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UKRI Engineering and Physical Sciences Research Council

A machine learning based tool for predicting geometry-induced wrinkles in fabric preforming

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HEXCEL

DASSAULT SYSTEMES

GORDON MURRAY DESIGN

GKN

University of Bath | University of Bristol | Brunel University London | University of Cambridge | Cranfield University | The University of Edinburgh | University of Glasgow | Imperial College London | Manchester 1824 | University of Nottingham UK | CHINA | MALAYSIA | The University Of Sheffield. | University of Southampton | Ulster University | Warwick The University of Warwick | Prifysgol Glyndŵr Wrecsam | Wrexham Glyndŵr University

Motivation

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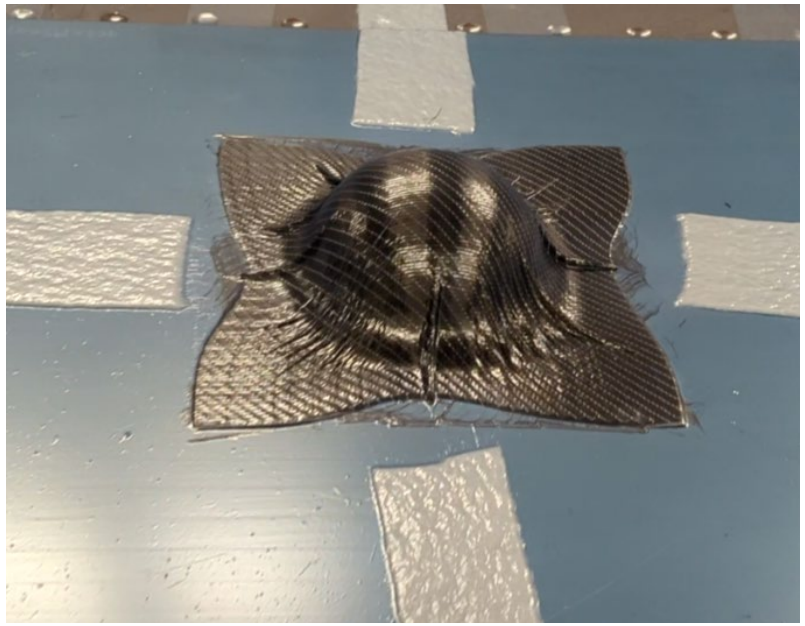
- Wrinkling simulations using FE are accurate but not practical for optimisation
- Deep learning models can be accurate with low computational cost
- The effect of tool geometry on wrinkling behaviour is not well understood



Aims

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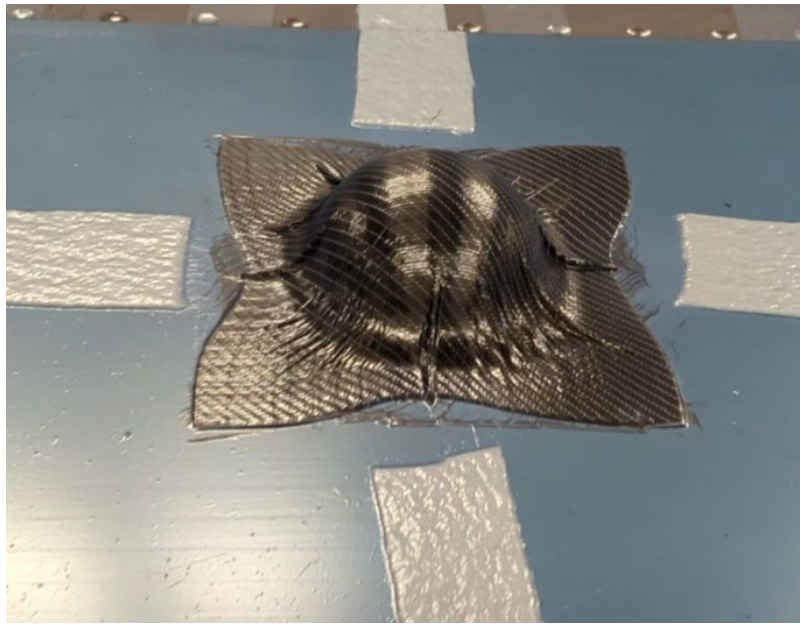
- Develop a deep learning model to predict wrinkling for a range of geometries
- Investigate the relationship between tool geometry and wrinkling



Outline

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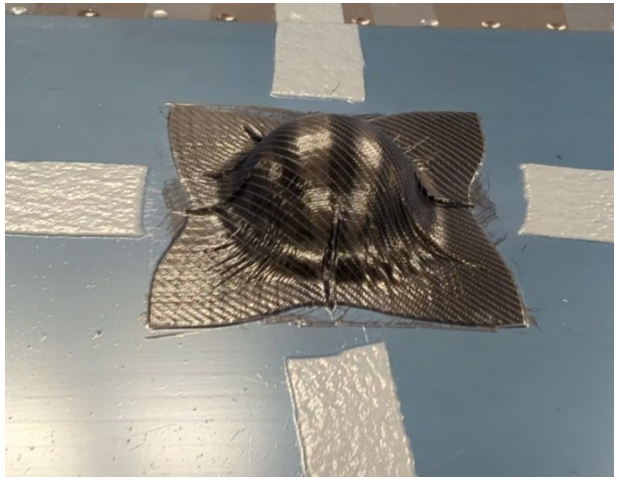
- Motivation and Aims
- Material and Process
- Method
  - Data Generation
  - Data Pre-processing
  - Surrogate Model
- Results
  - Effect of Tool Geometry
  - Model Performance
  - Computational Cost
- Conclusions and Future Work



