Predicting Remaining Useful Life of CAD/PADs Devices Utilizing *Sensorless Digital Twins*

2022

Smarter Decisions. Faster.

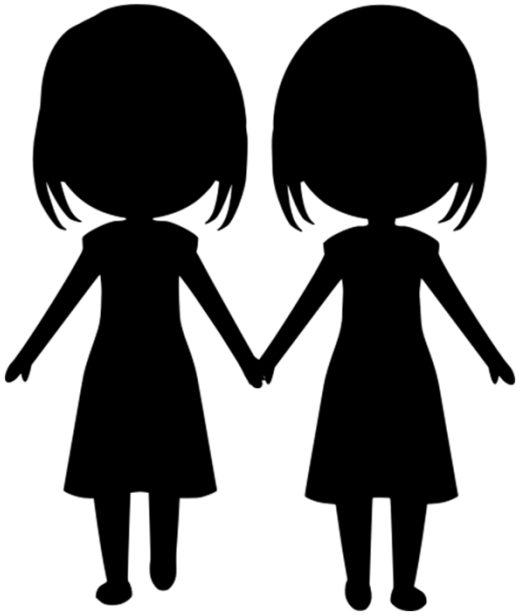
Topics

- Why – The Problem Addressed
- Digital Twin – What is That?
- Approach Chosen
- Key Issues Resolved
- Results

The Problem

- Calendar based replacement of F/A-18 CAD/PADs devices
  - Potentially Unsafe - Occasionally does not prevent adverse events
  - Is Wasteful

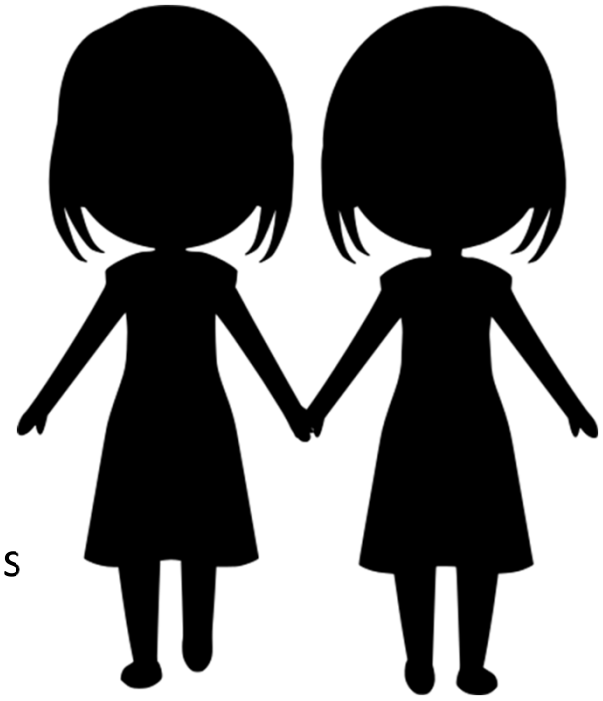
- Both problems impact
  - Readiness
  - CAD/PADs inventory cost
  - CAD/PADs inventory adequacy



Could Digital Twins Help Manage Remaining Useful Life?

Today, What do you mean, *"Digital Twin?"*

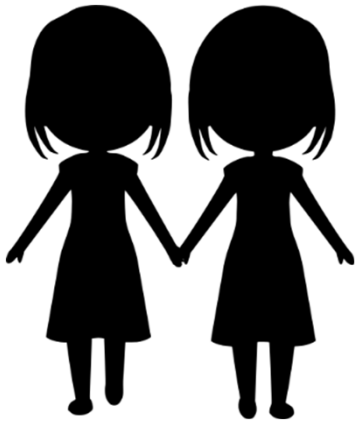
- **Agreed meaning** – matching the characteristics of items individually (for example, by seral number) to a digital representation – the digital representation is the twin
- Different & even contradictory definitions/nuances
  - *Configuration twin* – what is the configuration of this particular item?
  - *Functional twin* – how should this item perform? (simulation, or SYSML description)
  - *Failure twin* – how are stressors accumulating toward this item's failure?
  - *Hybrid twin* – some combination of these



