A comparison of Management Approaches for Asset Optimization

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AGENDA

1. Introduction
2. Overview of Asset Management for IGTs
3. Management Approaches
4. Predictive Methods
5. Implications to a Changing Energy Landscape

Condition Based Engineering (CBE)

- We create and deploy digital assets (twins) to support our customers & our business

2012 — **Proof of Concept**
Validation Testing

2014 — **Minimum Viable Product (MVP)**
System Development & Production

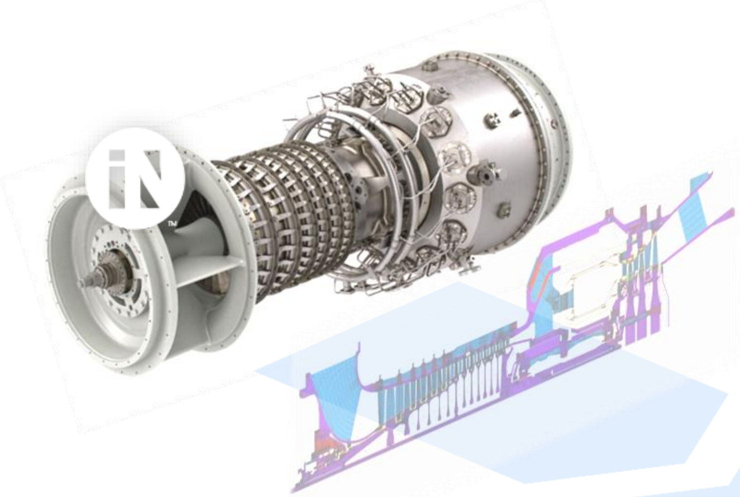
2016 — **Digital Asset Expansion**
for Engineering Applications

2018 — **Technology Integration**
into InSight Platform

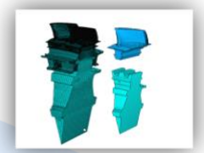
Present

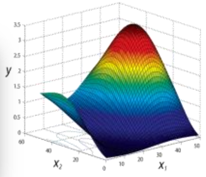
INSIGHT CONNECT

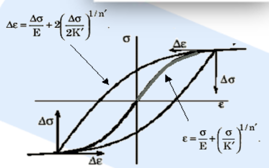
The Digital Asset (Twin)



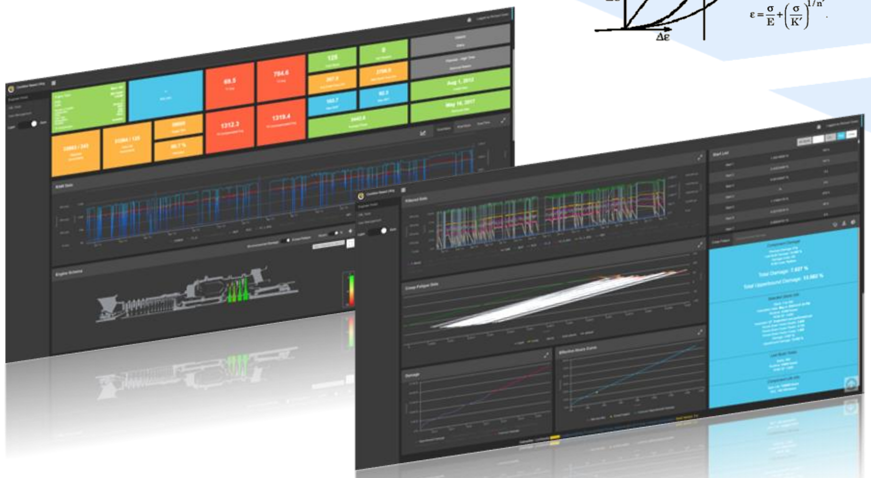
- The **Digital Asset** simulate the behavior of the physical asset operating at the customer site using **InSight data**

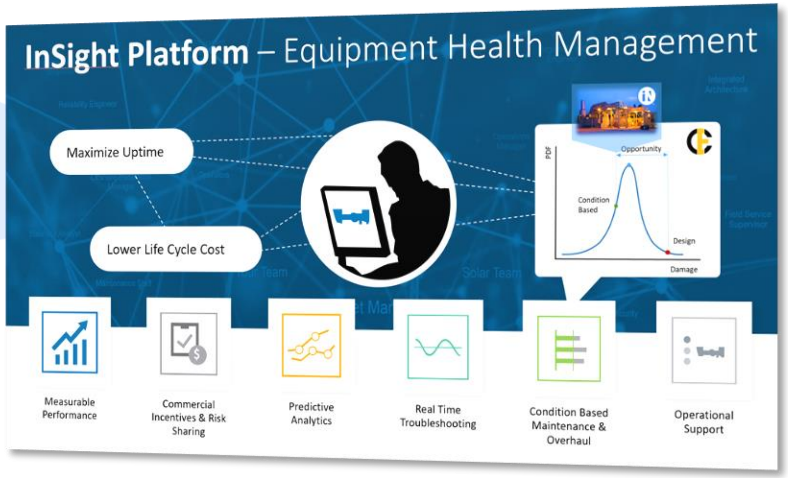






- Blends **Data Analytics** & **Physics Based Models** with **Machine data** to predict key aspects of the machine, such as **Durability**
- Predicts actual **Remaining Useful Life** (RUL) of key components to support **Equipment Health Management** (EHM)





