Towards Robotic Train Fluid Service in Today and Tomorrow Depots (CyberFluids+)

Dr. Mingfeng Wang
PhD CEng FHEA MIEEE MIMechE MIFToMM

Senior Lecturer in Robotics & Autonomous Systems
Depart. of Mechanical & Aerospace Engineering
Brunel University of London
Email: Mingfeng.Wang@Brunel.ac.uk

Vision: Specialised Robotic Systems for Challenging Environments

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Industrial Strategy | UK Research and Innovation

Industry Partners:

Rolls-Royce

Sellafield Ltd

syngenta

G's

RSSB

Chilternrailways by arriva

Confined Environment (Aeroengine)

Continuum Robots

Extreme Environment (Nuclear Facility)

Legged Robots

Train Maintenance Robots

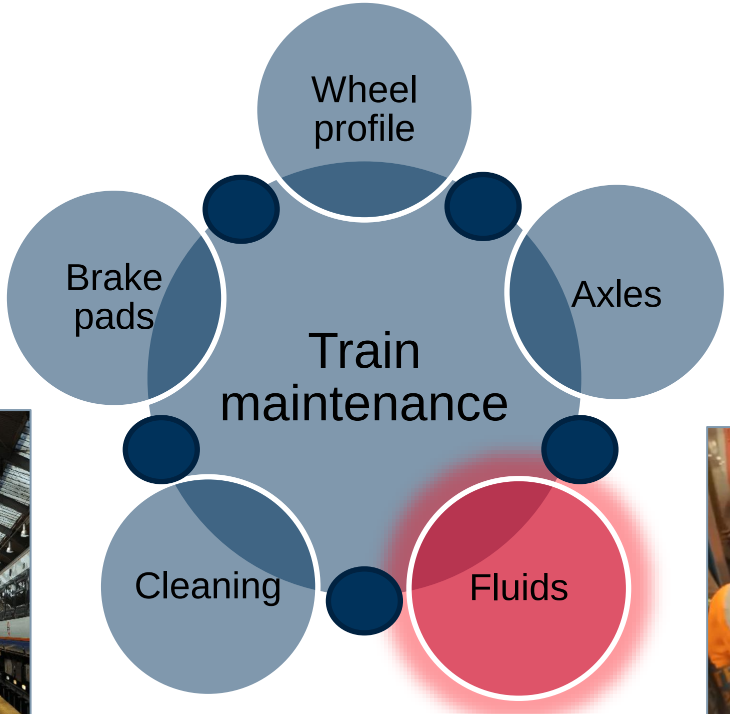
Labour-intensive Environment (Train)

Precision Farming Robots

Labour-intensive Environment (Organic Farm)

Harper Adams University

Background: Train Maintenance Challenge

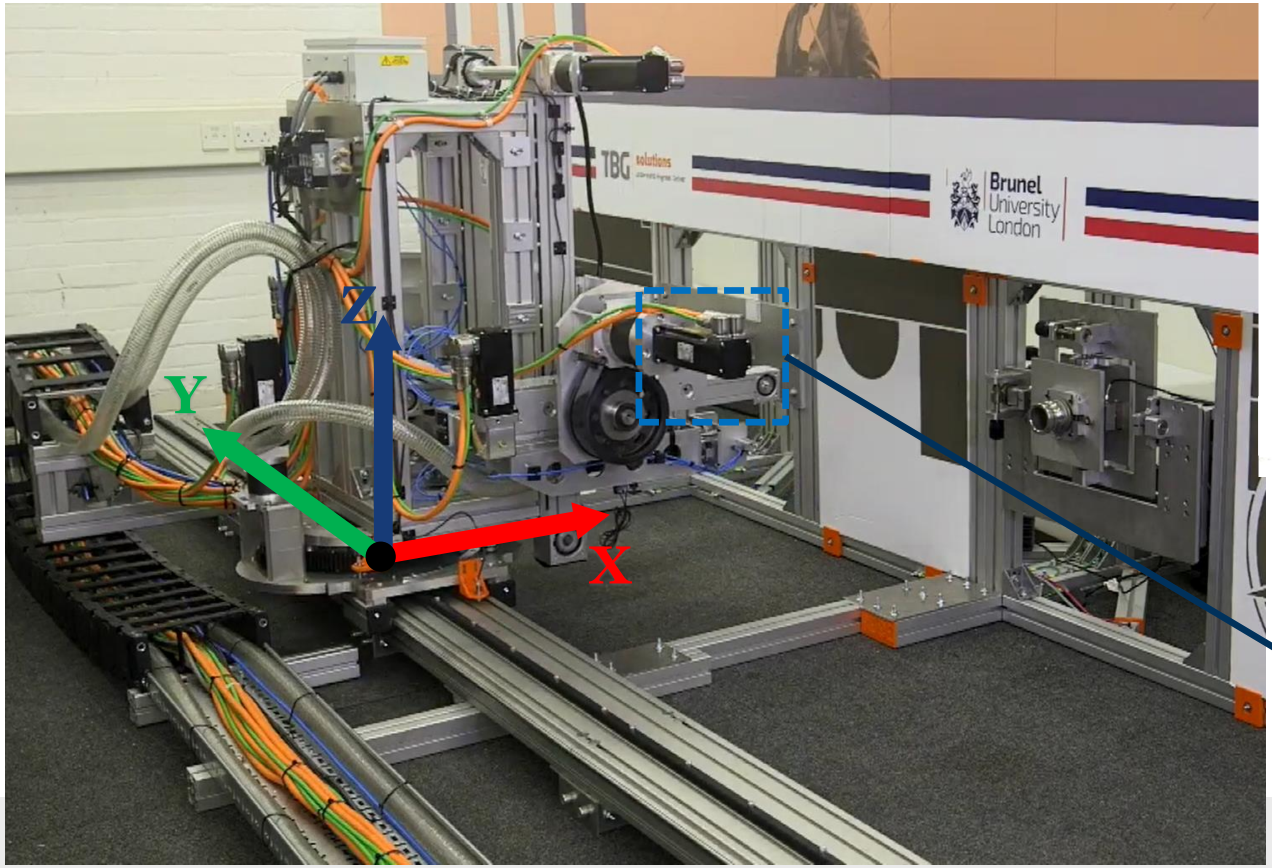


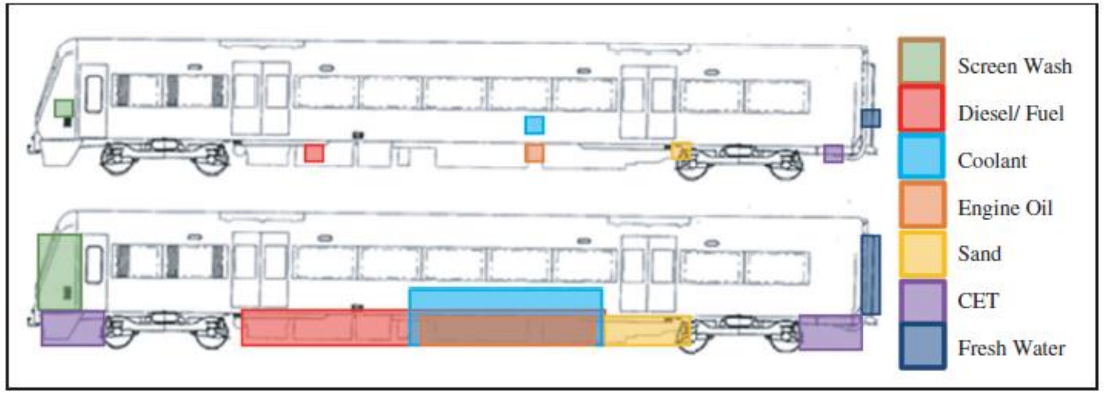
CyberFluids robot
By Brunel University London

Background: What's CyberFluids Robot?

