



Leveraging Digital Clones for Prognostics Health Management

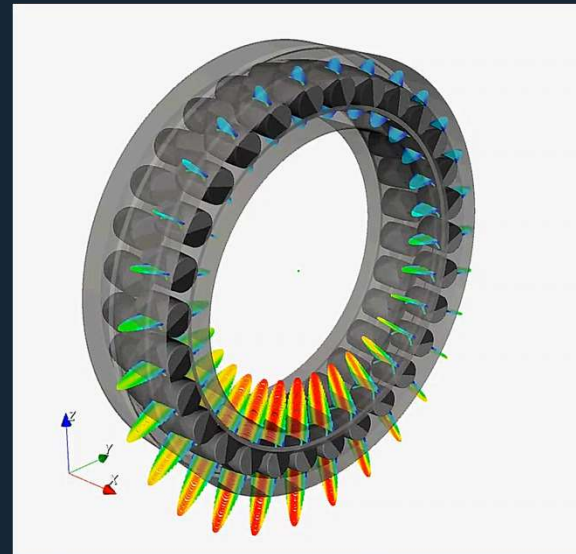
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Introduction

- What is a Digital Clone?
 - Ultra-high fidelity virtual model of a physical asset
 - Based in physical principles
 - Validated



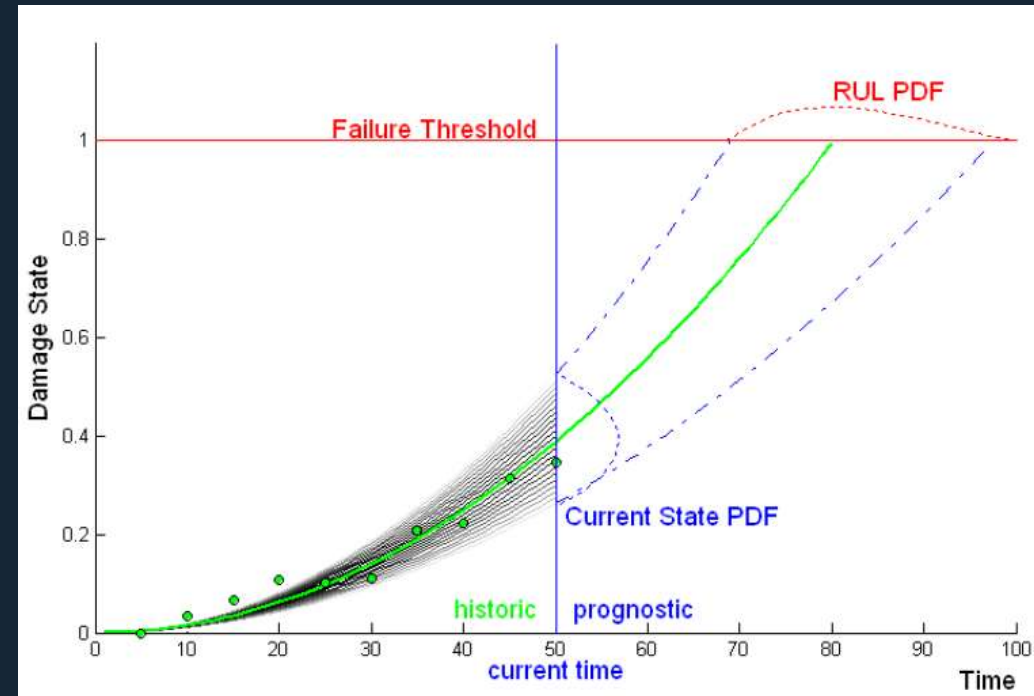
Key Enablers for Leveraging Digital Clones

- Computational power
- Data Storage Capacity
- Connectivity
- Platform Digitalization



