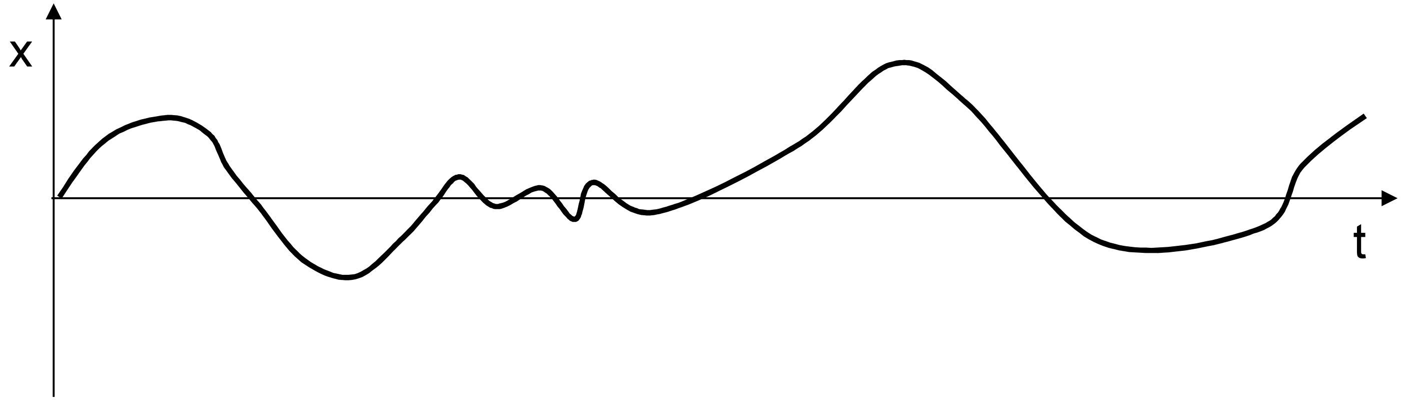
# Sensor Systems

# HUMS – Health and Usage Monitoring Systems

# Recap – averaging data




$$\left(\frac{1}{T}\int_0^T x^n(t)\,dt\right)^{\frac{1}{n}}$$

*Power means*

$$\frac{1}{T}\int_0^T \left[x(t)-\bar{x}\right]^i dt$$

*Moments*

$$\frac{\frac{1}{T}\int_0^T \left[x(t)-\bar{x}\right]^n dt}{\sigma^n}$$

*Standardised Moments*

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23 October 2012 Last updated at 16:00

# CHC, Bristow and Bond helicopters halt some flights after ditching

SIMON TRANBJERG VAMMEN

The first pictures of the ditched helicopter have emerged

**All three operators of North Sea offshore helicopters have grounded the type of aircraft involved in Monday's ditching off Shetland.**

A Super Puma EC 225, operated by CHC, carried out a controlled landing close to Fair Isle. All 19 people on board were rescued safely.

CHC said it was suspending operations using helicopters of the same type.

Bristow and Bond have now also delayed operations of EC 225 and L2 Super Pumas, during the investigation.

The Unite union said there was a growing fear among offshore workers over helicopter safety.

Unite industrial officer John Taylor said: "Mercifully there were no fatalities with this latest incident."

The manufacturer, Eurocopter, said it had full confidence in the aircraft.

A spokesman for Bristow Helicopters said: "The safety of our passengers

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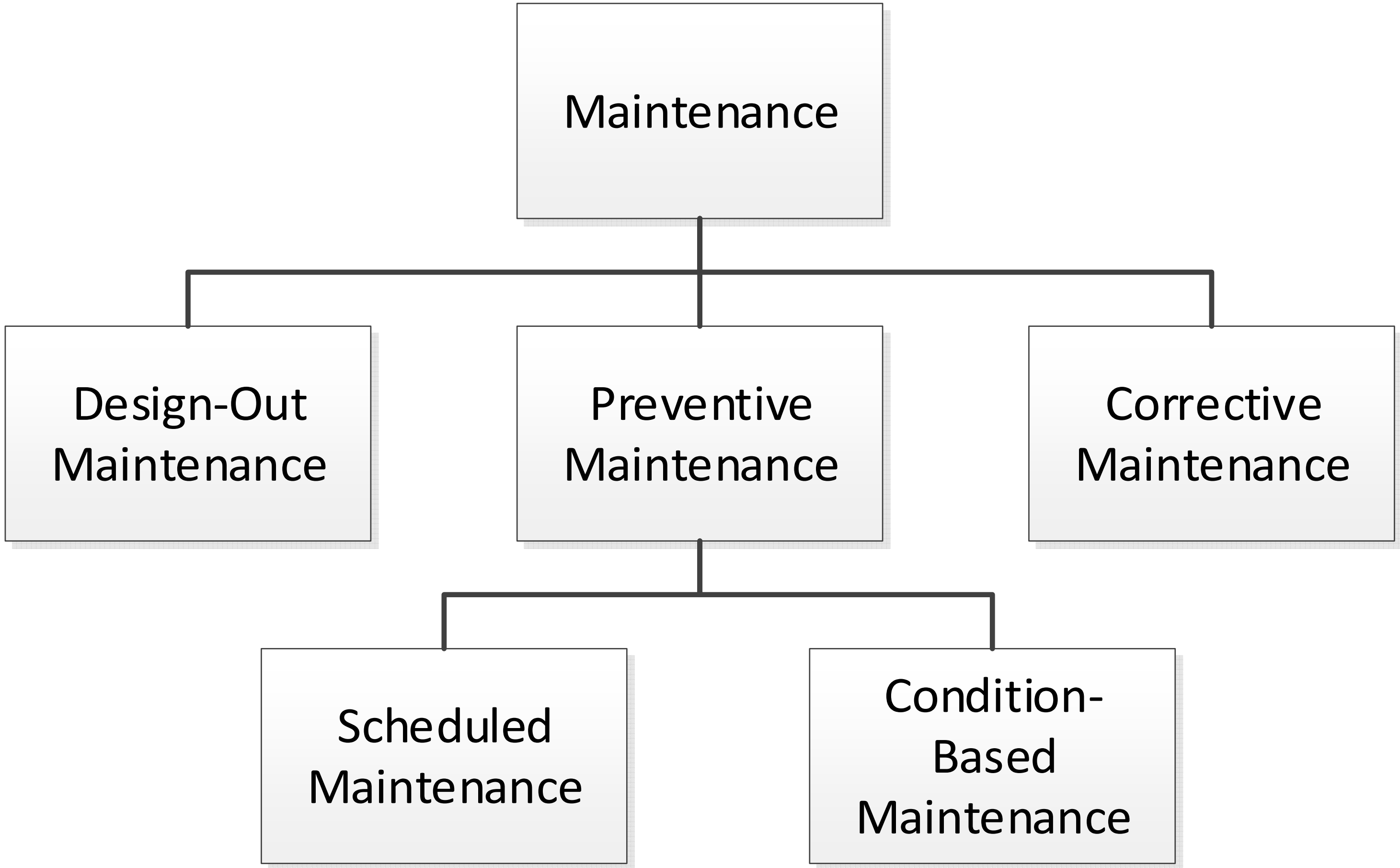
# Maintenance philosophies

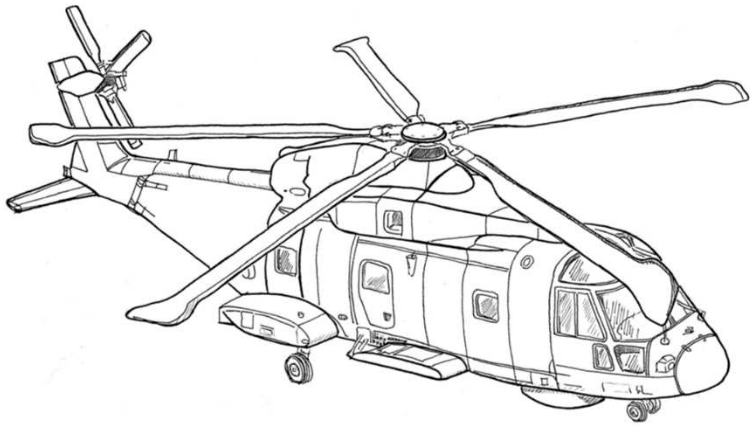
- Run to failure
  - *As title – keep operating until failure*
- Time based maintenance
  - *Inspect/maintain after so long or so many cycles*
- Condition based maintenance
  - *Measure/monitor continually*

# Hierarchy of maintenance



# What are HUMS?

Health and Usage Monitoring Systems are used to implement autonomous Condition Based Maintenance.



