CERTIFICATION FOR DESIGN:
RESHAPING THE TESTING PYRAMID

Structures 2025

Novel composite substructure testing approaches using multi-camera full-field imaging

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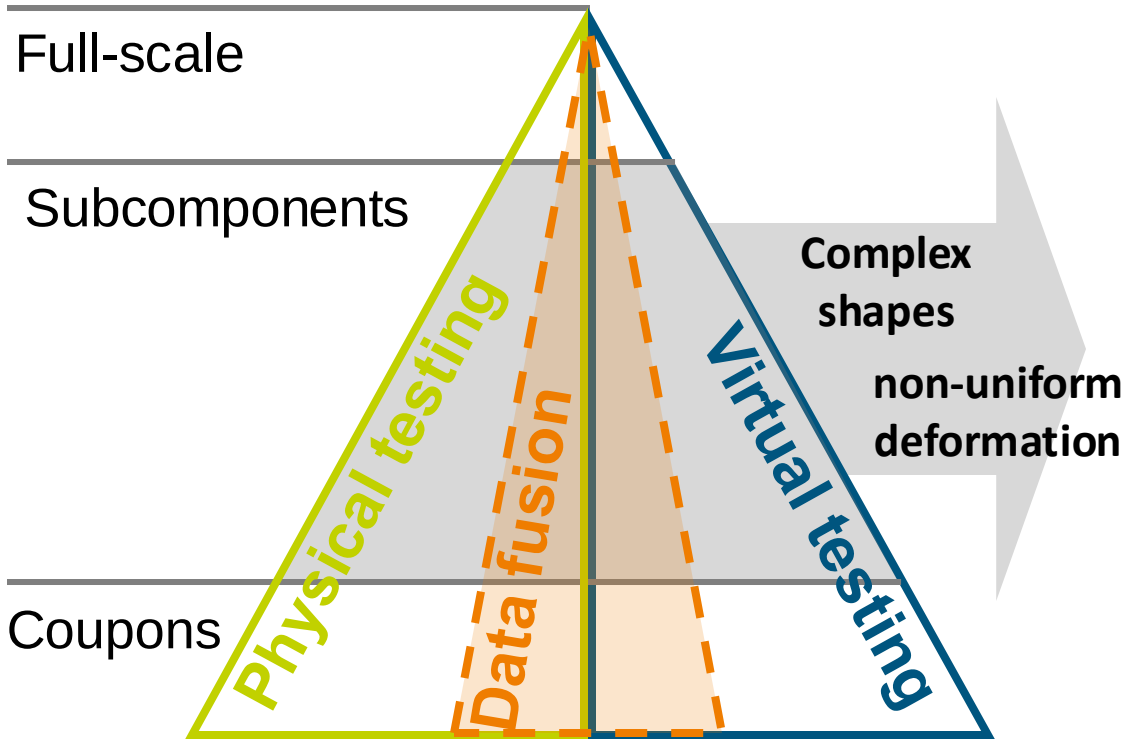
Next generation testing pyramids

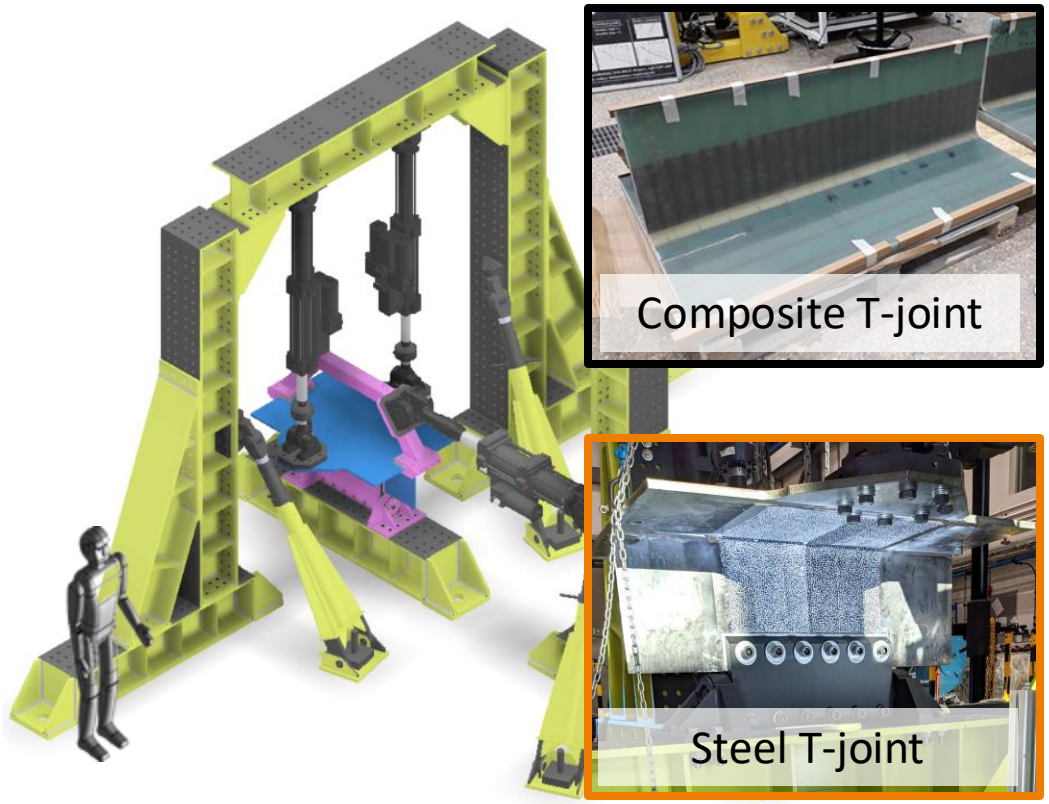
- Design & certification will increasingly rely on integrated ***physical*** and ***virtual*** testing
- Requirement for ***data fusion/correlation*** techniques to efficiently bridge the gap
- ***Multi-camera, full-field imaging*** can unlock the potential of integrated testing & modelling at subcomponent scale

DIC

IR, TSA

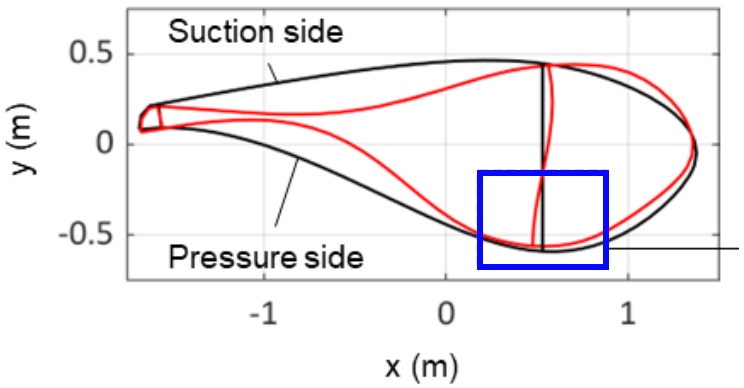
Aim & presentation overview

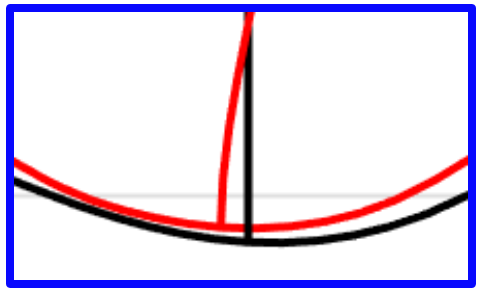
To advance and demonstrate the potential of structural evaluation on the subcomponent scale using multi-camera full-field imaging

