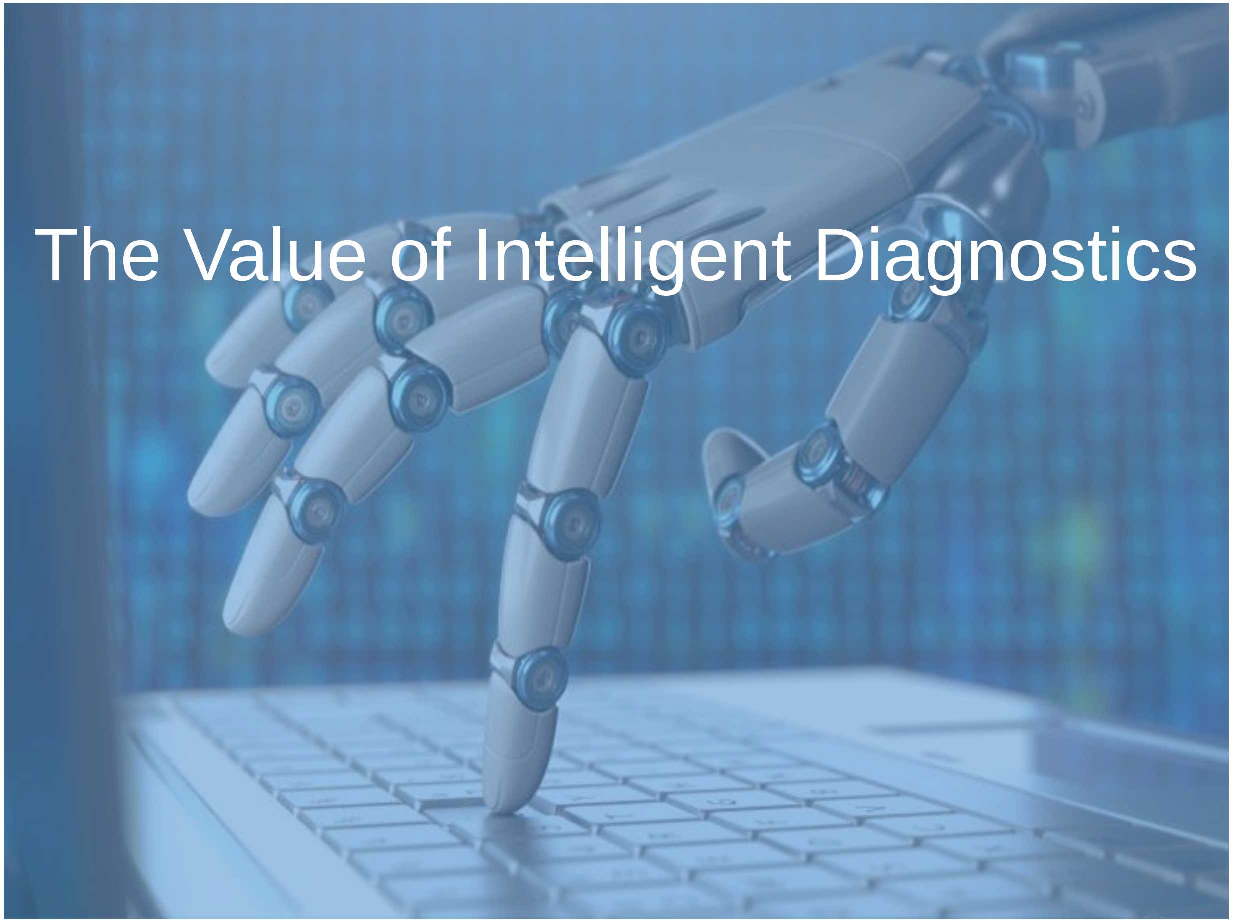
Cranfield University

The Value of Intelligent Diagnostics



Cranfield IVHM Centre

BOEING

Dr Steve King,

Senior Lecturer, IVHM Centre, Cranfield University

October 6th 2020

www.cranfield.ac.uk

Overview

- Key Drivers of Equipment Health Management
- Typical Data types and Analytics
- Intelligent Diagnostics
- Summary

Cranfield IVHM Centre

Possible Maintenance Strategies

1. **Don’t bother – just replace asset when it becomes defective**
2. **Wait until asset becomes defective then maintain**
3. **Maintain at regular intervals even when asset still functional (preventative maintenance)**
4. **Maintain when need arises (Condition Based maintenance)**
   - **Maintenance performed after one or more indicators show equipment deterioration or early signs of failure**
5. **Operate a combination of 3 & 4**

Key Drivers of
Equipment Health Management

Cranfield IVHM Centre

The design of any high-integrity complex machine involves significant analysis of potential failure mechanisms (e.g. the FMECA process).

Depending on likely probabilities and assessed severity, considered failure modes will either be designed out of the product, or the residual risk mitigated through in-service health monitoring.

To be effective, the health monitoring system needs to be based on sound engineering knowledge and incorporate robust models developed from reliable data.