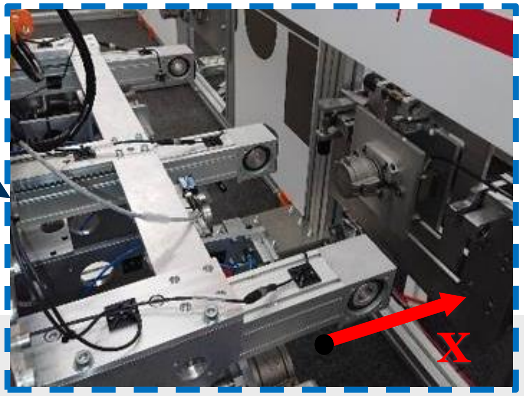
7-DoF Robotic System for autonomous passenger train fluid servicing (e.g., fuel, controlled emission toilets (CET), wheel sand, etc)

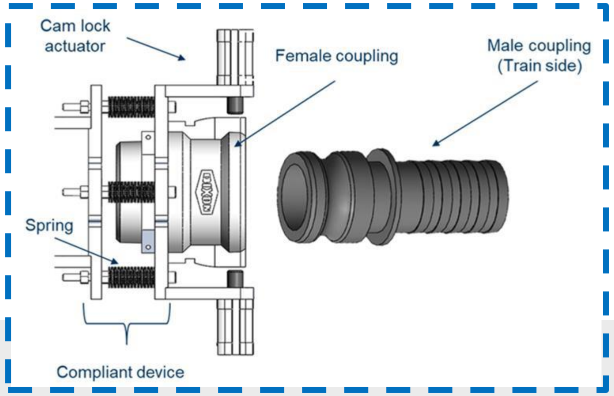
- **4 DoFs** for positioning (along Y- and Z-axes) and orienting (yaw and pitch);
- **3 DoFs** for three 1-DoF manipulation arms (along X-axis) with different end-effectors.



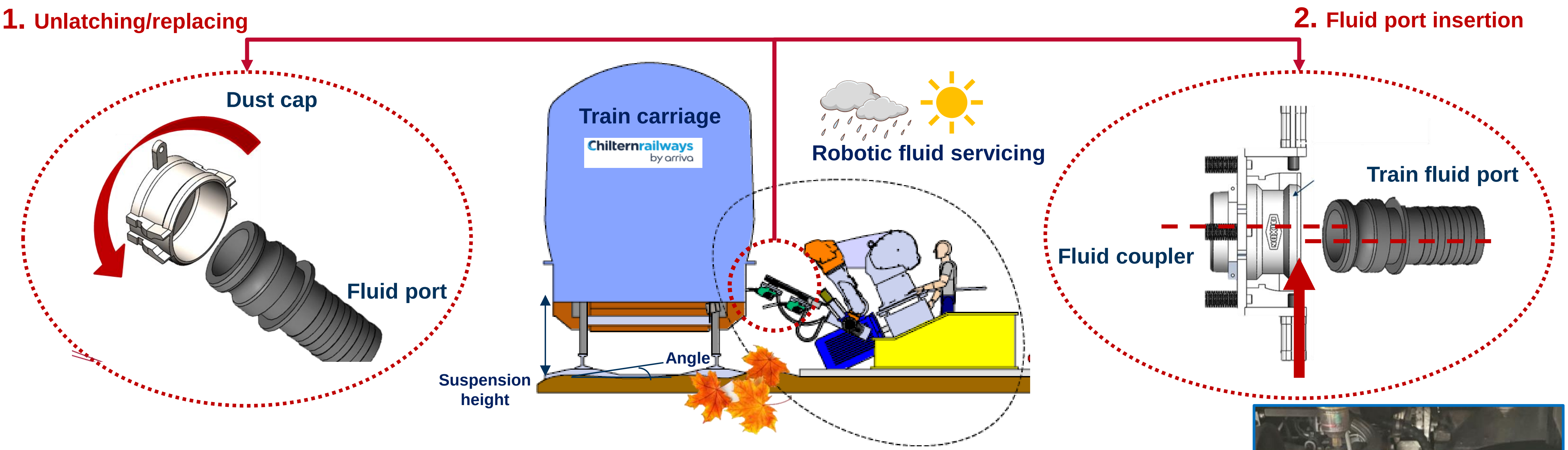


Fluid port locations on a BR Class 168 rail vehicle (top) and across similar vehicles (bottom)





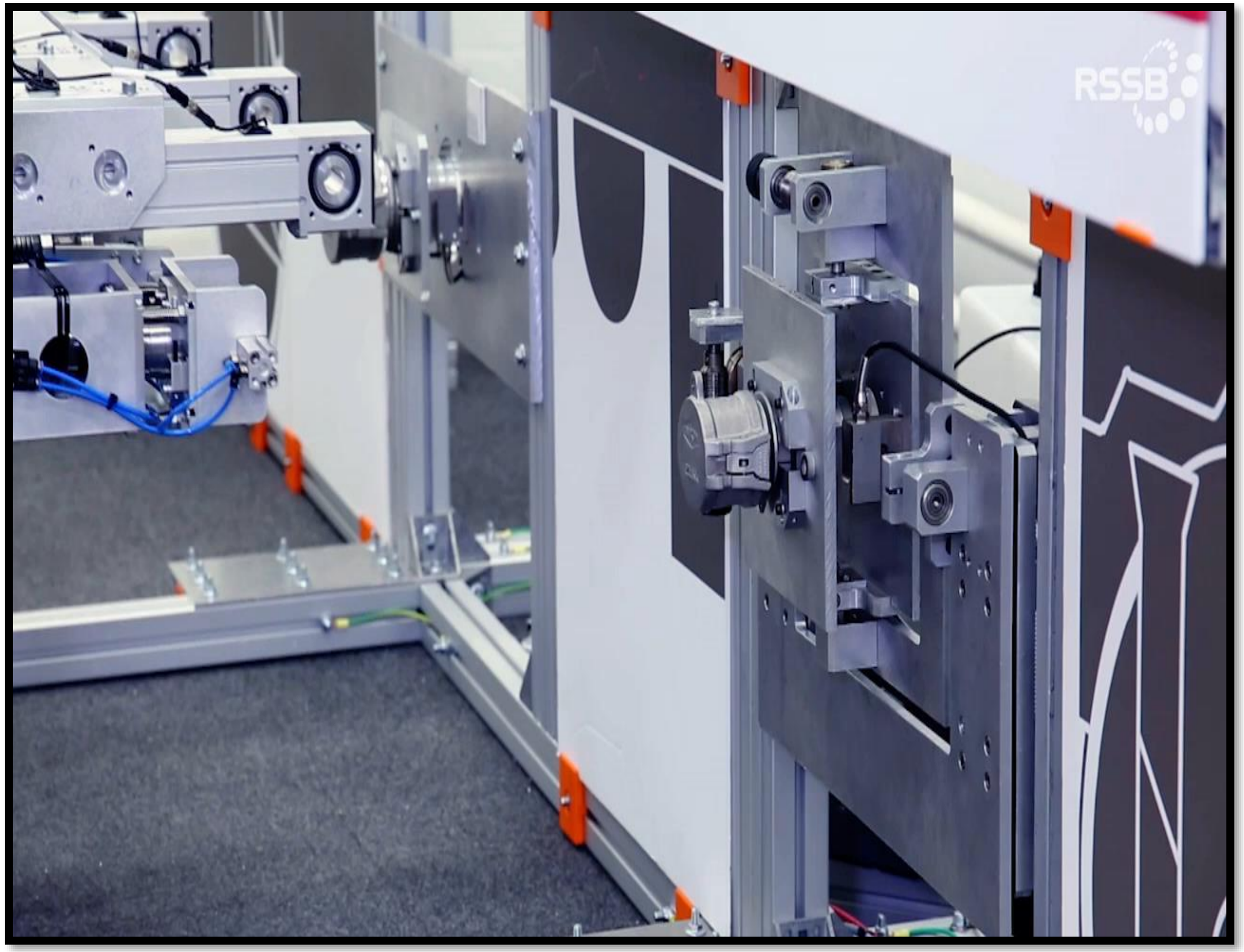
Problem: Misalignments in autonomous robotic servicing



