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Department of Mechanical Engineering

An innovative Prognostic Health Management system for turbojet

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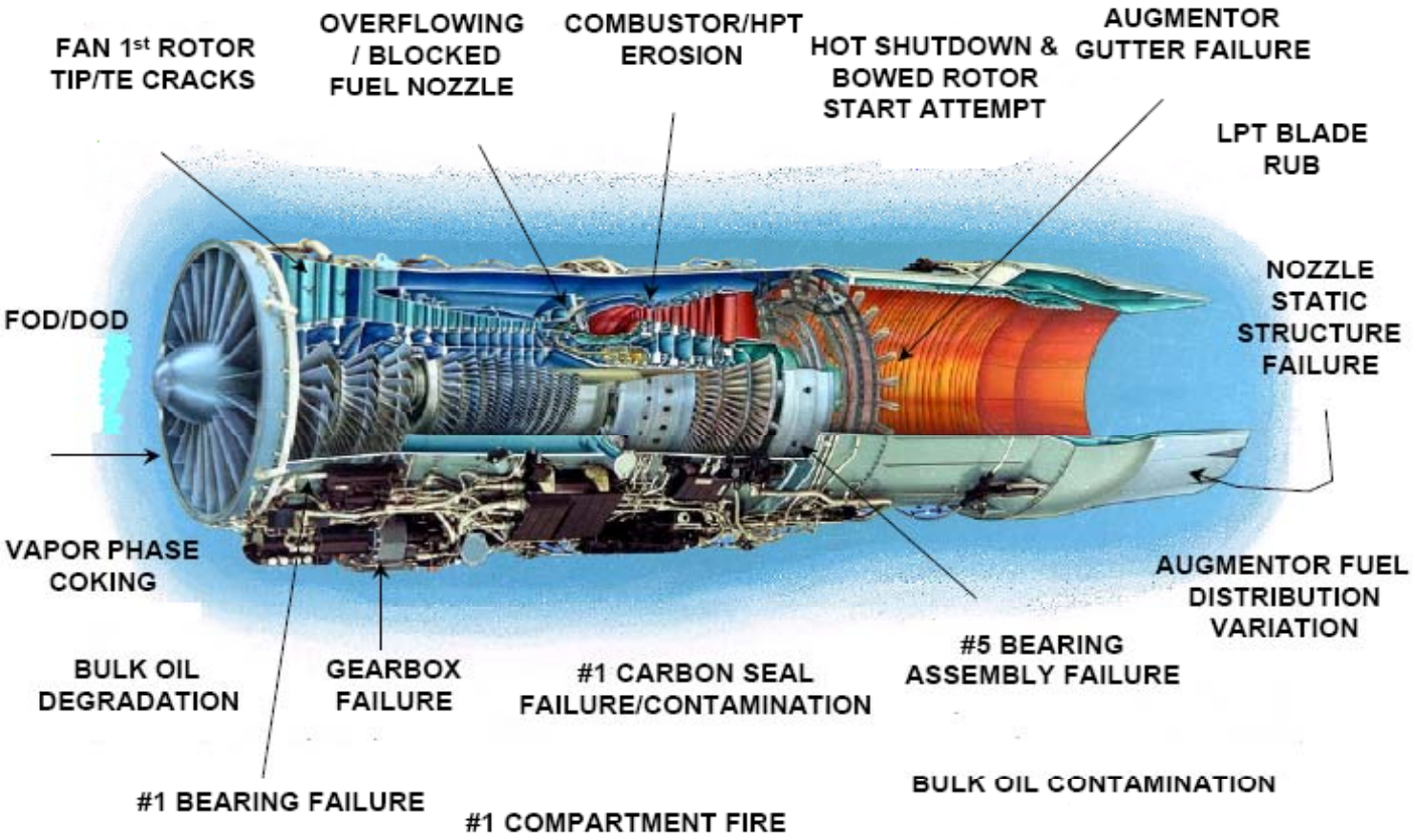
Background:

Turbine engine failures are the leading cause of class-A mechanical failures (loss of aircraft). The cost of these incidents is astounding: increasingly, commercial air maintainers are turning to **Prognostic Health Management (PHM)** systems to prevent these losses and to reduce maintenance costs.

1230 PM, Friday, June 2, 2006 at LAX.
American Airlines Boeing 767 doing a high power engine run had a #1 engine HPT (High Pressure Turbine) failure. HPT let go and punctured left wing, #2 engine, peppered fuselage and set fire to the aircraft.

