In-Service Structural Health Monitoring (SHM) Applications

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Walter Jarecki – Boeing Nondestructive Testing, Customer Support
Zeb Tidwell – Boeing Airframe Engineering, Customer Support
Dr. Jeong-Beom Ihn – Boeing Technical Fellow, BR&T

In-Service Structural Health Monitoring (SHM) Applications

Objective & Agenda

Objective

- This paper presents an approach on how to select aircraft SHM applications. It will review features of Comparative Vacuum Monitoring (CVM) and Piezoelectric (PZT) sensors. The paper will share upcoming Boeing in-service nondestructive inspections and our approach to re-examine these areas for use of SHM technologies.

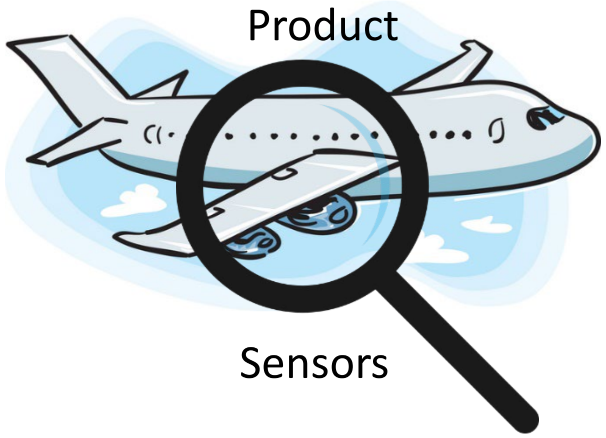
Agenda

- Structural Health Monitoring
- Regulatory Guidance
- Building Block Approach
- Approach for Selection
- Potential Next Application?
- Scheduled based Maintenance
- Future - Condition Based Maintenance
- Shared Data
- Summary

In-Service Structural Health Monitoring (SHM) Applications

Structural Health Monitoring

- A method to “Study of how a structures ages in regards to it performing its intended purpose”
  - Aging factors - loads/abuse/environment effects
- Monitor a product’s structural performance over time using periodically sampled response measurements to quantify changes to the material and geometric properties
- Use sensors (Piezoelectric transducer (PZT)/Comparative Vacuum Monitoring (CVM) to collect information - Data
- Data is ‘processed’ to provide ‘knowledge of a condition’ to allow for ‘decision making’ action. Acceptable/repair
- Data Science can also be used to benefit Boeing future airplane designs, manufacturing and maintenance



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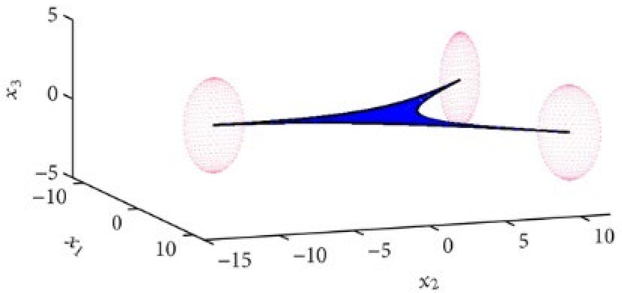
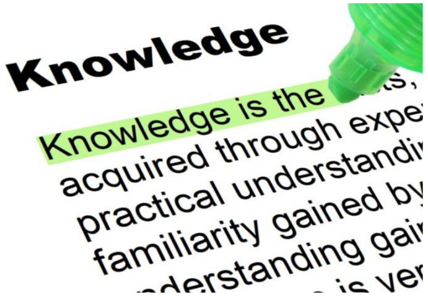


Process Information



Product Knowledge

Decision

In-Service Structural Health Monitoring (SHM) Applications

Regulatory Guidance

- Generic Issue Paper guidance on the use of sensors for inspection on new/existing type design
- ‘Target’ approach on specific airplanes structure that have known cracking issues
- Service Bulletins inspections are implemented where ‘known’ history of crack findings occur in fleet aircraft and are potential candidates for SHM applications
- Cert Plan is needed to address requirements for method of compliance

