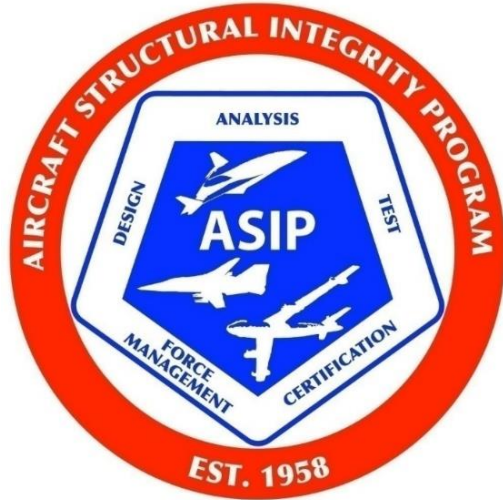


31st ICAF Symposium
Delft Netherlands, 26-29 June 2023



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

Chuck Babish
U.S. Air Force (USAF)



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Outline



- **DE Background**
- **ASIP Background**
- **DE for ASIP Goals**
- **ASIP Task II, Structural Design & Analyses**
- **ASIP Task V, Force Management**
- **Other Near-Term Focus Areas**
- **Summary**



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USAF Digital Engineering [1]



Key purpose:

“... achieving a measure of authoritative virtualization that replaces, automates, or truncates formerly real-world activities”

Key activities:

- Develop digital models of systems**
- Develop digital twins and digital threads**
- Implement an integrated digital environment**



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Some Key “Digital” Terms





Some DE Examples



- **3D Computer Aided Design (3D CAD) models or Model Based Definition (MBD)**
- **Air Vehicle Finite Element Model (AV-FEM)**
- **6 Degree of Freedom (6-DOF) models**
- **External loads models**
- **Dynamic response models**
- **Product Lifecycle Management (PLM) tool**
- **Select force management tools for:**
 - **Aircraft usage data collection & reporting**
 - **Individual Aircraft Tracking (IAT) execution**
 - **Aircraft maintenance data reporting**
 - **Engineering disposition request & response**



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USAF ASIP



Established 12 Jun 1958 in response to 4 B-47 aircraft losses in 1 month due to fatigue failure of structure [2,3]



Aircraft	Date	Failure Location	Number of Flight Hours	Cause of Failure
B-47B	13-Mar-58	Center Wing, BL 45	2,077	Fatigue
TB-47B	13-Mar-58	Center Wing, BL 35	2,419	Fatigue
B-47E	21-Mar-58	Disintegration	1,129	Fatigue
B-47E	10-Apr-58	Wing to Fuse Fitting, FS 515	1,265	Fatigue
B-47E	15-Apr-58	Disintegration	1,419	Overload?