Not all "Twins" are Identical

Two Types of Digital Twins

Automatic Data Feeds, Continuous Operation



Batch or Data Base Fed On Demand Operation

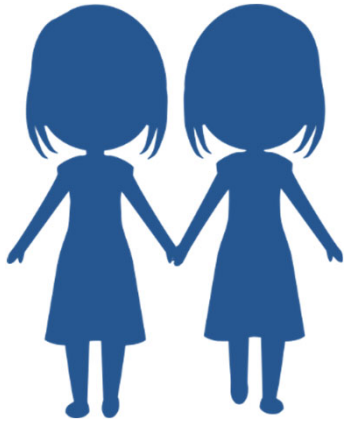
- **Continuous models** operate over long periods of time
  - Send alerts or call for action as needed
  - Queries by human operators are optional, available on demand
  - Can run anywhere but usually on an edge device, or in a cloud
- **Batch models** operate on demand
  - Can run on a laptop

Approach to the CAD/PADs Digital Twin

- Lone Star has created many twins for diverse customers and applications
  - Oil production assets
  - Aerospace systems
  - Transportation rolling stock
  - Combined cycle electrical power generation

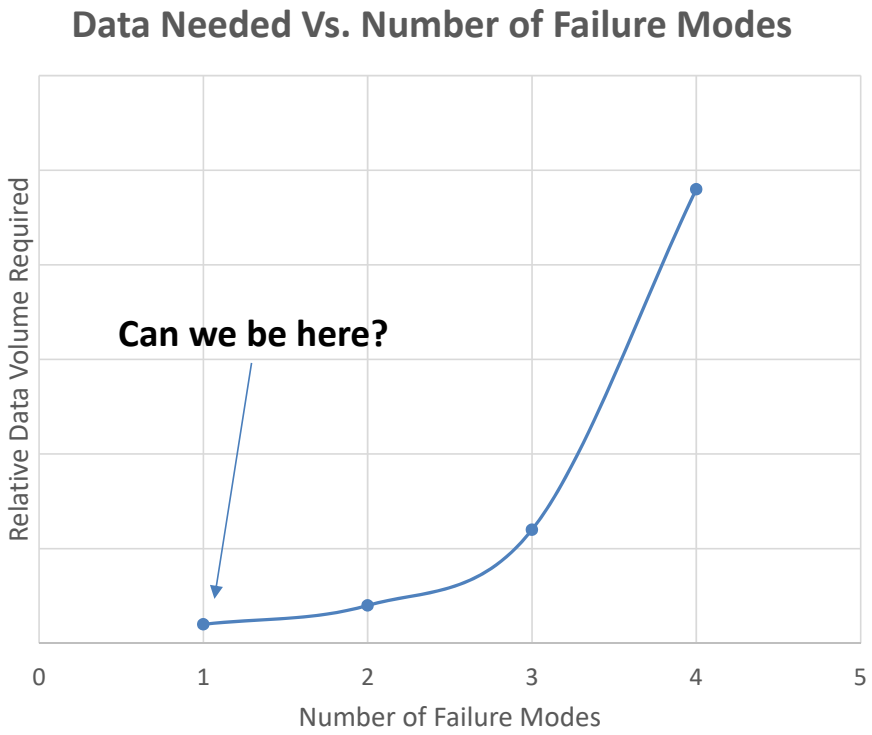
- Based on experience with digital twins the following choices defined the CAD/PADs proof of concept
  - Batch, on demand
  - Failure Twin (or a Hybrid)

