A Variable Stiffness Skin for Morphing High-lift Devices

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08/10/2010

Outline

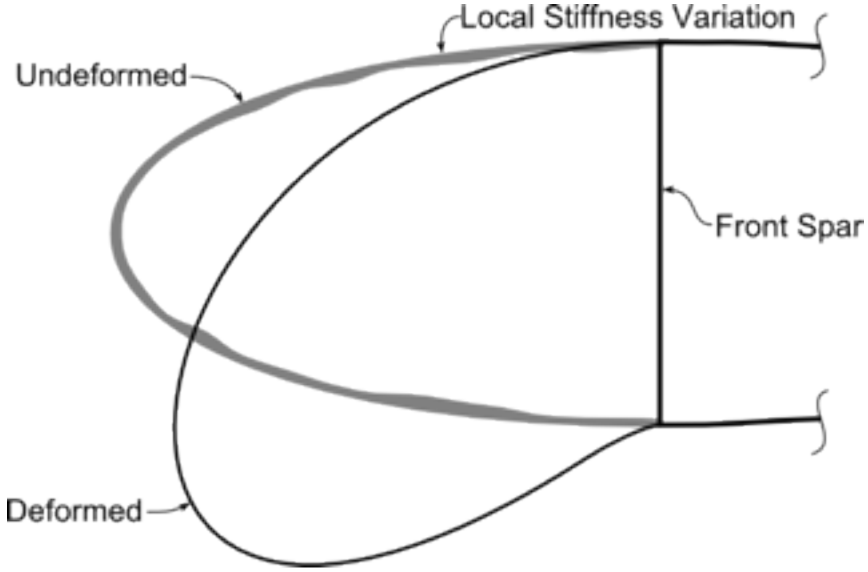
- Introduction: Skin Concept
- Aero-servo-elastic Framework
- Skin Stiffness Results
- Initial Actuation Topology Results
- Test Results
- Conclusions

Introduction: Skin Concept

Variable Stiffness Composites

Goal

- Design a composite skin having a variable stiffness



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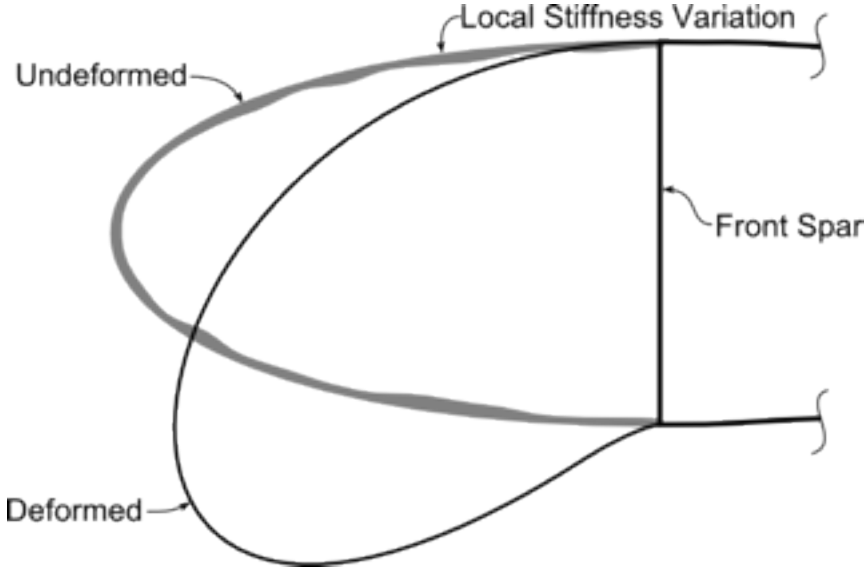
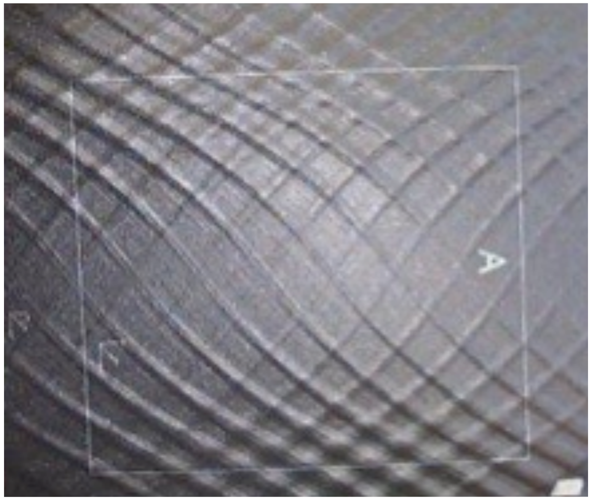
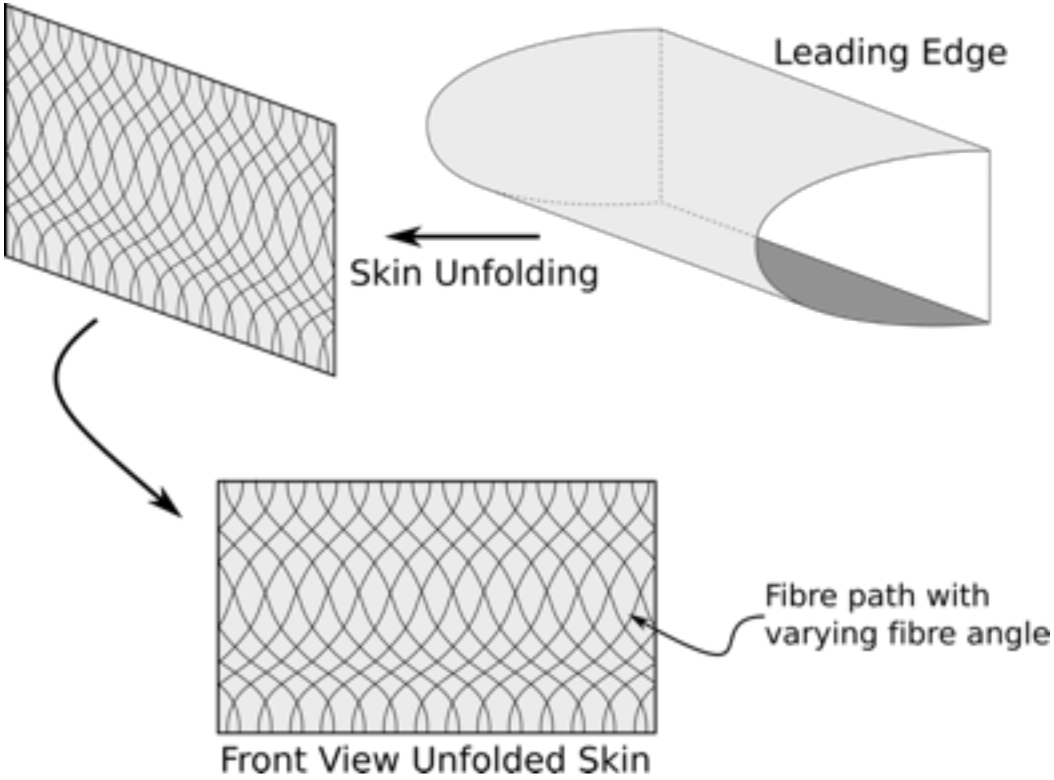