- In outdoor environments of train maintenance, robot workspace is **unstructured**.
- Autonomous locating of fluid ports may **not accurate.**
- There will always be **misalignments** between the robot and the train fluid ports.
- **Compliant end-effectors** are required for **flexible coupling** and **gripping**.

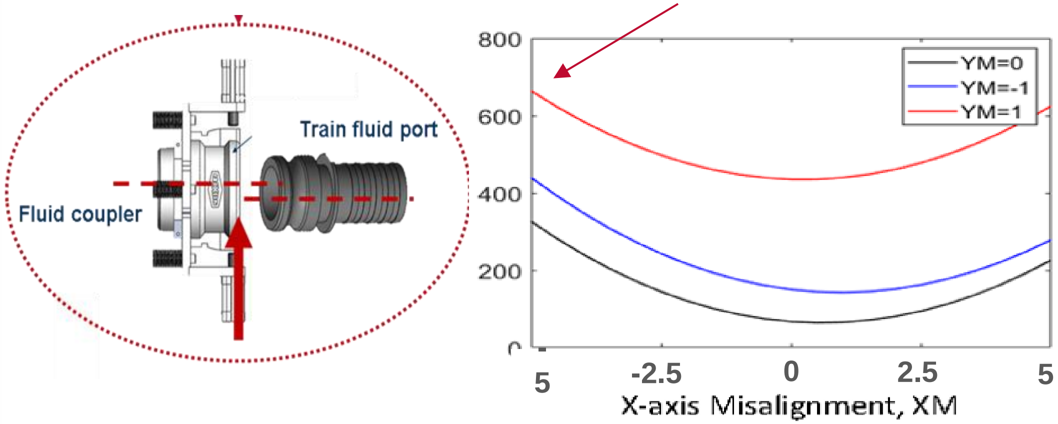
Problem: Misalignments in autonomous robotic servicing

CyberFluids robot

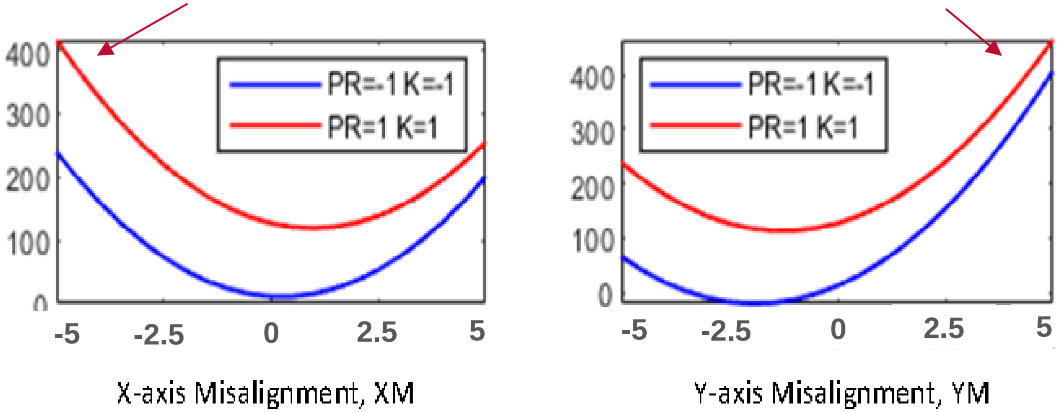


Maximum Insertion Force vs Misalignments

NOMINAL: 5mm parallel misalignment ≈ 700 N insertion force



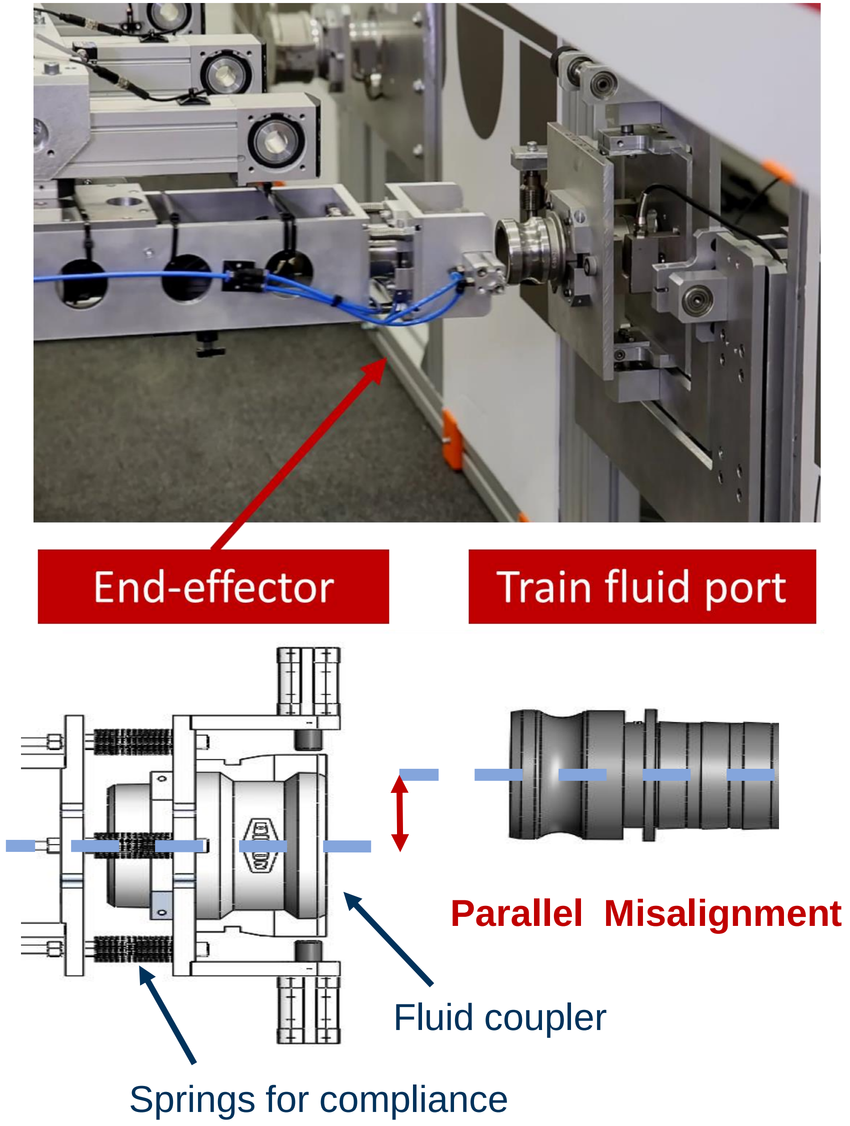
OPTIMISED: 5mm parallel misalignment ≈ 400 N insertion force