The 'holy grail' of the discipline to perform prognosis - i.e. to predict remaining lifetime of components of structures

HUMS can be used to determine the state of a component or structure (diagnosis)

# Conventional time-based ‘assumed usage’

HUMS are being used as a supplement to conventional methods: inspection (expensive, time consuming) and estimated lifetime (inaccurate, conservative).

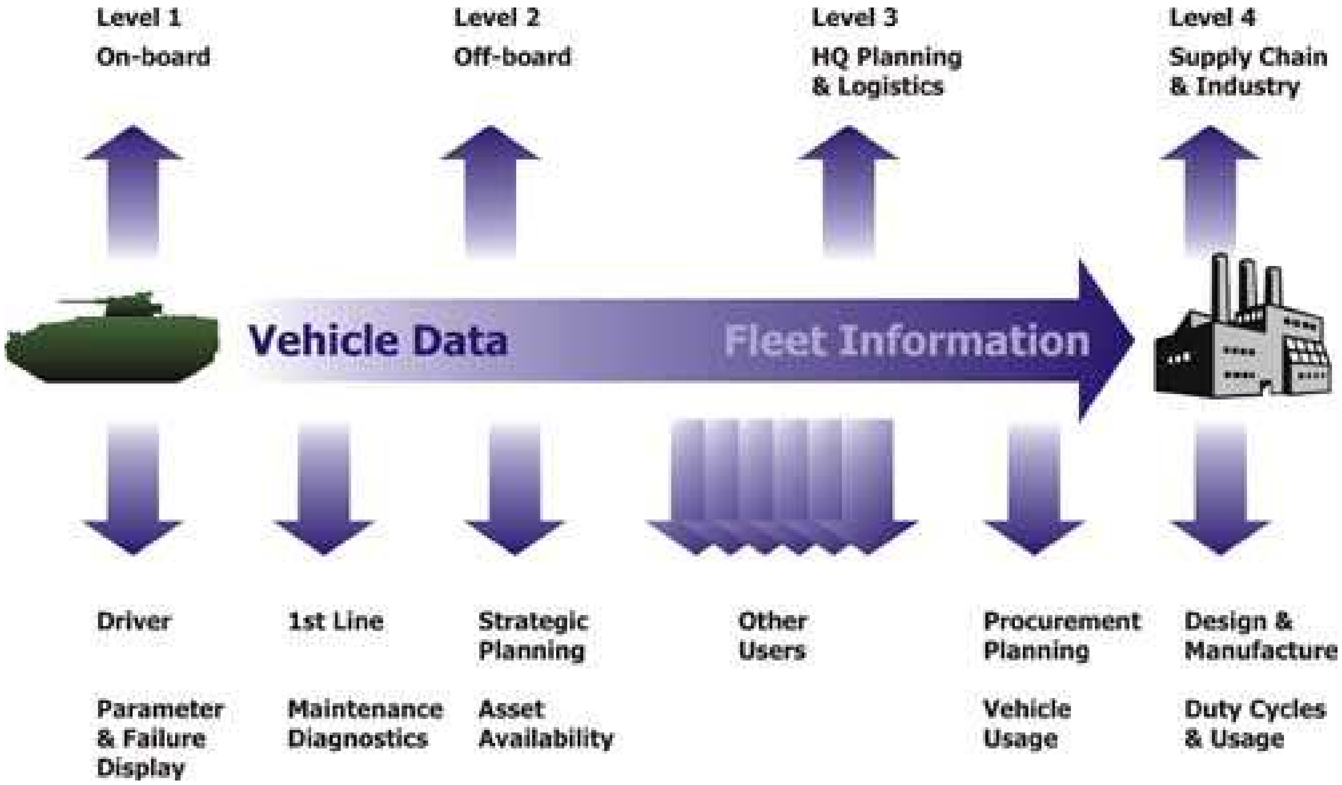
Conventionally, lifetime is estimated by testing many specimens of a particular part in lab trials and the failure point recorded. A large safety margin will then applied to the actual lifetime to give a service life to the part.

This is often described as ‘assumed’ usage because we have no actual information about the condition of the part after it is fitted. There are two important consequences:

1) Parts are often discarded long before they are worn out.

2) Unforeseen conditions are not taken into account resulting in unexpected occasional failure.