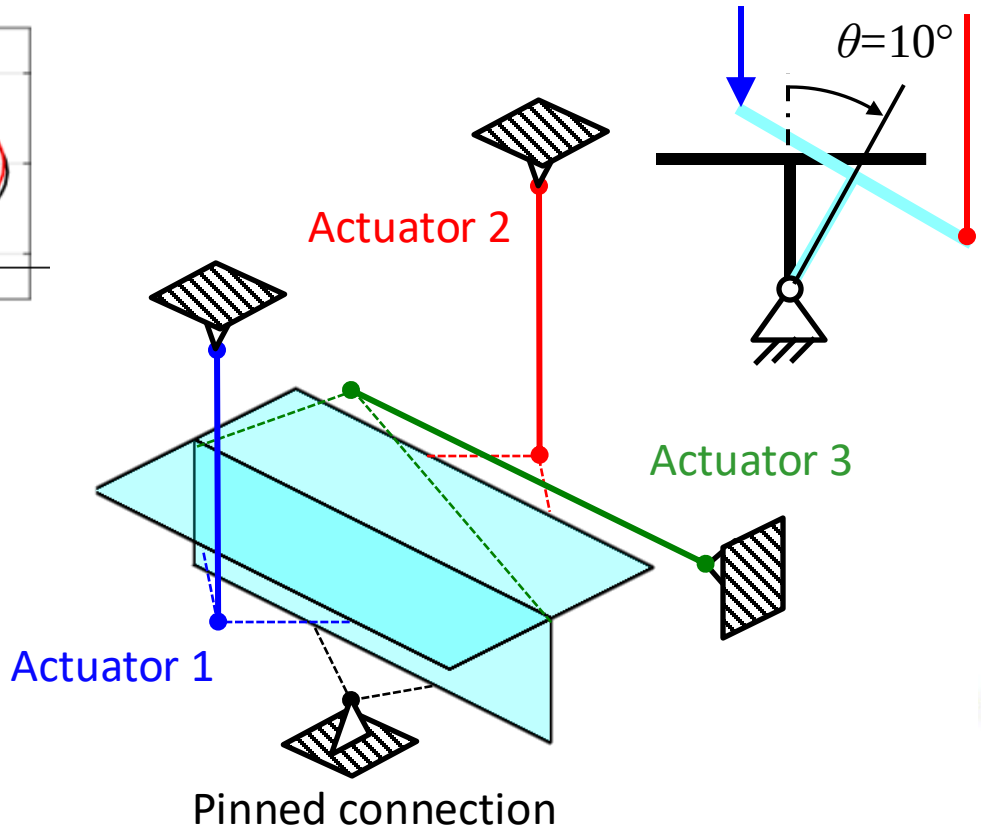


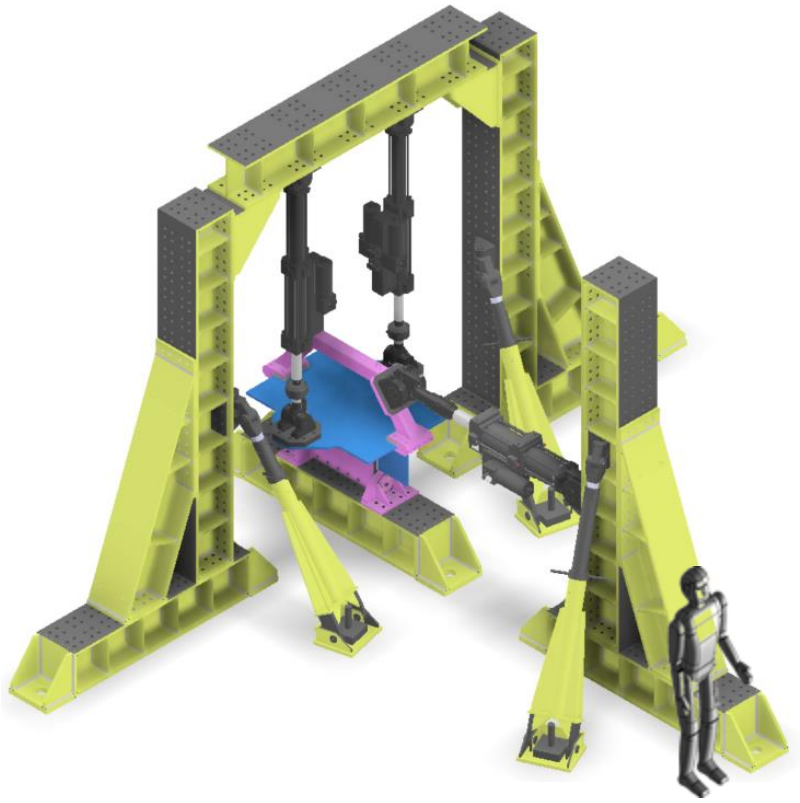
1) Definition of substructure demonstrator
2) Experimental set-up and procedures
3) Finite element model (FEM)
4) Full-field data fusion to assess gap between experiment and FEM (DIC)
5) Challenges of imaging large structures (DIC)
6) Preliminary results on composite T-joint (DIC & TSA)
7) Conclusions & future work