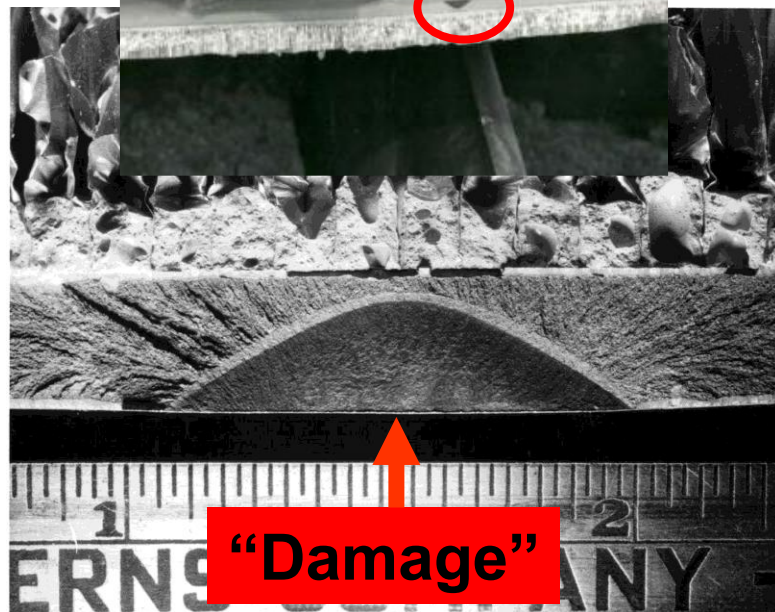
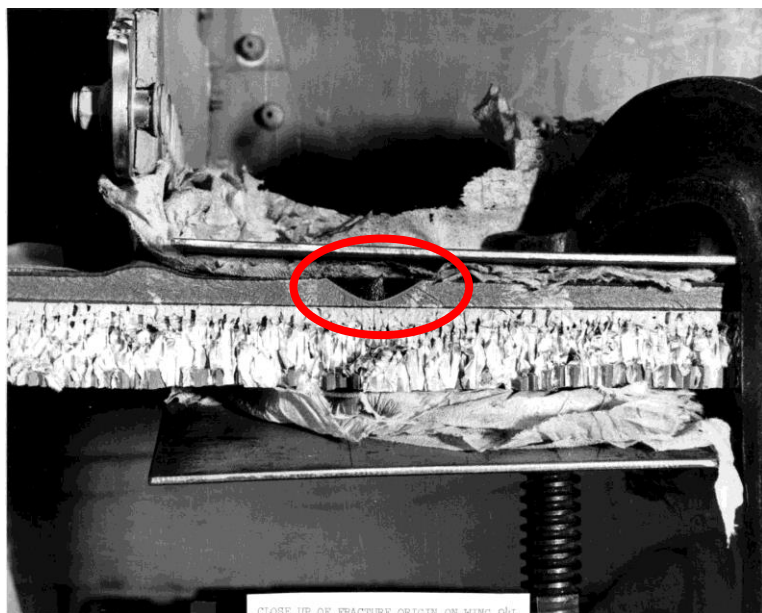
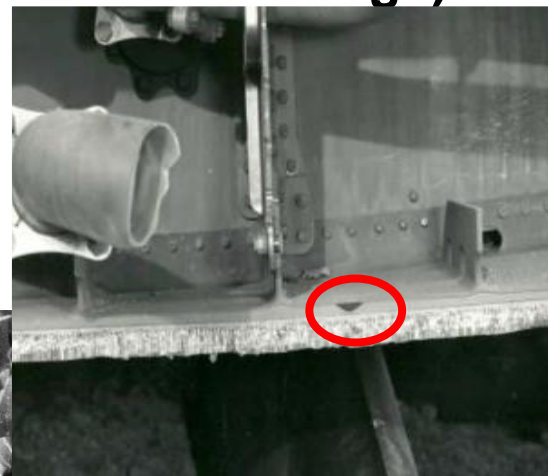


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ASIP Damage Tolerance Update

- F-111 loss on 22 Dec 1969 and F-5 loss on 20 Apr 1970 demonstrated ASIP fatigue controls not effective [2,3,4]
 - F-111 structural failure due to fatigue cracking from a manufacturing defect (design unable to tolerate damage)





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ASIP MIL-STD-1530D [5]