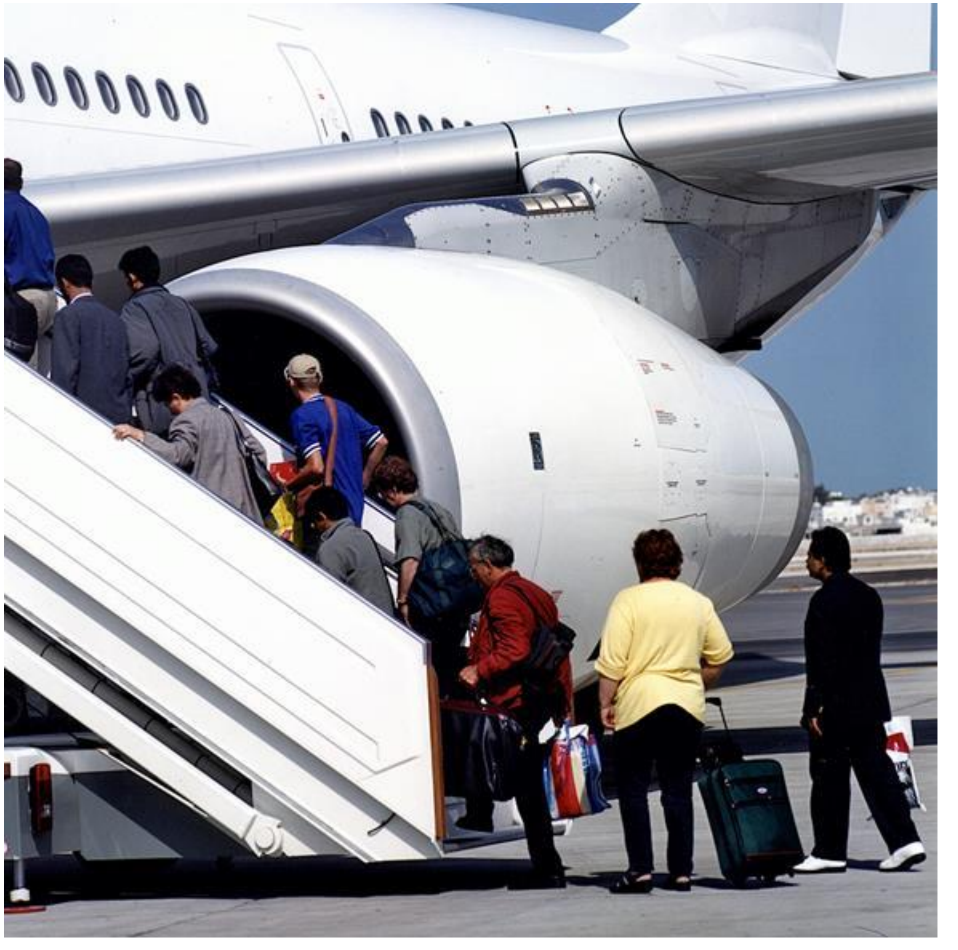
Hence a key enabler in this process is in providing data analysis methods that are accurate, meaningful and timely.

Equipment Health Management
Airlines demand predictable operation

- EHM is all about
  - avoiding surprises
  - keeping the fleet flying reliably and passengers happy

- To accomplish this, airlines need
  - timely 24/7 troubleshooting
  - unambiguous advice

- It is very simple, apart from…
  - data complexity
  - immediate advice required
  - events must not be missed
  - avoiding giving false advice



Airlines demand predictable operation

- Customers want a dependable service
- Cost of disruption is significant, for example, an in-flight shut-down can lead to:
  - diversion to remote site
  - overnight for passengers
  - replacement aircraft
  - supply spare engine
  - disrupt follow-on flights

Certain component assets are highly complex in their design & operate in hash environments:

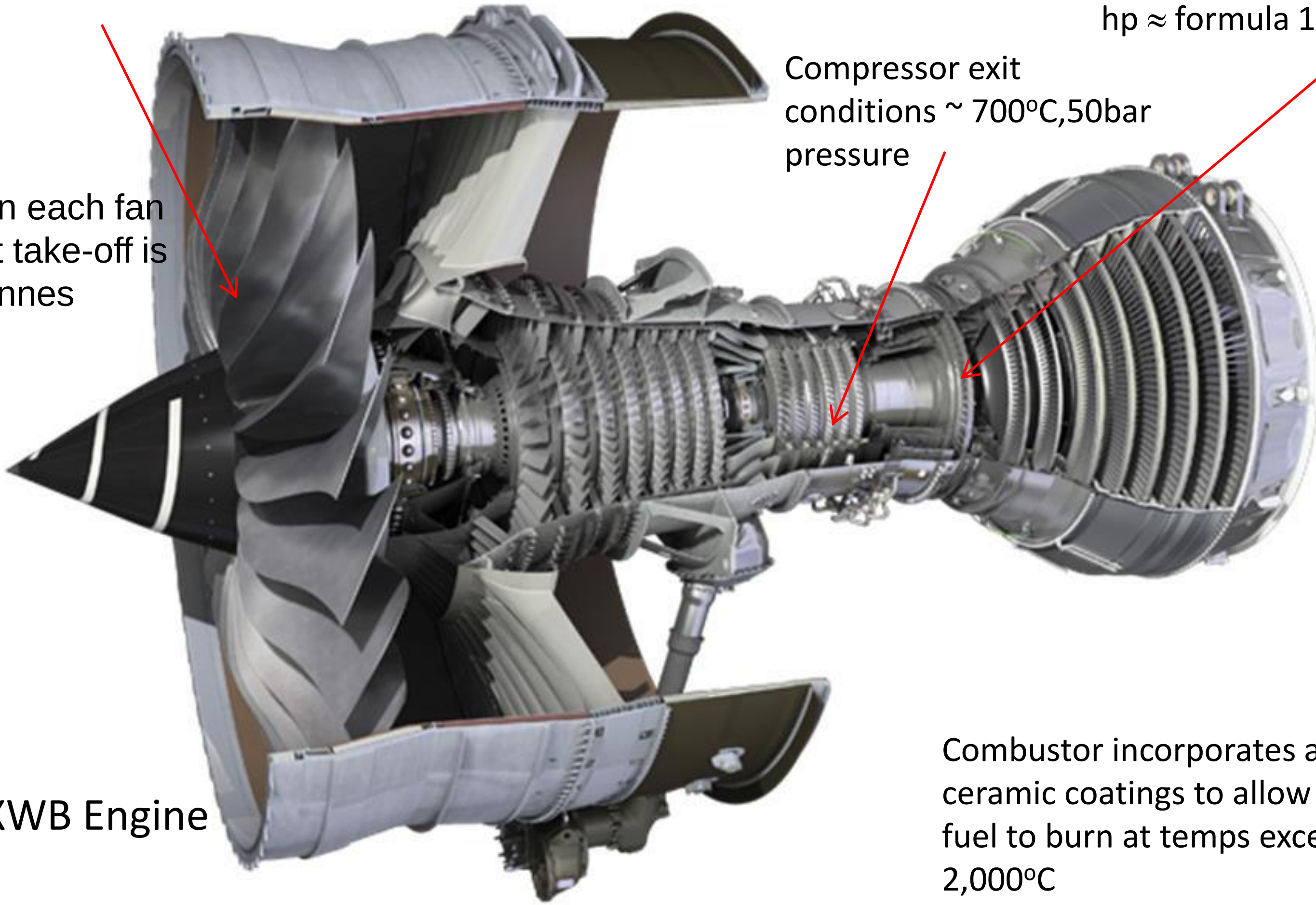
Cranfield IVHM Centre

Ultra efficient swept fan for reduced operational noise & optimum core protection.