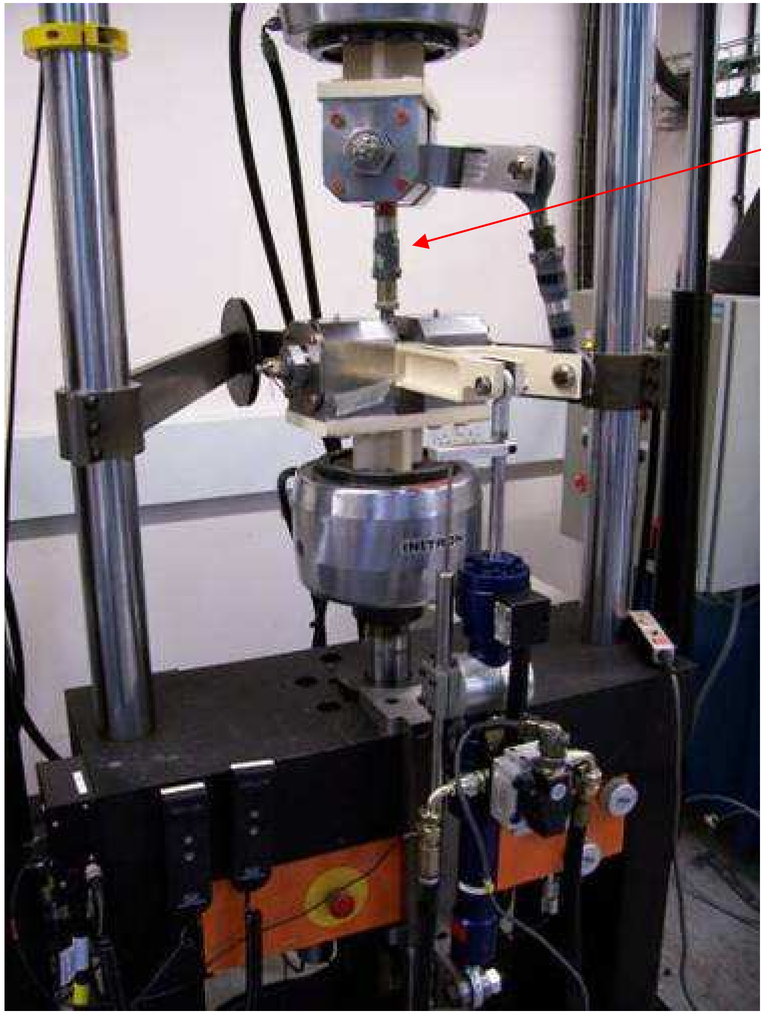
# Advantages of HUMS




***Picture: Syen***

# Usage monitoring

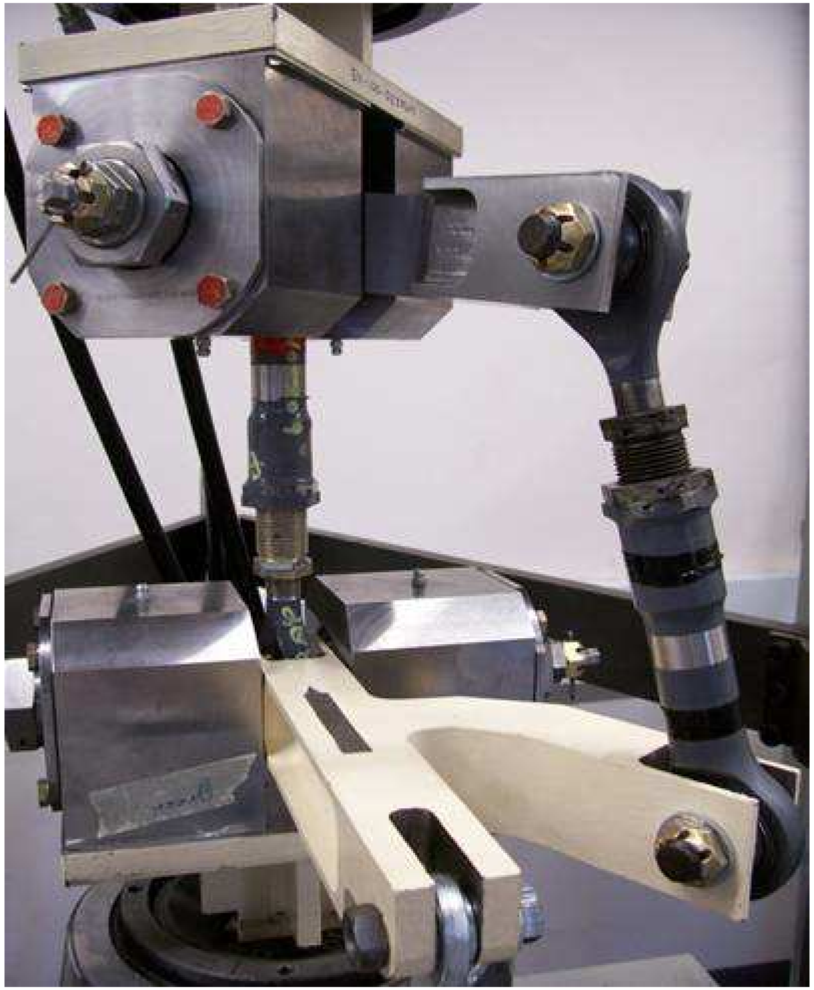
# Conventional wear testing




Pitch link under test

Pitch link cycled through loading designed to replicate flight conditions

# Conventional wear testing



Example wear tests carried out at Bristol;

Ground conditions (rotor acceleration)
40,000 cycles of 600N ± 1100N

Level flight and banked turns (Vno)
400,000 cycles of -150N ± 2200N

Low speed and transitions (climb)
25,000 cycles of -300N ± 1300N

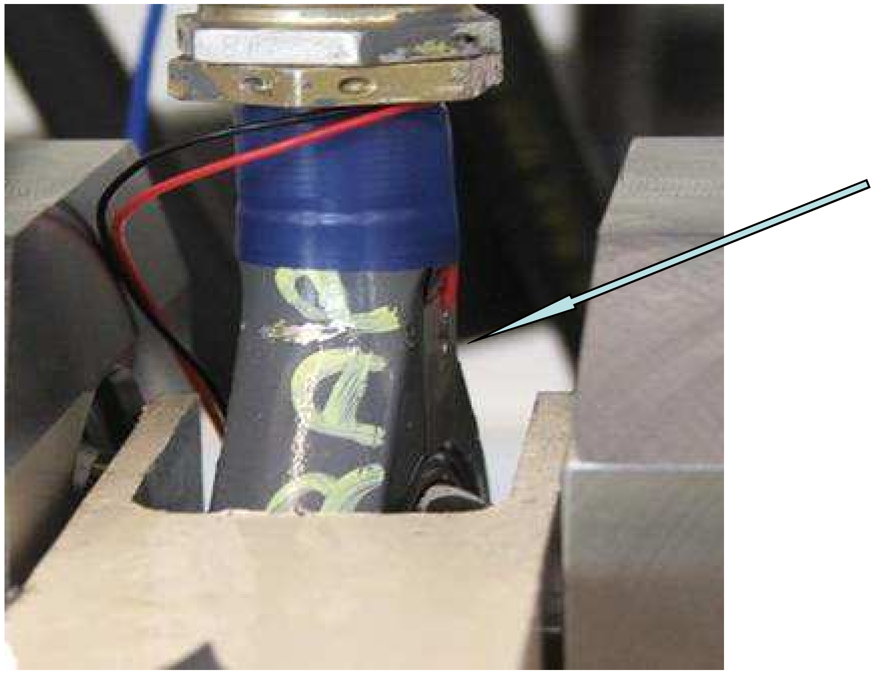
Once per flight
65 cycles of -2247N ± 6283N

Test takes ~ 24 hours and replicates just 10 flight cycles, even at increased loads. After each test the wear to the part is measured by hand.

It may take many weeks continuous testing to wear one part to failure and then the information is only as good as the predicted conditions.

# Health monitoring

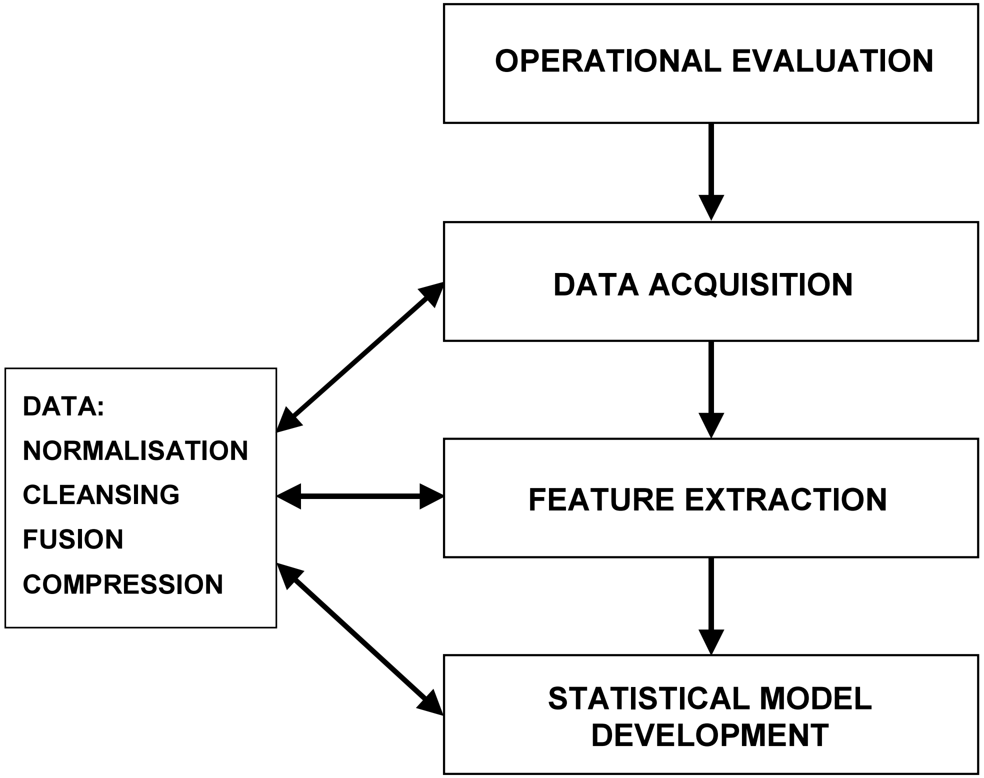
Determining which variable will give the best correlation with the event we wish to monitor requires a certain amount of engineering judgement. A large amount of test data, with a known relationship between wear and the measured signal, is also required to develop and validate the feature extraction process.



Piezo-electric strain sensor fitted to pitch link undergoing lab wear trials.

A large amount of training data was acquired to allow a feature extraction algorithm to be developed for in-service health monitoring.

