DATA-BASED LEAKAGE DETECTION IN THE MANUFACTURING OF LARGE-SCALE CFRP COMPONENTS

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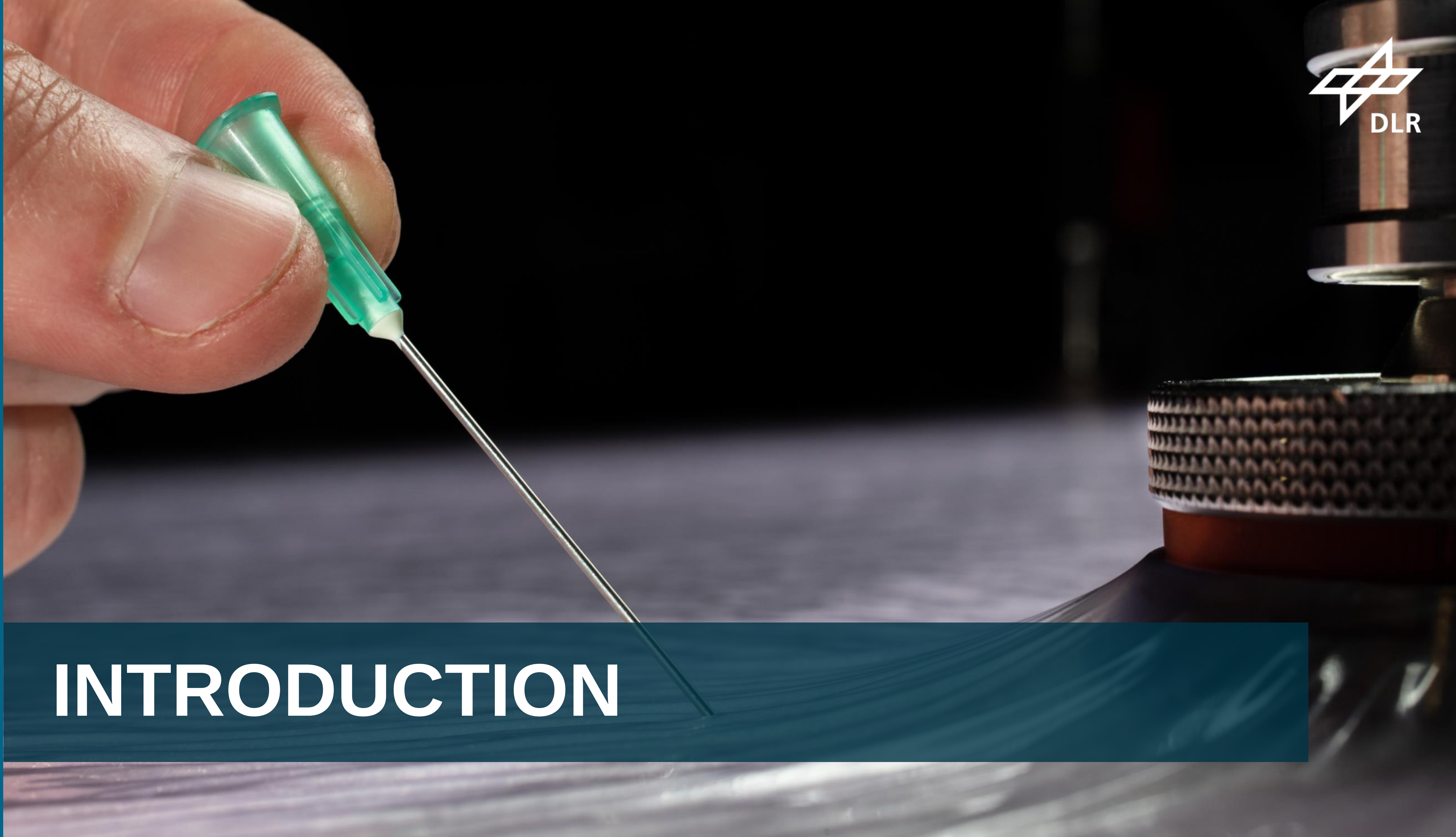
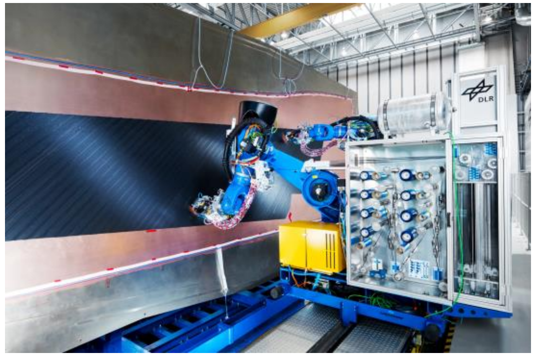
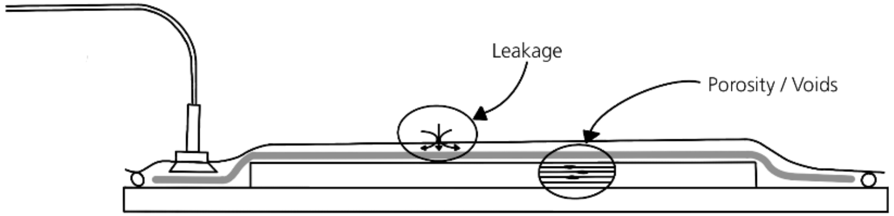
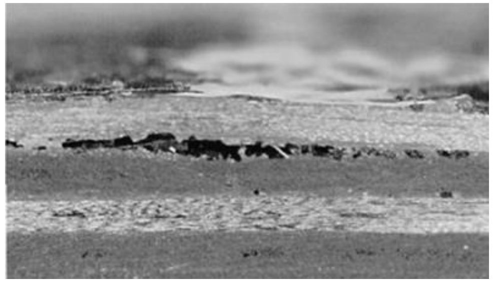


