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International Committee on Aeronautical Fatigue and Structural Integrity

Digital Engineering II

Dr. Yuval Freed
Israel Aerospace Industries

Dr. Eric Lindgren
Air-Force Research Laboratory

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General

Digital Engineering theme:

- Data science is rapidly adopted by many industries with emerging data-driven concepts (such as machine learning and digital twins) that are ideal for high-dimensional multi-objective optimization problems
- While the aviation industry is very traditional and highly regulated, there is potential of integrating data-driven science and engineering into design, manufacturing and services

Terminology

- Digital Twin
  - A virtual (multi-physics, multi-scale, probabilistic) representation of a physical asset
- Artificial Intelligence (AI)
  - Simulation of human intelligence processes by machines, especially computer systems
- Machine Learning (ML)
  - An AI technique that uses computational and statistical algorithms to “learn” information directly from data without relying on a predetermined equation as a model
- Virtual Testing
  - Simulation of a physical test, usually using finite element analysis tools, to derive accurate loads, motion and damage of an air vehicle

USAF Terminology

- Digital Engineering
  - An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal
- Digital Thread
  - An extensible, configurable and component enterprise-level analytical framework that seamlessly expedites the controlled interplay of authoritative technical data, software, information, and knowledge in the enterprise data-information-knowledge systems, based on the Digital System Model template, to inform decision makers throughout a system's life cycle by providing the capability to access, integrate and transform disparate data into actionable information

USAF Terminology

- Digital Twin
  - A virtual replica of a physical entity that is synchronized across time. Digital twins exist to replicate configuration, performance, or history of a system. Two primary sub-categories of digital twin are ***digital instance*** and ***digital prototype***.
  - ***Digital Instance*** is a virtual replica of the physical configuration of an existing entity. The digital instance typically exists to replicate each individual configuration of a product as-built or as-maintained
  - ***Digital Prototype*** is an integrated multi-physics, multiscale, probabilistic model of a system design. The digital prototype may use sensor information and input data to simulate the performance of its corresponding physical twin. The digital prototype may exist prior to realization of its physical counterpart

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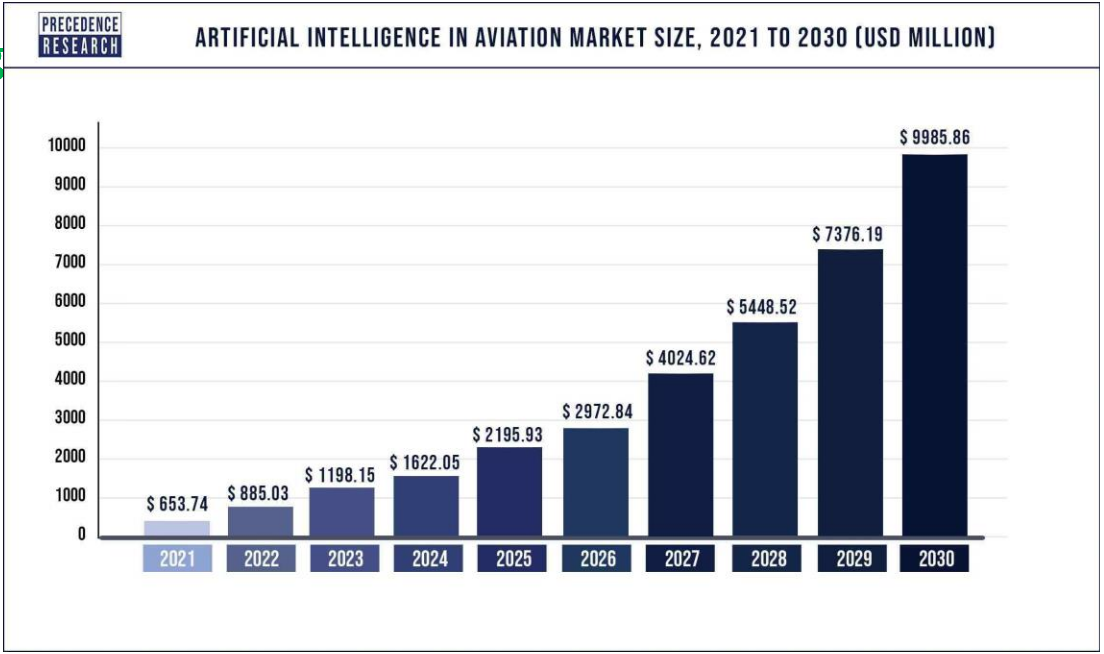
Objective

- Provide a collective overview of digital engineering trends in the aviation industry, with special focus on aeronautical fatigue and structural integrity
  - Few examples from ICAF 2023 national reviews
- List opportunities, challenges and related concerns

Market Overview

- Forecasts indicate a ***significant rise of AI products***, owing to the rising usage of big data analytics in aerospace industry
  - Performance optimization
  - **Design, Analysis and Testing**
  - Flight operation
  - Training and virtual assistants
  - Dynamic pricing
  - Smart manufacturing
  - **Smart Fleet Management**
  - **Smart maintenance**
  - Optimized flight route
  - Customer support
  - Fuel efficiency



