



smarHUMS

smarHUMS for helicopter gearboxes
SiME Darmstadt 2026

HELICOPTERS

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15.09.2026



Agenda

- Project overview and motivation
- “Voice of the customer” – What does the market expects?
- smartHUMS concept
- Proof-of-Concept
 - Design
 - Data analysis & AI approach
 - Experimental analysis & Testing
- Conclusion and outlook



smartHUMS: Project overview

- “Entwicklung intelligenter, KI-basierter HUMS Systeme für Hubschraubergetriebe und e-Aktuatoren zur Rotorsteuerung - smartHUMS”
- Main objective: Integration of leading-edge modern Health- & Usage sensor technology within dynamic components of helicopters with minimal physical interfaces to the aircraft
- LuFo project, Funding under research contact 20D1918A of the BMWF

Gefördert durch:



Bundesministerium
für Wirtschaft
und Energie

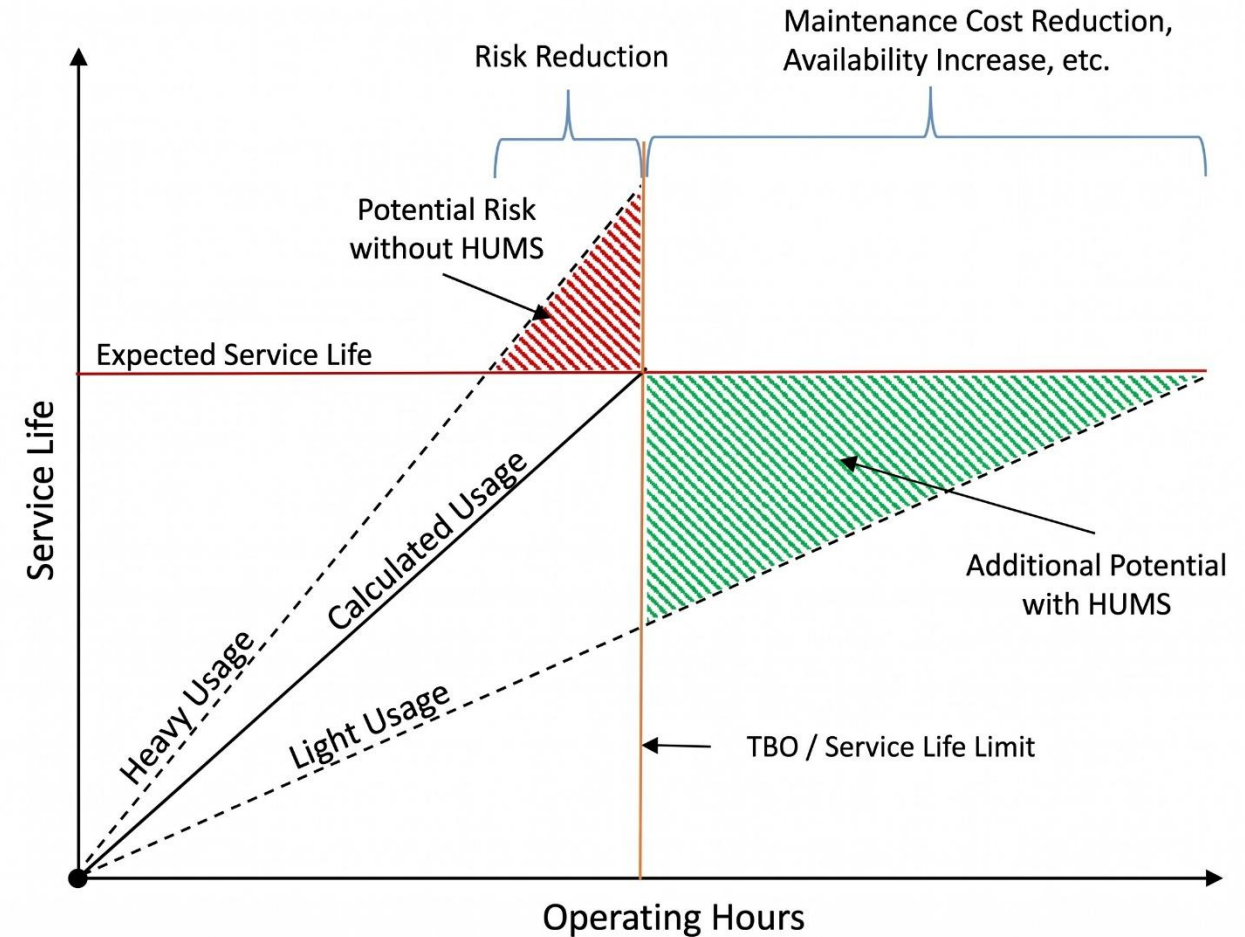
aufgrund eines Beschlusses
des Deutschen Bundestages

Partner	Focus area	Core deliverable to the project	
Airbus Helicopters Technik GmbH	Gearbox & Actuator	Project leader, specification, design / sensor integration, safety and reliability, testing	
Diehl Aerospace GmbH	Gearbox	Avionic platform (CANSAS™ HPC), data compression, Radio module (5G/WLAN), broker	
TU Darmstadt (FSR)	Gearbox	Concept & Integration of ML/AI algorithm, load aggregation, damage characteristics	
Deutsches Institut für Luft- und Raumfahrt (DLR)	Actuator	Investigation concerning actuation, FMECA, sensor concepts and test environment	



smartHUMS: Motivation

- To date, the monitoring of dynamic system components in helicopters is primarily carried out to identify acute damage during flight, serving solely as a warning system for the crew.
- Predictive or condition-based maintenance planning based on actual operational loads is rarely implemented.
- Transfer of established approaches from other industries (e.g., wind power, railway technology, automotive) to aviation technology.
- Objective: Reduction of maintenance costs and increase in fleet availability.





smartHUMS: “Voice of the customer” – What does the market expects?

MRO concept today: Scheduled Maintenance

Fixed maintenance intervals (TBO / SLL): Component replacement takes place after a set number of flight hours – regardless of the actual state of wear.

Disadvantages: Unnecessary early inspections, high material maintenance costs, and unpredictable downtime during ongoing fleet operations.

Target concept smartHUMS: CBM

Condition-Based Maintenance (CBM): Continuous monitoring of component condition and precise calculation of remaining service life based on real load profiles.