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Overview of Asset Management for IGTs

Overview of Asset Management for IGTs

- Key performance indicators (KPIs) for managing Industrial Gas Turbines is principally based on:

Performance
- Controlled by fuel flow
- Degradation or Loss in performance immediately observable (for connected unit)
- Identifiable by fuel consumption or other sensors

Emissions
- Controlled by performance & durability
- Degradation or Loss in emissions can be measured instantaneously
- Typically identified by in situ emissions monitoring

Durability
- Controlled by performance (operation)
- Degradation or Loss in durability is difficult to observe and can be long term
- Degradation is based on inspection or prediction

Overview of Asset Management for IGTs

- **Performance** & **Emission**s can be determined instantaneously
  - Degradation are not necessarily diagnosed immediately
  - Performance loss can be observed through fuel consumption
  - Emissions can be measured and monitored
  - Both are quantifiable

- **Durability**, however, requires different considerations
  - Parts may appear in good condition up until failure
  - Once physical distress is observed, the part maybe on the path to failure
  - Physical inspection is not always capable of quantifying remaining useful life

Overview of Asset Management for IGTs

- Durability management can be sub categorized into 3 tiers

Tier 3 - Scheduled Maintenance

- A consistent replacement / service schedule based on predetermined criteria (usually OEM design)

  i.e. Does not account for site specific conditions

Tier 2 – Inspection Based Maintenance

A replacement / service schedule based on the observable condition of a part / system and is qualitative in nature

i.e. Including, but not limited to, data analytics and physical inspection

Tier 1 – Condition Based Maintenance

A replacement / service schedule based on the operational conditions of the parts / systems and is quantitative in nature

i.e. Condition Based Life (CBL) prediction

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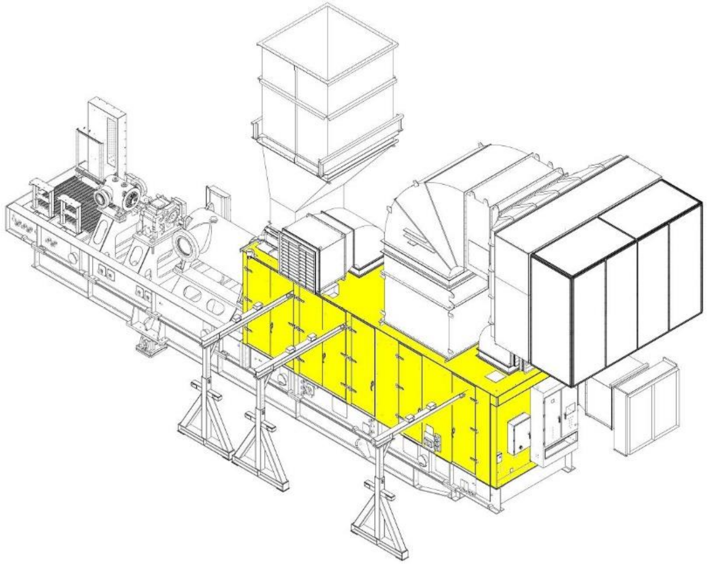
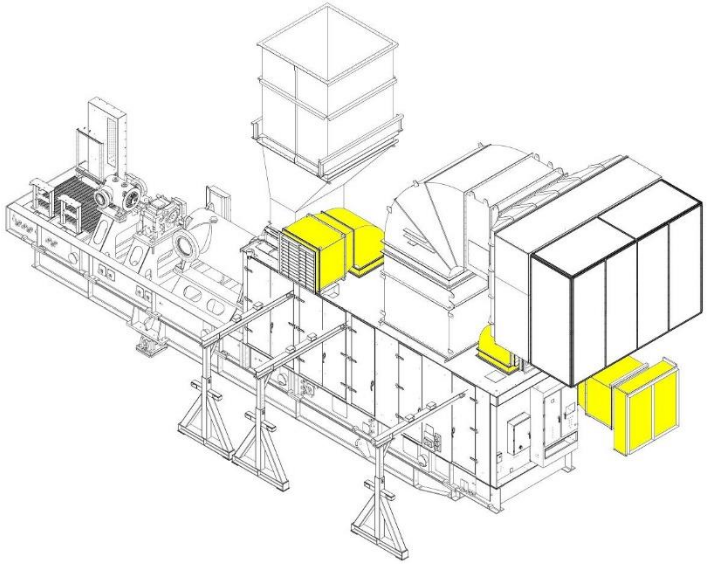
Management Approaches

Management Approaches

- **Scheduled Maintenance**
  - Best suited to applications with low complexity and high impact
  - Risk versus reward balance is unfavorable for a condition based approach
    - Package Hose Replacement Example:

      A package hose is relatively accessible, and the complexity of the failure mode is relatively low, (simple degradation model), however the impact of failure could be severe, (Unplanned downtime) therefore, this would not warrant a condition based approach to maintenance, the balance of risk is unjustified in this case



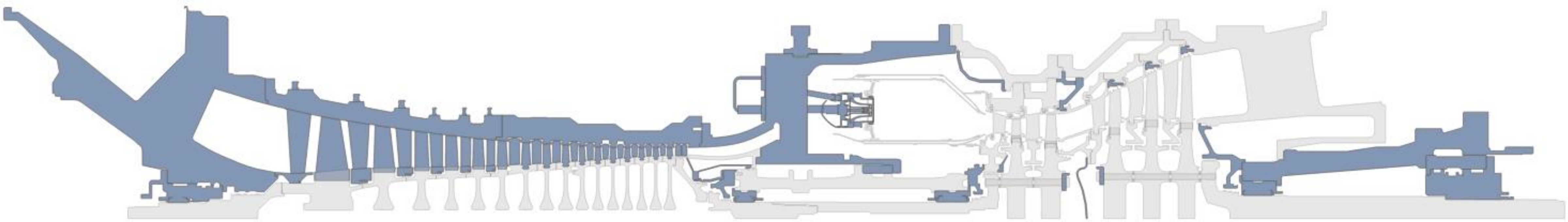


Management Approaches

- **Inspection Based Maintenance**
  - Best suited to applications with low complexity and low impact, or unpredictable applications
  - Risk versus reward balance is favorable for a condition based approach, (Including unpredictable events)
    - Foreign Object Damage (FOD) Monitoring of a Compressor Blade Example

      Monitoring impact of FOD in a compressor blade, which may increase the risk of HCF, but is unpredictable supporting an inspection based approach
    - Bearing Vibration Example

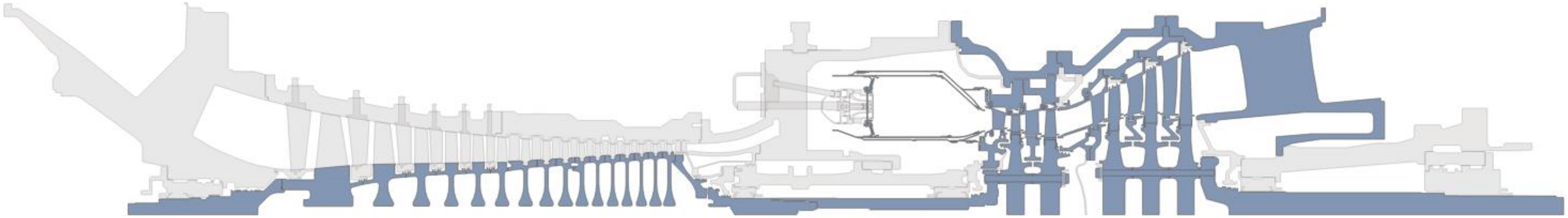
      Monitoring bearing vibrations and trending responses over time to search for signatures which are indicative of known issues, supporting a data analytics approach



Management Approaches

- **Condition Based Maintenance**
  - Best suited to applications with high complexity and high impact
  - Risk versus reward balance is favorable for a condition based approach, (predictable events)
    - Predicting the Remaining Useful Life (RUL) of a Turbine Disk

      Calculating the (RUL) of a nickel based supper alloy turbine disk which is subjected to creep –fatigue interaction, supporting a physics based approach which providing high degree of accuracy and a quantitative prediction for a critical component which is difficult to inspect



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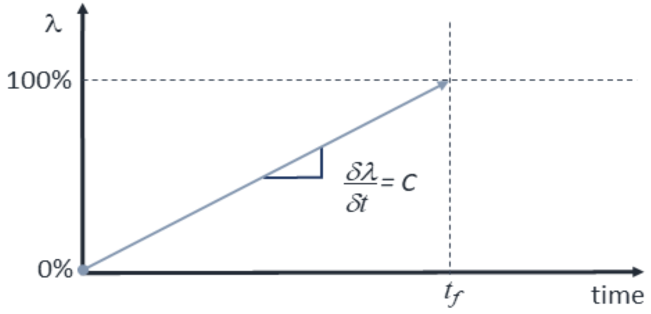
Prediction Methods

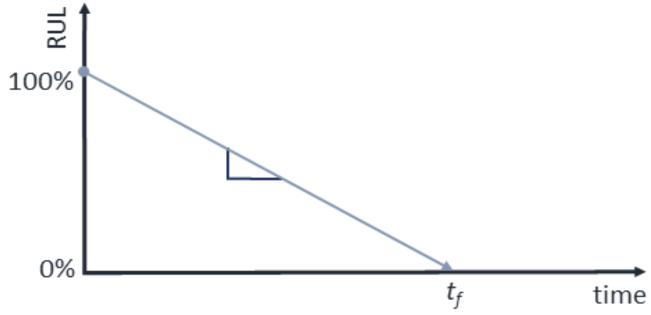
Prediction Methods

- **Time Based Lifing (TBL)**
  - Scheduled Maintenance is typically based on the TBL prediction and is the traditional approach to managing the remaining useful life (RUL) of key components
  - Based on hours of operation, regardless of condition
  - The life of a components is a ratio of operating hours against allowable hours
  - The allowable hours is determined from experience and operational assumptions, usually applied during design
  - Damage accumulation (λ) over time (t) is constant (C)

