Digital Twin

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Outline

- Digital Twin Concept Overview
- Motivating Factors
  - Structural Health Management
  - Newer Applications
  - Enabling Technologies
  - Why call it Digital Twin?
- Key Elements
- An Application & Development Example: AFRL's Airframe Digital Twin Program
- Exciting Frontiers: FDA's Computational Human Heart Modeling
- Limitations & Challenges
- Summary

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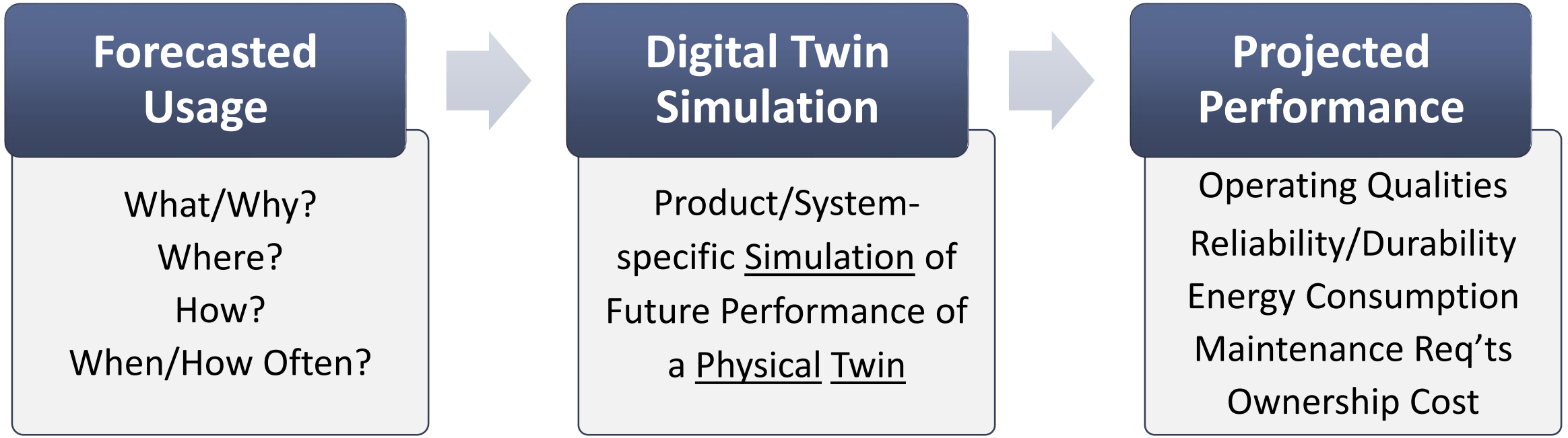
Digital Twin Concept Overview

Simulating Future System Performance Based on Current Knowledge



- Individualized short- and long-term performance predictions
- Delivered in an affordable, intuitive, & interactive manner
- Updated to become better when new knowledge is gained

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Early Motivation: Aircraft Structural Health Management

United States Government Accountability Office
Report to Congressional Committees

September 2018

WEAPON SYSTEM SUSTAINMENT

Selected Air Force and Navy Aircraft Generally Have Not Met Availability Goals, and DOD and Navy Guidance Need to Be Clarified

GAO-18-678

Figure 2: Sustainment Challenges Affecting Selected Air Force Fixed-Wing Aircraft

Aircraft	Aging aircraft		Maintenance		Supply support	
	Delays in acquiring replacement aircraft	Unexpected replacement of parts and repairs	Delays in depot maintenance	Shortage of depot maintainer personnel	Parts obsolescence[a]	Diminishing manufacturing source[b]
B-52		✓	✓		✓	✓
C-17		✓	✓			✓
E-8C		✓	✓		✓	✓
F-16	✓		✓			✓
F-22		✓	✓	✓		✓

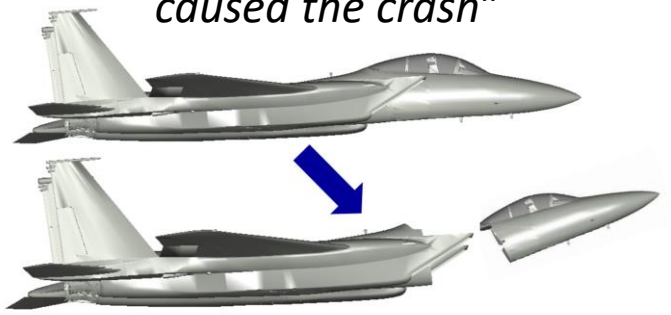
Source: GAO analysis of Air Force data. | GAO-19-120T

[a]Obsolescence is a lack of availability of a part due to its lack of usefulness or it is no longer current or available for production.

