



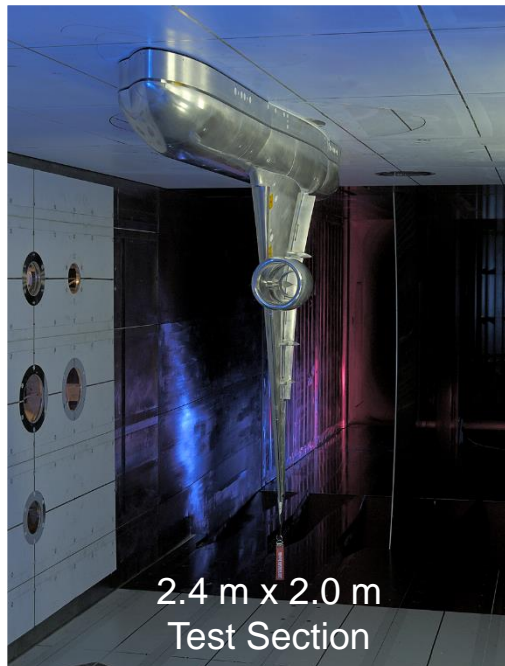
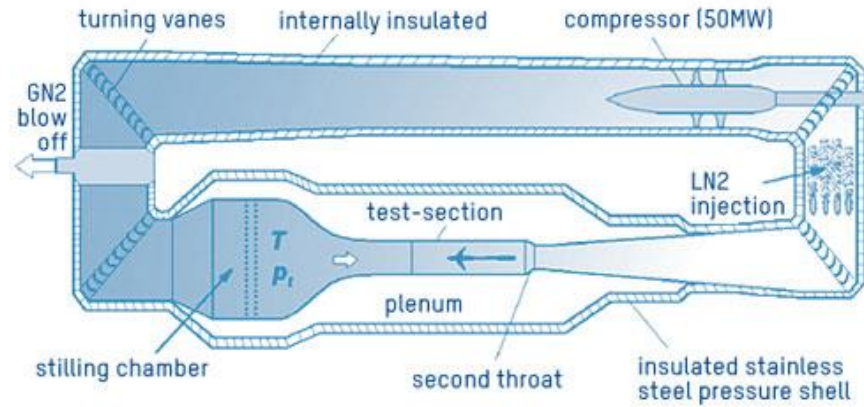
EUROPEAN TRANSONIC WINDTUNNEL



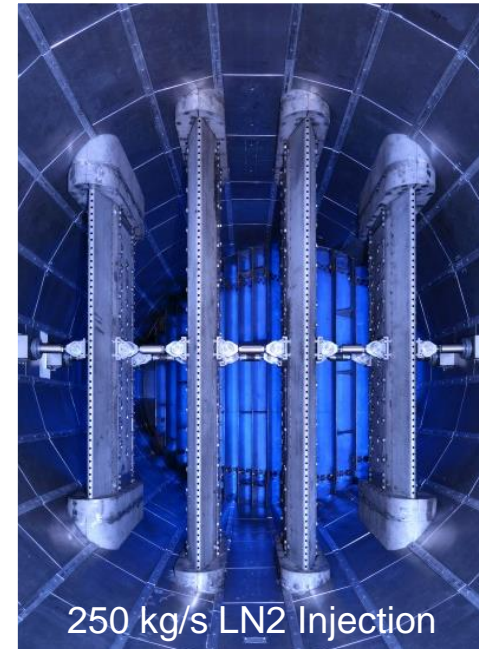
# Half-Span Model Testing Capability at the European Transonic Windtunnel (ETW)

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Test & Data Systems Engineer

# ETW Aerodynamic Circuit

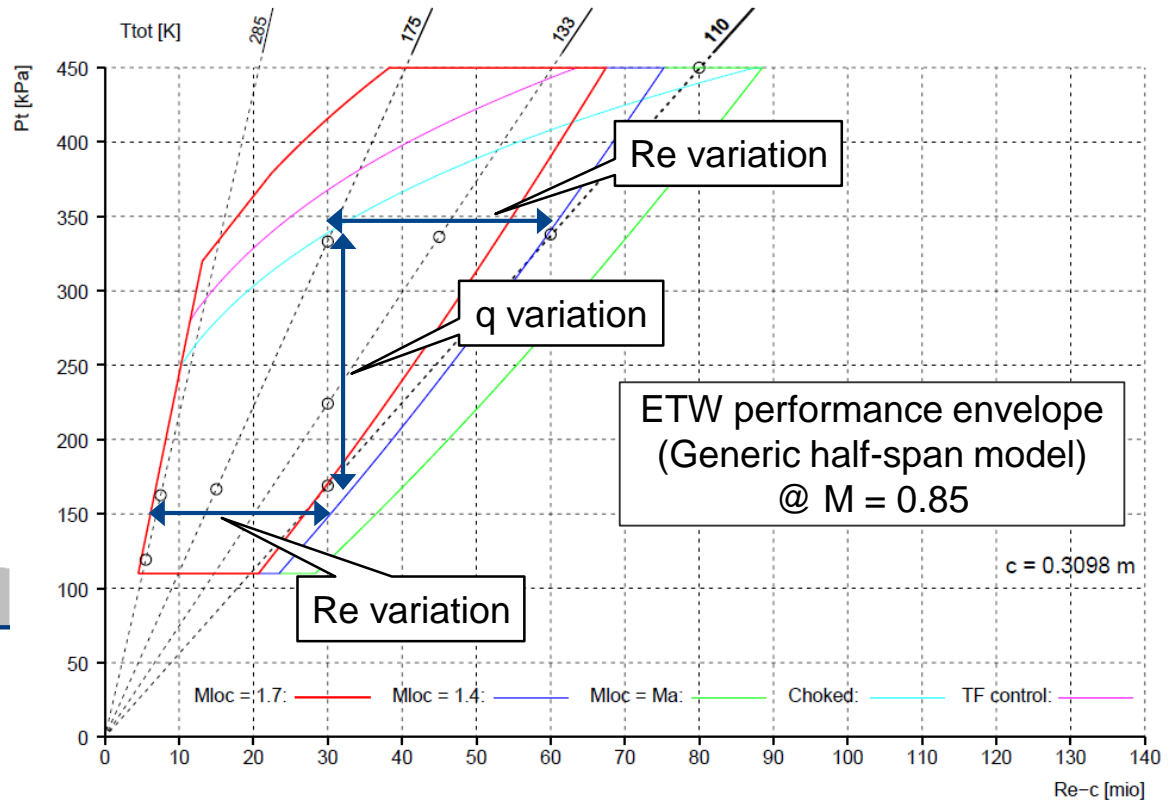
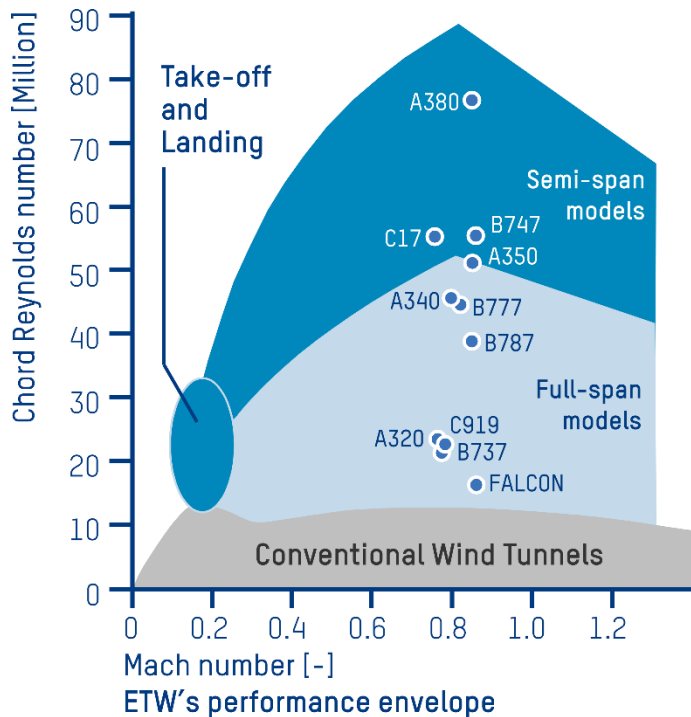