Material, Layup & Process

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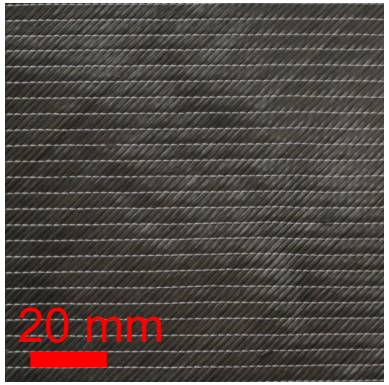
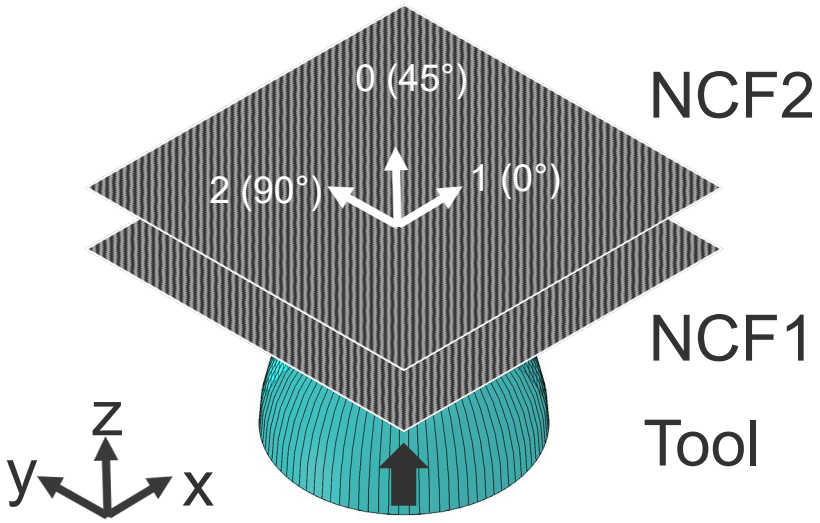
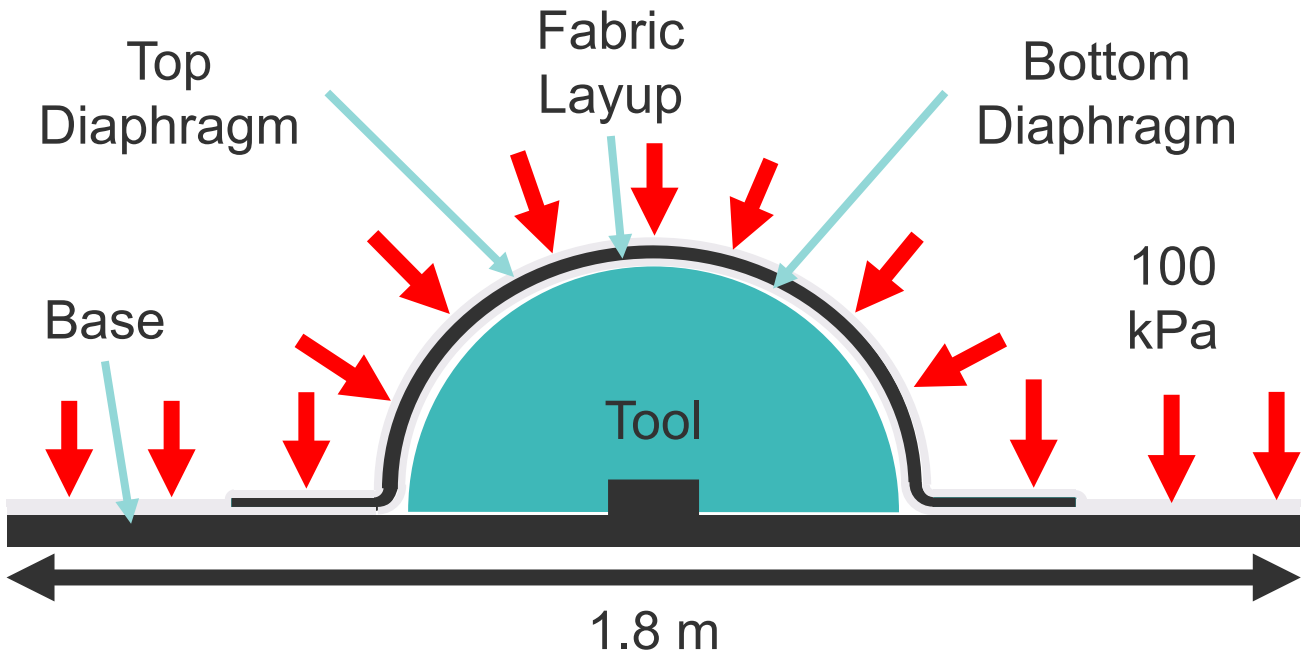


Material
Hexcel `FCIM359'
Biaxial carbon NCF
±45°, pillar stitch

Layup: [0°/90°,0°/90°], stitch along 45°



Forming Process: Double diaphragm forming



Method Outline

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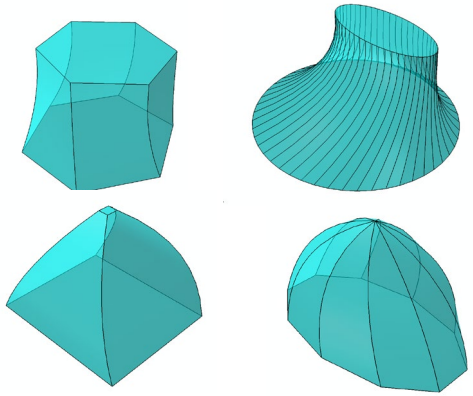
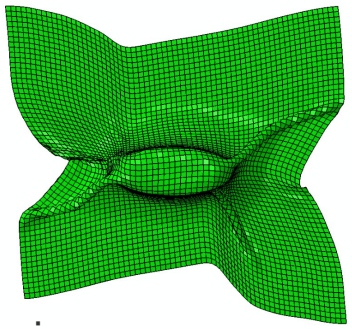
Data Generation → **Training** → **Evaluation**

Data Generation

Tool Geometry



Wrinkle Surface



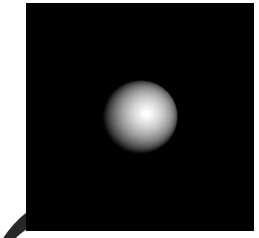
FE Forming Model

Yu et al. (2021)