High pressure turbine generates over 50,000hp. Each blade generates 800 hp ≈ formula 1 racing car

Compressor exit conditions ~ 700^{o}C,50bar pressure

Force on each fan blade at take-off is ~100 tonnes



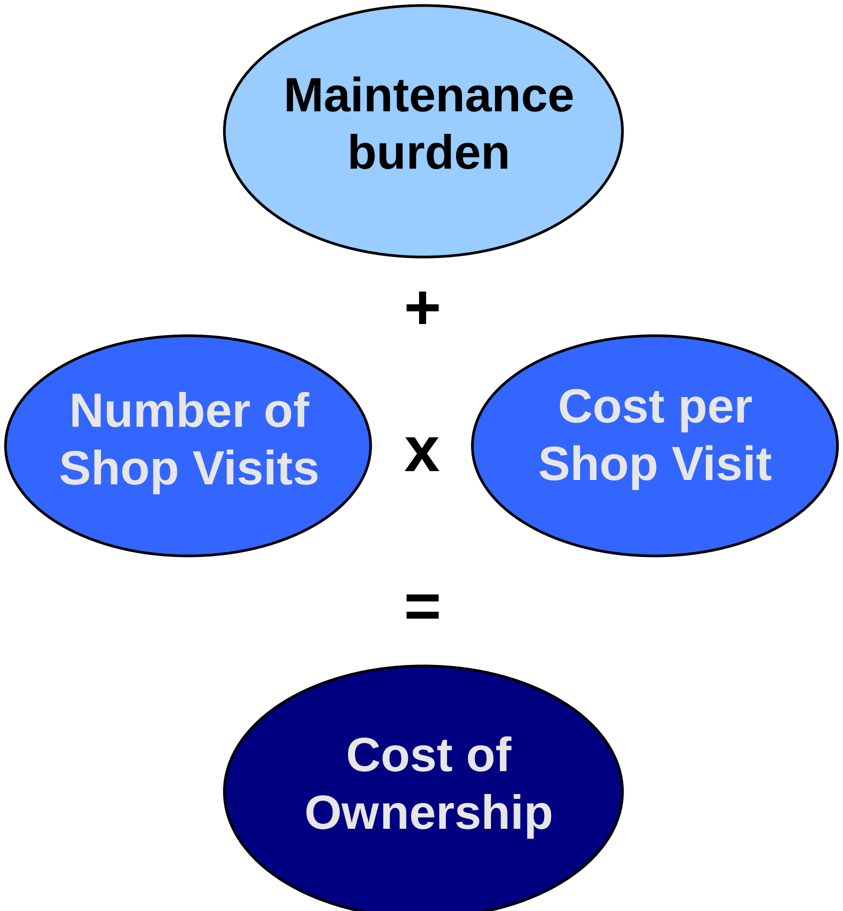
Delivers 75,000-97,000 lb_f thrust with a 10% fuel burn advantage over legacy engines

Combustor incorporates advanced ceramic coatings to allow mix of air and fuel to burn at temps exceeding 2,000^{o}C

Trent XWB Engine

but are expected to achieve long on-wing lives …

Cranfield IVHM Centre

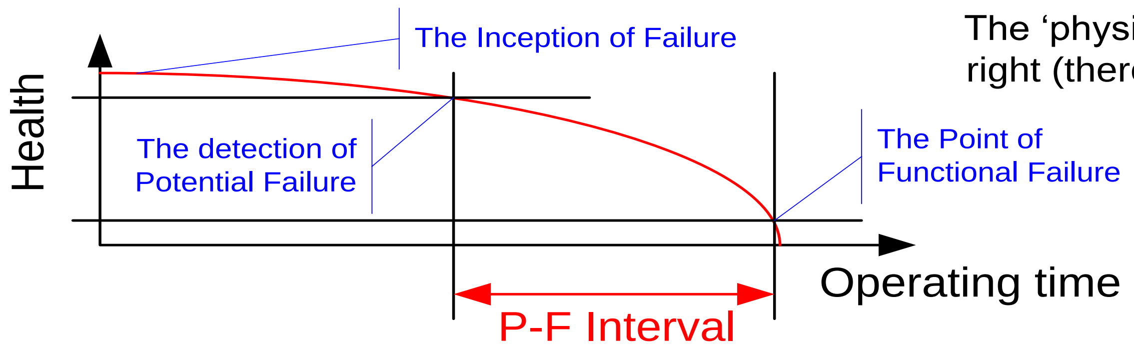


- Engine maintenance costs are directly related to time between overhauls
  - modern engines achieve
    8-10,000 flights
- Service events, such as IFSDs, are to be avoided
  - ETOPS* requires fleet IFSD* average MTBF* > 12 yrs
  - engines are expected to be significantly better:
    - Trent 800 MTBF > 120 yrs