# Feature extraction

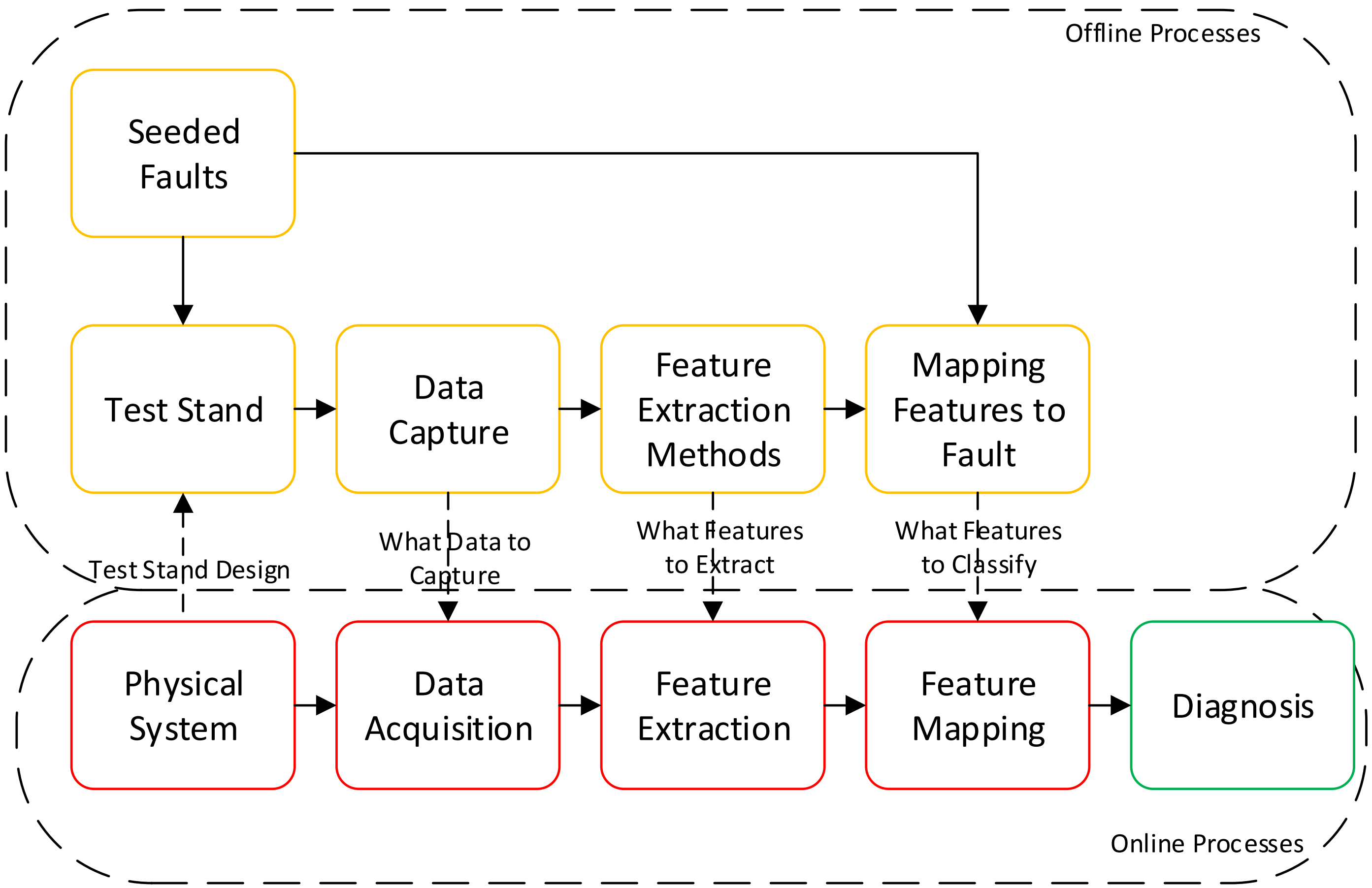



Feature extraction is the correlation of characteristics of the sensor signal with a particular parameter we wish to measure.

It typically requires extensive testing and/or modelling of the subject.

The characteristic we look for may be a consequence of changes in parameter we wish to monitor, e.g. when detecting for wear we may look for one of the consequences of wear.

# Data-driven HUMS processes




*This is the process used to develop the HUMS i.e. work out what to capture and how it relates to health*

*This is the bit of the HUMS that is implemented on the aircraft*

# Feature extraction - Bearing wear

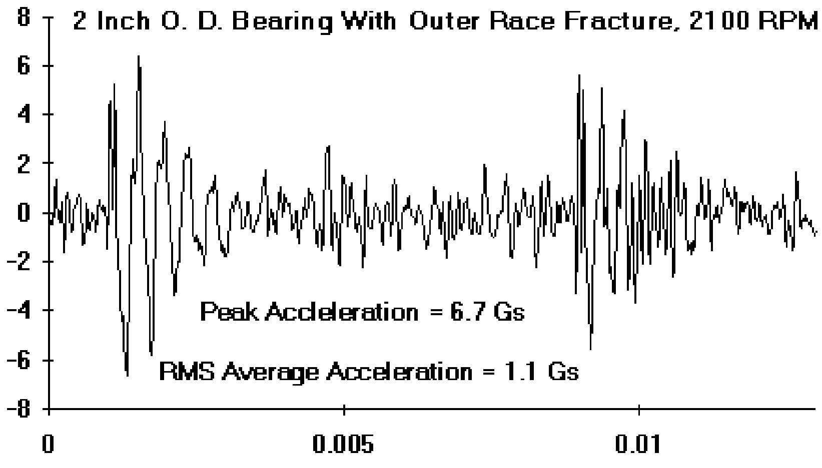


Figure 1

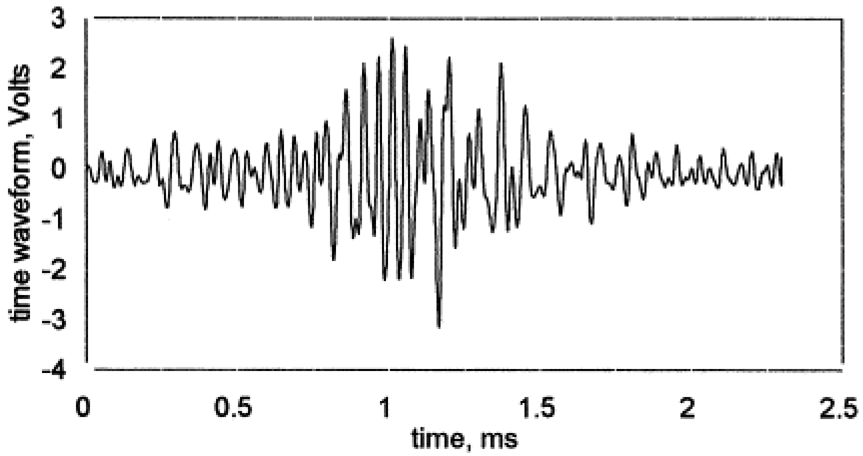
Bearings are a common part we might wish to monitor.

Everyday experience tells us vibration levels will increase rapidly as a bearing wears, so can we use measurements of vibration to indicate the health of the bearing?

Various measures can be applied to the signal to indicate wear, however the result is rarely clear cut, often requiring some judgement/interpretation.