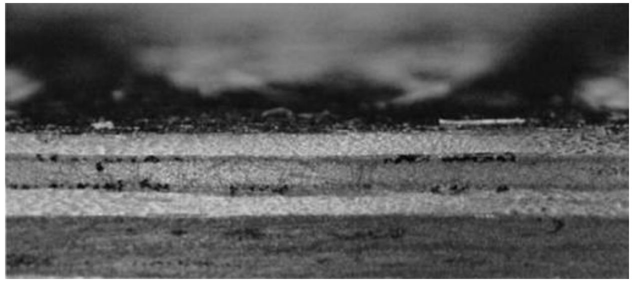
INTRODUCTION

Leakage Detection



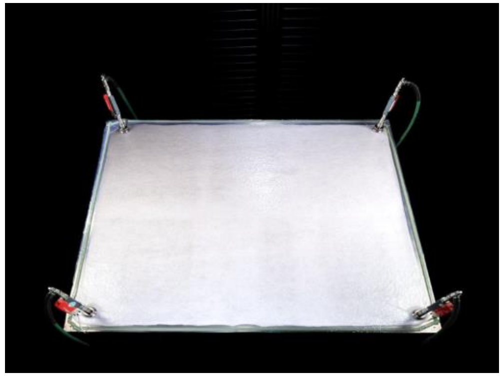


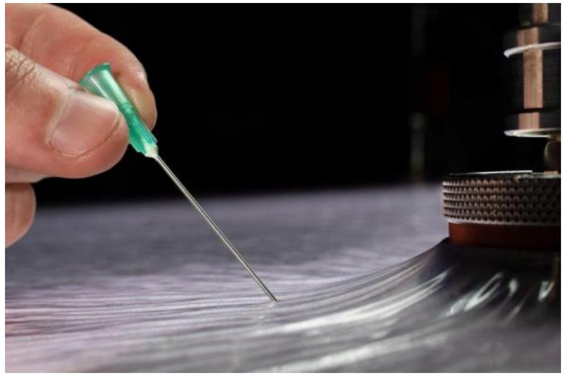


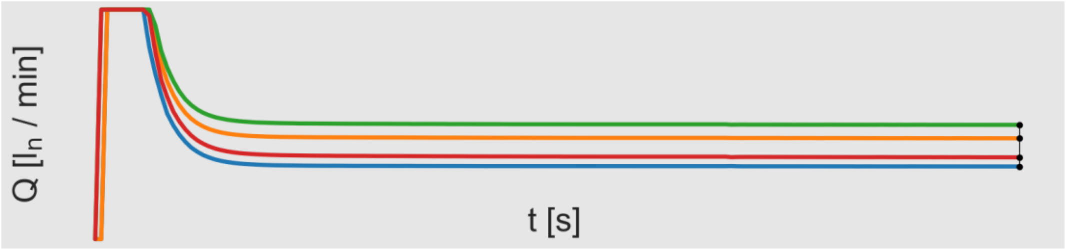


- Context: Production of fiber composite components
- Laminates are cured by means of heat and pressure
- Pressure is applied through vacuum setup
- Leakages in the vacuum bag lower the quality
- Manual detection approaches are time-consuming and costly

Small-Scale Setup



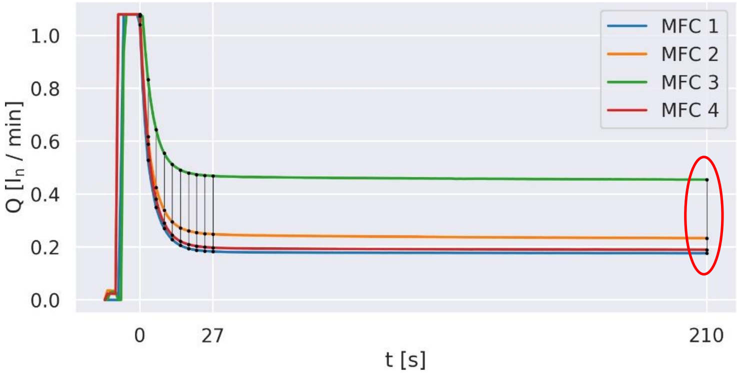


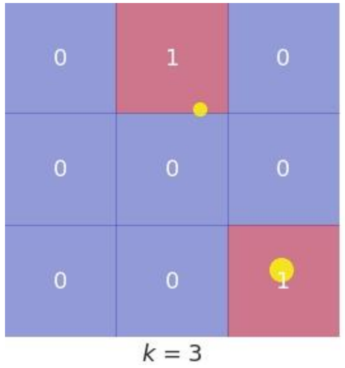


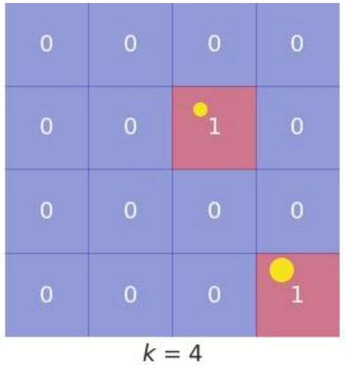
- Quadratic workpiece with edge length 1.5m
- Manually introduced leakage at random position
- One vacuum pump plus flow meter per corner
- 900 training examples and 100 for testing
- Task: Predict leakage positions from residual flow