AFRL Engineers:
Can we increase fidelity and timeliness of analyses which inform structural maintenance planning?

airforcetimes.com/news/your-air-force/2019/07/26/aircraft-mission-capable-rates-hit-new-low-in-air-force-despite-efforts-to-improve/

"A failure of … a critical support structure in the F-15C Eagle, caused the crash"



Based on Pilot Testimony

Source: The Effect of Manufacturing Variability on Air Force Systems, *Dr Jeff Calcaterra* - USAF, ASIP 2008

Source: Sue Sapp via af.mil, VIRIN 081112-F-5350S-002

Current Motivation: Engineered Products & Systems

Delivering and sustaining predictable, safe, reliable, and affordable operational capability of engineered products and systems to achieve the outcome desired or required by the end user

Photos: unsplash.com

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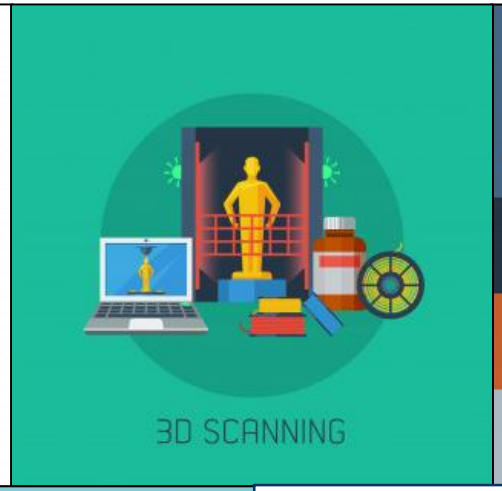
Enabling Technologies



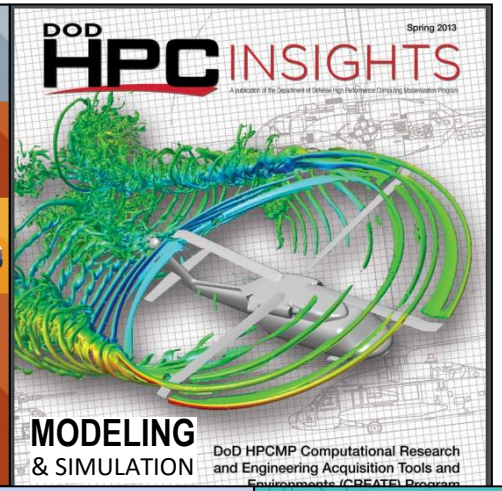
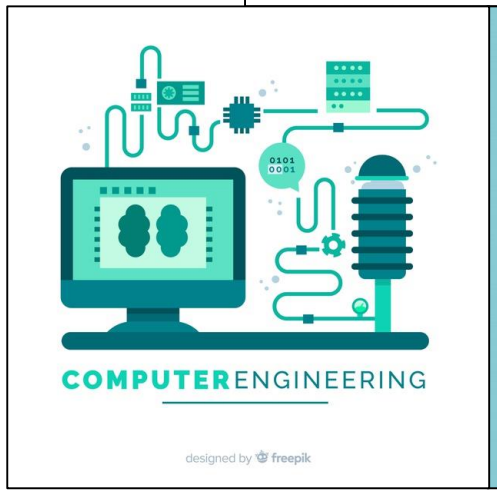
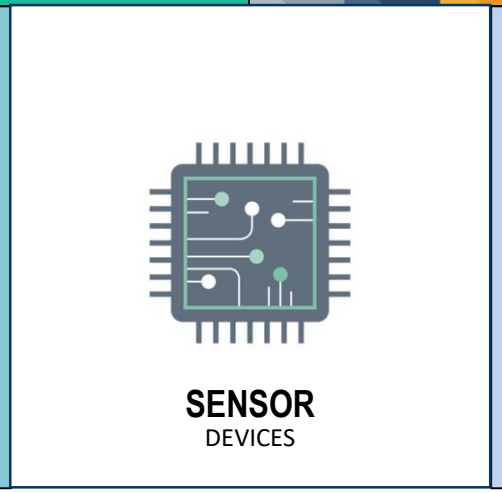
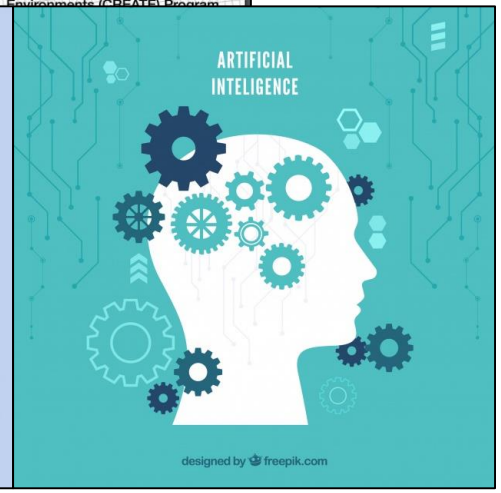