# Feature extraction - Bearing wear

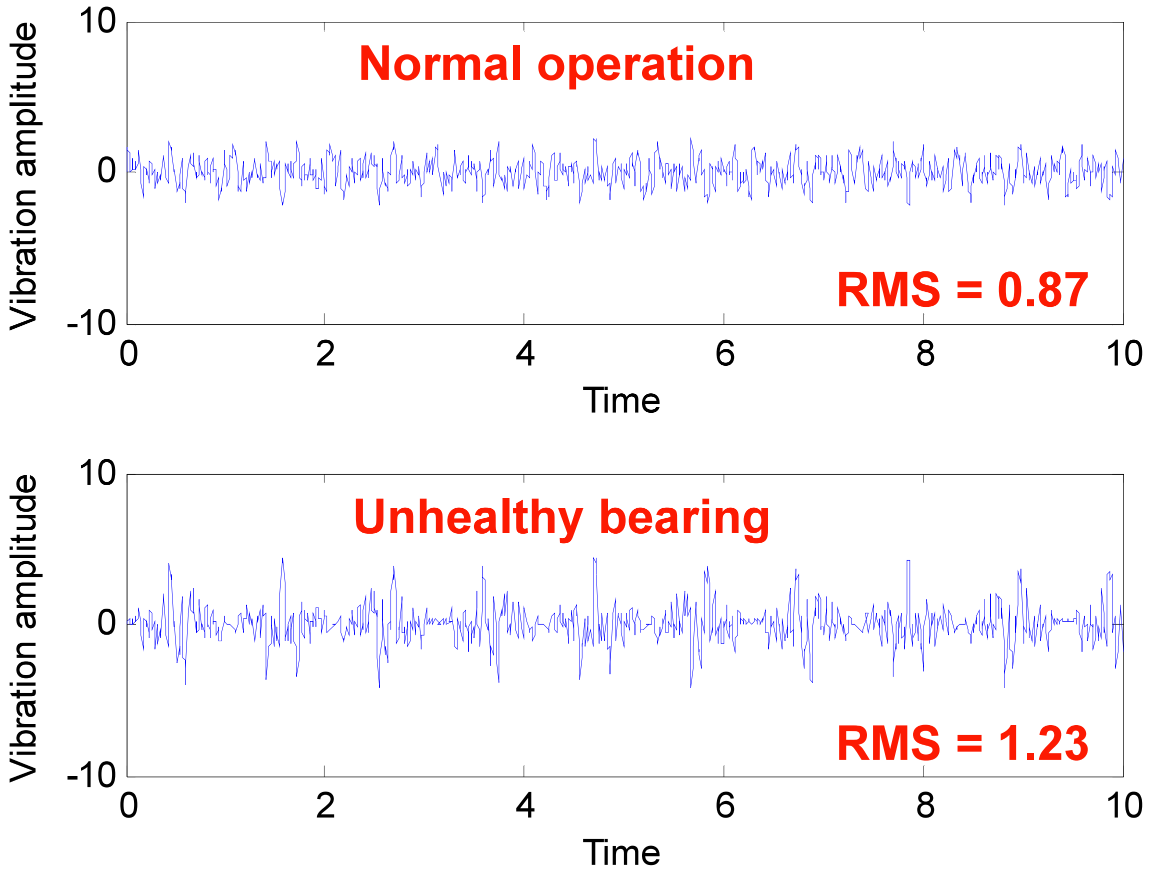
How can we characterise this signal?




a

1. Min/Max values
2. Peak-to-peak value
3. Mean value
4. Period of dominant components
5. Envelope – rise times, fall times
6. RMS – *good indication of 'energy'*
7. Moments

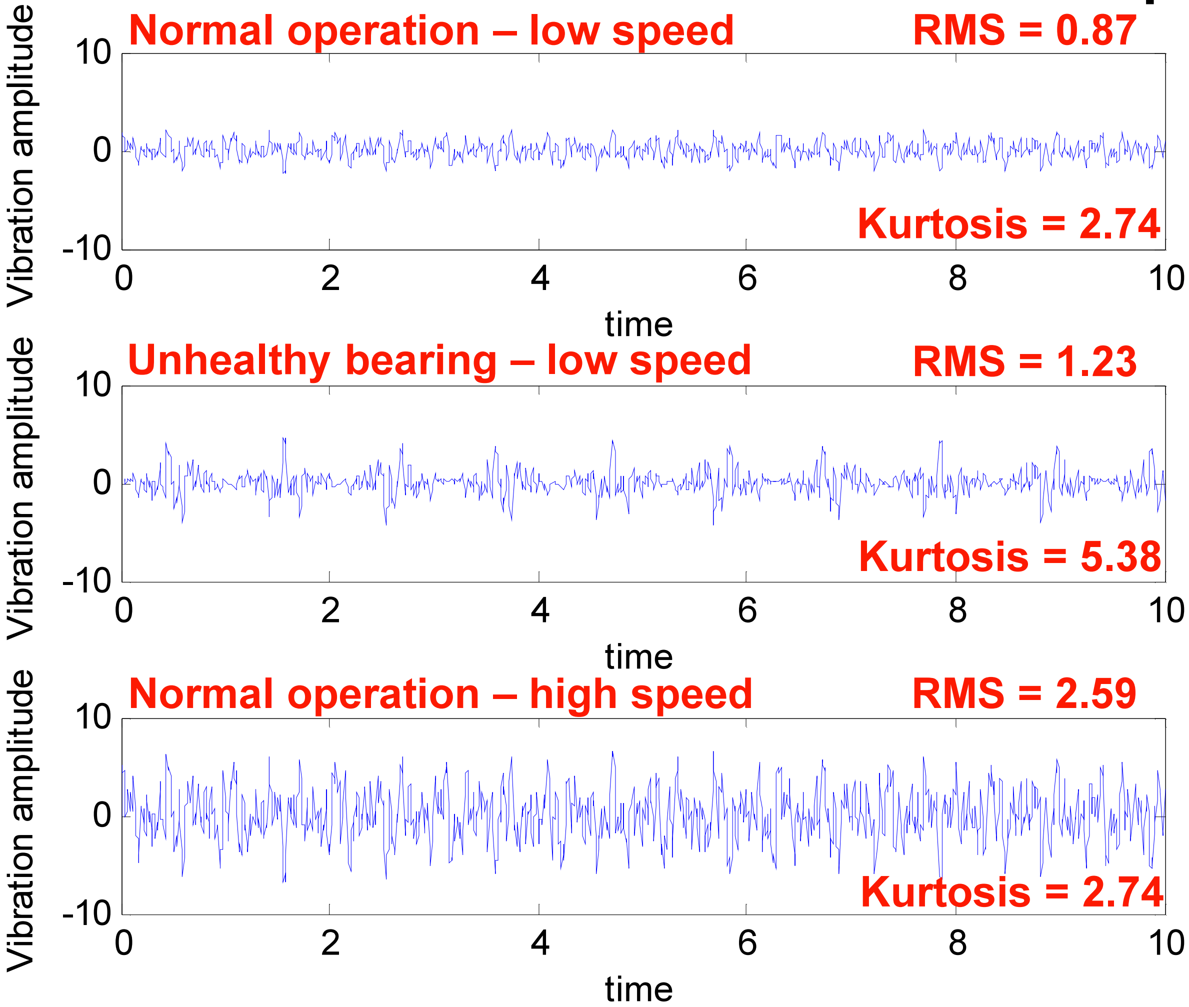
# Time domain statistic - example




Consider the case of a pump operating at a fixed speed.

It is clear that the unhealthy bearing has vibrations of a higher amplitude and it is straight forward to use a technique to identify this.

# Time domain statistic - example



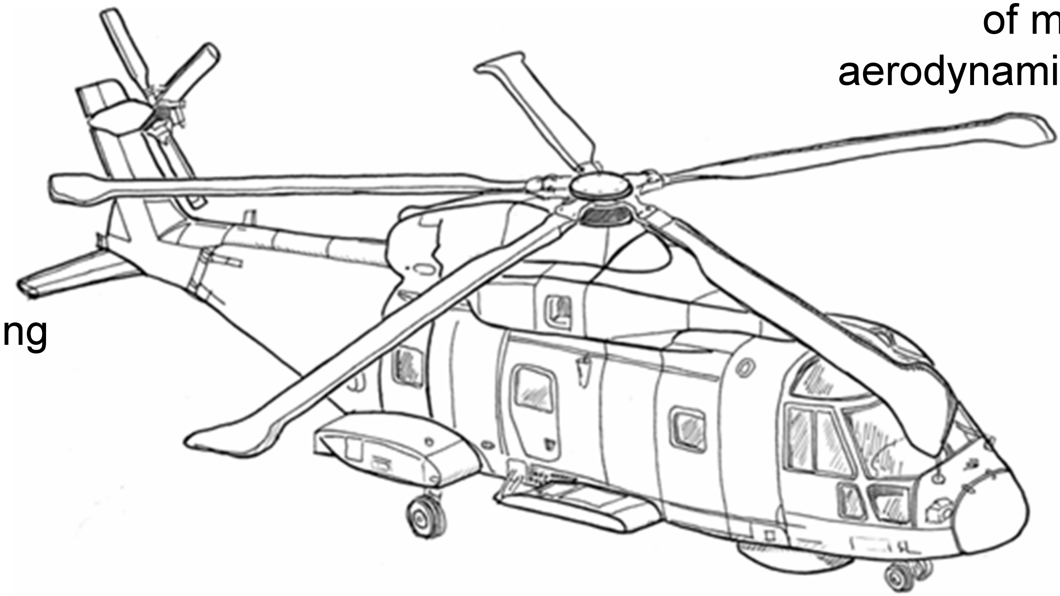

Now consider a two-speed pump. In this case the normal vibration levels at high speed may be greater than the vibration levels at low speed with a damaged bearing.