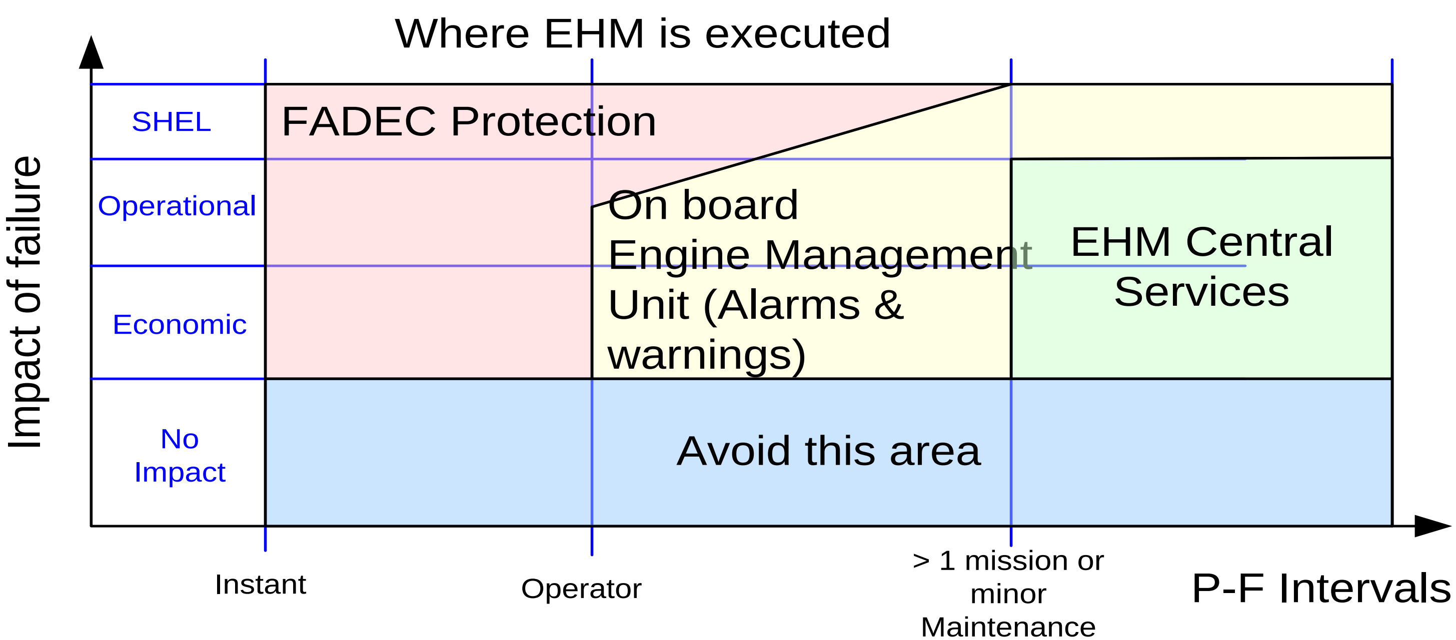
*ETOPS:	Extended Operations
IFSD:	In Flight Shut Down
MTBF:	Mean Time Between Failure

The Value of Health Monitoring

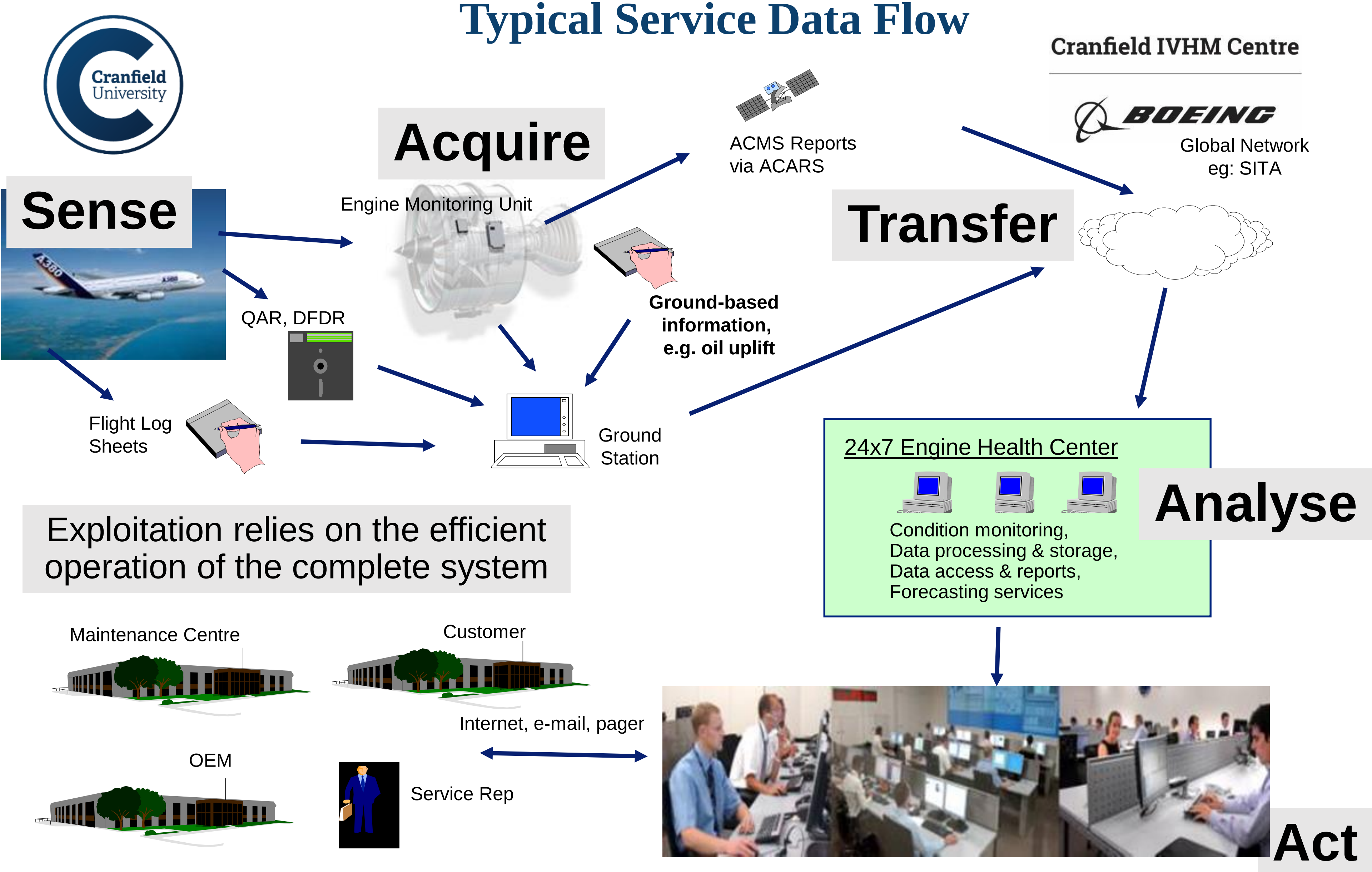
Cranfield IVHM Centre



The ‘physics’ of failure must be right (there must be a time lag)