Novel T-joint test set-up







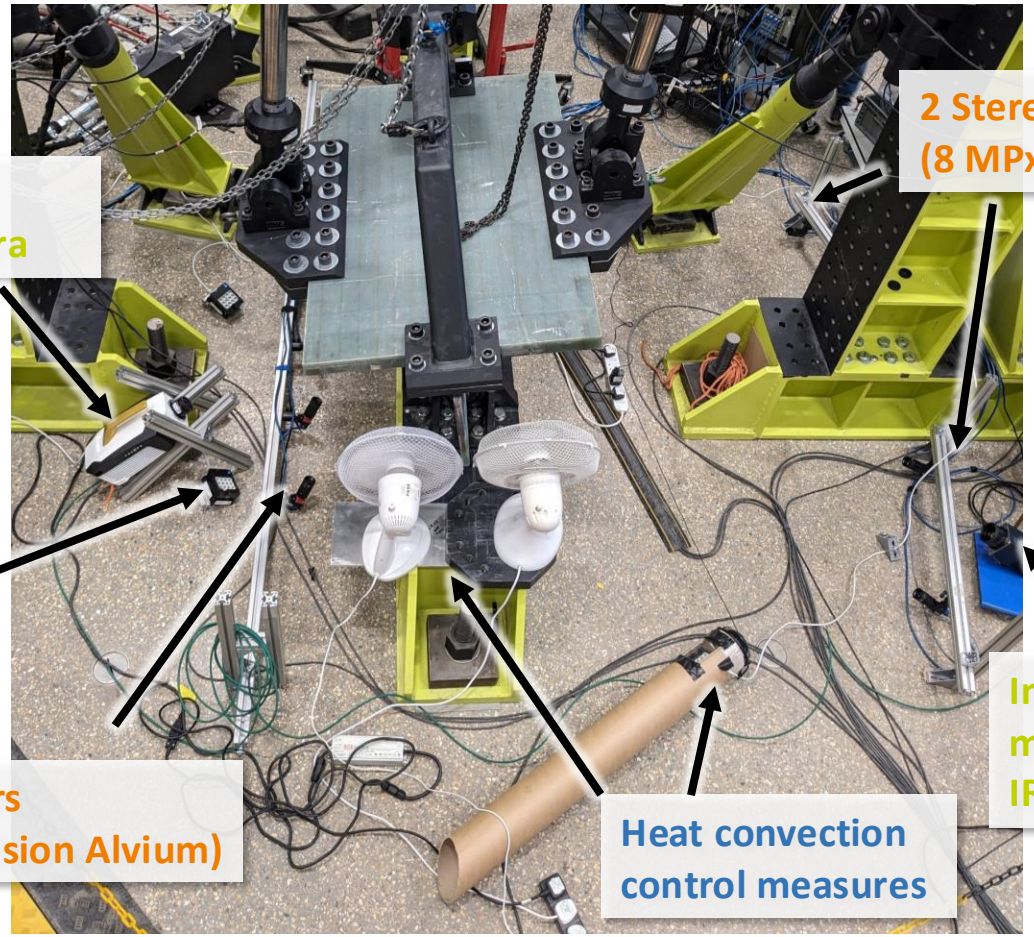


FE prediction → Test schematic → Detailed test design

Imaging set-up composite T-joint

Far side

Near side



Telops cooled sensor IR-camera

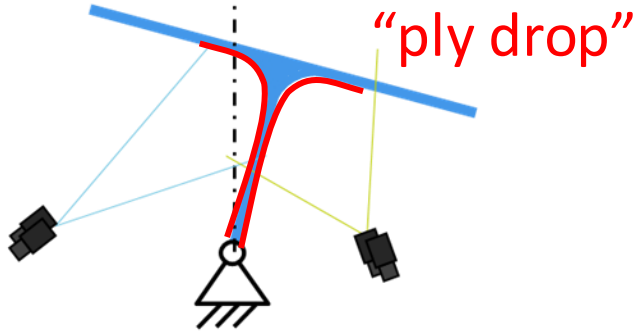
2 Stereo DIC pairs (8 MPx FLIR Blackfly)

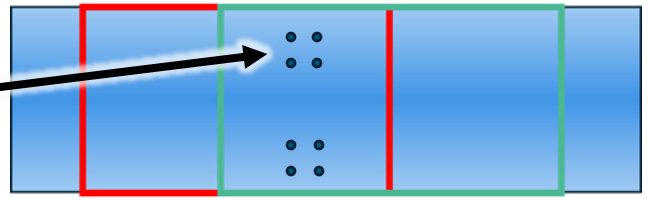
DIC strobe Lights

Infratec microbolometer IR-camera

2 Stereo DIC pairs (12 MPx AlliedVision Alvium)

Heat convection control measures



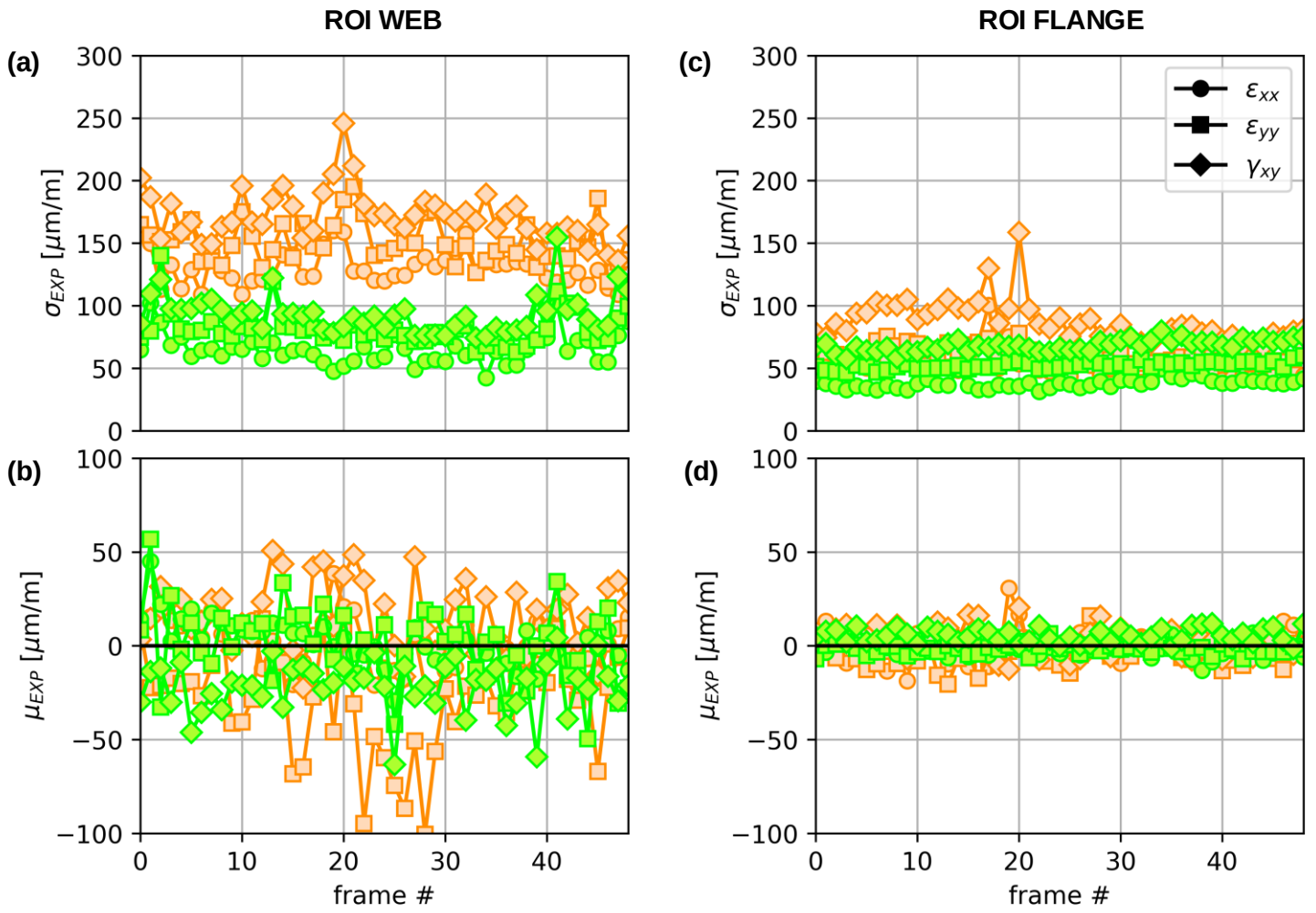


- Overlapping FoVs for multi-cam reconstruction/common fiducials
- Cross correlation between different stereo pairs

Mitigating effects of heat waves on DIC

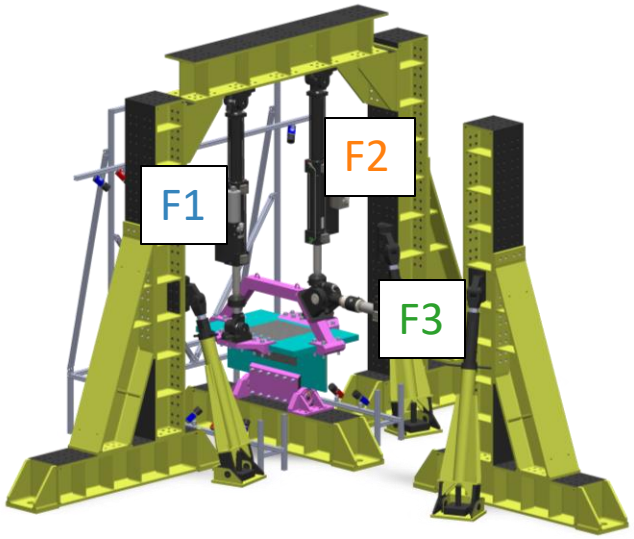
No fans,
no shield

Fans and
shield [1], [2]