⇒ Internal actuation provided by partner

Variable Stiffness Skin

- Variable stiffness can be achieved by:
  - fibre angle variation
  - thickness variation





Aero-Servo-Elastic Framework

Optimisation of High-lift Devices

Aero-servo-elastic framework

Non-linear Euler-Bernoulli beam model (2D)

Inviscid panel code (2D)

Aero-servo-elastic framework

Aeroelastic Analysis (2D)

- Skin stiffness defined as:

$$EA = \beta E_1 h \qquad EI = \alpha \frac{E_1 h^3}{12}$$

Aero-servo-elastic framework

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$$\mathbf{f}_{act} = \mathbf{f} \cdot \mathbf{c}$$

Aero-servo-elastic framework

Aeroelastic Analysis (2D)

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- Actuation loads defined as:

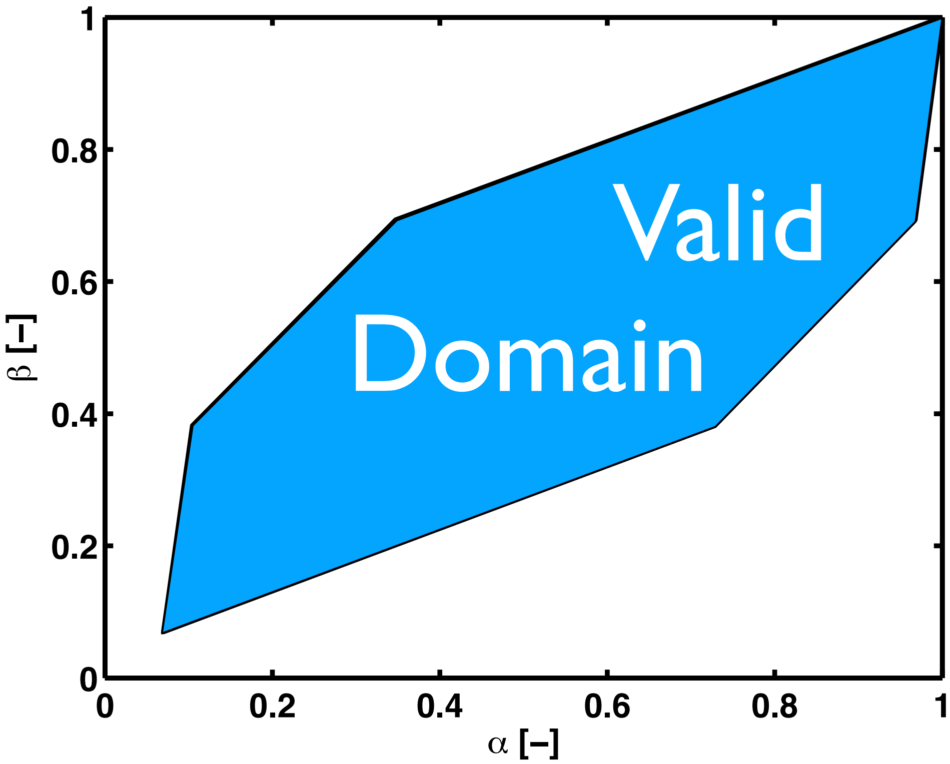
$$\mathbf{f}_{act} = \mathbf{f} \cdot \boxed{\mathbf{c}}$$

- Design variables become:

$$\mathbf{x} = \{\alpha, \beta, \mathbf{h}, \mathbf{c}\}$$

Feasible region

- Feasible skin design possible when α and β are within the feasible region
- Domain for balanced symmetric 12 layer laminate is conservative for thicker laminates
- Feasible domain ensures a valid relation between axial and bending stiffness



Optimisation Formulation

- Objective: $$\min \mathbf{I} = \sum_{i=1}^{N} \left\{ \frac{L_i}{2} \int_{-1}^{1} \left[\kappa_i(\eta) - \kappa_{t_i}(\eta) \right]^2 \mathrm{d}\eta \right\}$$

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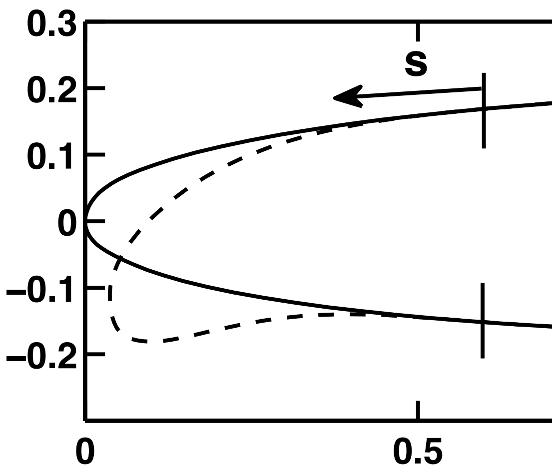
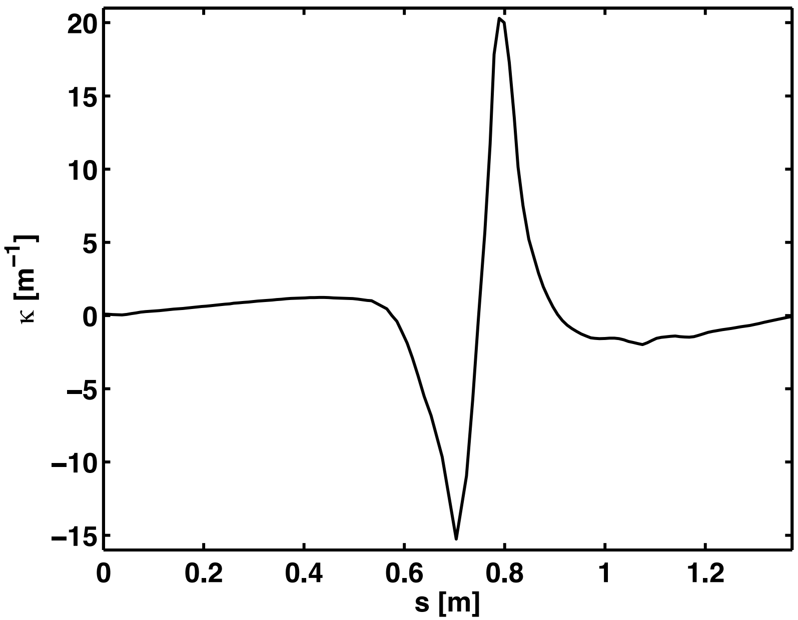
- Target curvature defined using SADE's target shape:





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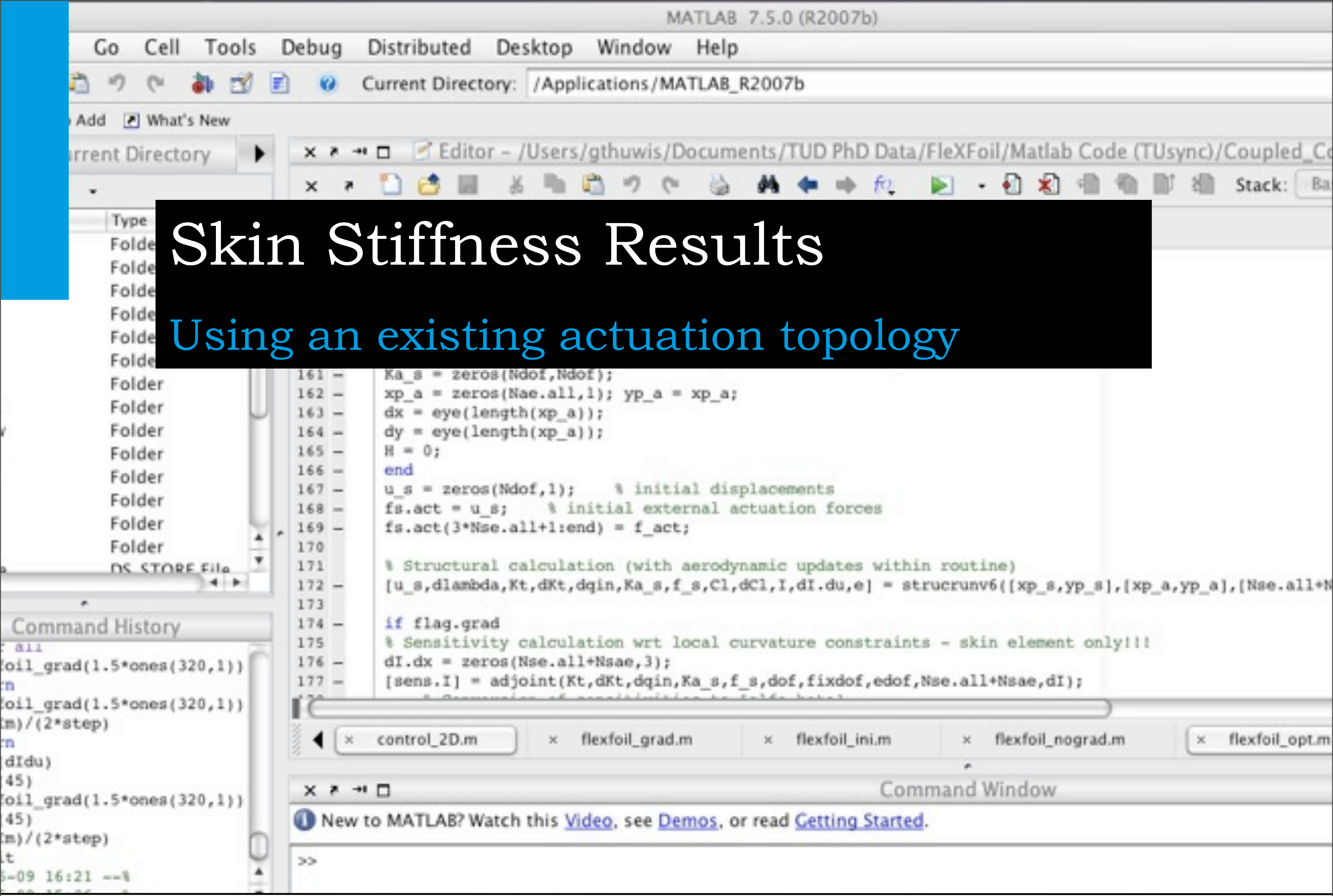
- subject to skin strain constraints:

$$\frac{\epsilon_i}{\epsilon_{max}} - 1 \leq 0$$

- Optimisation performed using **gradient** based optimiser GCMMA by Svanberg where sensitivities are provided by application of the adjoint method

Skin Stiffness Results

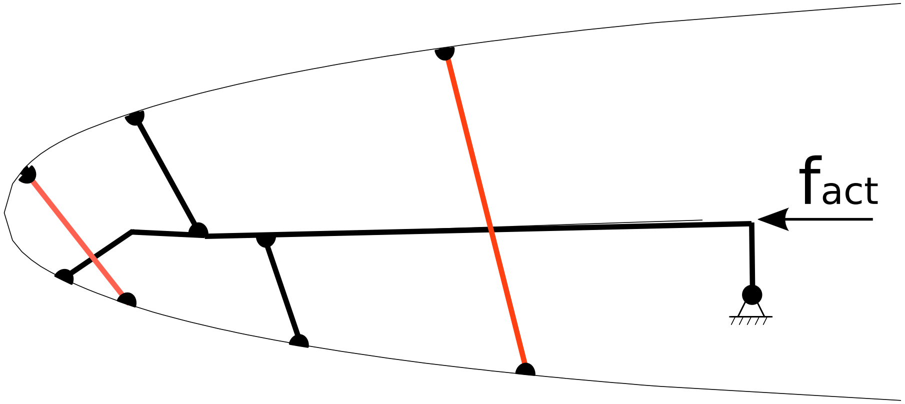
Using an existing actuation topology



Study Cases

	Local variable	Global variable	Constant
Case 1	α, β, h	-	-
Case 2	α, β	h	-
Case 3	h	-	α, β