Example of fault scenarios in a turbojet



Problem Statements:

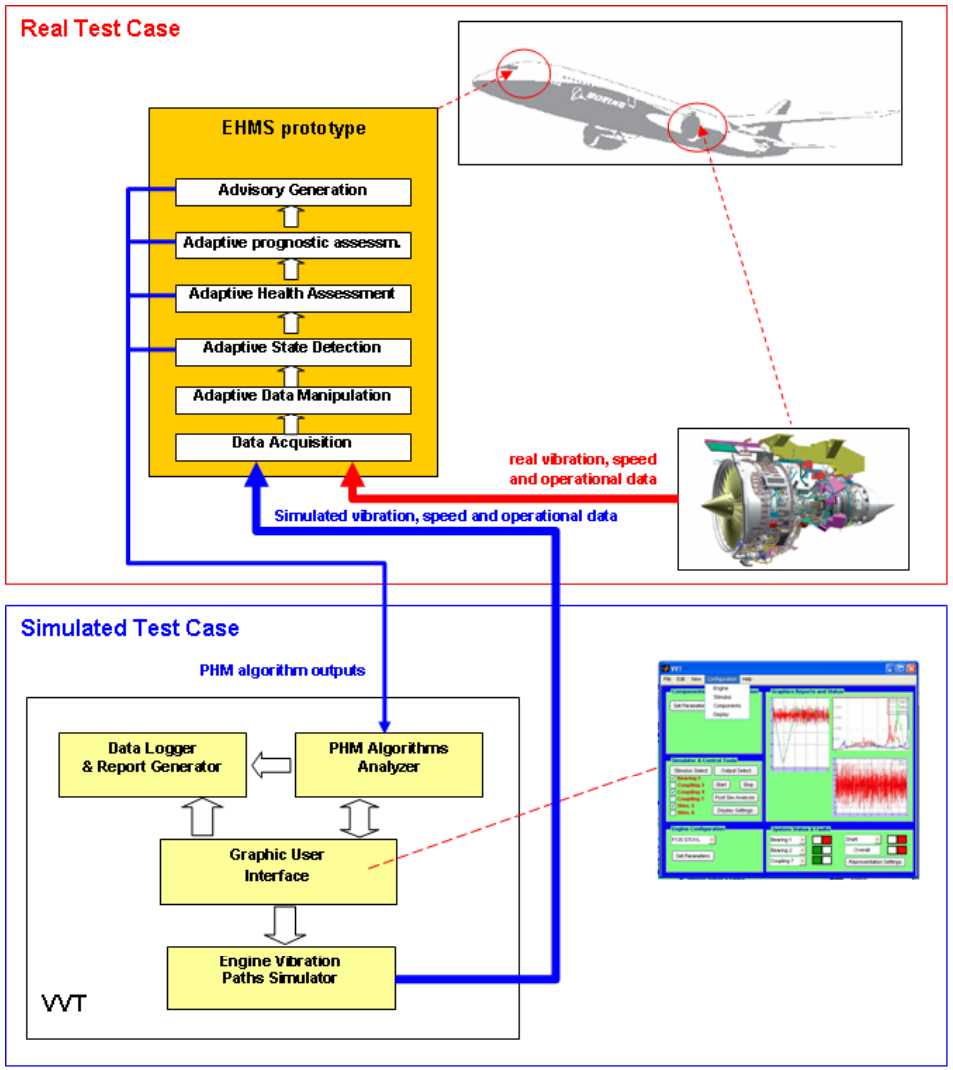
- **The most common health monitoring parameter in the aerospace industry is vibration.**
- The validation and verification of prognostic capabilities requires access to quality data for both healthy and faulted systems.
- While data for healthy systems is often readily available, faulted data is much more difficult to obtain.
- Seeded fault tests are time consuming, expensive, and are not always representative of actual operation.

Key Idea

- To implement an innovative and advanced system to reduce PHM development time & cost: deployment of **high-fidelity Vibration Validation Tool (VVT) able to support physical testing.**
  - Vibration modeling for healthy and faulted systems
  - Dynamic simulating of mechanical transmission paths, including the insertion of a realistic measurement noise

