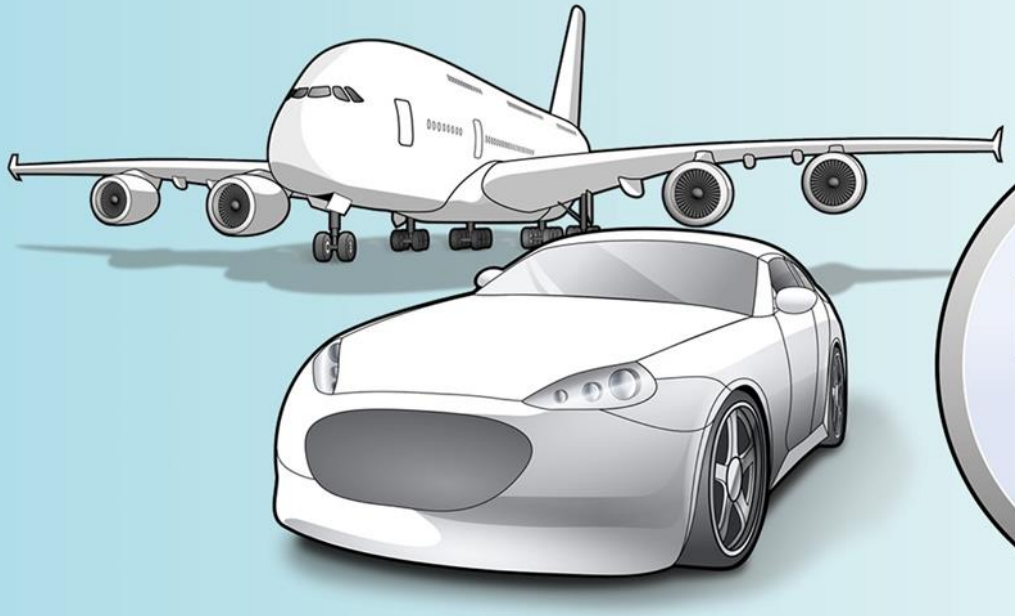
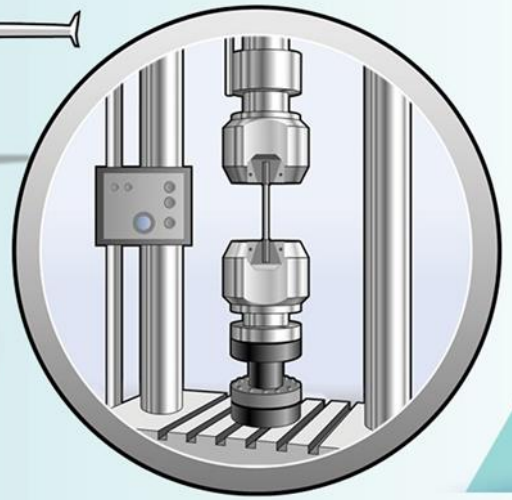
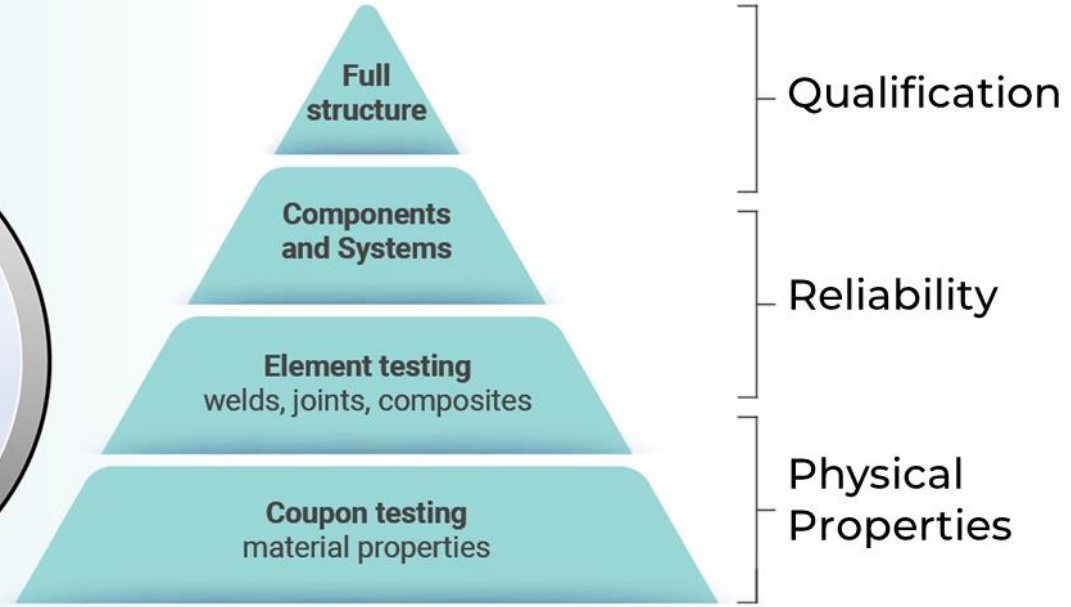






2023 HBK Technology Days

7 November 2023

Rapid EF Enablers: Accelerating Full-scale Fatigue Testing

(*a combined presentation*)

- **The "Rapid EF" project for Accelerated Full-Scale Fatigue Testing,**
  Marco Wagner,
  Measurement and Control System Engineer, Airbus
- **HBK contributions to Rapid EF to reduce test downtime,**
  Sandro Di Natale,
  Product and Application Manager - Test and Measurement, HBK

Rapid EF Enablers: Accelerating Full-scale Fatigue Testing

- Abstract (*for combined presentation*)
  - AIRBUS desire to shorten their product development cycle, to become more agile to better adapt to market demands. Rapid EF (Rapid Essais de Fatigue) is a LuFo [*] funded aviation research programme to significantly accelerate full-scale airframe fatigue testing. The biggest testing challenge to fulfil LuFo goals is to shorten multi-year duration fatigue tests to reduce the overall development cycle time from a minimum of 8 years to less than 5 years. Rapid EF aims to reduce a fatigue test by reducing setup time (quicker instrumentation), cycle time (improved control algorithms) and downtime (anticipation of damage through digital twin). Rapid EF is a collaboration led by AIRBUS with project partners: IZfP (Fraunhofer), ZEISS (gom), Applus+ (IMA), DLR, ifas (University of Aachen) and HBK.
  - [*] LuFo (Luftfahrtforschungsprogramm) is a German funding programme for aviation research, led by the German Aerospace Center DLR (Deutsches Zentrum für Luft- und Raumfahrt). LuFo VI-2 Global Goals include environmentally friendly aviation, future mobility, hybrid-electric aviation, alternative propulsion, hydrogen fuel cells, supplier diversification, digitalization and more.
  - Rapid EF aims to reduce the fatigue test by reducing setup time (quicker instrumentation), cycle time (improved control algorithms) and downtime (anticipation of damage through digital twin). HBK contributions to Rapid EF are mainly responsible for reducing downtime. This presentation will address these challenges and their solutions including:
    - to provide redundancy in the DAQ measurement chain to avoid or reduce single point failures
    - to provide quick exchange in the DAQ measurement chain when required to avoid DAQ shutdown and reboot
    - to provide an open DAQ architecture enable inclusion of tactile sensors, optical & thermal cameras, sound, etc.
    - to automate and simplify sensor parameterisation, particularly for the 100’s or 1000’s of strain gauges required
    - to quantify and minimize measurement uncertainty
    - to provide virtual sensors to complement physical sensors for digital twin model correlation
    - to provide measurement data streams for subsequent automated cleansing, analytics and data management

Rapid EF Enablers: Accelerating Full-scale Fatigue Testing

- Co-author, Marco Wagner, Measurement and Control System Engineer, Airbus
  - Marco Wagner has a background in electrical engineering with a specialization in communications engineering. He began his career as a software developer at Harman/Becker, focusing on digital signal processing and I/O controller programming. In 2009, he joined Airbus Defense and Space, where he worked on the development of test and simulation systems for avionics and weapon systems. During this time, Marco was responsible for the FPGA development and introduced several new FPGA technologies. In addition, he worked on the development of real-time software and established Embedded Linux as the standard operating system for real-time data processing in the test system.
  - In 2022, Mr. Wagner made a career move to Airbus Commercial. In his current role, he is responsible for the measurement and control systems at the Structural Test in Hamburg. His main focus is on modeling and simulating test setups as well as post-processing measurement data for continuous structural health monitoring (SHM).

- About the presenter, Sandro Di Natale,
  Product and Application Manager - Test and Measurement, HBK
  - After completing his master's degree in physics at the University of Heidelberg and a brief experience in Consulting Sandro joined HBK as Product Manager in 2014. Since then, he has been responsible for data acquisition products (hardware and software) focusing on large-scale structural testing and high precision. One main focus of his work is finding solutions with customers to make data acquisition of hundreds or even thousands of sensors more reliable and more efficient.