Image:
DoD HPC Insights
Spring 2013 Cover







Vector graphics: freepik.com

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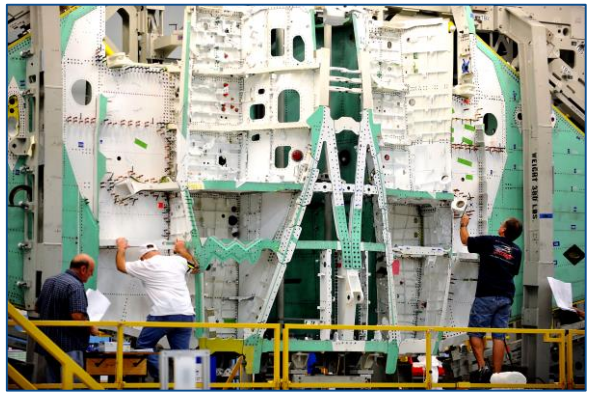
Why call it Digital Twin?

"Digital Twin" Flight Simulations to Compute Engineering Parameters

Source: Tom Tshida via nasa..gov, EC04-0288-4

Unique "Digital Twin" Simulations for Each "Physical Twin" to Account for Config. Differences

Source: af.mil, VIRIN 180709-F-PM645-3223



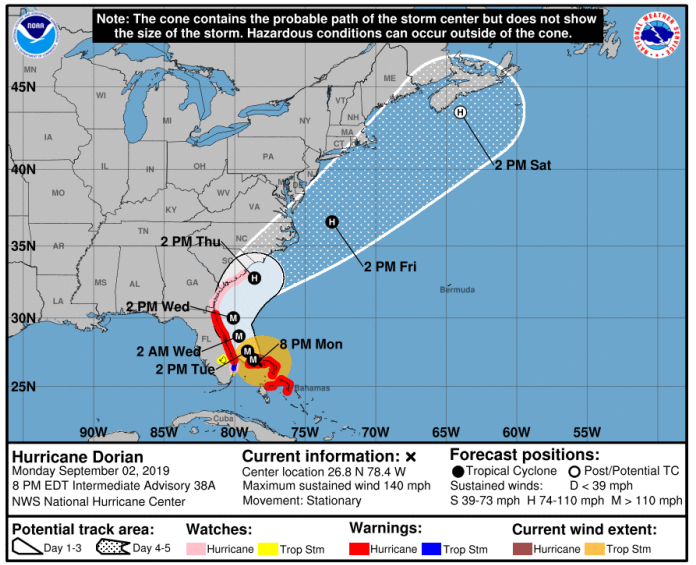
Source: defenselink.mil, VIRIN 090831-D-7203C-028