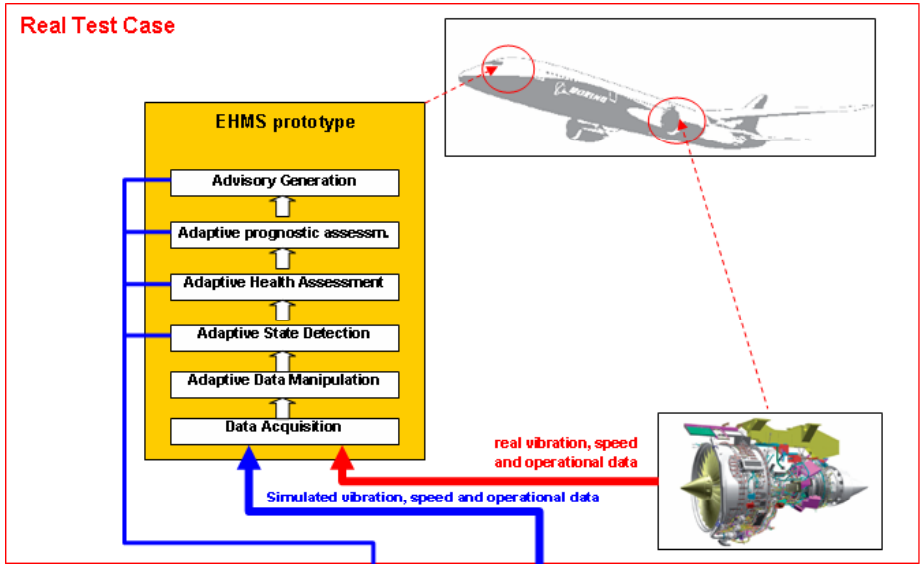
The main aim of this article is therefore to illustrate the concept, objectives and relevance of this novel VVT based PHM system showing architecture and approaches.

PHM at a glance



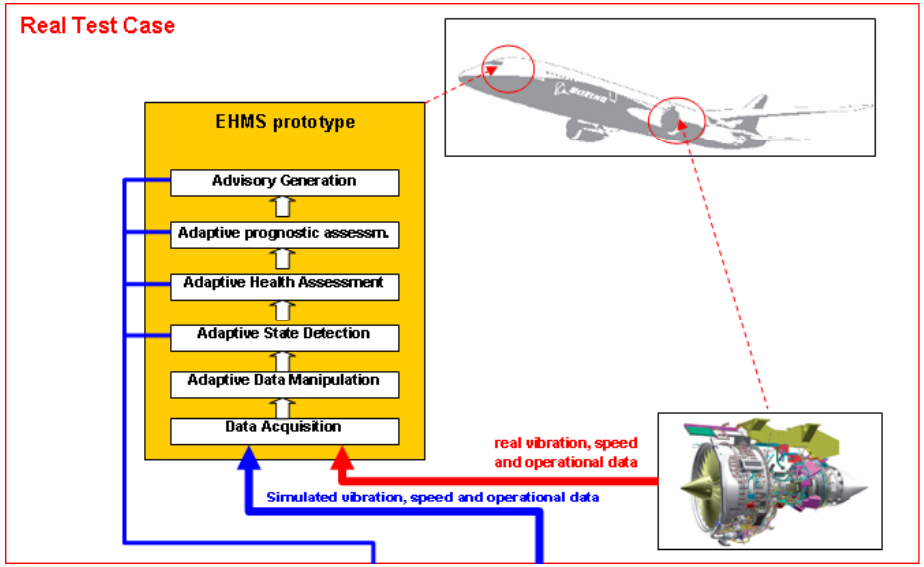
Concept of the PHM

- Data acquisition (DA): collection converting and recording of sensor data and information;
- Data manipulation (DM): signal processing, diagnostic/prognostic feature extraction and transformation. Noise elimination performed by novel de-noising based on the modified wavelets and adaptive filters.
- State detection (SD, i.e. fault detection): feature comparison against baselines or operational limits, generation of enumerated condition indicators, determination to which abnormality zone the data belong, generation of alerts, identification and tracking of engine critical component should be performed primarily by novel model based, non-stationary time frequency linear and non-linear second order signal processing



Concept of the PHM

- Health assessment (HA, i.e. fault **diagnosis**): determination of the health of components; if the health is degraded, generation of diagnostic information that proposes possible fault conditions with an associated confidence;
- Prognostic assessment (PA, i.e. **prognosis**): health projections of components, including Remaining Useful Life estimation;
- Advisory generation (AG): provision of actionable information regarding maintenance or operational changes required.



Concept of the PHM

a) Acquiring and recording all vibration engine data, speed data and operational data. Vibration sensors distributed throughout the engine collect data on the condition of components and subsystems,

b) On flight diagnostic/prognostic analysis to provide near real-time fault isolation and early warning of engine faults. On-board processor assesses engine health and predicts possible deterioration and remaining useful life.