Typical Service Data Flow

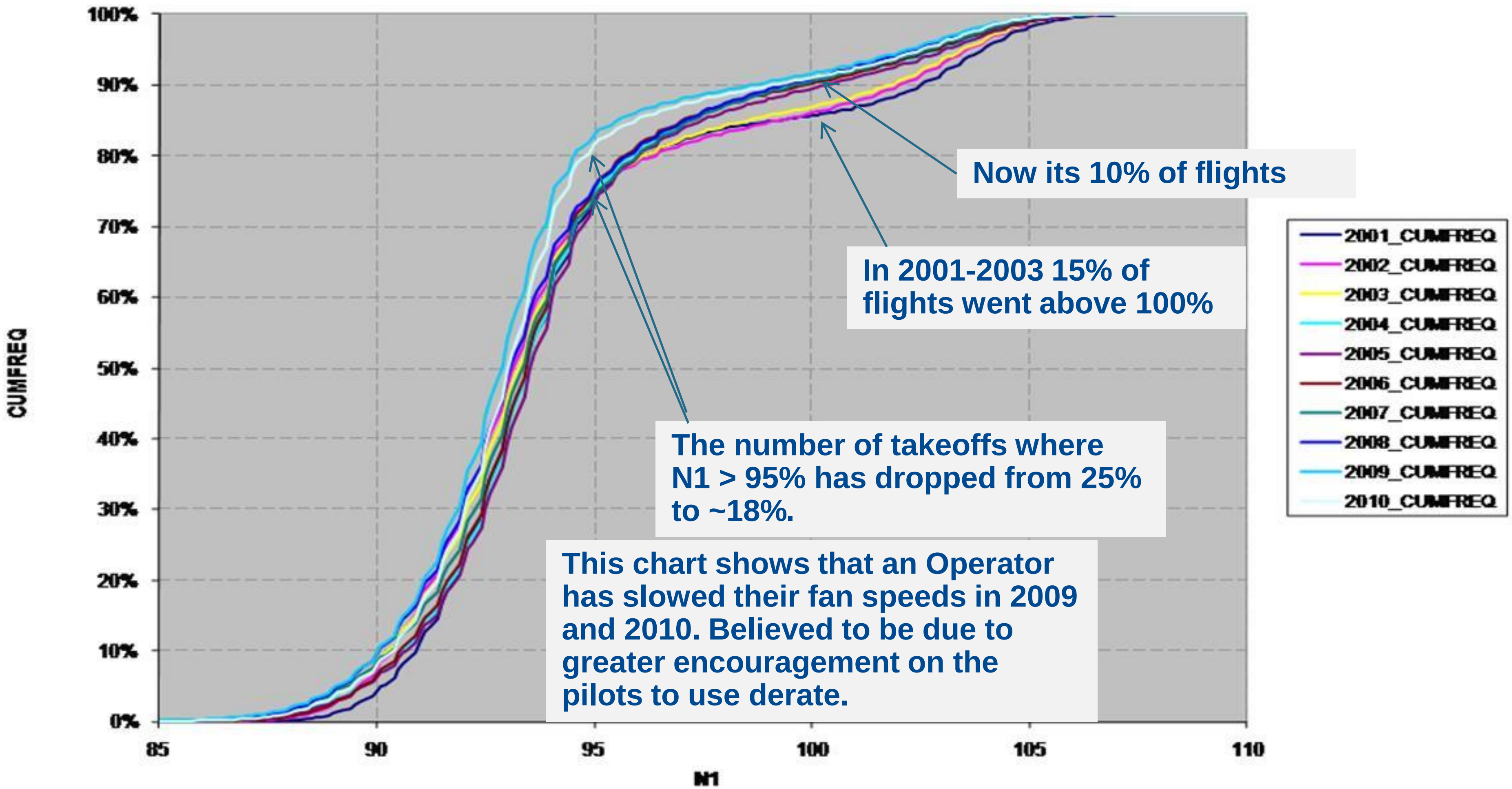


Typical Data Types & Analytics

- As indicated, service data exists in many forms:
- Written logs help provide the engineering context for other data
- Snap-shot data (e.g. hourly readings covering a mix of parameters or measurements taken at a given flight condition) can be used for trending and basic analysis:
  - Monitor parameters against fleet-wide threshold
  - Compare mean of most recent 20 points with previous 20 points
  - Identify step change in trend data
  - Use of statistical process control methods (e.g. individual moving range)
  - CDF plots help identify areas in the fleet data that are different
- Continuous high-bandwidth data will require some form of data reduction combined with signal processing before more basic comparative assessments can be formed
- Such methods provide comprehensive coverage, but tend to be applied to individual parameters and <u>target specific known conditions</u>

Example – Monitoring operational behaviour

Cranfield IVHM Centre



Intelligent Diagnostics

To be effective, the health monitoring system needs to be based on sound engineering knowledge and incorporate robust models developed from reliable data.

This raises the following dilemma:

- Training data for all conditions to be monitored will not naturally be available in quantities required (e.g., lack of fault data).
- Seeding abnormal conditions in an engine can be difficult and expensive and not necessarily representative.
- Some fault conditions may not have been seen before.