Training

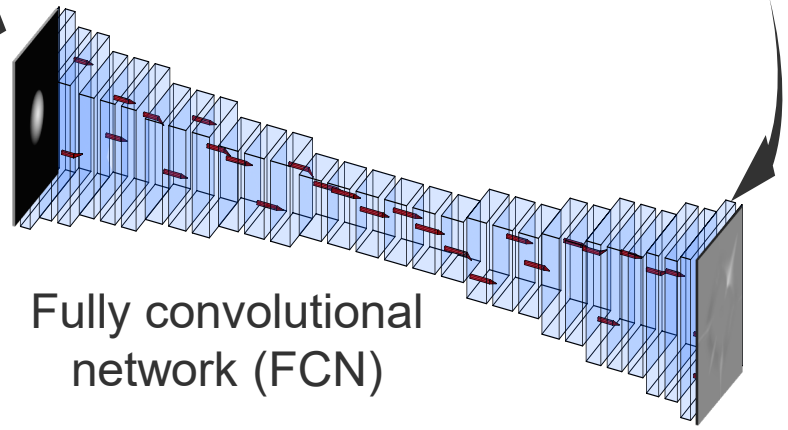
Data Pre-Processing

Tool Height



Wrinkle Amplitude

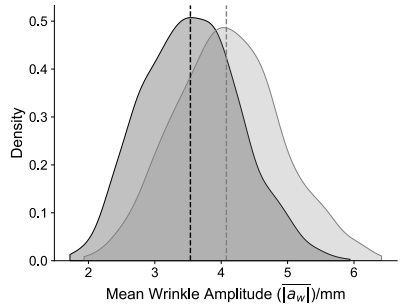
Training of Surrogate Model



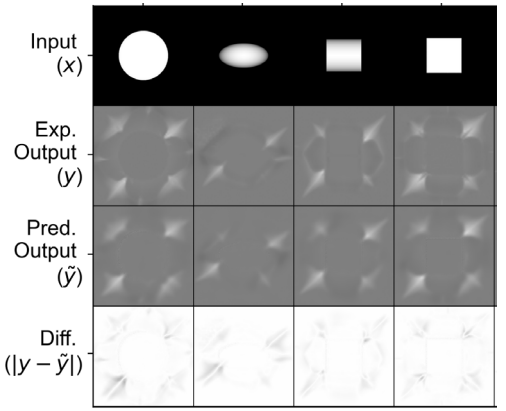
Fully convolutional network (FCN)

Evaluation

Effect of Tool Geometry



Model Prediction Accuracy



Data Generation

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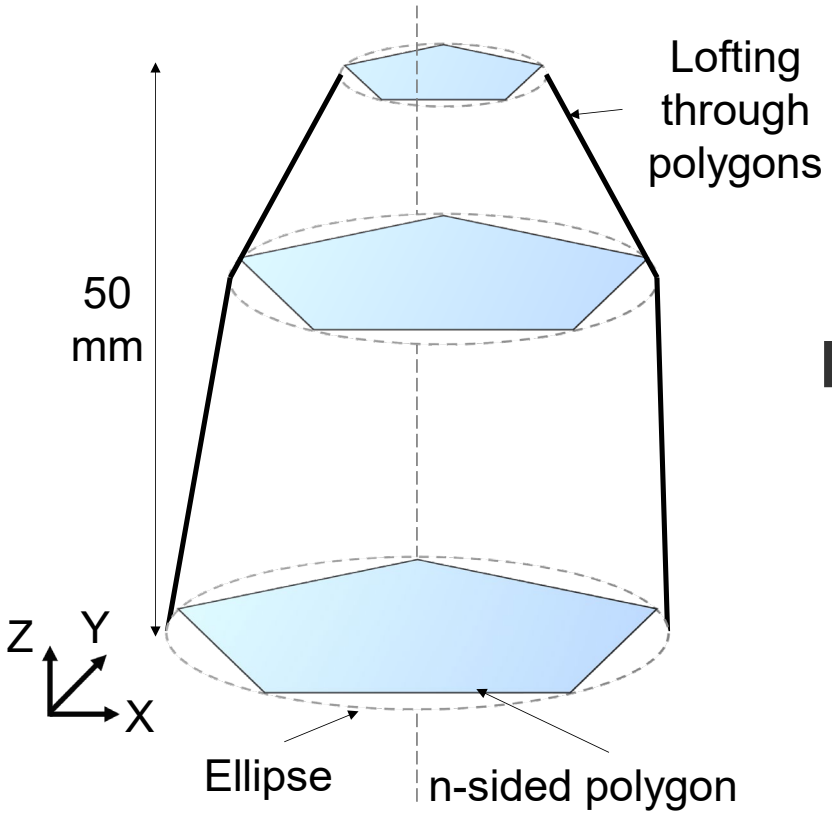
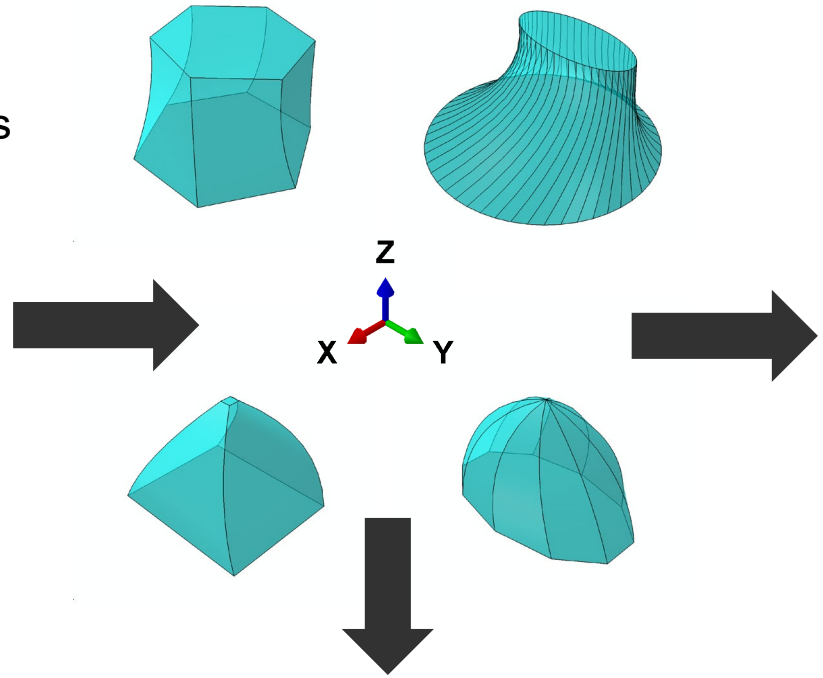
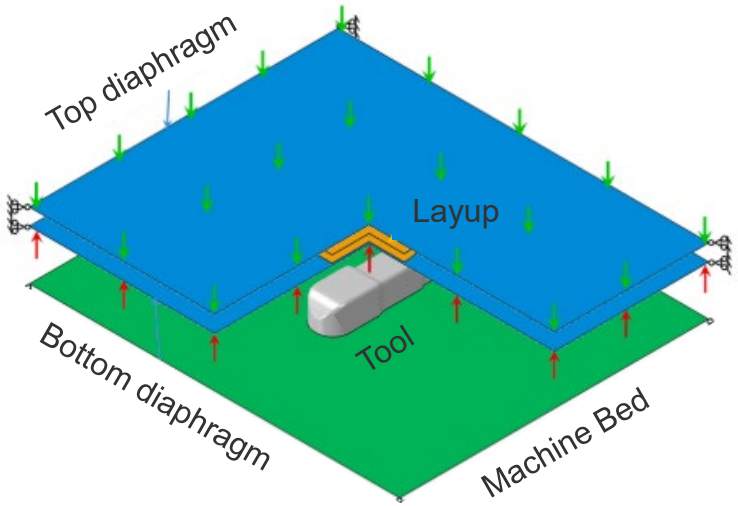
Geometry Generator