[1] EMC Jones et al., Exp Mech, 2018 [2] L Yu et al., Sci Rep, 2019

Loading and DIC/IR imaging procedure



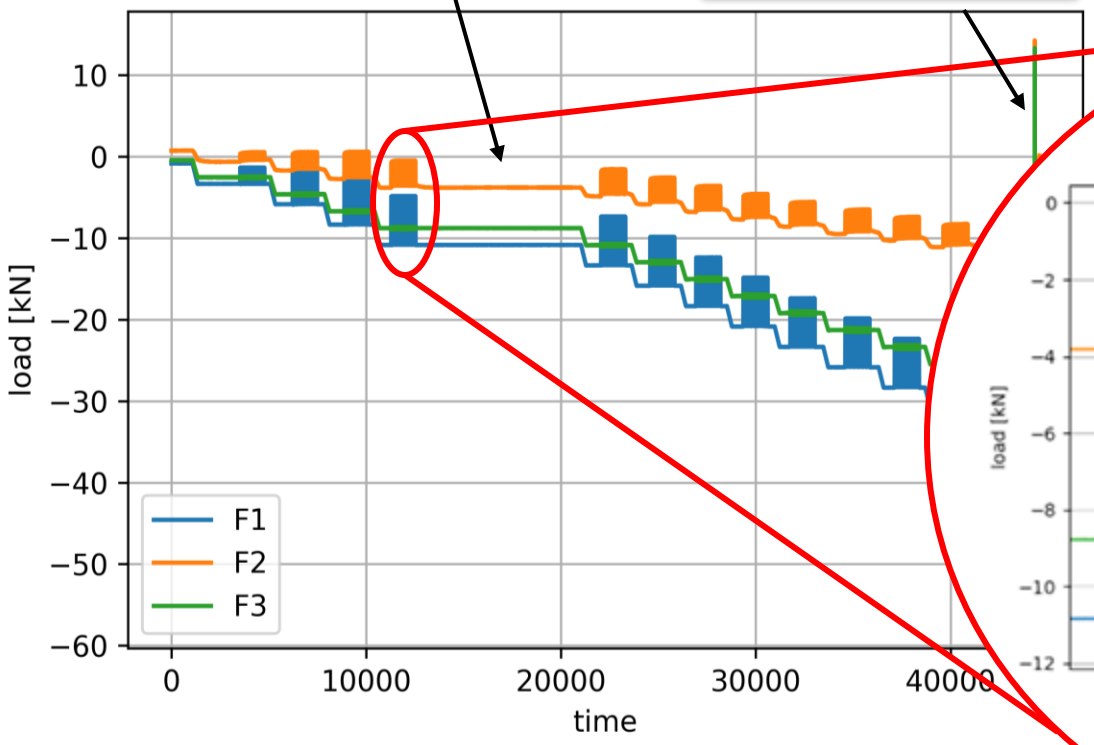
$F_1 = -2.5$ kN steps

F_2: displacement control

$F_3 = 0.833\ F_1$

Test paused for DIC and TSA data check

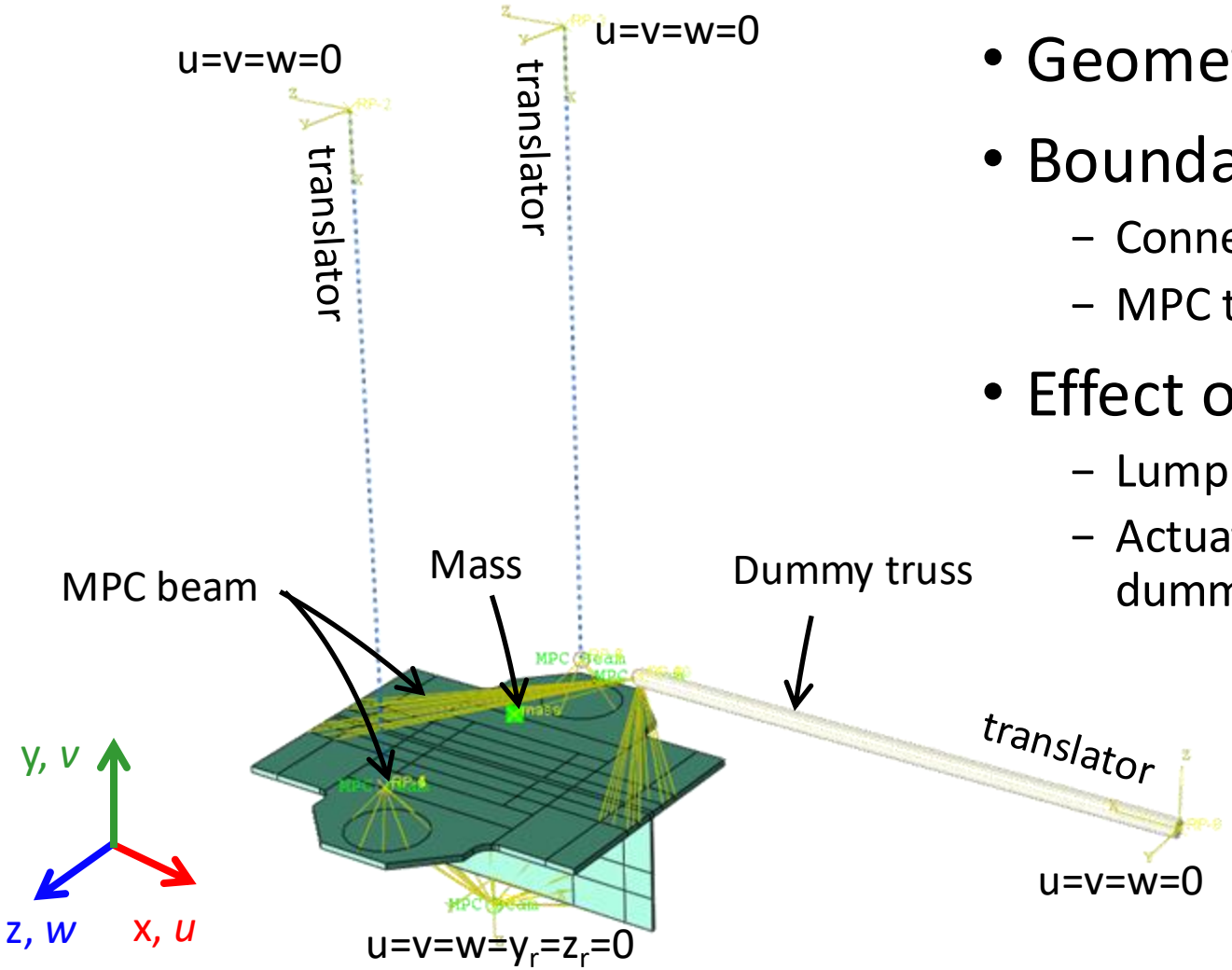
FAILURE AT:
$F_1 = -32.5$ kN
$F_3 = -27$ kN



TSA:
Cyclic load steps: $F_1 = 6\ kN$ (amplitude) and $f = 0.5\ Hz$ (frequency), to check for damage