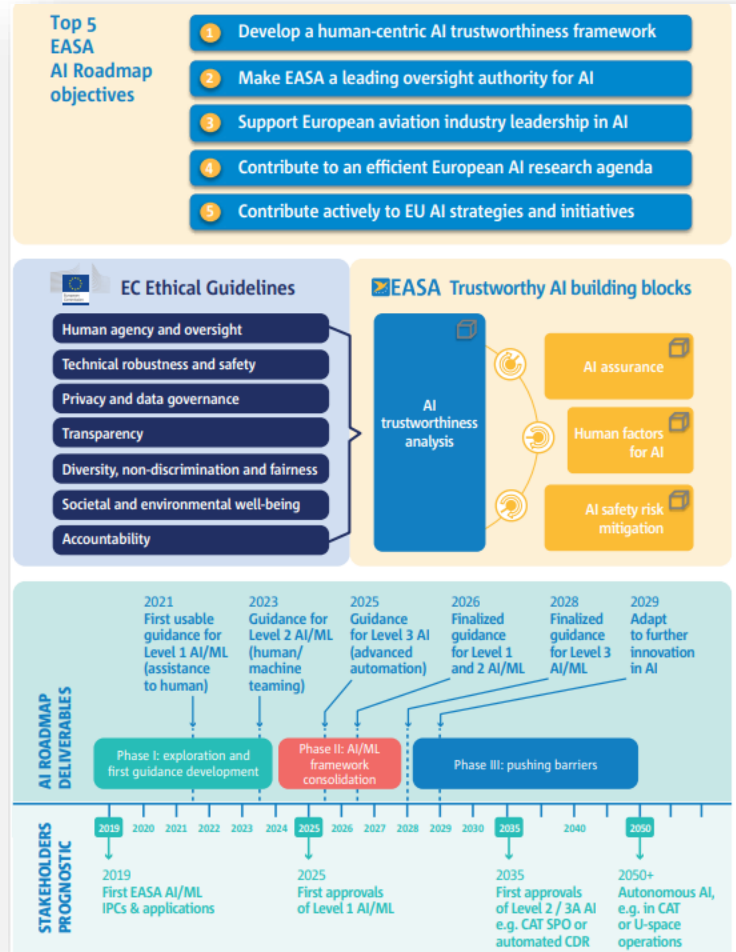
Vision

- Develop a data-intense aerospace engineering covering the entire product life management including the development phase, production, service support, fleet monitoring and end of life

Ref.: S.L. Brunton et al., Data-driven aerospace engineering: reframing the industry with machine learning, AIAA 59(8), 2021

Roadmap

- EASA has recently published a document forecasting the insertion of AI technologies to the aviation industry and the regulatory activities planned
- Consolidated EASA policy for AI planned for completion in 2028
- First step: human assistance/augmentation (2023-2025+)
- Second step: human-AI teaming (2025-2035+)
- Third step: advanced automation and autonomous AI (2035-2050+)



Ref.: EASA Document, Artificial intelligence roadmap 2.0 – human-centric approach to AI in aviation, May 2023

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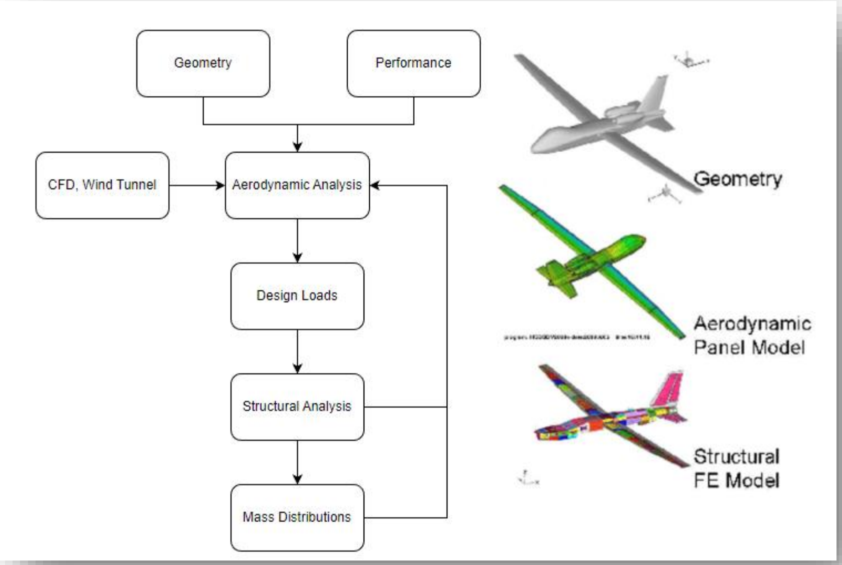
Examples from Israel National Review

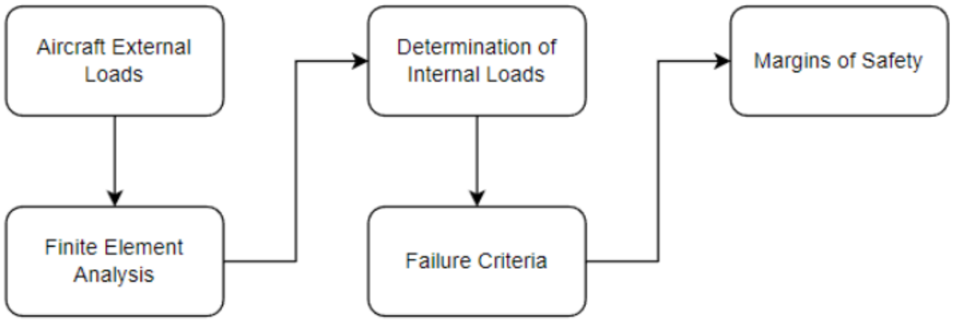
Efficient Design Cycle (Y. Freed, IAI)

- Development of a new aircraft is a joint effort of many disciplines, including mechanical systems, airframe design, aerodynamics, propulsion, manufacturing, avionics, etc.
- Specifically, for structure, the design process can be generally described as:



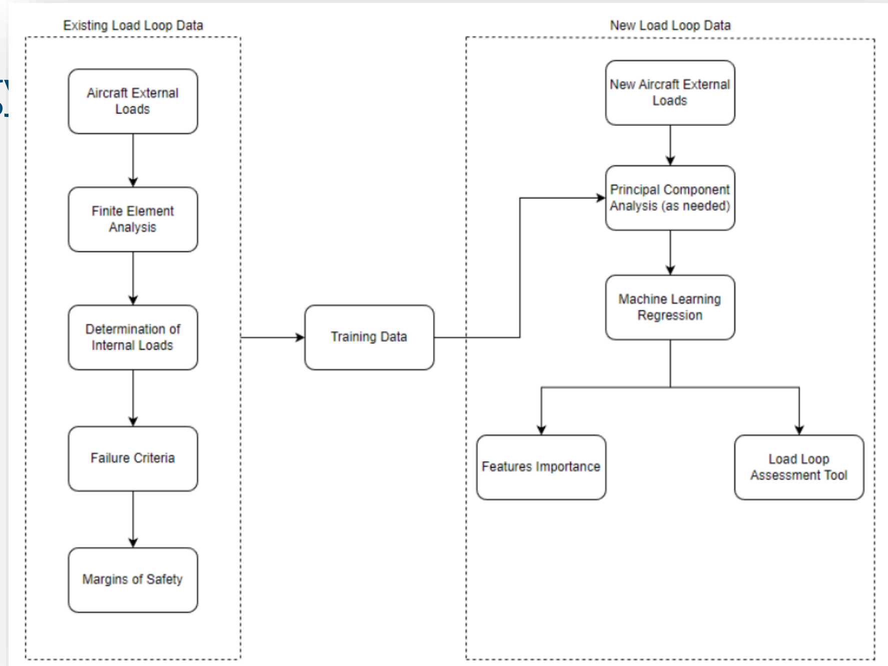
Efficient Design Cycle (Y. Freed, IAI)

- Typical structural substantiation process includes:
  - Application of external loads to Finite Element Model (FEM)
  - Determination of internal loads
  - Failure analysis in light of failure criteria
  - Determination of margins of safety
- This is a time consuming process, and may take months for each load loop!



Efficient Design Cycle (Y. Freed, IAI)

- This study proposes a development of a ML based assessment tool that significantly reduces the structural analysis duration upon issuance of new loads loop
- According to the proposed methodology, ***the established relations between the external loads and the margins of safeties during the previous load loop*** are used to train the algorithm



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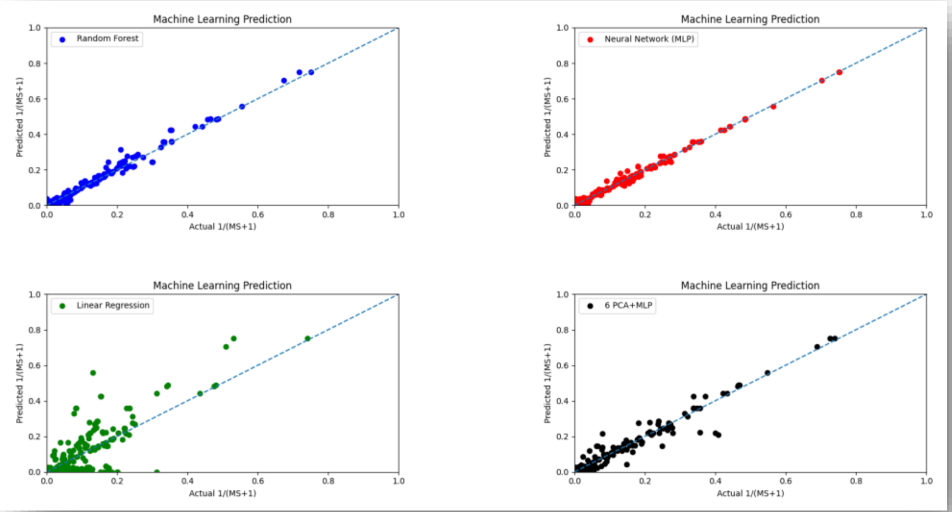
Efficient Design Cycle (Y. Freed, IAI)

- The performance of this algorithm was successfully demonstrated for a specific use case (cargo loading system device) using neural network and random forest algorithms
- Graphs present how well the ML predicts the margins of safety for validation data (~ 250 data points)

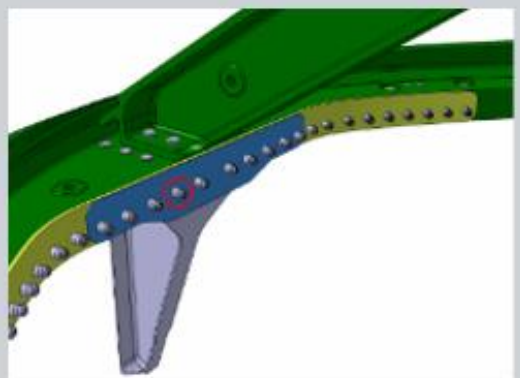


FSFT Anomalies Detection (E. Pinhas, IAI)

- Typical full-scale fatigue test duration is several years, and it is usually completed years after the first airplanes are delivered to the customers
- Any fatigue cracking detected in early stages of the test should be addressed, and design changes to preclude such cracks are introduced
- Retrofits to preclude fatigue cracking in airplanes that are already in service are ***extremely costly*** (requires removal of the aircraft interior, repair/reinforcements installation, downtime compensation, etc.)
- **Early detection of cracks in FSFT has the potential to save millions of dollars !!!**

FSFT Anomalies Detection (E. Pinhas, IAI)