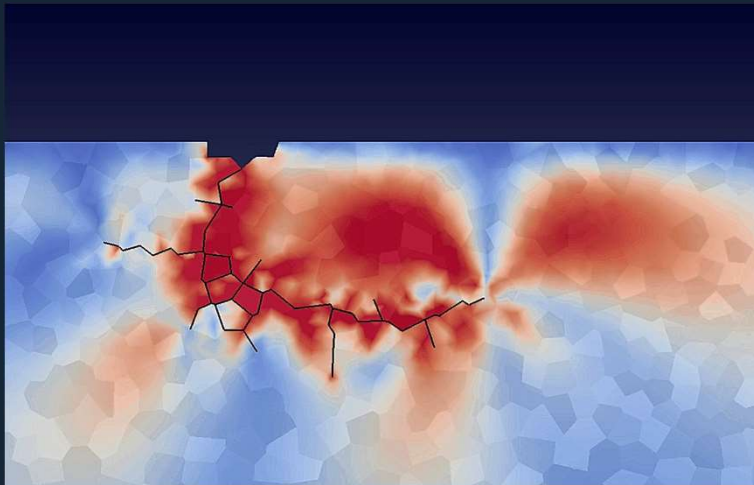
Developing Prognostics Capabilities

- Goal: Predict the future health state of critical assets
- Common Approaches:
 - Empirical / statistical / “AI” models based on historical data
 - Physics-based models
 - Hybrid approach



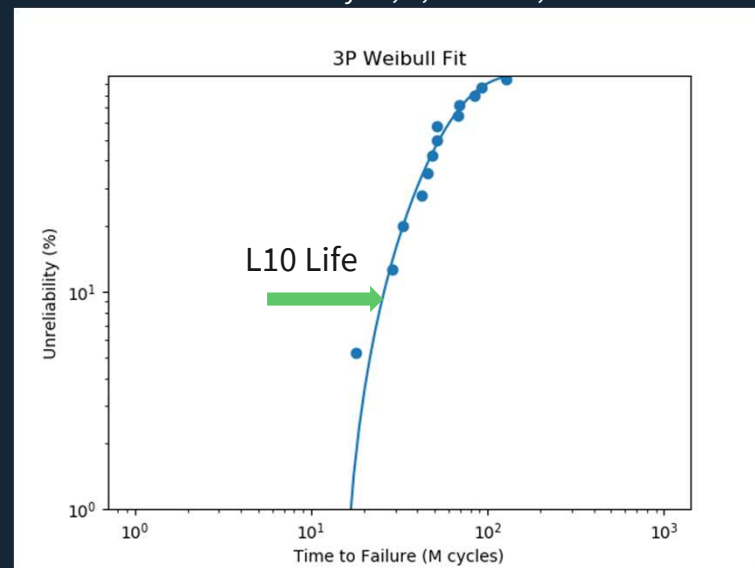
Nature of Component Failure

- Components fail when the material fails
- Material microstructure varies - so does time to failure



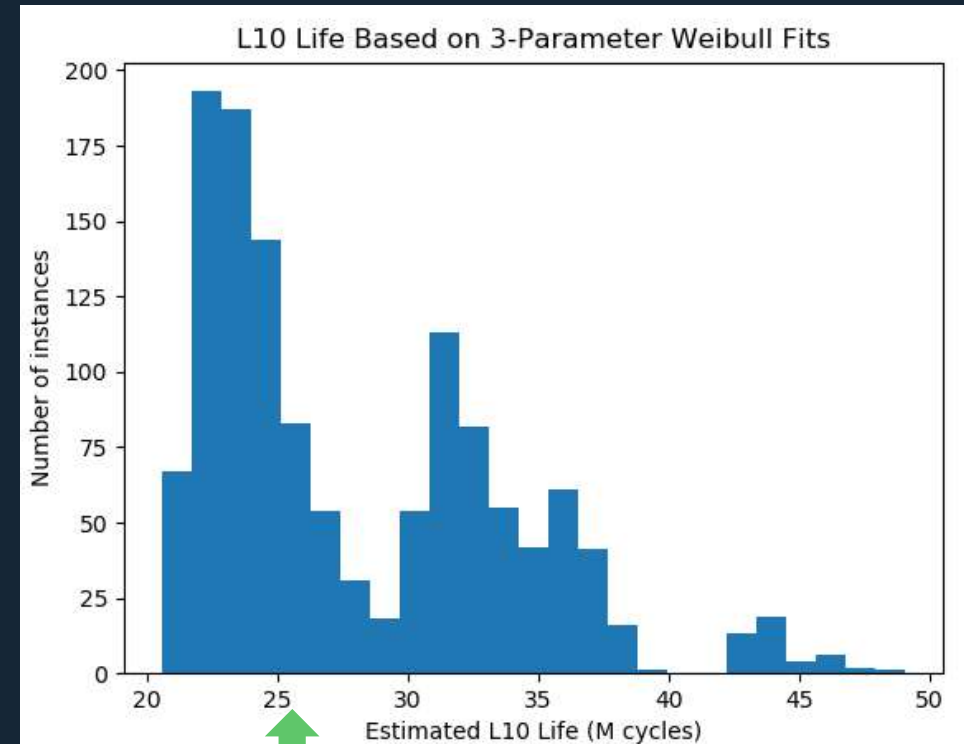
Bearing Failure Data (millions of cycles)	
17.88	28.92
33	42.12
45.6	48.48
51.84	51.96
67.8	68.64
84.12	93.12
127.92	