Source: US Navy – Scott Janes via dodlive.mil

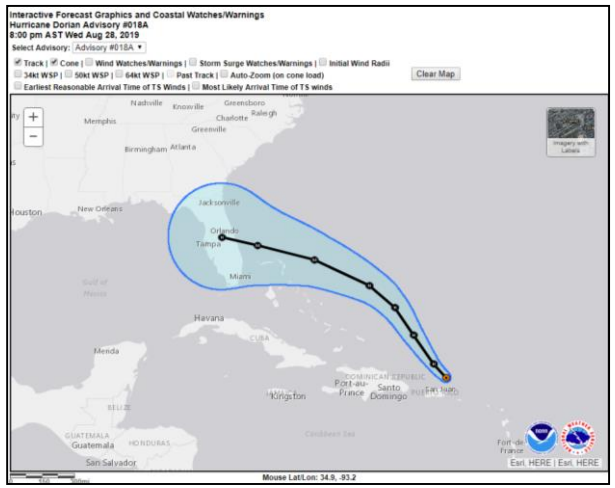
An Aircraft Digital Twin predicts the engineering performance of an individual aircraft over time

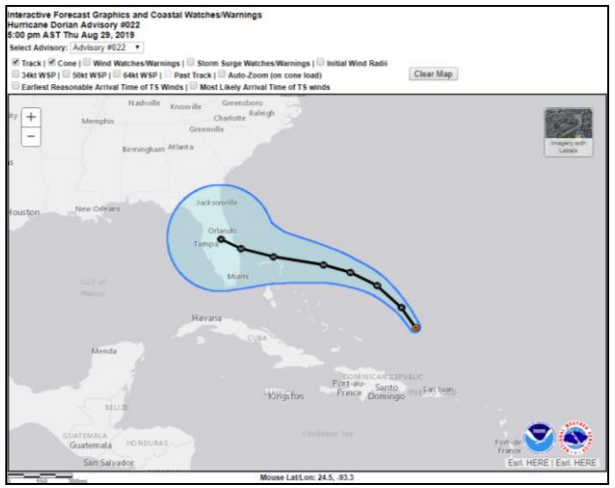
Key Elements

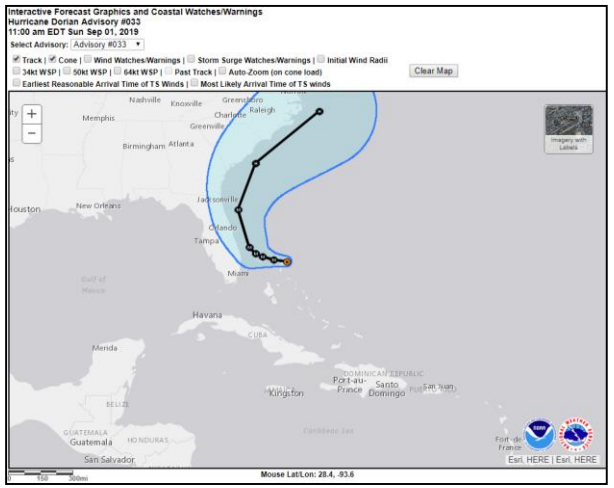
- Timely and Actionable Information
- Tailored for the Specific Physical Twin and Its Operator(s)
- Updated When New Information Becomes Available



Images: nhc.noaa.gov







Predicting engineering performance of an individual product/system over time is a bit like predicting the weather!

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An Example: AFRL's Airframe Digital Twin

Products: U.S. Air Force Aircraft

Owners: U.S. Air Force Major Commands

Operators: U.S. Air Force Squadrons / Pilots

Decision Makers: Structures Engineers

Decision: When to require critical structural inspections?

