The Inherent Need for Holistic Structural Integrity Application and Progress

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Overview

- Introduction to the HOListic Structural Integrity Process (HOLSIP)
- HOLSIP concepts and 50+ year historical perspective
- Digital engineering/transformation
- Aging F-16 issues (and how HOLSIP can help)
  - Fracture Critical Structure
  - Risk
  - Corrosion
- Conclusion and recommendations

Holistic Structural Integrity Process

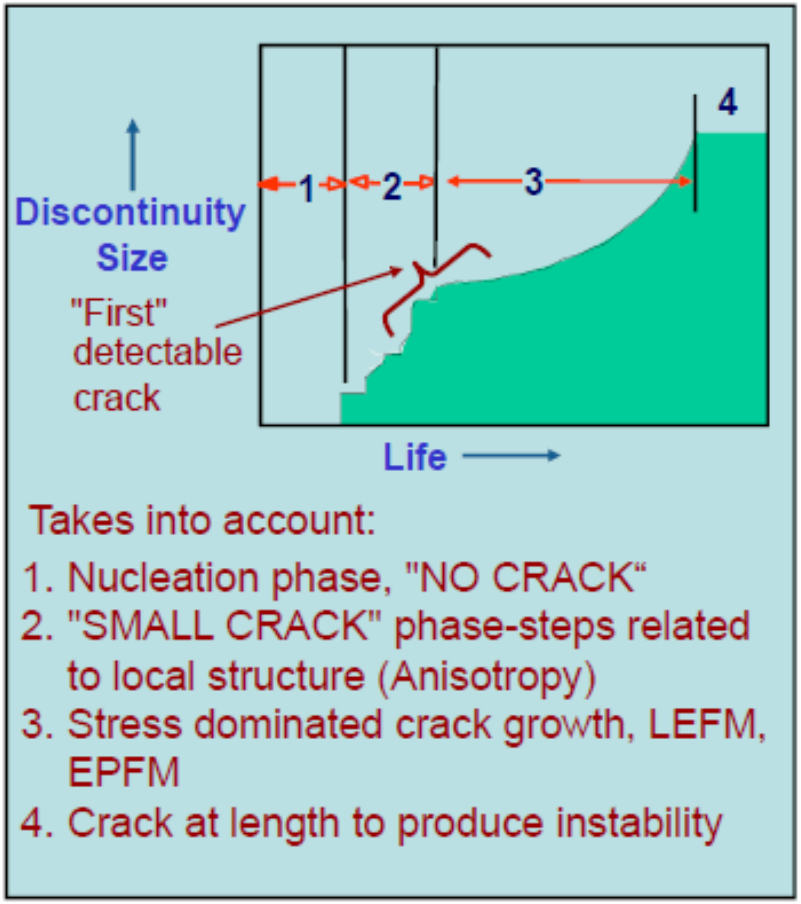
- HOLSIP is based on the fundamental idea that failure modes or mechanisms are interconnected
- HOLSIP is a physics based structural integrity design approach
  - Essential part of a reliability and integrity centered design system
- HOLSIP considers all fracture mechanisms for monotonic loading with consideration of the intrinsic nature of solids
  - Other ***extrinsic issues*** considered are rates of loading, temperature, time of loading, chemical environments, wear and contact mechanics, and neutron and other forms of irradiation
- Time dependent and time related mechanisms of degradation and their synergy are considered in HOLSIP

HOLSIP Elevator Pitch

- Whole life cycle design of engineered structures, including design, manufacturing, operation, retirement, ethics
- ….and really, so much more than aircraft structures!
- Examples of where HOLSIP has been applied include…
  - Art transportation at the Rijksmuseum in Amsterdam, Netherlands
  - Big mining trucks
  - Oil pipelines

HOLSIP in Terms of Cracks

- **Holistic Structural Integrity Process (HOLSIP)**
  - ***Motivation:*** **augment safe-life and damage tolerant paradigms.**
  - ***Key elements:*** **physics based model, probabilistic modeling, advanced NDI.**



Where did HOLSIP come from?