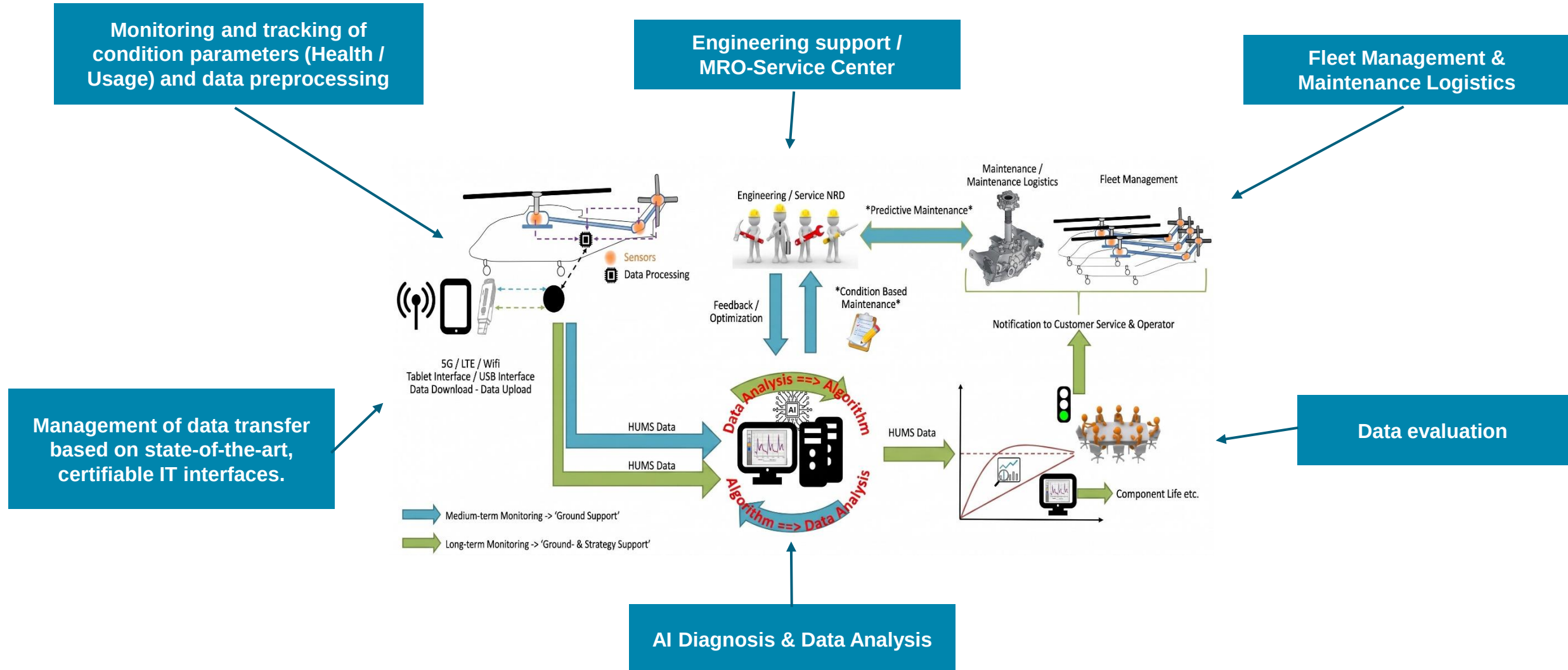
Benefits: Maximum fleet availability, targeted troubleshooting prior to failure, and optimization of MRO logistics.

Transformation of the MRO process based on expectations

- Excerpt: Analysis of operator requirements via stakeholder interview (operator – e.g., ADAC):
 - **Reduction of downtime:** Targeted avoidance of unplanned maintenance measures to ensure maximum operational readiness.
 - **Planning:** Use of real-time operational data for flexible maintenance planning based on actual component wear.
 - **Safety & Automation:**
 - Minimization of manual interactions combined with maximum data security, access control, and seamless interface integration.
 - Retention of the current functionalities (“Basic”) of existing HUMS systems (e.g., health monitoring)

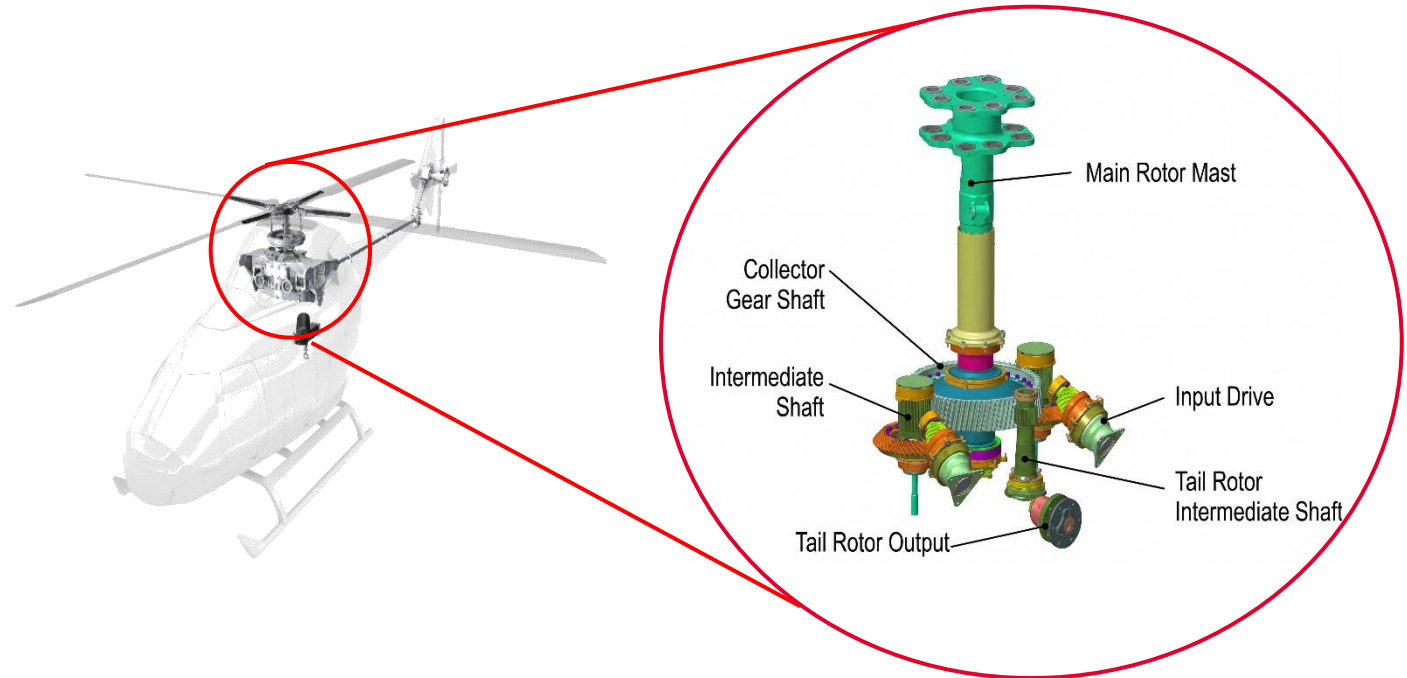


smartHUMS: Concept – High-Level



smartHUMS: Proof-of-Concept - Test platform (1)