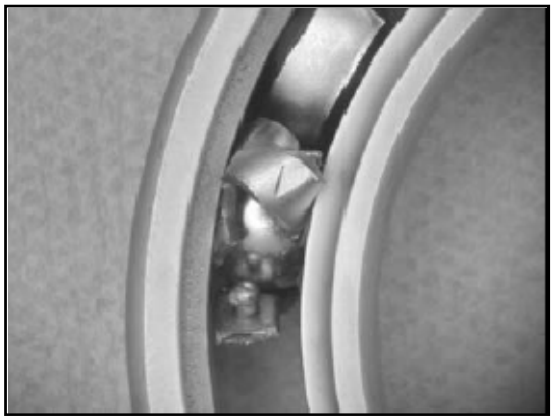
c) On ground diagnostic/prognostic analysis by in-depth processing of all data acquired during flights, so that all stressed engine events can be encompassed in this analysis. The resulting information can be used to improve maintenance, extend the life of both the whole engine and individual critical components.

Concept of the VVT

- **Generate high-fidelity realistic vibration data**
- **Populate a database with faulted data**
- **Support physical testing**
- **Validate prognostic algorithms**

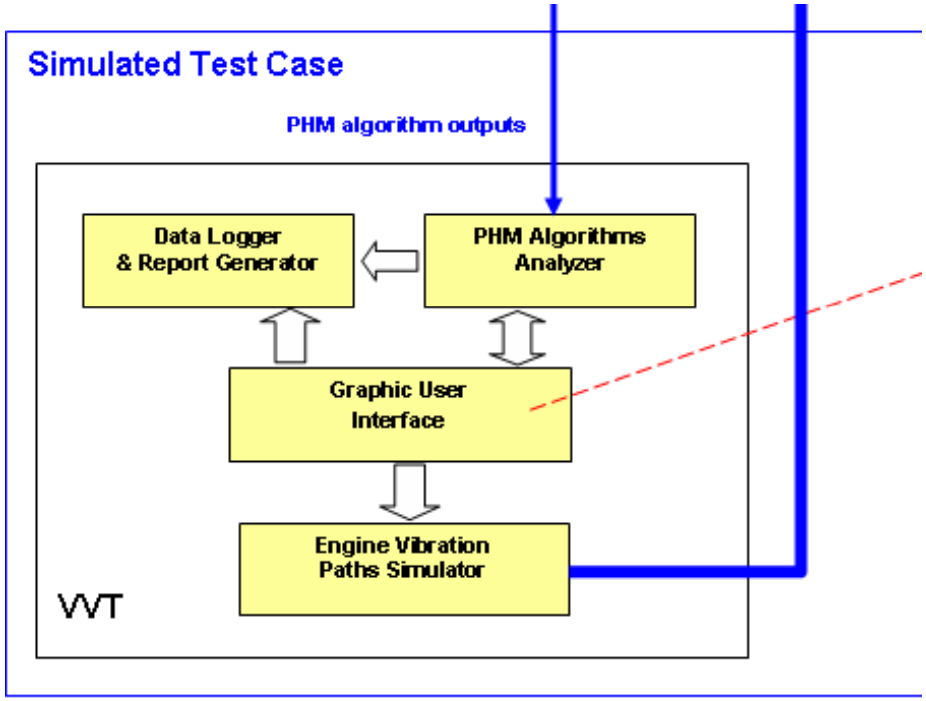
The VVT can reduce the costs and time required for the development of a EHMS system

VVT can then be used to generate realistic vibration signals for engine in different combinations of fault states and operating parameters



Architecture of VVT

- **Vibration Paths Simulator**, the core of VVT, can simulate individual component vibrations and the transmission paths of these vibrations to the sensor locations, thereby generating representative vibration signals at each sensor location.
- **PHM Algorithms Analyzer** can collect and analyze the outputs, in order to evaluate and validate their performance.
- **Data Logger & Report Generation** is able to store the results and produce the relevant test analysis and statistics.
- **Graphic User Interface (GUI)** can be developed for entering the simulation parameters, the relevant data of critical mechanical components (engine shafts, gearbox, bearings, couplings, etc.), and displaying the relevant results and statistics.