Caroni, "The Correct "Ball Bearings" Data", Lifetime Data Analysis, 8, 395-399, 2002



The Limitations of Data

- Obtaining 13 data points is optimistic for a test program. Assume we could run 8 tests to estimate life behavior.
- This histogram shows that, depending on which of the 1287 combinations of 8 bearings we might happen to test, the estimated L10 life (for example) can vary dramatically

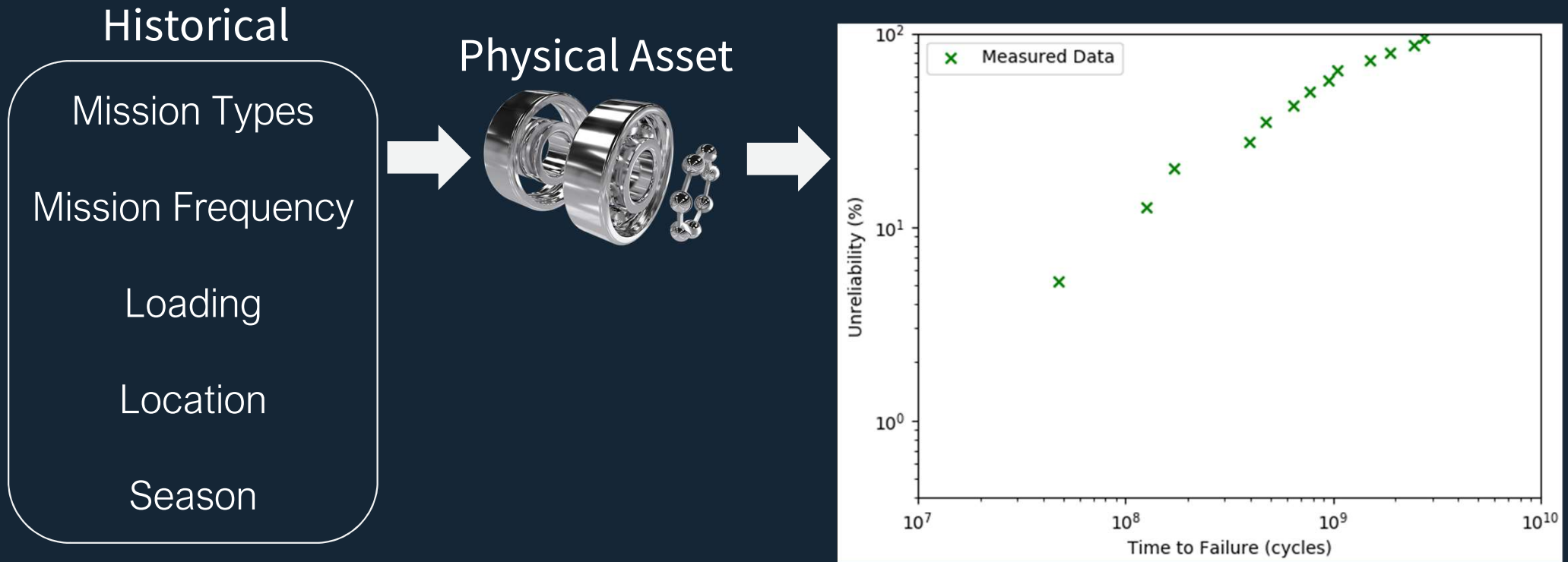


L10 life for full data set

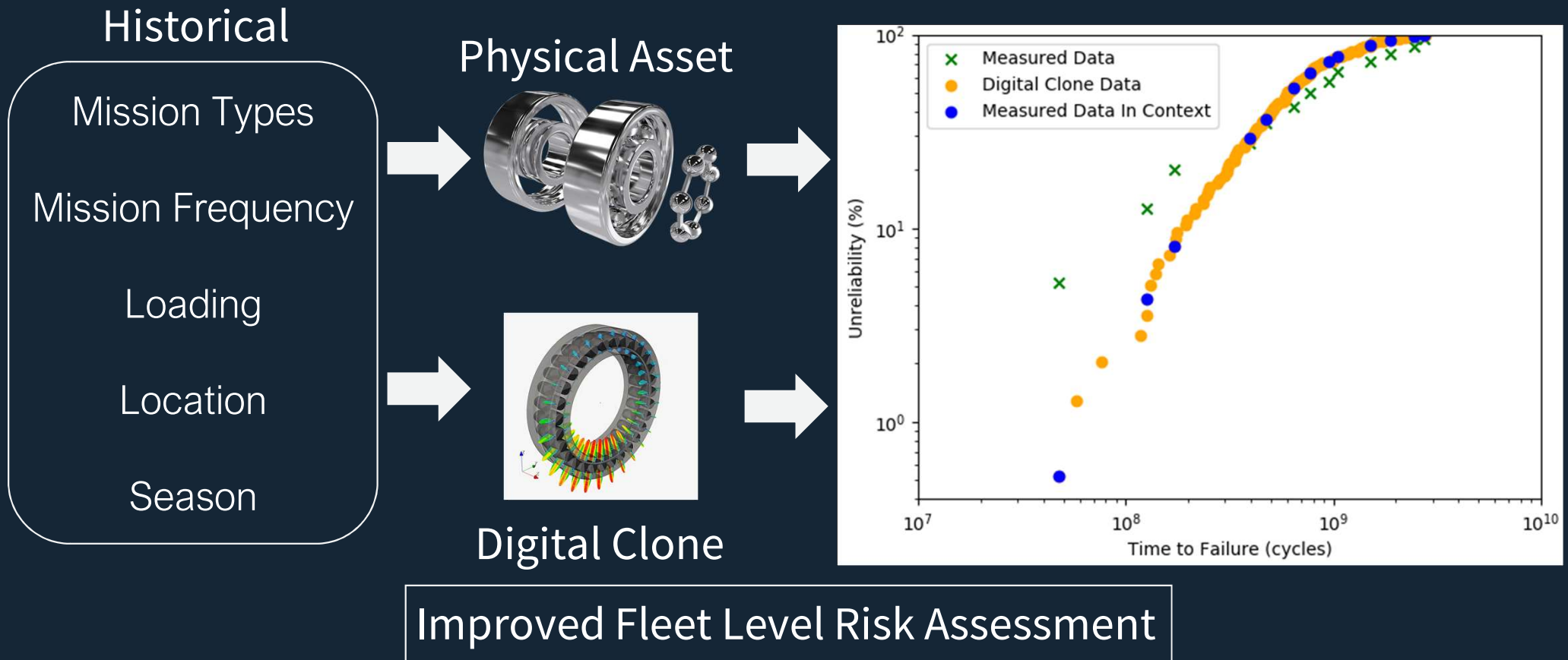
Test and Field Data Provide Limited Insight



Improving Diagnostic Efficacy with Digital Clones



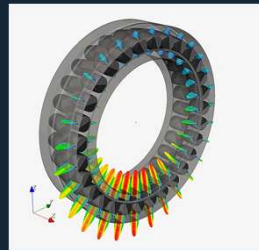
Improving Diagnostic Efficacy with Digital Clones



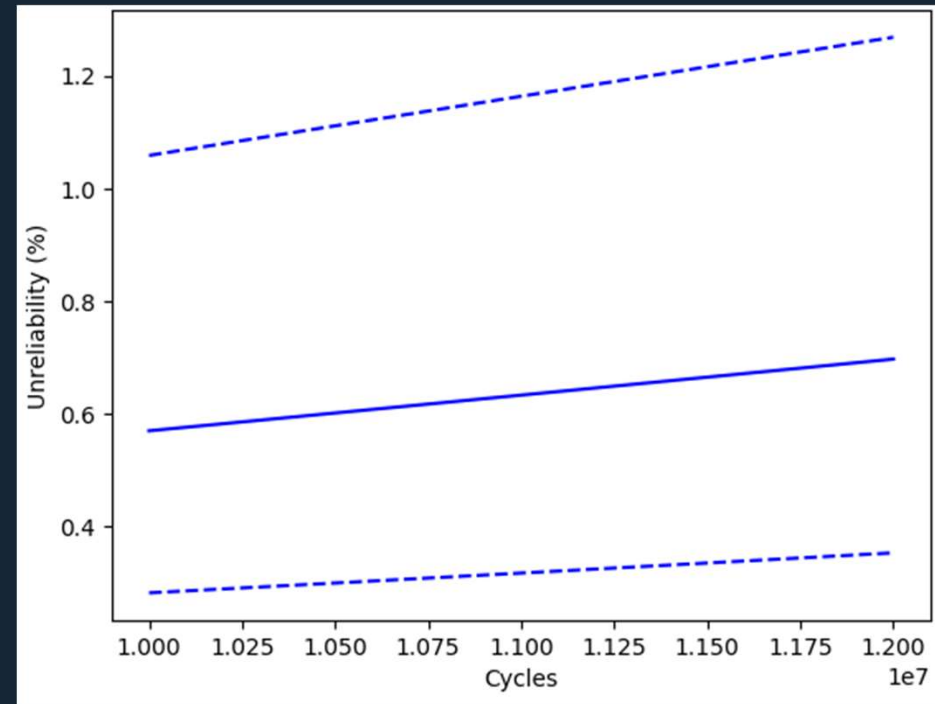
Simulating the Future for Improved Decision Making