ISSUE PAPER

PROJECT:	*[Applicant]* Model *[make & model]* Project No. *[project number]*	**ITEM:** A-# **STAGE:**
REG. REF.:	14 CFR § 21.50, § 25.571, §25.1529, Appendix H	**DATE:**
NATIONAL POLICY REF:	AC 25.571-1D	**ISSUE STATUS:** Open
SUBJECT:	Qualification of a Structural Health Monitoring System for Detection of Damage in Structure	**OFFICE ACTION:** AIR-621, AED **COMPLIANCE TARGET:**

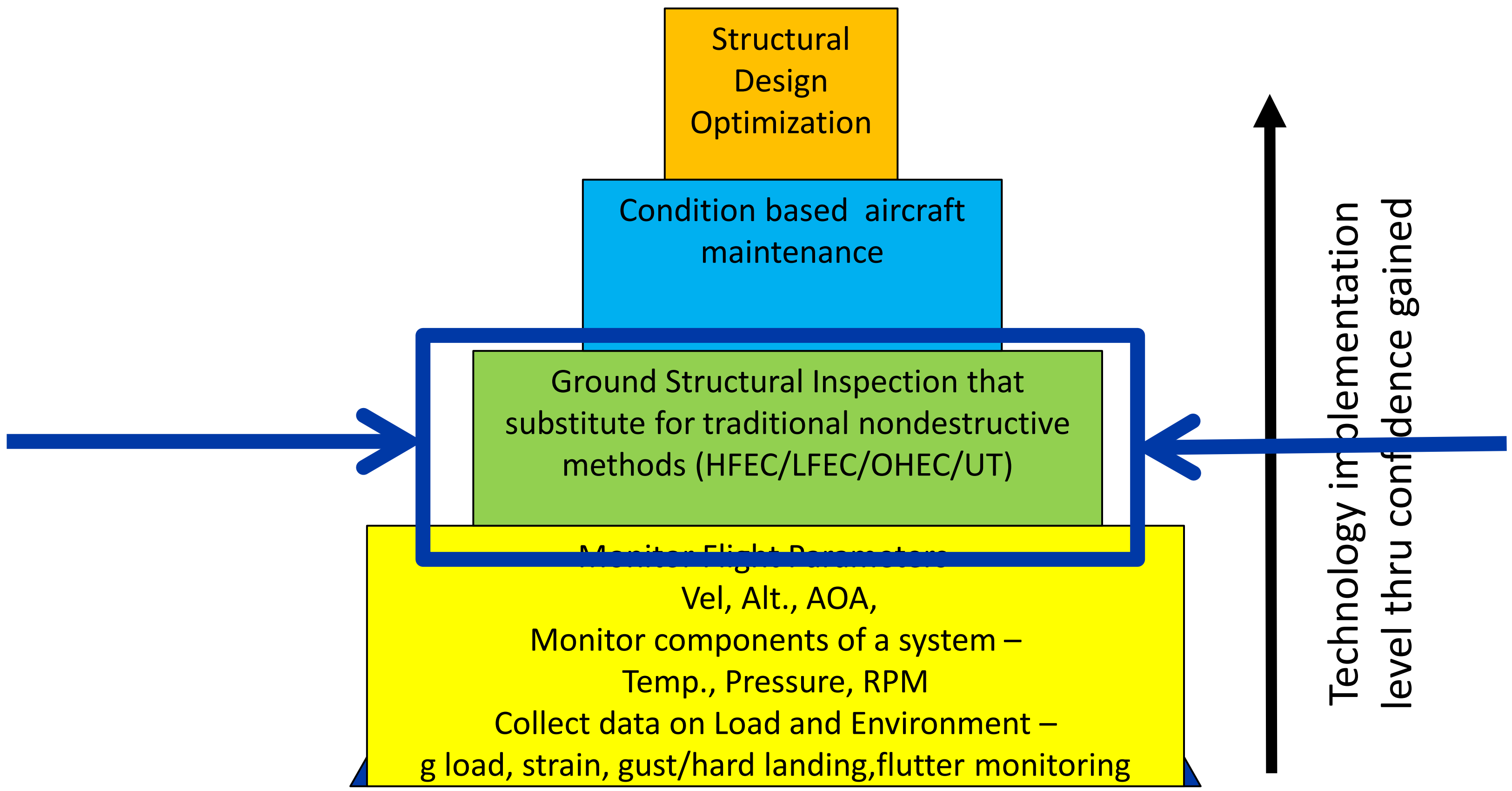
Method of Compliance

STATEMENT OF ISSUE:
The applicant proposes to install a Structural Health Monitoring (SHM) system on a model <Enter TCDS Model(s)> airplane. An SHM system evaluates the integrity of structure by acquiring and analyzing data from on-board sensors that interface with an electronic device (either on-board or off-board) that processes the data and provides an indication of the health of structure in terms of the existence of damage (e.g., fatigue damage). A SHM technology capable of reliably detecting damage of a specific nature and size over a specific line, area or volume is a candidate alternative to conventional non-destructive inspections (NDI) such as visual, eddy current, ultrasonic and X-ray inspections methods. This approach for detecting structural damage may supplement or eliminate the need for an inspector to physically access and assess structure. Over the past 30 plus years, industry has relied on accessing structure to assess its overall integrity and, as part of that assessment, perform NDI such as visual and eddy current inspections, to detect structural damage. The current industry practice and guidance used to validate conventional NDI techniques may not be adequate as a method of compliance with title 14, Code of Federal Regulations (14 CFR) 25.571 and 25.1529 for an SHM system. Therefore, this issue paper is necessary to establish an acceptable method of compliance.

BACKGROUND:
Section 25.1529 requires applicants to prepare Instructions for Continued Airworthiness (ICA) per Appendix H of part 25 that are acceptable to the Administrator. The Federal Aviation Administration (FAA) approves certain portions of the ICA, such as the Airworthiness Limitations Section (ALS). These ICA typically include manuals that contain procedures, or reference to procedures, and schedules for implementing NDIs (i.e., damage-tolerance-based inspections) established per § 25.571(a) and (b). The design approval holder (DAH) must develop and make ICA available to operators in accordance with the requirements of 14 CFR 21.50. In accordance with 14 CFR 26.47(c) for STC alterations that affect fatigue critical structure (FCS), the applicant (STC holder) must perform a damage tolerance analysis (DTA) and develop any necessary ICA