HBK
HOTTINGER BRÜEL & KJÆR

Rapid EF Enablers: Accelerating Full-scale Fatigue Testing

Sandro Di Natale (HBK)
Marco Wagner (Airbus)

HBK Technology Days

Virtual November 7th, 2023

Agenda

1. **Introduction**
2. Work Packages
3. HBK Contribution
4. Summary

Contributors

Sandro Di Natale

- Product Manager at HBK (Hottinger Brüel & Kjær) for 9 years
- Graduate physicist
- Application manager for Static and Fatigue Testing

- E-mail: sandro.dinatale@hbkworld.com

Marco Wagner

- Structural Test at Airbus Commercial for 2 years
- Electrical engineer
- Data acquisition and control system specialist

- E-mail: marco.m.wagner@airbus.com

LuFo VI-2 Global Goals

What is LuFo? Luftfahrtforschungsprogramm (Aerospace Research Program)

- Environmentally friendly aviation
  - Fulfill Paris climate agreement
  - Increase acceptance in society
- Hybrid-electric aviation, alternative propulsion, H_2, fuel cell
  - Partly electrification of propulsion
- Mobility of the future
  - Automation and autonomization
  - UAM incl. Unmanned aerial systems (UAS)
- Diversification of supplier landscape - SMEs
  - Driving innovation
- Strengthening European integration
- Digitalization, Industry 4.0 and AI
  - Data, data, data

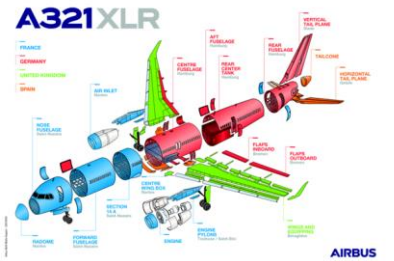


Image sources: Airbus, FU Berlin

Biggest Testing Challenge to Fulfill These Goals

- Currently the time frame from project start to certification is minimum 8 years.
- Big driver is the fatigue test with a duration of a few years.

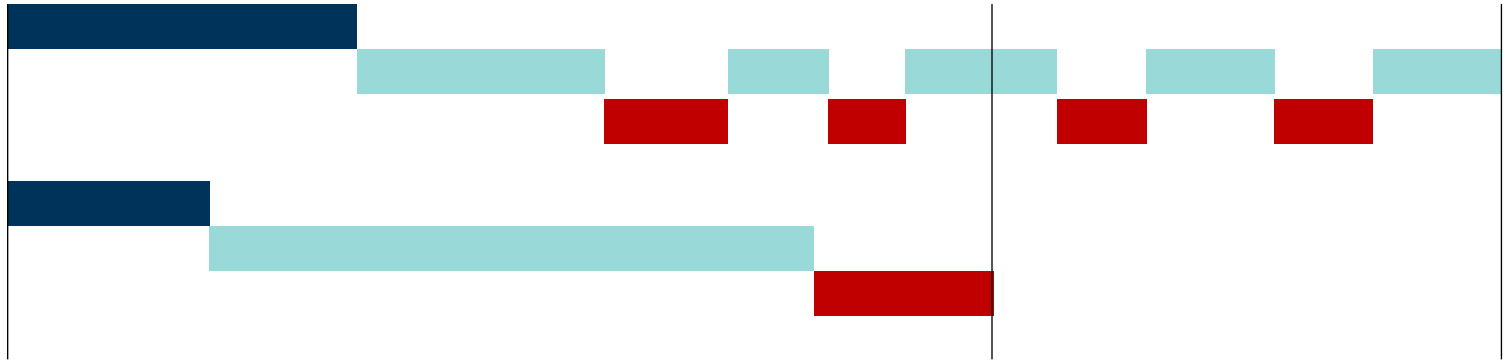
- Ambition: < 5 years

- Potential of currently used methods mostly exhausted
- New approaches to achieve this goal are needed:
  - Digitalization/Big Data
  - Automation and simulation

- Simulation of the whole test setup to reduce
  - Setup time (E.g., Quicker instrumentation)
  - Cycle time (E.g., improved control algorithms)
  - Downtime (E.g., Anticipation of damage through digital twin)

LuFo Project RapidEF

- Duration: 2022-2025
- RapidEF – Accelerated Full-scale Fatigue Test (EF: Essais de fatigue)



Preparation/setup time

Cycle time

Downtime

Project Partners

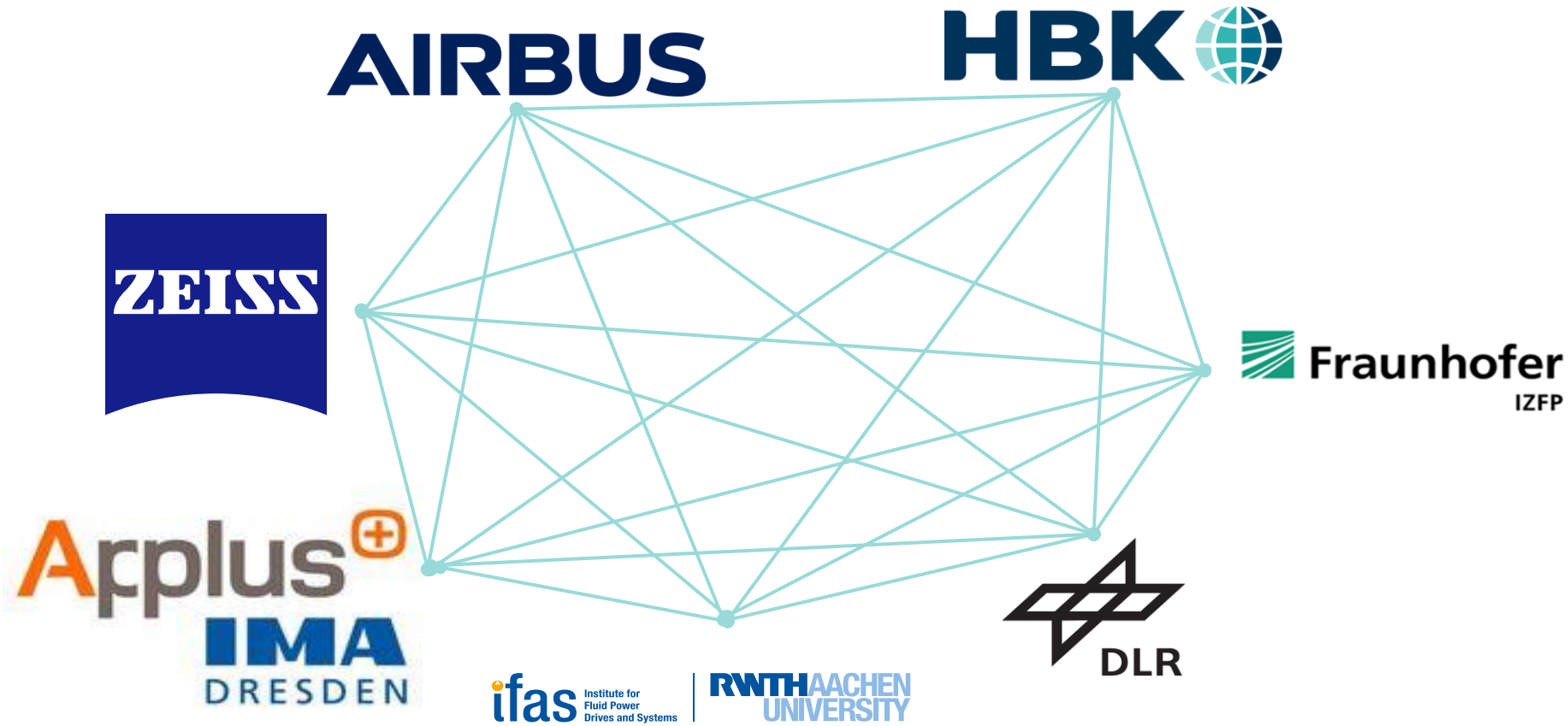


Image source: Company websites

Top-level Overview and SMART Goals

Bundesministerium für Wirtschaft und Klimaschutz

Method development

Validation

Demo

Evaluation

Setup time reduction

- Modelling and Digital Twin
- Virtual Sensors
- Optimized Instrumentation
- Influence on Certification

SMART goal:
30% reduction

Cycle time reduction

- Hardware in the Loop Test Rig
- Optimization Load Control
- Multichannel Test Rig and DuT

SMART goal:
Doubling test speed

Downtime reduction

- Multi-camera system
- SHM and Online Multi-modal Non-destructive Test
- Continuous DAQ and Data Management
- AI Methods and Software

SMART goal:
80% reduction

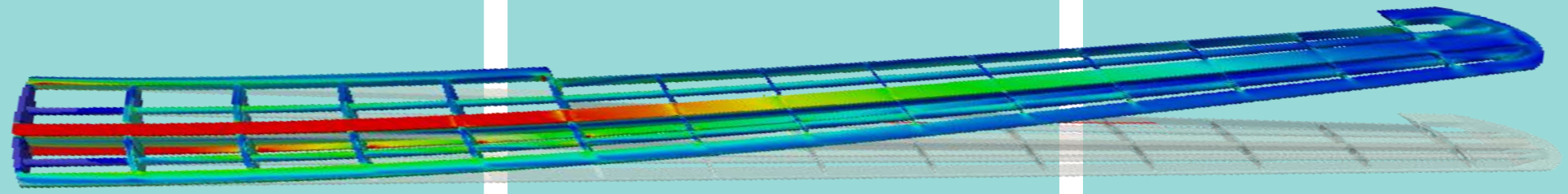


Image source: SimScale

HBK HOTTINGER BRÜEL & KJÆR

No Project Without Time Plan

Nr.	Vorgangsname
HAP1	**Verkürzung der Rüstzeit**
AP1.1	Modellierung und Digit. Zwilling
AP1.2	Virtuelle Sensoren
AP1.3	Optimierte Instrumentierung
AP1.4	Einfluss auf Zertifizierung
AP1.5	Anforderungen und Validierung
MS1	Konzept zur Anwendung von virtuellen Sensoren
MS2	Prozess zur Rüstzeitoptimierung
MS3	Technologie validiert
HAP2	**Verkürzung der Versuchslaufzeit**
AP.2.1	Hardware in the Loop Prüfstand (HiL-Prüfstand)
AP2.2	Optimierung Regeltechnik
AP2.3	Vielkanalprüfstand und Prüfkörper
AP2.4	Anforderungen und Validierung
MS4	HiL-Prüfstand
MS5	Vielkanalprüfstand
MS6	Validierung der Technologie HAP2
HAP3	**Verkürzung der Stillstandszeit**
AP3.1	Optisches Multi-Kamera-Deformationsmesssystem
AP3.2	Zustandsüberwachung und on-line zfP
UAP3.2.1	*Schallbasierte Verfahren*
UAP3.2.2	*Optische und thermographische Verfahren*
AP3.3.	Kontinuierliche Datenerfassung und -management
AP3.4	KI-Methoden und Software zur Zustandsüberwachung
UAP3.4.1	*Datengestützte Anomaliedetektion*
UAP3.4.2	*Multi-modale Schadenserkennung*
UAP3.4.3	*Zustandsüberwachung und -bewertung mittels Digit. Zwilling*
UAP3.4.4	*Integration Algorithmen*
AP3.5	Ermüdungsversuch
AP3.6	Anforderungen und Validierung Gesamtsystem
MS7	Konzept für Strukturzustandsüberwachung
MS8	Protoytp Deformationsmesssystem entwickelt
MS9	Datenmanagementsystem
MS10	Algorithmen integriert
MS11	Beginn Ermüdungsversuch
MS12	Abschluss Ermüdungsversuch
MS13	Validierung der Technologien HAP3