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An Example: AFRL's Airframe Digital Twin

Req'd Outcome 1: Successful/Safe Missions

Req'd Outcome 2: Required Service Life Achieved

Desired Outcome 1: Sufficient Maintenance Lead Time

Desired Outcome 2: Minimum Maintenance Downtime

Desired Outcome 3: Minimum Maintenance Cost

Airframe Digital Twin Needs to Provide Information about Operational and Economic Risks

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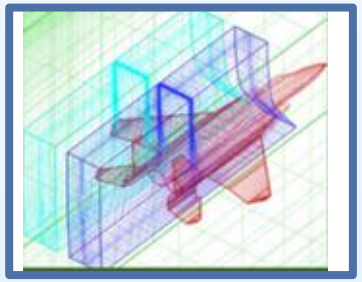
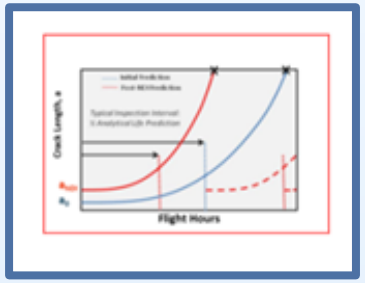
Airframe Digital Twin Predicts the Likelihood of Fatigue Cracking

Modernize lifecycle management of airframe structures by integrating data, models and probabilistic analysis methods to provide actionable output for tailoring airframe maintenance by tail number



Aerodynamic Model

Finite Element Model



Damage Growth Models

Loads & Environment Model ⟷ System Response & Degradation Model ⟷ Components Response & Degradation Models

DTw requires validated, reduced-order probabilistic models formulated for updating.

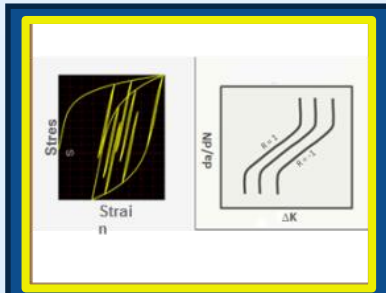
Flight Data

Inspection & Maintenance Data

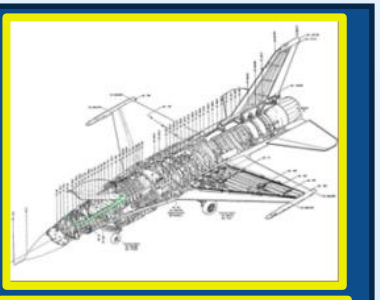
DTw requires FDR & Mx data feedback, including certain types of onboard sensor data when available.

Record Usage

Assess Actual Condition



Material Properties



Tail-number-specific Geometry

Manufacture/Repair/Replace

DTw requires accurate as-built & as-maintained configuration data.

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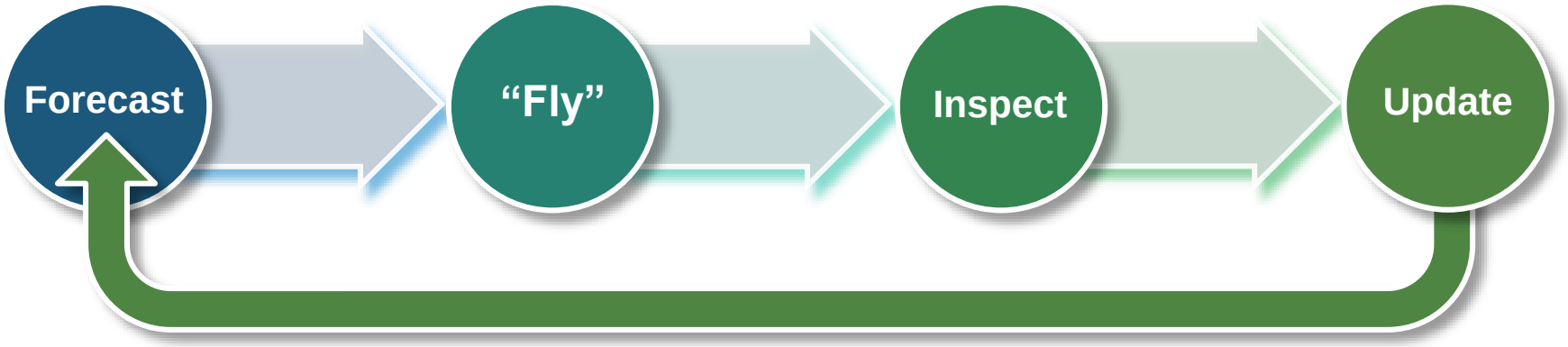
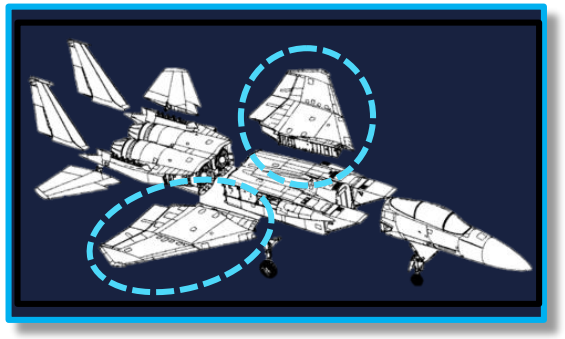
Exciting Results: Laboratory-based Proof of Concept