Batch or Data Base Fed
On Demand Operation



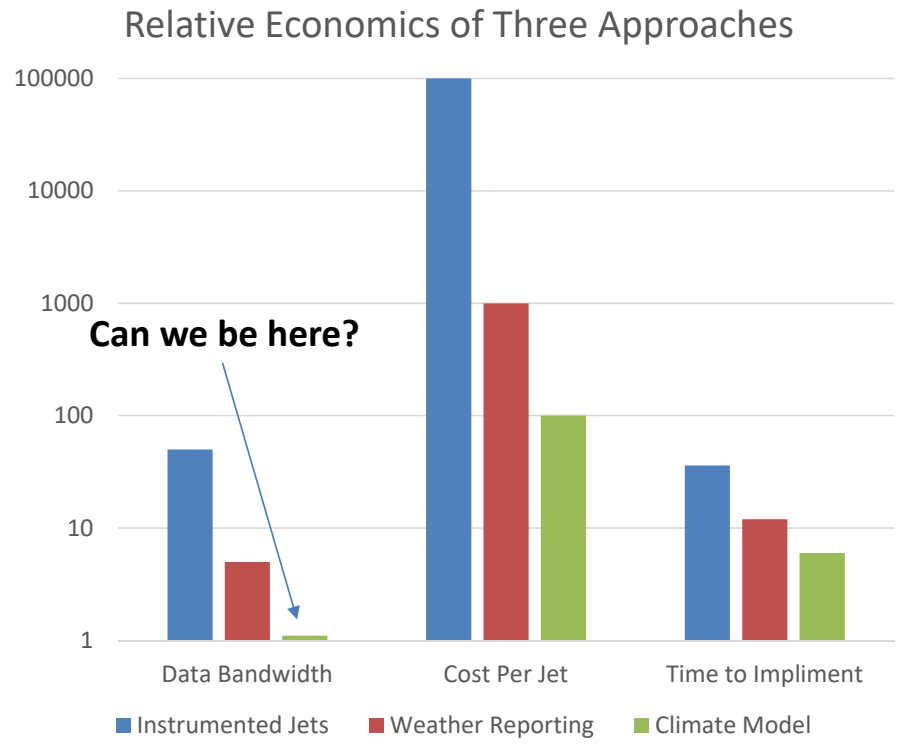
What Failures to Predict?

- Failure prediction is the beginning of “Information Economics”
- Data collection and processing grows with the number of failures
- For the modeled devices, ***stabilizer depletion seemed to be the one failure mode “that mattered”***



What data should drive the depletion twin?

- Several alternatives but generally:
  1. Instrument each F/A-18
  2. Map live weather data to the location of each jet
  3. ***Use a generalized climate model (no live weather) - SENSORLESS***
- Agreed to avoid instrumentation - weather based, or climate-based temperature input to the twin
- DECKPLATE data includes BUNO location; Navy data which already existed
- Climate only was desirable, but would it work?
  - Navy previously collected some data on Hornet cockpit interior conditions
  - Lone Star funded an IRAD effort to collect more thermal data with the help of China Lake



CAD/PADs Sensorless Digital Twin

CAD/PADs Digital Twin Project

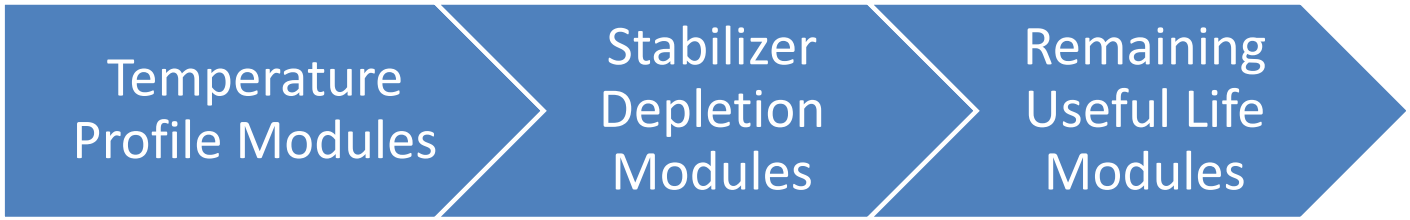
CAD/PADs Digital Twin project focused on three questions:

1. Can a digital twin be developed that provides accurate measurements and predictions of remaining useful life of device stabilizers?
2. Is the current RCM approach to removing and replacing devices after two years of service impacting safety and readiness?
3. Can a digital twin be created to achieve results without adding sensors?

