Dedicated to innovation in aerospace

Developing predictive models and algorithms

NAG workshop Predictive Maintenance in the Aerospace Industry

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Dedicated to innovation in aerospace

MENTIMETER

- **Buzz Word Bingo:**
  Everyone will have their own associations with Predictive Maintenance, but what are yours? (below are just some suggestions..)

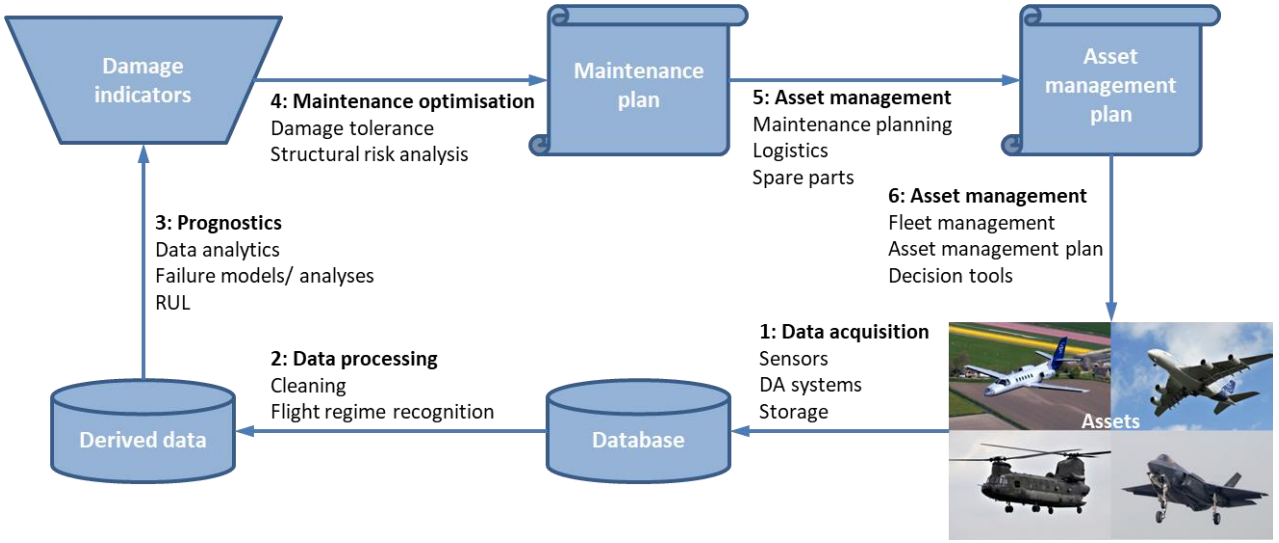
- Industry 4.0
- IOT
- Smart Maintenance
- Diagnostics
- Sensors
- Digital Twin
- HUMS
- CBM
- PHM
- Detection
- Fleet Life Management
- PredMx

- NDI
- Big Data
- AI
- Decision Support
- Condition Monitoring
- Health State
- Prognostics
- RUL
- MRO
- IGO
- ……