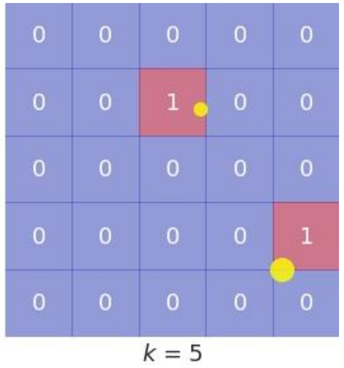
Multi-Label Classification Approach

Input	Output









$x \in \mathbb{R}^4$

Equilibrium flow

$y \in \{0, 1\}^{k^2}$

Grid fineness k

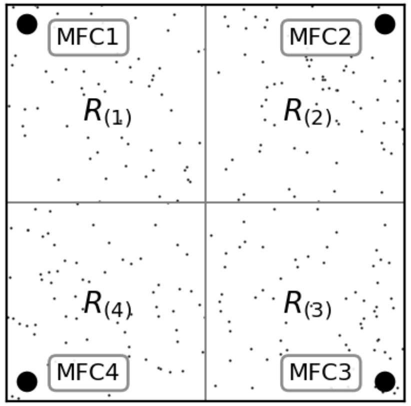
Outlook

1. Parameter-Free Model
2. Group Equivariant Network
3. Numerical Results
4. Full-Scale Setup

PARAMETER-FREE MODEL

Prior Knowledge 1

Voronoi Diagram

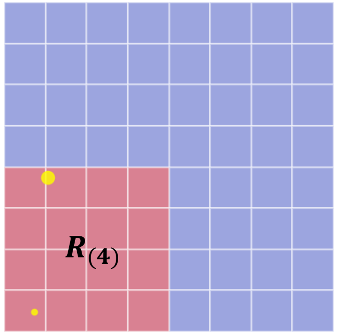


<u>Assumption 1</u>

Largest flow at sensor i

$\Downarrow$

Region $\mathrm{R}_{(\mathrm{i})}$ contains leakage

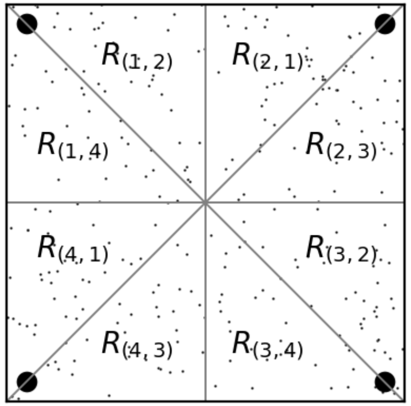


$$x = [0.09, 0.06, 0.05, 0.19]$$

MFC1 MFC2 MFC3 MFC4

$$R_{(i)} \coloneqq \{z \mid \|z - \mathrm{MFC}_i\| \leq \|z - \mathrm{MFC}_k\| \text{ for all } k \neq i\}$$

Generalized Voronoi Diagram

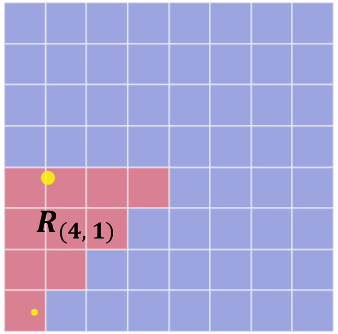


<u>Assumption 2</u>

Largest flow at sensor i and second largest at sensor j

$\Downarrow$

Region $\mathrm{R}_{(\mathrm{i},\,\mathrm{j})}$ contains leakage



$$x = [0.09, 0.06, 0.05, 0.19]$$

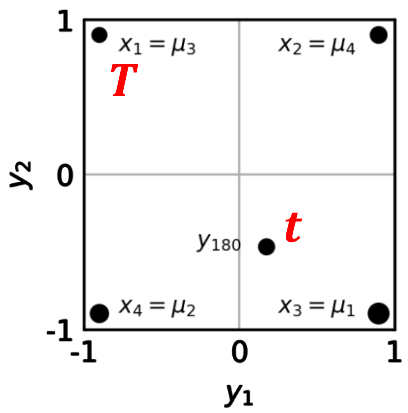
MFC1 MFC2 MFC3 MFC4

$$R_{(i,j)} \coloneqq \{z \mid \|z - \mathrm{MFC}_i\| \leq \|z - \mathrm{MFC}_j\| \leq \|z - \mathrm{MFC}_k\| \text{ for all } k \notin \{i, j\}\}$$

