Panel Session 4: PHM for Space Applications

Tuesday, 24 Sept 2019
3:15 – 4:45 PM

Session Chairs:

Derek DeVries *(NGIS)*

Andy Hess *(The Hess PHM Group)*

Panelists:
Derek R. DeVries *(NGIS)*
Terry Haws *(NGIS)*
James A. Larkin *(Aerojet Rocketdyne)*
Mark Walker *(D2K Technologies)*

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Panel Session 4: PHM for Space Applications

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Description: The planned use of manned and long term crewed space platforms, as well as quick to launch and reusable space vehicles, is increasing on a very accelerating rate. After the legacy NASA developed Space Shuttle and LEO ISS; among many things, there are near term NASA plans for: a lunar Gateway station, a permanent lunar base, asteroid present, and Mars bases. Vehicles and platforms to accomplish these far reaching goals will include: crewed space and surface based stations and habitats; various types of launch, long range transportation, and orbit to surface vehicles; and all kinds of support subsystems and technologies. Beside NASA and other government directed organizations; commercial based entities are aggressively developing systems to achieve these same and additional space related goals. These associated commercial focused applications include space tourist to LEO, space based hotels, and resource mining. This panel will focus on issues and challenges associated with these applications; and how PHM capabilities can be applied to reduce risks, increase efficiencies, and ensure resilient sustainment of these vehicles, platforms, habitats, and systems.

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PHM for Space Applications

24 Sept 2019

Derek R. DeVries, P.E.
Senior Fellow, NGIS

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PHM for Space or Aerospace Applications

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- Why PHM for space applications?
- What have we learned about PHM of Systems?
- What systems need to have PHM in Space Applications?
- How can the PHM society support the future needs of Space System's Commercial and Government Applications?

Why PHM?

- Prognostic health management (PHM) systems are required when a system or component is known or suspected to change behavior with time and the risk of an inaccurate prediction of future behavior is not acceptable
  - Safety, Reliability, and Cost
- System behavior changes are generally caused by one of the following types of conditions:
  1) **Cumulative Physical Damage** caused by induced loads
  2) **Material Changes** due to chemical aging mechanisms or exposure to environments
  3) **State or Condition Changes** caused by exposure to environments
- PHM is an enabling requirement for implementing systems with robust condition based maintenance plus (CBM+) capability
- **PHM technologies can provide invaluable insight into the performance of a material or product**
- **PHM technologies are comprised of the same technologies used to produce diagnostic/performance Assessments of the current state of the asset(s)**

PHM systems enable CBM+, which has been proven to reduce life cycle cost while ensuring reliable operation for the life of the systems

Prognostic Health Management (PHM)[3]