  - **Advantages**
    - Simple and robust
    - The constant linear damage increment is easy to interpret and apply
    - Scalable across fleets (every engine is managed the same way)

  - **Disadvantages**
    - Typically, conservative assuming worst case scenario
    - Qualitative, requires experience to deviate from baseline
    - Does not account for changes in operation
    - Does not support full optimization of the asset



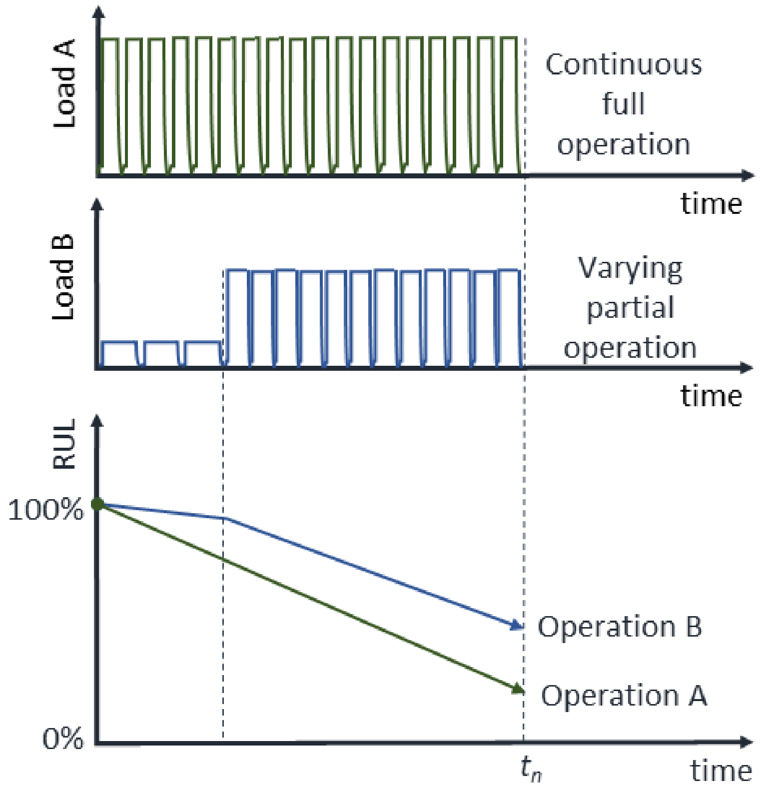


Prediction Methods

- **Equivalent Operating Hours (EOH)**
  - The EOH approach can be used to support Condition Based Maintenance
  - A method of accounting for changes in operation through the application of a predetermined factor
  - Similar application as the TBL Approach for discrete aspects of operation, such as load and starts
  - As in the TBL approach, each discrete event is defined by a constant (linear) damage increment (λ)
  - The damage increments can be accumulated over time, reflecting variations in operation

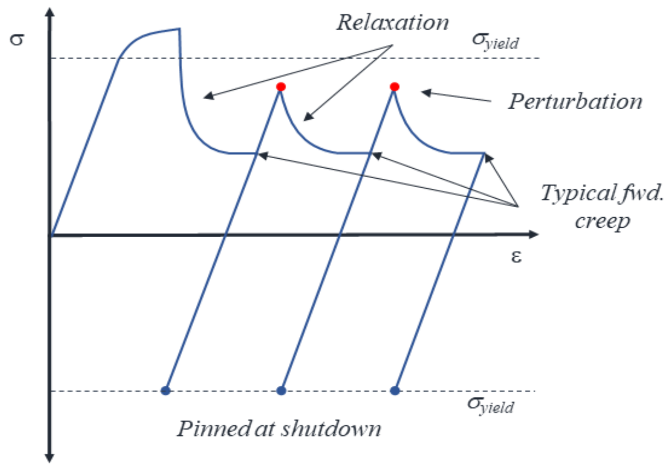
    - i.e. An EOH factor for part load my result in a damage increment of less than 1, therefore, for every hour run at this part load condition, the damage accumulation is lower than at full load condition, resulting in lower equivalent hour factor

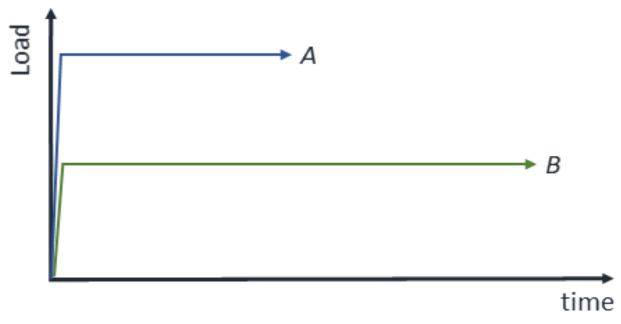
    - As the engine is run in this condition, the equivalent hours approach would support the option of running the engine beyond the recommended service period defined by the TBL approach