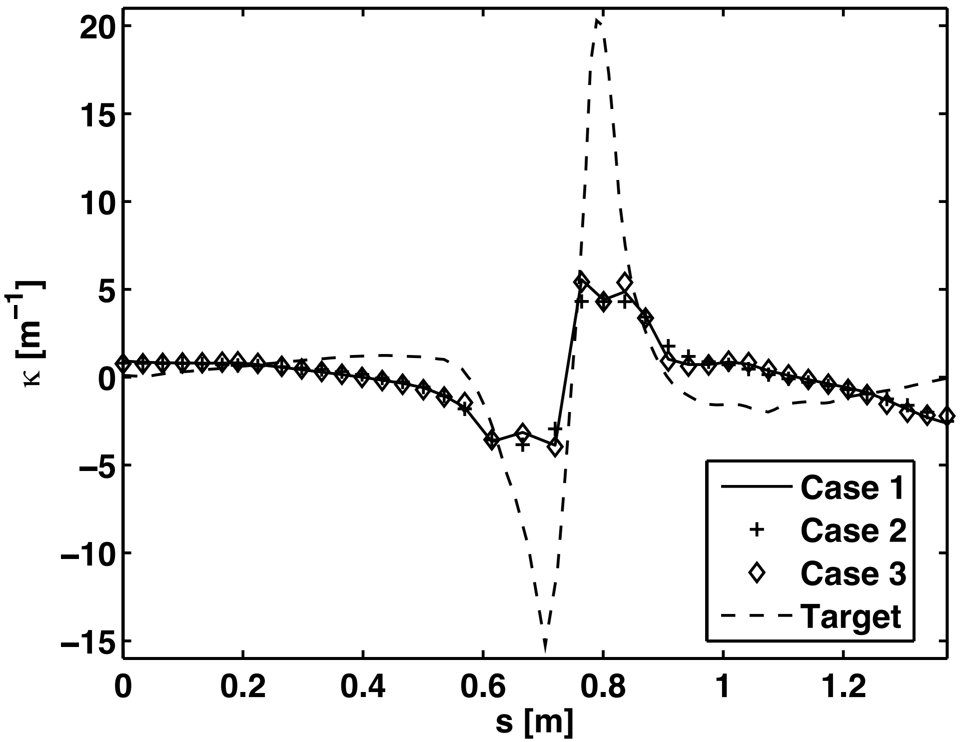
- Initial values: α = β = 0.9 and h = 12 layers
- Wing at angle-of-attack of 10 degrees, and velocity of 50 m/s