1802 Tool Geometries



FE Forming Simulation



Yu et al. (2021)

Geometry Characterisation

Conicity	Area Ratio	Volume Ratio	Tortuosity	Angularity	Mean Curvature	Gauss Curvature	Asymmetry

Data Pre-Processing

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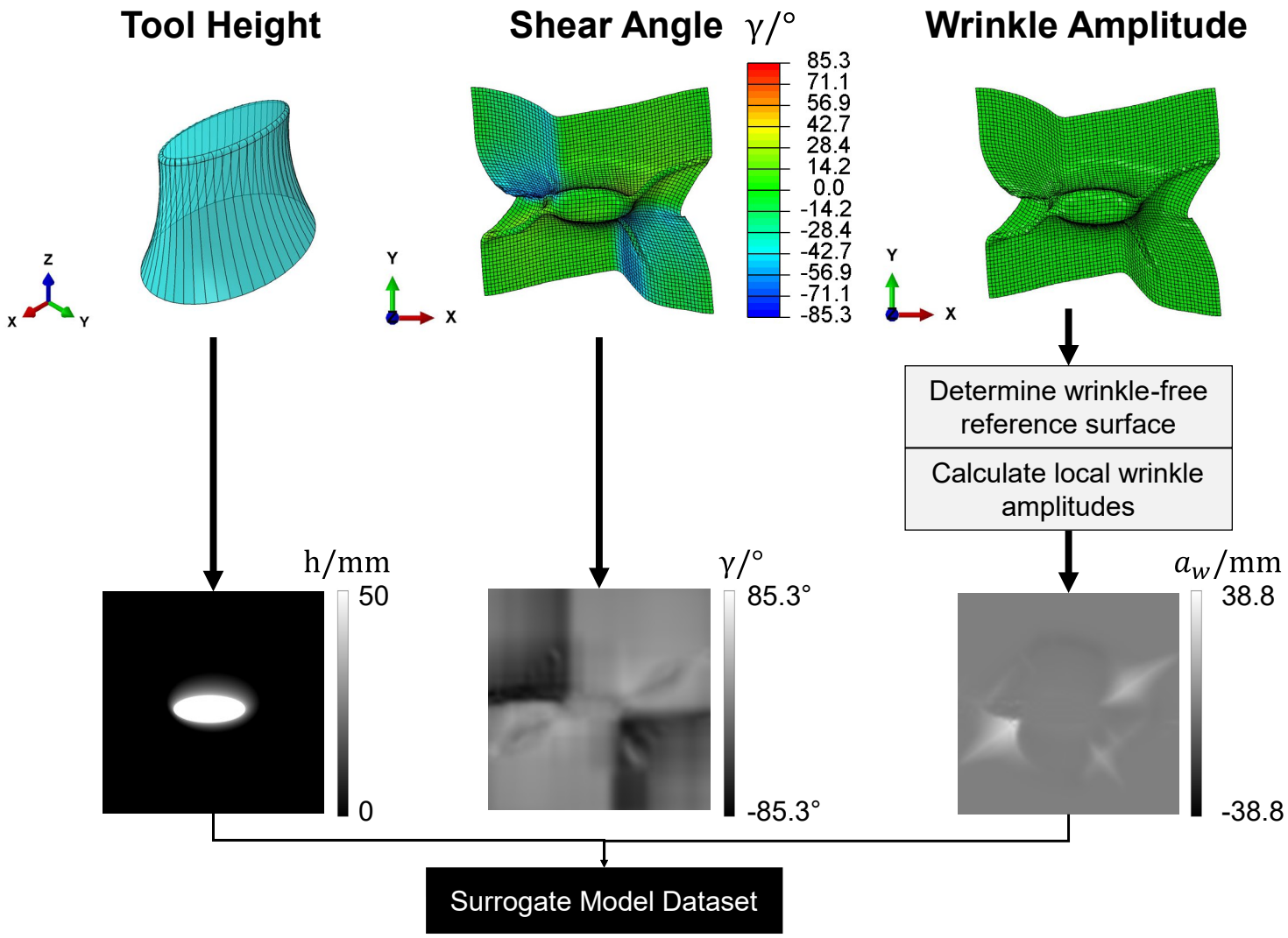