One-of-a-kind Full-scale Structural Experiment



External Aerodynamic Loads from Individual Flights Applied to Aircraft Wings in AFRL’s Full-scale Structural Validation Facility



Demo Underway
Target Completion Date 12/19

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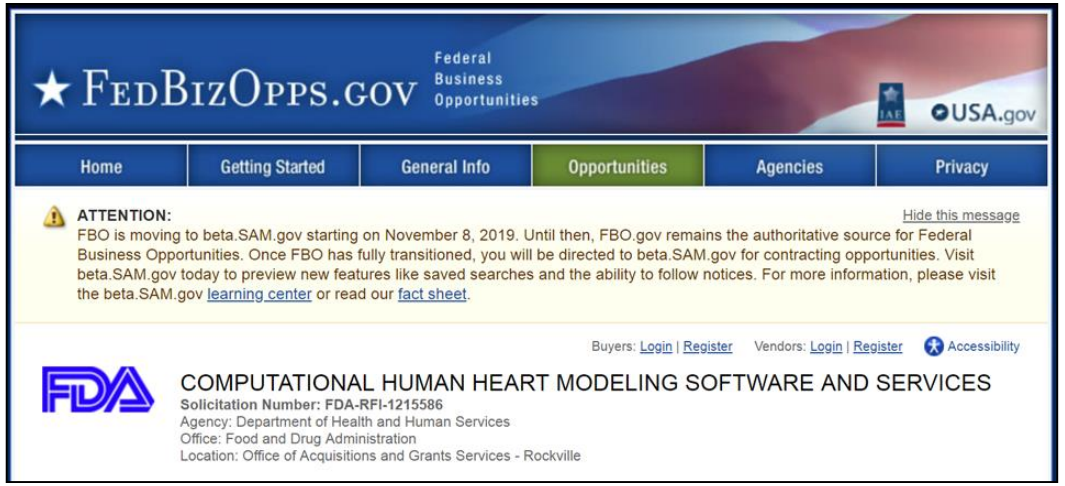
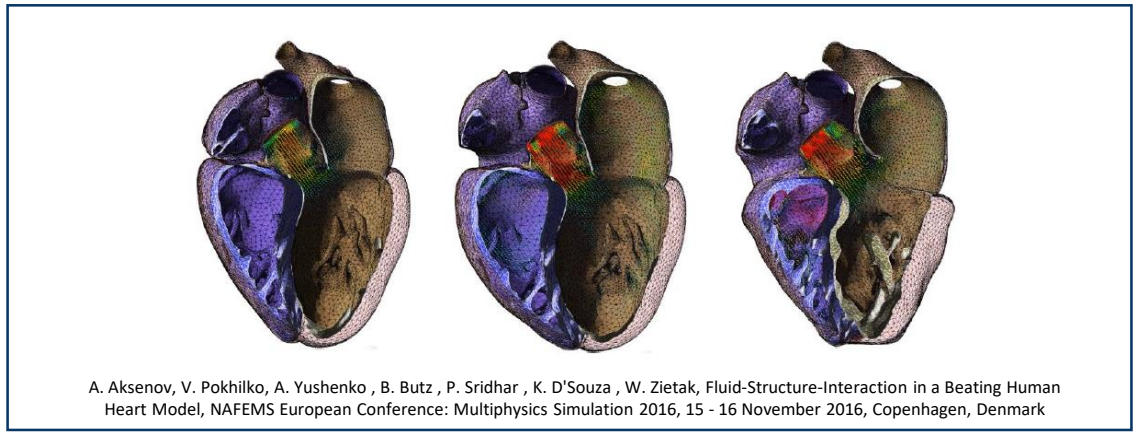
Frontiers: U.S. FDA's Computational Human Heart Modeling