Project Results

- Digital Twin parallels reality by device and BUNO generated results consistent with expectations
- Digital Twin does not require additional aircraft sensor installations
  - Developed using previously conducted thermal studies, historical weather data, regression analysis, and existing stabilizer depletion equations
- Analysis suggests replacing devices after 2 years of service introduces a safety risk in some cases and sub-optimizes life of components in others
  - Depending on location, stabilizer depletes in as little as 12 months or in excess of 5 years
  - CAD/PADs are routinely tested after removal and in some cases have shown greater than 90% of effective stabilizer life remaining
- Results highlight the need to transition from Calendar Based Service Life to Condition Based Service Life

Digital Twin Architecture



Model Overview

- The objective of the model is to estimate when a CAD/PADs should be replaced due to low effective stabilizer levels
  - PDRM, USRM, and WB-15 devices are supported
- The analyst configures the model by selecting the BUNO and device, for each month of the simulated period (single input)
- The model simulates a period of 60 months with an analyst defined start date
- The model supports 50+ pre-defined locations
  - Selected the top fifty locations in historical data (2020 - present) representing 99.5% of total location hours
- The effective stabilizer remaining for each device (PDRM, USRM, WB-15) is estimated for each month of the simulated period

Model Layout

User selects BUNO and Device Type

Regression Parameters

Calendar Calculations

Mechanite-19 Parameters

Solar Calculations

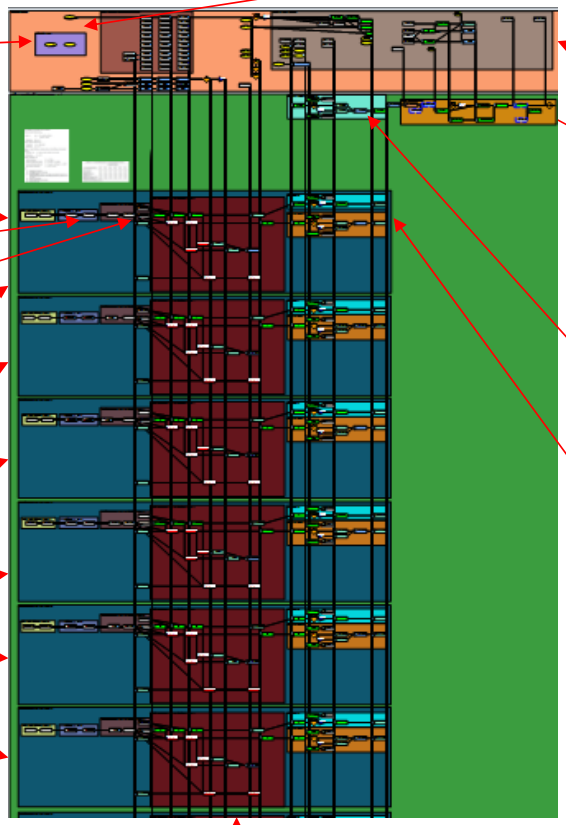
Irradiance

Device Replacement Calculations

Outside Temp Est

Energy Exposure from "Controlled Environment"