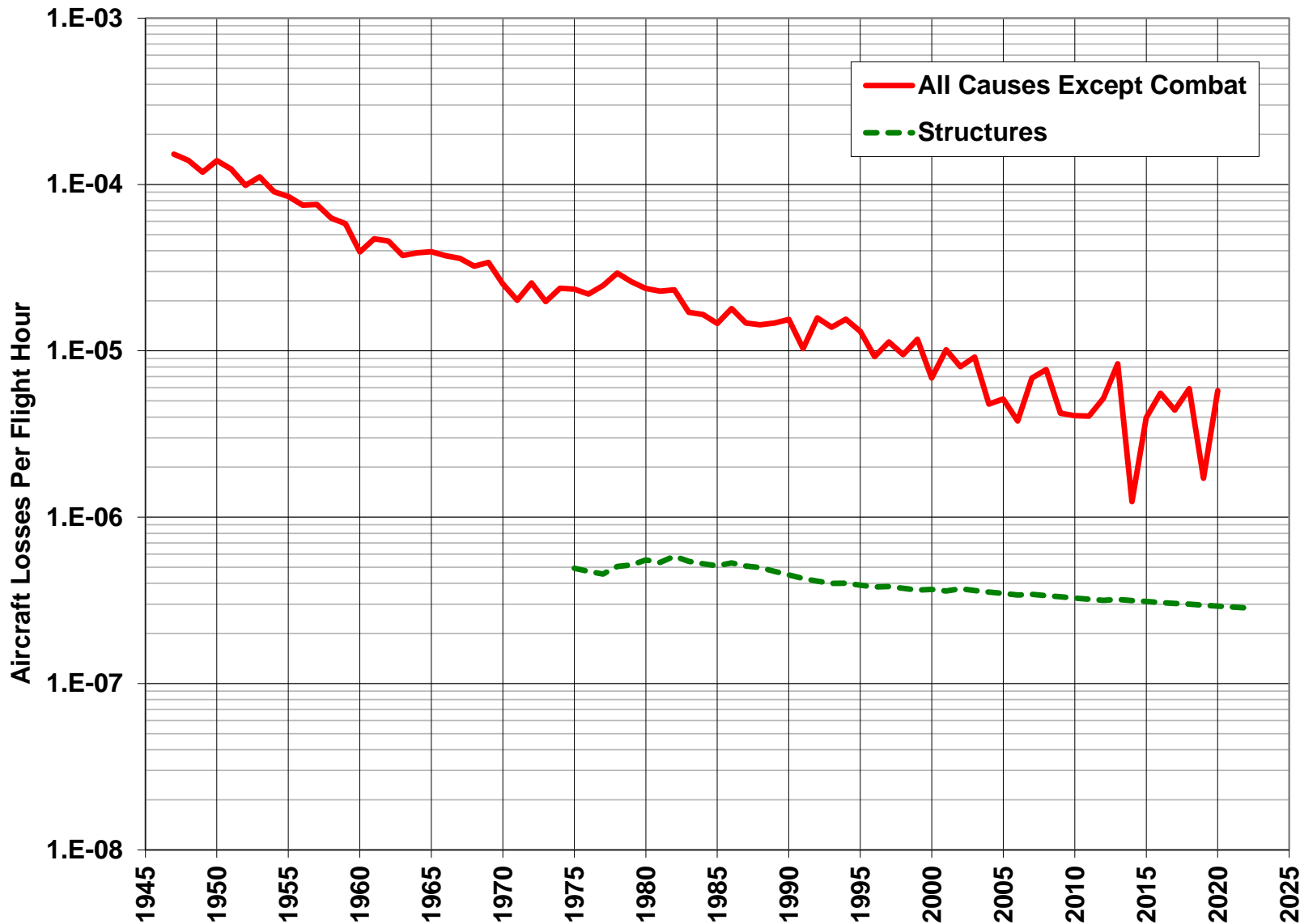


Task I	Task II	Task III	Task IV	Task V
Design Information	Design Analyses & Development Testing	Full-Scale Testing	Certification & Force Management Development	Force Management Execution
1. ASIP Master Plan	1. Materials and Structural Allowables	1. Static Tests	1. Structural Certification	1. L/ESS Execution
2. Design Service Life & Design Usage	2. Loads Analysis	2. First Flight Verification Ground Tests	2. Strength Summary & Operating Restrictions (SSOR)	2. IAT Execution
3. Structural Design Criteria	3. Design Loads/Environment Spectra	3. Flight Tests	3. Force Structural Maintenance Plan (FSMP)	3. DADTA Updates
4. Durability & Damage Tolerance Control	4. Stress and Strength Analysis	4. Durability Tests	4. Loads/ Environment Spectra Survey (L/ESS) System Development	4. L/ESS and IAT System Updates
5. Corrosion Prevention & Control	5. Durability Analysis	5. Damage Tolerance Tests	5. Individual Aircraft Tracking (IAT) System Development	5. NDI Updates
6. Nondestructive Inspection	6. Damage Tolerance Analysis	6. Climatic Tests	6. Force Management Database Development	6. Structural Risk Analysis Updates
7. Selection of Materials, Processes, Joining Methods & Structural Concepts	7. Corrosion Assessment	7. Interpretation & Evaluation of Test Findings	7. Technical Orders	7. CPC Plan & Corrosion Assessment Updates
	8. Sonic Fatigue Analysis	8. Resolution of Test Findings		8. Analytical Condition Inspection
	9. Vibration Analysis			9. FSMP Updates
	10. Aeroelastic and Aeroservoelastic Analysis			10. Technical Orders Updates
	11. Mass Properties Analysis			11. Repairs
	12. Survivability Analysis			12. Structural Maintenance Database Execution
	13. Design Development Tests			13. Structural Certification Updates
	14. Structural Risk Analysis			14. Economic Service Life Analysis Updates
	15. Economic Service Life Analysis			15. Others as Required