- Many early fatigue and fracture mechanics pioneers created the framework
  - Griffith, noted discontinuities existed in solids
    - Irwin, Orowan, Peterson, Neuber, Hartman, Crichlow, and many others contributed through research
- Hoeppner
  - Approached by corporate legal council attorney who pointed out that a crack or intrinsic discontinuity does not equal defect or flaw (1971)
    - Defective parts are very bad in the legal and technical world!
  - Terminology is important
    - HOLSIP has list of terms and definitions
    - See Swift ICAF 2011 and Hoeppner, ICAF 2011 and AGARD Greece, 1992

First International Symposium on Corrosion Fatigue

- Held at U of Connecticut, 1971
  - Hoeppner, D. W., Featured keynote paper- Corrosion Fatigue Considerations in Materials Selection and Engineering Design, A systems based framework for introducing corrosion, corrosion fatigue, creep fatigue, and fretting fatigue into engineering design.
    - Corrosion Fatigue, NACE 2, pp 3-11
    - Edited by McEvily, Staehle, Devereux
    - Published by NACE, Houston, TX, 1972
- Later to become basis of HOLSIP (1980)

Hoeppner Paper, 1971

USE OF SYSTEMS APPROACH TO DESIGN FOR CORROSION AND CORROSION FATIGUE, 1971- CURRENT

NUCLEATION ← IDENTIFY PROBLEM → PROPAGATION

Control corrosion or fretting and stress levels to eliminate/ prevent corrosion or fretting

Protect surface
- plating
- anodizing

2 Sacrificial coating
3 Cathodic protection
4 Change material

5 Inhibitors

6 Shielding

7 Inspection
8 Repair

→ Change material response to the environment

→ Change or modify the environment separate the environment and material

PROPAGATION GOAL → After creation of d*, h* from initial d*, h*

Control environmental contribution to allow life prediction, inspection, and maintenance based on baseline information

1 Separation

2 Baseline data
3 Environment
- Frequency
- Loading sequence

4 Inspection

STEPS TO IMPLEMENT CORROSION FATIGUE PREVENTION PLAN

I Obtain baseline information and effect of environment for conditions of interest (load spectra/frequency)
II Change material response to the environment
III Change or modify the environment
IV Separate the environment and material
V Obtain propagation information and set inspection intervals

Where did HOLSIP come from? (cont.)

- Early 2000s, USAF financed a Corrosion Fatigue Structural Demonstration Program
  - LM Aero was the prime contractor; subs included NRC-Canada, University of Utah, and APES, Inc.
    - Basic research on Initial Discontinuity States (IDS) of aluminum alloys was one of the topics studied – developed understanding of constituent particle types, sizes, and shapes and they were physically identified and modelled
    - Corrosion fatigue and associated physics-based modeling were included in the program
    - Definitions and terminology developed to establish consistent framework to avoid inconsistency

Where did HOLSIP come from? (cont.)

- Players from CFSD were founding members of the HOLSIP movement (left to right):
  - David Hoeppner (University of Utah, FASIDE, Int.)
  - Jerzy Komorowski (NRC-Canada)
  - Craig Brooks (APES, Inc.)
  - Nick Bellinger (NRC-Canada)

20+ Years of HOLSIP Advancement

- Holistic ideas and concepts have been presented in journal articles, conferences and other meetings
  - Associated ICAF paper summarizes some of these
    - Shütz, Bellinger, Gallagher, Komorowski, Hoeppner, G. Clark, P. Clark, Swift, Brooks, Molent & Dixon, and Lindgren included
- Aircraft are being flown well past design life
  - Damage tolerance is often not enough to deal with aging aircraft issues and maintain aircraft availability