- Serial FS108 main transmission of the EC135 serves as the test platform => EASA CS-27 certification (CAT A)



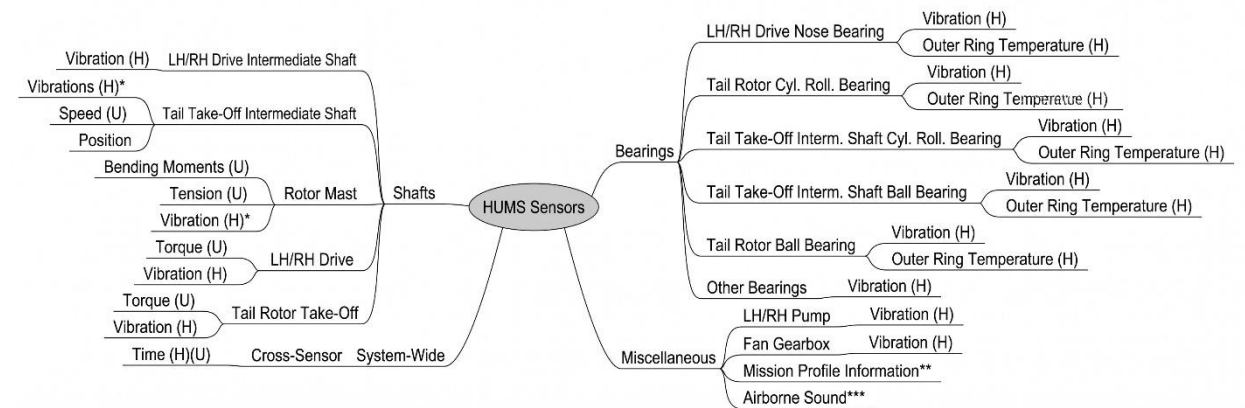


smartHUMS: Proof-of-Concept - Test platform (2)

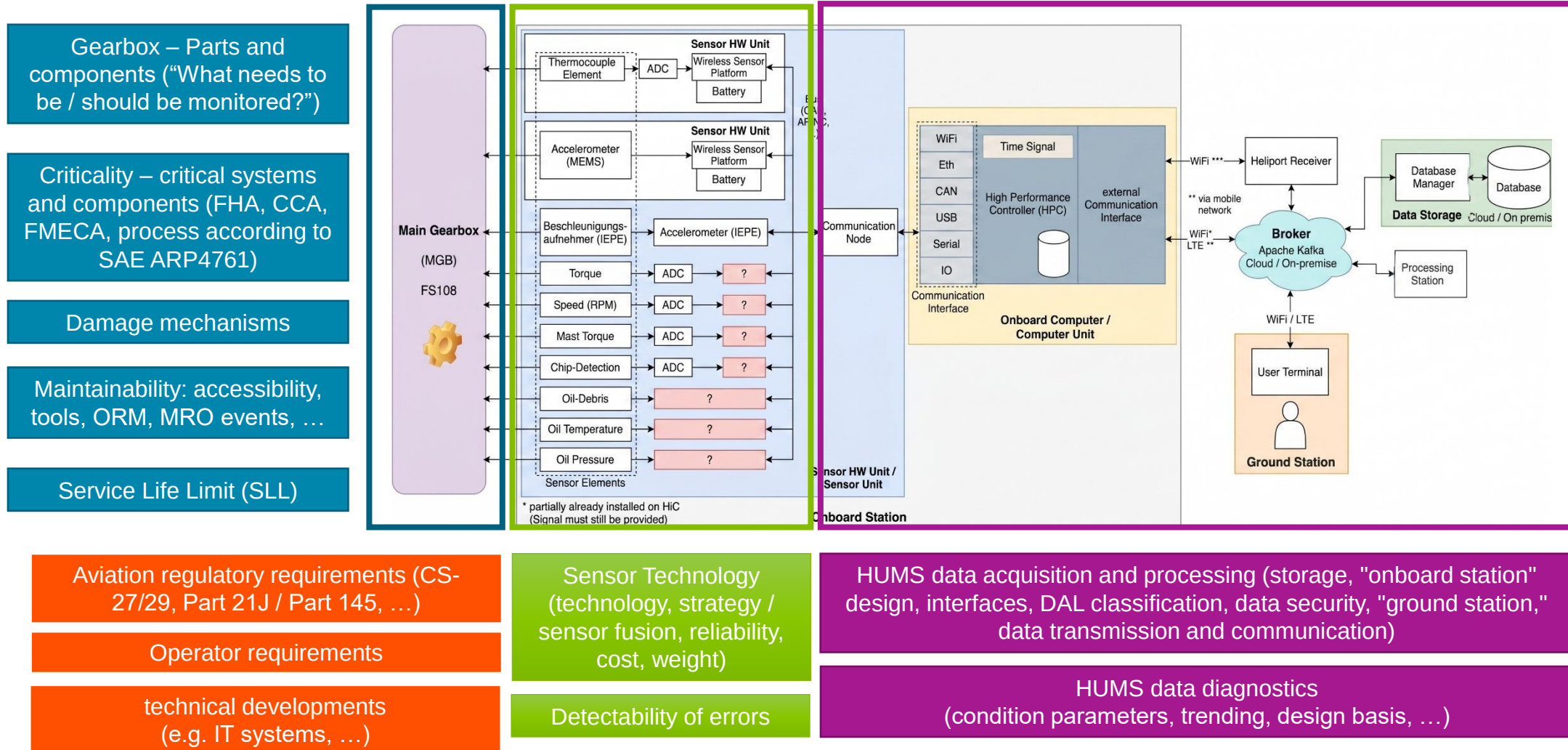
- FMECA-based selection of relevant components and cross-referencing with long-standing MRO experience (statistical analysis)
- Sensor specification taking system requirements into account