The characteristics of the vibration pattern are still obvious but we need a statistical measure to highlight those features. Kurtosis will provide that in this case.

# Example WISD project

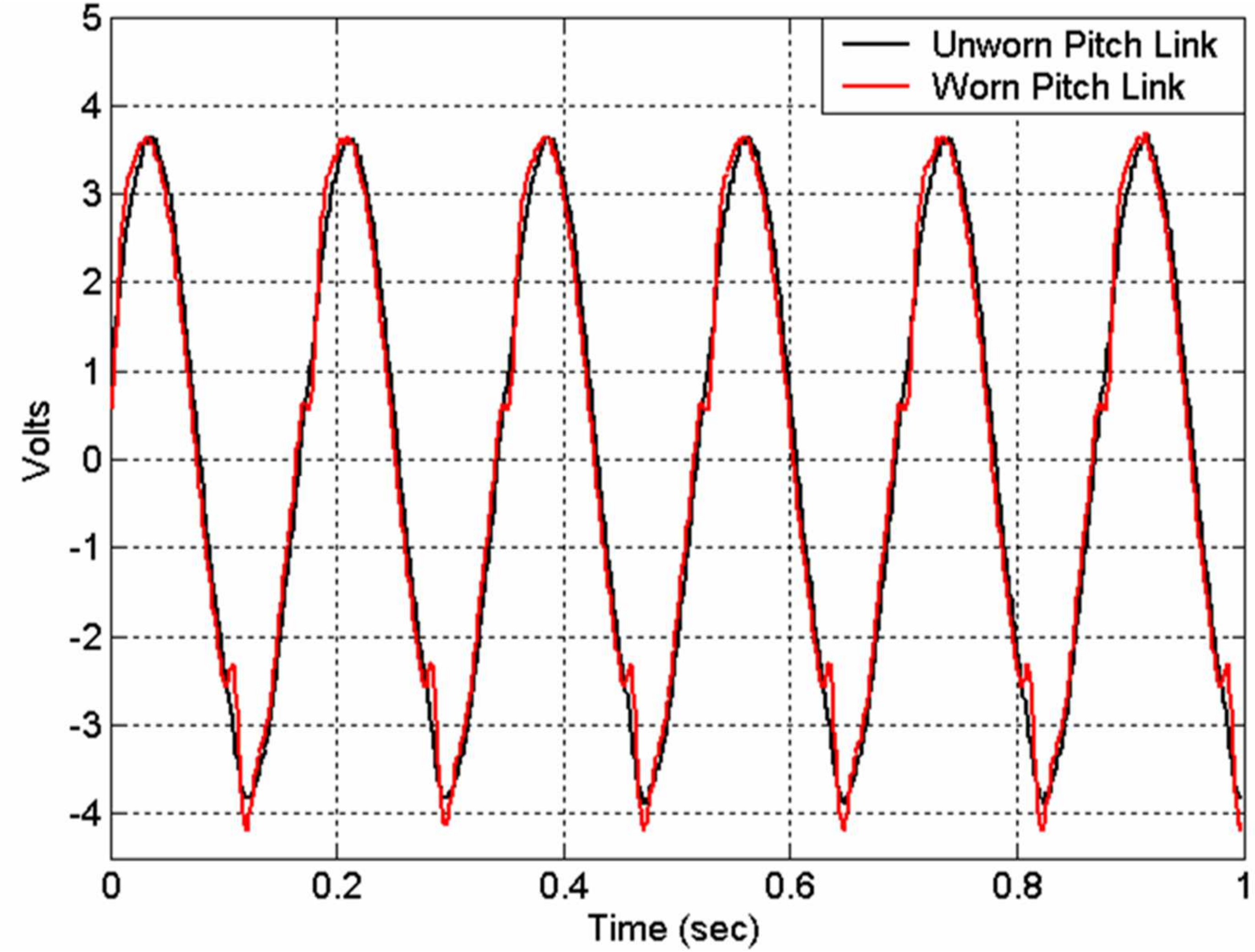
Complex stresses as result of mechanical and aerodynamic environment

Many safety critical components, including moving parts



The pitch link wear example was part of a HUMS research project by Bristol and Agusta-Westland. The goal was to provide HUMS on the rotating parts of the helicopter. Helicopters are an ideal candidate for HUMS because they vibrate so much and have so many safety critical parts. Commercial HUMS systems are fitted to some helicopters currently – an example is monitoring of vibration levels of the main gearbox.

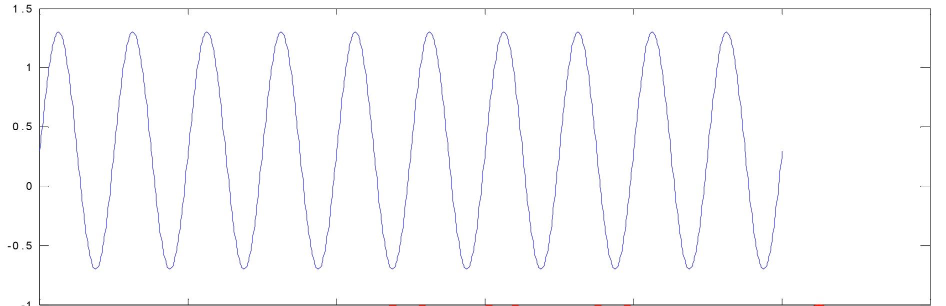
# Worn pitch link time domain signals



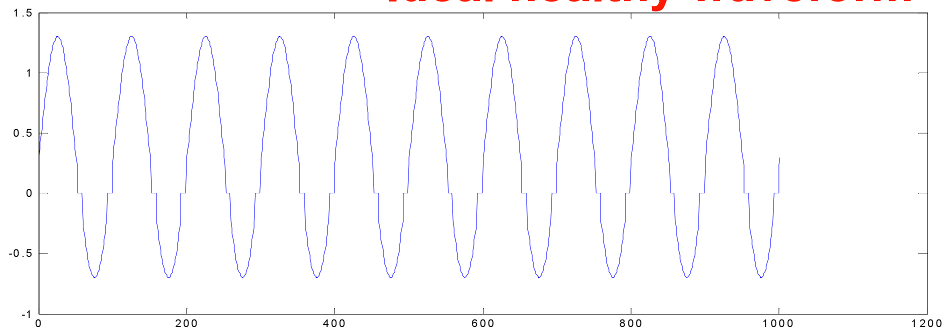

Time domain strain signals show a clear difference between worn and un-worn pitch links.

Beyond statistical techniques we can compare these waveforms in the frequency domain.

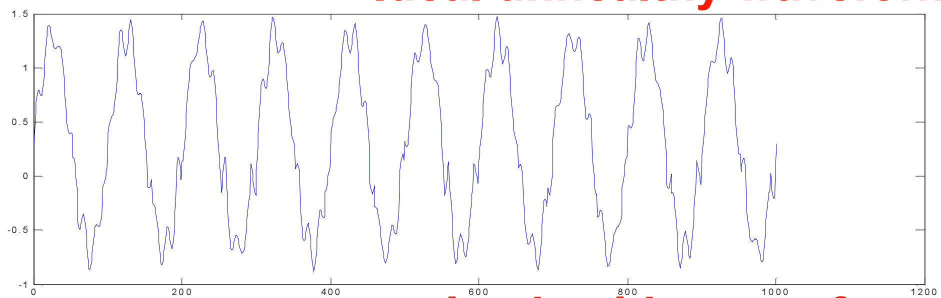
# Extracting signals from noise – pitch links