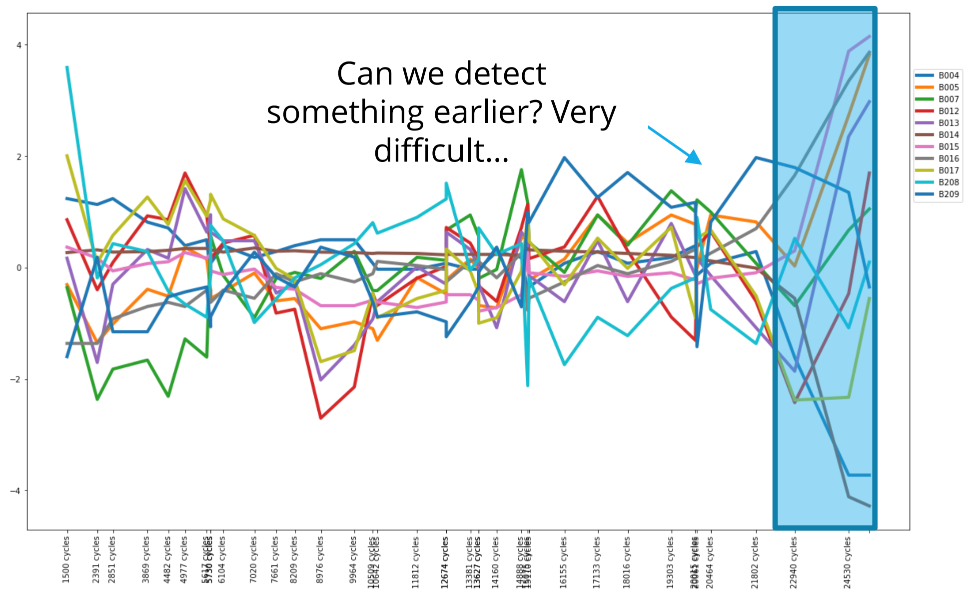
- In this study, several ML-based approaches were employed to demonstrate early detection of strain anomalies in FSFT

Flight	Crack Location
25,371	

FSFT Anomalies Detection (E. Pinhas, IAI)

- It is generally difficult to detect such cracks at such early stage based on strain measurements:

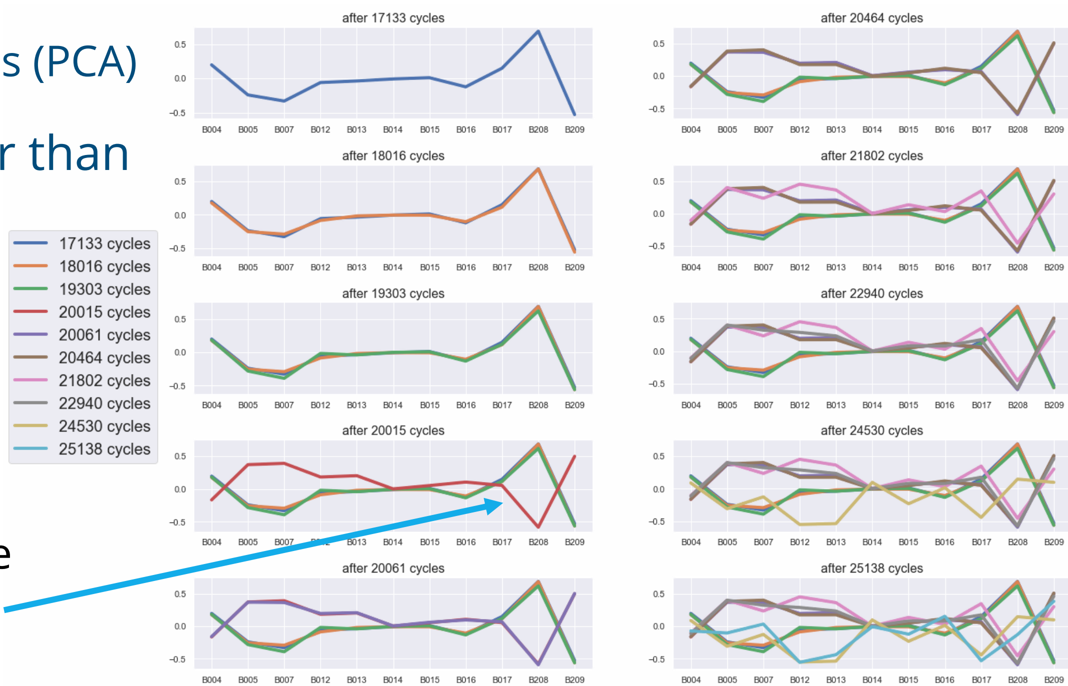
Clearly something happened
at ~ 25K flights



FSFT Anomalies Detection (E. Pinhas, IAI)

- Two unsupervised ML algorithms were employed
  - Isolated Forest
  - Principal Component Analysis (PCA)
- Earlier detection (20% earlier than actually detected in test) was demonstrated

The second PC starts to deteriorate significantly after 20015 cycles



USSF

AFRL

National Overview: Digital Engineering for Aviation

Eric Lindgren
Materials State Awareness Branch
Materials and Manufacturing Directorate
US Air Force Research Laboratory