GROUP EQUIVARIANT NETWORK

Prior Knowledge 2

Rotation Equivariance



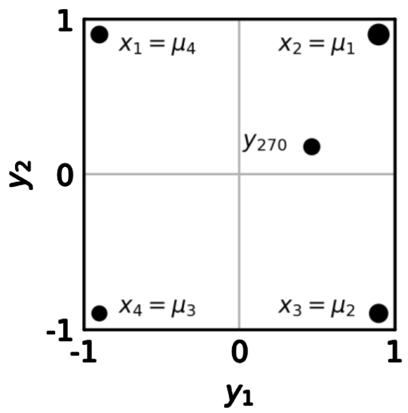
<u>Assumption 1</u>

Measurements (x_1, x_2, x_3, x_4) permuted according to 90° rotation

$$\Downarrow$$

Corresponding prediction rotates accordingly in output space

Flipping Equivariance



<u>Assumption 2</u>

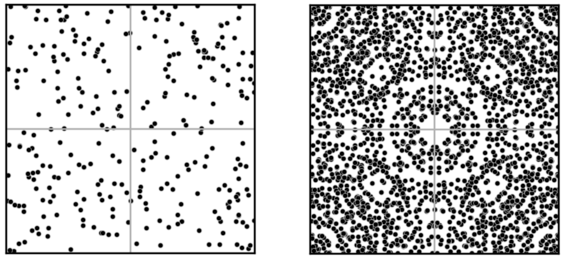
Measurements (x_1, x_2, x_3, x_4) flipped along axis

$$\Downarrow$$

Corresponding prediction flips accordingly along same axis

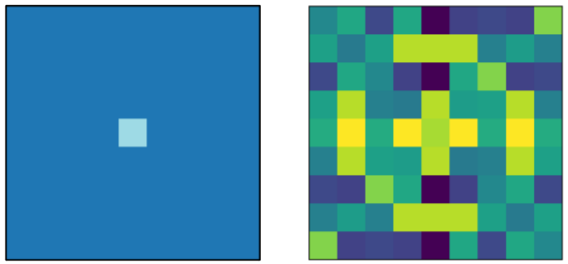
Where is the knowledge integrated?