Agenda

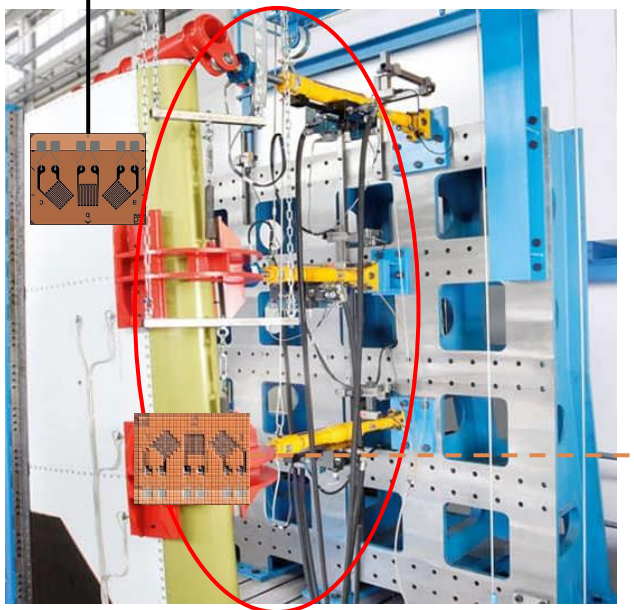
1. Introduction
2. **Work Packages**
3. HBK Contribution
4. Summary

Lead Time Reduction – Virtual Sensors

- Virtual sensors complementing physical sensors, e.g., in remote locations.

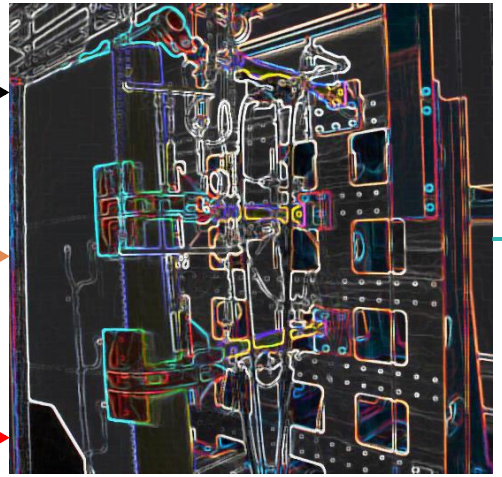
Calibration data

Real measurement data



Sensor position

External load



Virtual sensor data

Test specimen

Digital twin

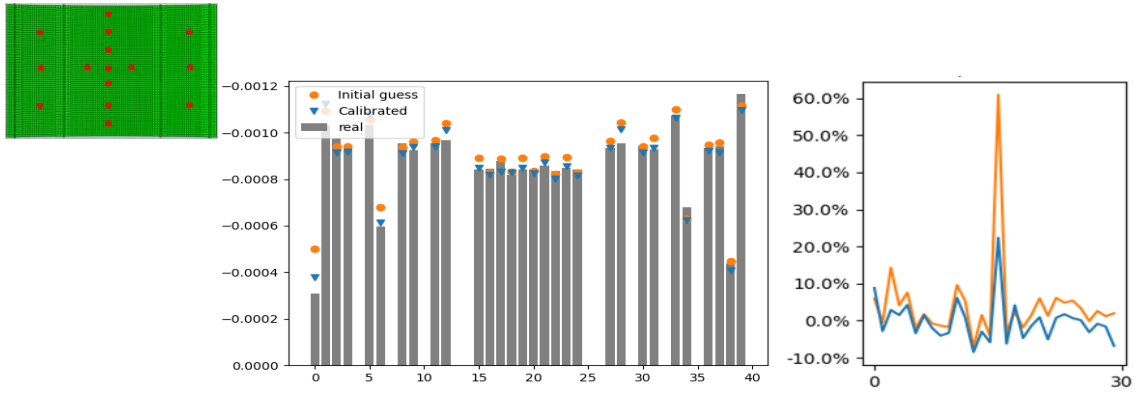
Image source: IABG, Zeiss

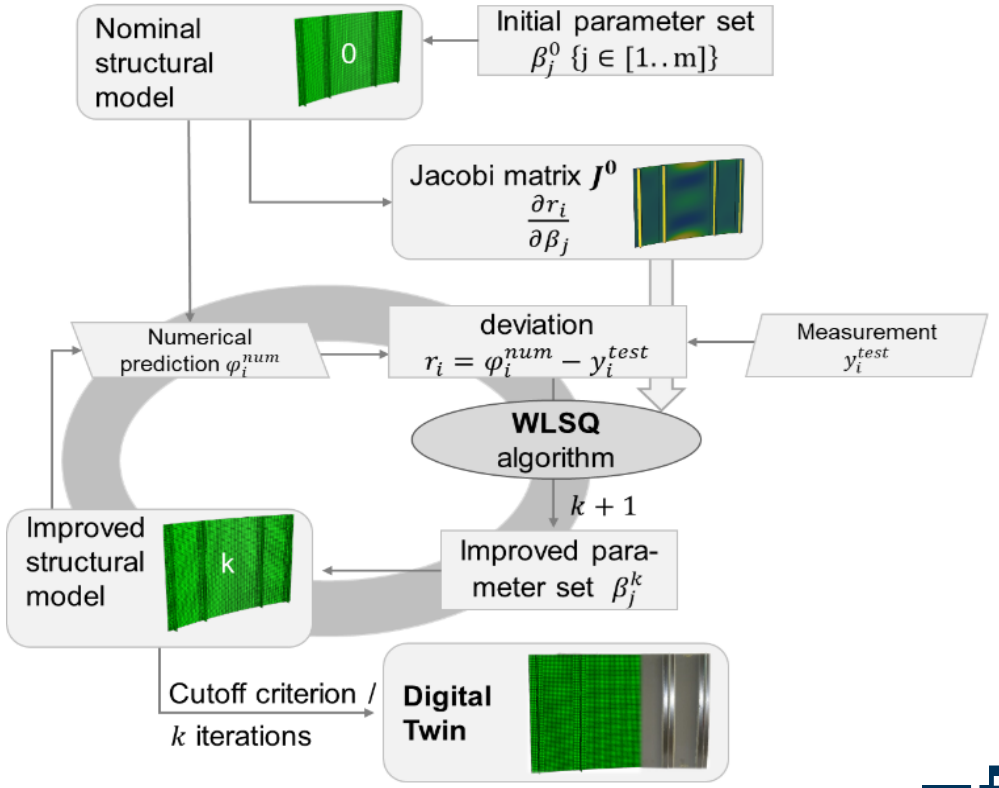
Lead Time Reduction – Digital Twin

- The model of a digital twin is based on an FE model which requires calibration to reduce uncertainties. During the fatigue test the DuT changes characteristics which requires continuous calibration of the digital twin.

Uncertainties

- Material properties
- Geometric uncertainties
- Load uncertainties
- Boundary conditions
- Environmental condition
- Changes during Fatigue Test





Lead Time Reduction – Other Aspects

Development of alternative methods for load introduction and sensors

- Optimized Instrumentation
  - Simplified load introduction (air cushions, pulley system)
- Influence on Certification
  - Effect of simplified load introduction and reduced instrumentation on certification tests