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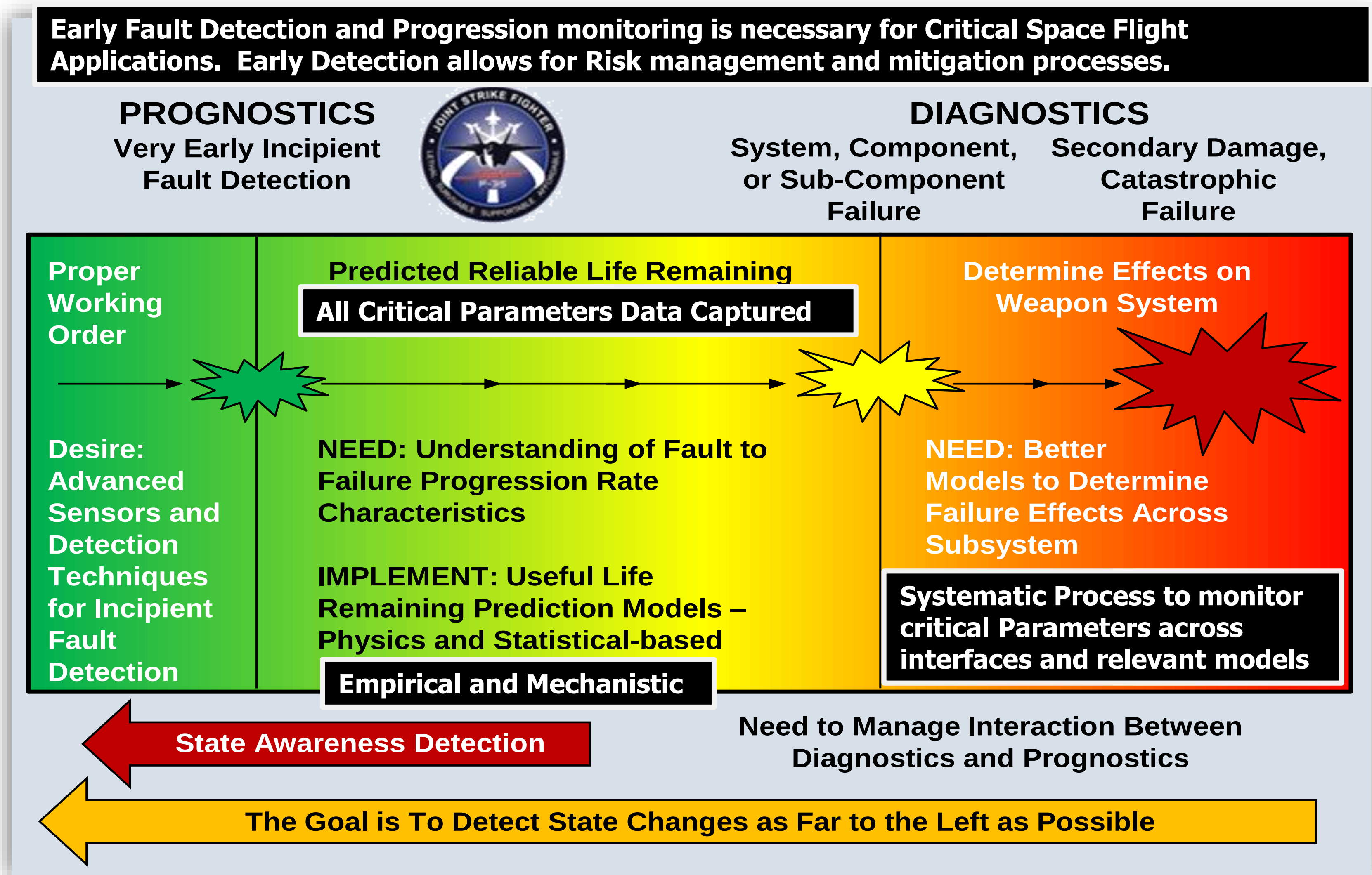

3. *A. Hess, T Dabney, "Joint Strike Fighter PHM Vision," IEEE Aerospace Conference, Big Sky MT, Mar 2004.*

The Space / Aerospace PHM Challenge

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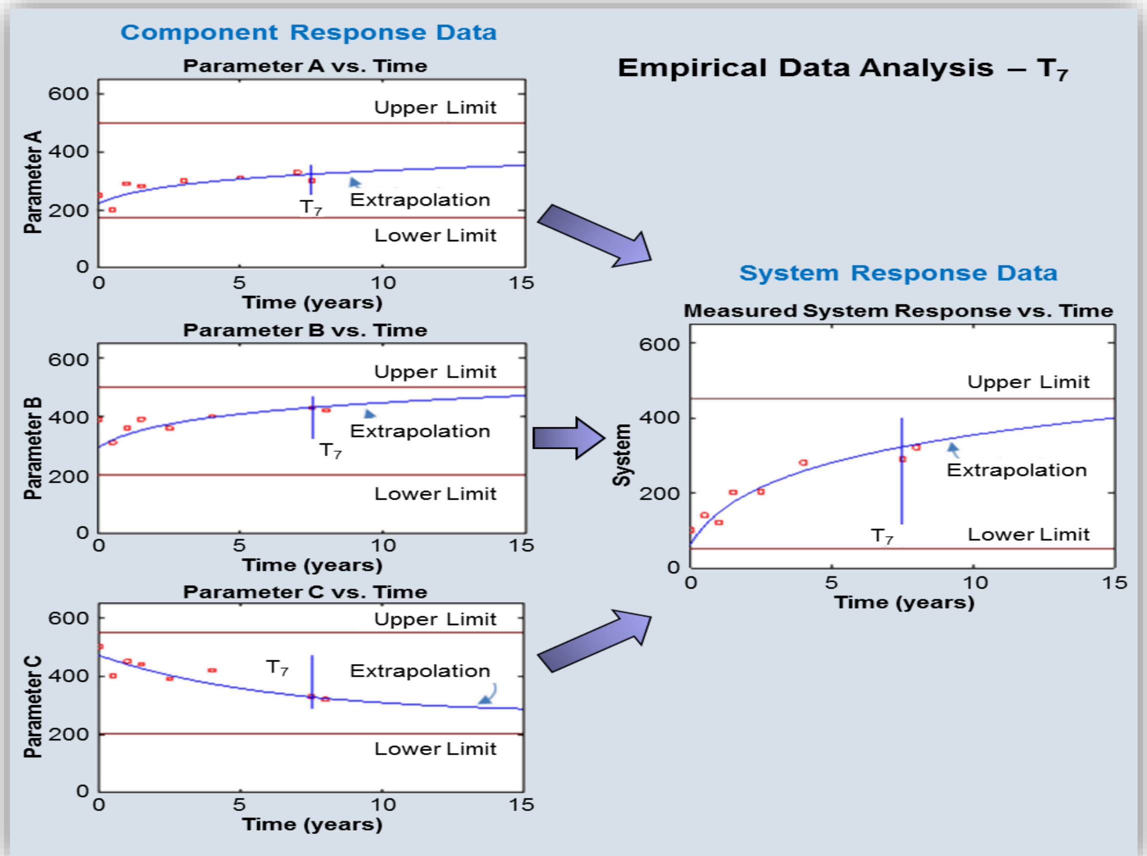
- Trend extrapolations hope past and current propulsion system behavior will predict future propulsion system behavior
  - Often this is not the case
- The fundamental challenge of a propulsion system PHM is to identify bad assets in the inventory and remove/repair them before they can be used or cause harm
  - The current state of solid rocket motor viability prediction is based on using data from motor sets with significant motor-to-motor variability
    - Often the representative data is obtained by a sample of the fielded motor set and/or separate accelerated aging samples of representative motor constituents
  - Perform an empirical extrapolation of key motor properties associated with a sampled motor and apply that prediction to the full set of motors
  - This variability results in large standard deviations, making accurate individual motor prediction difficult and results in conservative service life estimates, which retire systems early