- Cryogenic and pressurized transonic windtunnel
- 2.4 m x 2.0 m x 9.0 m test section
- 50 MW two-stage axial compressor
- Flow temperature & pressure level are controlled by injection of LN2 and exhaust of GN2
- Anti-turbulence screens and large contraction ratio (12:1) prior to the test section ensure low turbulence levels



# ETW's Key Characteristics and Capabilities

- Take-off, landing, cruise and off-design testing at real-flight Reynolds numbers
- Separate analysis of compressibility (Mach number), viscosity (Re-number) and aero-elasticity (dynamic pressure) effects possible





# 30 Years of ETW's Half-Span Model Testing

- 1992 Development plans
- 1995 - 97 Design and manufacturing of HMB1
- 1998 Commissioning of HMB calibration rig
- 1998 First calibration of HMB1
- 1998 PETW HM test section selection tests
- 1999 First Client HM tests
- 2002 HM wall interference tests
- 2002 First high-speed half model tests
- 2014 First HM acoustics measurement
- 2014 Develop and manufacturing of HMB2
- 2018 Develop and manufacturing of HMB3
- 2019 First HM tests with SMA remote controls
- Since 1999 Multiple low- & high-speed half-span model tests successfully performed



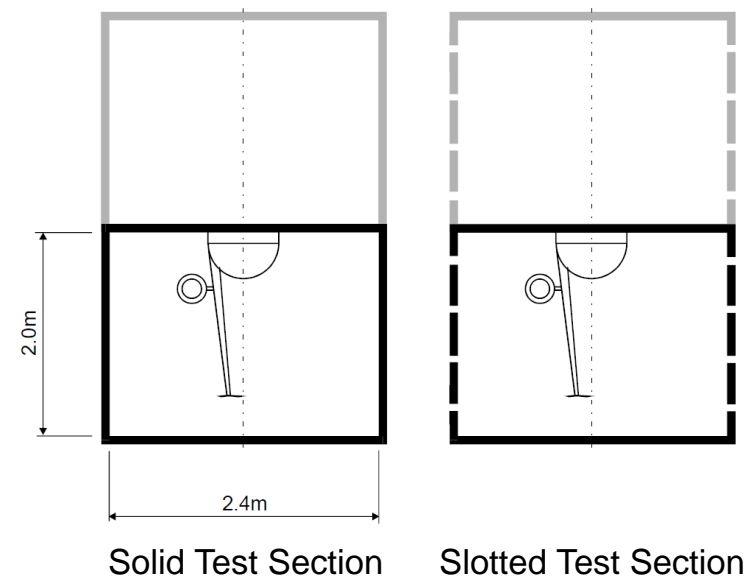
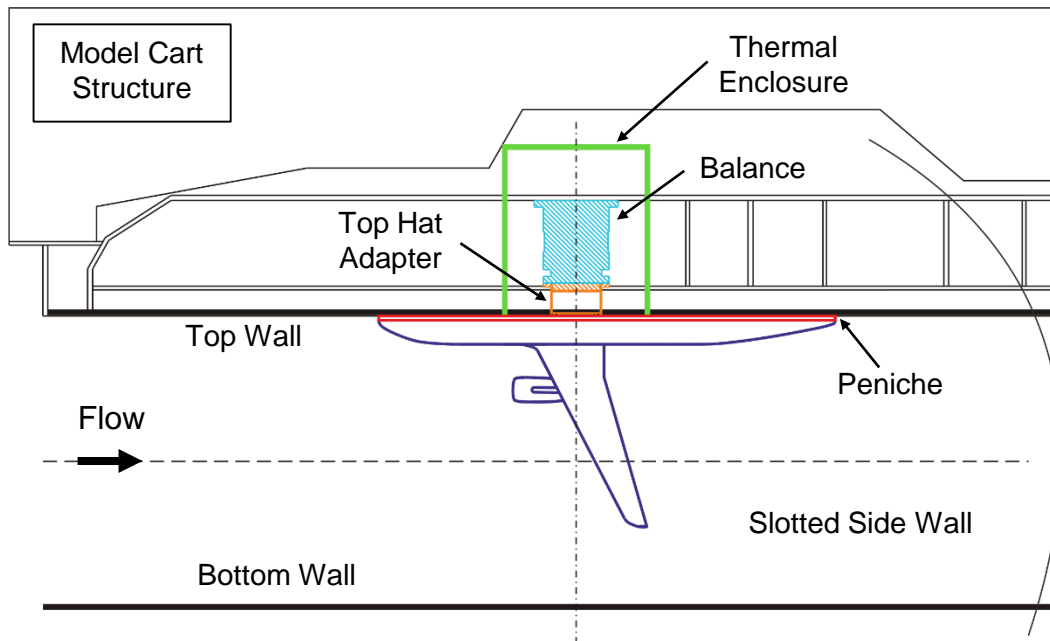
Half-span model in the PETW test section



Commissioning Half Model (CHM) in the ETW test section

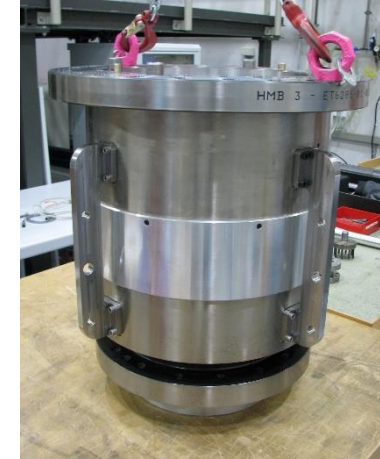
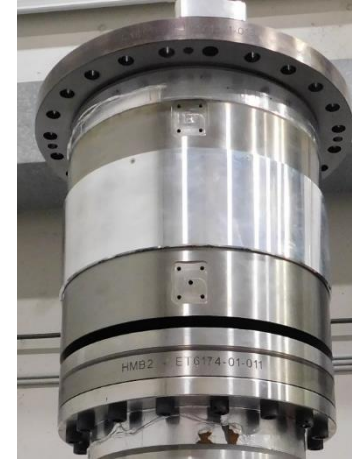
# Half-Span Model System