June 27, 2023

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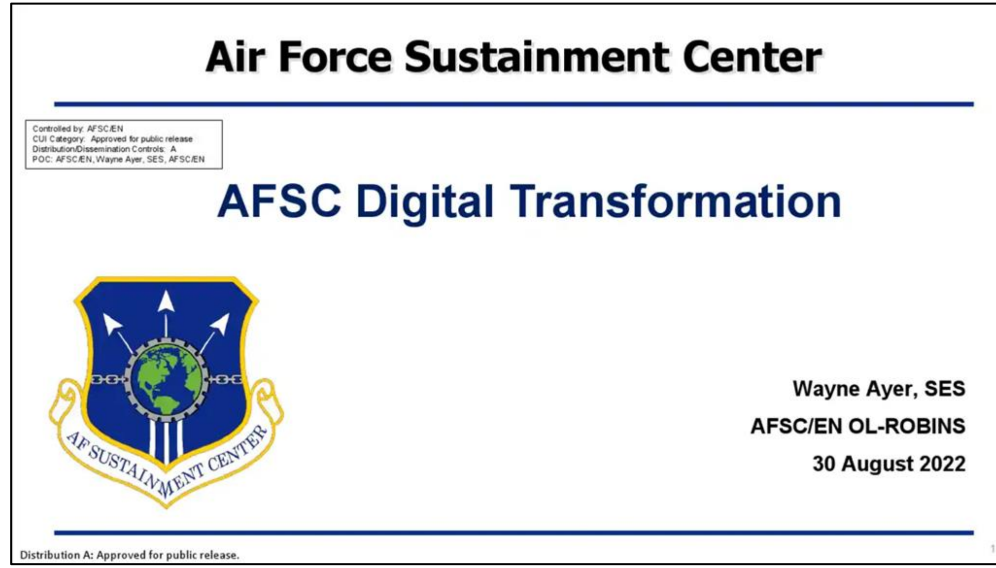
Broad-based Initiatives



- National Airworthiness Council – Aircraft Airworthiness and Sustainment 2021
- Air Force Sustainment Center – Aircraft Airworthiness and Sustainment 2022

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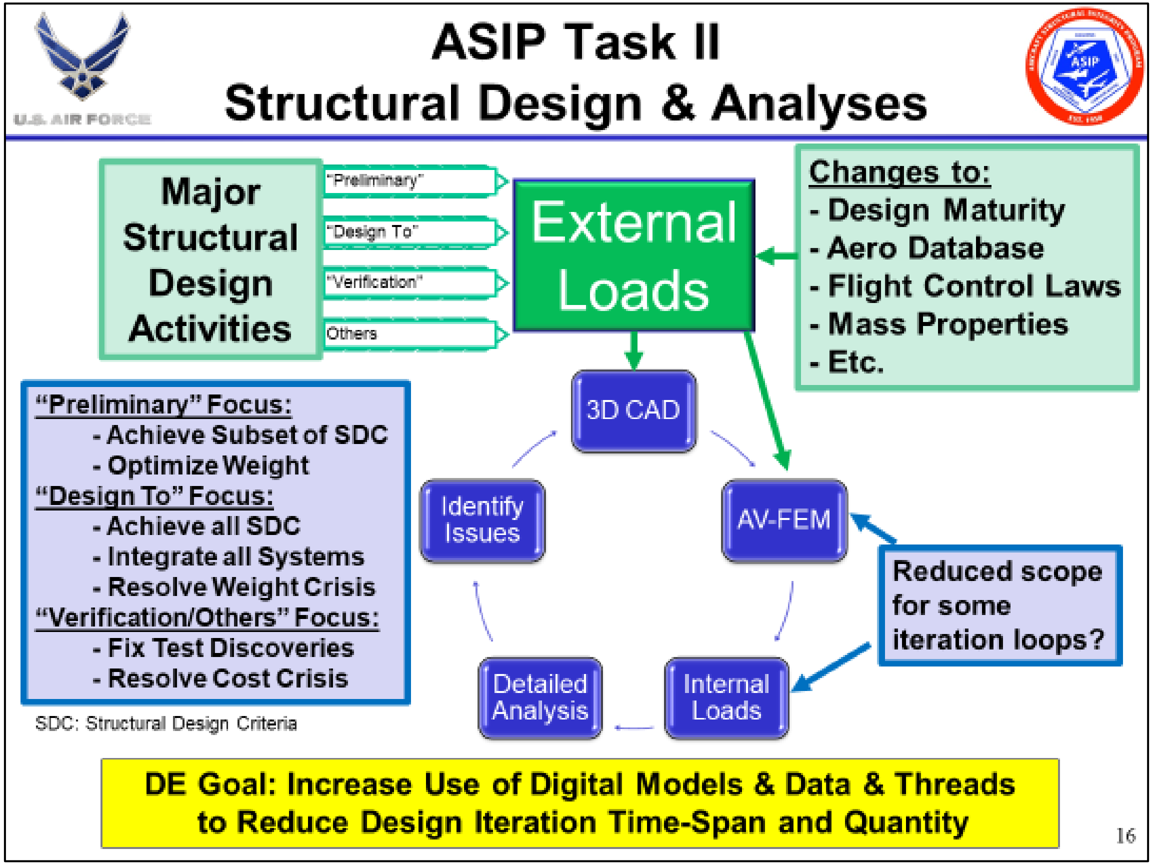
A Structural Integrity Perspective

31st ICAF Symposium
Delft Netherlands, 26-29 June 2023

Digital Engineering (DE) for Improved Aircraft Structural Integrity Program (ASIP) Execution

Chuck Babish
U.S. Air Force (USAF)

ASIP Task II – Structural Design and Analysis*



*Babish, C, "Digital Engineering for Improved Aircraft Structural Integrity Program Execution" ICAF 2023