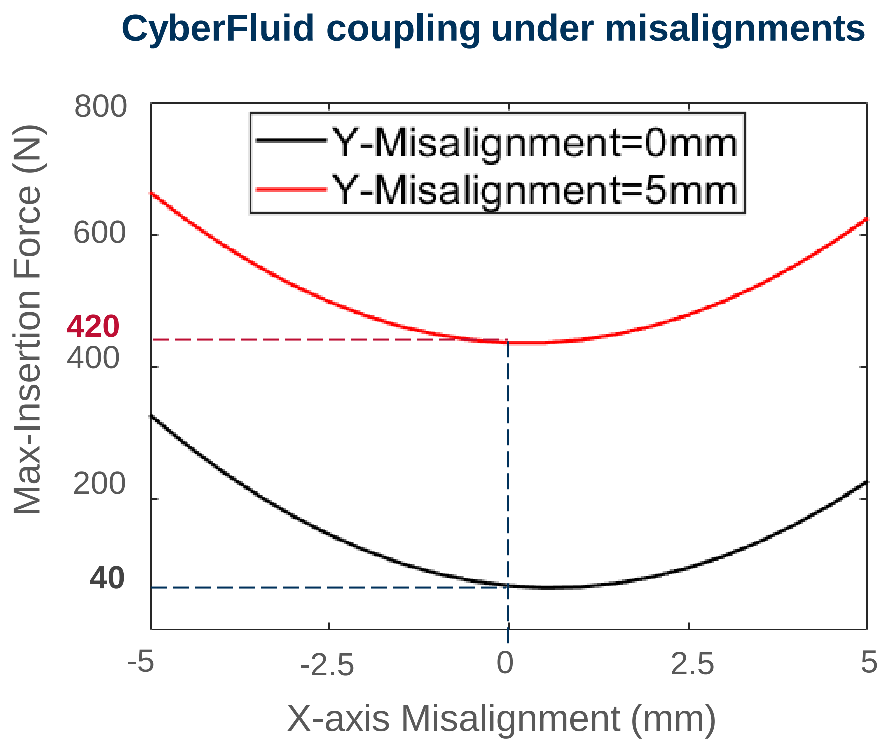


[Eshraghi *et al.* (2020)]

Eshraghi, K., *et al.* (2020). ‘Preliminary study on end-effector compliance in automated fluid coupling for trains’ *Proceedings of TMCE 2020, (pp. 205-216*). Dublin.

Problem: Misalignments in autonomous robotic servicing

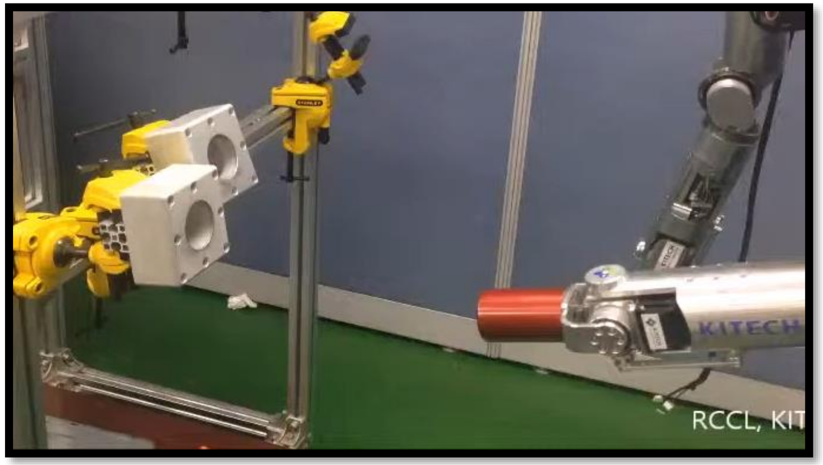


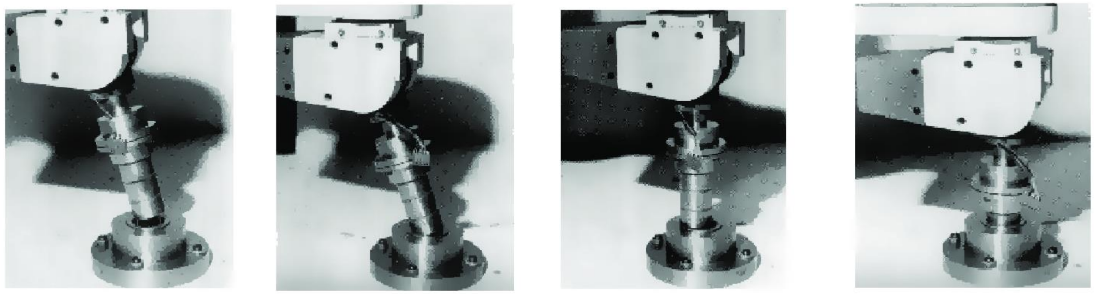


Misalignments introduce significant insertion force
(e.g., approx. 10 times with 5mm parallel misalignment)