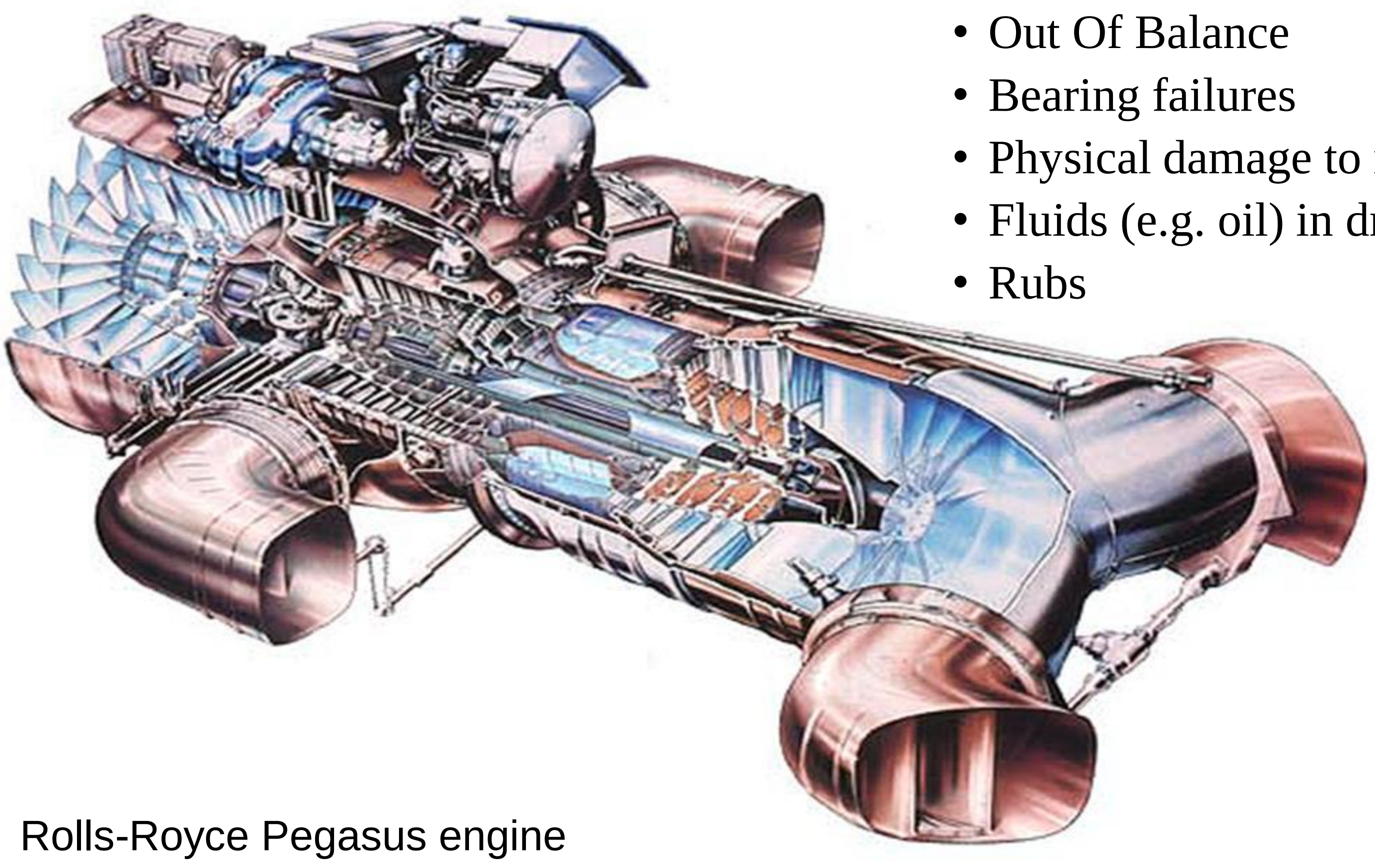
Novelty detection only requires sufficient examples of normal operation and therefore may be more robust than training a system to recognise a range of faults.

Intelligent Diagnostics
Detection of vibration anomalies

Cranfield IVHM Centre

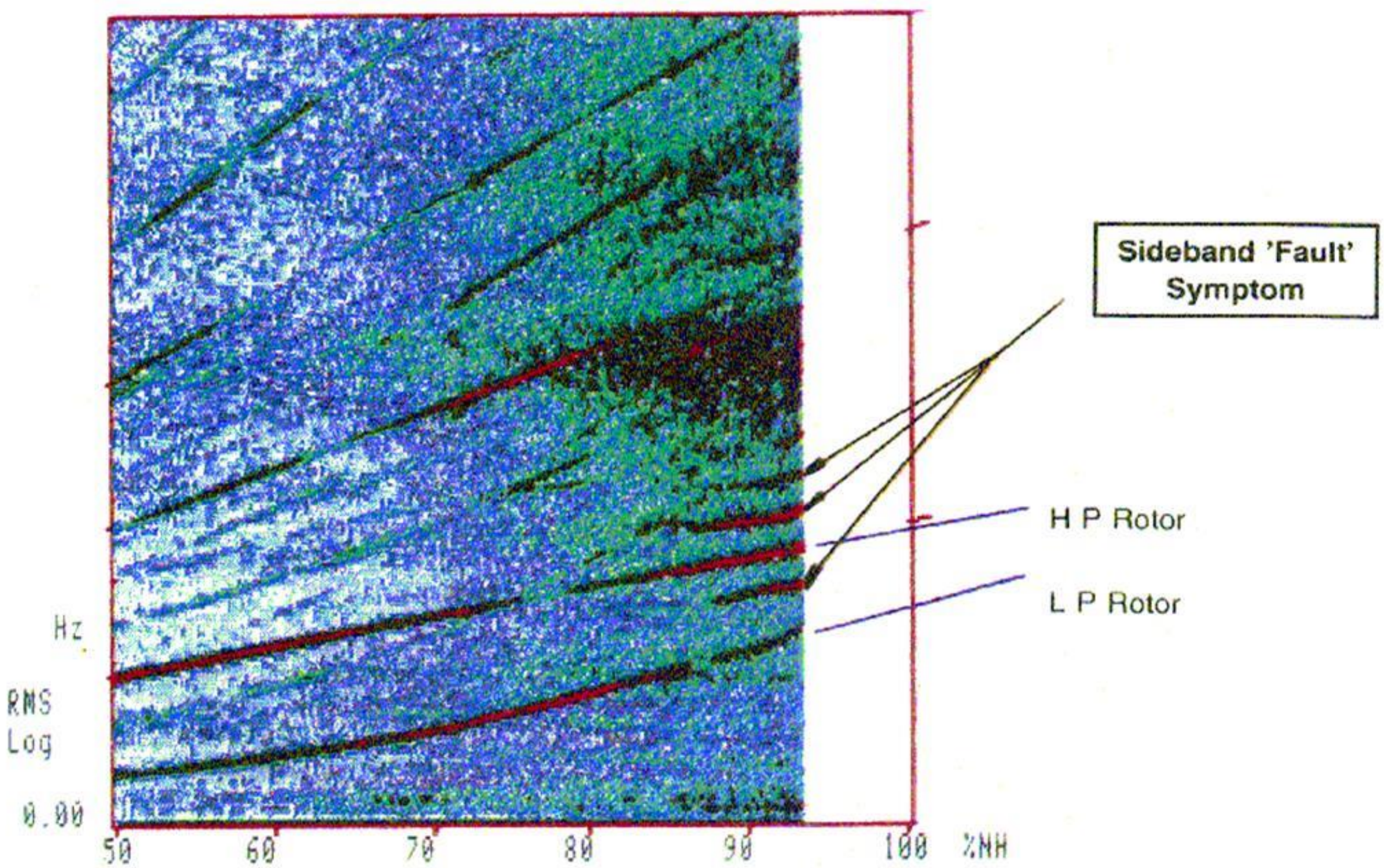
Vibration - A key monitoring parameter!