"capability to perform whole human heart computations with a virtually implanted generic medical device …using high-performance cloud computing"



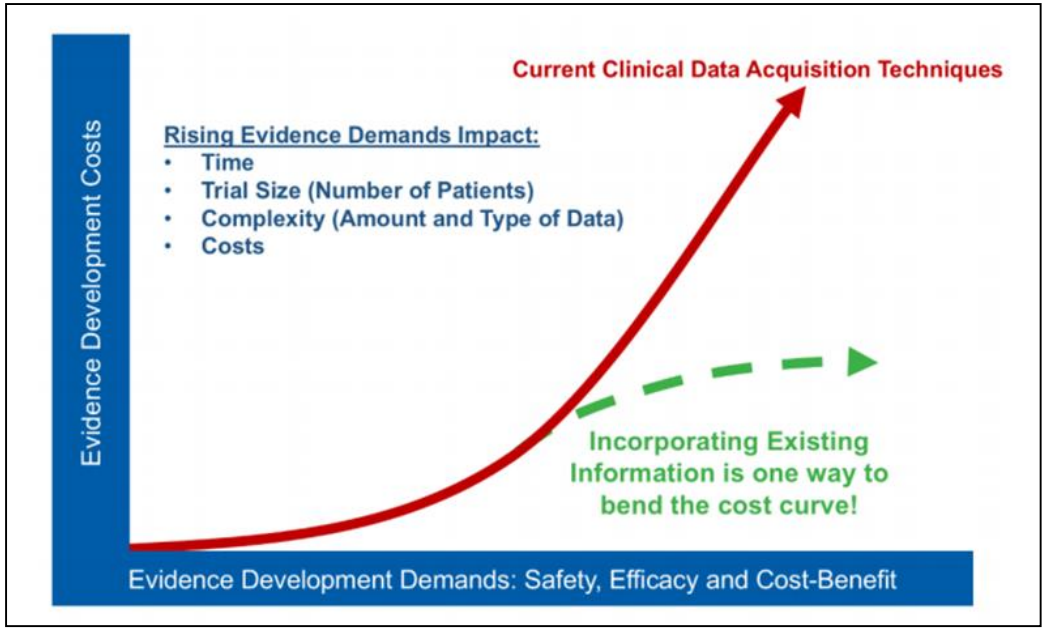
A. Aksenov, V. Pokhilko, A. Yushenko , B. Butz , P. Sridhar , K. D'Souza , W. Zietak, Fluid-Structure-Interaction in a Beating Human Heart Model, NAFEMS European Conference: Multiphysics Simulation 2016, 15 - 16 November 2016, Copenhagen, Denmark

The ENRICHMENT in silico Clinical Trial

A Dassault Systèmes – U.S. FDA Joint Project

"demonstrate how digital evidence in the form of VPs* can be used to significantly reduce the time, cost, and risk with human clinical trial data collection"

**VPs= virtual patients*



Summary

SUSTAINING OPERATIONAL CAPABILITY

OPERATE

USAGE DATA

WHEN

SIMULATE

STATE DATA

WHAT

MAINTAIN

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For Discussion: Limitations & Challenges

- Determining what information to present to the decision maker and how often to update it
- Determining the proper level of fidelity for the simulations
- Developing methods to reduce the order of underlying models to reduce computation time
- Deciding how much to tailor the simulations to the individual asset/operator
- Developing affordable, reliable means of collecting state and usage data
- Developing computationally efficient methods of updating probabilistic simulations
- Developing methods to validate probabilistic simulations
- Developing methods to synthesize usage and state data
- Protecting personal privacy and intellectual property
- Securing data and models
- Addressing liability for operational failures

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