In-Service Structural Health Monitoring (SHM) Applications

Building Block Approach



In-Service Structural Health Monitoring (SHM) Applications

Current Implementation Approach and Benefits

- Faster inspections / indications
  - In-situ detection with less access/restoration
  - Reduce accidental damage associated with access/restoration
  - Solution for inspections not aligned with scheduled maintenance (C/D checks)

Equivalent or better continued airworthiness, safety and reliability level

In-Service Structural Health Monitoring (SHM) Applications

Approach for Selection

- Identify Service Bulletins (SB) or Maintenance Planning Data Items (MPD)

Opportunity Evaluation

Item	Threshold/ Repeat Interval (FC)	Active Fleet Size	Repeat Interval (FC)	Fleet Size	Access/ Removal	Meet Existing Safety Lndi Coverage	Environment (Fus/Wing)	Total	SHM Technique
737 Fus Aft Pressure Bulkhead (LFEC)	25,000/1,200	6,575							
737 Fus Frame Webs at Overwing Emergency Exits Between Stringer-	12,000/6,000	1,930							
757 Fus Section 46 - Body Station 1681 Frame Inspection	31,000/3,200	897							
757 Fus Section 46 - Body Station 1640 Frame Inspection	20,000/2,500	897							
747 Fus Section 41 - Main Frame STA 320 Crown Frame - Web	4,000/3,000	536							
737 Maintenance Planning Data (MPD) DTR 57-20-09 UT/HFEC	50,000/2,400	6,575							

In-Service Structural Health Monitoring (SHM) Applications

Approach for Selection

- Utilize scoring criteria/evaluation to down select ('targeted') candidate(s)

Opportunity Scoring

	Repeat Inteval
1	10K - 8K
3	8K - 6K
5	6K - 4K
7	4K - 2.5K
10	2.5K - Less

	Lndi Coverage
1	Require significant DTR adjustment
3	Require DTR adjustment
5	Meet Existing Safety
7	Smaller detection possible
10	Exceed Expectation

	Environment
1	WING - New - Testing required
3	N/A
5	FUS - Outside Pressure Vessel not exposed to airstream Similar to SB CWB CIC + Fuel
7	FUS - Inside Pressure Vessel Similar to SB CWB CIC
10	No Testing required

	Access/Removal
1	Full - open door
3	Open - restricted
5	Interior (Liner)
7	Monument (Lavs/Galley/Instrument Panel)
10	Inside Wing Tank