An advanced space PHM system must monitor individual assets and their environments to improve service life predictions and confidence in the asset's current and future state performance assessments

Empirical Performance Analysis Example

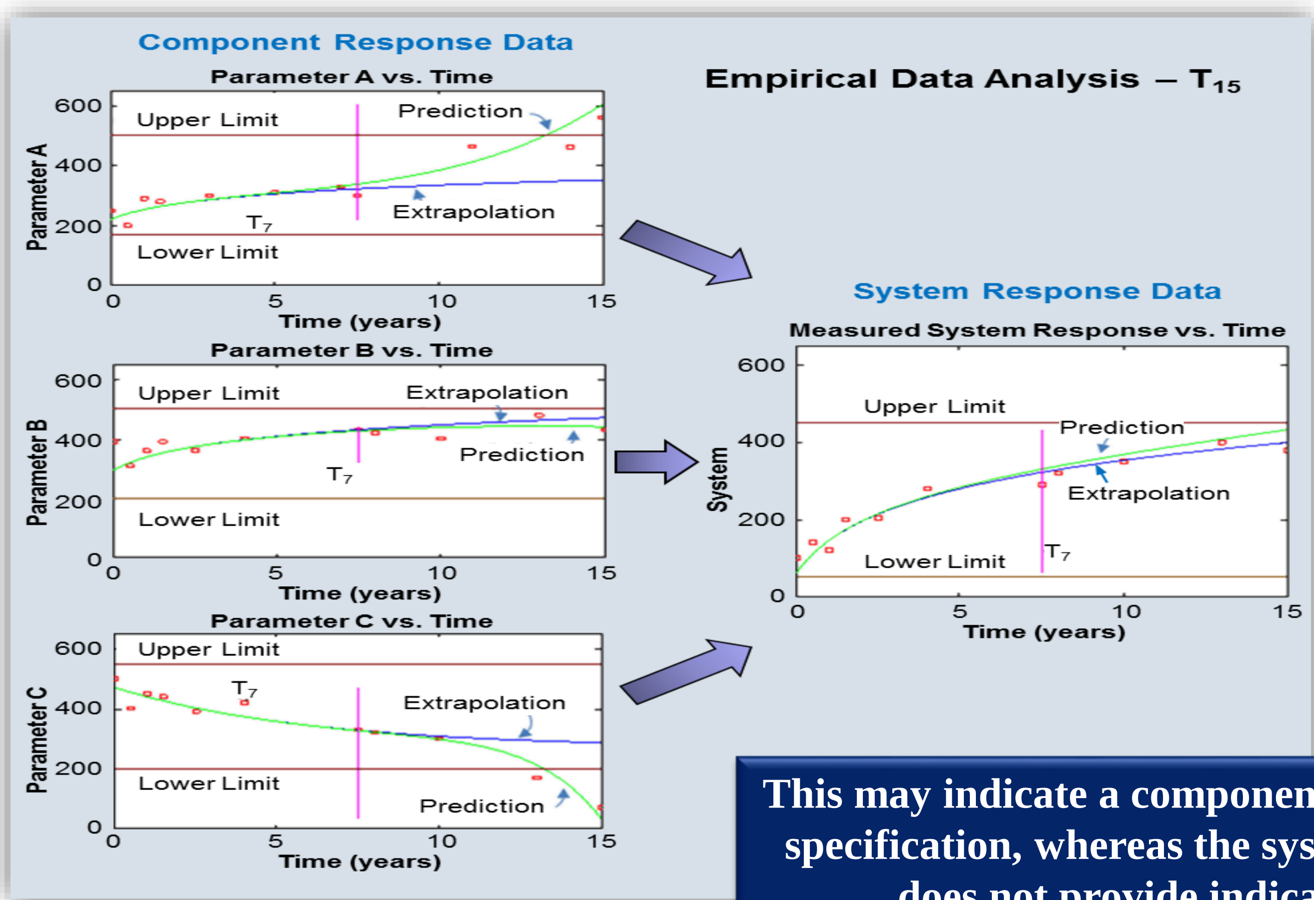
Representation of data from time T0-T7 and an extrapolation of the data out to time T15