Selection of Failures, which should be detected with smartHUMS	Not Mentioned	Vibration	Acoustic Emission	Current	Temperature	Angular Position	Rotational Speed	Torque	Lubricant Condition	Sound
Failure Modes / Failure mechanisms	BCCI									
Abrasion / Erosion, Wear		x	x	x	x	x	x		x	x
Adhesion / Cold Welding										
Blockage / Clog									x	
Contact Fatigue										
Contact with Contaminants / Contact with Impurities and Foreign Matter				3	3				x	x
Contamination / Impurities				3	3				3	3
Corrosion / Fretting			x	x						x
Cracking / Rupture		x	x		x	x	x			x
Deformation / Distortion				x	x				x	x
Erosion / Cavitation, Distortion Deformation						x	x			x
Faulty heat treatment / Improper heat treatment			x		x					
Faulty installation / Misalignment		x	x		x	x	x		x	x
Faulty machining / Inaccurate processing		x		x	x	x	x		x	x
Fatigue / Fracture, Degradation		*	*	*					*	*
Fluid Leakage / Escape		*	x					*		
Fluttering / Unsteady operation										
Galling / Seizing			x	x	x					x
Inadequate lubrication / Improper lubricants			x	3	x				x	
Ingress of contaminants / Ingress of Impurities				3					3	3
Misalignment / Clearance, Overload		x					x			
Overheating / Overloading		x	x	x	x	x	x		x	x
Overpressure						*	x			
Plastic Flow / Permanent flow					x					
Pulsation / Rippling					x					
Rooting / Decomposition				x					x	x
Scuffing / Seizing										
Shearing / Stress, Strain		x				*	x	x		
Stress Corrosion / Stress corrosion, Fretting			x							
Squeaking / Grating noise		*			x					*
Undersize / Out-of-tolerance								*		
Wear / Erosion, Wear		x	x	x	x	x	x		x	x
Beating Damage, uneven operation		x	x	x	x		x		x	x
Clearance		*	x	*						*
Fatigue / Failure										

Existing sources sufficiently confirmed
... IT/2004-2000
* - (partially)
Sources insufficient
No sources available/verified



smarHUMS: Proof-of-Concept - Architecture / Elements and influences

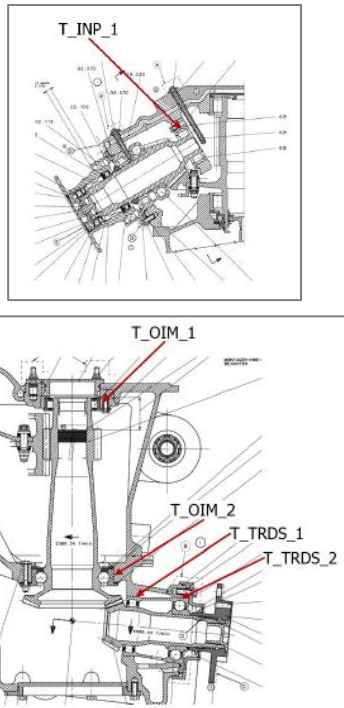




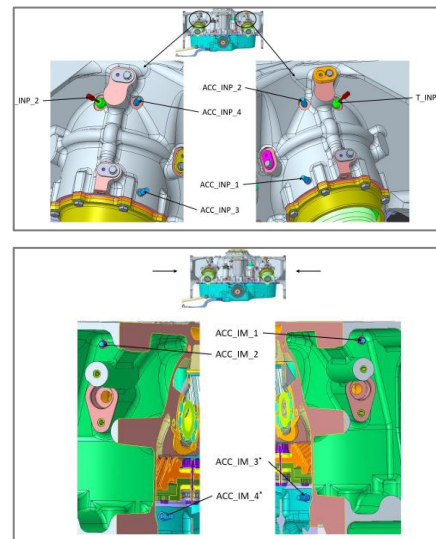
smartHUMS: Proof-of-Concept Design – Sensor Technology – Implementation

Main gearbox sensor system (“smartHUMS”)

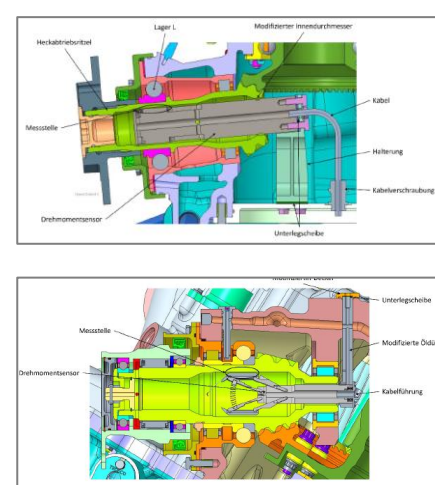
Temperature



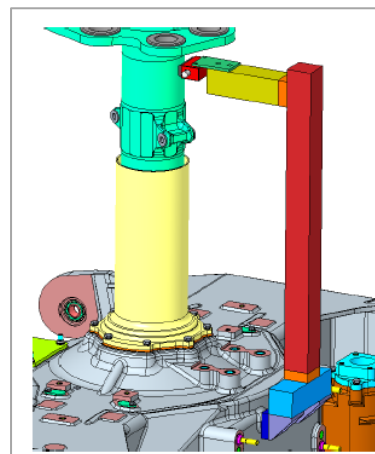
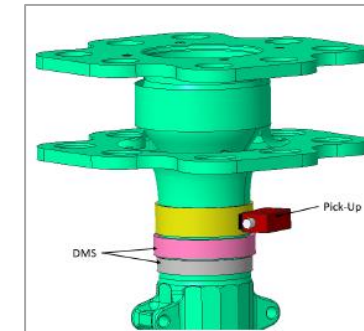
Vibrations



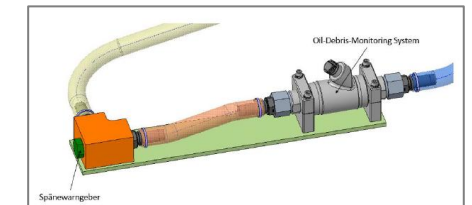
Torque



Forces (MRS)



Particles / Chips

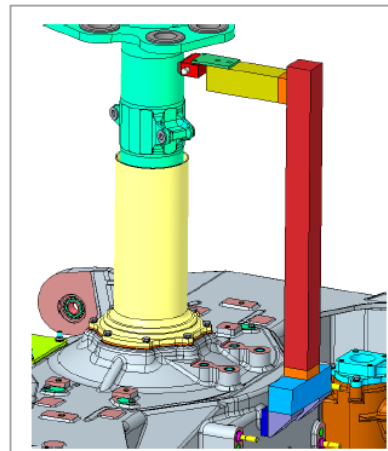
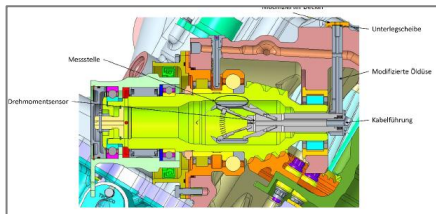
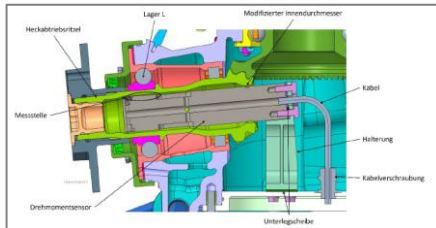