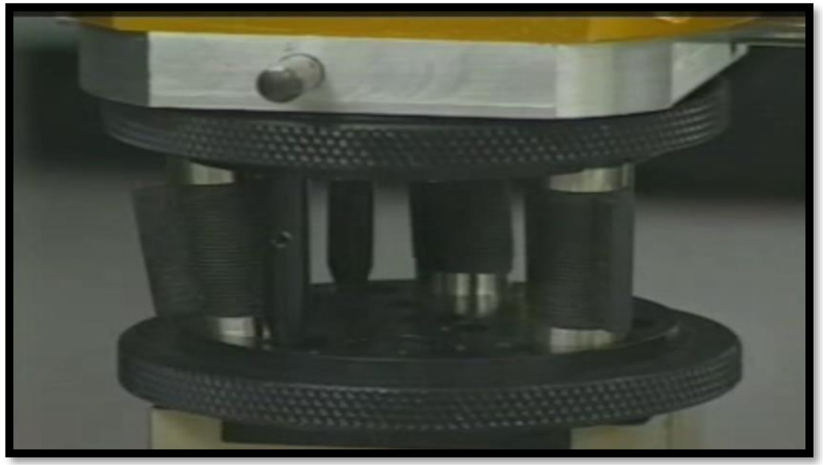
Potential Solution: Active vs Passive

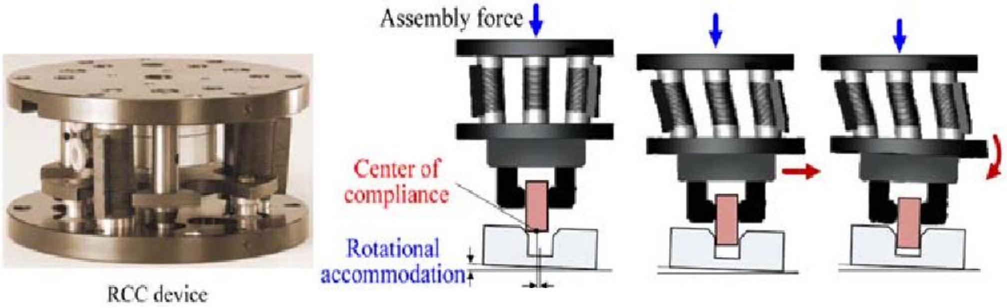
Active compliance
Sensing and controller required





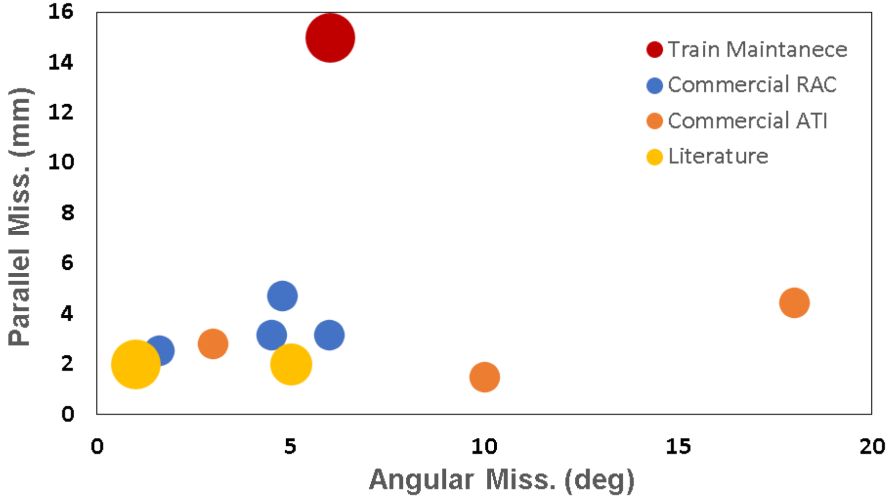
Passive compliance
No additional requirements



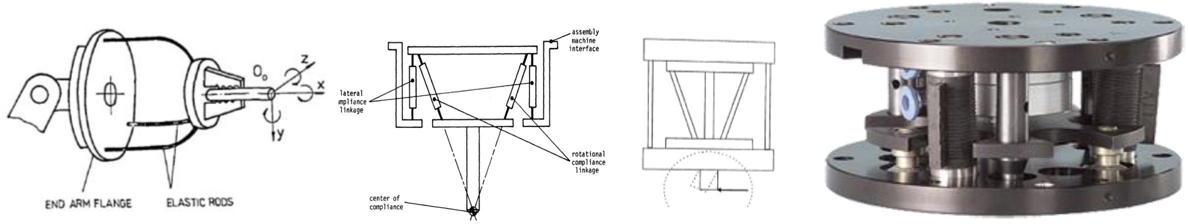


- **Cost-effective:** No additional sensing required:
- **Easy-to-maintenance:** No electronics, etc.

Literature: Remote Centre Compliant (RCC) Peg-in-Hole (PiH) end-effectors

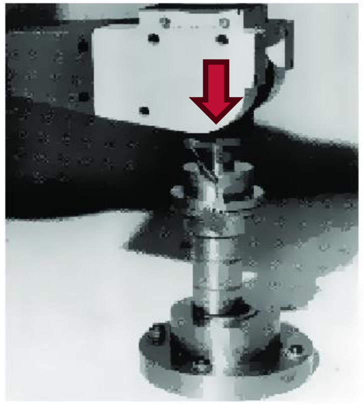


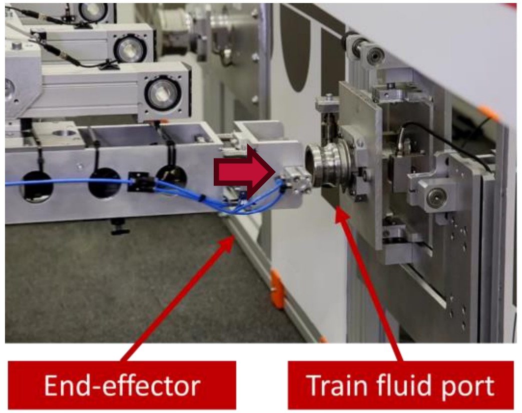
Mechanism	Authors	Parallel	Angular	Clearance
Compliant stage	McCallion 1978	1-2mm	1.5-2.5°	0.01-0.02 mm
Flexure RCC	Watson 1982	1 mm	1°	0.01 mm
ESP type RCC	Whitney 1984	2mm	1°	0.01-0.02 mm
CHVRCC	Haskia 2001	0.4 – 2mm	0-5	<0.375 mm



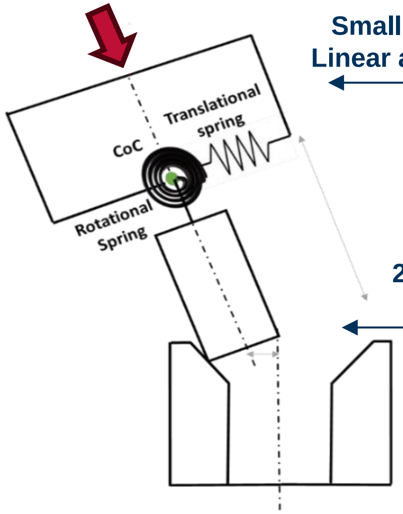
Train fluid servicing PiH

Clearance = 0.05mm ≠ Clearance = 0.5mm



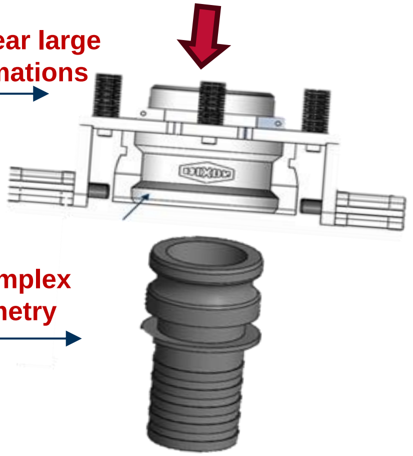


Insertion force



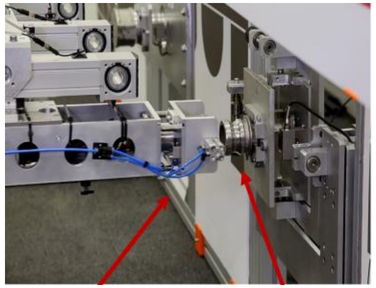
Small deflection/ Linear assumptions ≠ Nonlinear large deformations