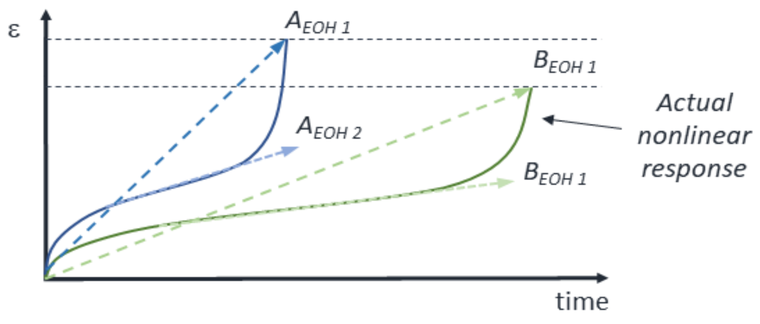


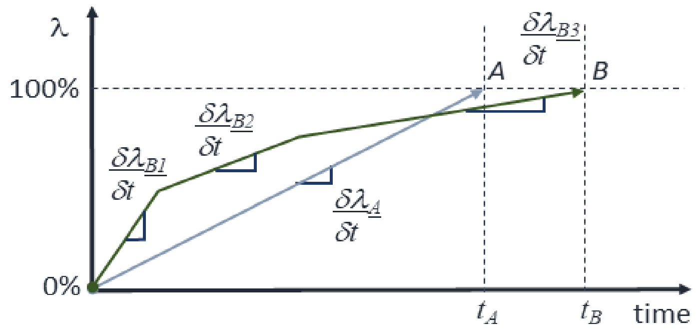
Prediction Methods

- **Equivalent Operating Hours (E0H)**
  - **Advantages**
    - More versatile than the TBL approach
    - Supports asset optimization
    - Depending on operation, the linear damage increment is relatively straight forward to apply
  - **Disadvantages**
    - Does not capture true non linear and path dependent behavior
    - Does not explicitly model interactions between damage mechanisms
    - Conservatism increases with operational complexity
    - Application becomes more challenging with operational complexity



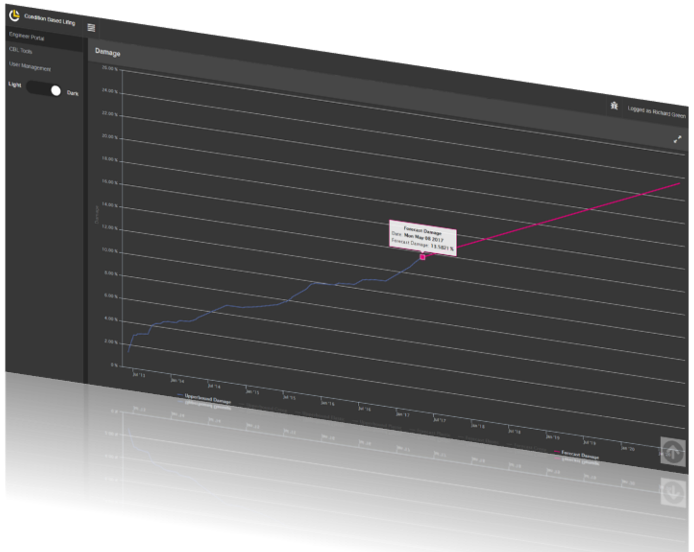




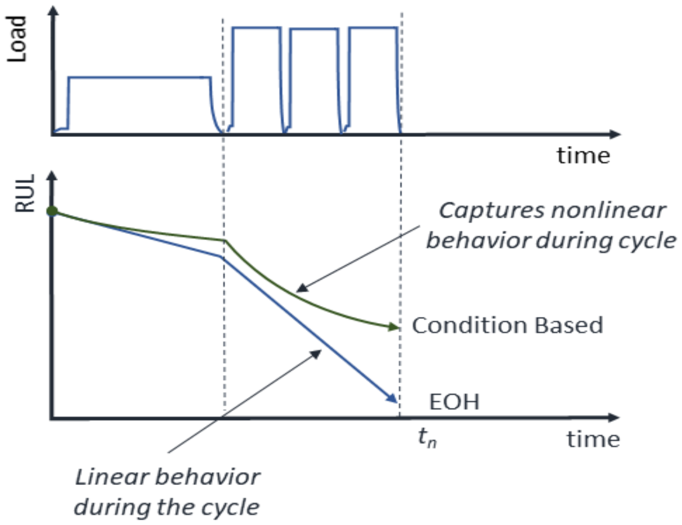


Prediction Methods

- **Condition Based Lifing (CBL)**
  - Condition based lifing is key for a true condition based approach
  - Represents the most comprehensive approach to asset management
  - Based on the operational conditions, calculates damage using machine data from the running unit using a digital twin
  - Damage accumulation (λ) is nonlinear and path dependent
  - The remaining useful life is determined explicitly, supporting forecasting and asset optimization