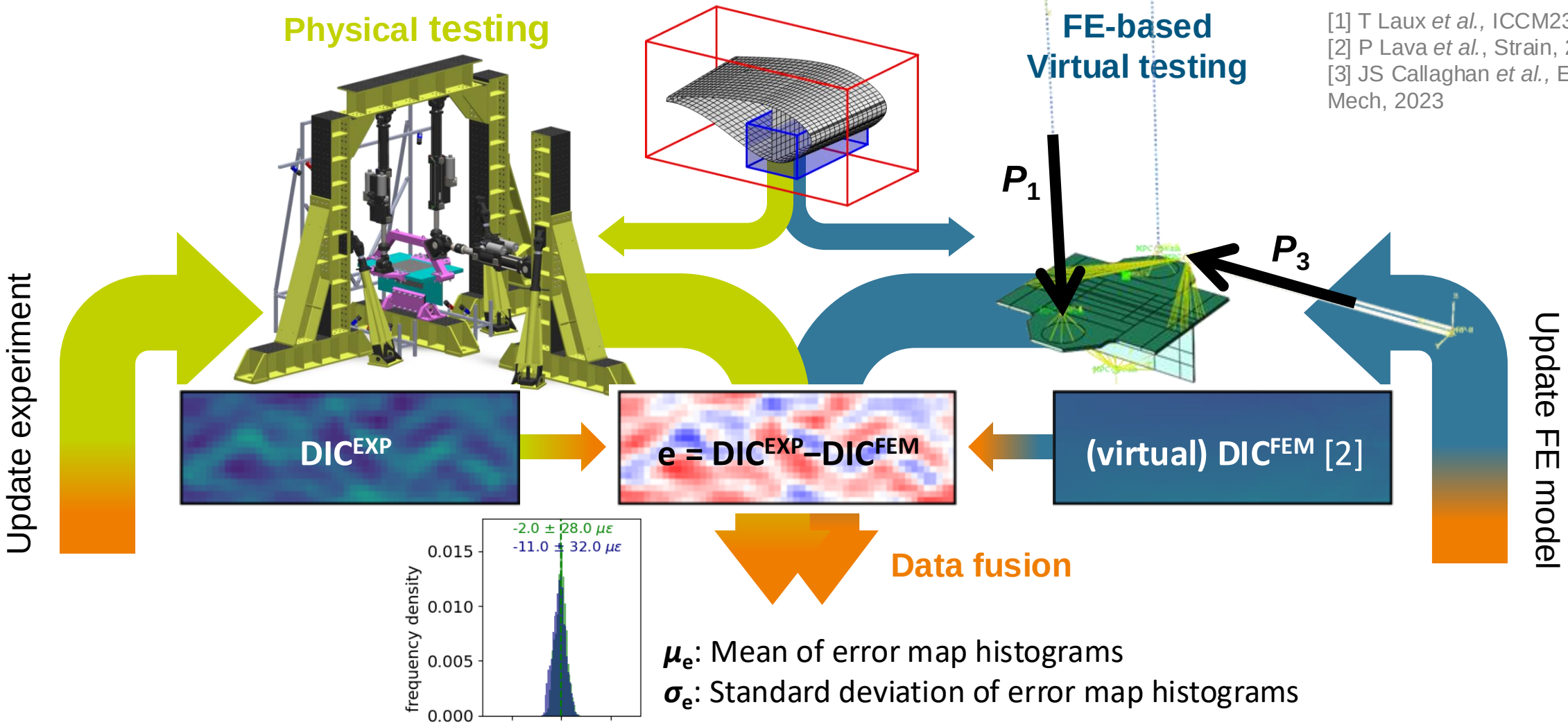
DIC: 20 images for image averaging

T-joint subcomponent FE model



- Geometrically nonlinear solid model
- Boundary conditions
  - Connector type translator for actuators
  - MPC type beam, coupling, and RPs to include clamps
- Effect of gravity
  - Lump mass for horizontal shear arc
  - Actuator 3 mass accounted for using truss element with dummy stiffness & density
- Thermoelastic effect
  - Included using user defined subroutine and heat transfer modelling
  - Comparison between adiabatic and non-adiabatic TSA solution

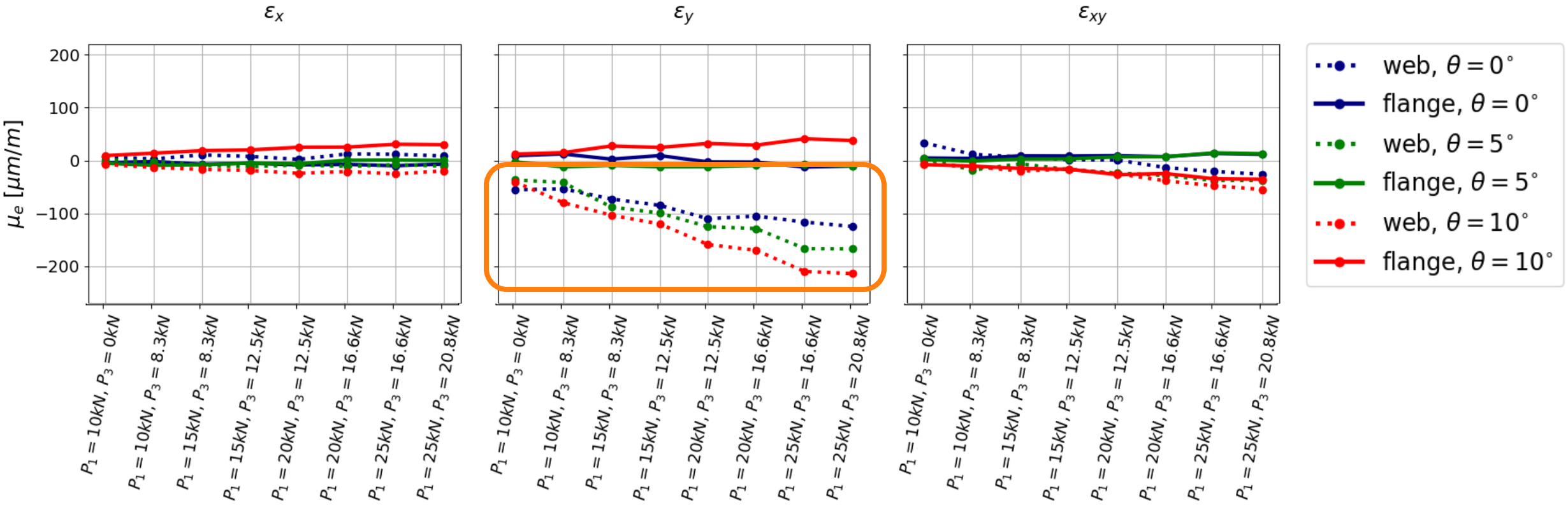
Full-field data fusion for integrated testing & modelling



[1] T Laux *et al.*, ICCM23, 2023
[2] P Lava *et al.*, Strain, 2020
[3] JS Callaghan *et al.*, Exp Mech, 2023