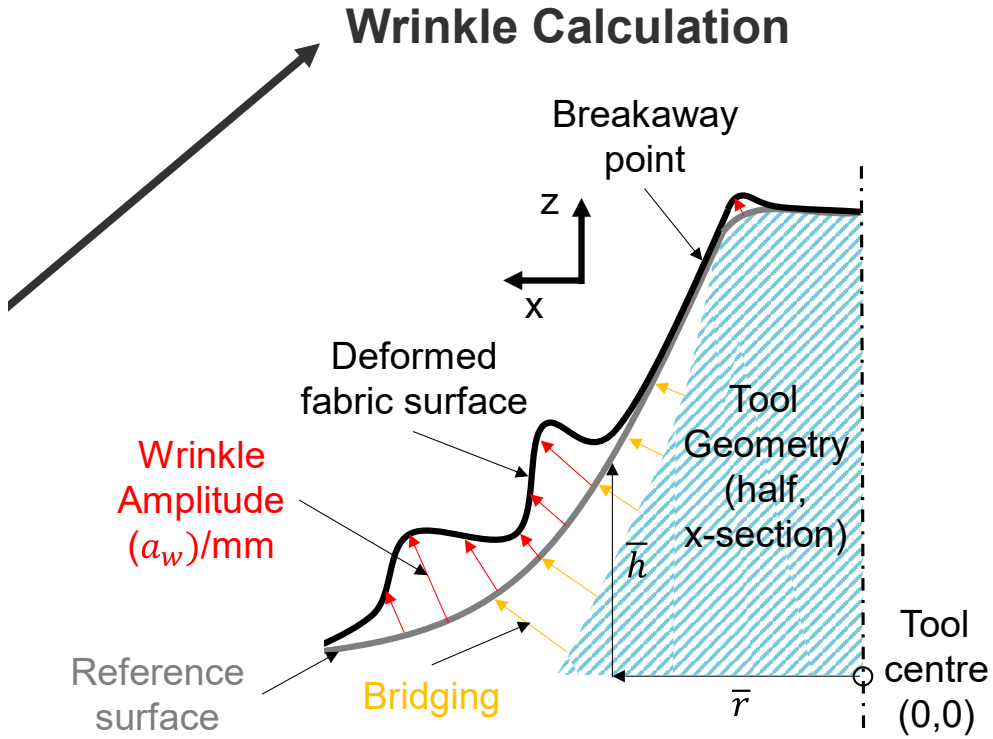

- Bridging excluded from wrinkle amplitude calculation

Deep Learning Surrogate Model

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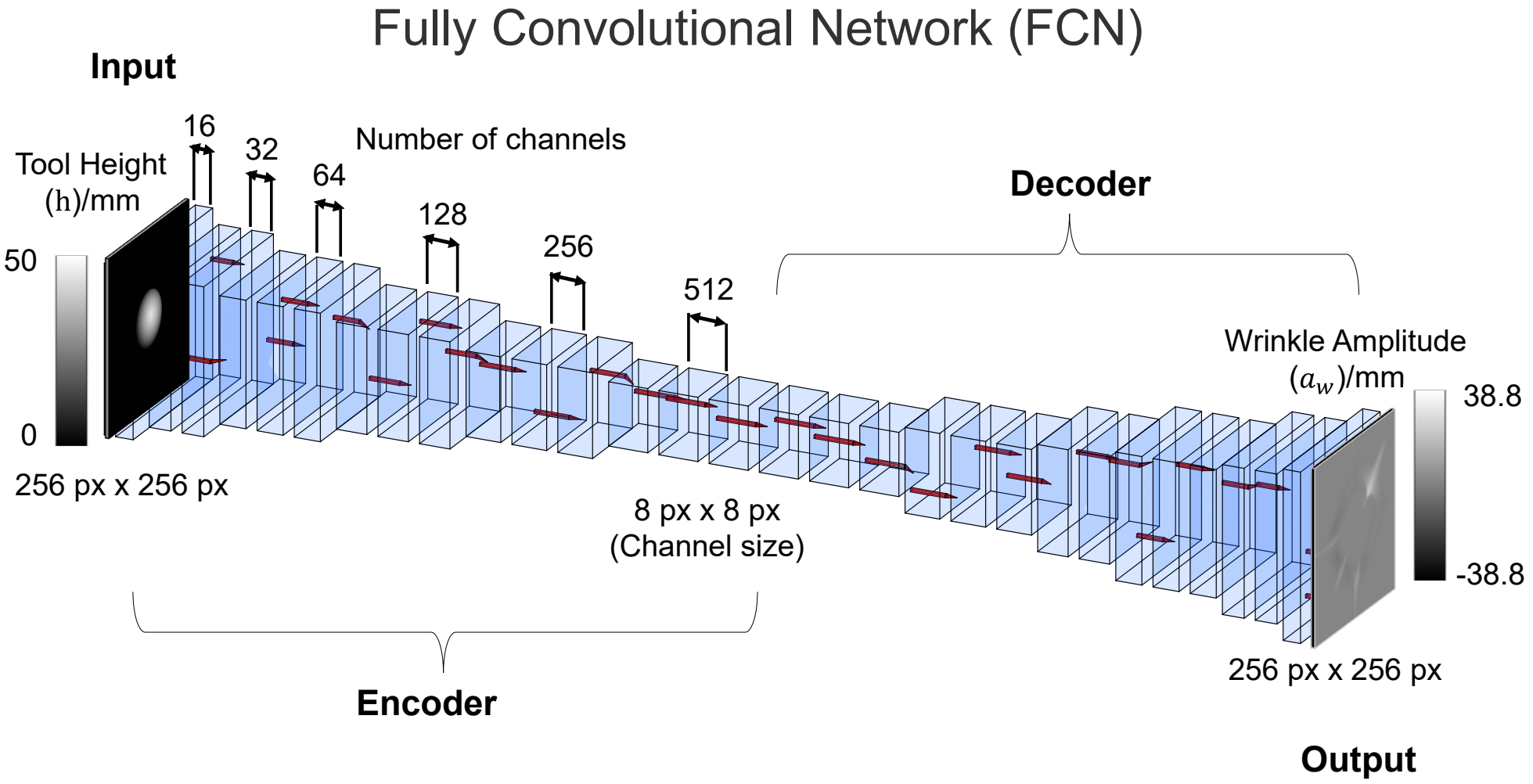
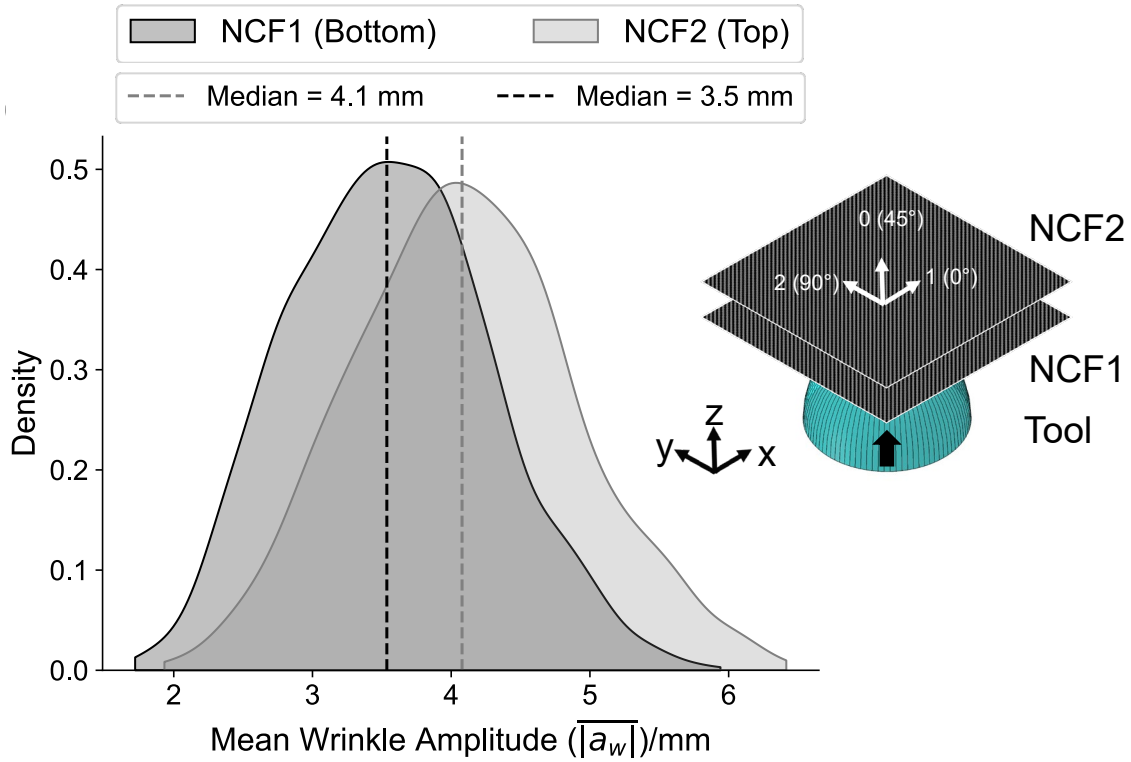