Training Data



→ Data augmentation

Hypothesis Set

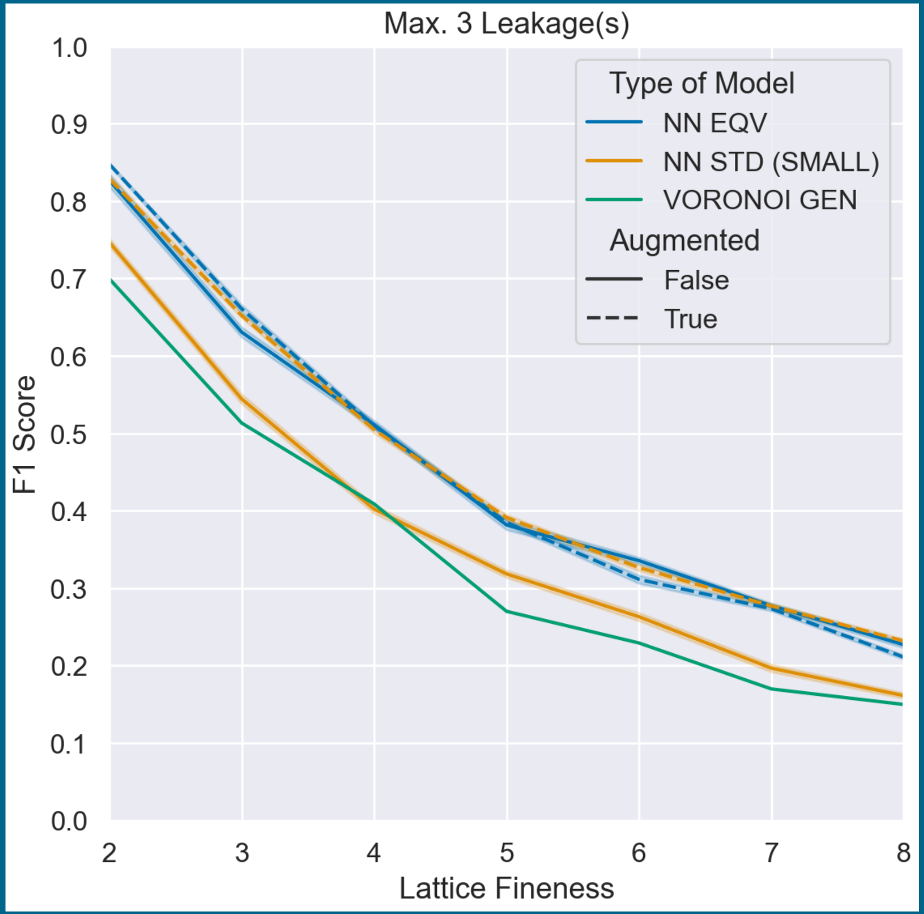


→ Group Equivariant Network

$$NN(Tx) = tNN(x)$$

NUMERICAL EXPERIMENTS

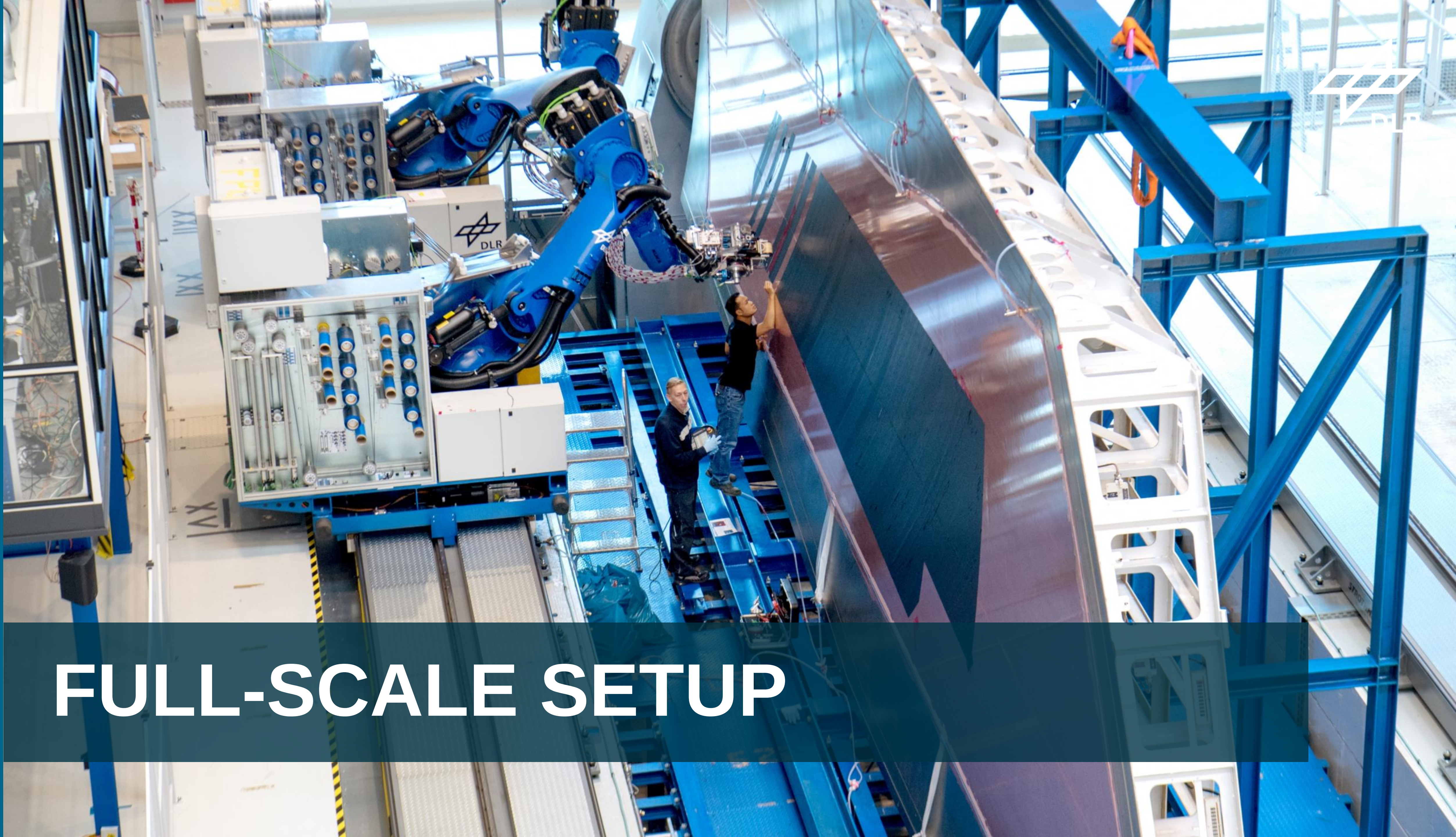