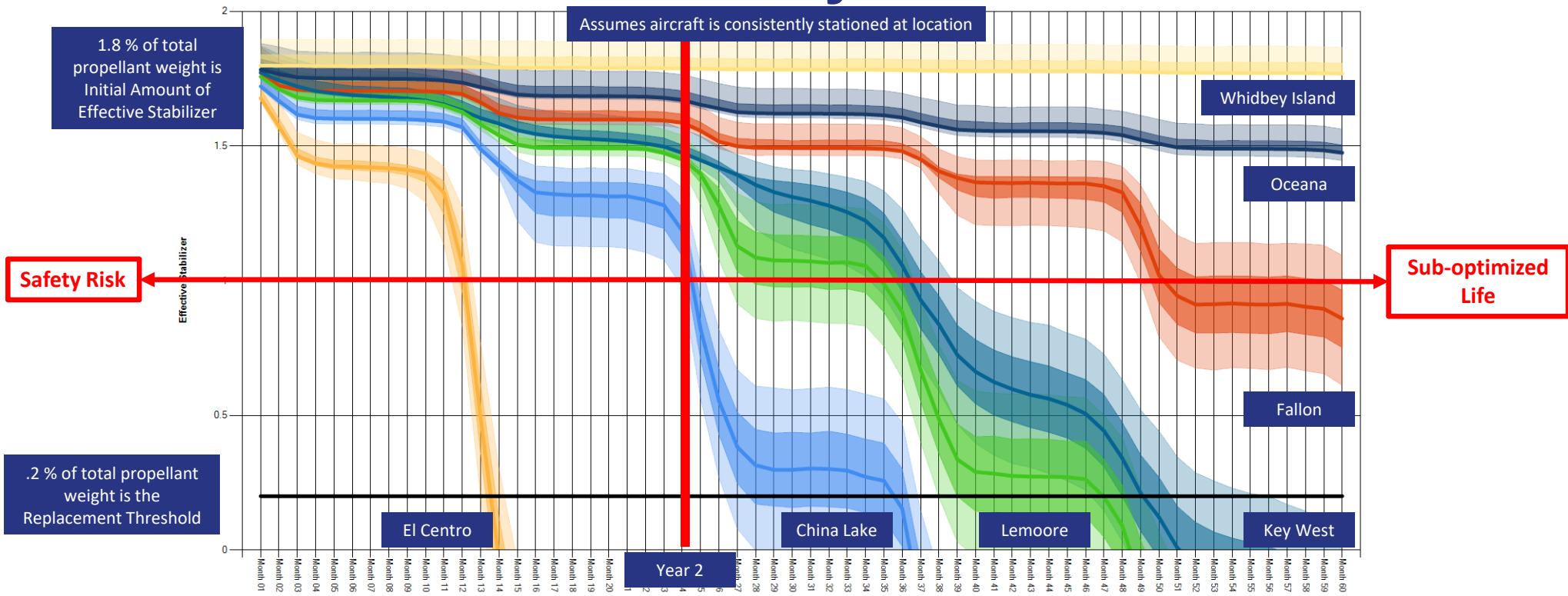
Each Row represents a single hour of the day:
Hour 0
Hour 1
Hour 2
…
Hour 23