Predictive Maintenance

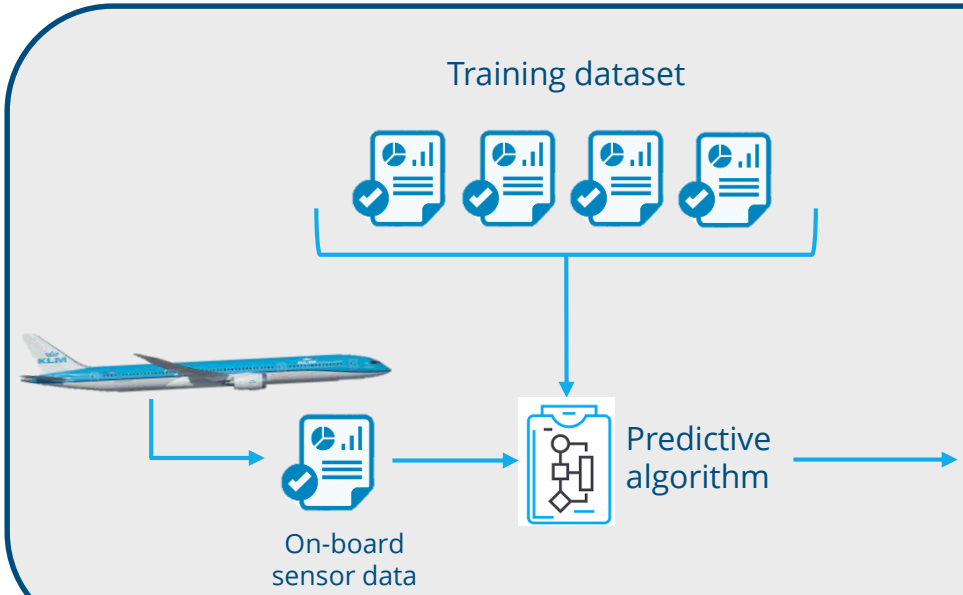
Process Chain

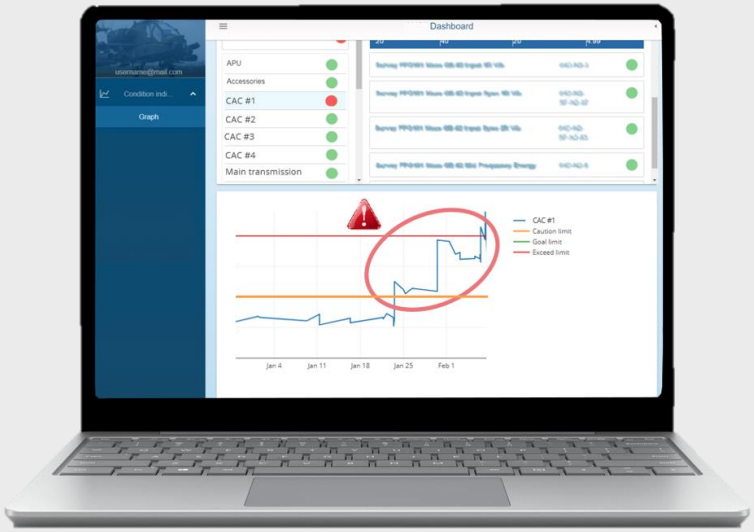
- Sensors in aircraft measuring the usage and/or loads
- Data acquisition and processing of sensor data
- Predictive (probabilistic) models for future health status
- Yields optimised maintenance planning and spare part prediction



Predictive Maintenance

Process Chain





1. Consistency: Data checks, Data quality

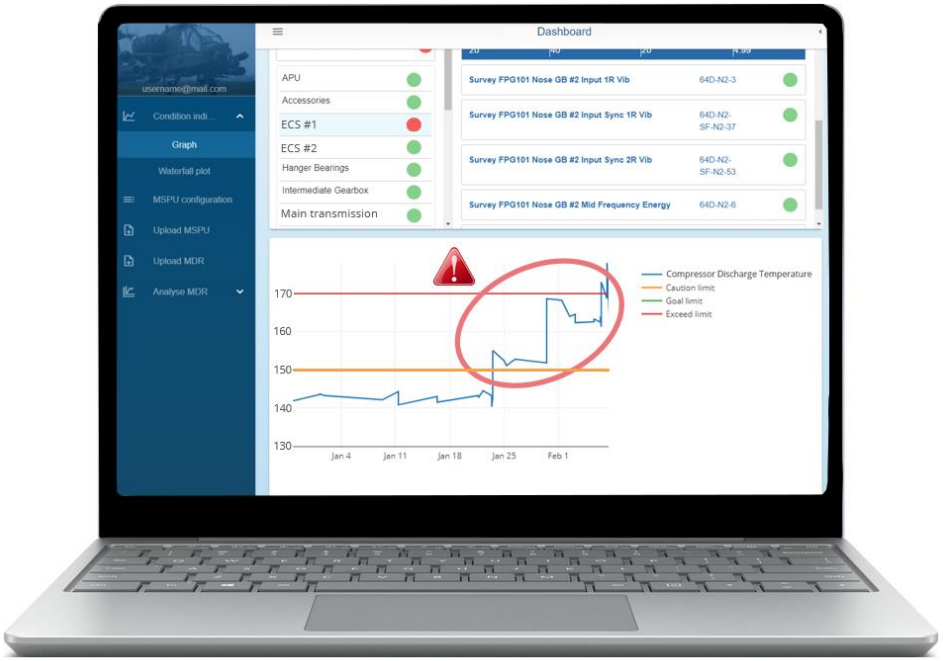
2. Target data: Classified failure modes? Sufficient failures?

