Integrity ★ Service ★ Excellence

Working Towards a Digital Twin

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Outline

- **The Digital Twin Vision**
- **Airframe Digital Twin Spiral 1 Program**
  - **Probabilistic Individual Aircraft (Fatigue) Tracking**
  - **Demonstration Experiment**

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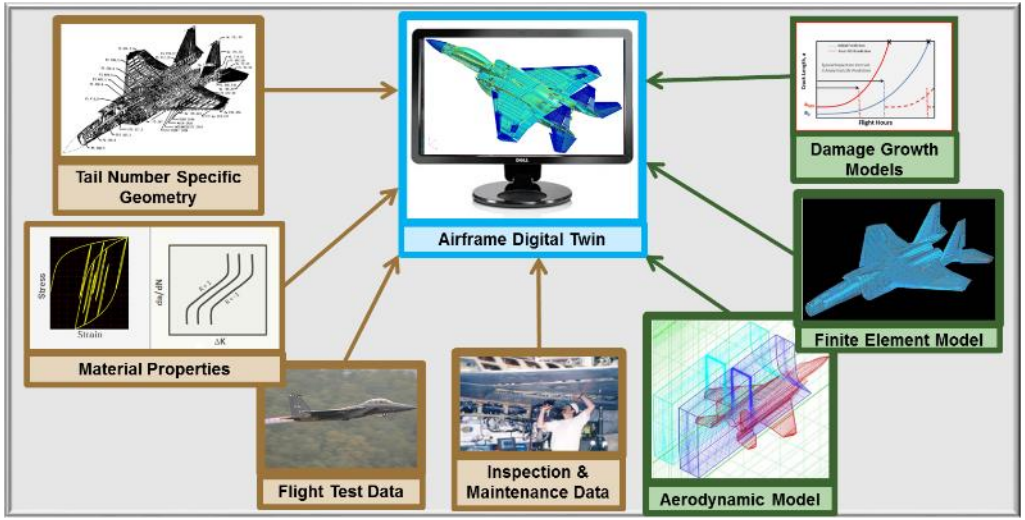
Digital Twin

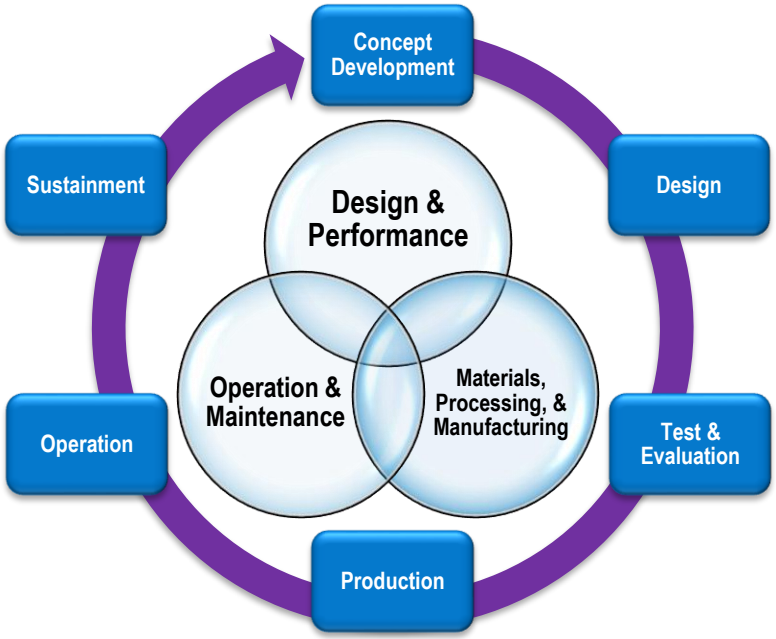
- **Probabilistic simulation of a unique individual by serial number**
- **Digital data, models and parameters, and forecasts for that individual**
- **Statistical updating of the Twin from observations of that individual**