smartHUMS: Proof-of-Concept Design – Sensor strategy usage vs. health



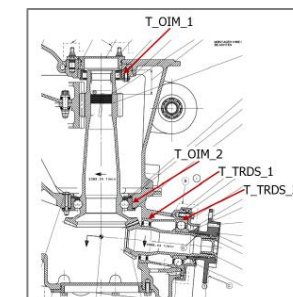
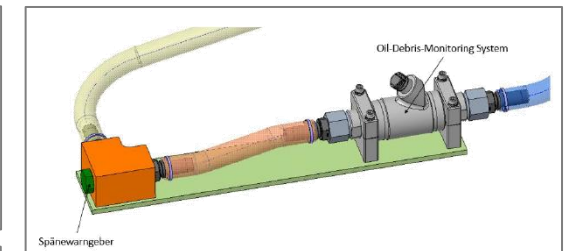
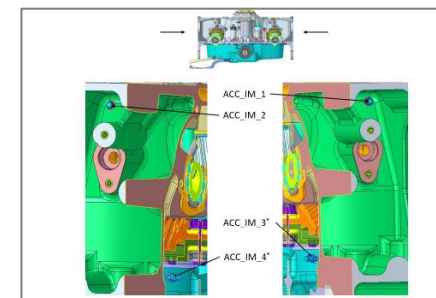
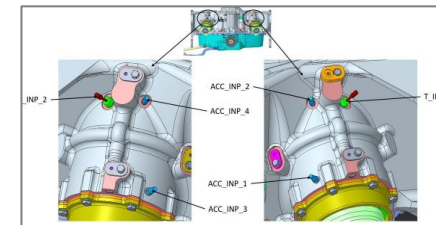
Usage Monitoring (Load)

- **Torque measurement:** Magnetostrictive sensors on the LH/RH drives and the tail drive output.
- **Speed monitoring:** Inductive pickups for speed and power sensing.
- **Rotor mast forces:** Strain gauge application for the direct measurement of bending moments & tensile forces on the mast



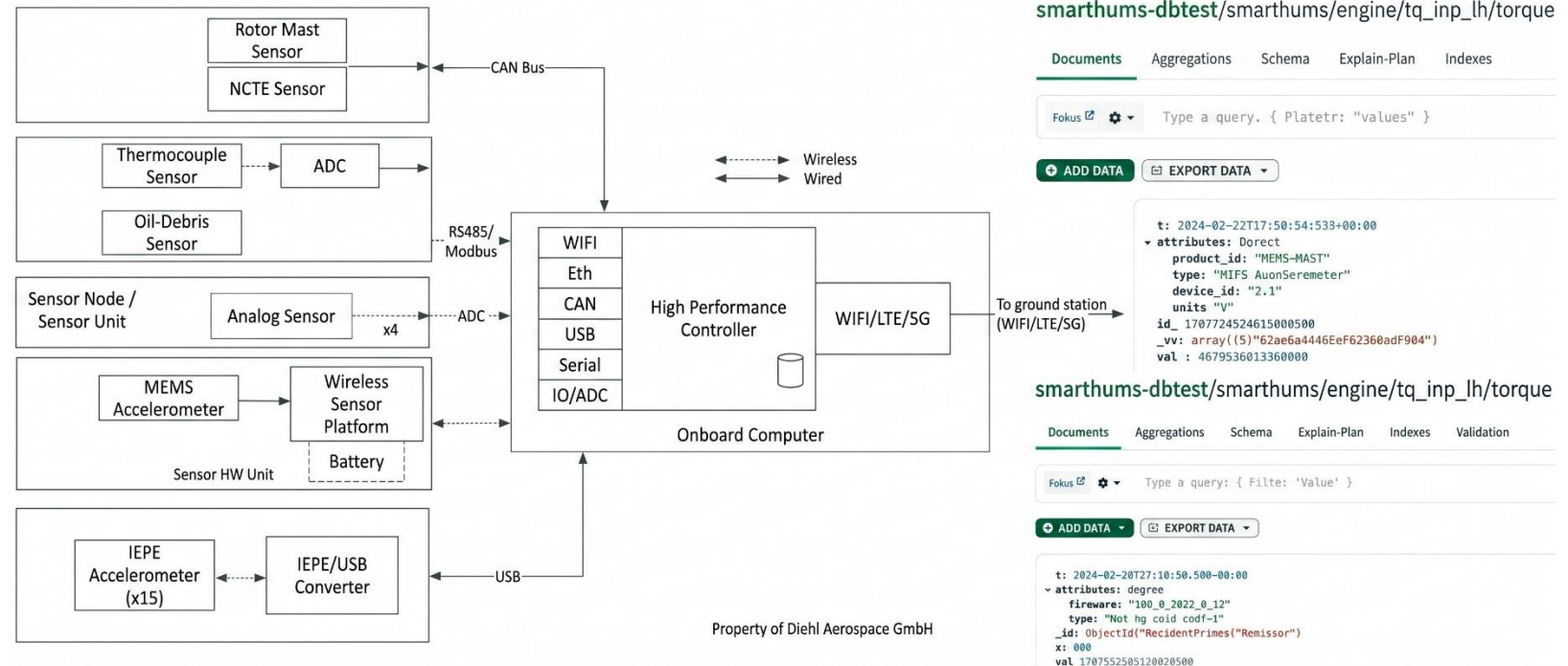
Health Monitoring (Condition)

- **Vibration:** Piezoelectric sensors (30 kHz)
- **Temperature:** Thermocouples on critical, rapidly rotating, and non-redundant bearings.
- **Oil condition & debris:** Oil debris monitoring system for detecting magnetic debris (quantity & size) over time.



smartHUMS: Proof-of-Concept Design – Architectural Data Recording

- Connection of all sensors via defined interfaces (CAN bus, USB, ...)
- Onboard Computer Design – CANSAS™ High-Performance Controller (HPC) with LTE and 5G modem as the central interface within the airborne equipment.
 - Interface for all sensor signals/measurements (e.g., CAN bus, analog, etc.)
 - Supplies power to all sensors
 - Stores all data/measurements
 - Interface for data transmission (e.g., USB, Wi-Fi transfer to the cloud)