by CIRA

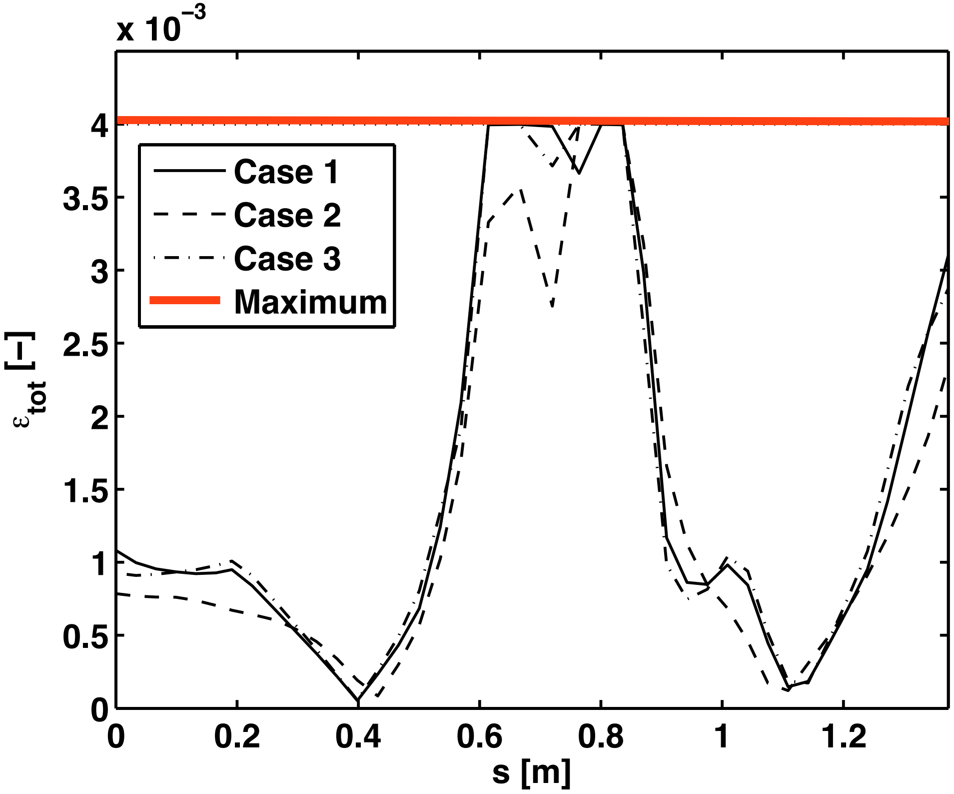
Curvature Objective

	Case 1	Case 2	Case 3
I	342	351	338

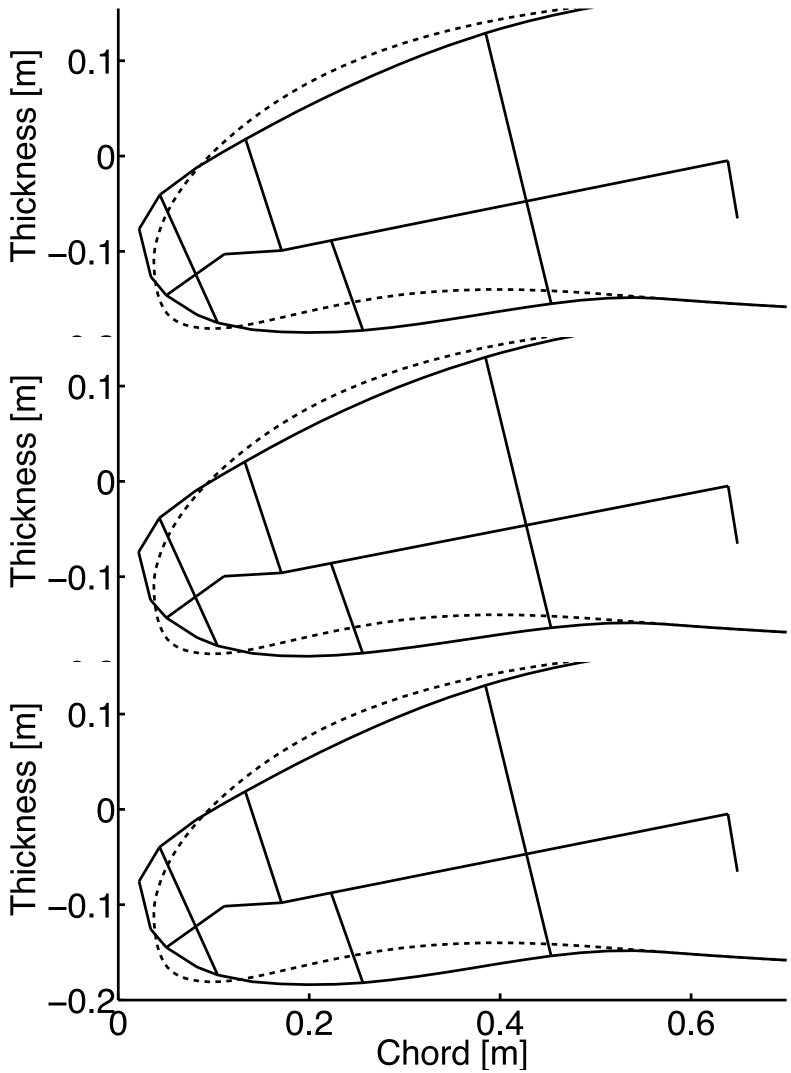


Applied Skin Strain

- Target curvature not achieved due to skin strain constraint



Final Deformed State



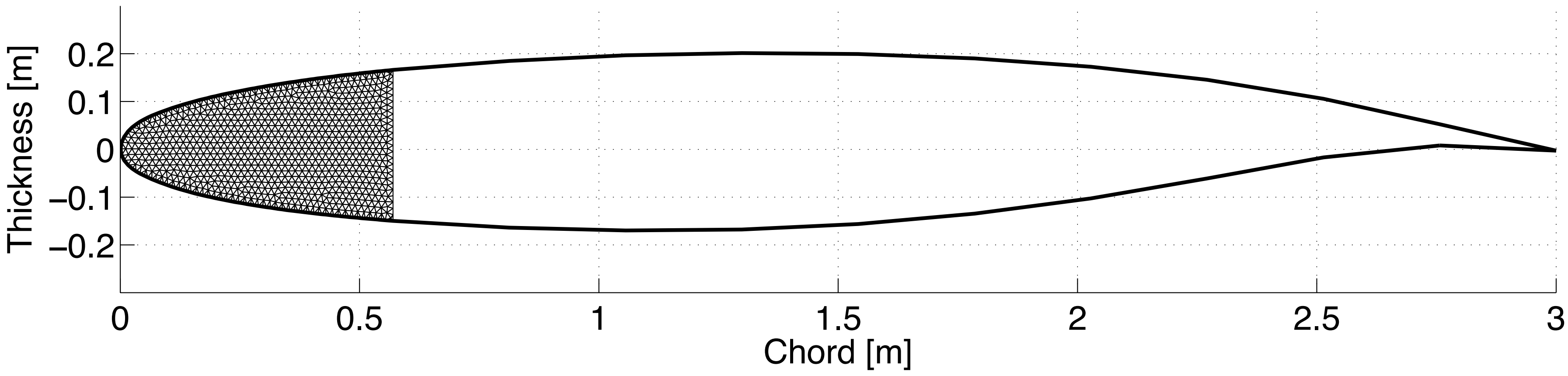
	Actuation force
Case 1	92 340 N
Case 2	78 570 N
Case 3	91 825 N

Actuation Topology Optimisation

Setup and initial results

Actuation Topology Design

- Create internal unstructured mesh
- Apply Simple Isotropic Material with Penalisation (SIMP) approach
- Combined skin stiffness/actuation topology optimisation possible