Device Energy Exposure

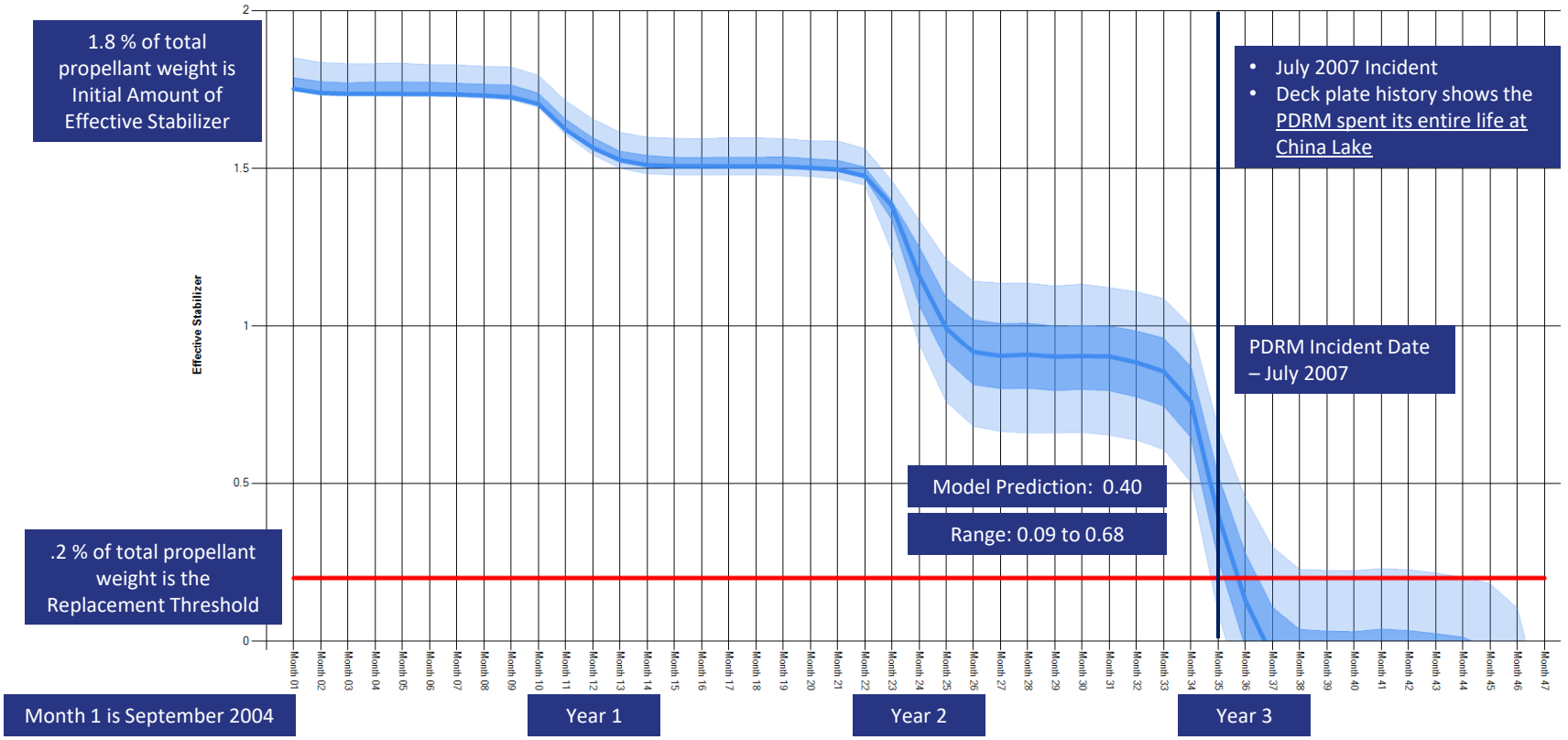
Device Temp Estimates

Effective Stabilizer Levels by Location