Ideal healthy waveform



Ideal unhealthy waveform



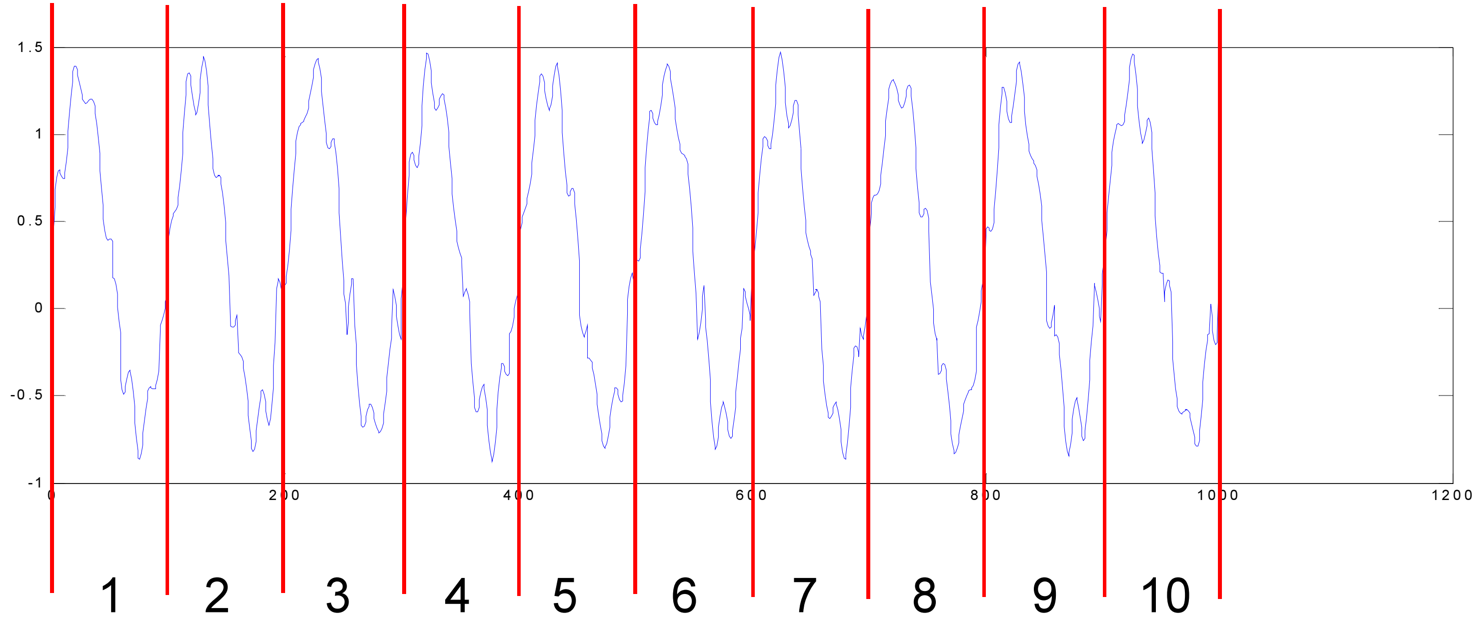
real unhealthy waveform

Our healthy subject produces a nice sinusoidally varying signal.

As it wears out, backlash causes a pronounced 'flat-spot' in the measured response. We could detect this with several statistical or frequency domain techniques.

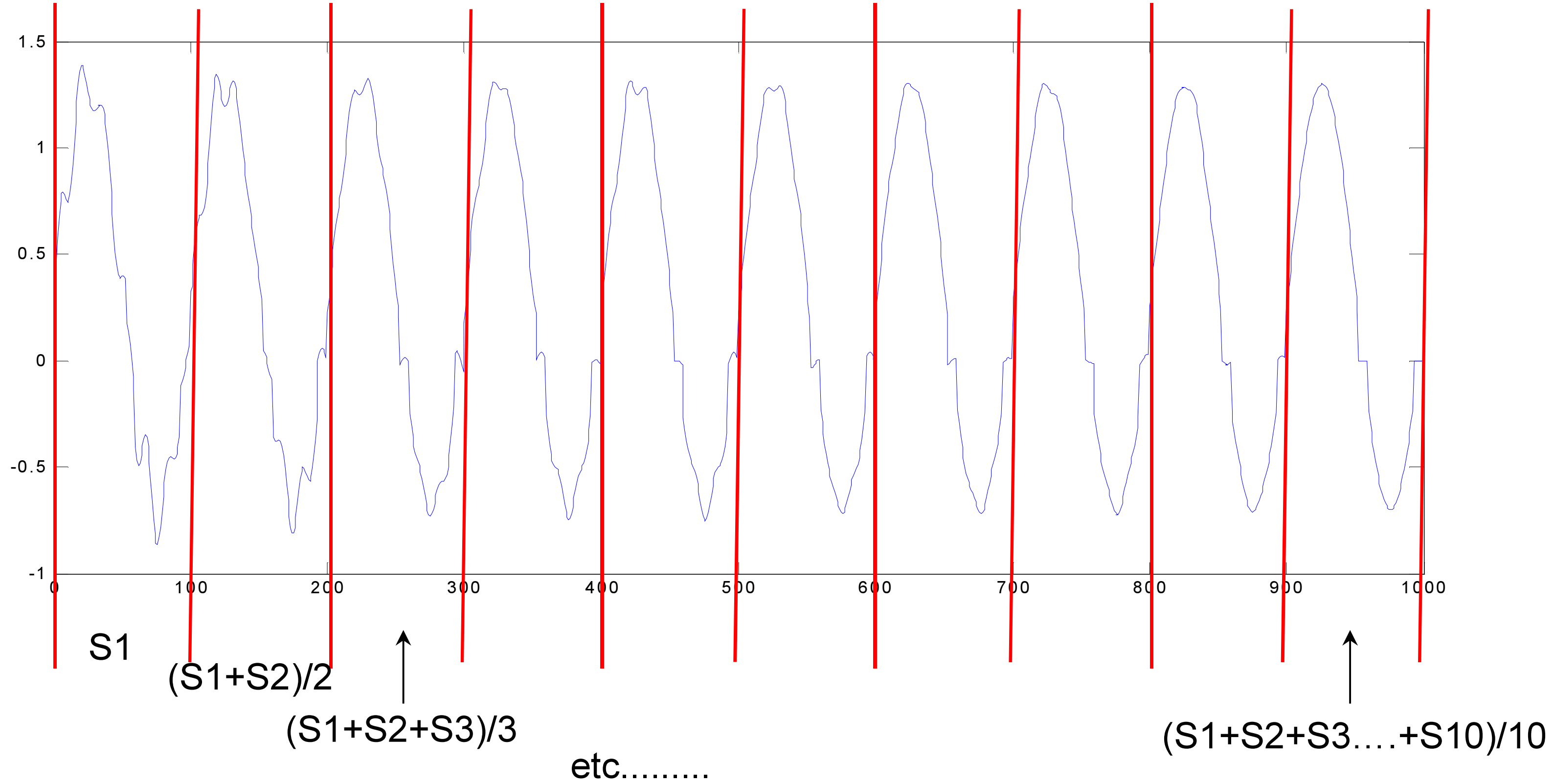
However, our aircraft has lots of other banging and clattering going on. The noise masks the feature we are looking for.

# Time averaging




The signal is cut into ‘slices’ of a period carefully chosen. With rotating mechanical systems this is most obvious (often a multiple of the speed of rotation) but the technique can be applied if the feature to be extracted is known to occur at a particular frequency.