- Out Of Balance
- Bearing failures
- Physical damage to rotating components
- Fluids (e.g. oil) in drums
- Rubs



Rolls-Royce Pegasus engine

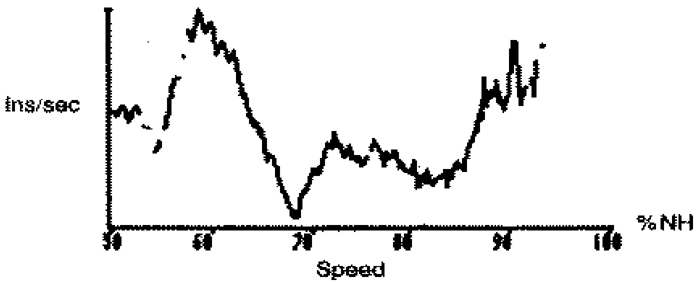
Intelligent Diagnostics
Detection of vibration anomalies



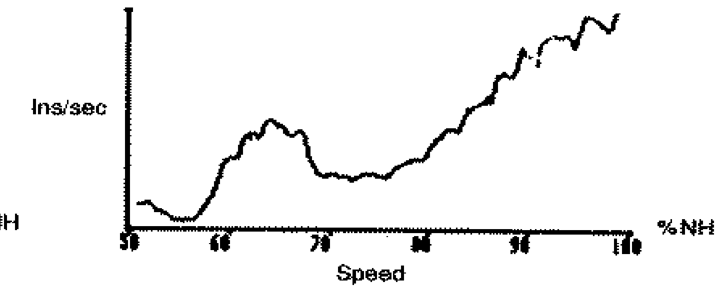
Intelligent Diagnostics
Detection of vibration anomalies

Cranfield IVHM Centre

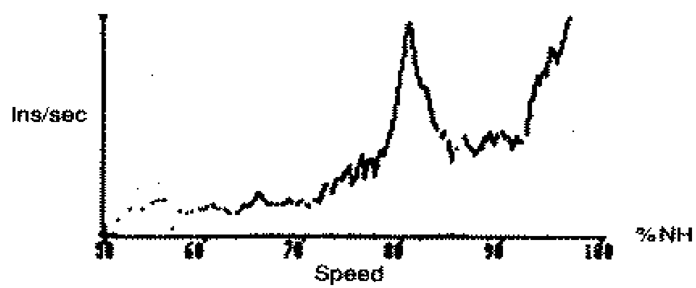
Typical out-of-balance signatures from a two-shaft engine



HP Turbine



HP Compressor



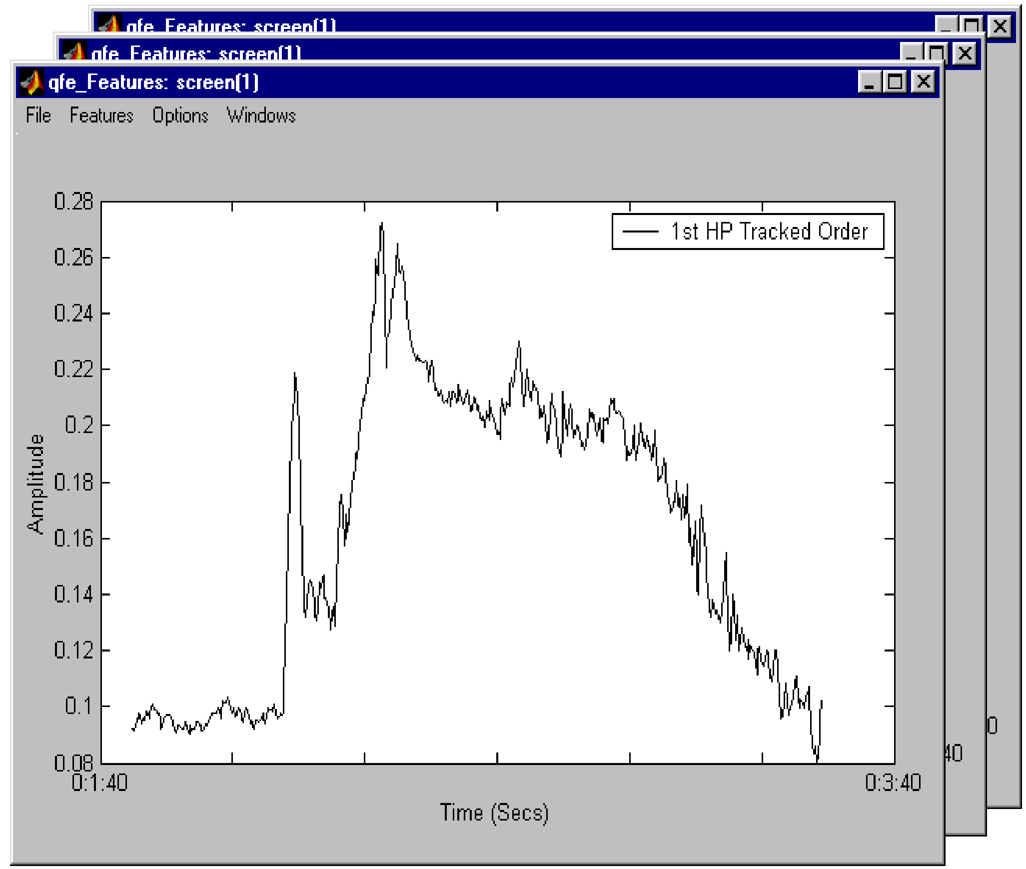
LP Compressor

Intelligent Diagnostics
Detection of vibration anomalies

Cranfield IVHM Centre

Models of normality can be derived by understanding how the data is distributed in its raw form.