Evolved from Initial 1972 to Rev D in 2016, Rev E In Work



One Measure of ASIP Success





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Outline

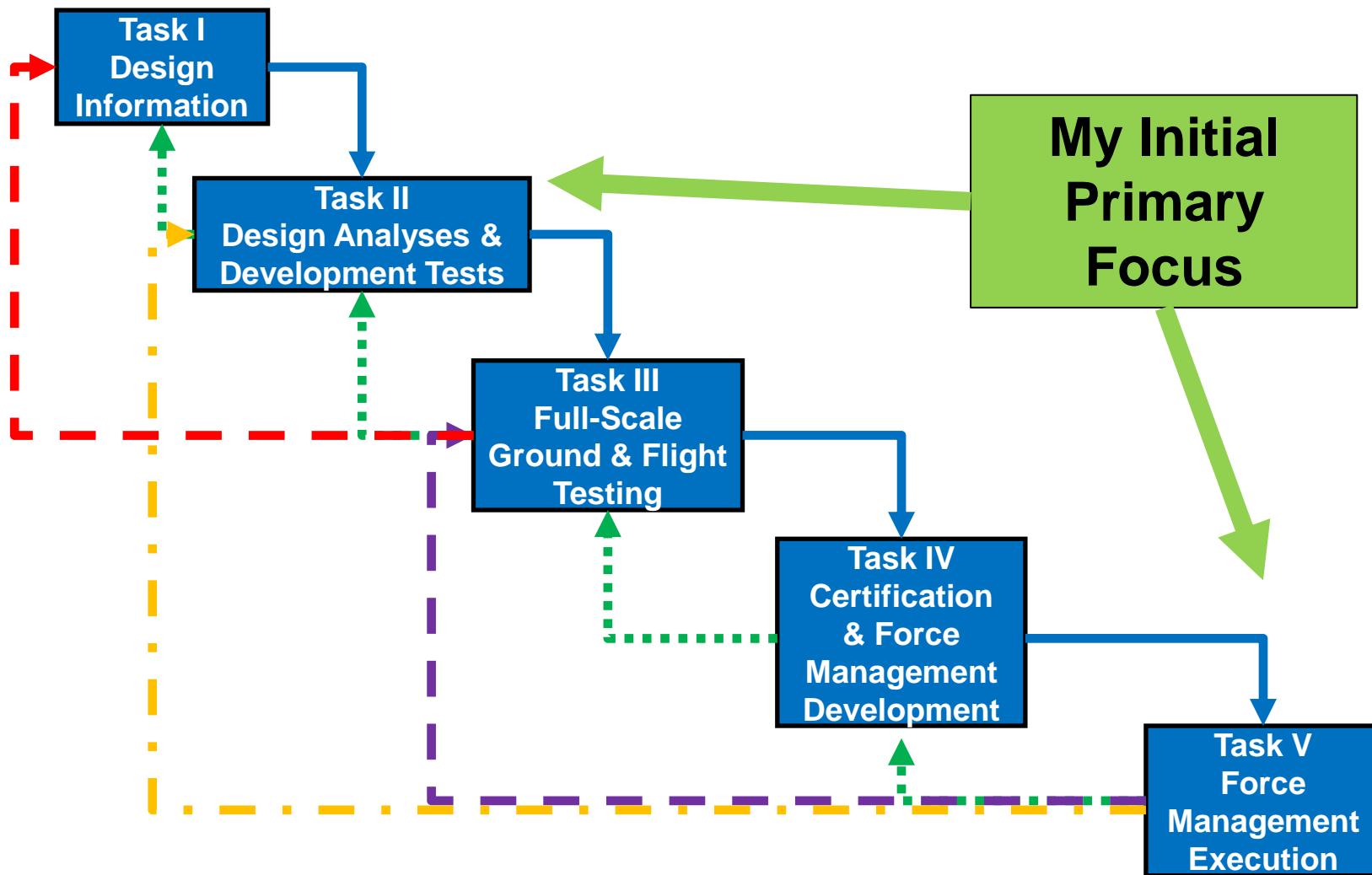


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ASIP Execution

Sequential & Iterative & Repetitive



DE Goal: Make Overall ASIP Execution More Efficient



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Example of Digital Thread Complexity; Service Life



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	13. Design Development Tests			13. Structural Certification Updates
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DE Goal: Establish Digital Threads to Link Data with Needs for it



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Task II
Design Analyses & Development Testing
1. Materials and Structural Allowables
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3. Design Loads/Environment Spectra
4. Stress and Strength Analysis