- Half-model balance installed in the Model Cart
- ETW has two Model Carts (MC), MC1 allows HM testing
- Comprehensive thermal control system decouples the balance and turntable from ETW's variable temperature operating environment
- Turntable system allows model incidence up to  $\pm 45^\circ$
- Both solid and slotted test section (up to 7.4% porosity) available



# ETW Half-Span Model Balances at a Glance

- Three HM balances
- Six-component design (one component in the direction of model weight, SF)
- Two independent strain-gauge bridge sets for each component
- Designed for operation at ambient temperature
- Diameter 400 mm, Height 500 mm
- MRC 500 mm above top wall



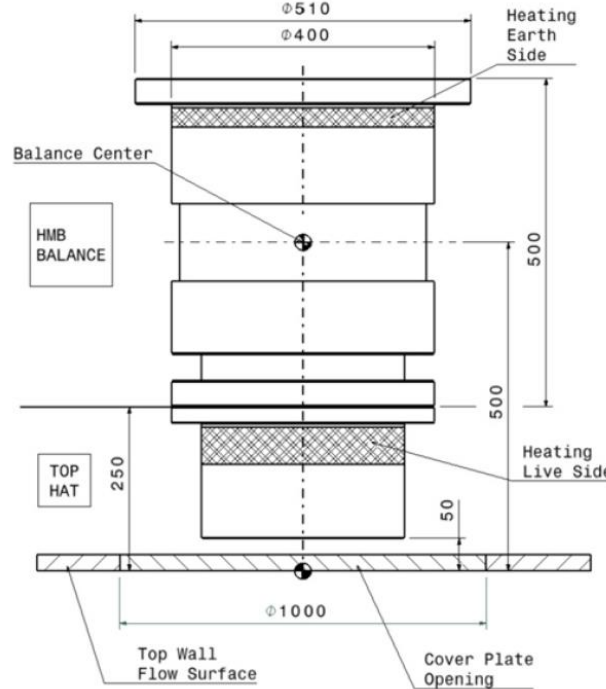
<sup>\*)</sup> Combined operating static loads about the Moment Reference Centre

		HMB1	HMB2	HMB3
At ETW since		1999	2014	2018
Manufacturer		ARA	NLR	NLR
Axial Force <sup>*)</sup>	AF	± 5 000 N	± 5 000 N	± 3 000 N
Normal Force <sup>*)</sup>	NF	± 50 000 N	± 50 000 N	± 30 000 N
Rolling Moment <sup>*)</sup>	RM	± 30 000 Nm	± 30 000 Nm	± 18 000 Nm
Pitching Moment <sup>*)</sup>	PM	± 4 000 Nm	± 4 000 Nm	± 4 000 Nm
Yawing Moment <sup>*)</sup>	YM	± 3 000 Nm	± 5 500 Nm	± 3 300 Nm

# Half-Model Balance 1 (HMB1)



Bare balance structure being inspected just prior to the gauge installation



Overall balance dimensions and reference centres

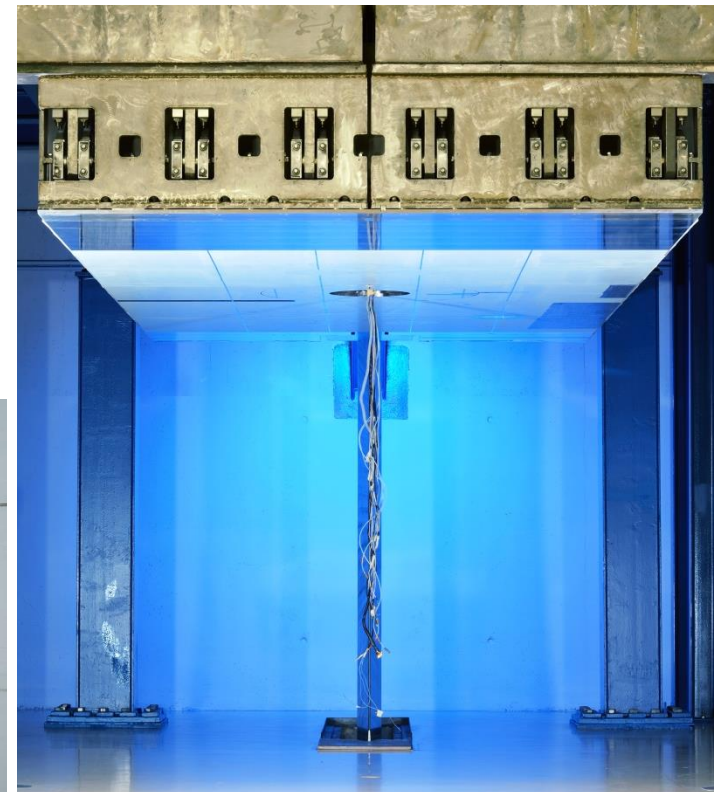
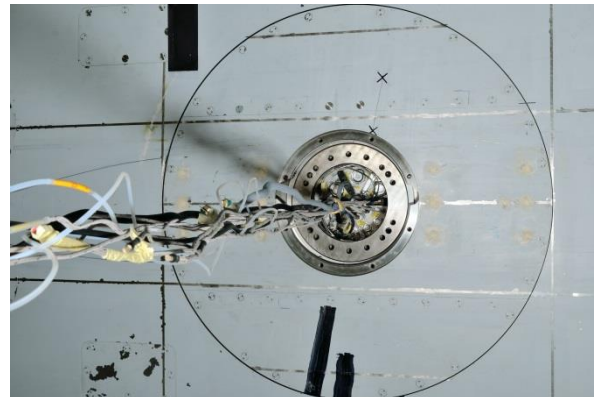
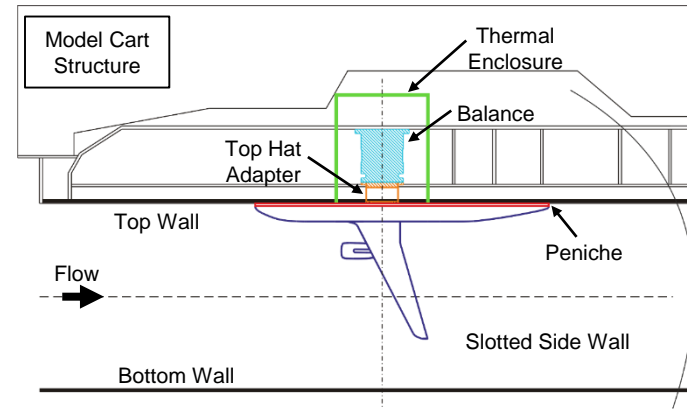
Component	Sensitivity [N/μV] (Each Bridge)
NF	8.0
AF	0.9
PM	3.5
RM	7.0
YM	1.0

- Maraging Steel
- NF, AF & PM Accuracy
  - 0.10% (50-100% FR)
  - 0.05% (0-50% FR)
- Two independent gauge sets for each load component
- 10x Pt100 temperature sensors
- Heating foils attached to the balance earth side and top-hat adapter (balance live side)