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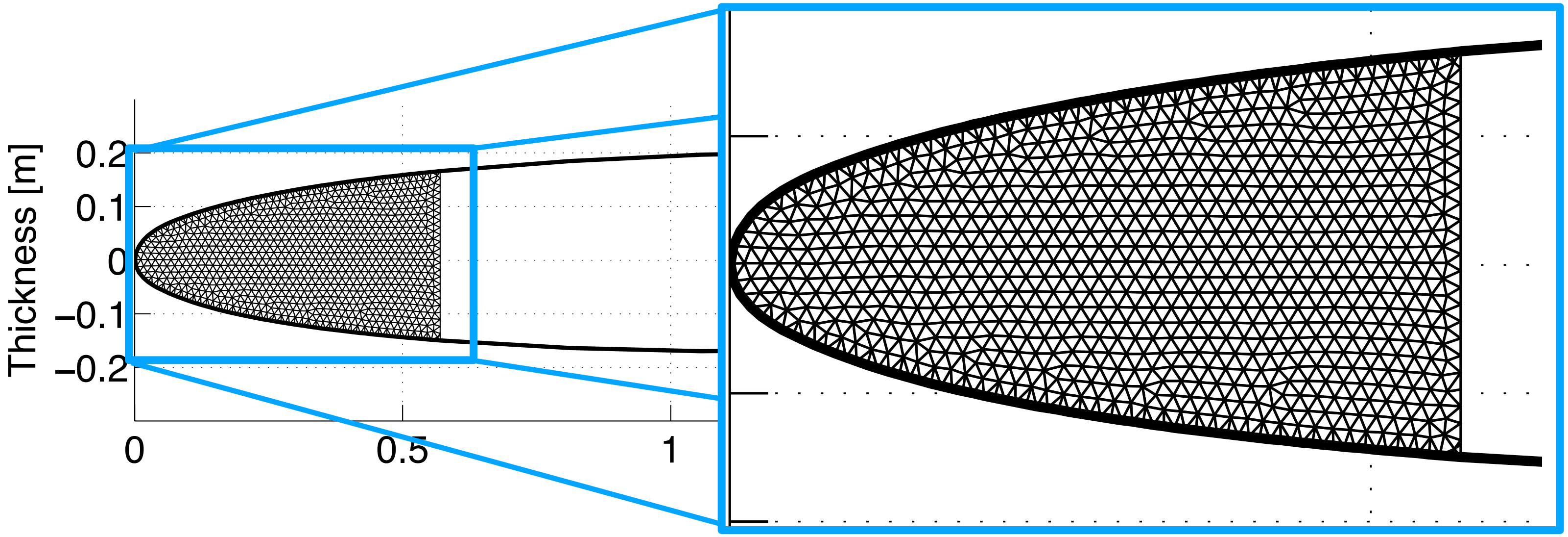
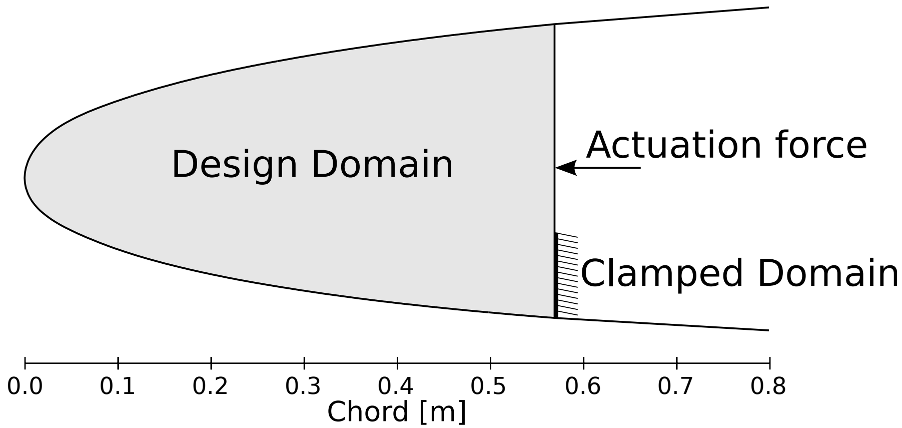
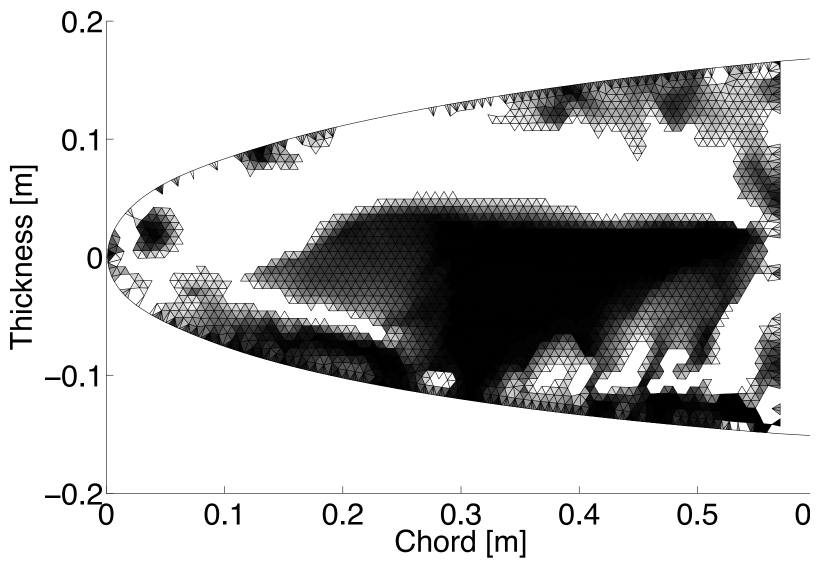
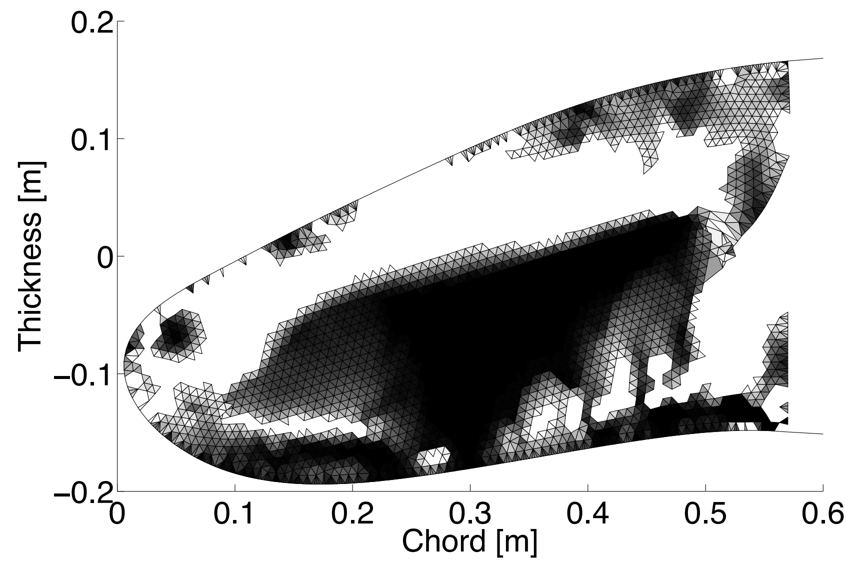


Initial linear results







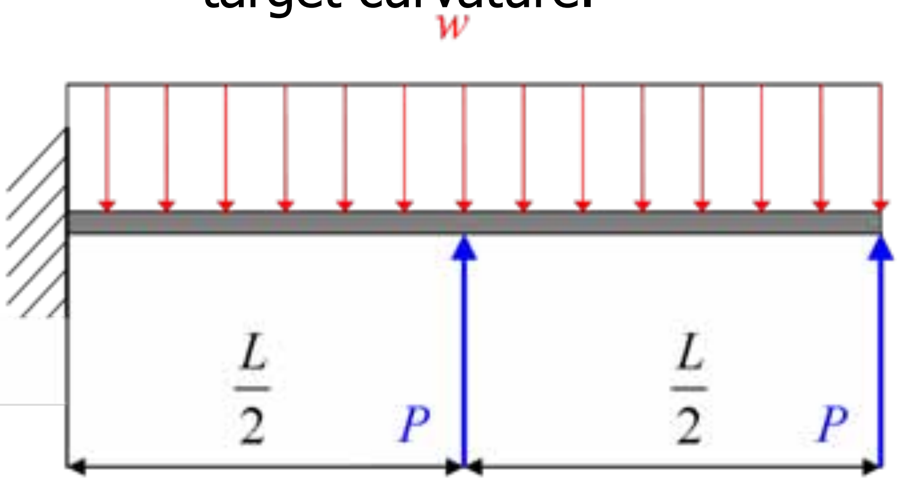
Test Results

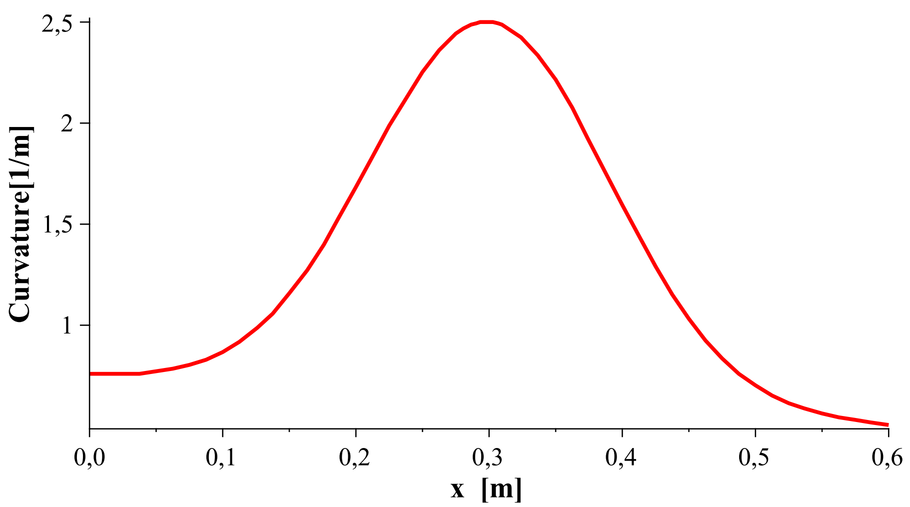
Validating 'Target Curvature Concept'