	Fleet Size
1	1 - 500
2	500 - 1, 000
3	1,000 - 1, 500
4	1,500 - 2,000
5	Over 2,000

In-Service Structural Health Monitoring (SHM) Applications

Approach for Selection

- Rank of Potential Candidates

Item	Threshold/ Repeat Interval (FC)	Active Fleet Size	Repeat Interval (FC)	Fleet Size	Access/ Removal	Meet Existing Safety Lndi Coverage	Environment (Fus/Wing)	Total	SHM Technique
737 Fus Aft Pressure Bulkhead (LFEC)	25,000/1,200	6,575	10	5	3	5	6	29	CVM PZT
737 Fus Frame Webs at Overwing Emergency Exits Between Stringer-	12,000/6,000	1,930	3	4	5	5	7	24	CVM PZT
757 Fus Section 46 - Body Station 1681 Frame Inspection	31,000/3,200	897	5	2	5	3	7	22	CVM PZT
757 Fus Section 46 - Body Station 1640 Frame Inspection	~~20,000/2,500~~	~~897~~	~~10~~	~~2~~	~~7~~	~~5~~	~~7~~	~~31~~	CVM PZT
747 Fus Section 41 - Main Frame STA 320 Crown Frame - Web	4,000/3,000	536	7	2	7	5	7	28	CVM PZT
737 Maintenance Planning Data (MPD) DTR 57-20-09 UT/HFEC	50,000/2,400	6,575	10	5	7	3	1	26	PZT

In-Service Structural Health Monitoring (SHM) Applications

Approach for Selection – Lesson Learned

- Customer Collaboration – Fleet Conferences
- Cost of testing

Opportunity Evaluation

Item	Threshold/ Repeat Interval (FC)	Active Fleet Size	Repeat Interval (FC)	Fleet Size	Access/ Removal	Meet Existing Safety Lndi Coverage	Environment (Fus/Wing)	Total	SHM Technique	Customer Collaboration
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In-Service Structural Health Monitoring (SHM) Applications

Potential Next Application?

737NG STA 663.75 Failsafe Strap Inspection

- PZT - Ultrasonic Inspection (UT) and an external Detailed Inspection (DET) of the STA 663.75 failsafe strap on the left and right sides of the airplane

737NG Stub Beam Straps at STA 559 TO STA 639 Inspection

- PZT - Ultrasonic Inspection (UT) and an Detailed Inspection (DET) of stub beam straps

All Model Skin - Fuselage Skin Chem-Mill Step Crack Inspection

- PZT - Mid Frequency Eddy Current Inspection (MFEC)

777 FUSELAGE - Section 43 - Left and Right Underwing Longeron Inspection

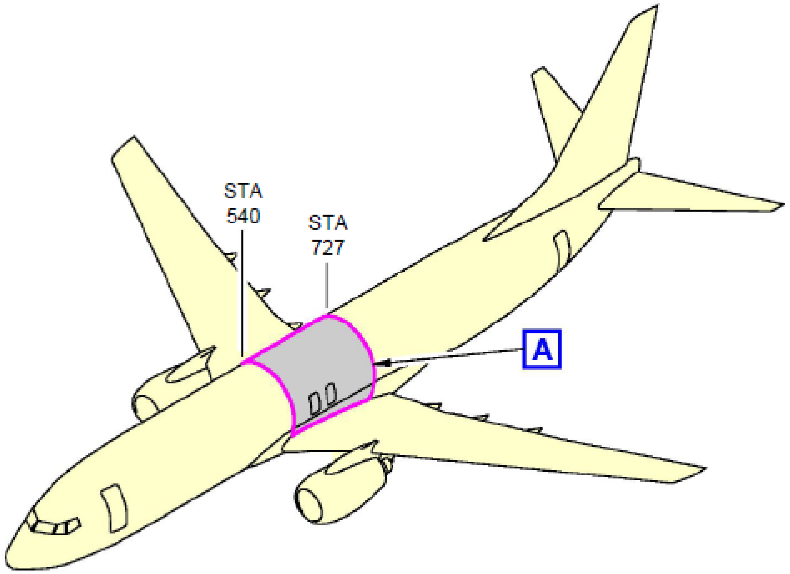
- CVM - Ultrasonic Inspection (UT) and an Detailed Inspection (DET) of external longeron and fuse skin