# Half-Model Interfaces

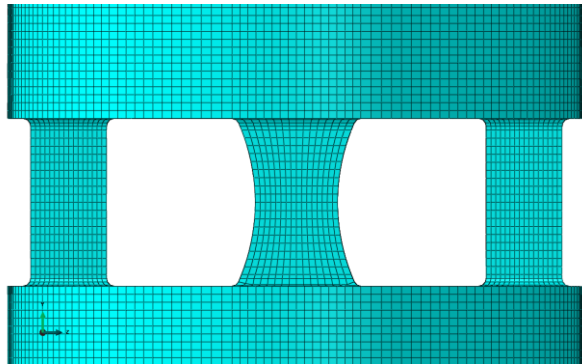
- Current interface design of HMB1 requires removal of top wall from the model cart to provide sufficient clearance for the balance to be removed or installed from above
- HMB2 & HMB3 have been designed with a removable top flange to enable installation from below without removing the top wall
- Significantly reductions in time and manpower requirements to exchange HM balances





# Half-Model Balance 2 & 3 (HMB2 & HMB3)

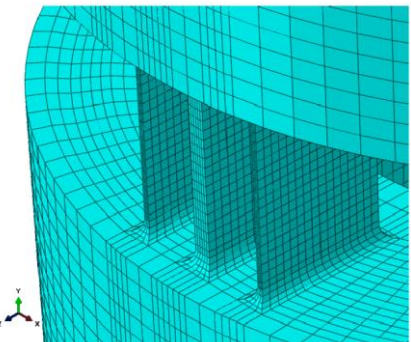
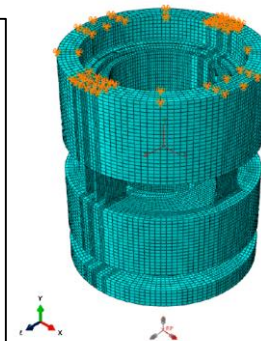
- Two new members of ETW's balance family
  - Designed and manufactured by NLR (Netherlands Aerospace Centre)
  - Overall design based on HMB1 single piece concept
    - With improved mounting features (e.g. removable top-flange joint)
    - Optimized flexure design by using parametric FEM model
  - HMB2
    - Same load limits as the HMB1, a direct successor of HMB1
  - HMB3
    - Lower load limits (60% of HMB1), but higher sensitivity
    - Optimized for low-speed performance & laminar testing



Parametric FEM Model

### Design parameters

- Single flexure root width
- Single flexure mid width
- Single flexure thickness
- Triple flexure root width
- Triple flexure mid width
- Triple flexure thickness
- Flexure height



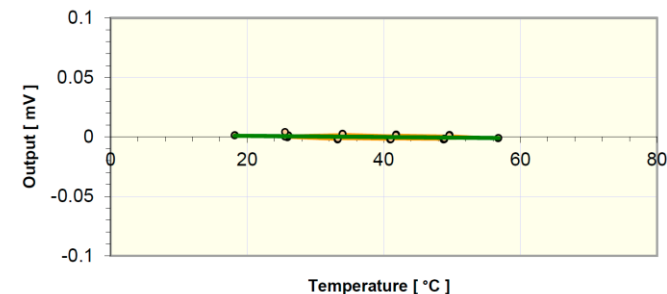
Final HMB3 FEM Model after Design Optimization Process

# Instrumentation Details

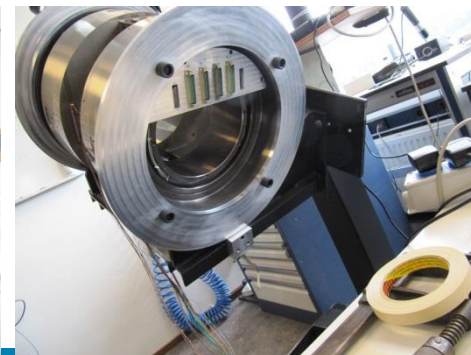
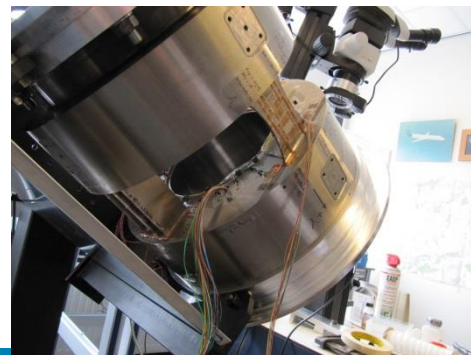
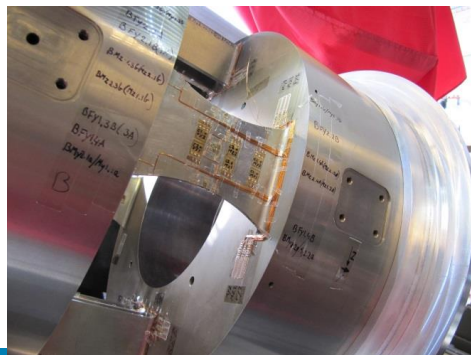
- Two independent gauge sets
- Each bridge has six wire configuration
- Instrumented with 10 Pt100 temperature sensors
- Usage of dedicated material for potentially severe environmental conditions:
  - Strain gauges
  - Wiring material
  - Solder material
  - Bonding
  - Coating
- Connectors:
  - Connectors and pin definitions duplicated from existing balance