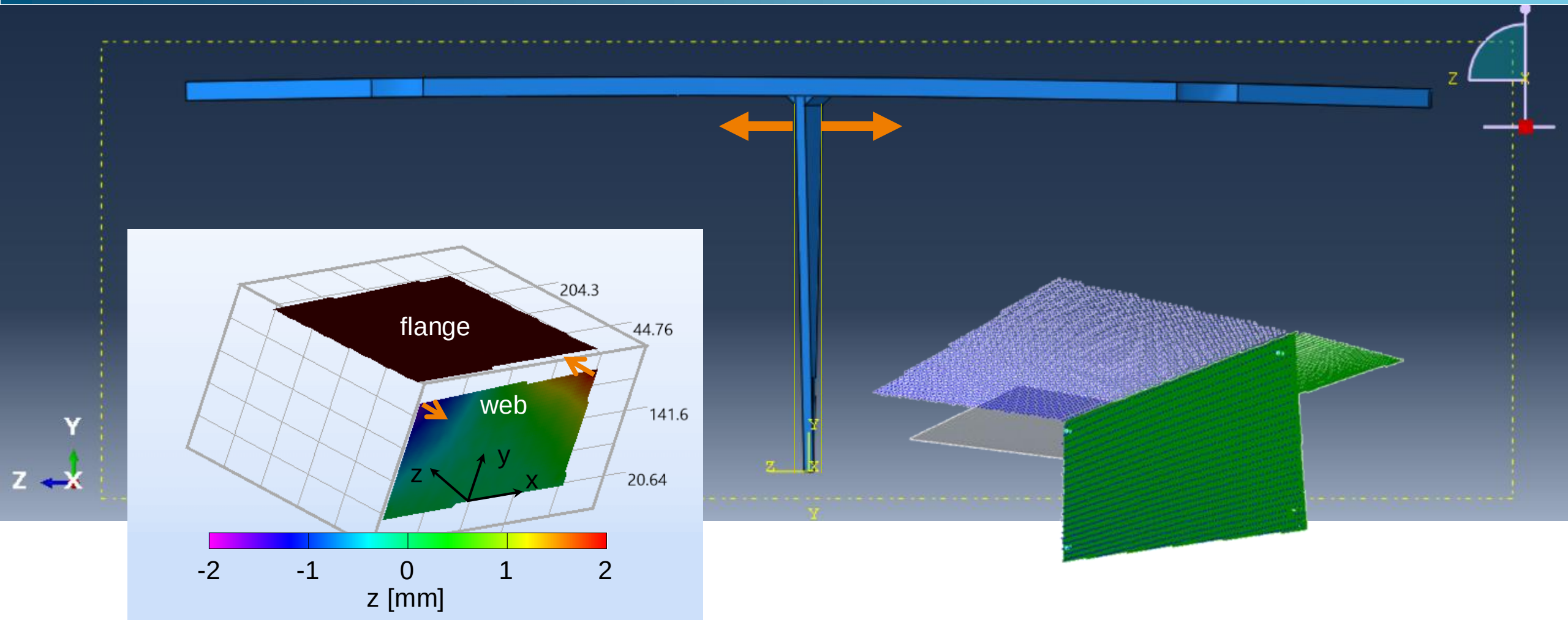
μ_e: Mean of error map histograms
σ_e: Standard deviation of error map histograms

Comprehensive initial model evaluation

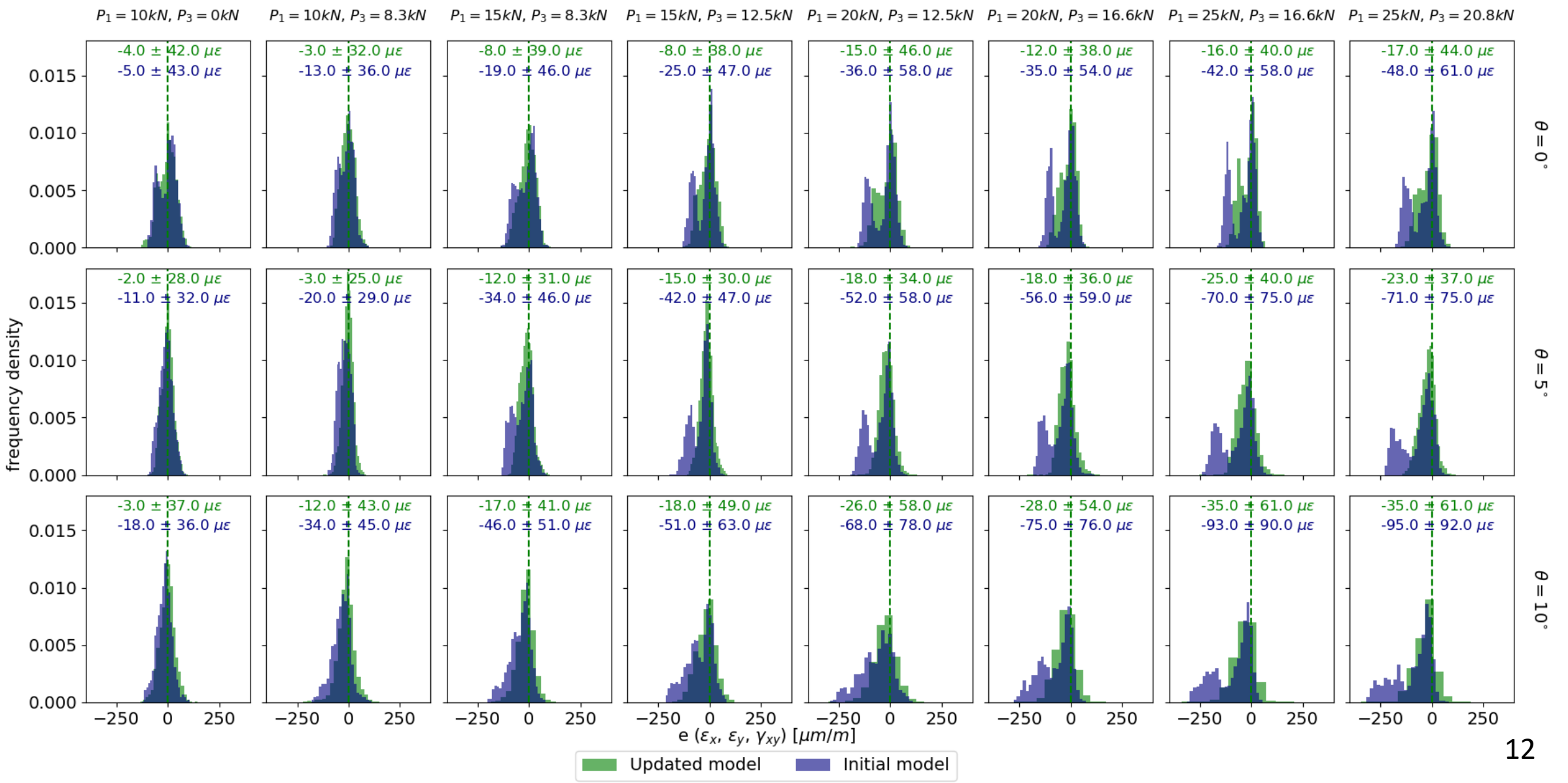


- Most $\boldsymbol{\mu_e}$ within +/-50 με
- Exception is $\boldsymbol{\varepsilon_y}$ in the web ROI where $\boldsymbol{\mu_e}$ builds with load up to 200 με, indicating a significant discrepancy between model and experiment