Effect of Tool Geometry on Wrinkling

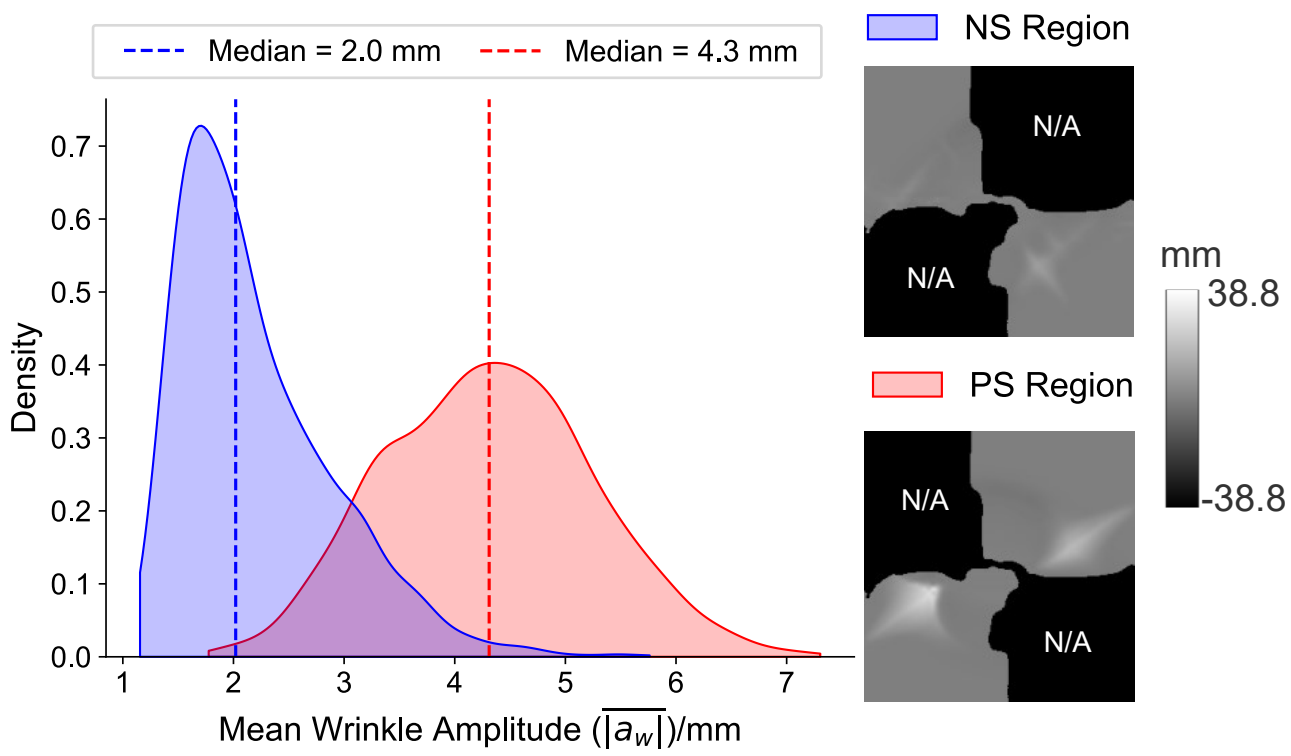
By NCF ply in layup

- [0°/90°,0°/90°] - two NCF layup
- Similar effect for both plies



By NCF shear region

- Asymmetric shear behaviour due to stitch along shearing direction
- Different wrinkling modes in each region
  - Shear (NS) vs lateral compression (PS)



- Note: probability density distributions based on all 1802 simulated tool geometries