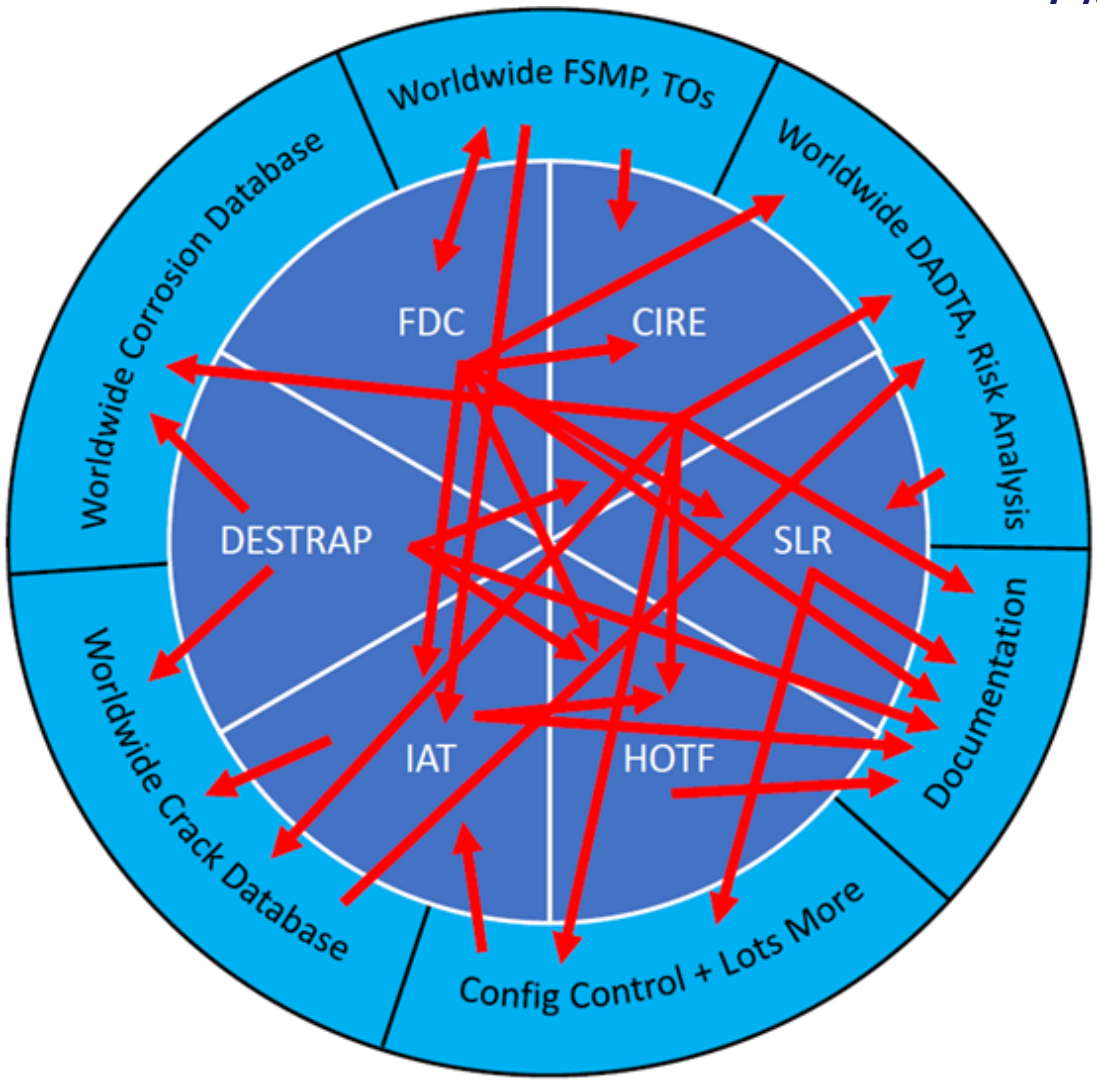
Digital Engineering/Transformation as a Part of HOLSIP

- United States Air Force has been driving towards advanced digital engineering
  - Presentation at 2021 ASIP Conference by Mr. Thomas Fischer detailed the USAF digital campaign
    - Cited the importance of data and seamless data sharing as drivers to speed and agility
  - Mr. Charles A. Babish wrote a whitepaper in response to Fischer's presentation
    - Defined digital engineering as "the use of models and data for design, analysis, structural certification, and sustainment to enable informed decision making over the entire life cycle"
    - These digital engineering efforts are not new within ASIP
      - Practiced within the HOLSIP community to have the necessary data and analysis capabilities for whole life modelling concepts