3. Algorithm development: Data cleaning, data normalization, train/validation test split

4. Brag about results!

Predictive Maintenance Example

Environmental Control System (ECS) of a defence helicopter

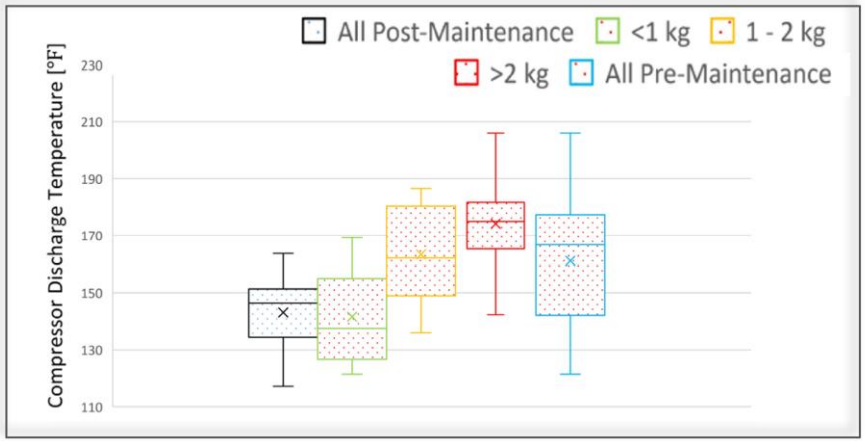


- Condition indicator:
  - Threshold on average Compressor Discharge Temperature
- Simple demonstration of end-to-end process chain from the sensor data to maintenance action
  - Less unplanned downtime
  - Makes maintenance more plannable
  - Increases platform deployability

Predictive Maintenance Example

Environmental Control System (ECS) of a defence helicopter

- The considered helicopter is troubled with a Vapor Cycle Cooling System (VCCS) which is known to leak refrigerant.
- The Compressor Discharge Temperature (CDT) is demonstrated to be a reliable indicator for refrigerant deficits
- Validated thresholds:
  - Caution: 1 kg deficit
  - Warning: 2 kg deficit



Threshold value [°F]	Post-maintenance (27 CDT entries)	Pre-maintenance (24 CDT entries)		
	False positives [%]	False negatives [%]		
		Total	Shortage $[kg]$	
			$1-2$	>2
150	33	12	8	4
160	4	25	17	8
170	0	34	17	17
180	0	50	25	25

MENTIMETER

- **Ambition level?**
  So we have an end-to-end process chain from the sensor data to maintenance action for a non flight-critical item. How would a maintenance organization react when this is fielded as an add-on to maintenance?