5. Durability Analysis
6. Damage Tolerance Analysis
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8. Sonic Fatigue Analysis
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11. Mass Properties Analysis
12. Survivability Analysis
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14. Structural Risk Analysis
15. Economic Service Life Analysis



ASIP Task II

Structural Design & Analyses



Major Structural Design Activities

- ▶ "Preliminary"
- ▶ "Design To"
- ▶ "Verification"
- ▶ Others

External Loads

Changes to:

- Design Maturity
- Aero Database
- Flight Control Laws
- Mass Properties
- Etc.

"Preliminary" Focus:

- Achieve Subset of SDC
- Optimize Weight

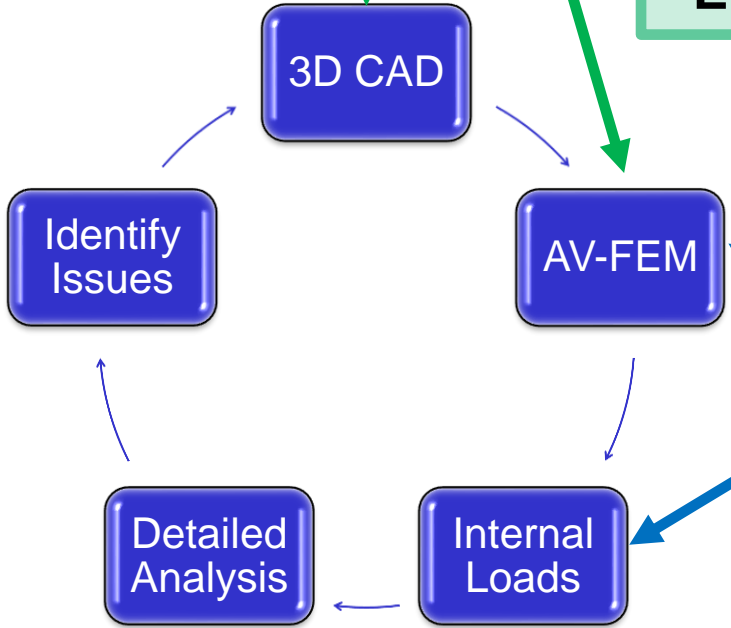
"Design To" Focus:

- Achieve all SDC
- Integrate all Systems
- Resolve Weight Crisis

"Verification/Others" Focus:

- Fix Test Discoveries
- Resolve Cost Crisis

SDC: Structural Design Criteria



Reduced scope for some iteration loops?