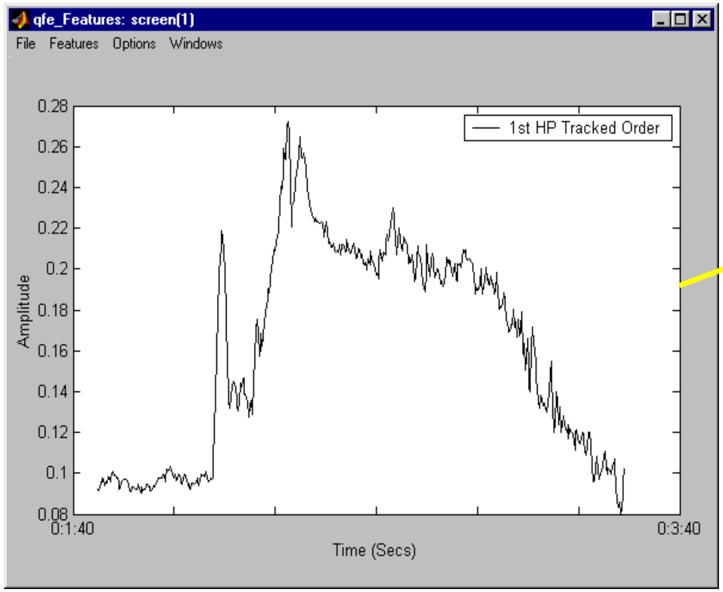
However, raw data usually exists in a high number of dimensions (each tracked order is represented by ~500 points). Thus, part of the process is to model the data using a lower dimensional representation.

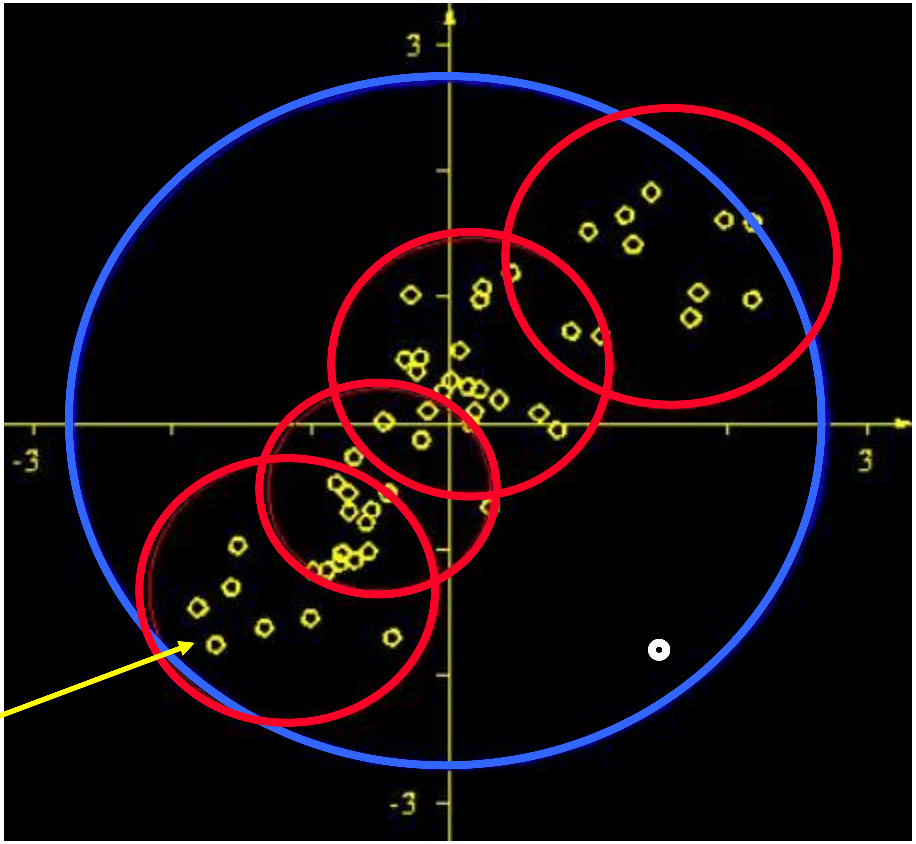


Intelligent Diagnostics
Detection of vibration anomalies

Cranfield IVHM Centre

Models of normality can be derived by understanding how the data is distributed in its raw form by projecting points onto a 2D representation using techniques such as Principal Component Analysis, Neuroscale, etc.





Cranfield University

Cranfield IVHM Centre

BOEING

Intelligent Diagnostics

The SATAA framework

- **Sense** — Dedicated sensors and systems to measure key parameters/performance indicators
- **Acquire** — Automatic acquisition systems to capture key operational activity (e.g. snap-shot and continuous data
- **Transfer** — Real-time data transfer from asset via comms network
- **Analyse** — Analysis and diagnosis systems to determine current and immediate future health condition given operational context
- **Act** — Use of decision support tools, that account for health metrics and operational knowledge, to provide timely advice with the goal of minimising operational disruption

Intelligent Diagnostics
some example Decision Support techniques

Cranfield IVHM Centre

- **Expert/Knowledge Based Systems**
  - Use if...then type rules to capture knowledge. Can be simple procedure languages or rule-based systems which evaluate the rules via an inference engine using forward or backward chaining (or combination of both) in a goal driven manner
- **Rule Induction**
  - Derives a decision tree based (set of rules) from a set of examples
- **Fuzzy Logic**
  - Employs notion of membership functions to represent knowledge in a qualitative form.
- **Inference systems**
  - Bayesian Networks
- **Case Base Reasoning**
  - Data-base of historic reference cases that can be searched for similarity
- **Natural Language Processing/ Text Mining**
  - Use of machine learning/AI techniques to mathematically analyse text (e.g. maintenance logs)

Summary

Cranfield IVHM Centre

- **Equipment Health Management (EHM) is a key capability in ensuring optimum asset utilisation:**
  - **non-intrusive: embedded sensors/wireless data transfer**
  - **Smart: intelligent use of data to extract timely information via physics and empirical modelling techniques, underpinned with domain knowledge**
  - **effective: good track record of detecting operational issues**

- **An effective EHM system provides two key benefits to operators:**
  - **enables on-condition asset maintenance and therefore can be used to optimise through-life costs**
  - **minimises operational disruption to asset operation**

Thank you for your attention

Any questions?