Comparison in Terms of F1 Score



$$Precision = \frac{TP}{TP+FP}$$

$$Recall = \frac{TP}{TP+FN}$$

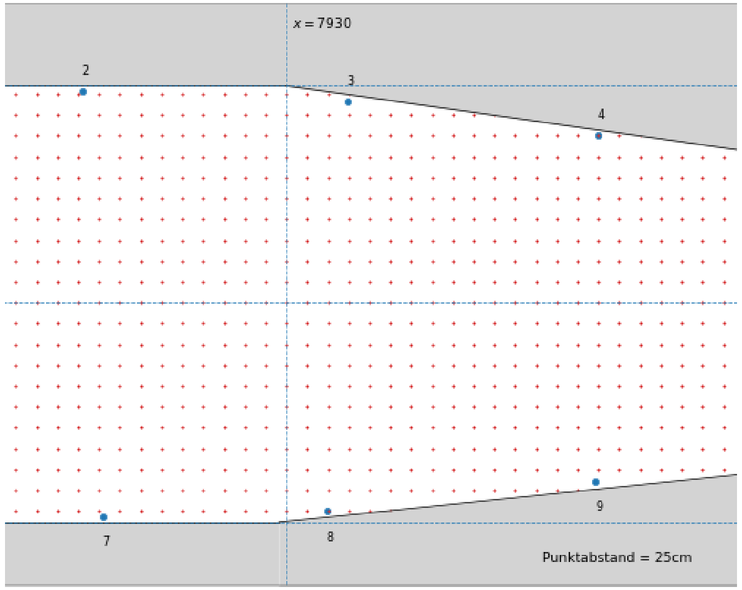
$$F1 = \frac{2}{\frac{1}{Precision} + \frac{1}{Recall}}$$