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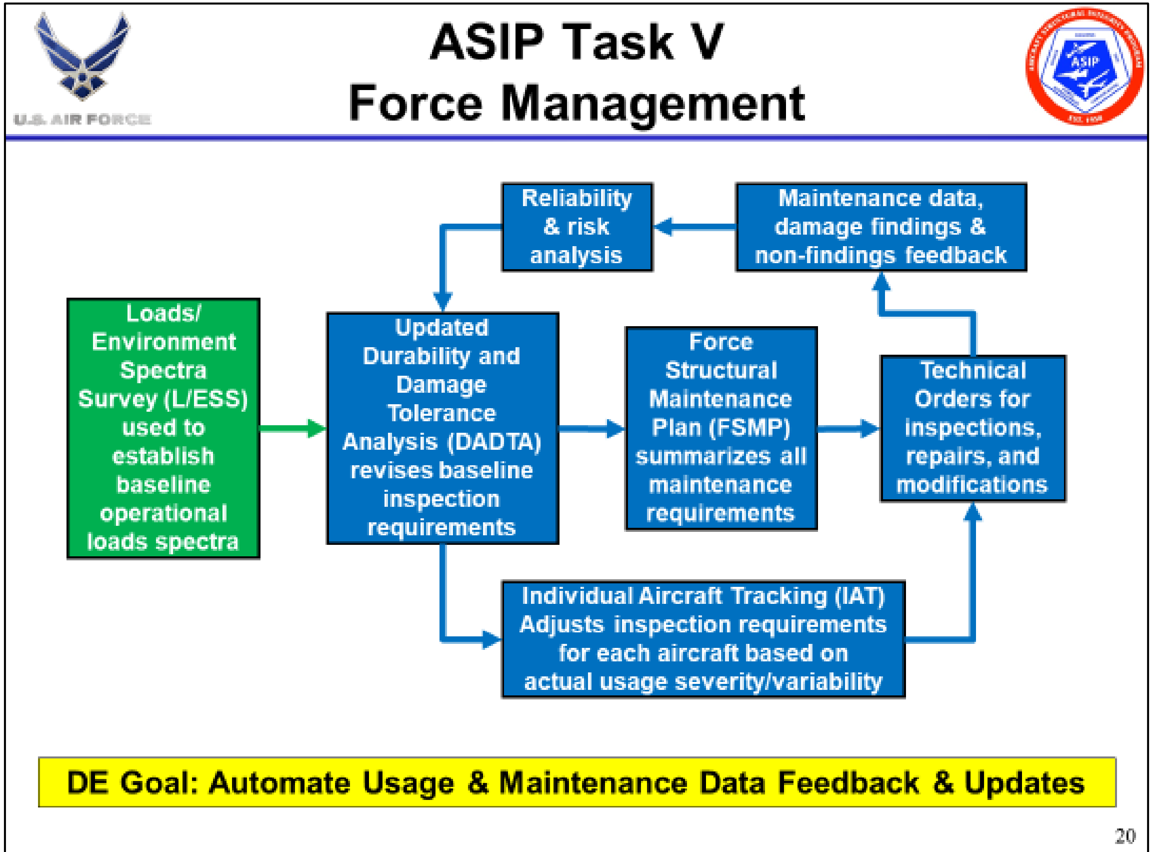
ASIP Task V – Force Management*

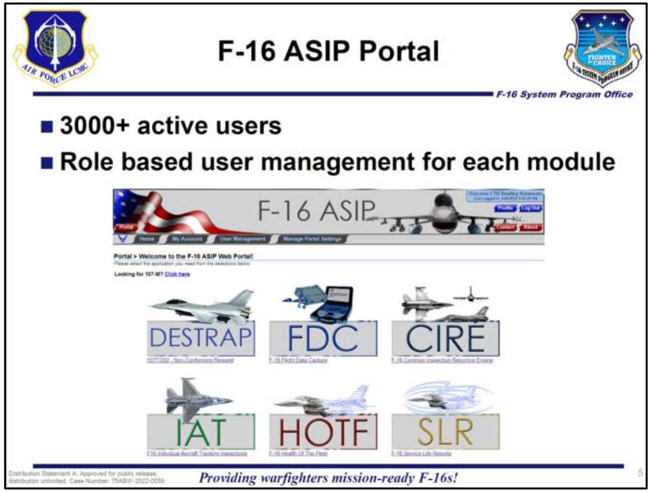


*Babish, C, “Digital Engineering for Improved Aircraft Structural Integrity Program Execution” ICAF 2023

Examples of USAF Force Management

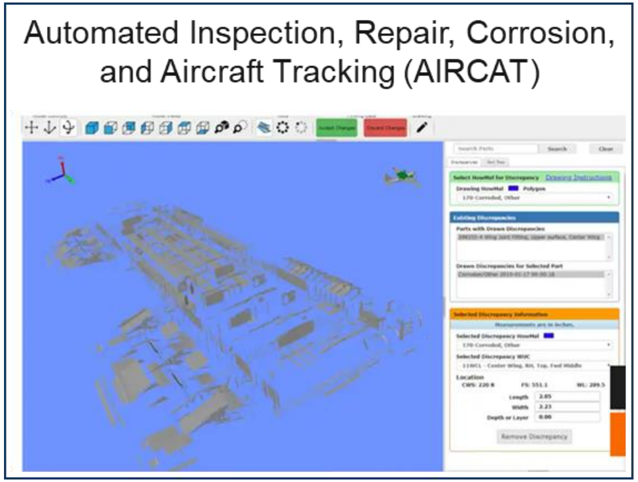
Options dependent of funding used for development:

- Source code and data format owned by USAF
- Data rights, source code, and data format owned by contractor



http://www.arctosmeetings.com/agenda/asip/2022/proceedings/presentations/P23268.pdf

http://www.arctosmeetings.com/agenda/asip/2022/proceedings/presentations/P23269.pdf



https://www.merc-mercer.org/project/aircat/

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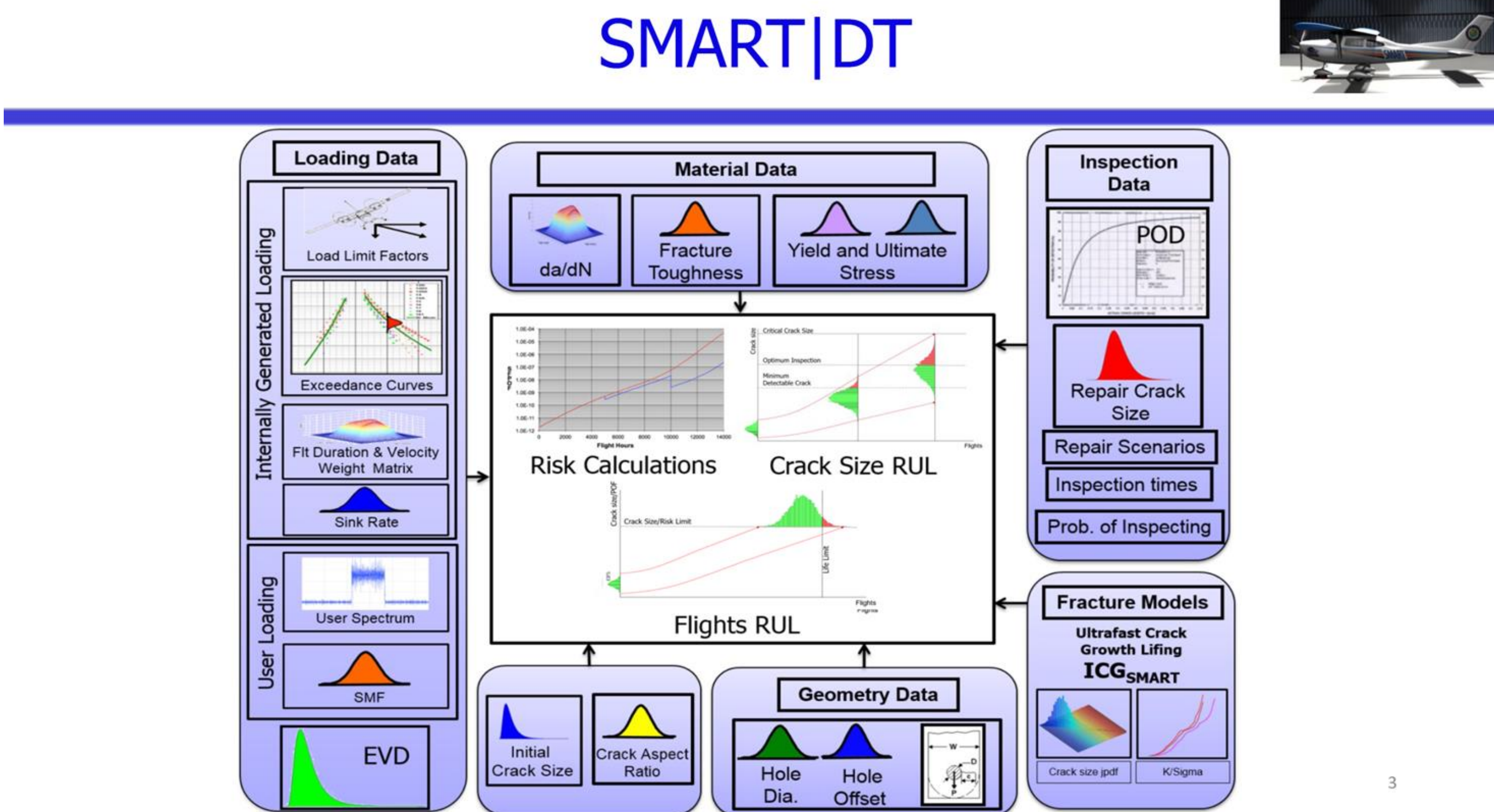
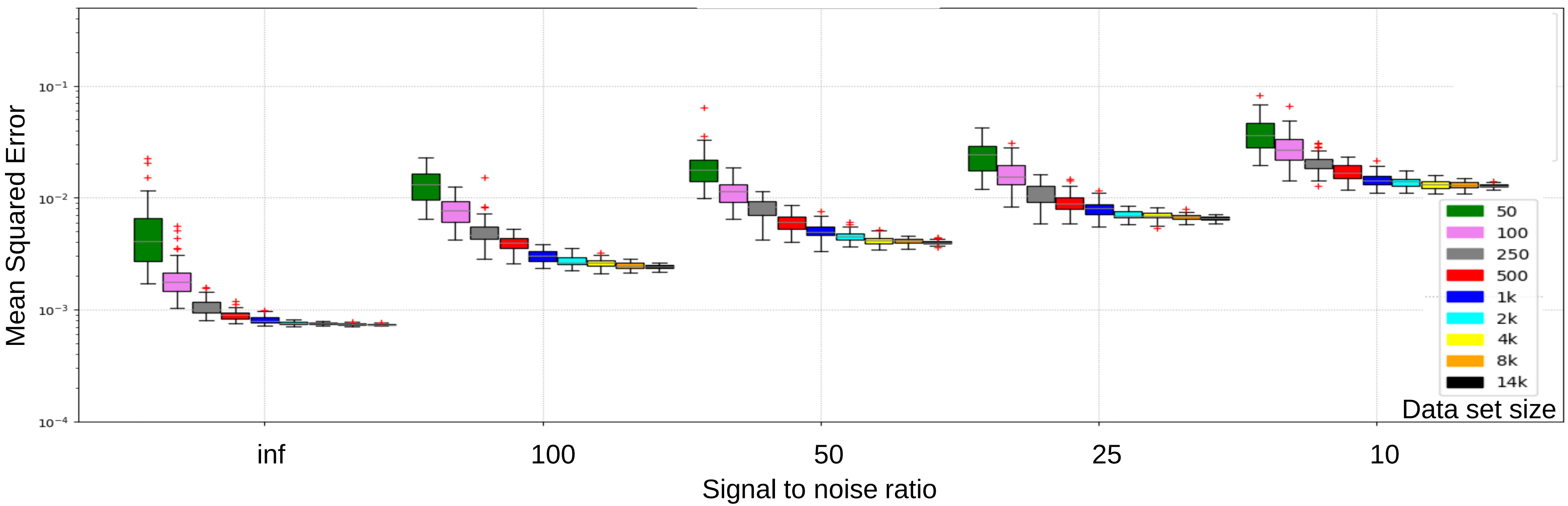
Example: FAA General Aviation