F-16 ASIP Portal

- For more than 20 years, USAF F-16 SPO has developed and maintained the F-16 ASIP Portal for data and lifecycle management purposes
  - Engineering dispositions, inspection data, flight data recorder files, and service life information stored
    - Can be used for risk analyses, fatigue crack modelling/correlation, and maintenance planning
  - USAF F-16 data is combined with F-16 OEM information
    - Creates a powerful, data-driven tool needed to apply HOLSIP principles
      - Improves aircraft inspection intervals
      - Better manage aircraft life

F-16 ASIP
Engineering "Threads"



Fracture Critical Parts

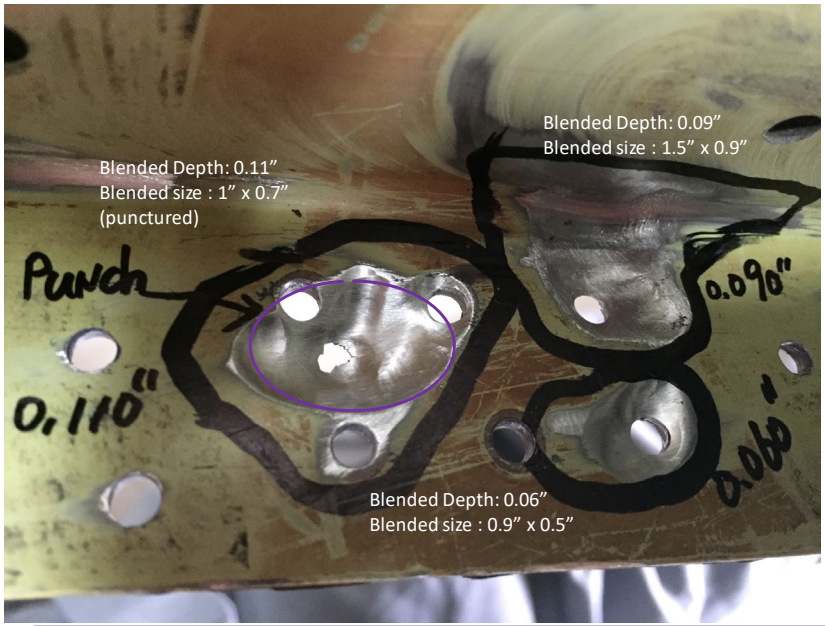
- Major current F-16 concern:
  - Fracture critical part
  - Part condition (gouges/scrapes/cracks)
    - Gouges not acceptable using either damage tolerance or holistic principles without characterization/analysis
  - Surface preparation for eddy current inspection