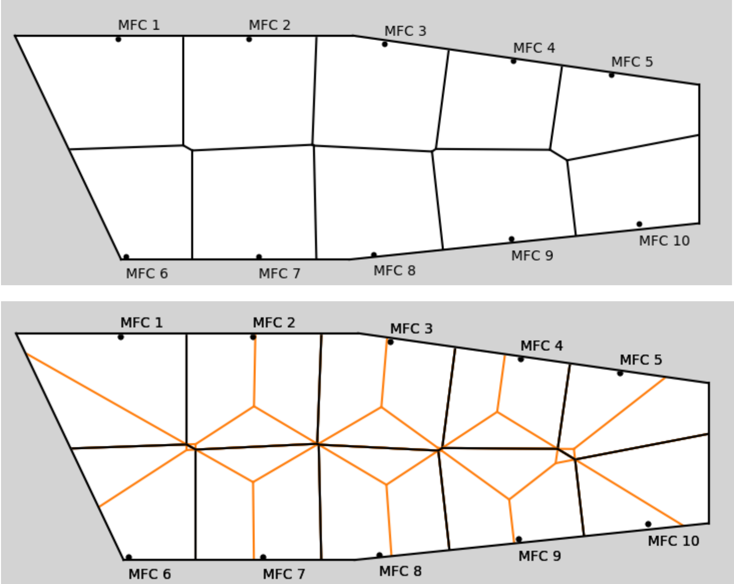


FULL-SCALE SETUP

A350 Wing Cover

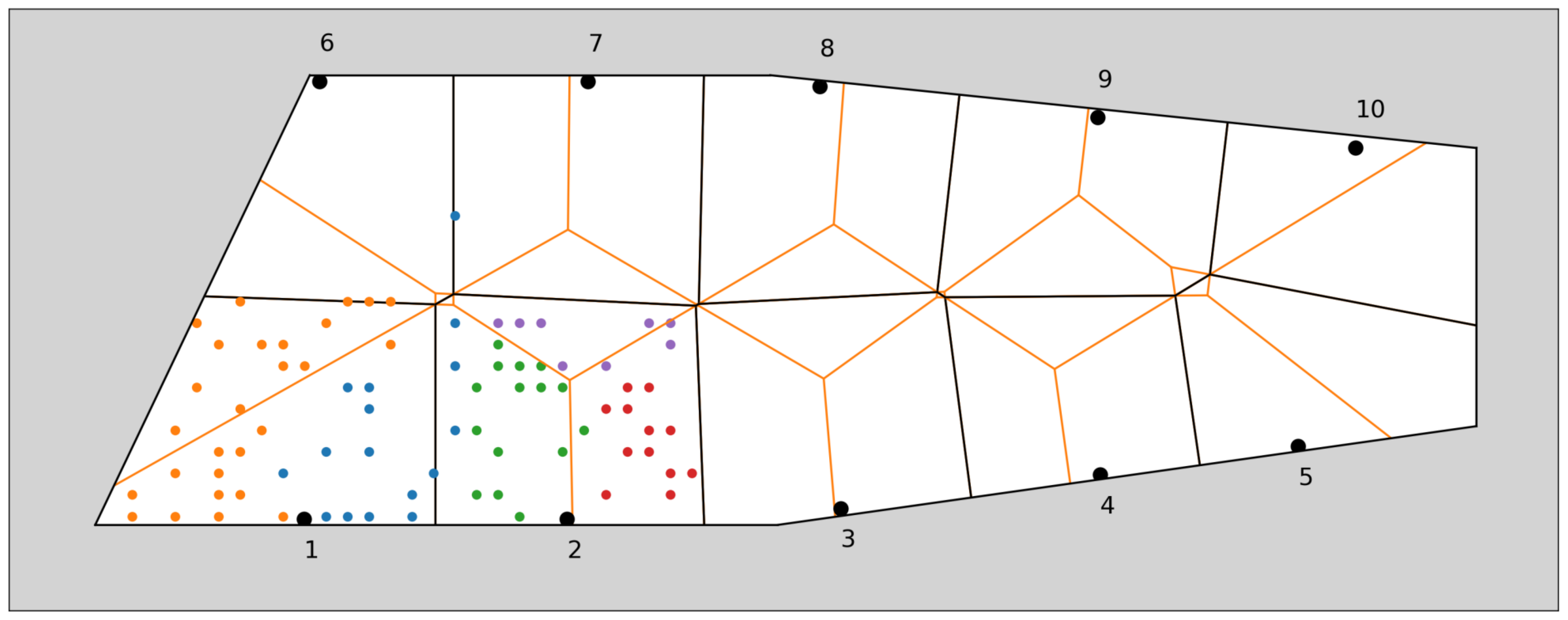
Experimental Setup	Data Acquisition	Voronoi Diagrams





- Transfer of data based leakage detection to A350 wing cover
- Currently in the data acquisition phase
- Next Step: validation of different network architectures and Voronoi diagrams

A350 Wing Cover – First Results



… and so on

SUMMARY

Summary

- Equivariant NN > Standard NN > Voronoi (Toy Setup)
- Data augmentation enhances standard NN (Toy Setup)
- Initial results suggest that Voronoi performs reasonably well in full-scale scenario (Wing Setup)
- Multi-leakage scenario and other approaches to be validated in full-scale scenario (Wing Setup)
- Presented approaches can be used for a first narrowing followed by infrared thermography
- Still a gap to be closed for the real application

Thank you!