A. “Perfect, what can we do to start skipping regular inspections? “

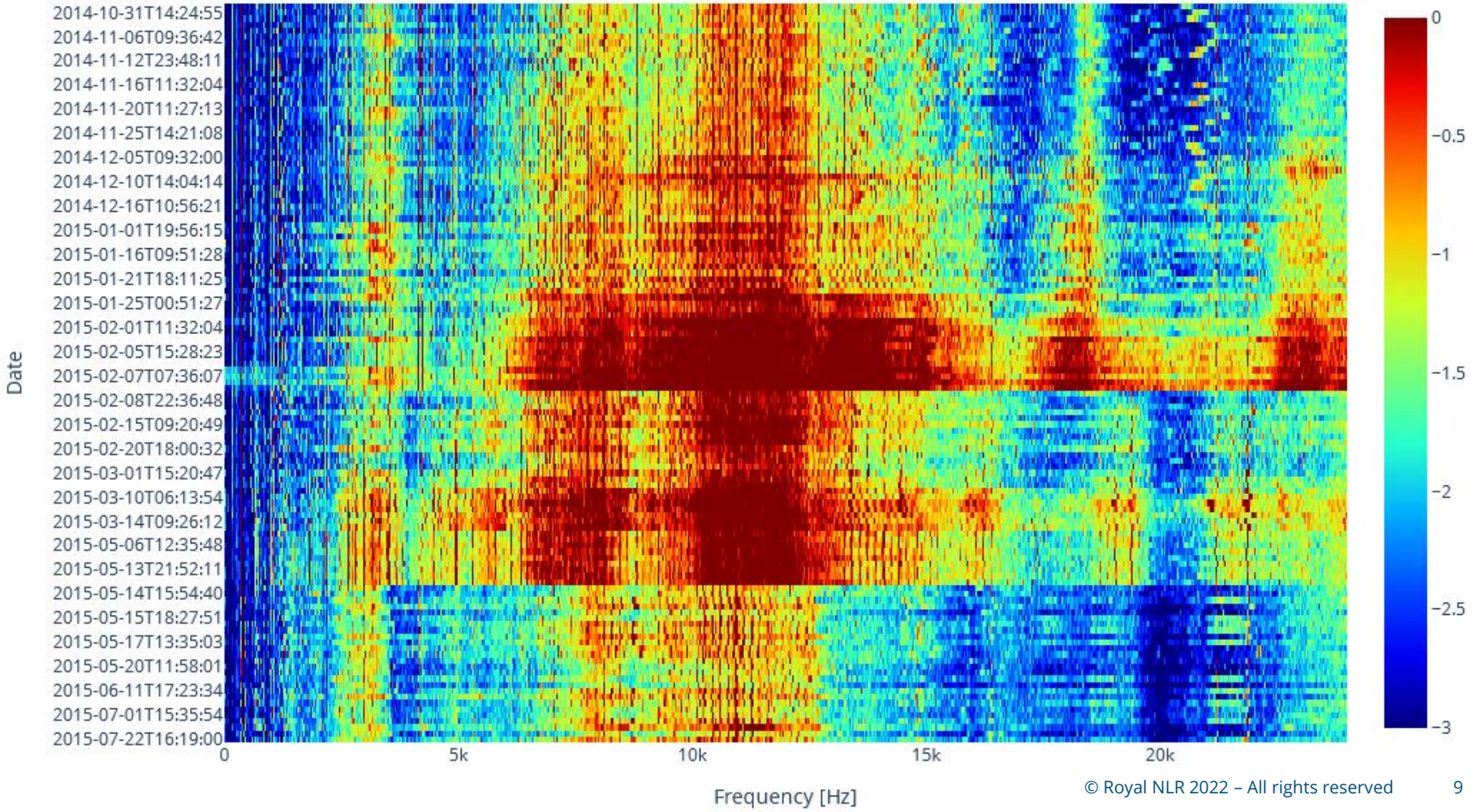
B. “That is a useful add-on to be informed; now we can plan maintenance at a suitable time such that it does not disturb daily flight operations. “