2D simple shapes ≠ 3D complex geometry

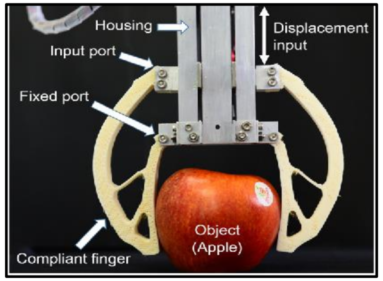


Methodology: A new outlook and approach to passive compliance design problems

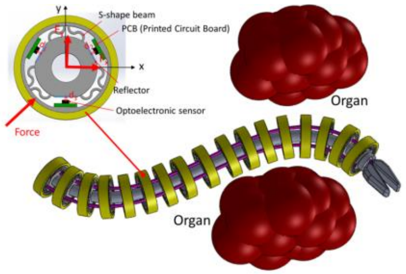
PiH and servicing

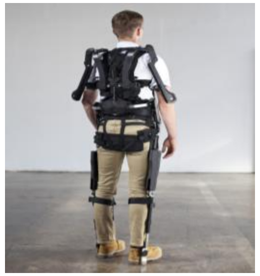



Graspping



Medical





Practical and unstructured robot environments

- Design factors (X) ← Complex models / Empirical solution ← Large deformations; Complex geometry and contact ← Material / Geometry
- Design factors (X) → **Robust Design** → Robust Performance
- Noise factors (Z) → **Robust Design**
- Noise factors (Z) ↔ Uncertainty ↔ Misalignment / shape
- Material / Geometry → **Compliance Design** → Motion / force performance
- Misalignment / shape → **Compliance Design**

$$\text{Min}\ (Mean; Variance)$$

Subject to:

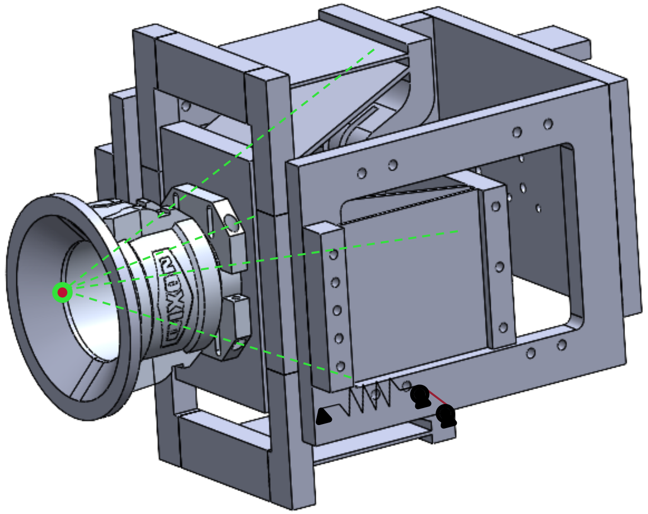
$$x_{min} \leq x \leq x_{max}$$

$$z_{min} \leq z \leq z_{max}$$

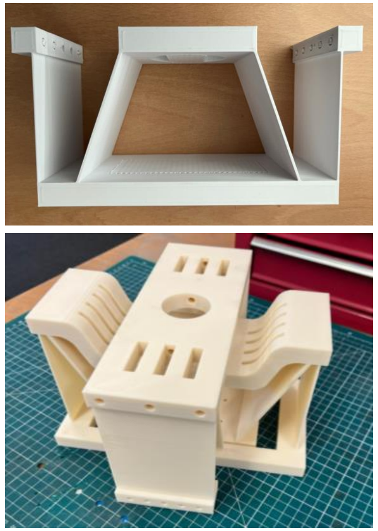
Eshraghi, K., Wang, M. and Mares, C. (2023) ‘Towards robust and effective passive compliance design of end-effectors for robotic train fluid servicing’, *Machines*, 11(11), p. 997.