An advanced aerospace PHM system must monitor individual assets and their environments to improve service life predictions and confidence in the fleet's reliability assessments

Empirical Performance Analysis Example

The same representation with additional data obtained over time T7-T15 showing prediction lines behaviors changed with respect to the earlier extrapolation



This may indicate a component tolerance is out of specification, whereas the system response data does not provide indication of such

PHM Analysis System Basis

- PHM analysis systems are typically based on either:

  a) Trend extrapolation

  - Defined as "**Empirical Analysis**" approach

  or

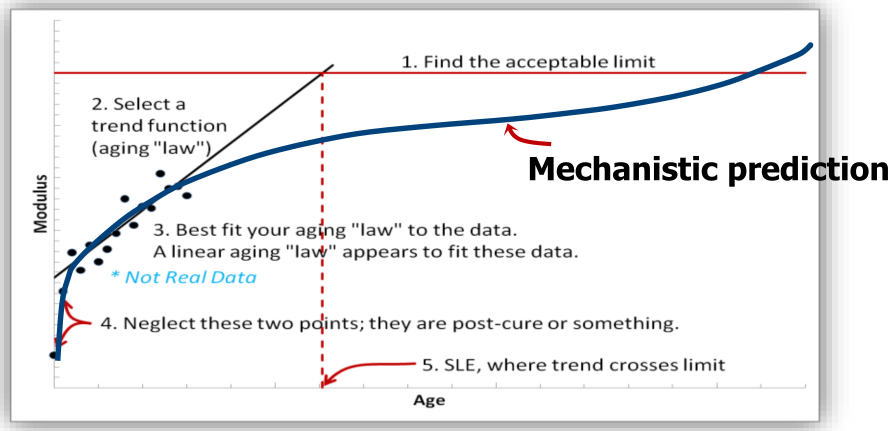
  b) Knowing the fundamental causes of the changes in system behavior

  - Defined as "**Mechanistic Analysis**" approach

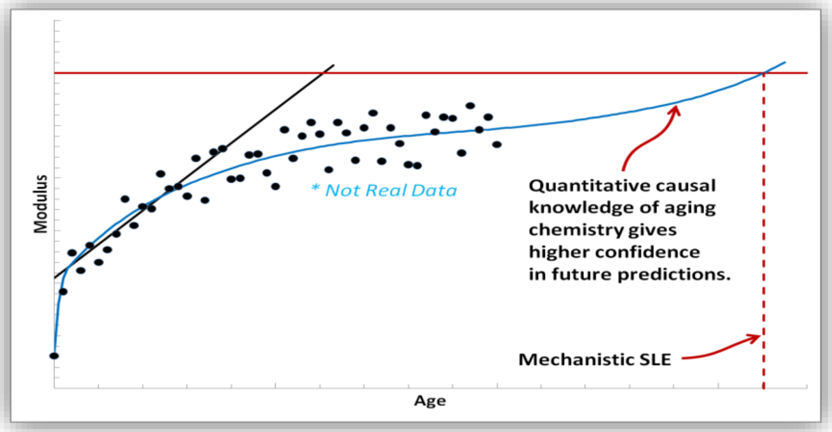
  or

  c) Both

Empirical Approach



Mechanistic Approach



Mechanistic approaches are necessary when a system or component reliability predictions are needed beyond existing empirical data