by Jaap Dekker MSc

Design for Target Curvature Concept

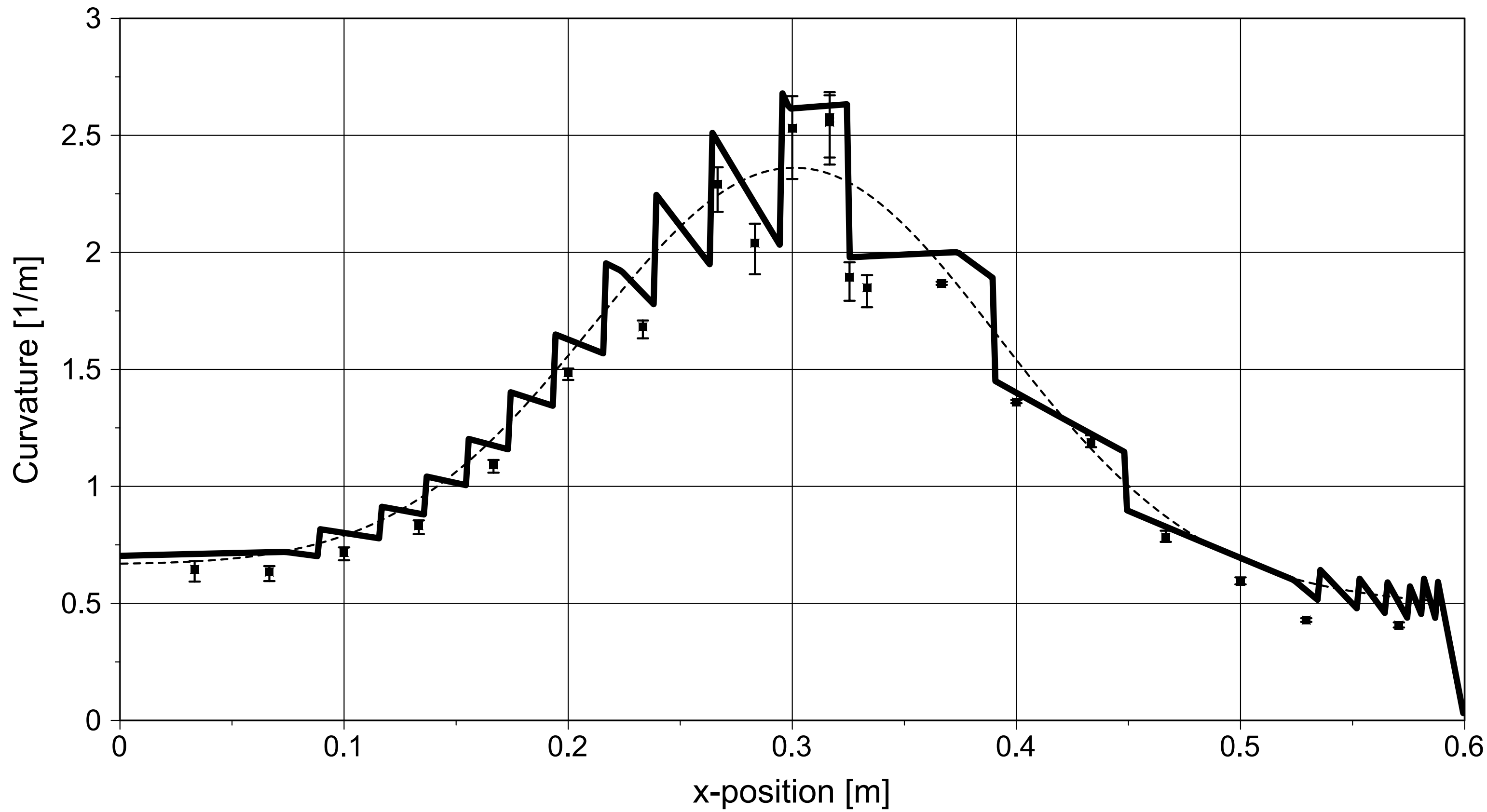
- The stiffness distribution of the panel has to be designed such that the panel, in its deformed shape, matches the predefined target curvature.