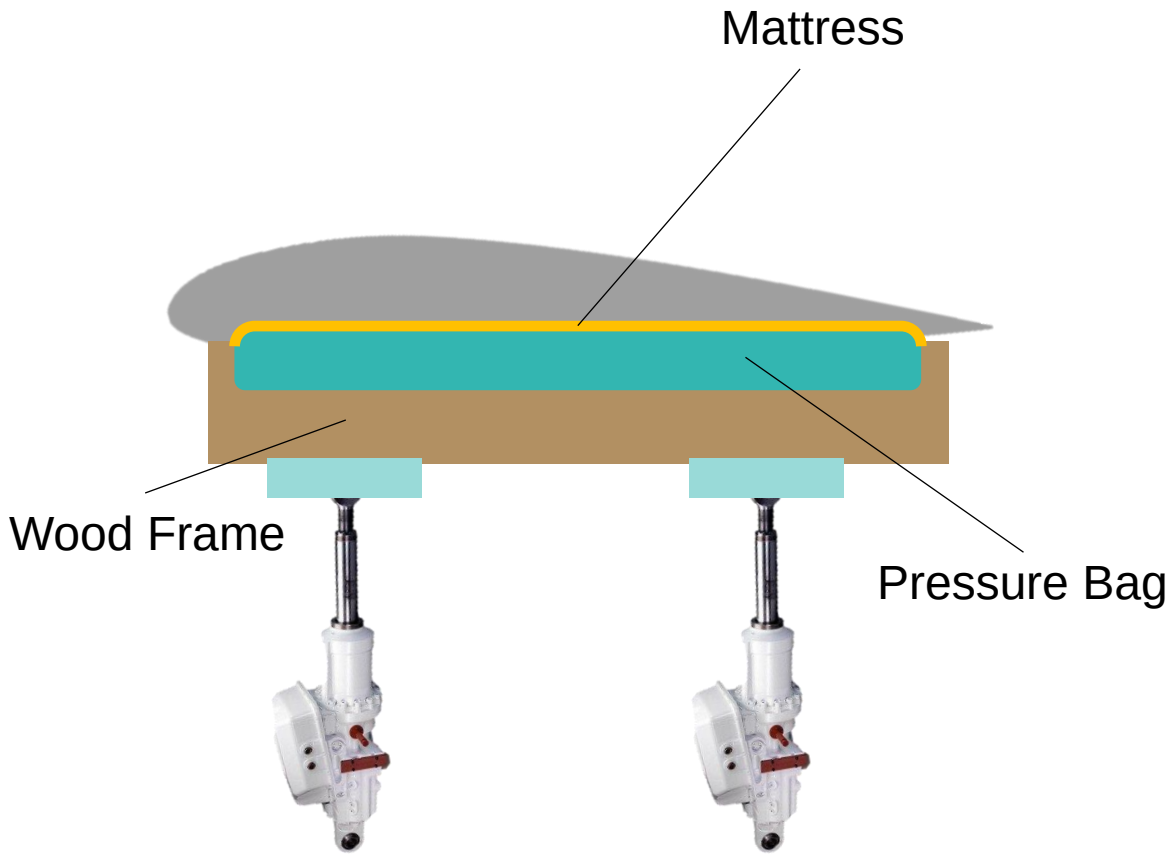
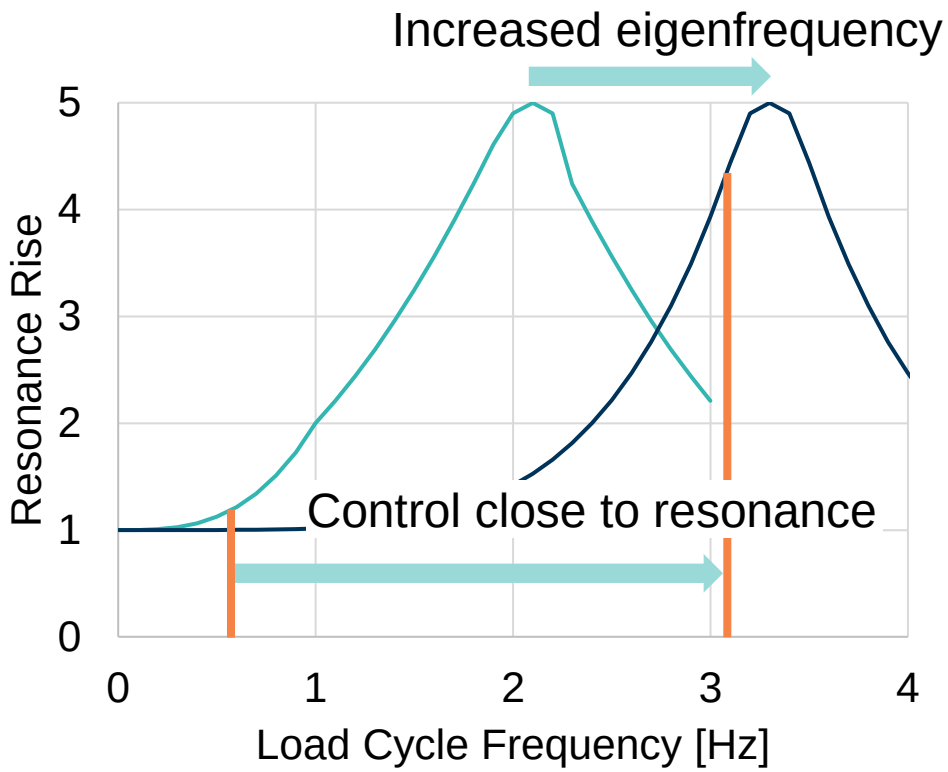


Image source: Moog

Cycle Time Reduction

Basics to perform fatigue cycles close to resonance of the test rig-DuT system.

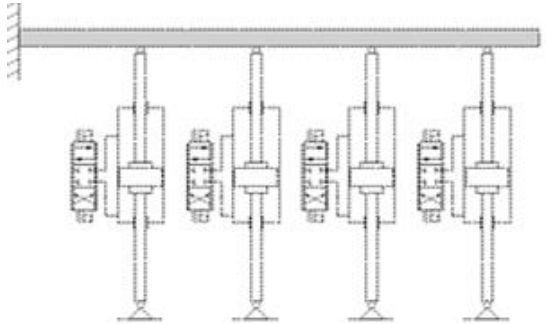
- Hardware in the Loop Test Rig
  - One-channel test rig
  - DuT replaced by hydraulic system able to simulate any reaction curve and interaction with simulated, coupled cylinders
- Optimization Load Control
  - Methods to model DuT-characteristics avoiding dynamic disturbances
  - Use of electro-hydrostatic actuators to increase efficiency
- Multichannel Test Rig and DuT
  - Creation of calibration strategy to adapt to changing parameters
  - Comparison tests with DuT excited to eigenfrequency



Cycle Time Reduction – Accelerating Control

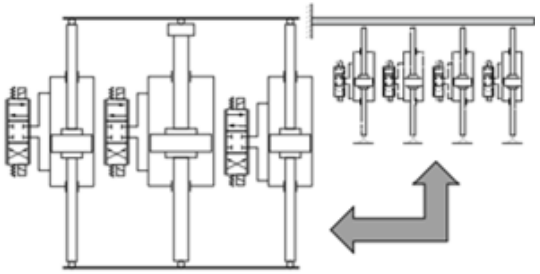
- The test excitation time is reduced to a range close to the first eigenfrequency of the structure.
- To avoid overshoot, instability and damage of the specimen at this short cycle time, advanced and innovative control algorithms are developed and tested.

Model



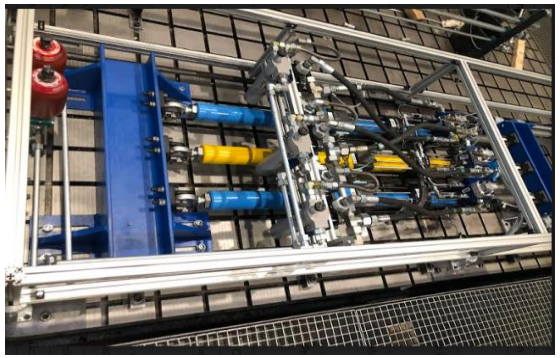
- Simulative image of the test stand

HiL Test Stand

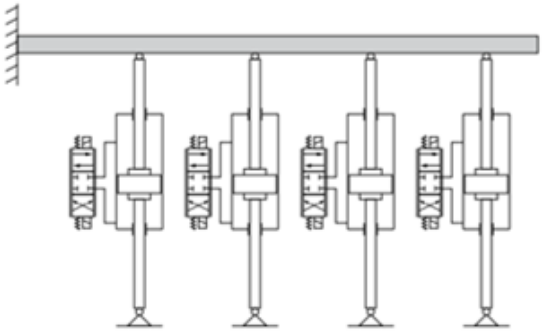


- Servo axis with load units
- Simulation of DuT and additional actuators

HiL Test Stand



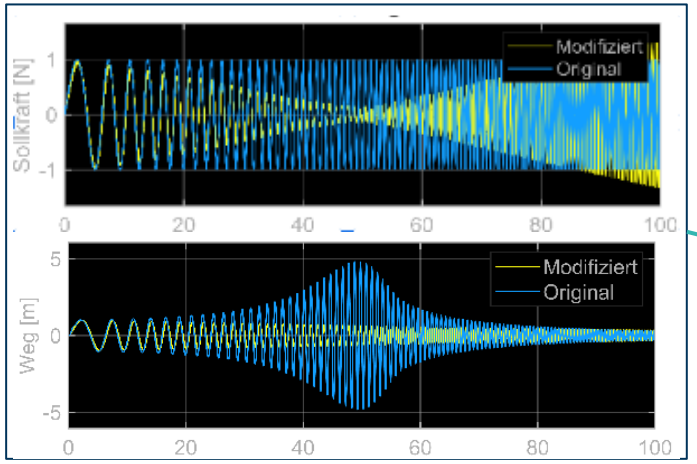
Multichannel Test Stand



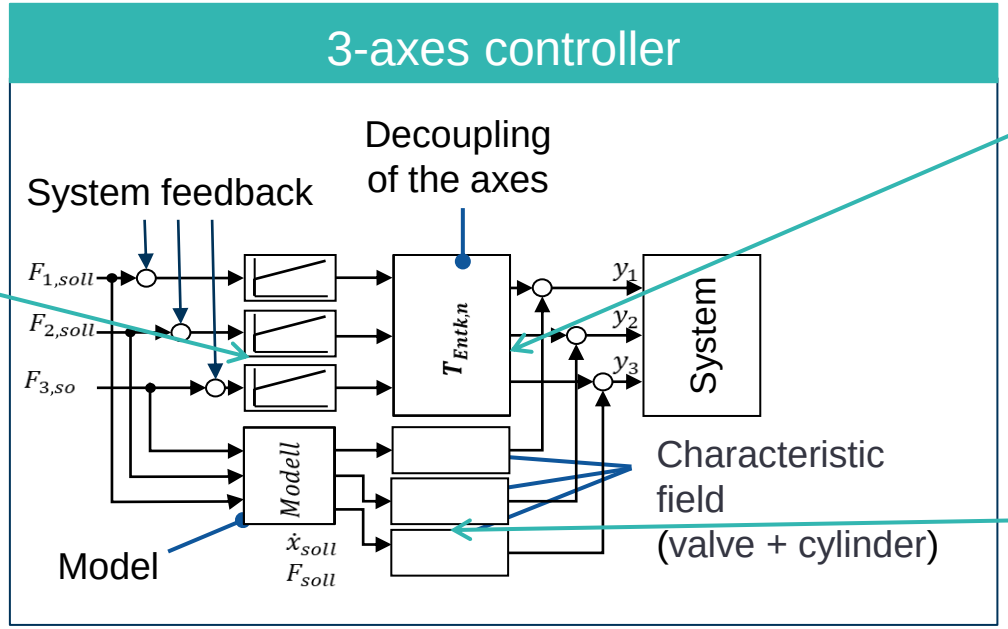
- Test rig with physical DuT

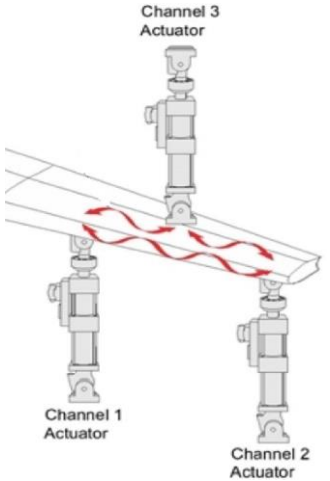
Cycle Time Reduction – Accelerating Control

- The controller consists of 3 main control algorithms.