System Engineering Approach

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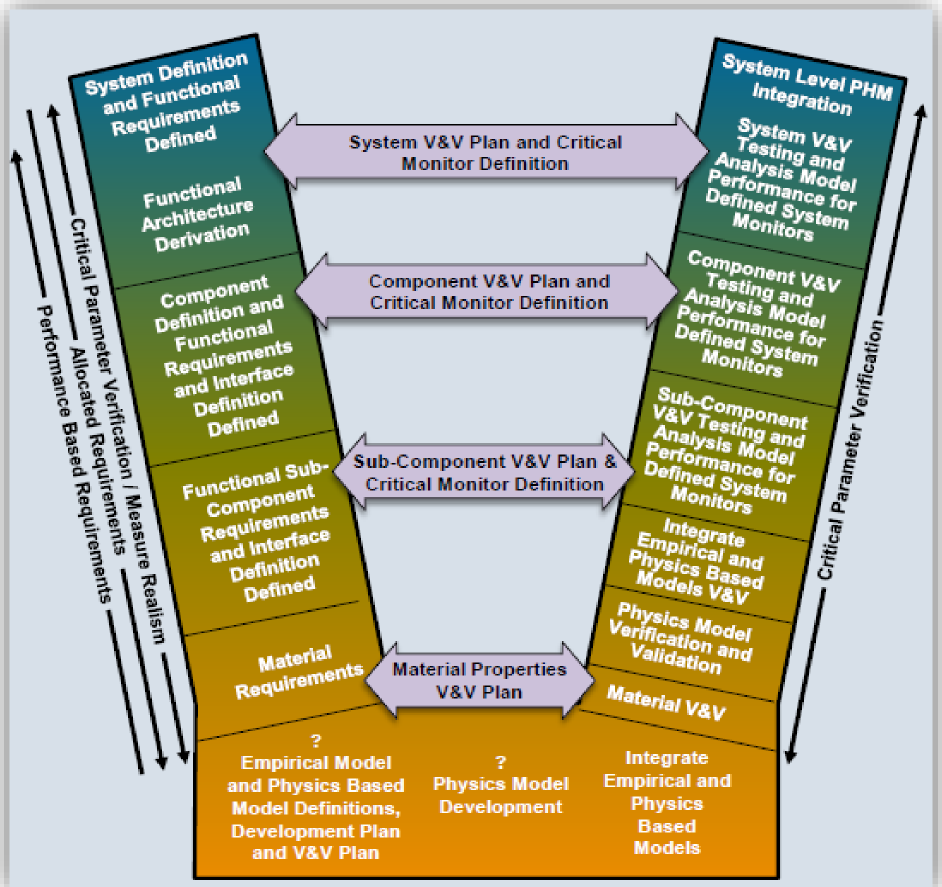

System engineering V diagram showing requirements capture, allocation and verification and validation (V&V) process.[1,2]

[1] Derek R. De Vries, Bryan De Hoff, et.al, *"Systems Engineering approach to IMLM DAAS goal achievement,"* JANNAF 61st JPM, Charleston, SC, May 2014.
[2] *SE Handbook Working Group International Council on Systems Engineering (INCOSE), INCOSE Systems Engineering Handbook v. 3.2.2, Oct 2011.*

System Engineering Approach

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A multidisciplinary, system engineering focused approach to motor diagnostic and prognostic predictions is the only approach that allows for successful development of a PHM system that can monitor critical parameters from the motor system and use these to determine current and future performance information of each critical component of the motor system