Future

Mission Types
Mission Frequency
Loading
Location
Season



Digital Clone

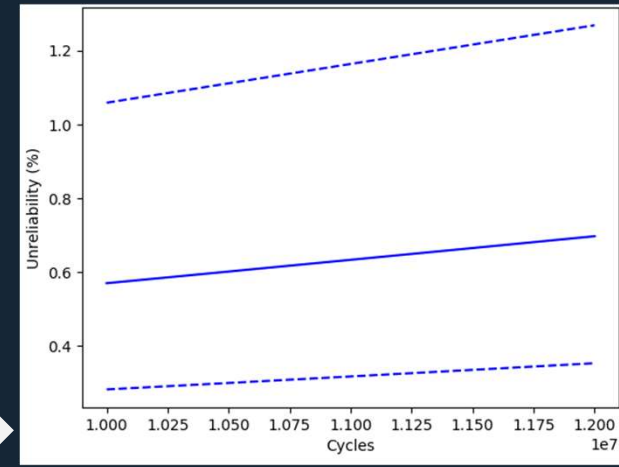
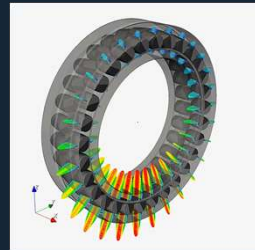


Validation of Maintenance Free Operating Period



Simulating the Future for Improved Decision Making

Unique Use Cases



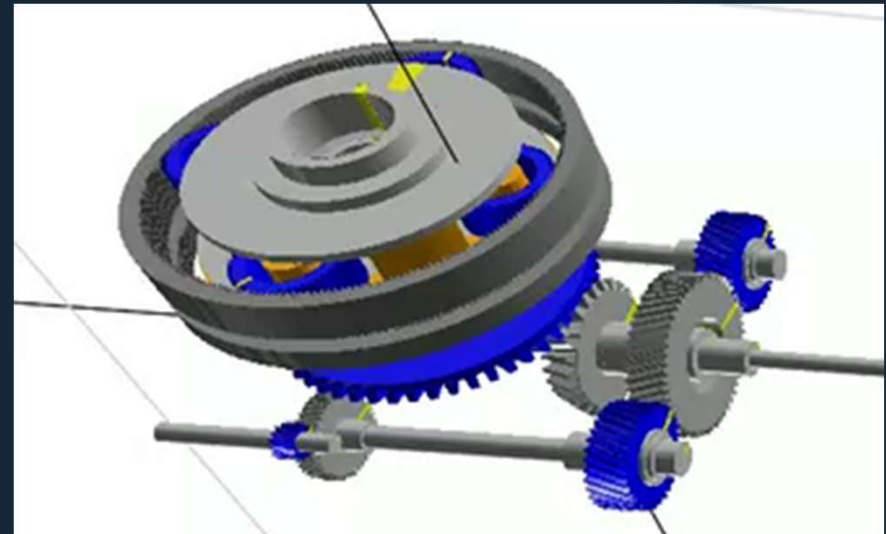
Digital Clone

Validation of Maintenance Free Operating Period



Where else do Digital Clones uniquely support PHM?