C. “Lets first write an instruction with common ground how add-on info is used in maintenance. ”

D. “Why would we use the tool, there are no instructions to do so in the maintenance manual?”

Predictive Maintenance Example

Nose Gearbox Ball Bearing

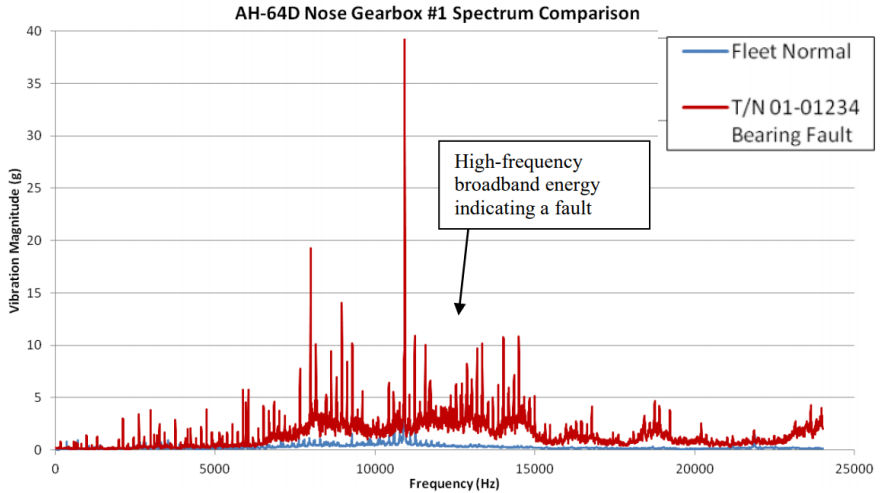


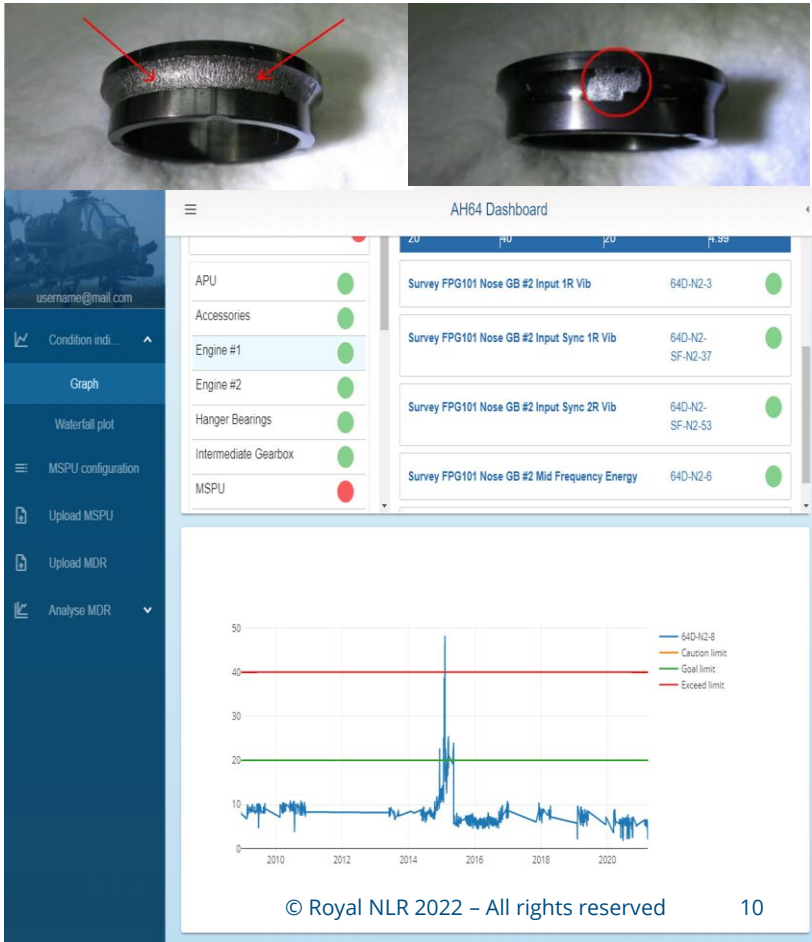
Predictive Maintenance Example

Nose Gearbox Ball Bearing

Condition Indicators

- **Broadband energy**
  → bandwidth > 500 Hz → 'catch all CI'
- **Peak-Pick**
  → shaft imbalance en bearing/gear fault
- **Narrowband energy**
  → known vibration characteristic based on failure data





MENTIMETER

- **Reliance or compliance?**
  For helicopters, HUMS systems that monitor drivetrain health were introduced to enhance safety. What is the motivation of your organization?