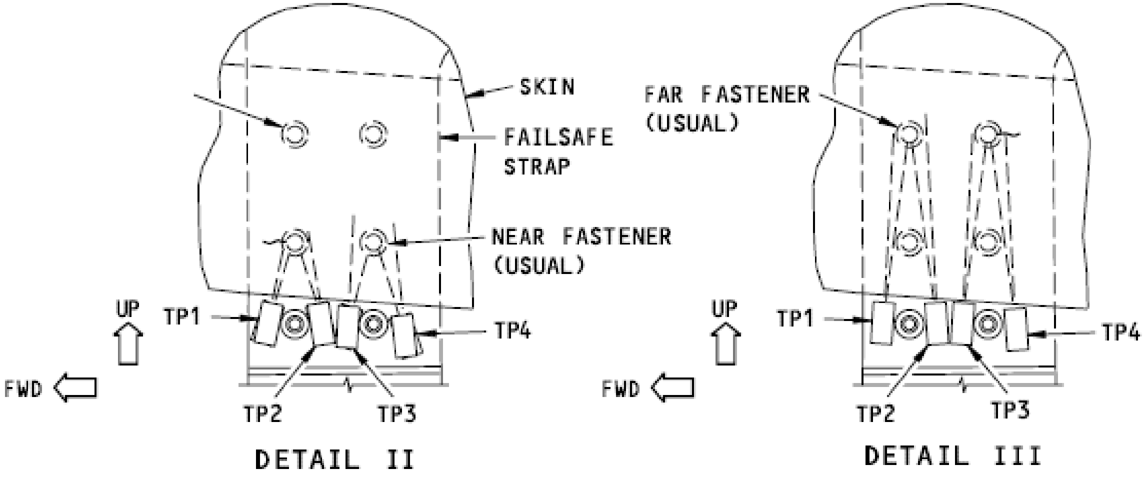
In-Service Structural Health Monitoring (SHM) Applications

Potential Next Application?

737NG STA 663.75 Failsafe Strap Inspection

- Ultrasonic Inspection (UT) and an external Detailed Inspection (DET) of the STA 663.75 failsafe strap on the left and right sides of the airplane



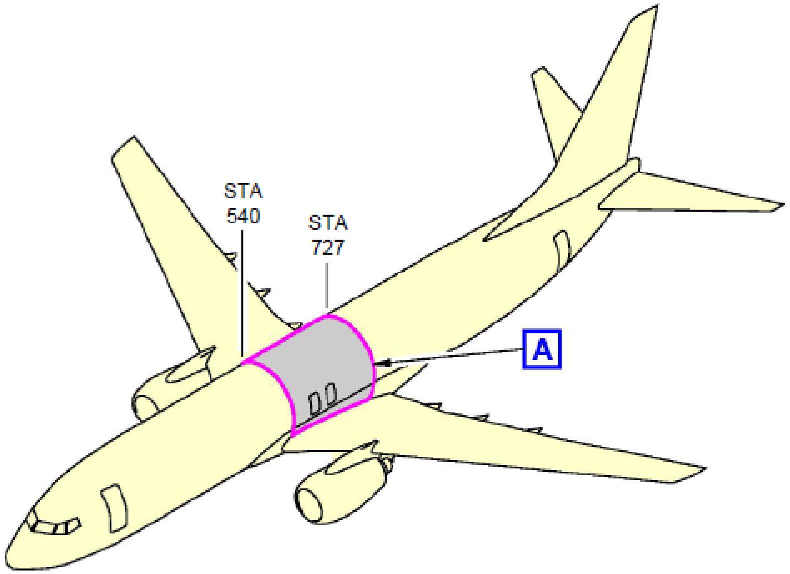


In-Service Structural Health Monitoring (SHM) Applications

Potential Next Application?