# Time averaging




The slices are then averaged. Features that are present in the same place all slices are revealed, features that do not occur in the same place in every slice are suppressed (i.e. noise and signals with differing periods to the slice)

# Time averaging

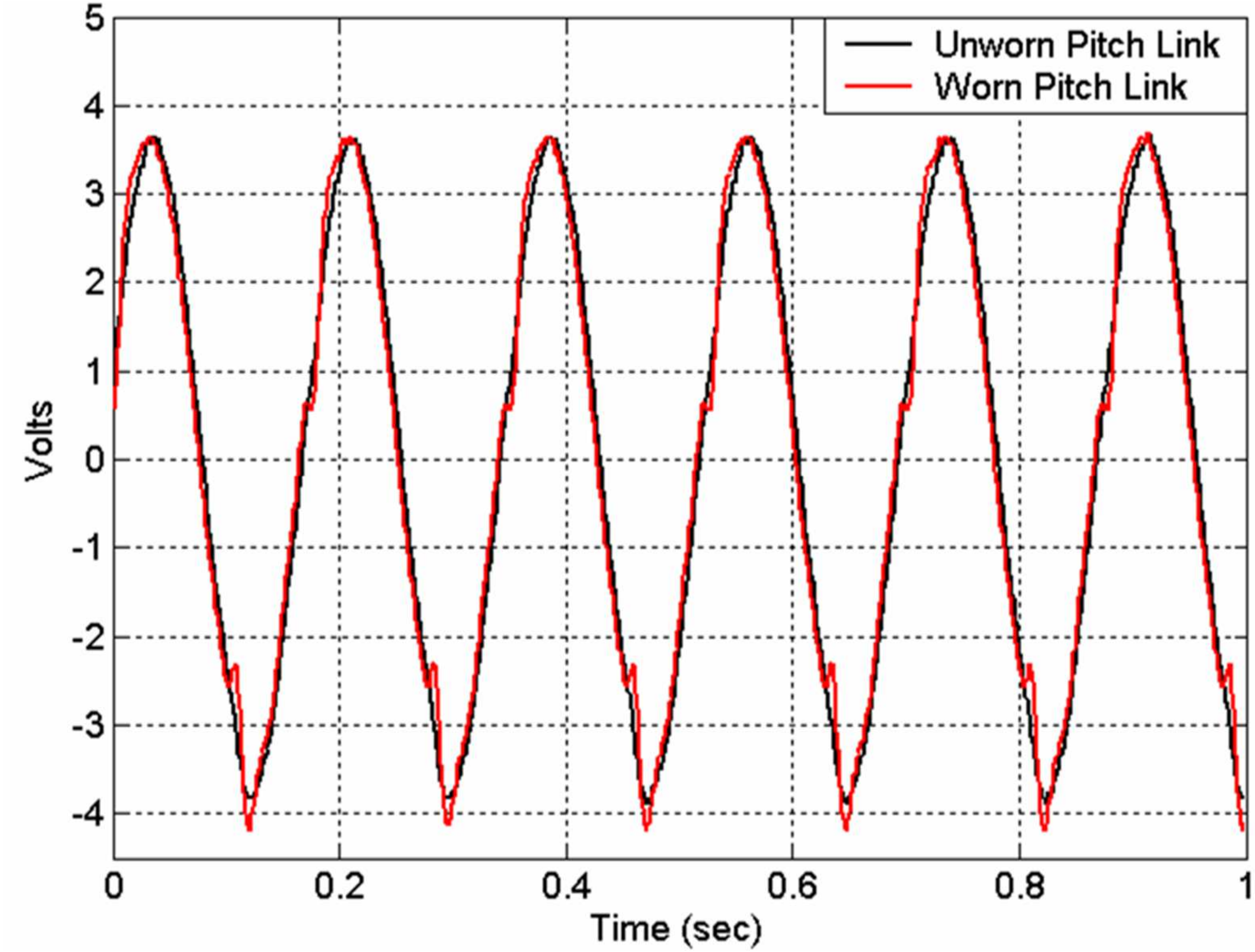
- Time averaging is a common technique to improve signals for feature extraction.
- Time averaging works particularly well for periodic signals with *uncorrelated* signals superimposed.
- The signal is split into ‘slices’ with a period a multiple of the period of the feature of interest.
- These are then averaged together. This reinforces components with periods related to the ‘slices’ and suppresses other components.
- Time averaging is a way of exchanging resolution between domains.

# Time averaging

- Time averaging is used in many engineering disciplines to extract a wanted signal from background noise or other uncorrelated signals– for example receiving radio transmission from spacecraft.

- It requires
  - The signal feature to be periodic,
  - An accurate estimate of the frequency of the signal feature,
  - The unwanted signal features not to have a frequency related to the wanted signal i.e. it would not distinguish between multiple pitch links (we would use other techniques for this!)

# Worn pitch link time domain signals

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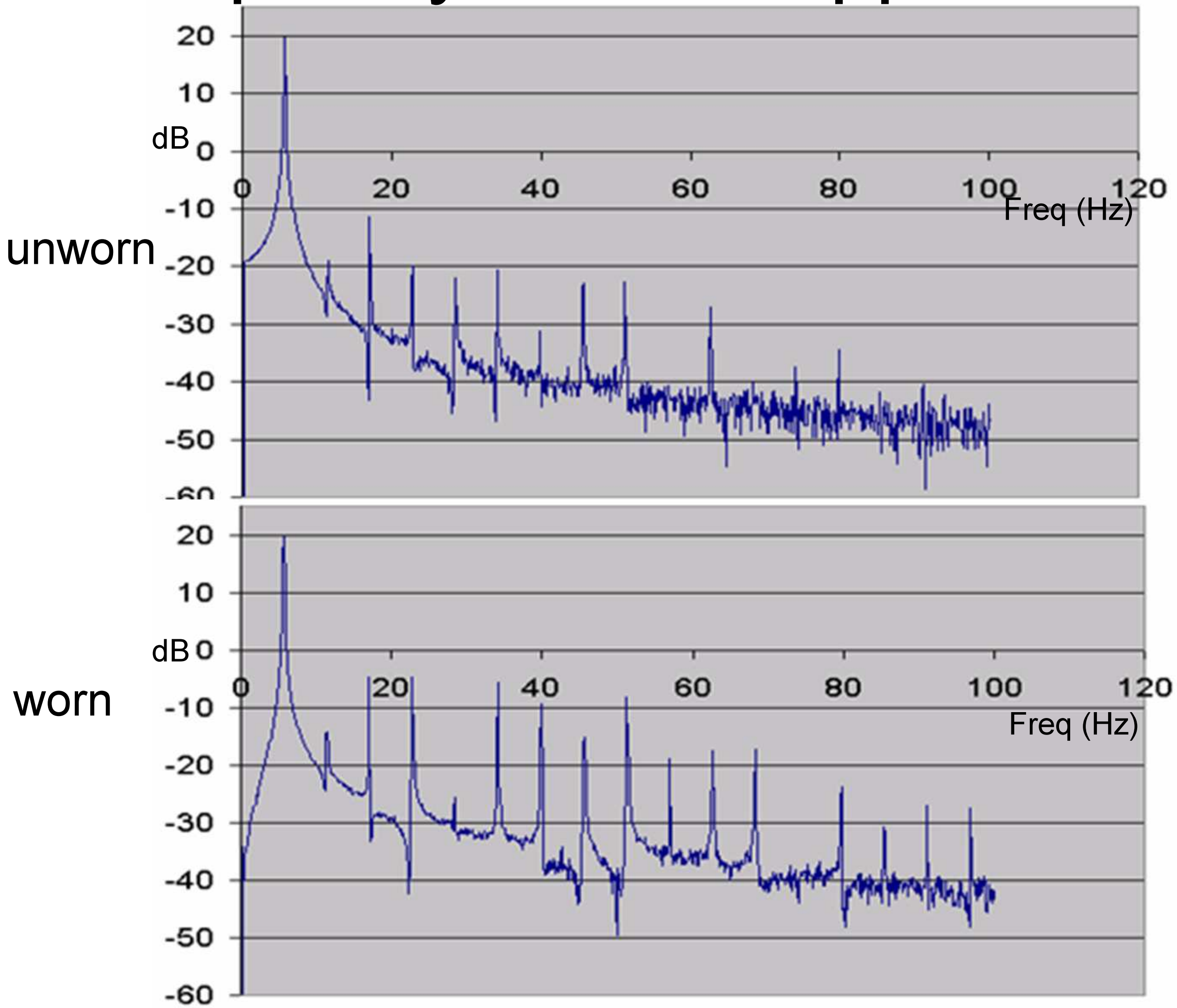
# Frequency domain approaches




In the frequency domain the changes in the time domain appear as an increase in the magnitude of higher harmonics.

So one approach to detect wear is to look at the magnitude of these harmonics, or more reliably the relative size of the harmonics to the fundamental.

# Sensor Systems

# HUMS – Health and Usage Monitoring Systems