A *DIGITAL SIMULATION* of an *INDIVIDUAL ASSET*

Digital Thread

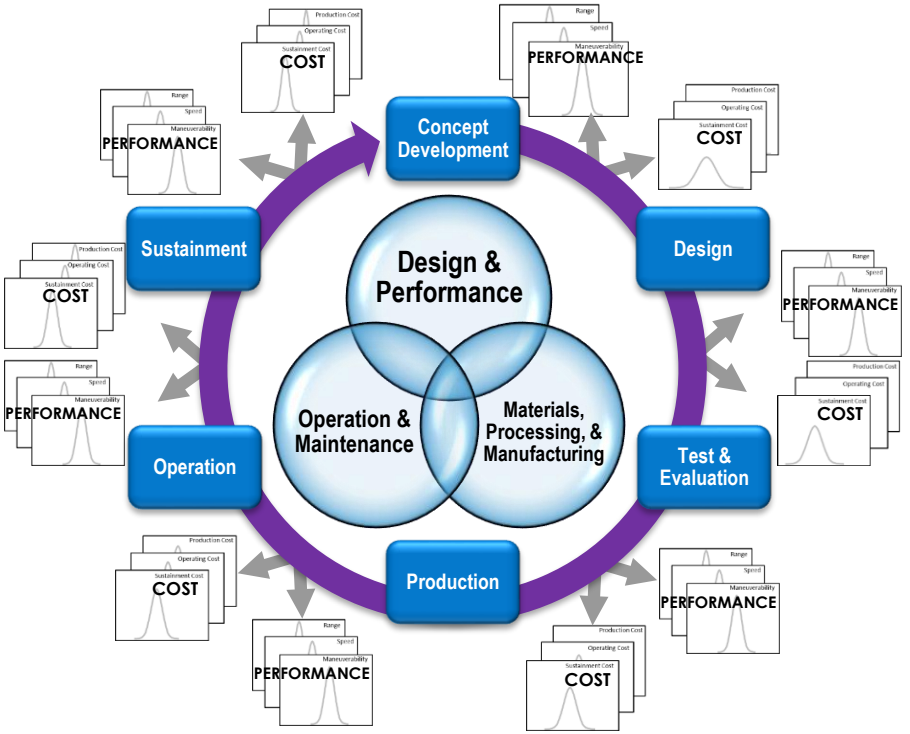
- **Complete digital accessibility to all data, models, analyses, and simulations**
- **Tools to access, authenticate, integrate, & transform data, models, analyses, and simulations**
- **Probabilistic framework for presenting, analyzing, and updating uncertainty in the data, models, analyses, and simulations.**



The *DIGITAL NETWORK supporting DIGITAL TWINS*

Digital Thread/Twin Tenets

- Use **ALL AVAILABLE INFORMATION** in simulations
- Use **PHYSICS** to inform models
- Use **PROBABILISTIC METHODS** to quantify uncertainty
- Use **FEEDBACK** to reduce uncertainty in models and simulations



Developing the Digital Twin

- **Develop in small pieces**
  - **Define requirements**
  - **Demonstrate benefits**
- **Identify a decision process that could be improved**
- **Identify the owner of that decision process**
  - **Interest in improving process**
- **Apply DT tenets to the process**
  - **Needs to be strategic in advancing DT**