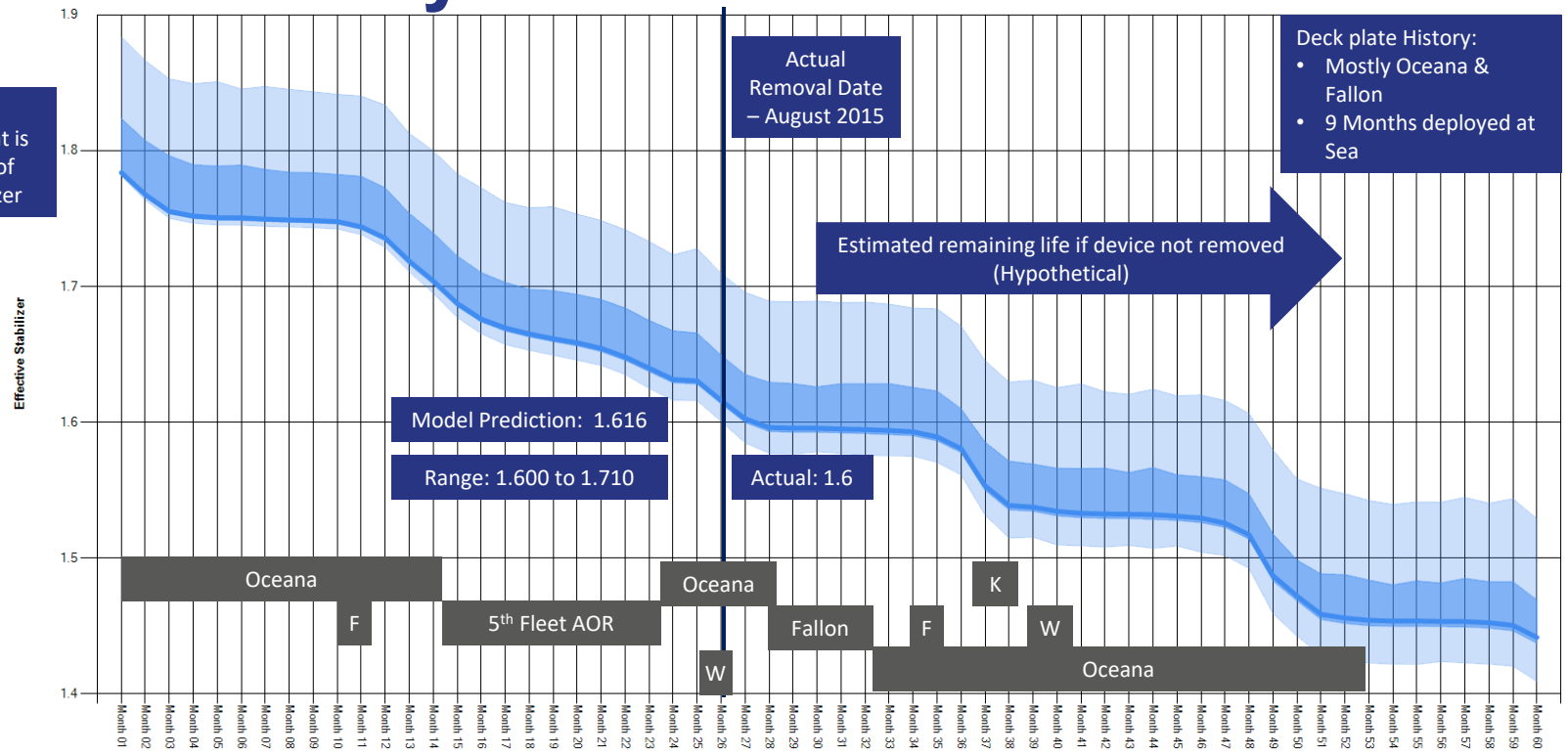
Policy of removal and replacement after 2 years of service does not provide optimal utilization or elimination of risk