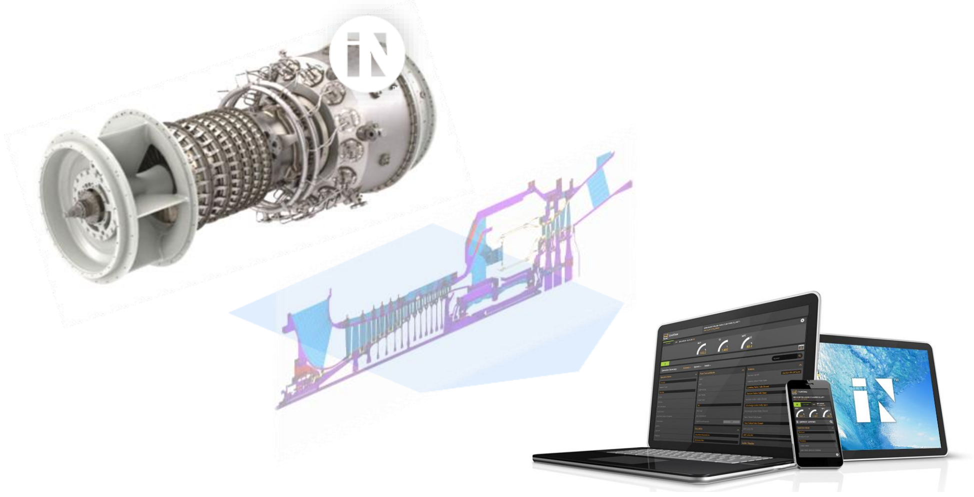


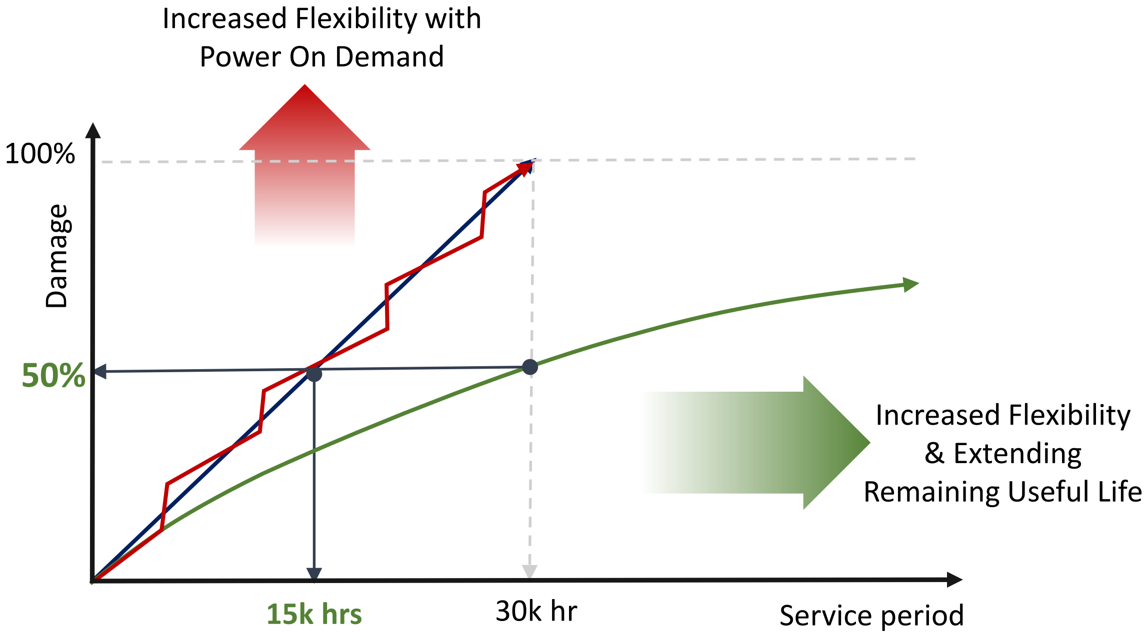
Damage is Non-Linear & Path Dependent



Prediction Methods

- **Condition Based Lifing (CBL)**
  - **Advantages**
    - The most versatile and accurate approach to modeling damage accumulation
    - Supports complex operation
    - Damage / RUL is quantitative and supports forecasting
    - Supports full optimization
    - Explicit modeling of Interactions between damage mechanisms
    - Digital twin supports application
  - **Disadvantages**
    - Complex and requires significant investment to establish
    - Requires an equipment health management system to support data collection and processing
    - Requires digital twin for computational efficiency, scalability and application