A. Enhance Safety

B. Improve uptime

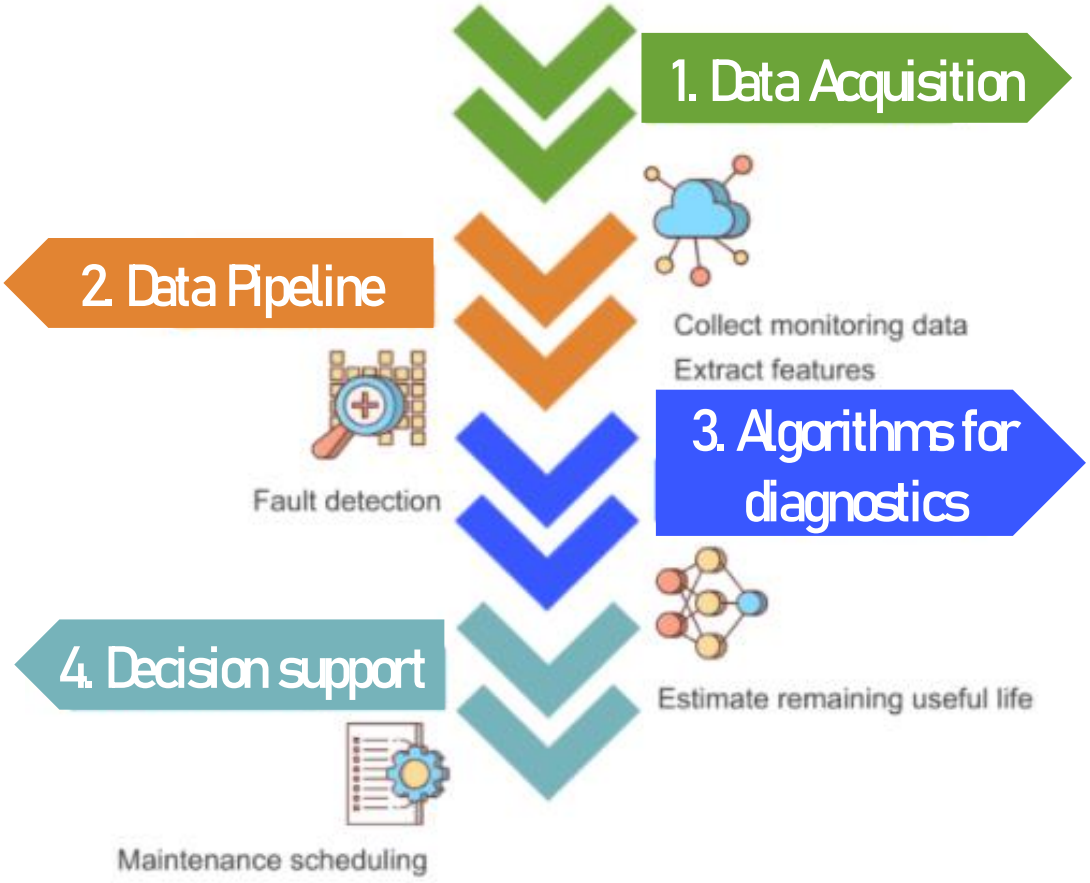
C. Drive down cost

D. Because the maintenance manual says to do so

E. MRO organization may attract more customers with PredMX in place?

Predictive Maintenance

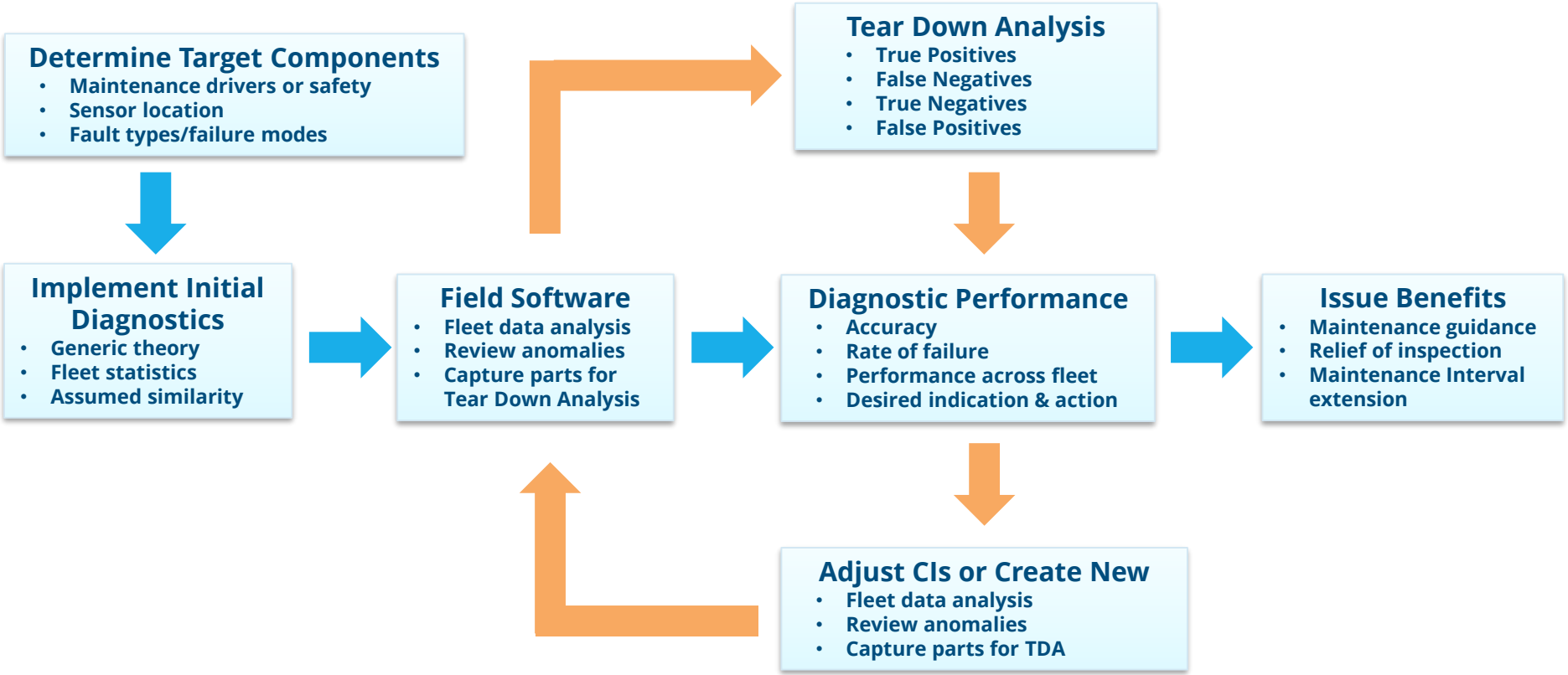
Building Blocks



https://towardsdatascience.com/data-driven-predictive-maintenance-in-a-nutshell-ccc65a13b998

Predictive Maintenance

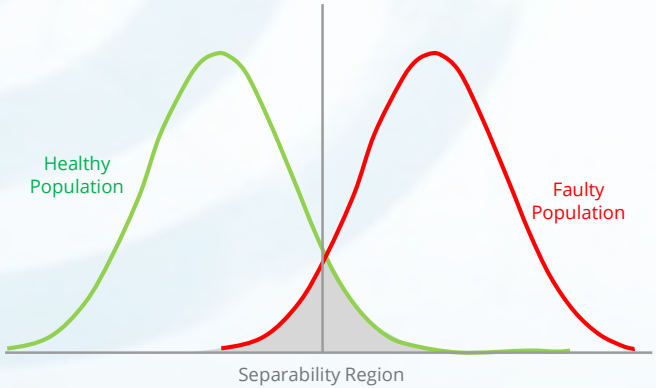
Building Blocks



Predictive maintenance

Confidence Level Diagnostics

- Diagnostics should have high confidence of: **accuracy**, **detectability**, **identifiability**, and **separability**
- Confidence comes from the ability to separate healthy and faulted populations
- For safety critical items:
  - According to ADS-79 (*Aeronautical Design Standard: Handbook for Condition Based Maintenance*), **separability** is achieved when " 6-9's " of reliability
    - False Positive (false alert) rate < 10%
    - False Negative (missed detection) rate < 1 in 10^{-6}



‘Too little failures’ for diagnostic algorithm development

Now What?

A. Wait for components to fail naturally on an operational asset
   - \+ Will produce the most effective diagnostics
   - − Takes a long time to populate a ground- truth database
   - − May not have prior indication of a fault during development period

B. Conduct ‘seeded fault’ testing on an operational asset
   - \+ Measured data will closely resemble a real fault
   - − Obvious risk associated with operating degraded components on an asset

C. Conduct ‘seeded fault’ testing on a test stand
   - \+ Safe
   - \+ Operate on a schedule regulated by user
   - − Great care must be taken to ensure test resembles operational conditions
   - − Can be expensive

MENTIMETER

- **Go the extra mile..**
  Sufficient (tear-down) inspections needed to relate measured sensor data to physical state. Would your organization be willing to do an extra inspection?

A. Yes, as long as the extra costs weighed up to benefits later

B. No, why would we? It does not say to do so in the maintenance manual.

Existing sensor data not suitable for diagnostics

Now What?

Development of a sensor temperature and/or vibration sensors for aircraft (system) health monitoring:

- Demanding enviroments - *high & low temperatures, turbulence, etc.*
- Non-intrusive en passive - *electromagnetically compatible*
- Stand-alone - *power supply, data-storage, data-transfer*
- Scalable - *suitable for mulitple systems*

Part of development work:

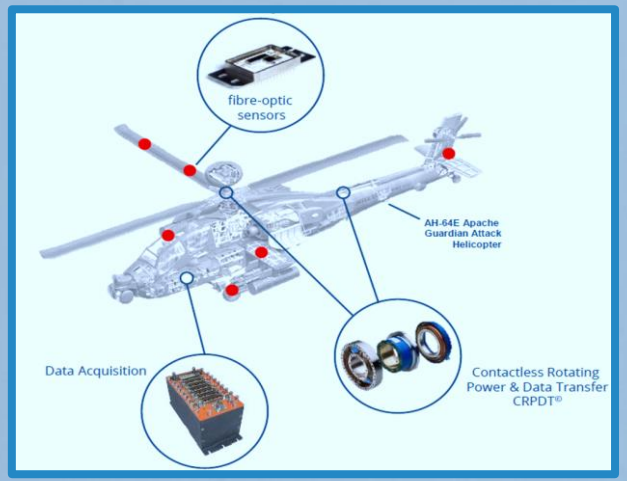
- Which type of sensor?
- Sampling rate? Data storage
- How many sensors?
- Data pipeline

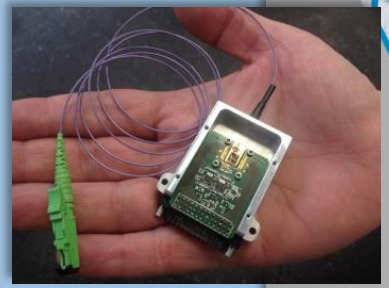
Fibre Optic Sensing @ NLR

Landing gear loads & usage monitoring

In-flight demonstration

- Enhanced exceedance detection
- Enhanced airframe monitoring
- Enhanced Rotor-Track and Balance





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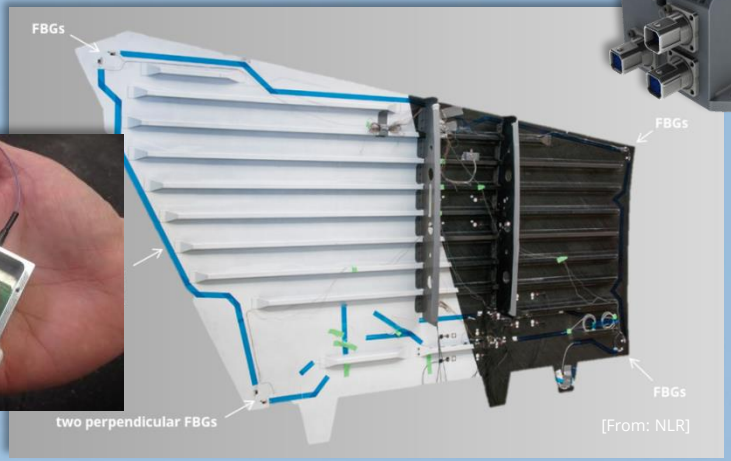


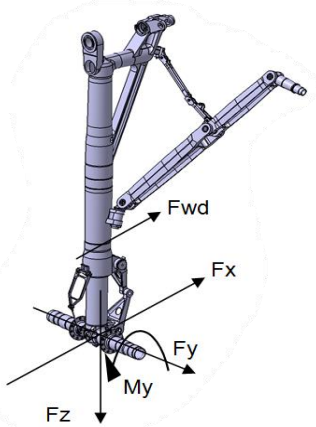
[From: NLR]

Fibre Optic Sensing @ NLR

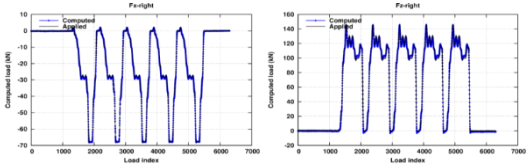
Landing gear loads & usage monitoring

EU PROJECT

- Embedding fibre optic sensors in landing gear axles
  - Measures forces and torque
- Applications
  - Estimation of RUL
  - Detection of hard landings
  - Measurement of aircraft weight and balance
  - Monitoring of braking torque and temperature
  - Accurate detection of air-ground transition
  - Reporting of runway anomalies



[From: Airbus]



[From: ALGeSMo]

MENTIMETER

- **Towards maintenance credits..**
  Would your organization install additional sensors on aircraft?

A. Yes, we know from experience that the extra costs weigh up to benefits later. We would add sensors to get even more credit/benefit.

B. We aim to use those sensors that were installed by the OEM and if the OEM instructions demand us to do so.

C. No, why would we? It does not say to do so in the maintenance manual.

Dedicated to innovation in aerospace

Fully engaged

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