Mechanistic Approach to Physics-based Model Determination

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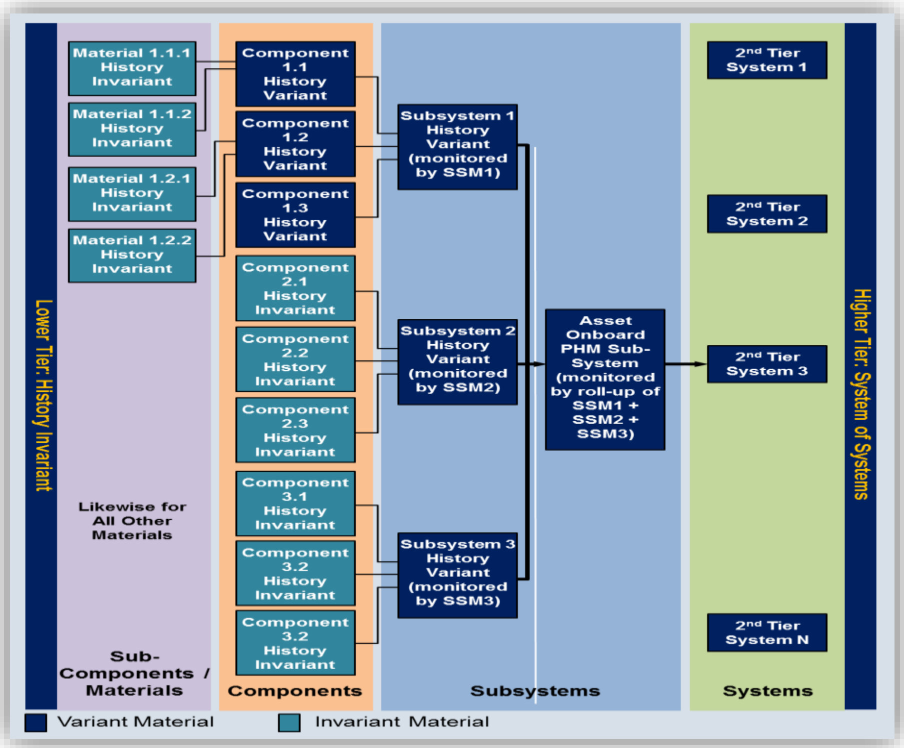
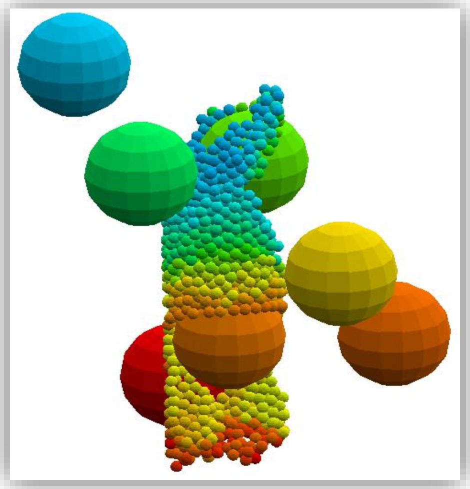
- An asset is usually comprised of various systems, which themselves are comprised of still smaller subsystems and so forth
- History variance implies the system or component changes behavior under the conditions it is used
- If a system's or system's component is history invariant, then its behavior can be measured
- If the system's component is history variant then the behavior must be predicted
- If a model correctly describes the physics of evolution of the asset, then the physics-based model is causal



Physics-based Models

- Mechanistic physics-based models can be categorized into three groups:
  1. The evolution models that describe how the state variables evolve under the influence of the boundary condition history operator
  2. The conversion models that convert from state variables to the properties required by the performance assessment models
  3. The performance assessment models that predict how the asset will operate with a given set of properties



Example:

- Concrete has varying sizes of history invariant particles (sand, gravel, etc.)
- Cement bonding agent, which is history variant, is the cohesion material used to bond the history invariant materials into a new history variant material – concrete
- Generation of a PHM mechanistic model that can reliably predict the final performance of the concrete given any environmental or aging conditions in its life cycle

This provides the ability to predict if a system's capabilities can meet the requirements of the user over its expected useful life