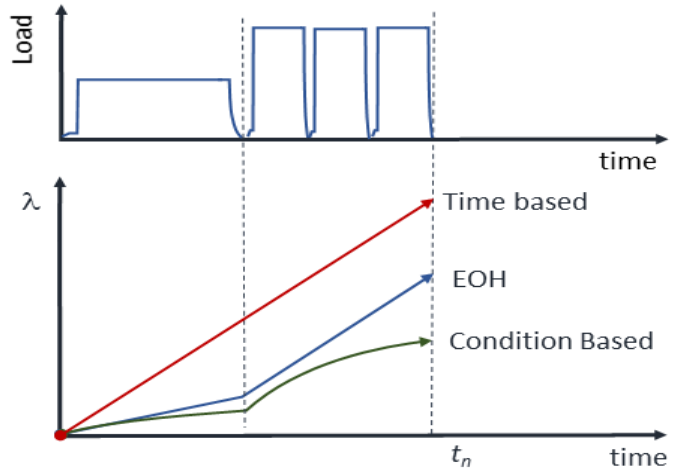


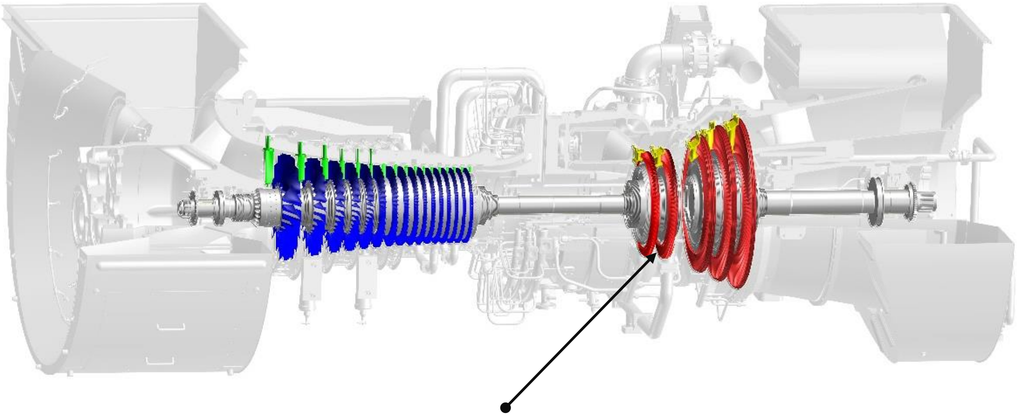


Prediction Methods

- **Summary**
  - All 3 methods provide both advantages and disadvantages and should be applied based on the desired level of risk management
  - Generally, the more accurate and representative the method, the more complex the requirements
  - Optimization targets are key to understanding which approach to employ

- Comparing the Time Based and Condition Based Approaches
  - Turbine Disk Example for Industrial Applications

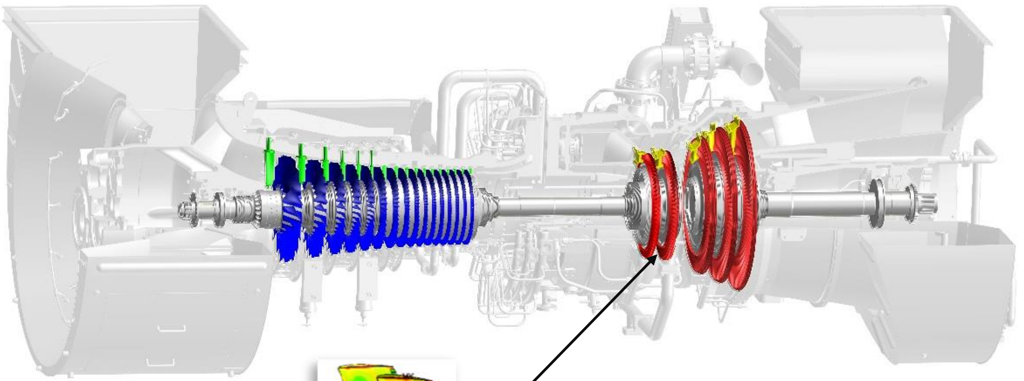


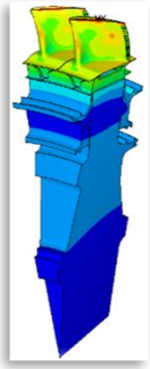


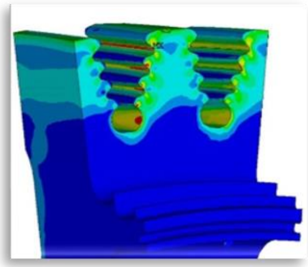
2nd Stage Gas Producer (GP) Turbine Disk