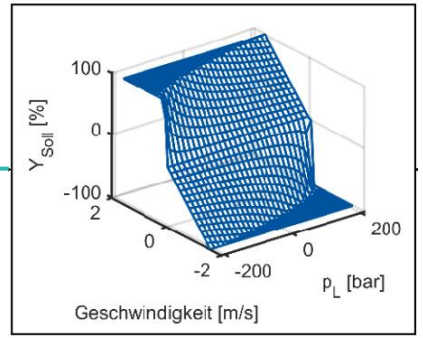


Pre-filter





Cross-coupling compensation

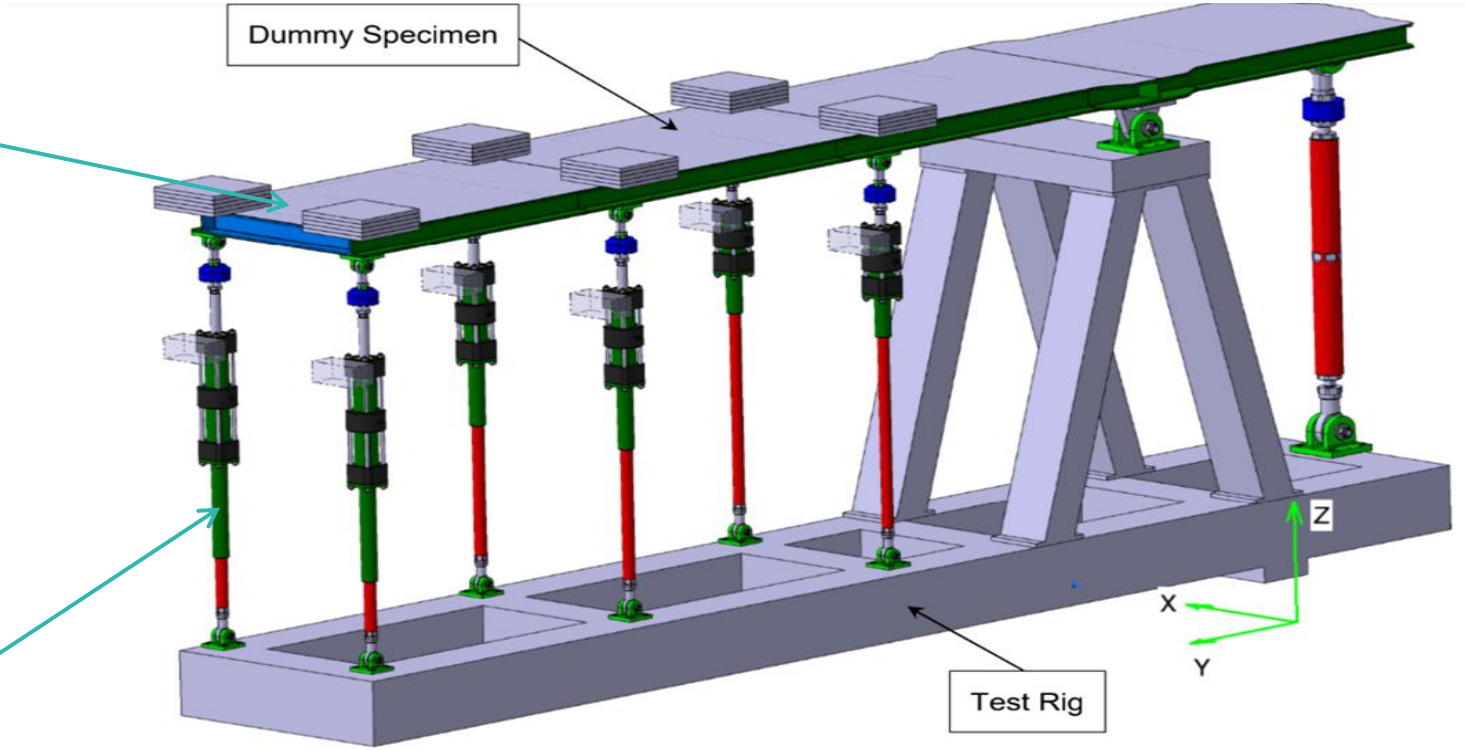


Hydraulic flow prediction

Cycle Time Reduction – Accelerating Control

- Demonstrator for a multi-channel test with fast control

Length 6.5 m
Height 3 m
Width 1.2 m



6 hydraulic cylinders (25 kN)

Downtime Reduction

No test interruption for repair and/or inspection without risk of catastrophic failure

- Optical Multi-camera Deformation Measurement System
- SHM and Online Multi-modal Non-destructive Test
- Continuous DAQ and Data Management
- AI Methods and Software for Condition Monitoring
  - Data-based Anomaly Detection
  - Multi-modal Damage Detection
  - Condition Monitoring and Evaluation with Digital Twin
  - Integration of Algorithms
- Fatigue Test

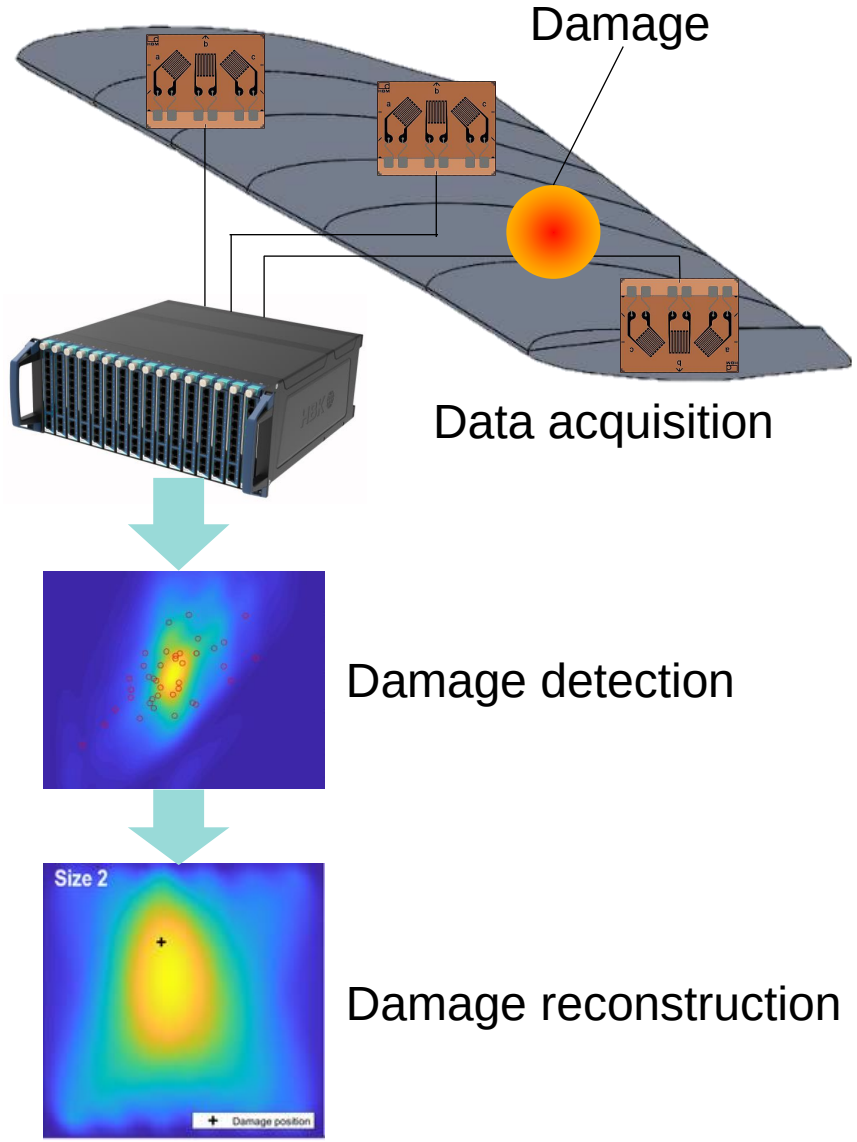
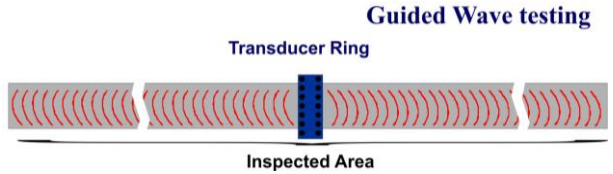


Image source: Scientific Figure on ResearchGate, Guided Waves for Damage Detection in Complex Composite Structures: The Influence of Omega Stringer and Different Reference Damage Size (Applied Sciences), Simulation-based Data-driven Damage Detection for Highway Bridge Systems

Downtime Reduction

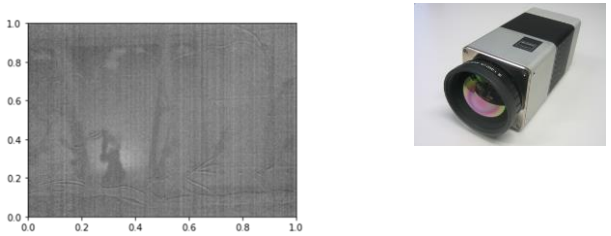
- The traditional time-based inspection will be replaced by an event-based inspection.