HMB3 Moisture Check



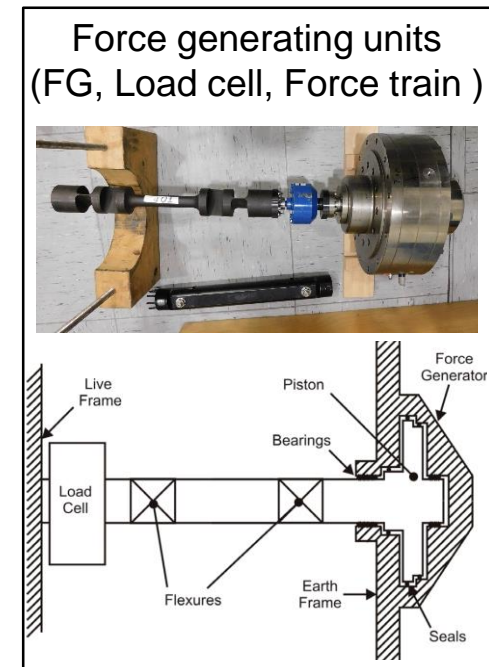
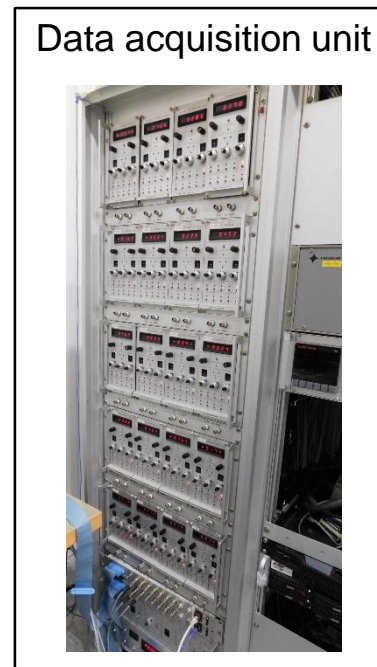
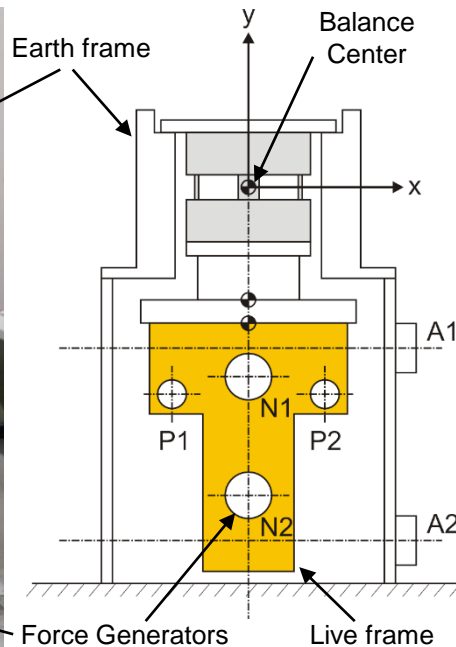
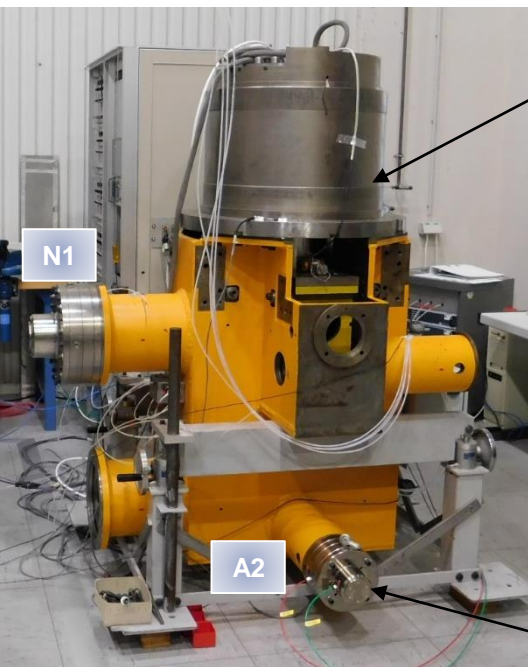
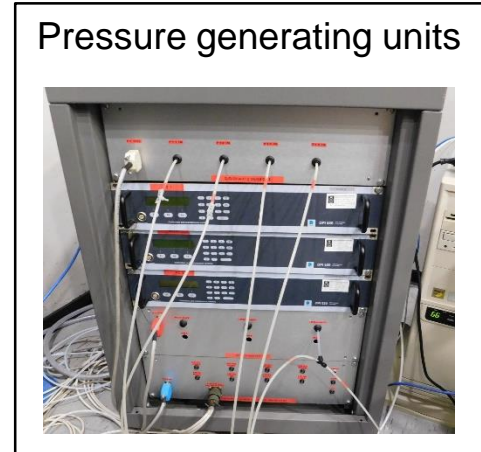
Zero-Shift Compensation  
(HMB3-BF<sub>z</sub>, 25°C – 55°C)



# Half-Model Balance Calibration Rig

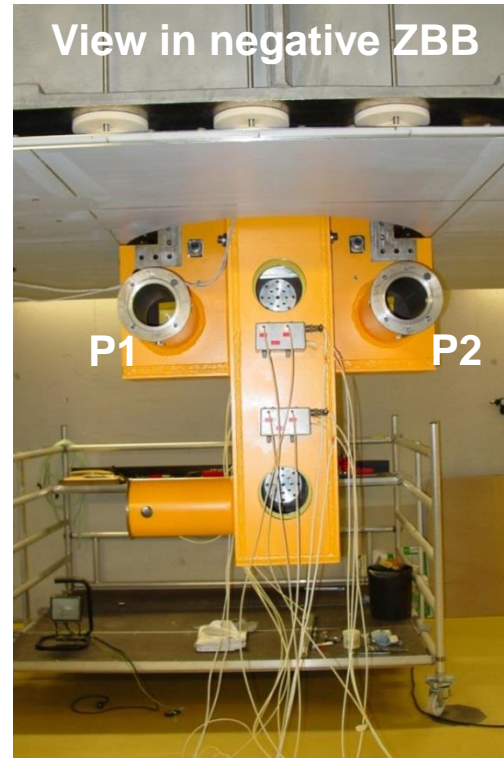
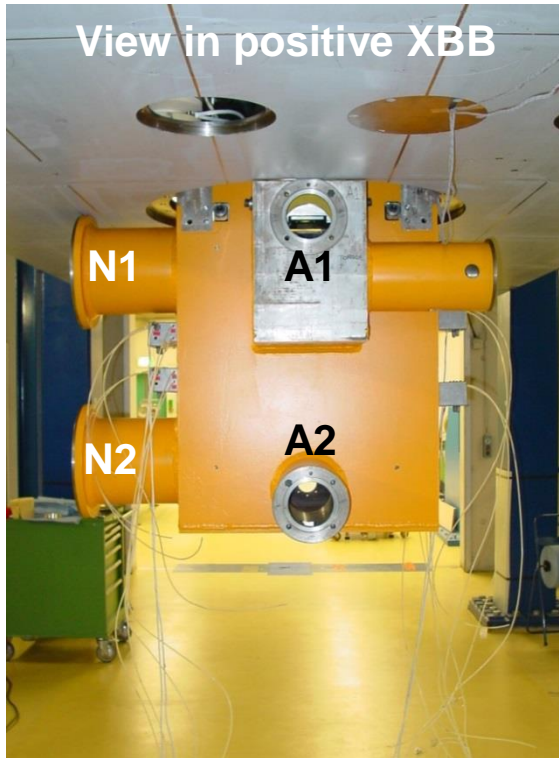
## In Balance Calibration Room

- PC-controlled, semi-automatic, five-component calibration for HM balance
- Comprehensively air-conditioned facility for calibration at ambient condition
- 2x 50 kN, 2x 5 kN pneumatic Force generators controlled by three PGUs (working medium: GN2)
- Applied load is measured by high quality “Interface” load cells, installed between the Live frame (Force train) and the Force generator
- Combined loading of up to four components possible





# Half-Model Balance Calibration Rig Attached to Model Cart



- Original calibration equipment designed for in-situ calibration on model cart
- Earth loading frame connected to base of turntable
- Live loading frame attached to base of balance / top hat