Linear-Elastic Modeling Using Empirically Derived Material Properties

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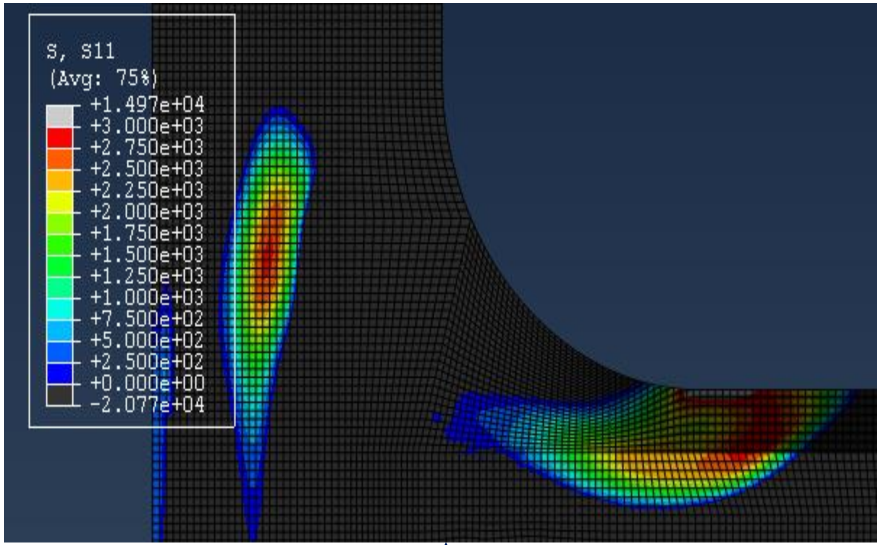
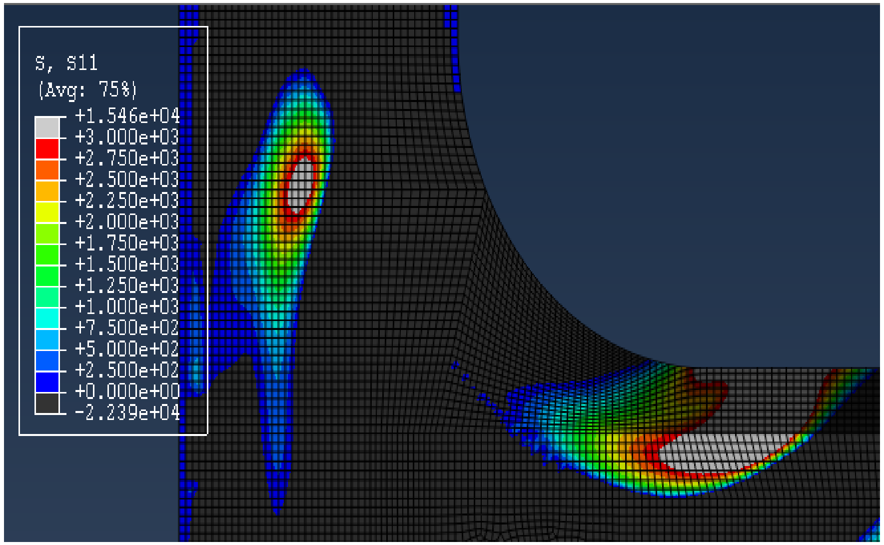
Comparison of Empirically Derived Statistically Nominal vs. Point Derived Material Properties Model Effects