Structural Health Monitoring



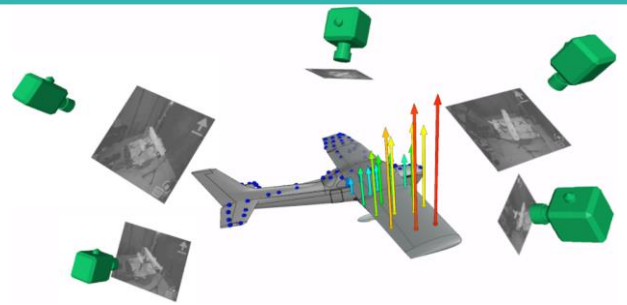
Guided wave testing

Acoustic emission

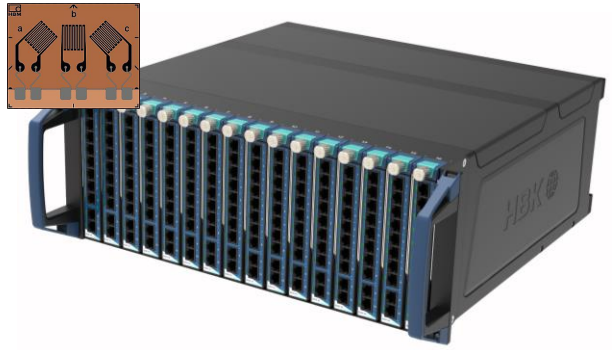


Thermography

Deformation



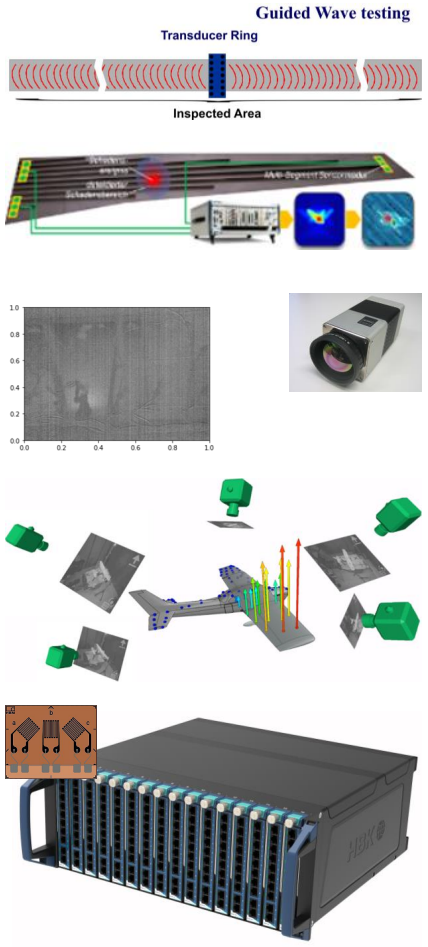
Digital image correlation



Tactile sensors

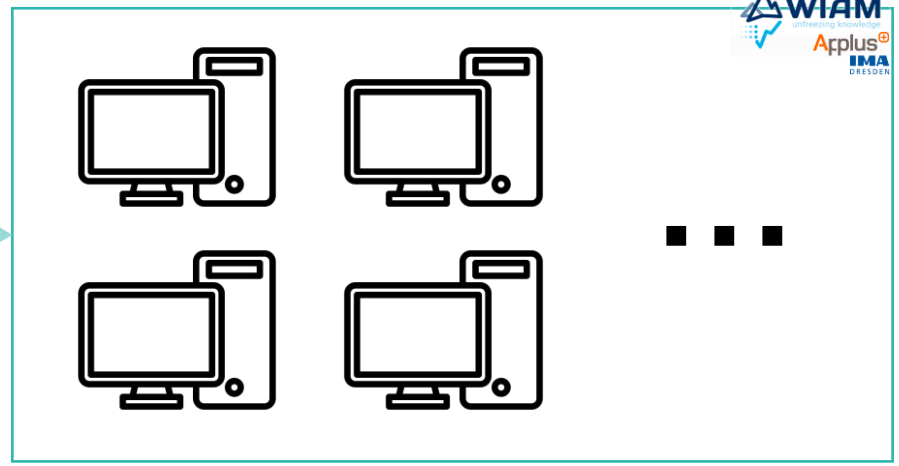
Downtime Reduction

- The so-called Hamster is the central data management system in the project. It provides these services to all project partners.

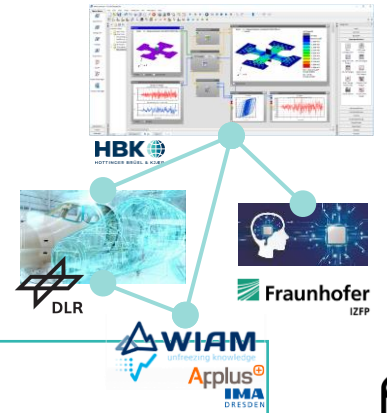


Gateway

Load distribution



Hamster cluster



Database

NAS/SFTP

HBK HOTTINGER BRÜEL & KJÆR

Simplified DuT for Downtime Reduction

More Affordable Aircraft through eXtended, Integrated and Mature nUmerical Sizing

- “Recycled” from previous projects

MAAXIMUS Shell

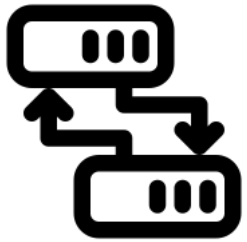
Image source: University of Stuttgart

Agenda

1. Introduction
2. Work Packages
3. **HBK Contribution**
4. Summary

Improving Data Reliability and Quality

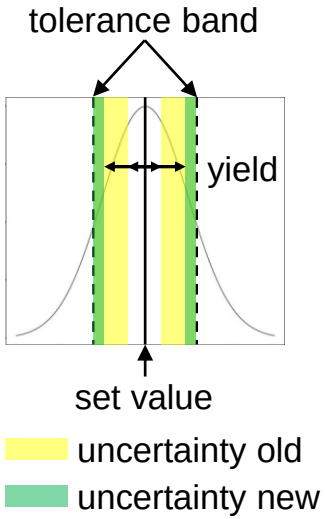
Redundancy



- Challenge: Single point of failures can cause the test to be invalidated or interrupted.
- Solution: Reduce single point of failures in DAQ scope
- Result: Data acquisition electronics with advanced network topologies
- Additional benefit: No external network equipment required!

Measurement uncertainty

- Challenges:
  - A measurement value without uncertainty is no measurement value.
  - Large uncertainty makes many measurement values questionable.

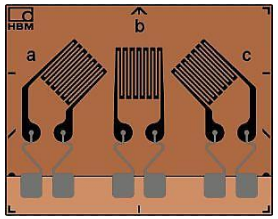


- Solution: Reduced measurement uncertainty which can be calculated easily.
- Result: Provide given uncertainties and facilitate calculation in software

Improving DAQ Preparation and Analysis

Automated Parameterization

- Challenge: Hundreds or even thousands of sensors need to be parameterized.



- Solution: Enable parameterization directly in the field

- Result: New approach for sensor parameterization (esp. strain gauges)
  1 patent granted
  1 patent pending

Streamed analytics

- Challenge: File-based data transfer and analysis lags behind the test proceeding.

- Solution: Analyze measurement results online/in real time.

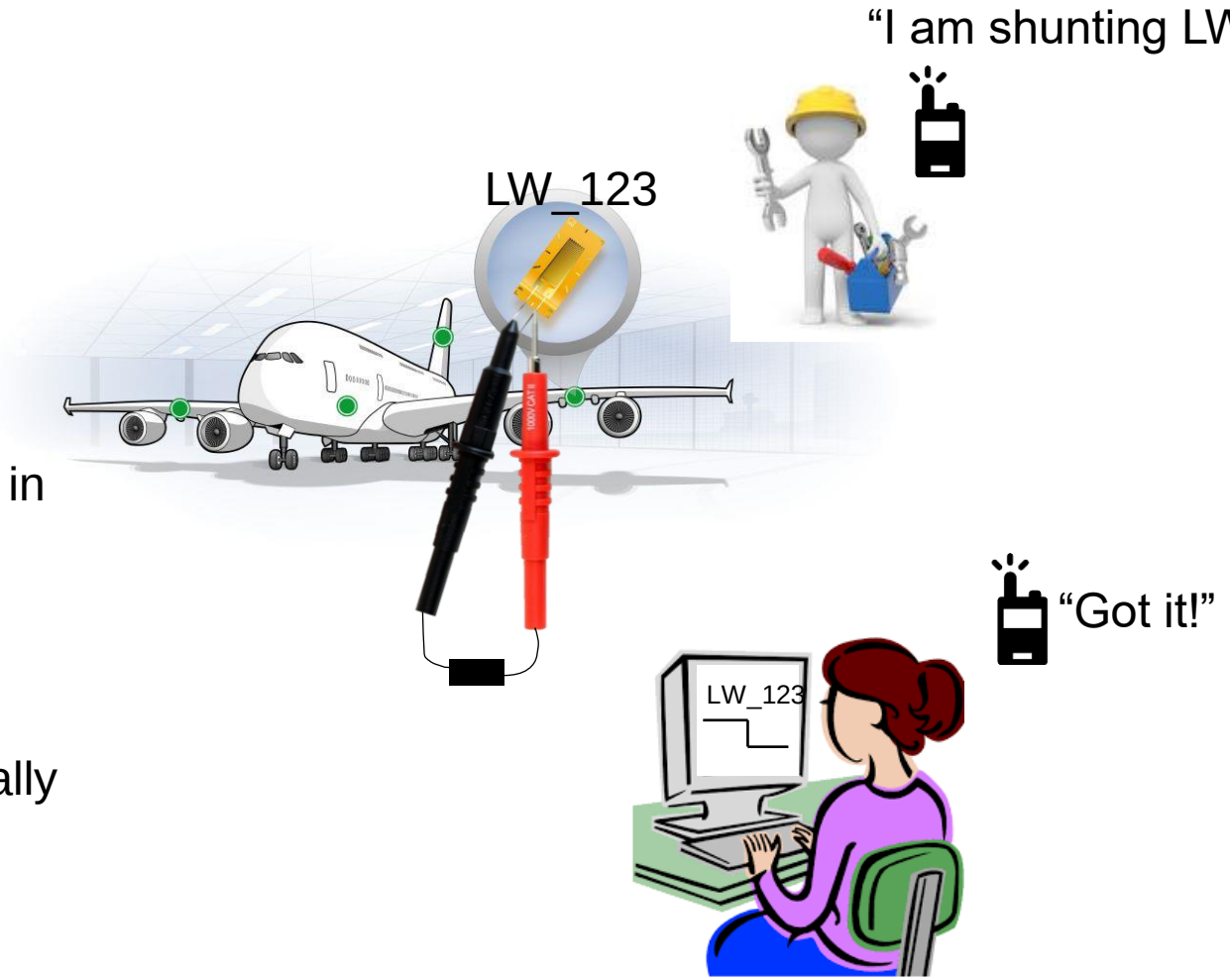
- Result: Fully published streaming protocol with “intelligent” measurement values