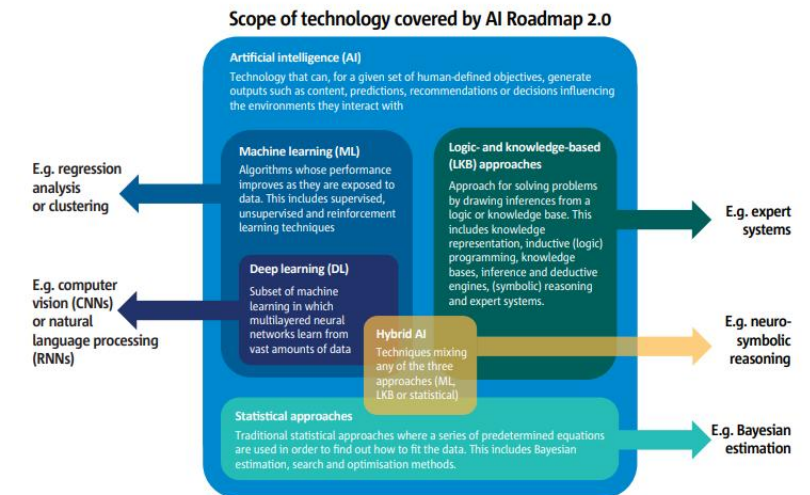
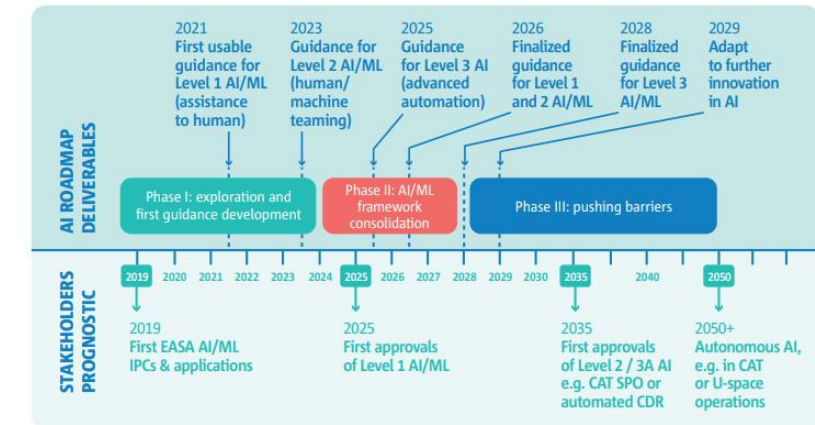


Note: Certain sensors still require their own signal conditioning units—the CANSAS™ HPC can only process signals based on the manufacturer's specifications.



smartHUMS - Proof-of-Concept – AI Approach Assessment

- The use of AI approaches has implications for certification and cannot be implemented in a product in the short term at this stage.
- There is currently no standardized approach for AI applications in aviation, although the EASA AI Roadmap does address relevant aspects.
- Key aspects for application in predictive and condition-based maintenance include:
 - Transparency, traceability, verifiability, and accountability
 - Functional safety (including product safety) and reliability
 - Prevention of unintended consequences affecting other systems, people, the environment, etc.
- Consequently, any AI application must be traceable (input → output) and measurable in an appropriate manner.
- As things stand, implementation requires a series of sequential steps and detailed cooperation with the regulatory authority.



Source: <https://www.easa.europa.eu/en/document-library/general-publications/easa-artificial-intelligence-roadmap-20> (05.08.2026)

smartHUMS: Proof-of-Concept – Evaluation & Selection of AI Algorithms

- Data management (due in part to the volume of data) requires the right methods and algorithms
- Requirements for subsequent approval (see previous slide) must be supported
- Selection is necessary, as various approaches exist for each stage (pre-processing, diagnosis, prognosis)
- Relevant criteria based on the objective
- "Best fit" selection using a 1–5 scale

Funktion	Algorithmus	Robustheit	Leistungs-fähigkeit	Vor-verarbeitung	Transparenz	Daten-Quantität	Komplexität / Kosten	Rechen-leistung	Score
		21.98%	20.88%	13.19%	12.09%	12.09%	10.99%	8.79%	
Cleaning & Denoising	TSA	5	4	5	5	4	5	5	4.67
Signal Characterization	DFT/FFT	5	5	4	5	5	5	4	4.78
	OT	4	5	4	5	3	5	5	4.41
	EnvA	3	5	4	5	4	5	5	4.31
	VMD	5	4	4	3	4	3	3	3.90
	EWTD	4	5	4	3	4	3	3	3.89
	LMD	3	4	4	2	5	4	4	3.66
	TDA	2	2	5	4	5	5	5	3.59
	WT	3	4	4	3	4	3	4	3.55
	STFT	4	3	4	5	2	4	2	3.49
	CA	3	4	4	3	3	4	3	3.45
Feature Construction	HHT	4	4	4	2	2	3	3	3.32
	EEMD	3	3	4	3	3	3	3	3.13
	EMD	1	2	4	3	4	4	4	2.80
	AE	5	5	5	2	3	3	2	3.91
	PCA	4	4	4	4	4	4	4	4.00
Feature Optimization	LDA / FDA	4	4	4	3	3	3	4	3.65

Funktion	Algorithmus	Robustheit	Leistungs-fähigkeit	Vor-verarbeitung	Transparenz	Daten-Quantität	Komplexität / Kosten	Rechen-leistung	Score
		21.98%	20.88%	13.19%	12.09%	12.09%	10.99%	8.79%	
Anomaly Detection	DBSCAN	4	5	2	5	5	3	4	4.08
	SOM	4	4	3	4	4	2	5	3.74
	TDA	2	3	5	4	5	5	2	3.54
	BN	5	4	2	5	2	1	4	3.51
	CNN	2	5	5	1	2	2	2	2.90
Clustering	DBSCAN	4	5	2	5	5	3	3	3.99
	SOM	4	5	3	4	4	2	3	3.77
	PCMeans	4	4	2	5	4	3	3	3.66
	Kmeans	3	4	2	4	4	3	4	3.41
	GMM	2	4	2	5	4	3	3	3.22
Classification	RF	5	5	3	3	4	3	4	4.07
	SVM	5	4	3	3	4	3	4	3.86
	DT	4	3	3	3	4	4	4	3.54
	NB	5	4	2	5	2	1	3	3.42
	HMM	3	3	2	5	4	4	3	3.34
	RNN	3	3	3	4	4	3	4	3.33
	ANN	4	4	3	2	3	3	3	3.31
	BN	5	4	1	5	2	1	3	3.29
	GMM	2	4	2	5	4	3	3	3.22
	LSTM	3	5	5	2	2	1	2	3.13
	CNN	2	5	5	1	2	2	2	2.90