737NG Stub Beam Straps at STA 559 TO STA 639 Inspection

- Ultrasonic Inspection (UT) and an Detailed Inspection (DET) of stub beam straps



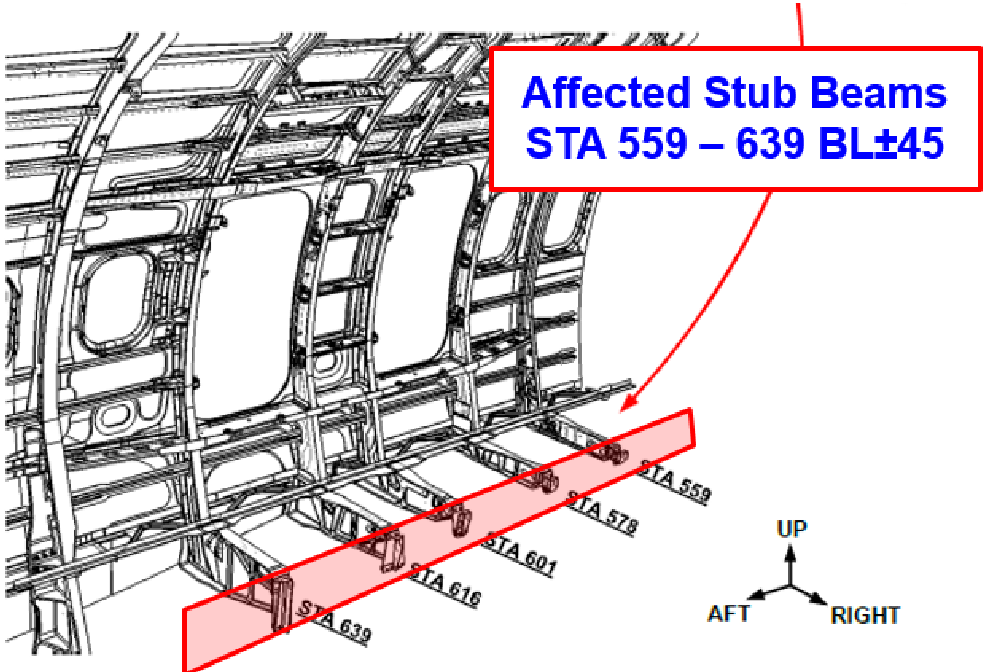


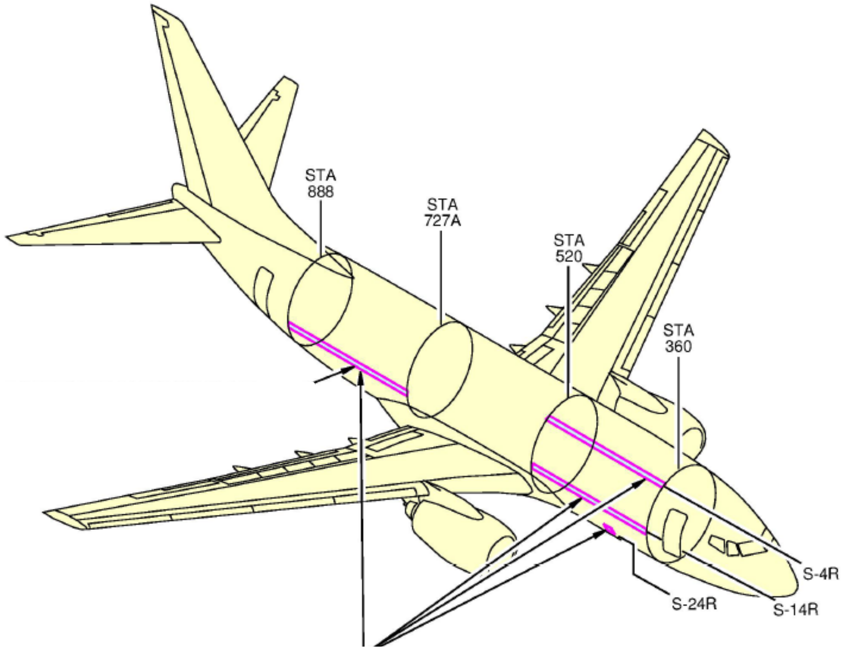
Figure 3-1: PSE 53-40-20-04 Overview

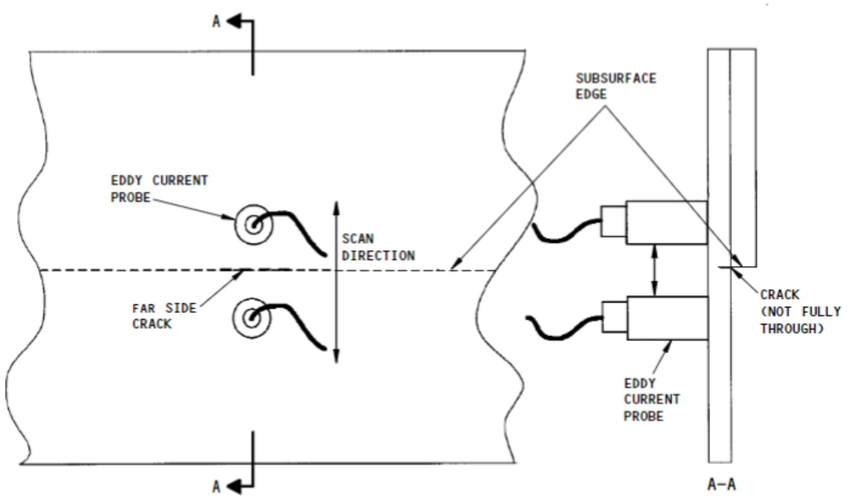
In-Service Structural Health Monitoring (SHM) Applications