Validation: July 2007 Incident



Validation: Early Removal

1.8 % of total propellant weight is Initial Amount of Effective Stabilizer



Month 1 is July 2013

Year 1

Year 2

Year 3

Year 4

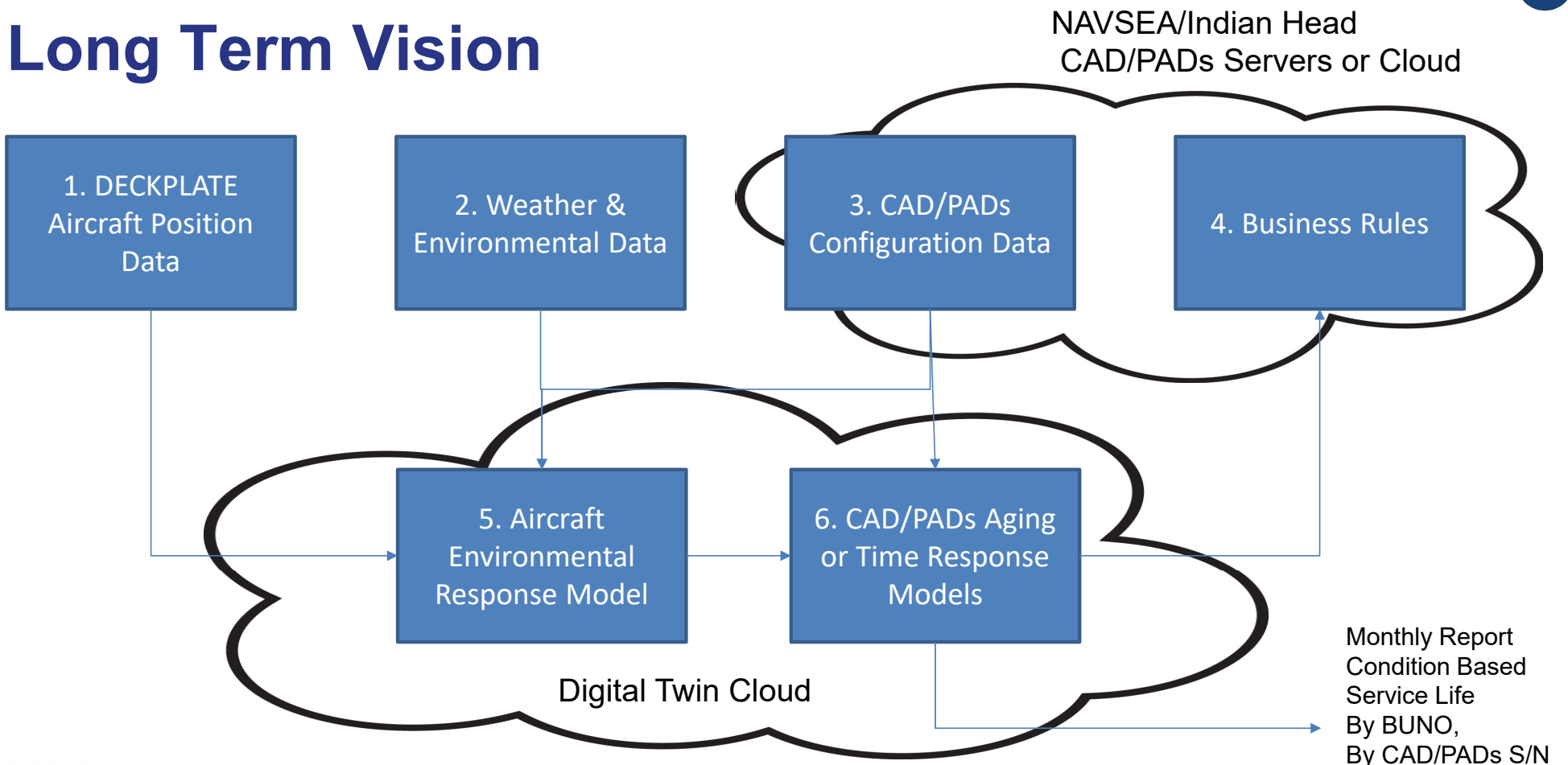
Year 5

Benefits of Condition Based Service Life

- Accurate predictions of operational performance and remaining service life improves aircrew safety margins by establishing real-time health assessments at the individual component level
- Digital twin prescriptive capabilities at the component level:
  - Improves operational readiness by minimizing unnecessary maintenance actions and providing the ability to systematically align removals with scheduled maintenance
  - Extends the life of a majority of individual components, reducing cost by eliminating unnecessary removals
  - Optimizes maintenance cycles through conditional maintenance of individual items vs. managing by the lot
  - Mitigates CAD/PADs shortages and obsolescence issues by reducing component demand

Digital twin technology is the key to migrating from Calendar Based to Condition Based Service Life

Long Term Vision



More than 1,000,000 Twins by CAD/PADs S/N?

Summary

- There are many kinds of digital twins; this effort built FAILURE TWINS of the Hornet cockpit CAD/PADs
- Aggressive information economics helped lower the cost of development and the cost of ownership
- CAD/Pad Digital Twins prove that sensorless modeling is both achievable and effective
- Condition Based Service Life – Promises Many Advantages
  - Improves operational readiness by minimizing unnecessary maintenance actions
  - Pinpoints optimal life replacement intervals
  - Optimizes maintenance cycles
  - Mitigates CAD/PADs shortages and obsolescence

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