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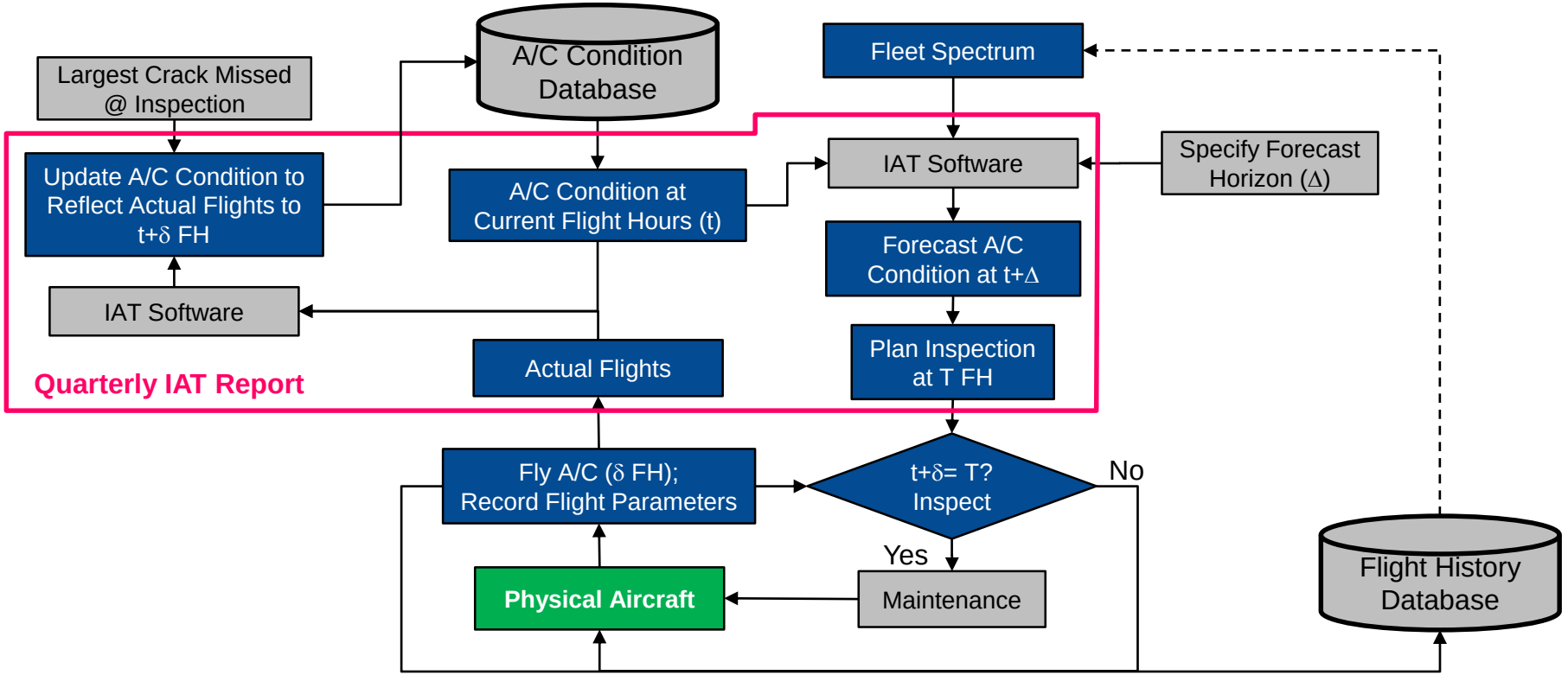
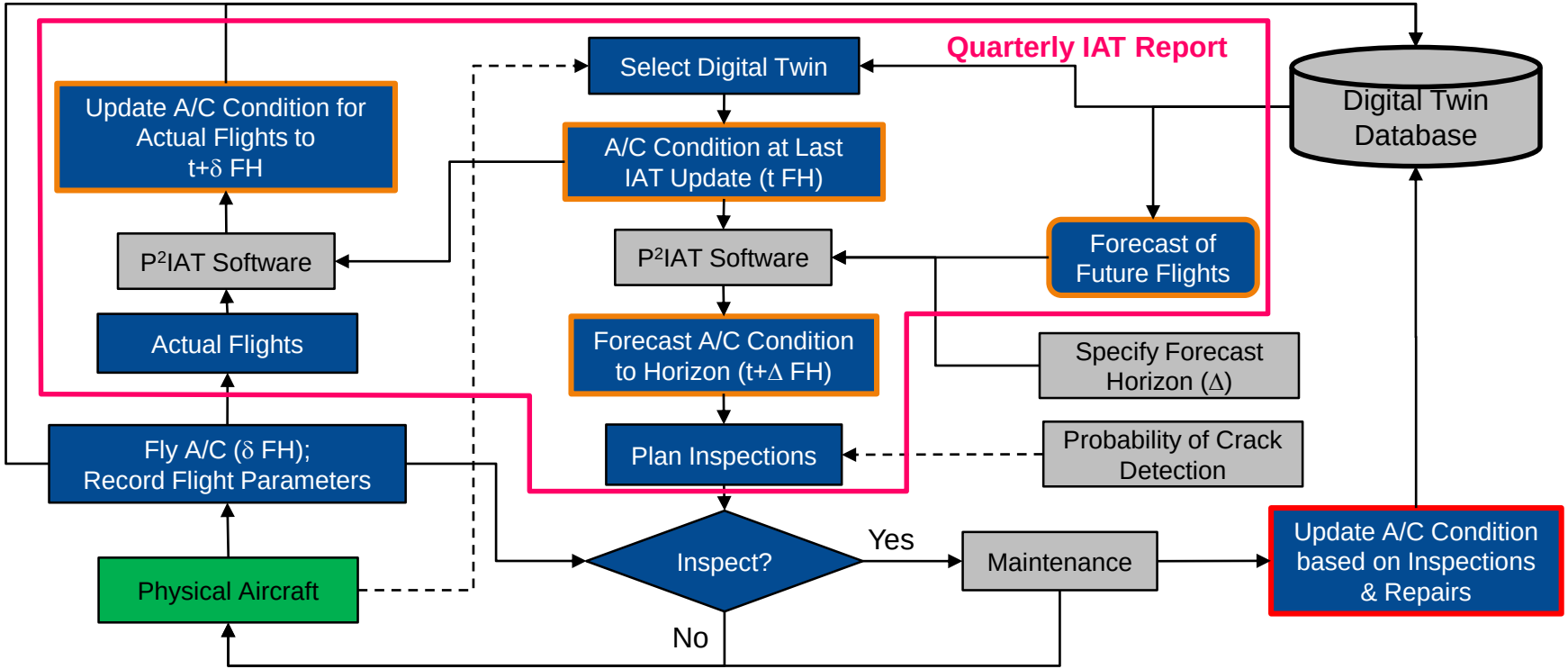
Airframe Digital Twin (ADT) Spiral 1