Statistically Nominal Compressive Properties



Point Derived Compressive Properties



This model is more representative of the actual part's performance

Embedded RFID Passive Sensor Application Example

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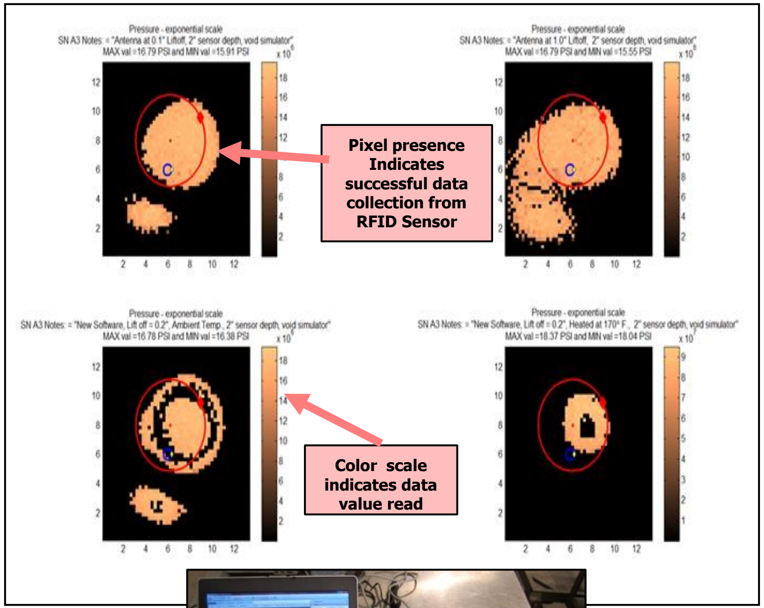
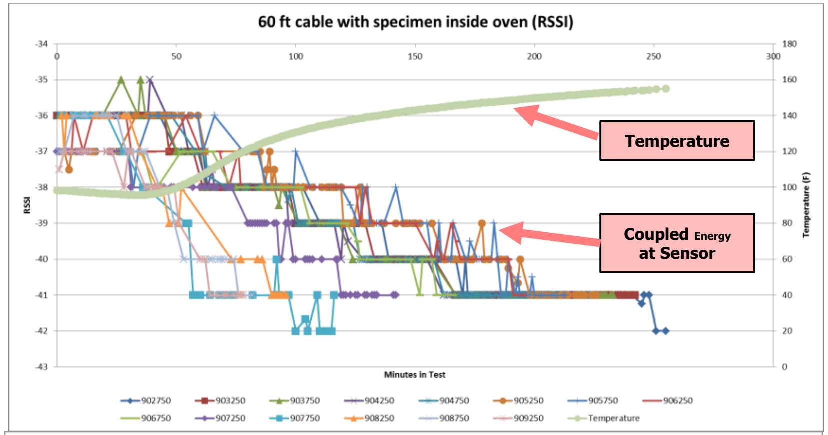
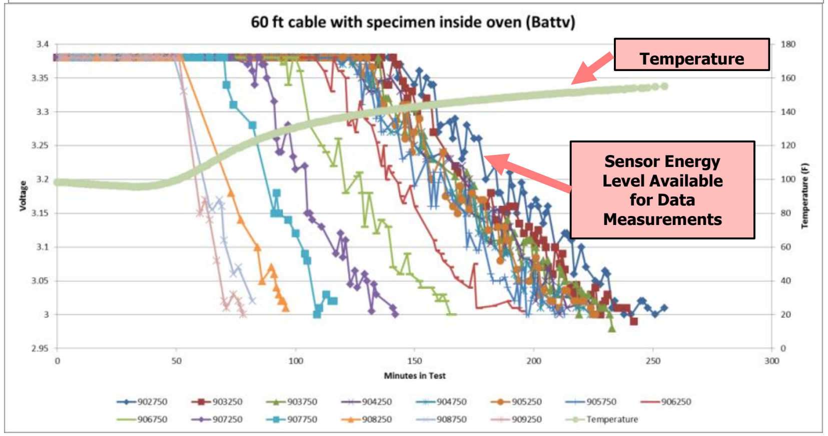
Signal Loss as a Function of Temperature, Location, Distance From Read Antenna to Sensor



Signal Loss as a Function of Temperature and Frequency





Understanding how the sensor is affected by the system and how the system responds to the sensor is critical to an accurate PHM system prediction

What about Space Applications?

- New technologies are going to be needed for space applications
  - New materials, components, and systems
  - New processes for materials Manufacturing, Integrations, and Application
  - Environmental exposures are different
    - Space Environments, controlled environments, launch environments, reentry environments, etc.
  - Long dormant times, cycled uses, single use applications, large operational environments
  - High performance expectations, must be safe, reliable, and cost effective

- Unknowns with implementing an PHM system are best addressed using a Systems Engineering Approach to Development and Integration
  - This Includes Assessing Potential Impacts During all Lifecycle Phases
    - Manufacture, Transportation, Handling, Storage, Deployment, Operation, and Demilitarization.

Systems Engineering's Structured Approach to PHM provides Efficient Methodology for Implementation

Summary

- PHM Capabilities Provide Invaluable Insight into the Performance, Safety, and Operational Constraints of the Weapon Systems and their Components
  - Can Provide Information that can be Used to Reduce Ongoing System Costs
  - Extend Service of Individual Assets and/or Weapon System.
- Commercial Technologies being Development for Automation and Internet of Things (IoT) can Provide Reduced PHM Implementation Costs and more Robust and Flexible IVHM Systems Overall.
  - Downside is that these Technologies often Require Digital Communication that require Defense Systems to Deal with Cyber Security.
  - Cyber Security Risks must be Identified and Mitigated during PHM Implementation.
- Implementation of PHM is inevitable over time as technology advances and the push for affordability throughout the systems life increases.

Systems Engineering's Structured Approach to PHM provides Efficient Methodology for Implementation

Backup

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Culture of Innovation

***"The biggest threat to innovation is internal politics and an organization culture, which doesn't accept failure and/or doesn't accept ideas from outside and/or cannot change"* ***

"Innovation requires cultural change and acceptance of manageable risk. Failure Enables Innovation."* *

*"Embrace **Intelligent failure** [1] as seeds to innovation."* [2]

Source: ***Gartner Financial Services Innovation Survey. July 2016**
****Derek R. DeVries P.E., Senior Fellow Orbital ATK, LinkedIn Dec 2016**
[1] Sim Sitkin, "Learning through failure" strategy of small losses, 1992
[2] Derek R, DeVries, P.E., Senior Fellow NGIS, 2019

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