- Some scenarios prove difficult for sensor-based diagnostics, much less prognostics
- Example: Rotorcraft planetary gearbox
 - Time varying load path between planets and gearbox housing hampers vibration based diagnostics

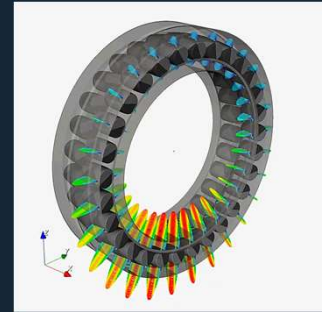


Enabling Comprehensive Component Health State Estimates

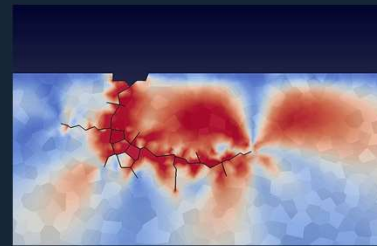


Validation and Acceptance

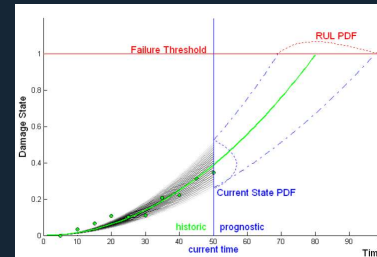
- Validation at each level of simulation
- Test programs produce limited data in limited fidelity environments
- Standards are often leveraged for guidance beyond their stated scope



- Contact Properties
- Statics / Dynamics
- Thermal Behavior



- Traction / Lubrication Models
- Material Representation
- Damage Initiation Models
- Numerical Representation



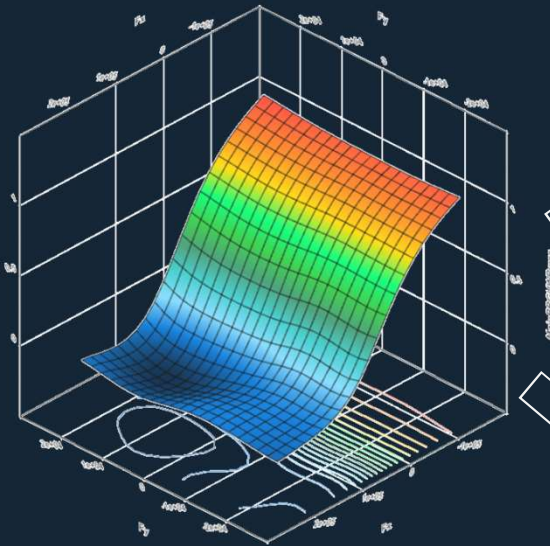
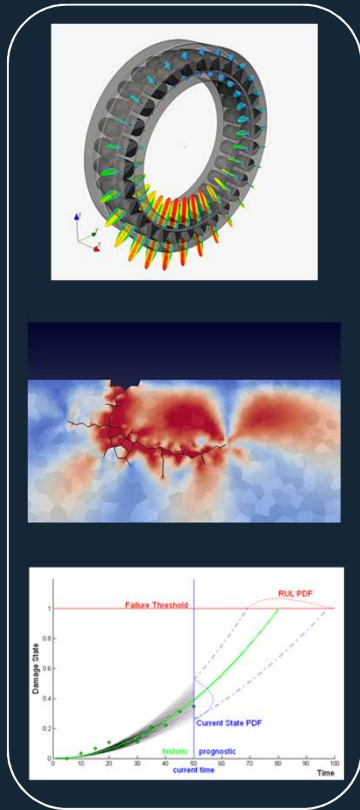
- Damage Progression Models
- Application of Loading
- Environment Representation

Enough Confidence to Enable the Business Decision You Are Trying to Make

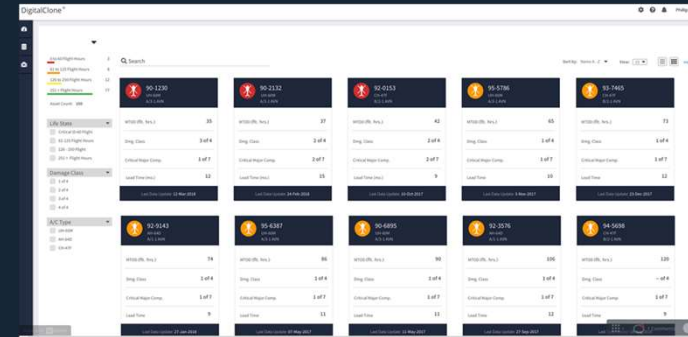


Implementation

Efficient Model Representation



On-Board
↓
Off-Board



Conclusion

- Digital Clones enable several benefits relative to Prognostics Health Management
- Modernization and digitalization will continue to accelerate adoption of these technologies