- **Process: Individual Aircraft Fatigue Tracking**
- **Owner: Senior Leader for Structural Integrity**
- **Digital Twin Tenets**
  - **Data rich process**
  - **Physics-informed models exist**
  - **Need to introduce probabilistics / uncertainty quantification**
  - **Information is not readily fed back into the process**
- **Strategic:**
  - **ID what DT needs to contain in order to sustain airframe**
  - **Models, etc., used in IAT are also used in Design of airframe**

Traditional IAT Process



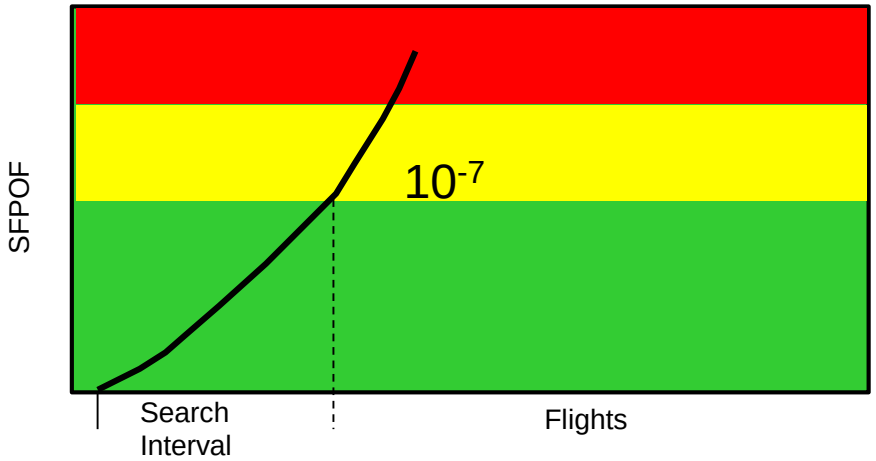
Overall P²IAT Process



Boxes outlined in **orange** indicate probability distributions.

Inspection Criterion

Maximum Information Gain



Modified Kullback-Leibler Divergence

$$D_{KL} = \int p(a) log \frac{2p(a)}{p(a)+q(a)} da + \int q(a) log \frac{2q(a)}{p(a)+q(a)} da$$

p(a) = CDF of crack length model
q(a) = CDF of crack length measurements (POD model for detections)

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Demonstrate Probabilistic IAT

- **Moderately complex structure**
  - **Maneuver load driven**
- **Cover range of variation, not just one point**
  - **Two test articles with different load spectra**
- **Demonstrate sustained execution speed**
  - **Track at least 10 control points per test article**
  - **Twelve months of loading**

Full Scale Test of Two Retired Wings

Outer Wing is loaded. Inner Wing is transition structure.

Demonstration Objectives

- **Determine Technical Benefits of Probabilistic IAT**
  - Protects safety and airworthiness
  - More efficient inspection schedule
  - Reduce uncertainty about condition of structure as test progresses
- **Develop Business Case for Probabilistic IAT**
  - Estimate cost savings due to more efficient maintenance
  - Estimate of development costs
  - Estimate of support costs
  - Compare to conventional IAT
- **Identify gaps and plan future R&D**

Questions