HBK
HOTTINGER BRÜEL & KJÆR

Automated Parameterization and Benefits

Process today

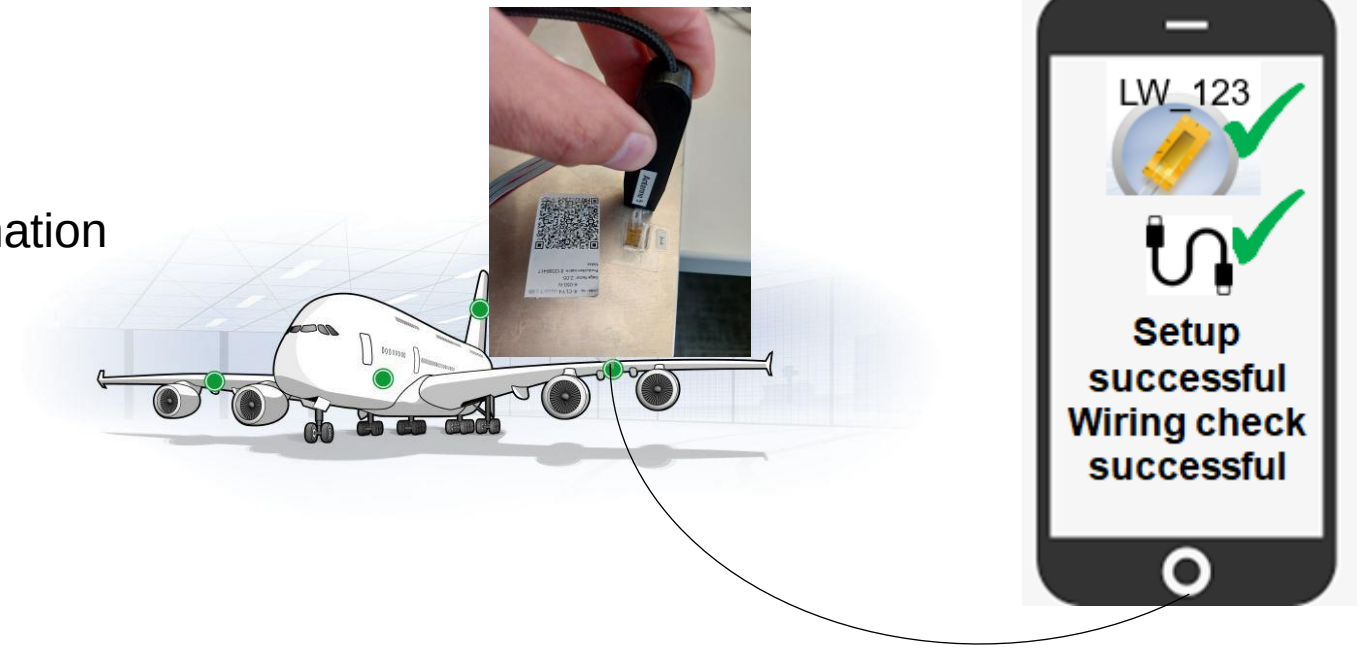
- Type in gauge parameters manually
  → error-prone and time-consuming
- Match gauge with DAQ channel for documentation
  → error-prone and time-consuming
- Verification of strain gauge is a two-man job in large test scenarios
  → time-consuming and expensive
- Shunting manually might destroy protective strain gauge cover
- Photo for documentation needs to be manually assigned to measurement channel



Automated Parameterization and Benefits

Process tomorrow

- Scan strain gauge data sheet with device
- Add channel name and other useful information
- Take a photo of the measurement location
- Transmit information to PC
- Software uses parameters automatically
- Software triggers change in strain gauge sensible for the device
- Optional: Match photo documentation to channel via WiFi or when returning to control room



Use case:

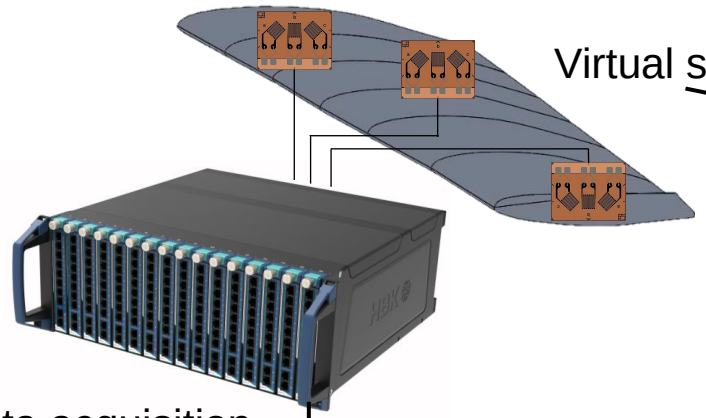
- Wing test with 2,500 strain gauges
- 5 minutes verification per strain gauge

	Today	Tomorrow
Number of technicians	2	1
Working time	420 h	210 h

+ potential for parallelization!

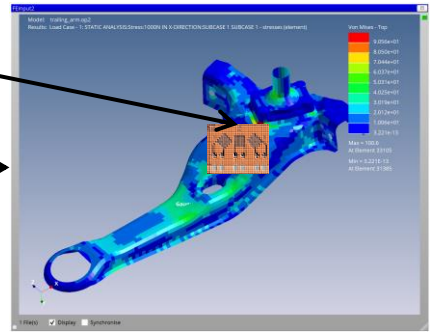
HBK
HOTTINGER BRÜEL & KJÆR

Virtual Sensors – HBK Aqira and nCode



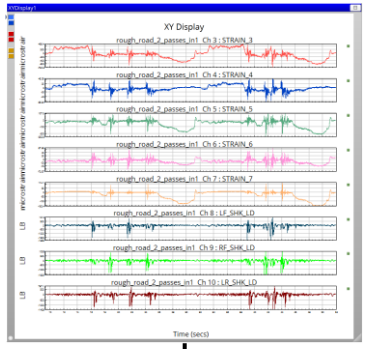
Data acquisition

Virtual sensor

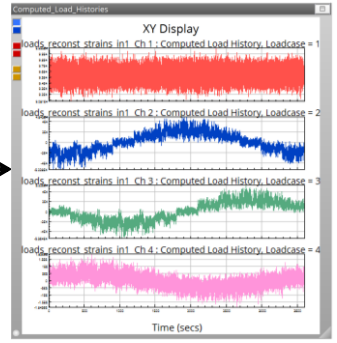


FE model (digital twin)