# Recent Modernization of Calibration Facility

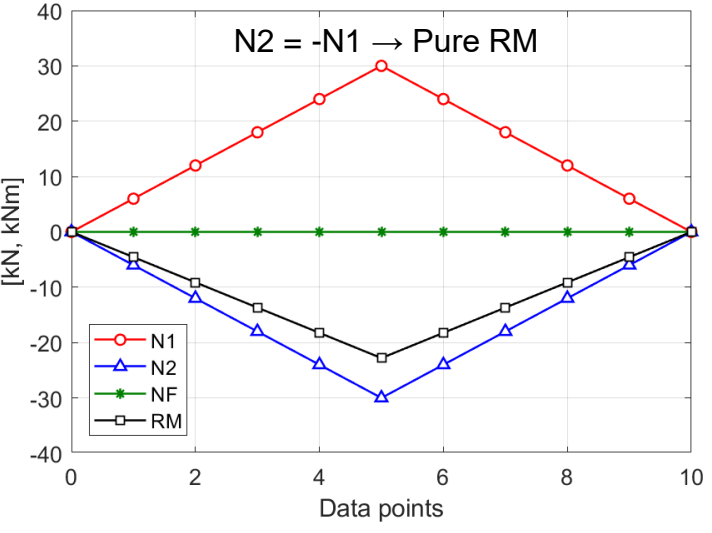
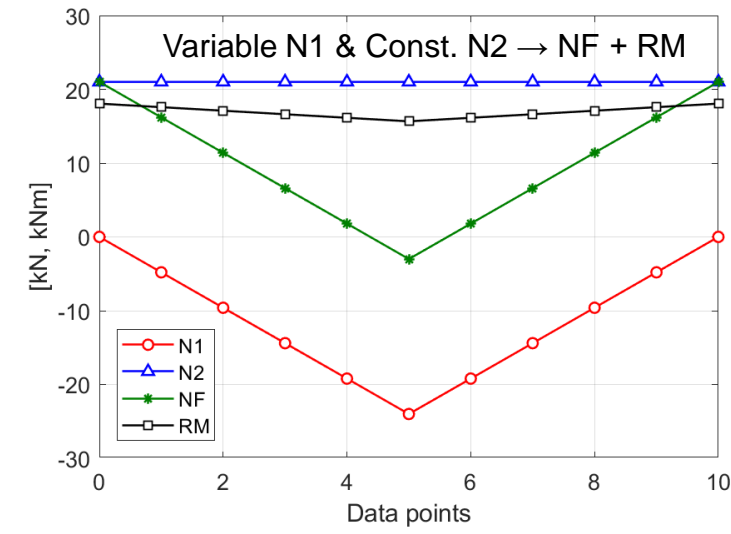
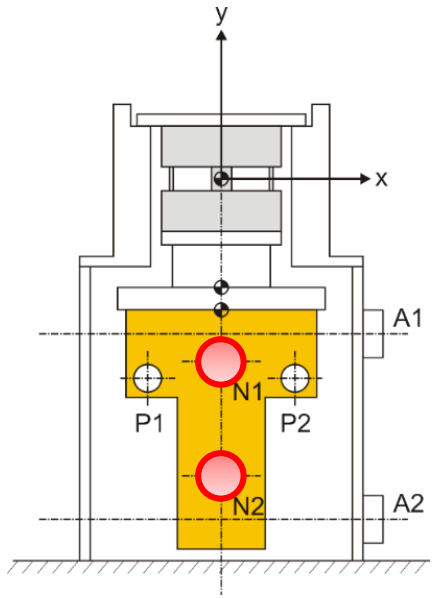
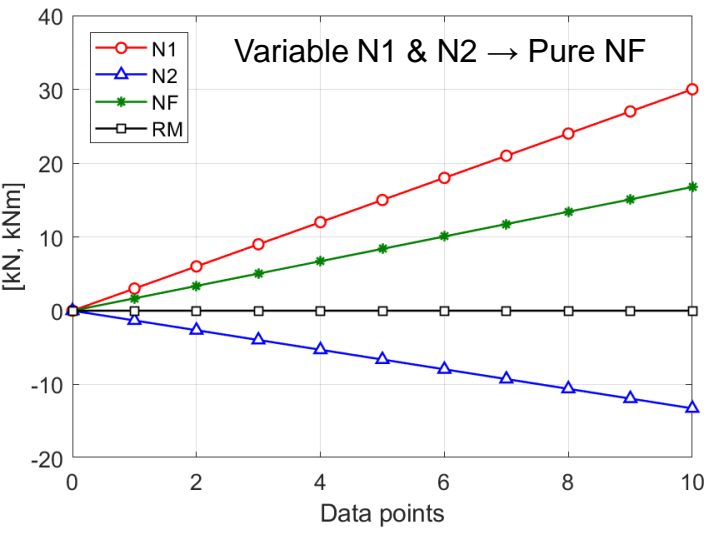
- Four new Pressure Generating Units with new Three-Way Valves
  - Provide more reliable, precise and faster pressure inputs to the Force Generators

- New Calibration Control & Monitoring and Data Acquisition Program
  - Provides enhanced protection against overload
  - Enables optimizing and automatizing calibration procedure → improving calibration efficiency

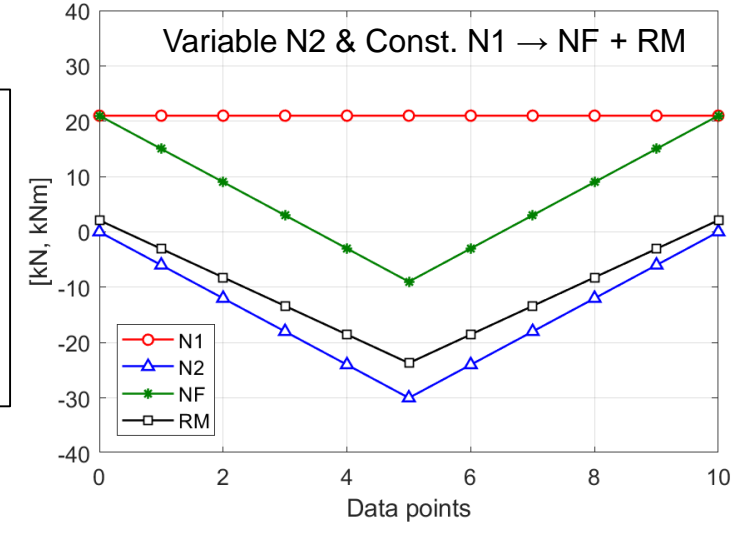


# Typical Calibration Scenarios

here, only  
N1 (upper FG) & N2 (lower FG) installed



**Further combinations:**  
 N%+A% → AF+NF+RM+YM  
 N%+P% → NF+RM+PM  
 P1+P2 → pure PM  
 A1+A2 → pure AF, pure YM & AF+YM