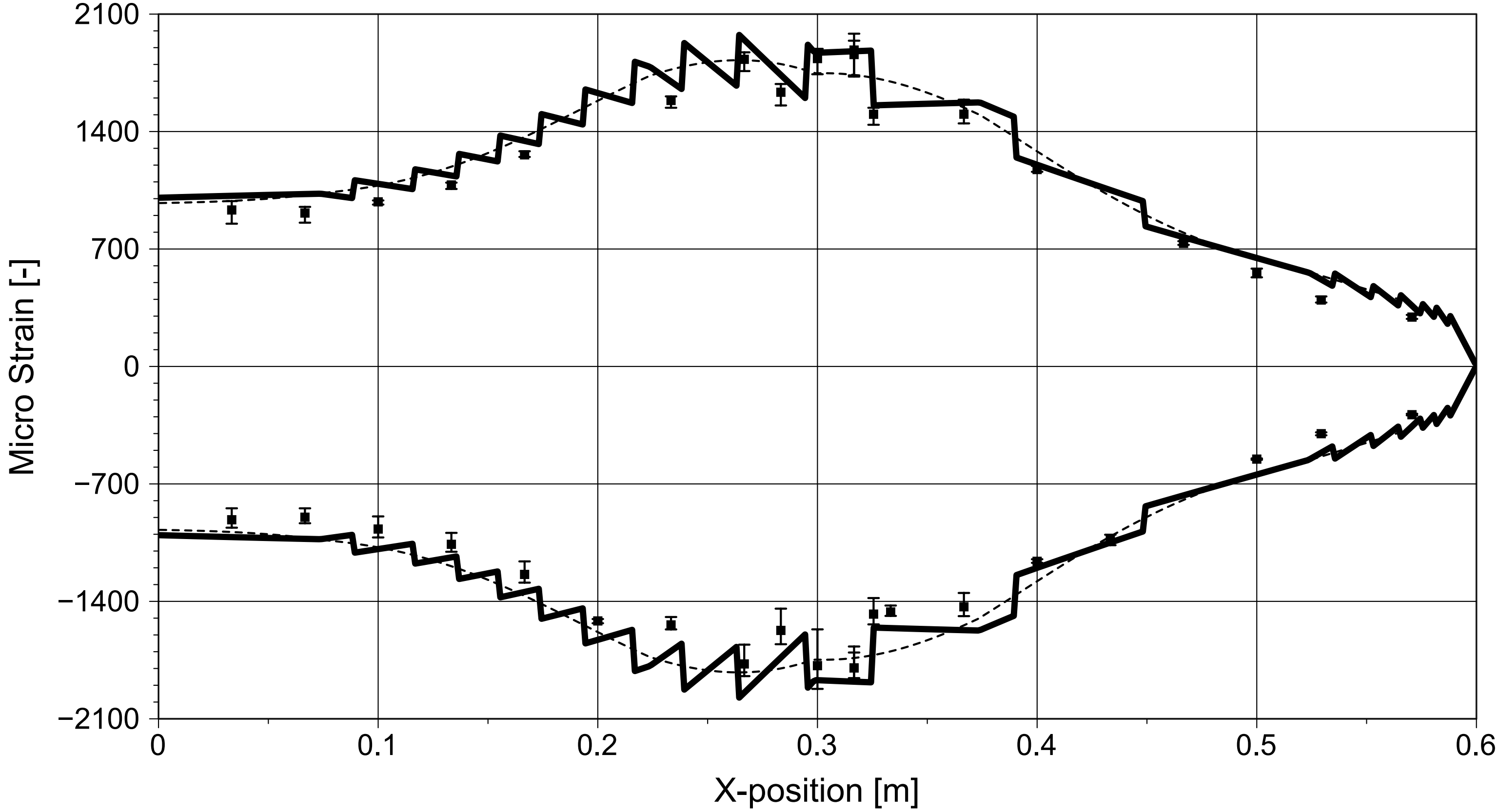
Curvature and Strain Measurements

- Measured (dots) versus expected (solid line) **curvature**

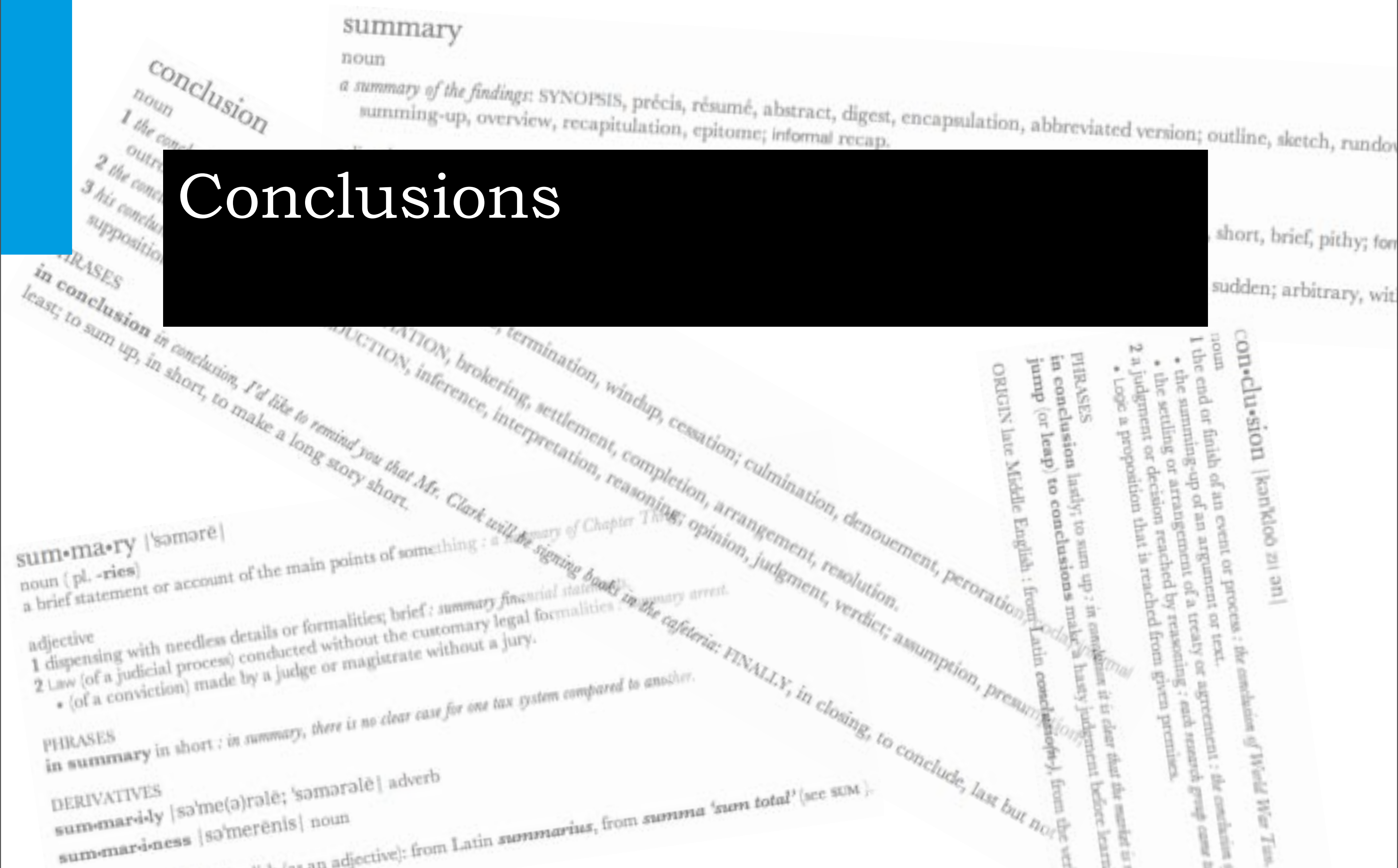


Curvature and Strain Measurements

- Measured (dots) versus expected (solid line) **strain**



Conclusions



Conclusions

- Variable stiffness skin has a broader design space compared to constant stiffness skin, local stiffness variation is beneficial
- Aerodynamic loads have a large influence on the final skin stiffness distribution and should thus be taken into account during the design process
- Initial actuation topology results show good potential, such a tool can be used to design a more coherent morphing high-lift system, i.e. combined skin stiffness/actuation topology design
- Test results validate the design for target curvature philosophy

Future work

- topology optimisation including aerodynamic loading
- application of topology optimisation to design an actuation system which facilitates the deformation defined in SADE
- improvement of the aerodynamic solver to include for example viscous effect and enable the definition of an objective function using aerodynamic performance, e.g. max lift, max L/D, min D

- Tests made possible thanks to:

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