Case study 1: Development of new end effector + parametric analysis

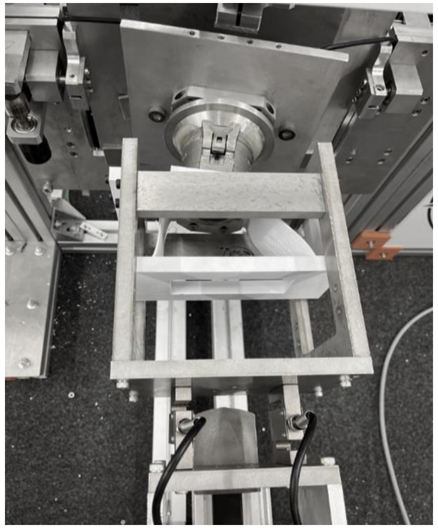
RCC End effector design



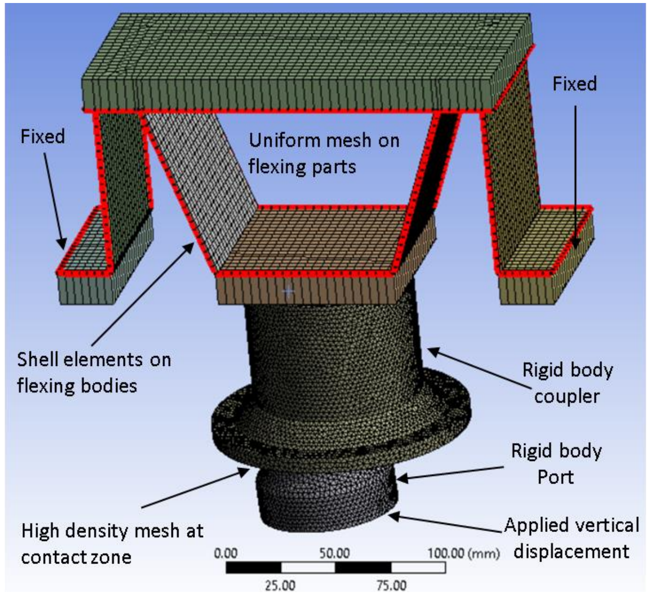
Compliant stage



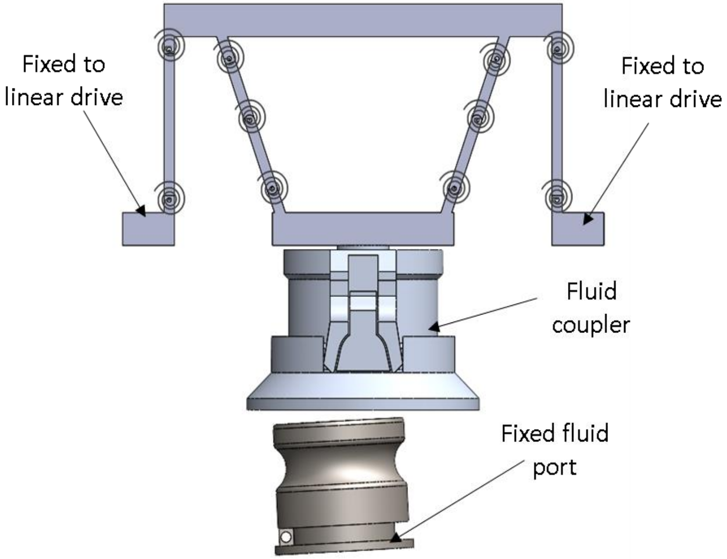
Experimental end effector



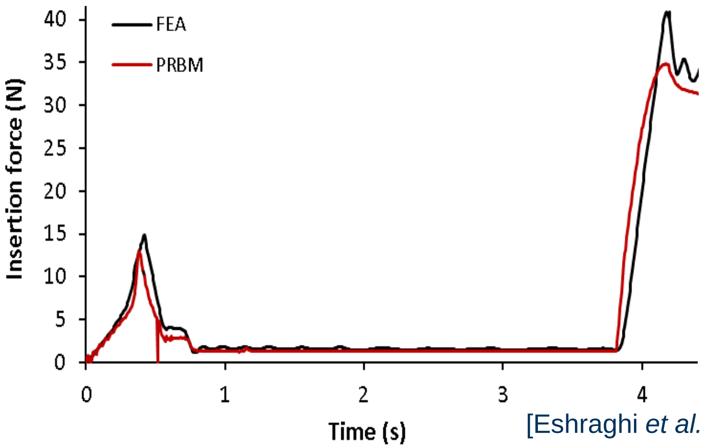
Proposed FEA model (35 hours)



Proposed PRBM (0.1 hours)

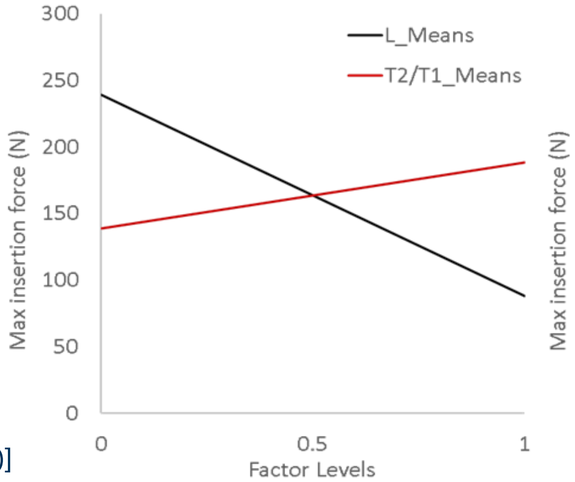


Model comparison



[Eshraghi *et al.* (2023)]

15 mm + 5 deg ≈ 150 N insertion force



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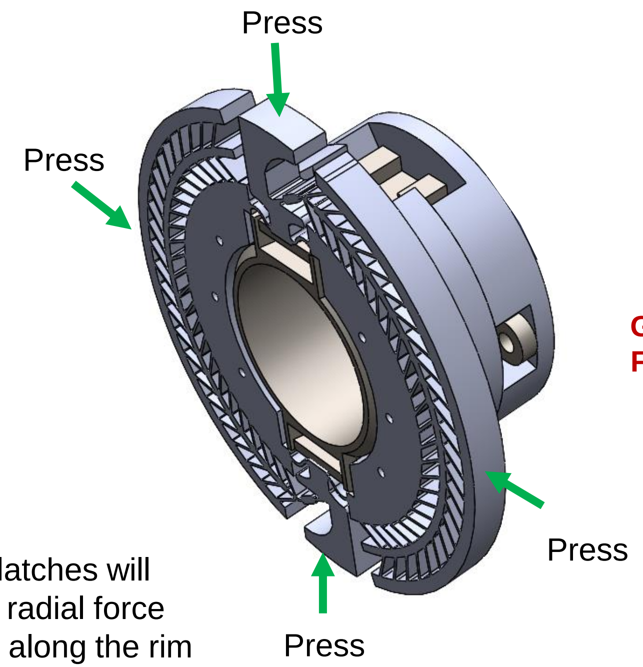
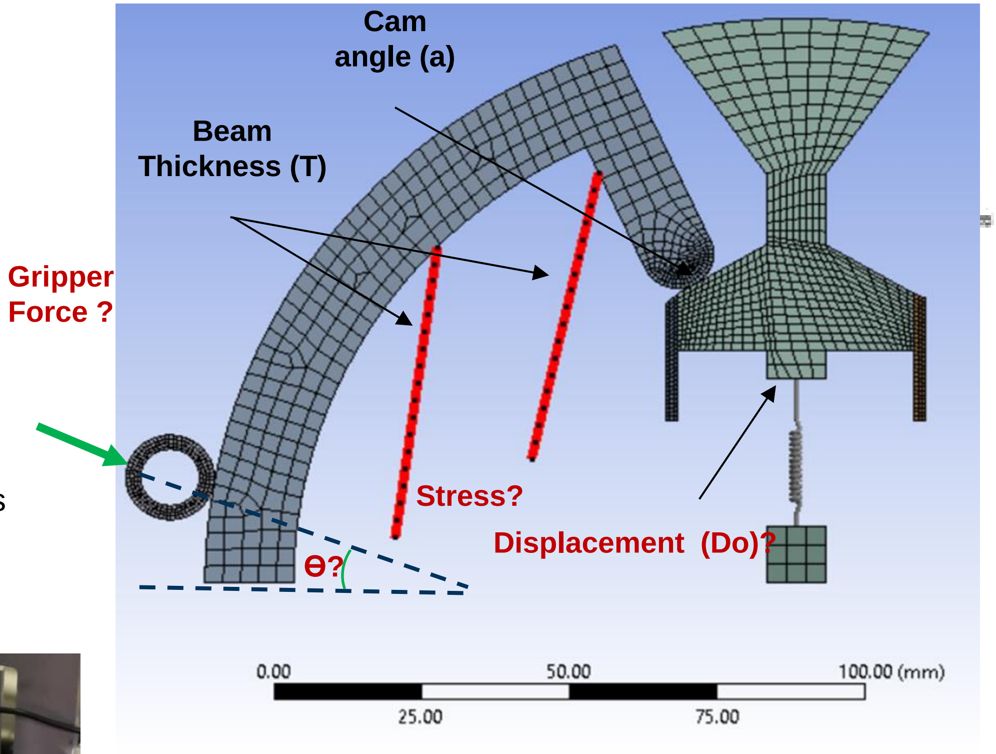
Case study 2: Development of new end effector + parametric analysis