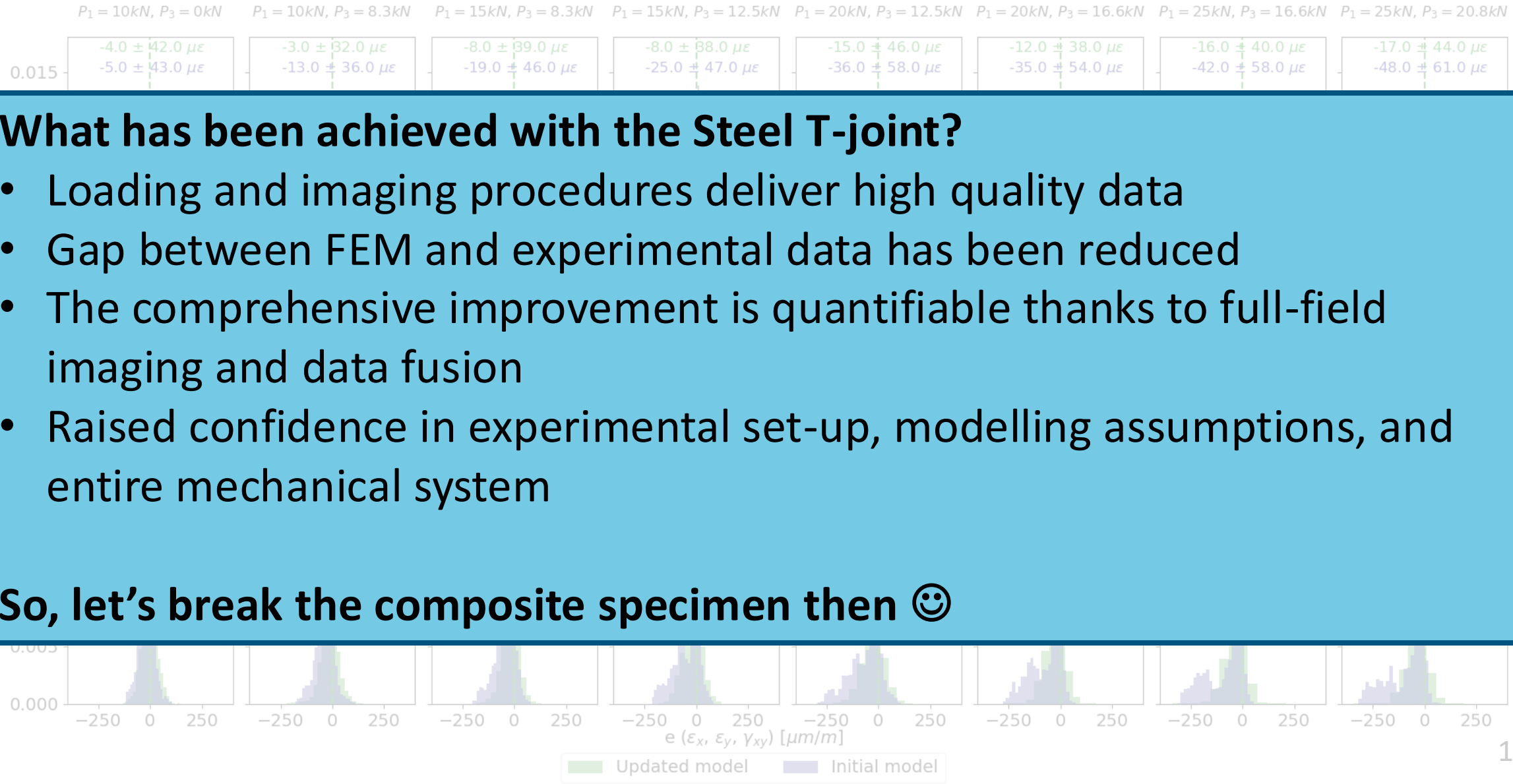
Updated FE model



Combined errors (ε_x, ε_y, γ_{xy}) – web



Combined errors (ε_x, ε_y, γ_{xy}) – web



What has been achieved with the Steel T-joint?

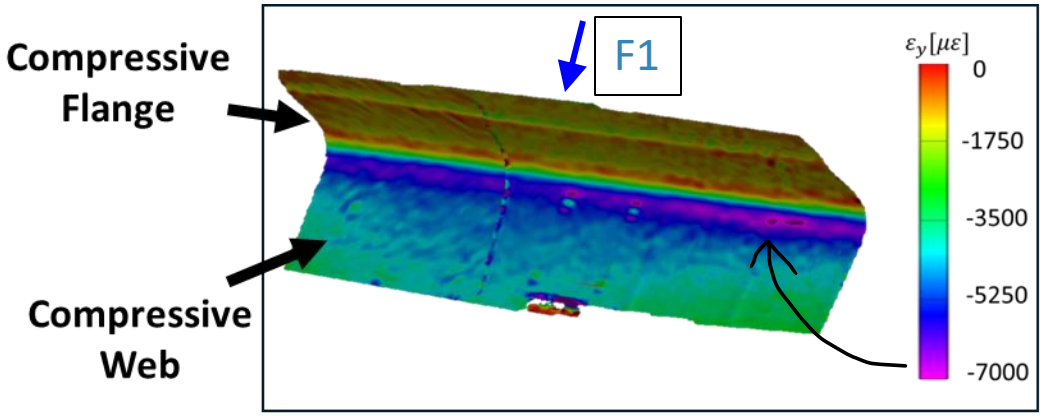
- Loading and imaging procedures deliver high quality data
- Gap between FEM and experimental data has been reduced
- The comprehensive improvement is quantifiable thanks to full-field imaging and data fusion
- Raised confidence in experimental set-up, modelling assumptions, and entire mechanical system

So, let's break the composite specimen then ☺

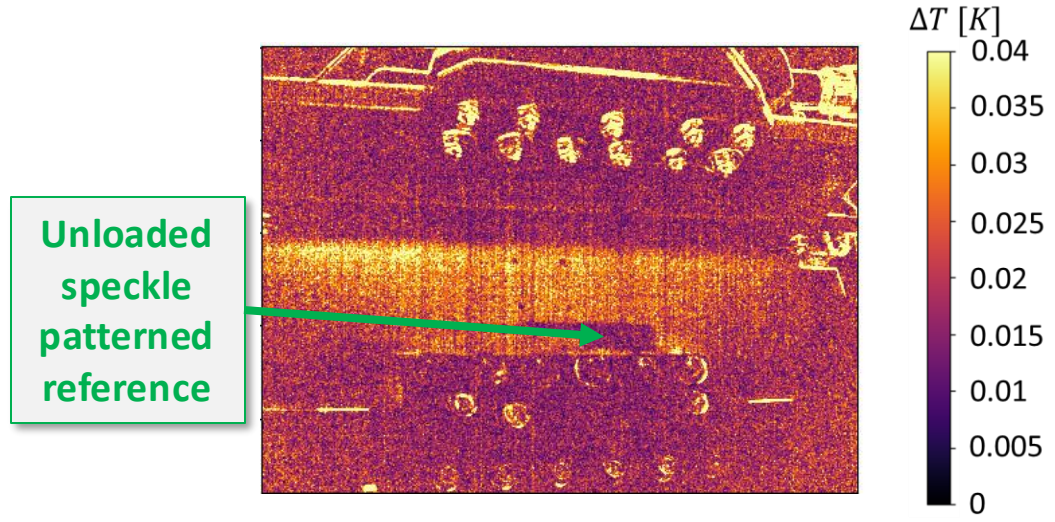
Composite specimen before initial failure