DE Goal: Increase Use of Digital Models & Data & Threads to Reduce Design Iteration Time-Span and Quantity



ASIP Task II

Structural Design & Analyses



- **Focus on highly iterative & repetitive tasks**
- **Automate topology optimization (major load paths & part arrangements) and part sizing optimization (part details & joints) considering as many structural design criteria as practical**
 - **Example for wing carry-through bulkheads:**
 - **Number & locations (e.g., 3 or 4 or...)**
 - **Arrangement of pockets & stiffeners for each**
 - **Pocket-by-pocket web & stiffener sizing**
 - **Joints, fittings, cutouts, etc. sizing**
- **Automate digital transfer of optimization results to 3D CAD for design & AV-FEM incorporation**



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ASIP Task II

Structural Design & Analyses



- Automate extracting design details from 3D CAD and internal loads from AV-FEM into detailed analysis performed using automated tools for:
 - Yield & ultimate strength
 - Flange & stiffener crippling
 - Web buckling
 - Lug strength
 - Fastener loads & joint strength
 - Global stability
 - Durability and damage tolerance considerations in terms of stress allowables (detailed analysis still required)
 - Etc.



Outline

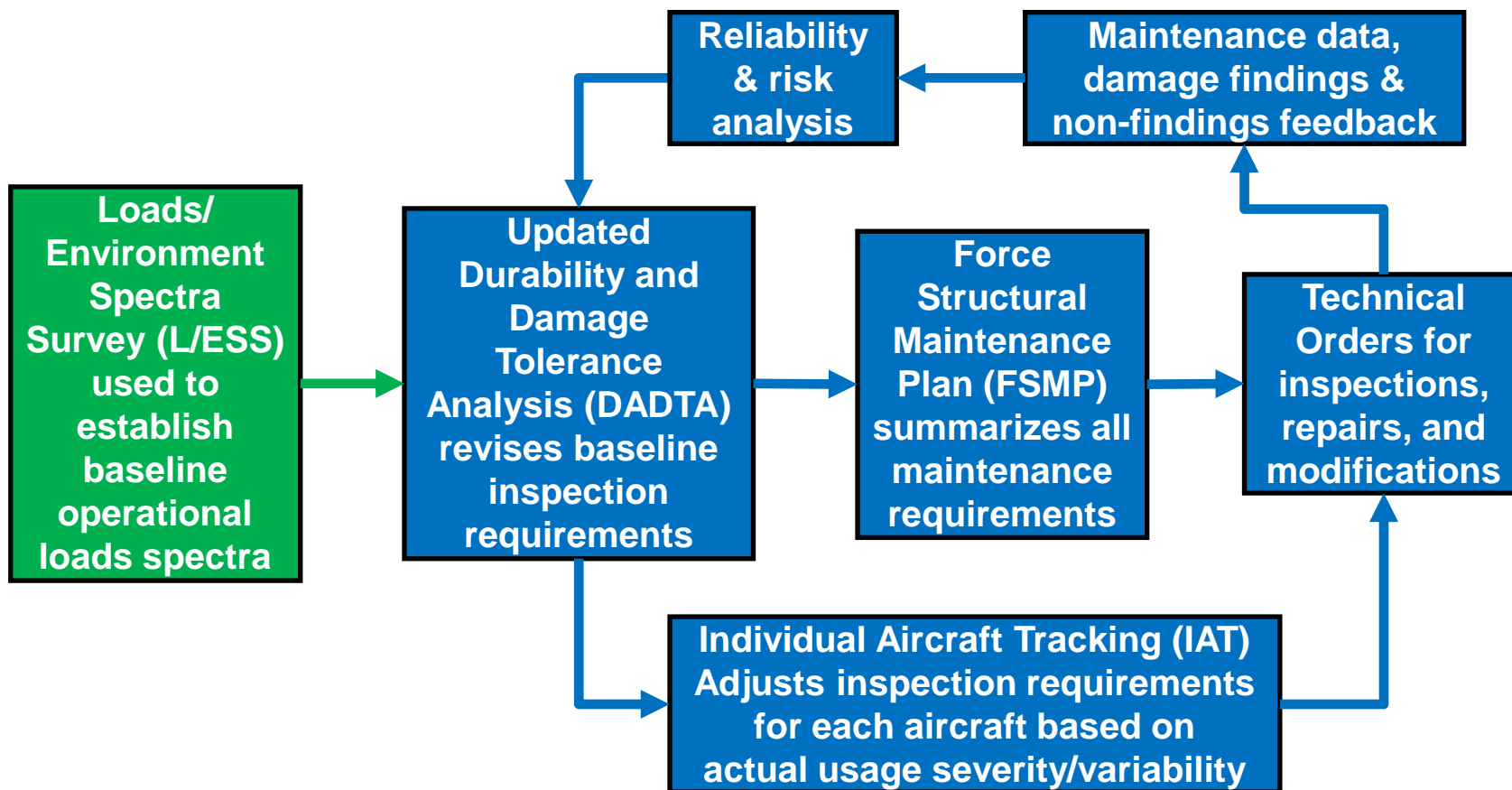


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Task V
Force Management Execution
1. L/ESS Execution
2. IAT Execution
3. DADTA Updates
4. L/ESS and IAT System Updates
5. NDI Updates
6. Structural Risk Analysis Updates
7. CPC Plan & Corrosion Assessment Updates
8. Analytical Condition Inspection
9. FSMP Updates
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ASIP Task V Force Management



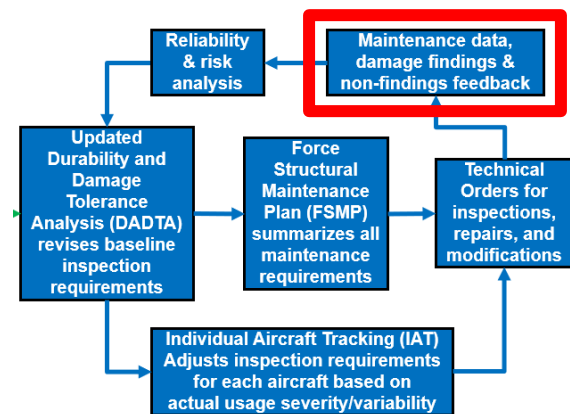
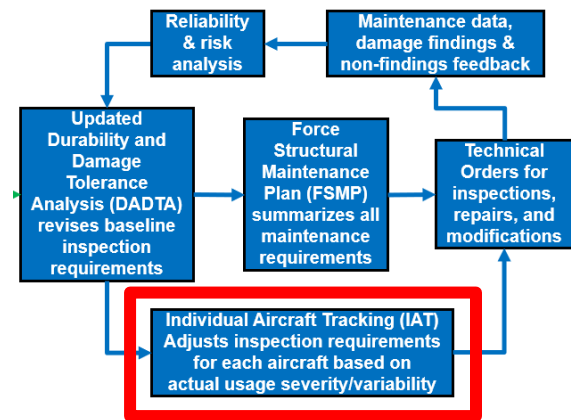
DE Goal: Automate Usage & Maintenance Data Feedback & Updates



ASIP Task V Force Management



- Focus on highly repetitive tasks
- Digital IAT tool: integrate & automate flight data collection & transmission, IAT calcs, revisions to maintenance tasks & intervals, force structure projection...
- Maintenance Data tool: automate capture of inspections performed, damage findings (location, type, size, etc.) & non-findings, repairs, part replacements...