Effect of Tool Geometry - Correlation

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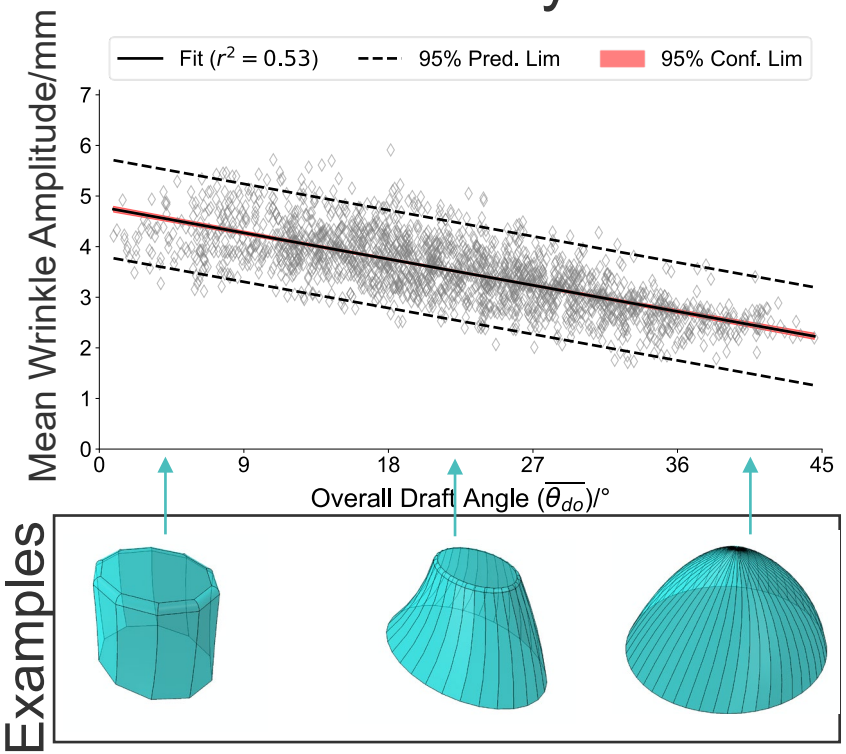
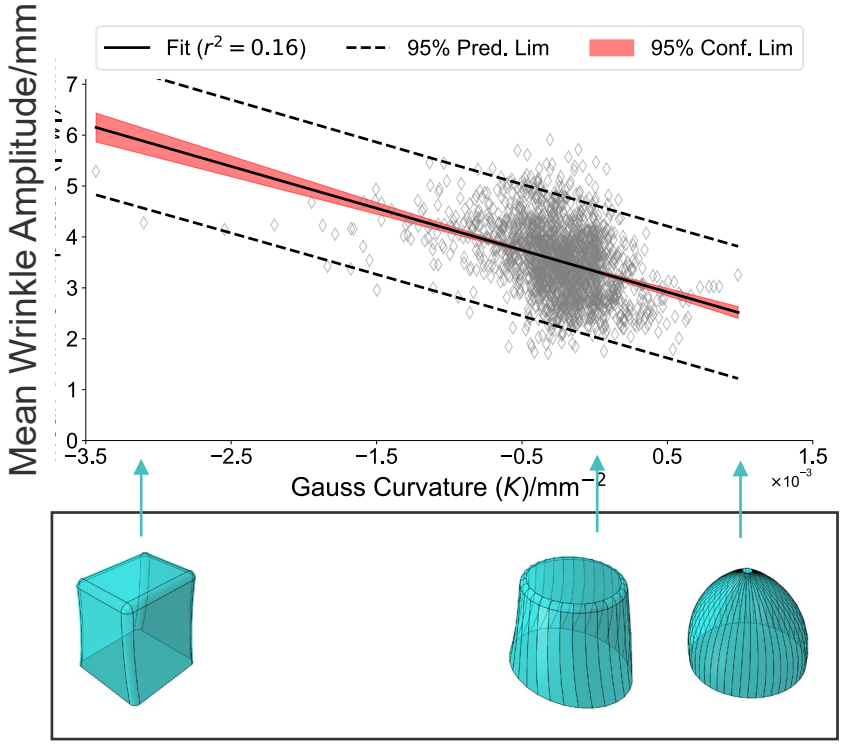
- Evaluation of correlation between geometry characteristics and wrinkle severity