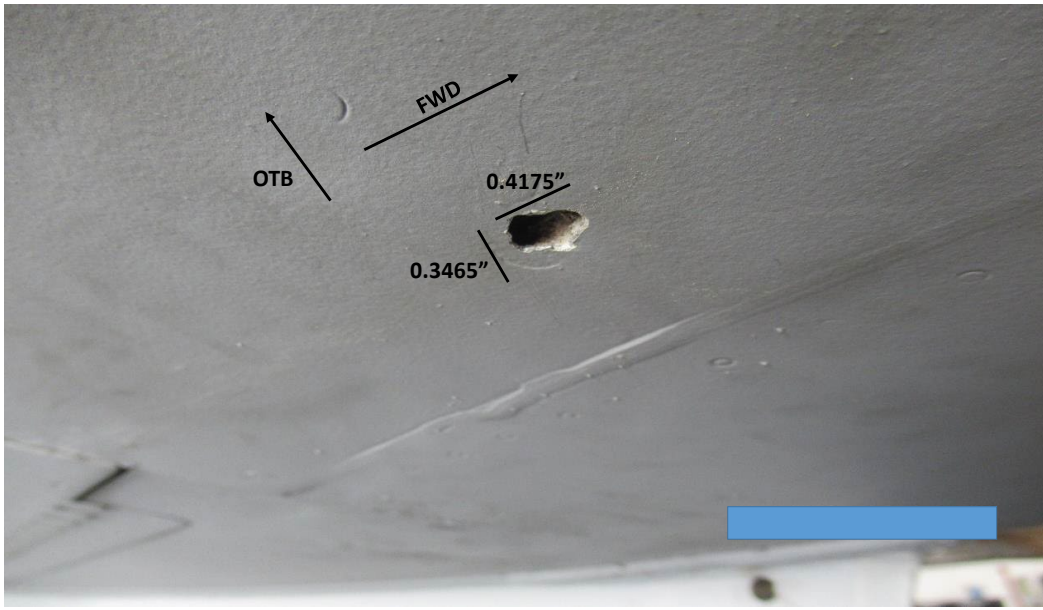
Practical Risk Analysis

- Prioritize depot inductions
  - Required due to limited depot capacity
- Multiple risk analyses considered to maximize induction intervals for applicable aircraft
  - Primary risk driver is lower end pad radii on center fuselage bulkheads near wing attach bolts/fuselage structure
  - Inspection and blend data critical for risk assessments and aircraft re-evaluation
- Flight data recorder and inspection info, combined with risk assessments critical to overall success of this individual aircraft effort

F-16 Corrosion Analysis Examples

- Guidance is limited on how to account for corrosion
- Various areas of corrosion including F-1 fuel cell and lower longerons and frames beneath the cockpit
  - Difficult to analyze and repair; lots of corrosion variability
- Corrosion variability can be human caused





The future is now…

- F-16s already have corrosion
  - If we abide by the “thou shalt have no corrosion” (or fretting) rules, all aircraft should likely be grounded
  - Find and fix will not be sufficient for the future
    - Already insufficient for F-16s
      - Repair programs in place to specifically identify and repair known corrosion problem areas
      - Several severely corroded aircraft were down for years being repaired/parts replaced
  - Fail safe analyses performed to determine urgency of fixing problem areas
    - Favorable results, allows for triage of aircraft for depot repair inductions

The future is now…(cont.)

- Using HOLSIP principles to understand the physics behind the degradation will improve models
  - LEFM models not sufficient currently to predict impact of damage being found
- Groups are proactive in using these concepts with efforts such as Engineered Residual Stress Implementation (ERSI)
- Use/creation of time based degradation models needs to gain traction in order to improve aging issue related safety, reliability, and ultimately, aircraft availability

Conclusions

- HOLSIP can be applied throughout the entire lifecycle for:
  - Engineered structures design
  - Manufacturing
  - Operations
  - Retirement
  - Ethics
- 50+ years of HOLSIP development and 20+ years of intentional holistic practice
  - Moved past some limitations of traditional design paradigms and LEFM
- Continued use and development critical to aging aircraft (and many other applications) safety, reliability, and availability

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HOLSIP 2019

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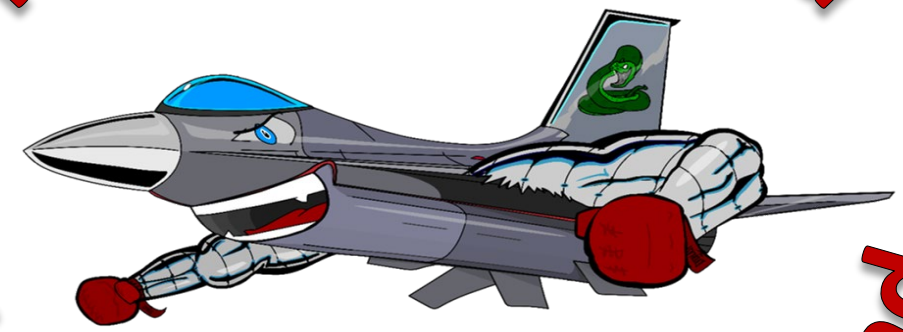
Pound For Pound



The Best Fighter Around