RCC End effector design

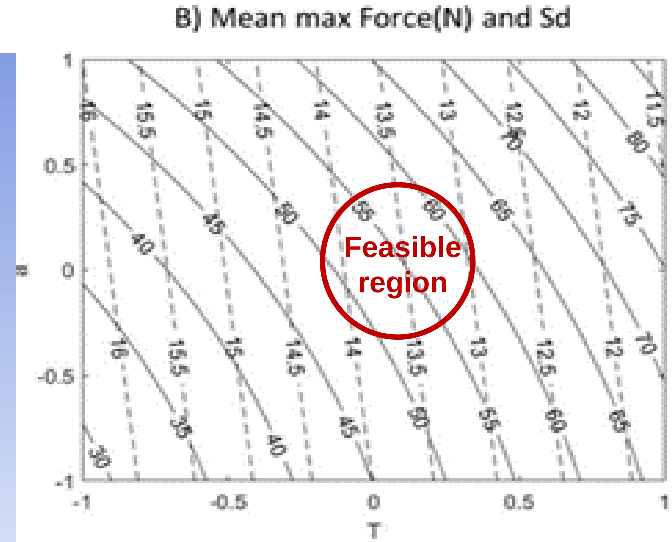


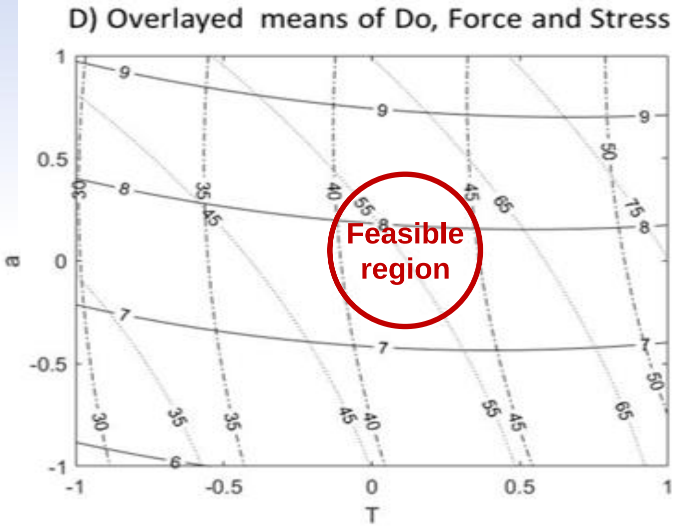
Dust cap latches will open with radial force anywhere along the rim

FEA model

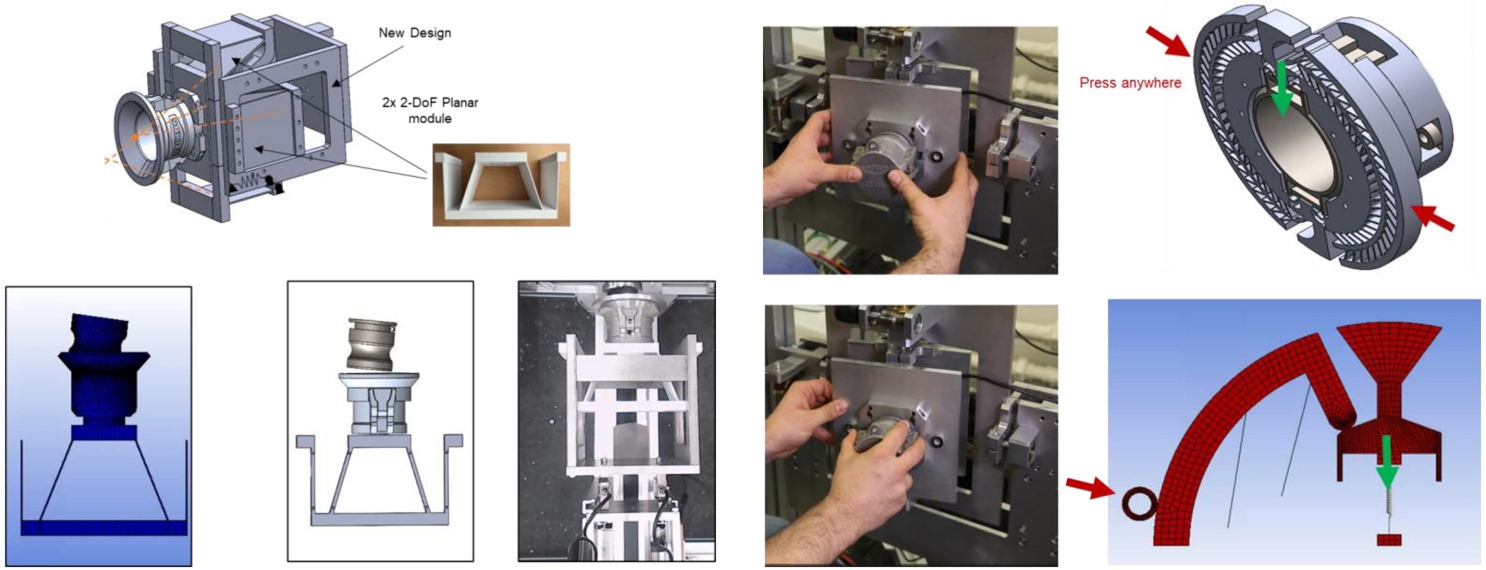


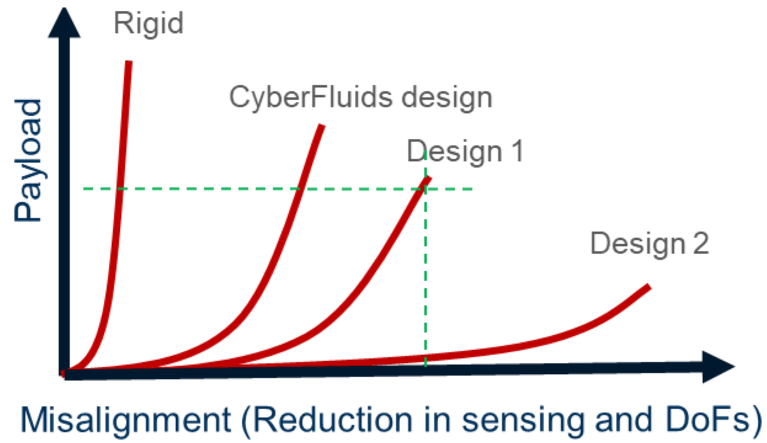
Parametric analysis





CyberFluids+: Easy-Adaptive & Cost-Effective Robotic Train Fluid Service





- **Proof of concept** → **Preliminary Feasibility study** → **Full scale prototype** → **Field testing** → **Commercialisation**
- **Proof of concept** → **Academic research** → **Full scale prototype**

Funded by: UKRI Engineering and Physical Sciences Research Council

Industry Partners: Chilternrailways by arriva

Vision-Based PiH Operation in Dynamic Environments

A 3-stage Vision-based Localization Methodology for Efficient Automatic Charging of Electric Vehicles in Dynamic Environments

Qi Chen, Mingfeng Wang, Huan Zhao, Weihua Li, Kai Wu

Thanks for your attention!
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Melissa Frewin, Paul Gray @ RSSB

Simon Jarrett @ Chiltern railways

Email: Mingfeng.Wang@Brunel.ac.uk