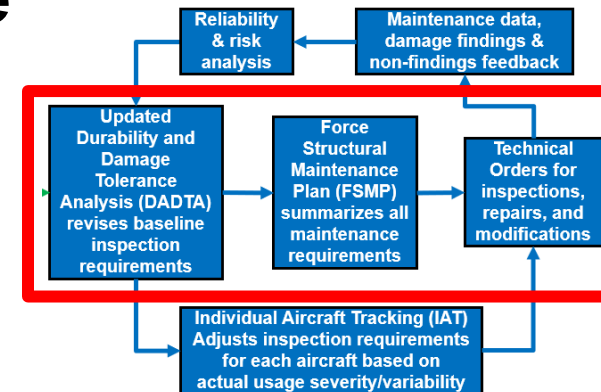
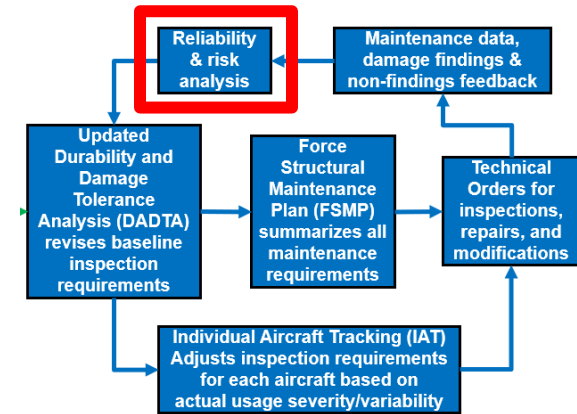




ASIP Task V Force Management



- **Reliability & Risk Analysis tool:** automate comparisons of damage probability distributions with predictions using Digital IAT and Maintenance Data tools
- **Digital Force Management Update tool:** use Reliability tool and usage data to determine when update is required and automate DADTA & FSMP updates and changes to maintenance requirements





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ASIP Task V

Force Management



- **Ultimate goal: Probabilistic Force Management Capability**
 - Determine probability of failure for each aircraft
 - Determine remaining life for each aircraft
 - Account for all significant sources of variability & uncertainty
 - Allow for user selected future usage and maintenance options
 - Quantify safety & availability & cost impacts
- Requires more comprehensive data integration & modeling of materials, designs, manufacturing, maintenance, usage, environments, sensing, etc.



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Other Near-Term Focus Areas



- **Ground testing**
 - Test loads & test adequacy evaluations
 - Test data comparisons to predictions
 - Digital record of test loading, instrumentation, etc.
 - **NOT ELIMINATION!!!**
- **Flight testing**
 - Continuation & knock-it-off criteria execution
 - Test data comparisons to predictions
 - Digital record of test conditions, instrumentation, etc.
- **Certification**
 - Linkage of models & data to Airworthiness certification criteria for showing & finding compliance



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Summary



- **ASIP is a disciplined approach for structural design development, certification, and force management**
- **DE journey for improved ASIP execution started decades ago**
- **However, more improvement is needed and possible**
- **Collectively we should take advantage of the increased emphasis on DE to further improve ASIP execution**
- **Priorities for structural design & analyses and force management described**



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Acronyms



- **DE: Digital Engineering**
- **ASIP: Aircraft Structural Integrity Program**
- **USAF: United States Air Force**
- **3D CAD: 3-Dimensional Computer Aided Design**
- **MBD: Model Based Definition**
- **AV-FEM: Air Vehicle Finite Element Model**
- **6-DOF: 6 Degree of Freedom**
- **PLM: Product Life-Cycle Management**
- **IAT: Individual Aircraft Tracking**
- **SDC: Structural Design Criteria**
- **L/ESS: Loads/Environment Spectra Survey**
- **DADTA: Durability and Damage Tolerance Analysis**
- **FSMP: Force Structural Maintenance Plan**



References

- [1] Official memorandum sent to all USAF members (2021)
- [2] Babish, C. (2008), *USAF ASIP: Protecting Safety for 50 Years.*, Proceedings of the 2008 ASIP Conference.
- [3] Tiffany, C. and Gallagher, J. (2010), *ASC-TR-2010-5002, Threats to Aircraft Structural Safety, Including a Compendium of Selected Structural Accidents/Incidents.*
- [4] Lincoln, J. (1985), *Damage Tolerance – USAF Experience*, Proceedings of the 13th Symposium of the International Committee on Aeronautical Fatigue.
- [5] MIL-STD-1530D (2016), *Department of Defense Standard Practice, Aircraft Structural Integrity Program (ASIP).*



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Questions???