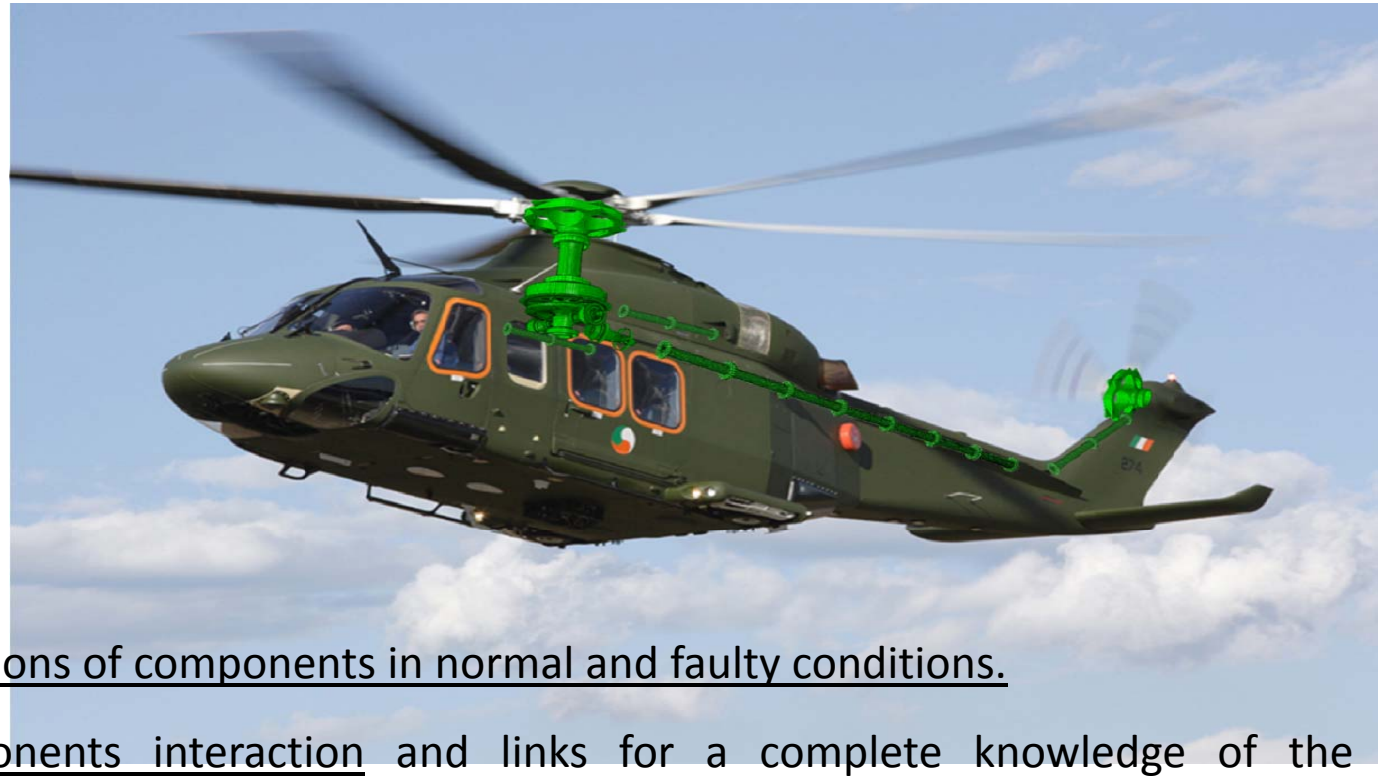


Vibration Paths Simulator

Three potential novelty approaches for the **systems modeling of Vibration Paths Simulator** :

- Physics-based modeling. The models should be targeted on capturing the mechanical interconnections between the components, the vibrations caused by the faults and the way the vibrations will propagate among the components of the engine and towards the sensor locations.
- Black-box empiric modeling. It uses real measurement data. At a first stage a candidate model with tunable parameters is identified. Then, its parameters are selected (parameter identification) in order to achieve a close matching between the model response and the measurements
- "Hybrid" modeling. The candidate model is derived according to physics-based modeling, and its uncertain parameters are set via parameter identification techniques using measured data.

Vibration Paths Simulator



- Vibrations of components in normal and faulty conditions.
- Components interaction and links for a complete knowledge of the engine vibrations.
- Transmission path from component locations to sensor locations.

PHM-VVT Perspective

- Developing **novelty technologies, methodologies and recommendations** able to directly impact on CBM, as well as on **flight safety**.

- **Reduce maintenance time and improve system availability** by getting the right information to correct problems before they occur or become serious.

- The **increased reliability** is also beneficially due to fewer unexpected failures that can result in gate delays, cancellations and partial mission aborts or re-routing.

PHM-VVT Applications

- In general, the PHM toolset can be used to **benefit any industry using rotating machinery.**
- Military applications mainly including (but are not limited to) **jet/rotor aircraft and helicopters.**
- The **wind turbine power** generation industry is a rapidly growing industry that is actively pursuing PHM.
- **Gearbox bearing failures** are among the primary causes of wind turbine downtime; vibration analysis is the most commonly used method to detect gearbox failure.

Thank You

for your attention