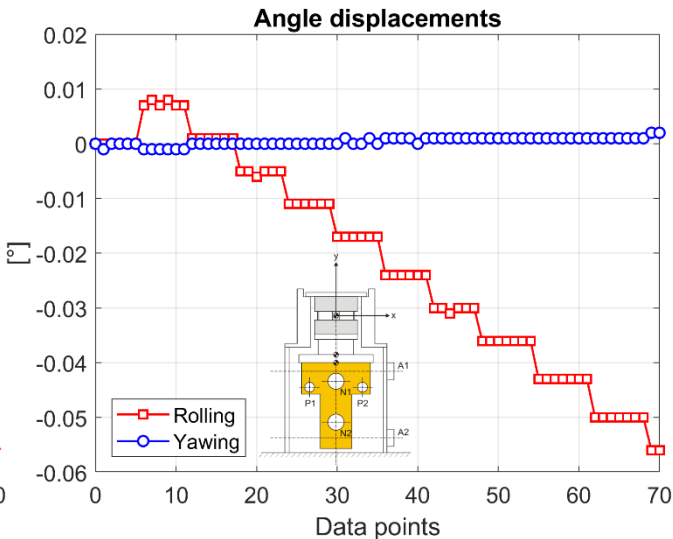
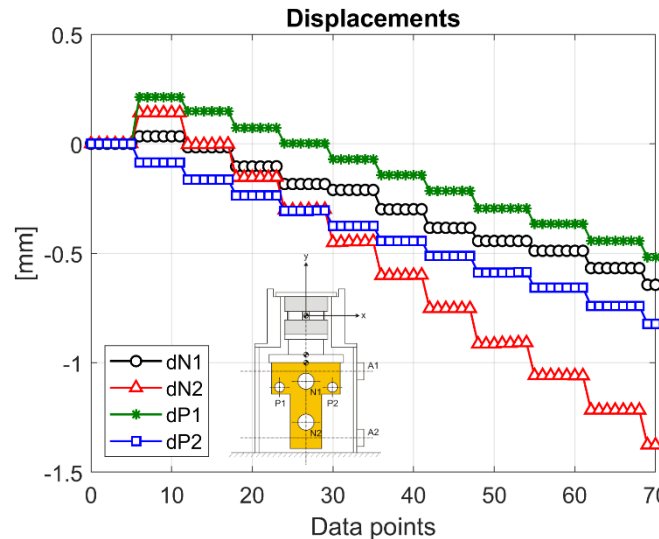
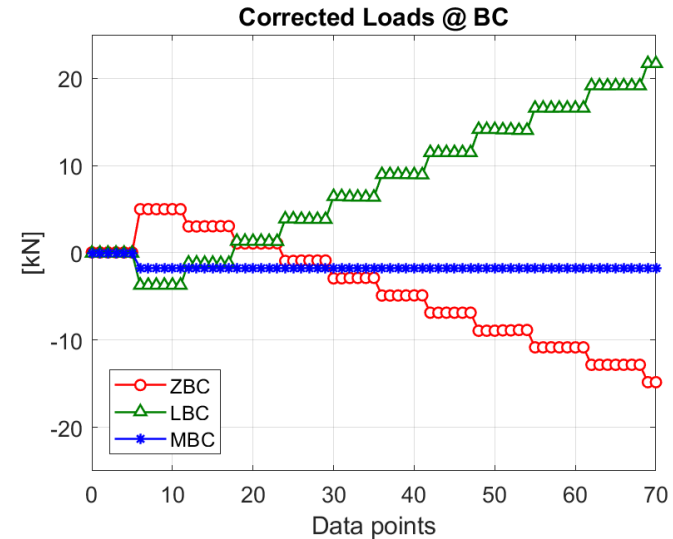
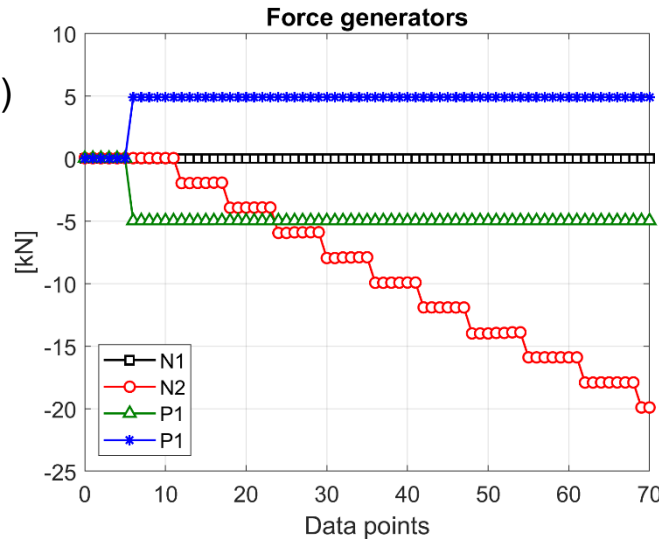
# Calibration Body Displacements

- Simultaneous monitoring of calibration body (Live frame) behaviour
- Instruments: 2x Q-Flexes, 4x digital dial gauges
- Applied loads are corrected for calibration body deformations

Digital Dial Gauge



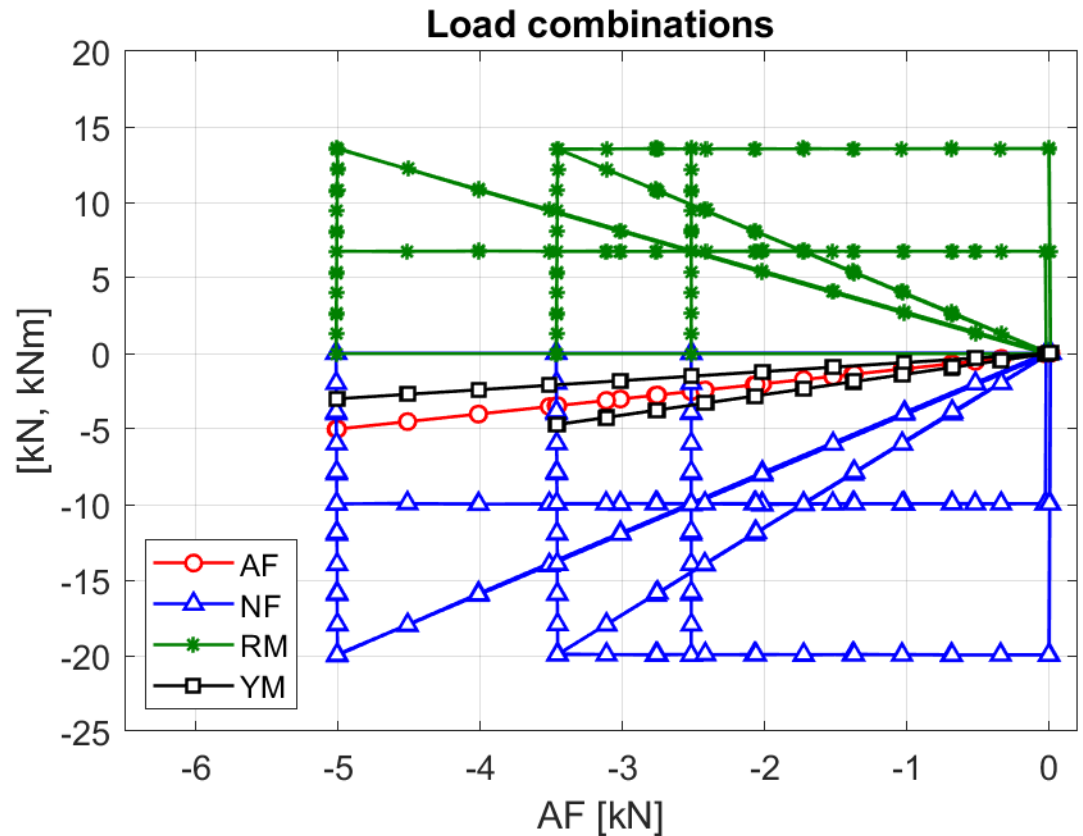
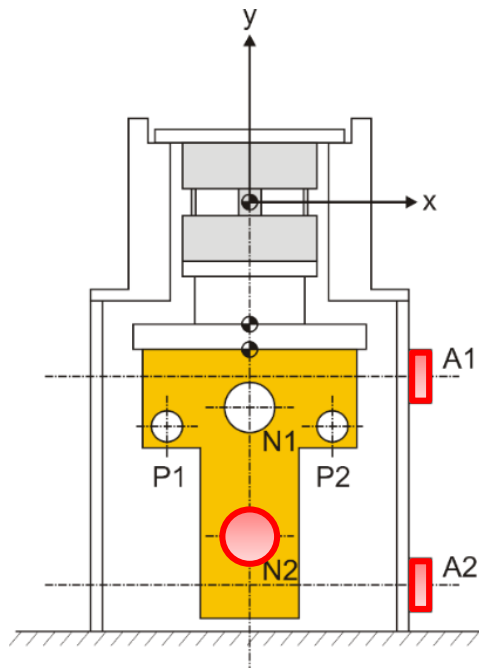
Q-Flexes on Cal. Body