Near side

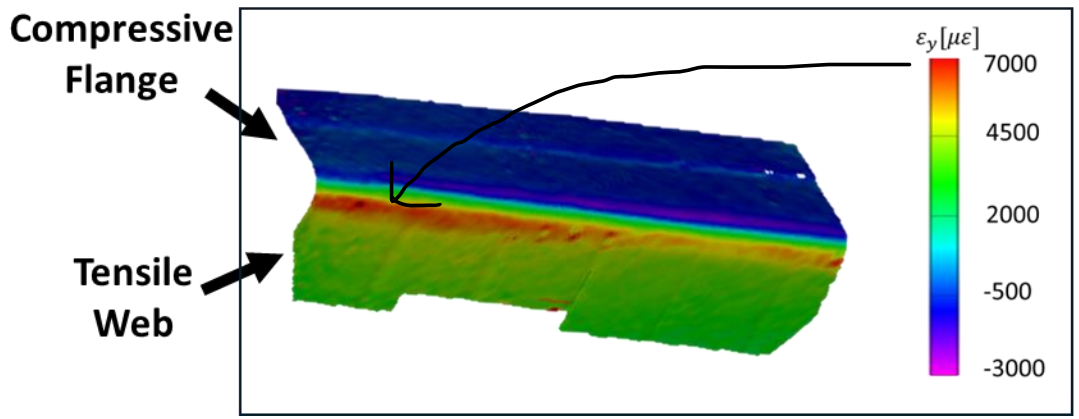
DIC

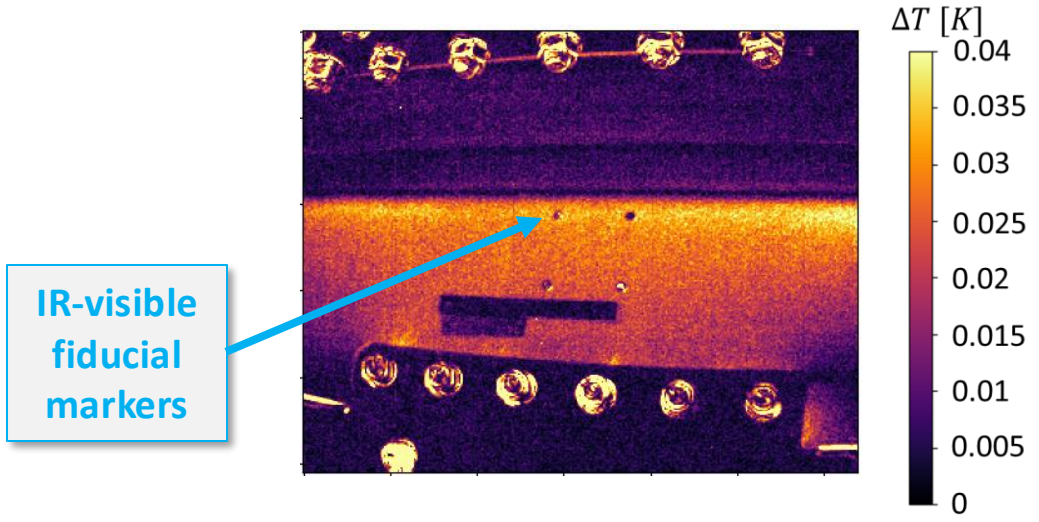


TSA



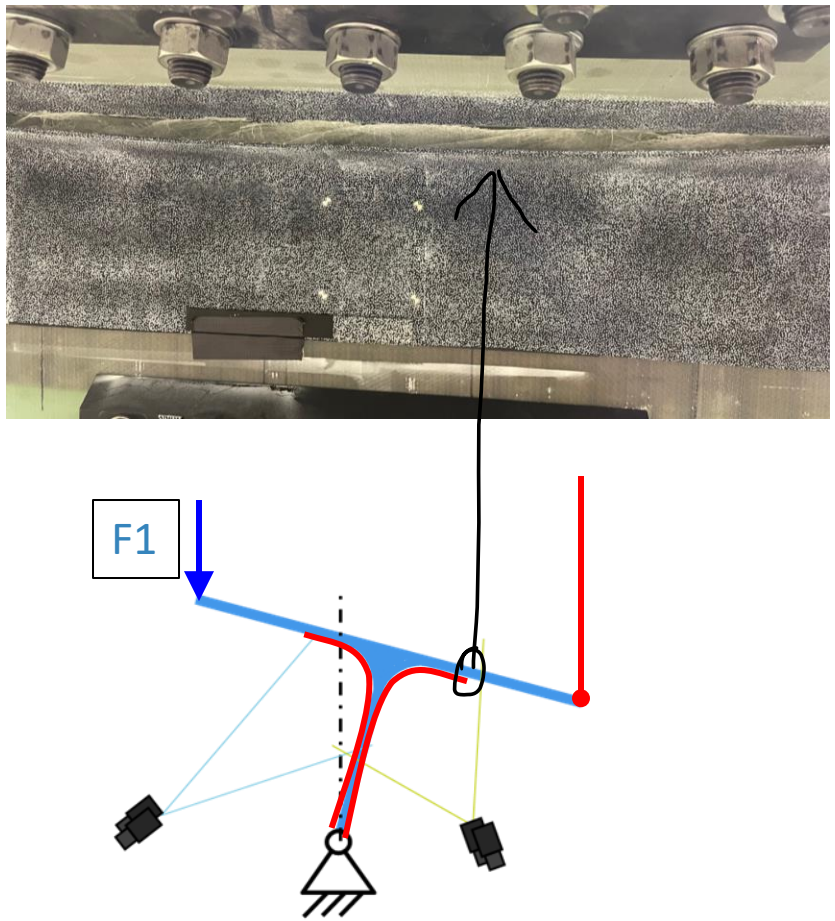
Far side





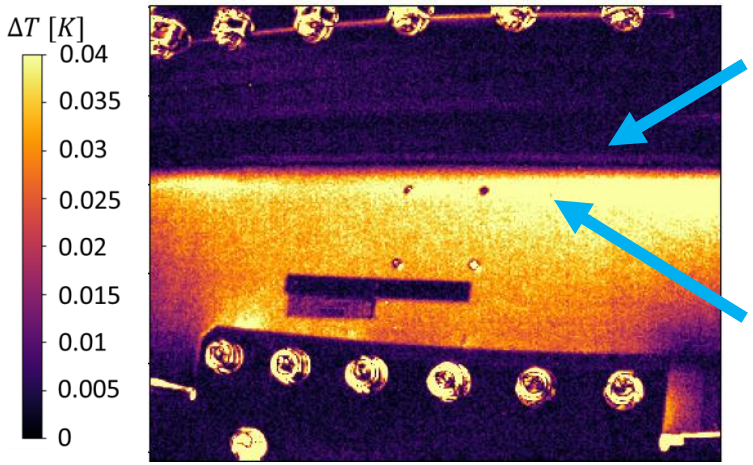
Forensic failure analysis

Post failure: ply drop delamination



Undamaged specimen

Damaged specimen



Reduction of thermoelastic signal on ply drop

Increase of thermoelastic signal in the web, indicating stress redistribution

Conclusions & future work

- Full-field imaging (DIC & TSA) and data fusion enables integrated testing and modelling at the subcomponent scale, providing an efficient and comprehensive means of structural evaluation and model validation.
- High quality DIC data on the subcomponent scale is challenging to obtain due to compounding sources of uncertainty (short focal length lenses, thermal errors, etc.)
- Future work: application of farmwork to composite T-joint experimental data; can we repeat the steel T-joint work given the increased uncertainties associated with the composite specimen, *i.e.* material properties, defects?

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Thank you for your attention.
Any questions?

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