Funktion	Algorithmus	Robustheit	Leistungs-fähigkeit	Vor-verarbeitung	Transparenz	Daten-Quantität	Komplexität / Kosten	Rechen-leistung	Score
		21.98%	20.88%	13.19%	12.09%	12.09%	10.99%	8.79%	
RUL	GPR	4	4	3	4	4	3	3	3.67
	HMM	5	4	2	5	2	1	3	3.42
	LSTM	3	5	5	2	4	1	2	3.37
	ANN	4	4	3	2	3	3	3	3.31
	BN	5	4	1	5	2	1	3	3.29

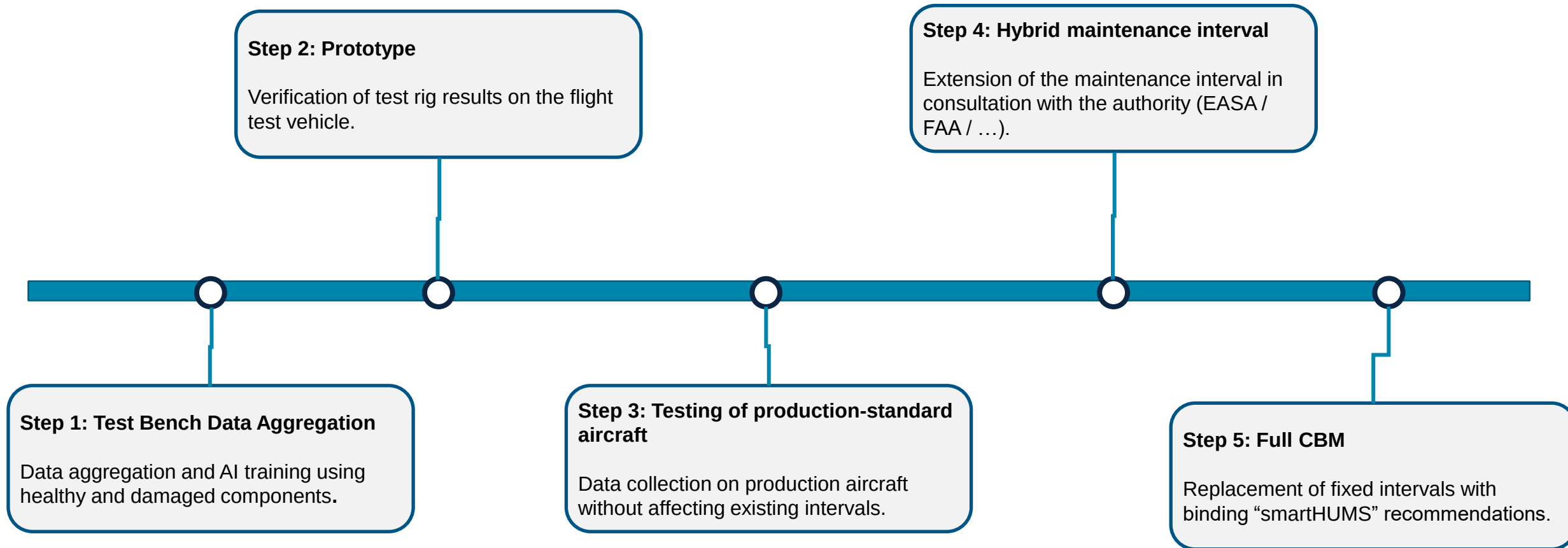
Pre-processing algorithms

Diagnostic algorithms

Forecasting algorithms



smartHUMS: Proof-of-Concept – Approach to using AI (step-by-step)





smartHUMS: Proof-of-Concept – Data analysis & AI approach

Data Analysis / Flight Monitoring

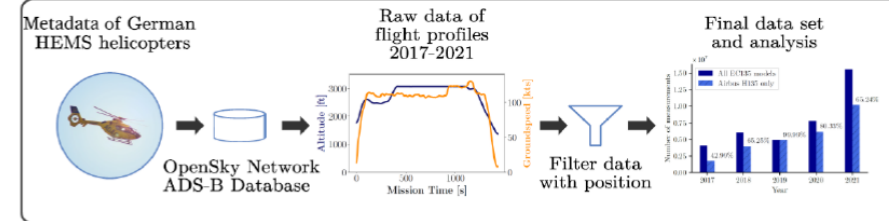
- Use of publicly available data (ADS-B)
- Limitation to relevant helicopter models (H135 in HEMS operations)
- Analysis of raw data and flight profiles
- Use of the Eurocontrol BADA-H performance model
- Derivation of a "usage index" relative to a reference profile
- Analysis/definition of parameter limits



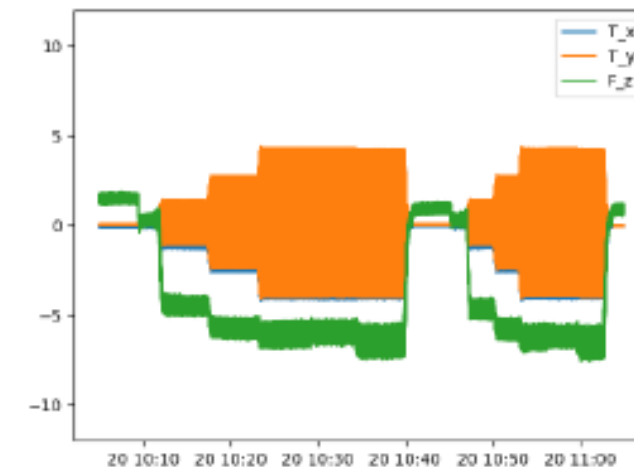
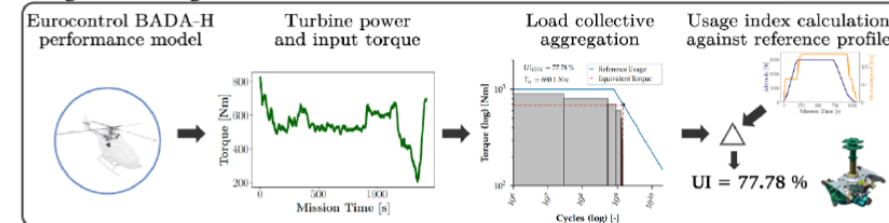
Simulation models to support "Step 1"

- Definition of necessary transmission simulations (kinematics / multi-body systems)
- Generation of synthetic data
- Implementation of virtual sensors
- Generation of "test bench data" – vibration and force profiles at defined load levels

Data Acquisition



Usage Monitoring





smartHUMS - Proof-of-Concept – Experimental analysis & Testing (1)

- Gearbox test on the AHTech main gearbox test rig
 - Principle: mechanical closed loop test rig
 - Usage: Development, serial production, and MRO
 - Complete system monitoring
 - Extensive database / experience
- Adjustments to the concept
 - Measured values output via test bench (torque of drives LH and RH, speed)

Rotor Mast Loading

- Bending Moment
- Tension
- Strain Gauge System

Temperature Sensors

- Thermocouples
- At critical bearings (6 pcs.)
- Bearing outer ring temperature

„Oil-Debris” Sensor

- Particle Counter
- Contamination over time

Chip Detector

- Production standard (test rig)



MEMS Sensors (Vibration)

Speed Sensor

- Rotational speed
- Production standard (replaced by test rig)

Accelerometers (Vibration)

- Piezoelectric
- Up to 30 kHz
- At bearing prints (15 pcs.)