Continuous loop



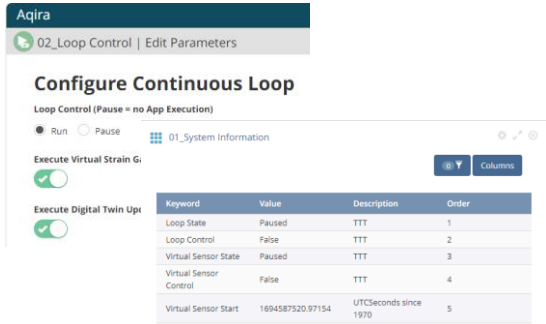
Virtual data



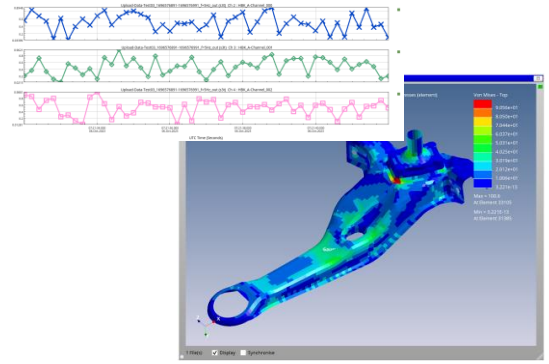
Measured data

Data management system

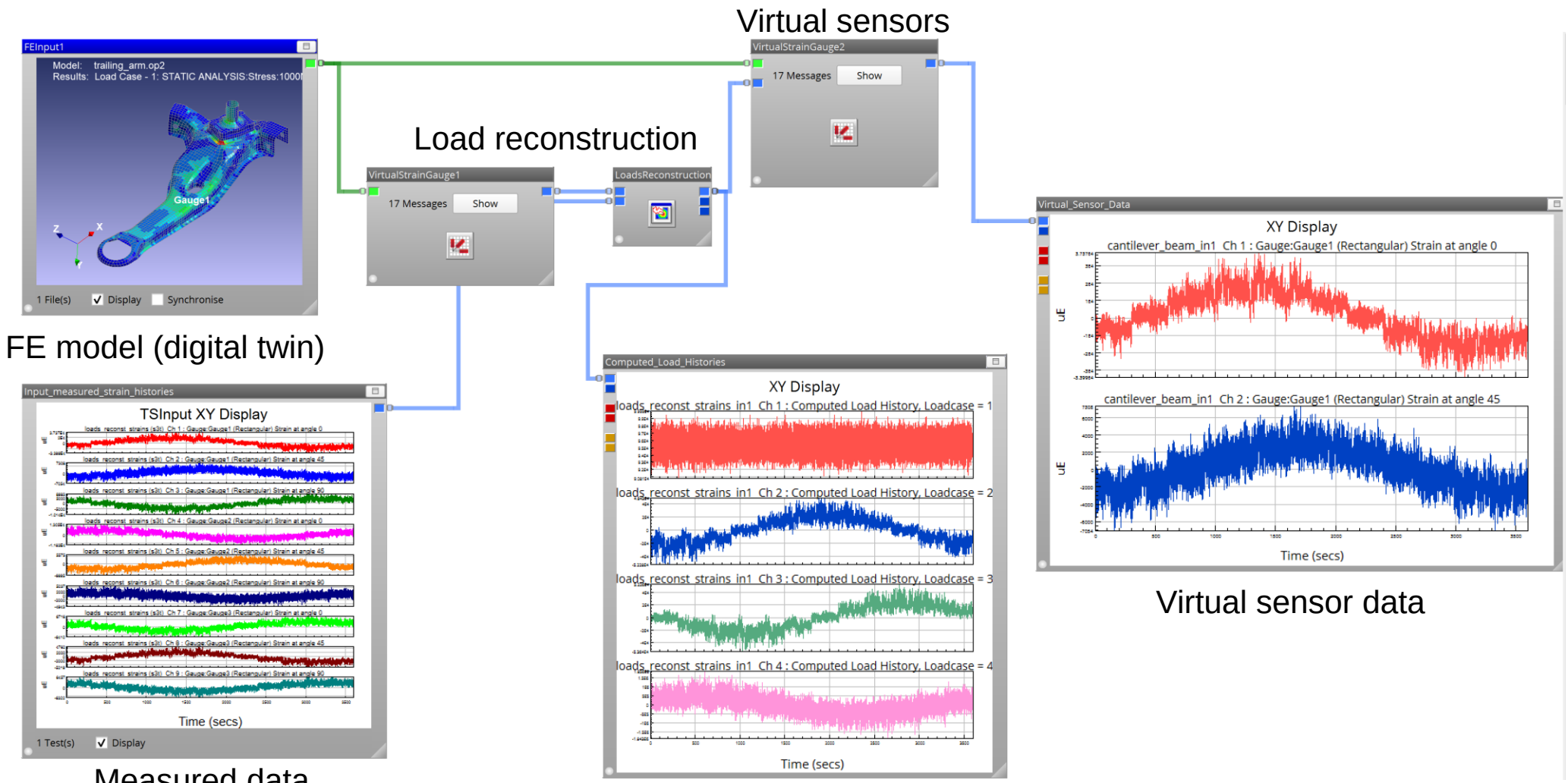
Loop control



Visualization



Virtual Sensors – Stepwise



FE model (digital twin)

Measured data

In-service load history

Virtual sensor data

HBK
HOTTINGER BRÜEL & KJÆR

Agenda

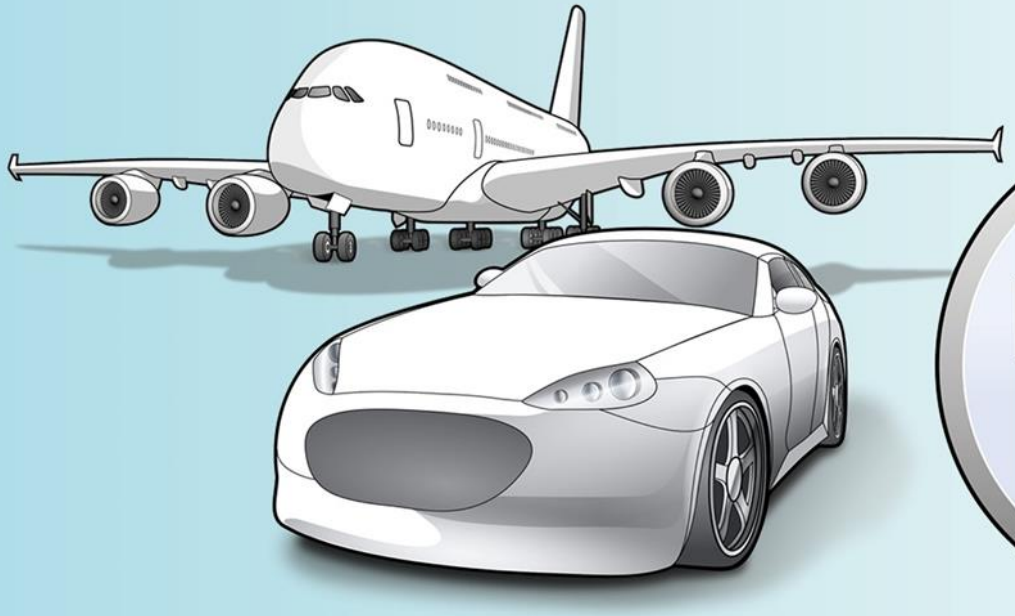
1. Introduction
2. Work Packages
3. HBK Contribution
4. **Summary**

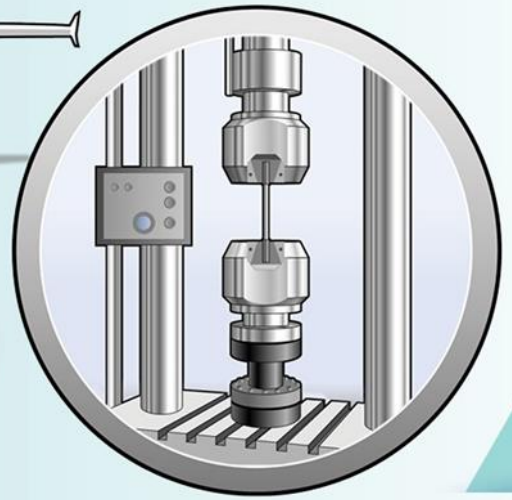
Summary

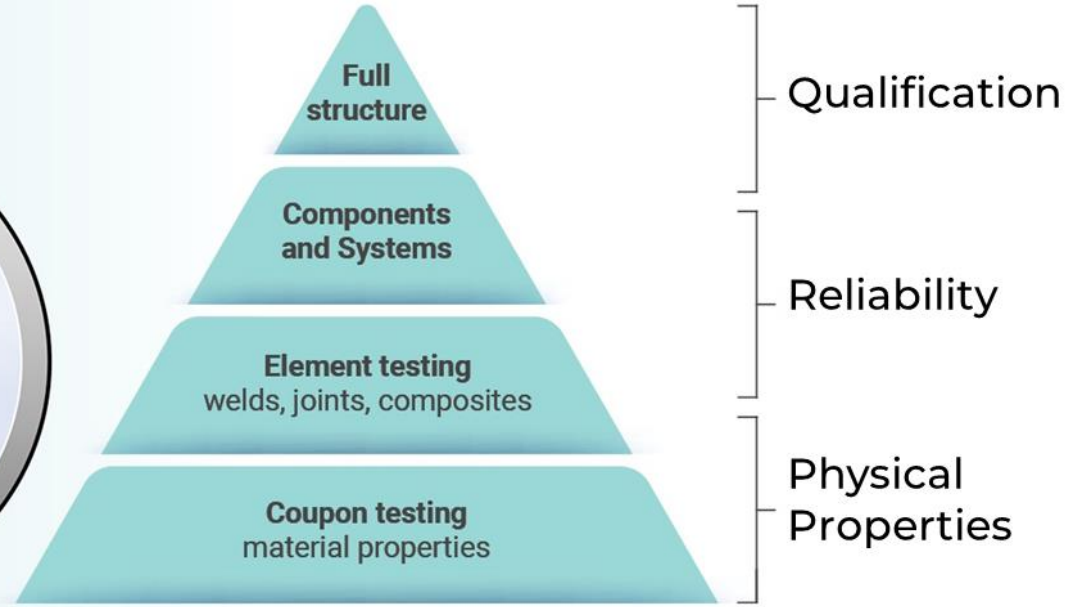
Innovation Contribution

- Use of digital methods to complement classical test technology
- Modelling and simulation of DuT and test rig for
  - Extrapolation of test results into “remote” areas of the DuT
  - Prediction and consideration of dynamic behavior
- Change of system (DuT + test rig) during test
  - Continuous adaption of model (“digital twin”)
- Condition monitoring through automated analysis of huge data amounts (“Big Data”)
- Interruptions for repair and inspection only to prevent catastrophic component failure

Thank You







2023 HBK Technology Days

7 November 2023

Rapid EF Enablers: Accelerating Full-scale Fatigue Testing

(*a combined presentation*)

- **The "Rapid EF" project for Accelerated Full-Scale Fatigue Testing,**
  Marco Wagner,
  Measurement and Control System Engineer, Airbus
- **HBK contributions to Rapid EF to reduce test downtime,**
  Sandro Di Natale,
  Product and Application Manager - Test and Measurement, HBK