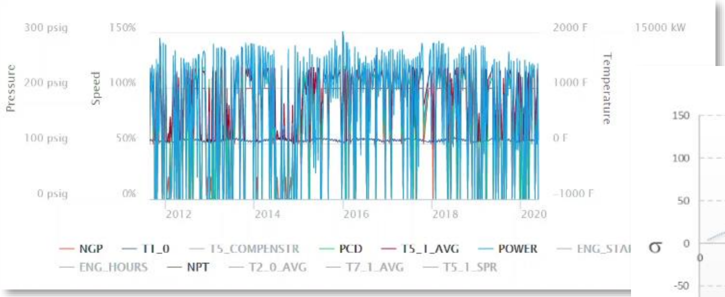
Management Approaches

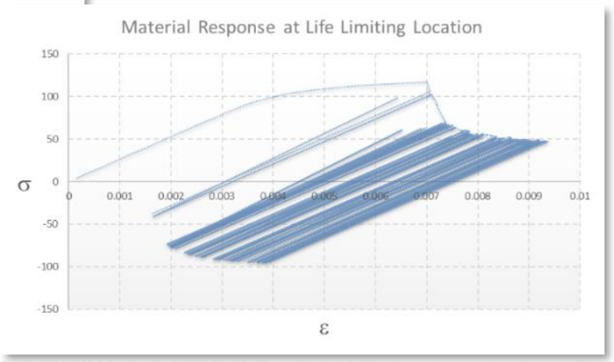
- Turbine Disk Example for Time & Condition Based Approach
  - The Time Based Lifing (TBL) method:
    - A structural integrity assessment is conducted for a range of typical operational duty cycles representing the most severe operation
    - The typical damage mechanisms are creep and fatigue
    - The results would be used directly to set a recommended service period for all engines, i.e. 30k hours
  - The Condition Based Lifing (CBL) method (Patent US 9.200,984 B2) :
    - The results from the above analysis would be used to train physics based surrogate models to support a digital twin
    - The digital twin uses the surrogate models along with engine data generating an engine specific response
    - The results are used to determine component level life predictions and including any creep-fatigue interactions





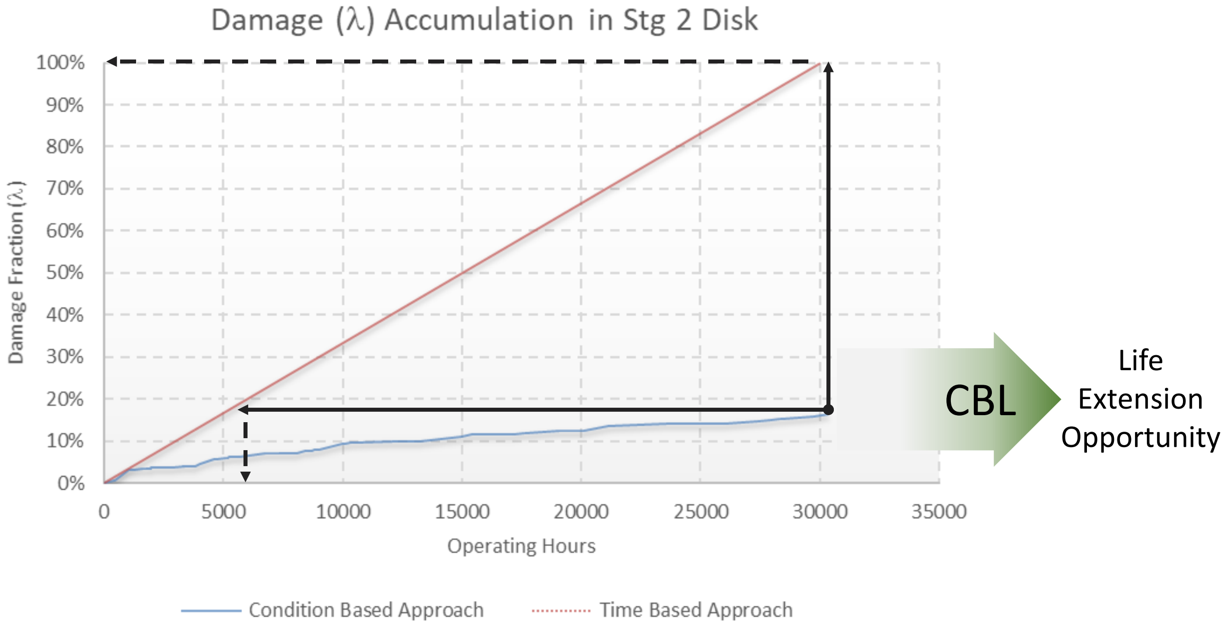






Management Approaches

- Turbine Disk Example for Time & Condition Based Approach
  - The two approaches can generate significant differences in the damage accumulation over time
  - The CBL approach takes advantage of the actual engine's operation, include part load, resulting in significantly lower damage over the same service period
  - The CBL approach is also nonlinear and path dependent capturing any potential creep fatigue interactions that may occur
  - The advantage of this approach is clear, when considering life extension or quantifying the risks of changing future operation



TBL = 100% Damage (λ) / 0% RUL at 30k hours
CBL = 18% Damage (λ) / 82% RUL at 30K hours

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Implications to a Changing Energy Landscape

Implications to a Changing Energy Landscape

- All 3 methods provide options to manage equipment with respect to risk management and asset optimization
- The importance of a CBL approach and the digital twin
  - Provides a path to complete asset optimization
  - Allows owner operators to manage their equipment with increased confidence and maximum flexibility
- The application of a digital twin is a Key element to supporting IGTs in an evolving energy market,
  - Integration with renewables, e.g. Grid code
  - CO_2 reduction by minimizing spinning reserve
  - CAPEX & OPEX reduction through right sizing equipment
  - Life extension and service optimization
- Given the critically of IGTs, should we consider an international standard for digital twins to ensure consistency and confidence for the future of asset management?

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