Conicity



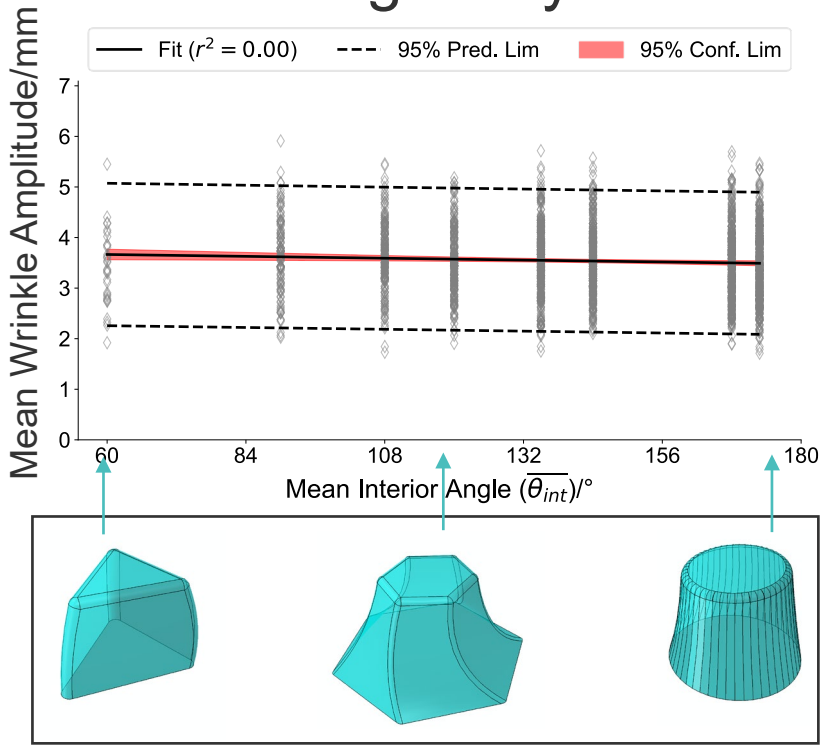
- Strong correlation

Gauss Curvature



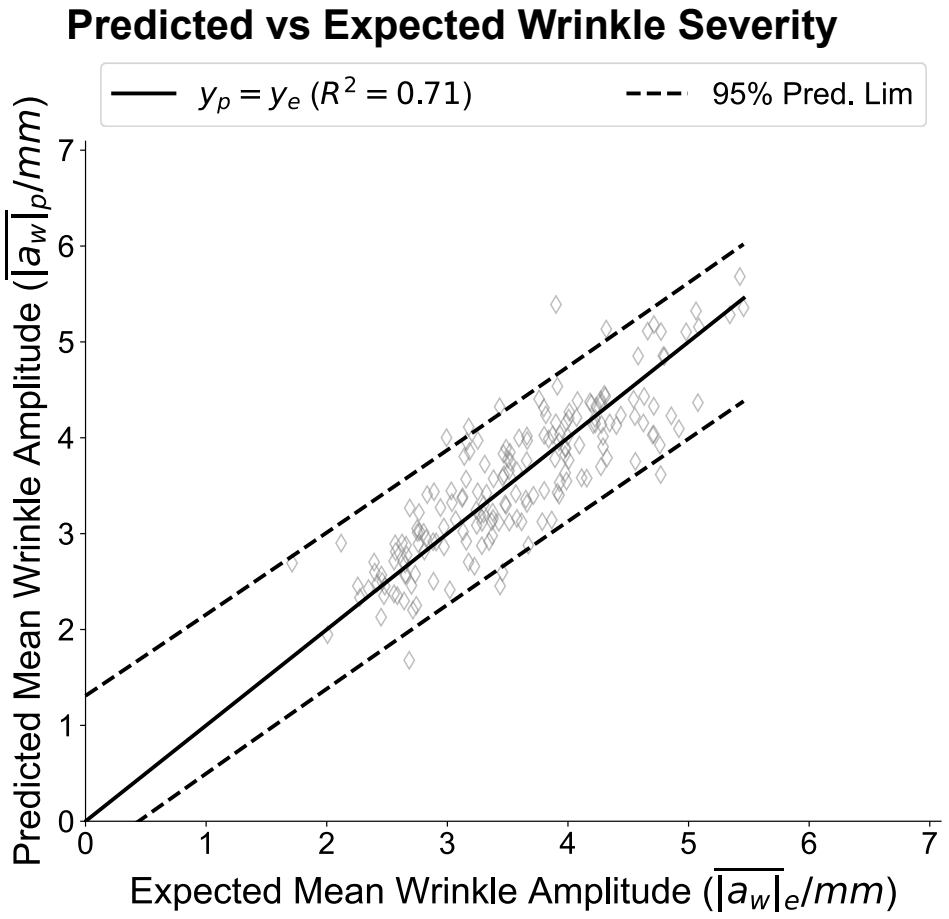
- Weak correlation

Angularity



- No correlation

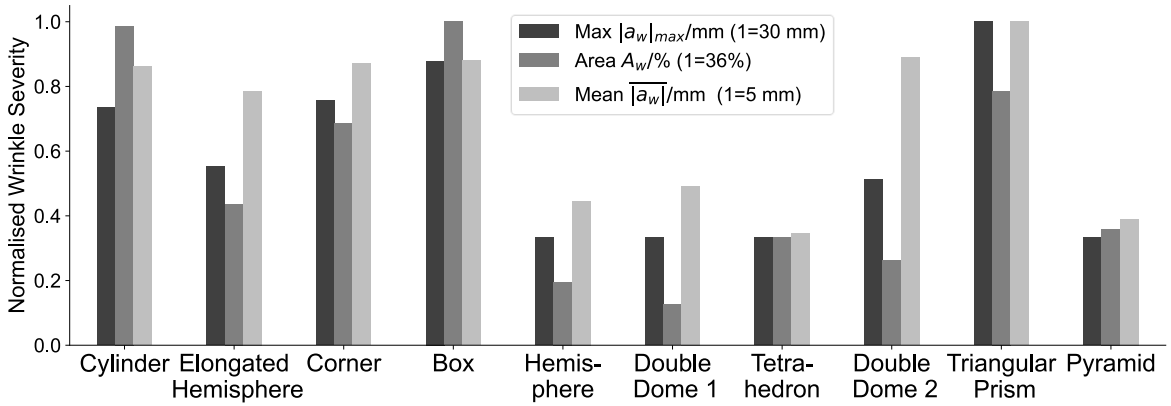
Model Performance – Test Set



- Test set: 186 geometries
- Not previously seen by surrogate model
- Mean wrinkle amplitudes from deep learning surrogate model correlate well with FE predictions

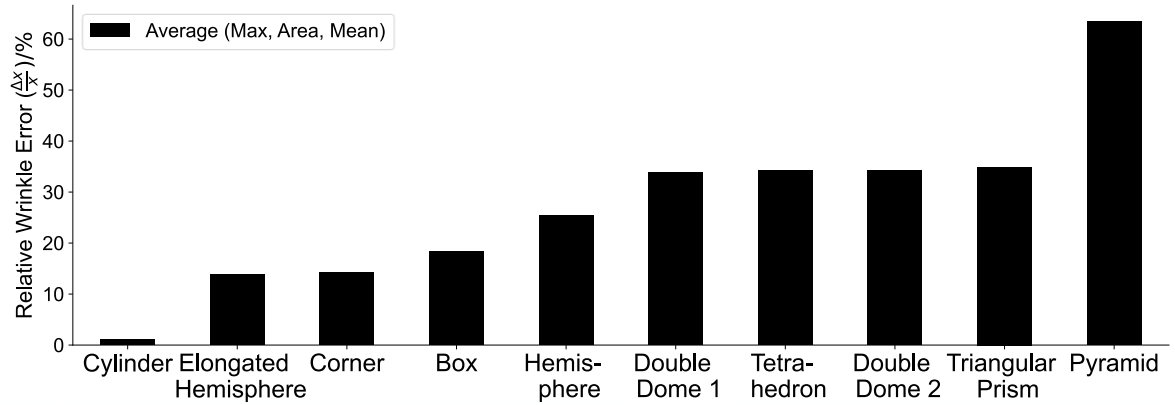
Model Performance – Evaluation Set

Wrinkle Severity

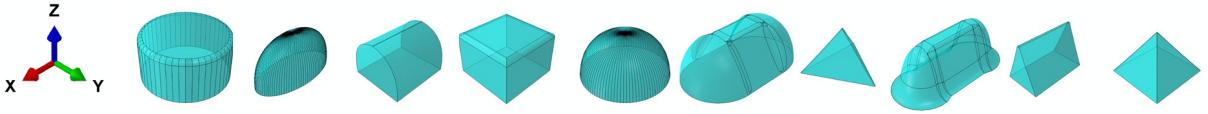


- Significant effect of geometry on wrinkle amplitude

Model Wrinkle Prediction Error



- Reasonable prediction accuracy
- Extrapolation capability limited



Evaluation Geometries

Model Computational Cost

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Prediction cost (FE vs DL surrogate model)

Model Type	*Computational Cost/hours*
Macroscale FE Model	1.33
Pre-trained Surrogate Model	0.000215 (0.7s)

DL surrogate model development computational cost (hours)

Surrogate Model Development	1308

Conclusions & Future Work

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Conclusions

- The effect of tool geometry on wrinkling severity is significant
- Greater tapering → less severe wrinkling
- DL surrogate model can predict fabric wrinkling behaviour during forming
- Surrogate model = approx. 6000x faster than FE model
- Development cost can be further reduced

Conclusions & Future Work

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Conclusions

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Future Work

- Numerical variability of wrinkle patterns
- Optimisation of a case study geometry
- Transfer learning to improve extrapolation
- Extension to industrially relevant geometries