# Calibration Results (HMB2)

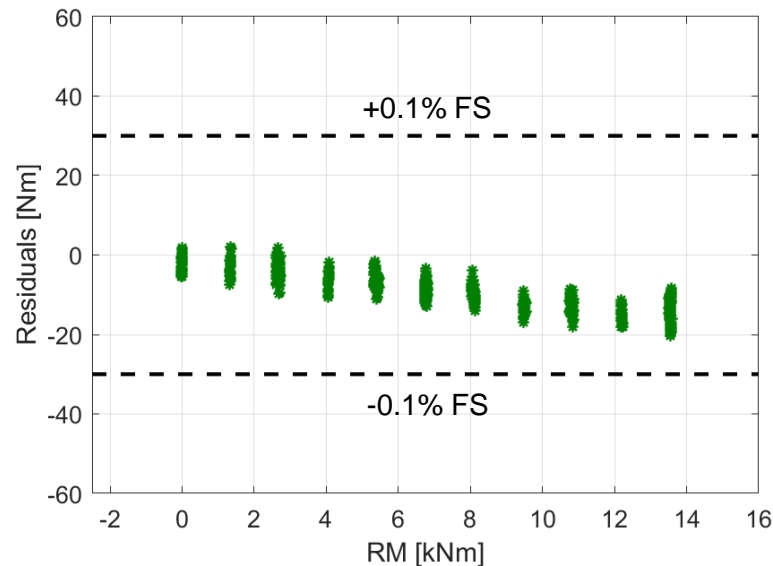
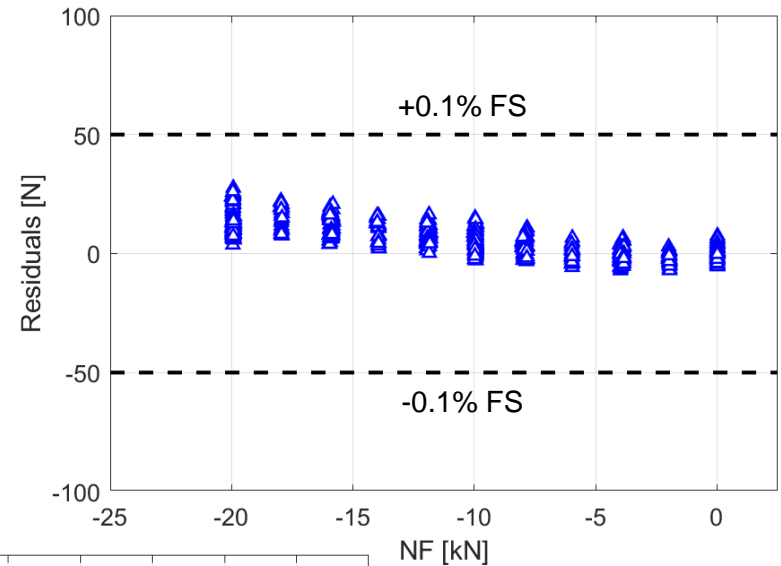
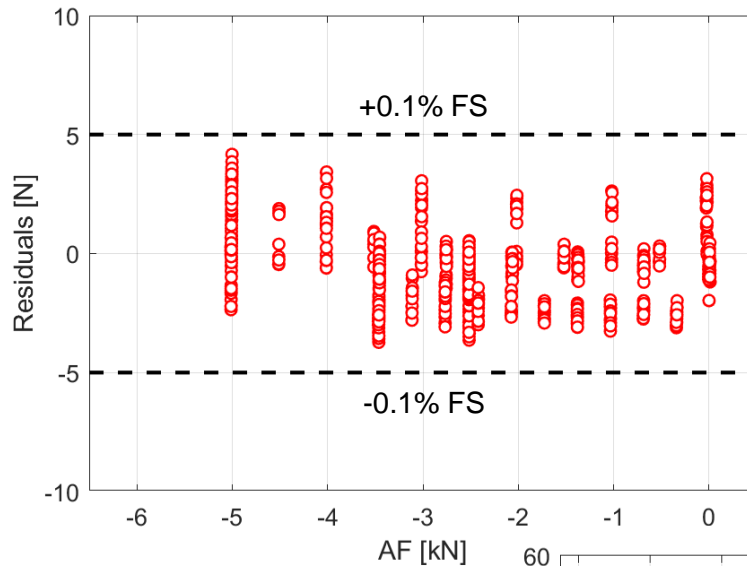
- First full calibration of HMB2 performed in 2020 → 453 load cases including repeat. control & zero measurements
- First full calibration of HMB3 conducted in 2021 → 423 load cases were tested

Load cases by using combinations of A1, A2 and N2 (lower)





# Calibration Results (HMB2)



- 2<sup>nd</sup> order matrix evaluated for each bridge sets (in the balance centre)
- AF, NF and RM residuals lie within 0.1% of full scale

# Calibration Results

- Comparison of theoretical (NLR-FEM) and actual (ETW-Calibration) strain-gauge bridge outputs for max. static single loads
- Both balances behave as predicted from the design phase

Theoretical outputs [mV]

HMB2	+AF	+NF	+RM	+PM	+YM
B1AF	7.25				
B1NF		9.21			
B1RM			5.03		
B1PM				14.10	
B1YM					4.90

Theoretical outputs [mV]

HMB3	+AF	+NF	+RM	+PM	+YM
B1AF	10.70				
B1NF		8.25			
B1RM			6.63		
B1PM				10.60	
B1YM					4.39

Actual outputs [mV]

HMB2	+AF	+NF	+RM	+PM	+YM
B1AF	8.93				
B1NF		10.52			
B1RM			5.77		
B1PM				19.02	
B1YM					5.12

Actual outputs [mV]

HMB3	+AF	+NF	+RM	+PM	+YM
B1AF	10.39				
B1NF		8.28			
B1RM			6.64		
B1PM				12.71	
B1YM					4.30

# Conclusions and Outlook

- ETW's half-span model testing capability allows high Reynolds number testing up to 80 million
- HMB1 is the key driver for success on ETW's half model testing
- HMB2 & HMB3 have been developed to enhance ETW's half model testing capability
- The new NLR balances have been optimized using current state of the art design methodologies to provide optimum sensitivity in all measured components combined with high levels of stiffness
- The balance interface with the model cart has been changed to improve balance exchangeability
- The first full calibrations of both balances show that they fulfil the ETW's strict specifications and are ready for client tests
- Validation Test using "Tandem Method" and Wind-on commissioning tests will be performed in the near future