Torque Measurement

- Internal
- Contactless
- At the output
- Input measured via test rig

Note: Due to the project scope, the sensors installed for test bench validation initially represent the industrial standard; implementation to aviation standards is possible at a later stage



smartHUMS - Proof-of-Concept – Experimental analysis & Testing (2)

- Test program on the test bench
 - ATP (Acceptance Test Procedure – production standard) performed with gearbox and sensor system
 - Verification of proper transmission operation
 - Accumulation of sensor data during operation
- Data accumulation test program executed
 - Approaching individual load steps to train the AI
 - Transmission similar to production specification
- Total operating time of gearbox with sensor system: approx. 10 h
- Test bench runs with damaged components were no longer possible due to the scope of the project.

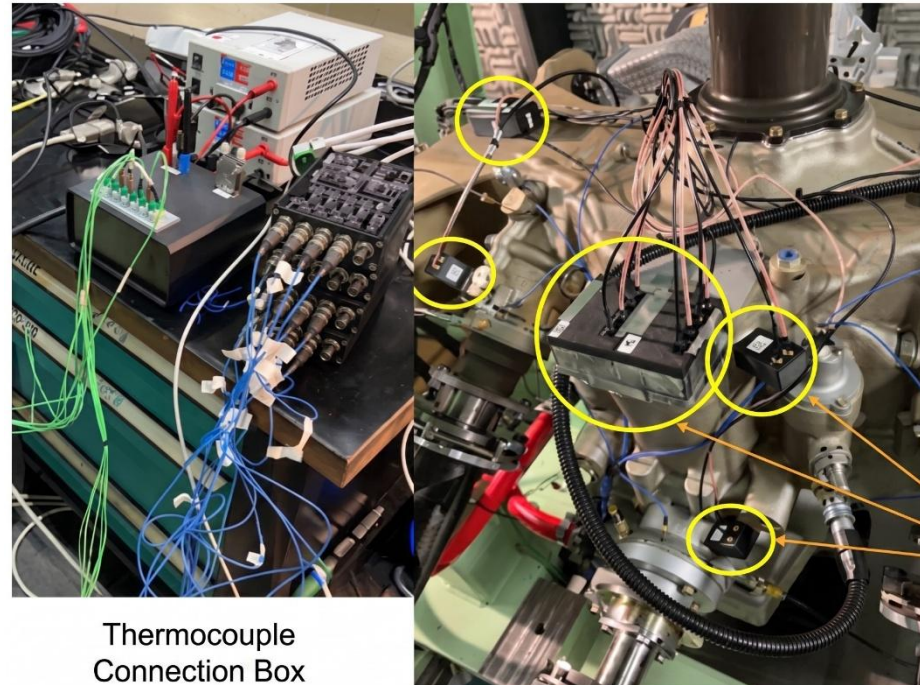
LS	Time t [min]	MGB-Input		Tail rotor output		Main rotor loads		
		Speed n [1/min]	Torque 1 & 2 [Nm]	Torque T _{HR} [Nm]	Speed n [1/min]	Thrust F _R [N]	Moment M _{B,x} [Nm]	Moment M _{B,y} [Nm]
Warm up	5 5	5898	81 188	67 152	4986	0	0	0
1	3	5898	100	20	4986	0	0	0
2	3	5898	150	20	4986	0	0	0
3	3	5898	200	20	4986	0	0	0
4	3	5898	250	20	4986	0	0	0
5	3	5898	300	20	4986	0	0	0
6	3	5898	350	20	4986	0	0	0
7	3	5898	400	20	4986	0	0	0
8	3	5898	450	20	4986	0	0	0
9	3	5898	500	20	4986	0	0	0
10	3	5898	550	20	4986	0	0	0
11	3	6000	550	20	5072	0	0	0

Excerpt from the test program for data accumulation

smartHUMS - Proof-of-Concept – Experimental analysis & Testing

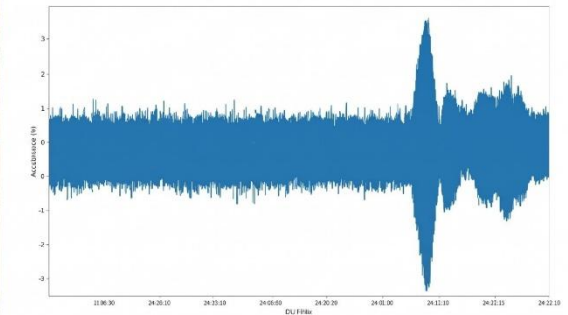
– Data System Integration

- Acquisition and compression of transmission sensor data on existing Diehl Aerospace GmbH computers
- Data communication via wireless modules – 5G and WLAN modules were installed in the CANSAS™ HPC and tested.
- Data reception and analysis at the ground station – The data were received on a PC via an AWS broker for analysis



Thermocouple
Connection Box
IEPE-USB Converter

MEMS Sensors on
Gearbox



MEMS Data Recording

MEMS Sensors



smartHUMS – Conclusion and way forward

- Concept and boundary conditions for a “smartHUMS” defined
- Successful design implementation, regarding sensor technology, the data management system, and data processing alike
- Successful test campaign with a helicopter main gearbox as part of “Step 1” of the utilization approach
 - All sensors provided the required measured values
 - Implemented data storage, the forwarding and storage of data in the cloud, and the monitoring of real-time data
 - Documentation and verification of a reference dataset – “healthy state” for the helicopter main transmission used
- Outlook:
 - Recording vibration spectra with damaged components – training the AI and validating the theoretically developed AI algorithms for damage detection
 - Revision of the sensors for a flight-capable prototype(CANSAS™ HPC conceived from the outset as a flight-capable prototype)
 - Flight tests with a “healthy” gearbox and damaged components – assessment of the transferability of AI approaches – best-case scenario: identifying underlying principles to transfer results from test-rig experiments to the vibration patterns observed on the aircraft
- Conclusion: “Proof of Concept” successful – full implementation as an operational aircraft is conceivable but requires close cooperation between the authority (EASA), the TC holder (Airbus Helicopters), and the users (operators)

Thank you

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