http://www.arctosmeetings.com/agenda/airworthiness/2022/proceedings/presentations/P23052.pdf

Enhanced Data Analytics: Data Quality Matters

Example: data quantity and signal-to-noise affect mean square error



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Challenges (ICAF Related)

- Education and capabilities development in traditional aerospace engineering sector
- Fostering a culture of data sharing, open science, and reproducibility
- High cost for data collection
- Heterogeneity, multimodality, and multi-fidelity of aerospace data, which is vast in some dimensions, and sparse in others
- Development of practical and general ML models that incorporate partially known physics
- Certifiable and verifiable ML models for safety-critical applications. ***Credibility is the main issue !***

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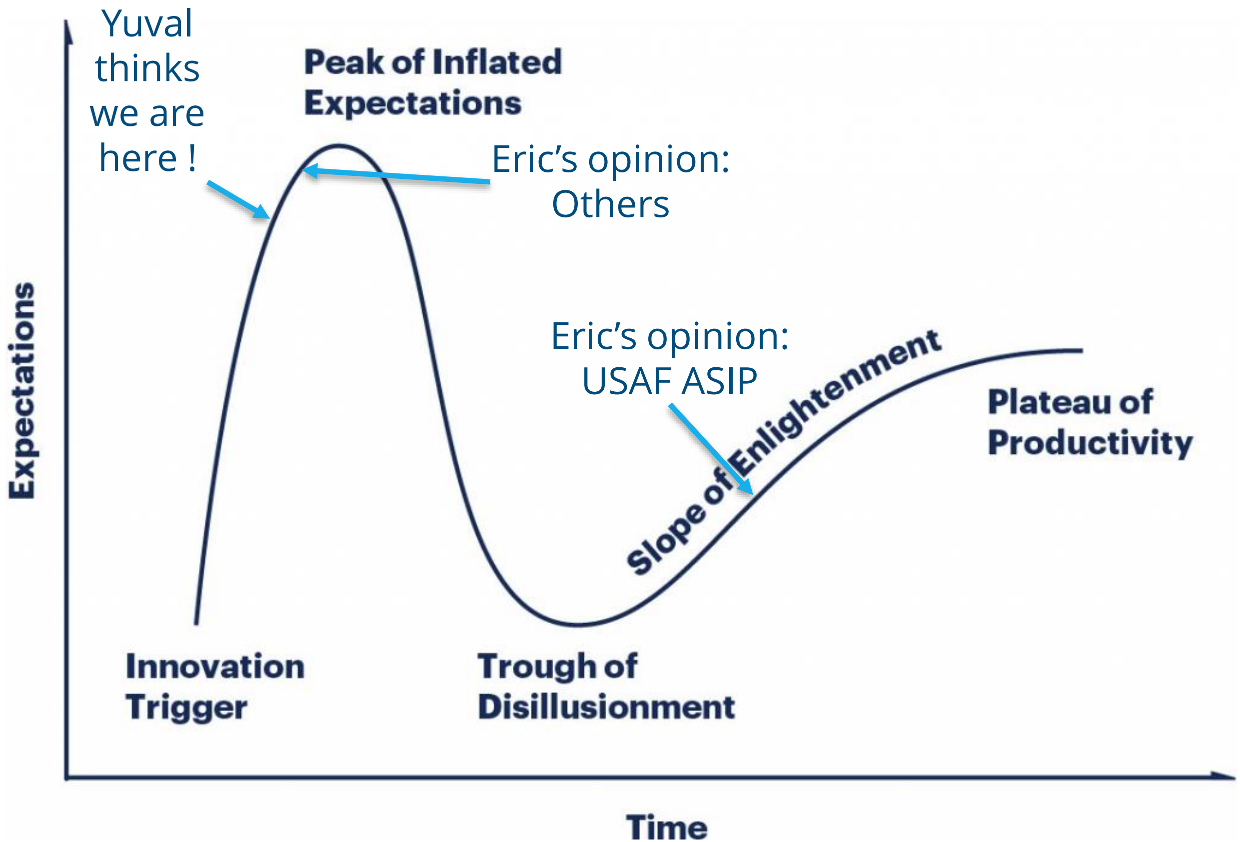
Opportunities (ICAF Related)

- Faster design / testing cycles with digital twins and efficient surrogate models
- Revolution of the test pyramid to integrate virtual testing
- Improved smart and condition-based maintenance
- Enhanced efficient fleet monitoring and management
- Streamlined and more reliable testing, evaluation, and certification, including anomaly detection
- Improved models for complex multiscale physics, such as solid-fluid dynamics, advanced materials and composites

Where are we with Digital Engineering?



Discussion