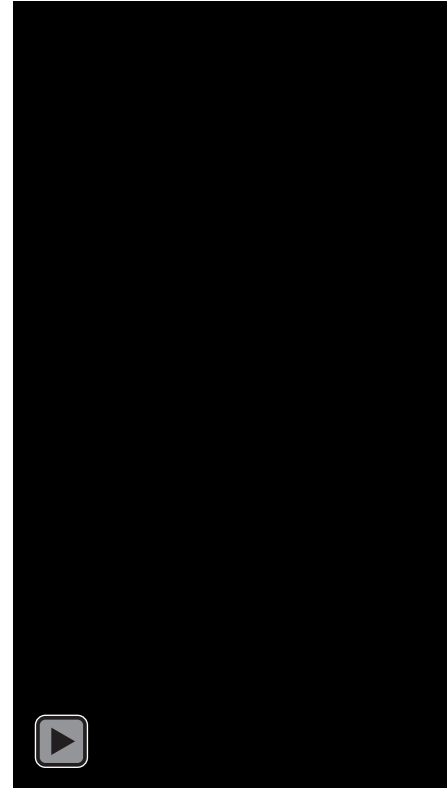
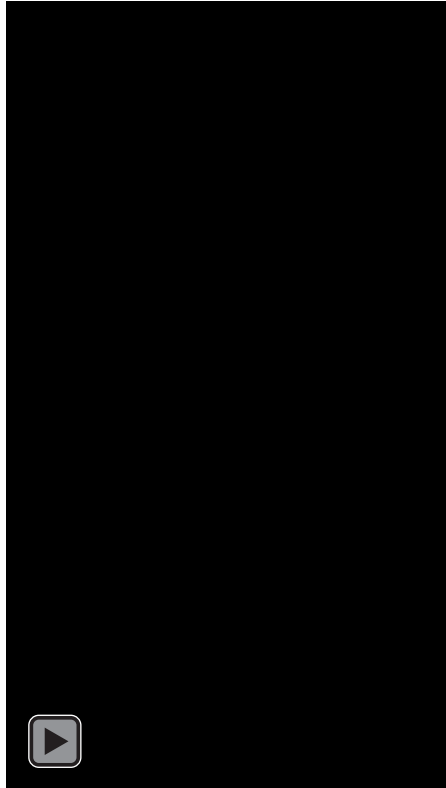
- Active morphing design with multidisciplinary state-of-the art technology development
- Morphing design is challenging in terms of design and manufacturing
- Piezo electric materials are suitable for novel sensor and actuator designs
- Fiber optic sensing methods for novel morphing structures
- Control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



# Future Work



# Smart-X adaptive morphing control



THANK YOU