Potential Next Application?

All Model Skin - Fuselage Skin Chem-Mill Step Crack Inspection

- Mid Frequency Eddy Current Inspection (MFEC)



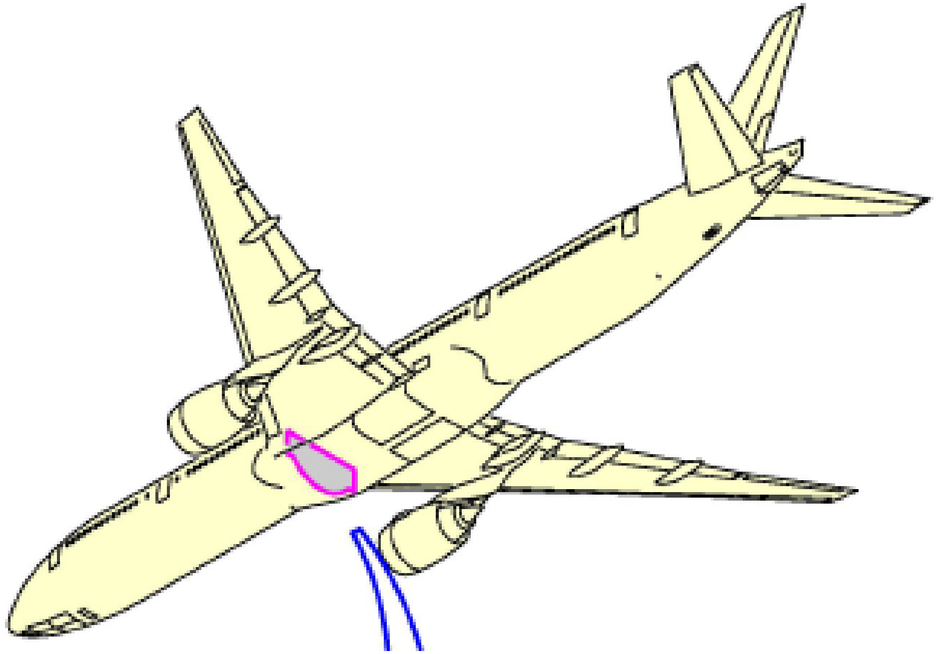


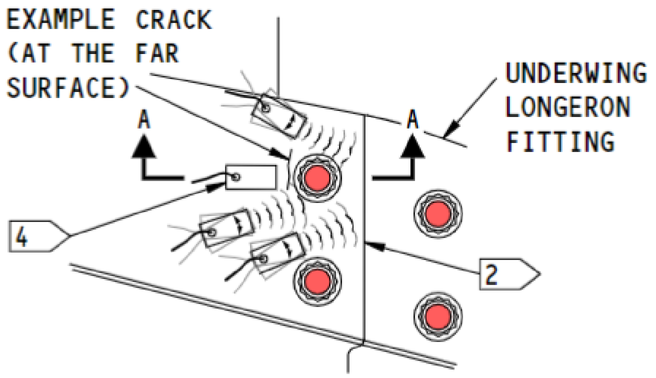
In-Service Structural Health Monitoring (SHM) Applications

Potential Next Application?

777 FUSELAGE - Section 43 - Left and Right Underwing Longeron Inspection

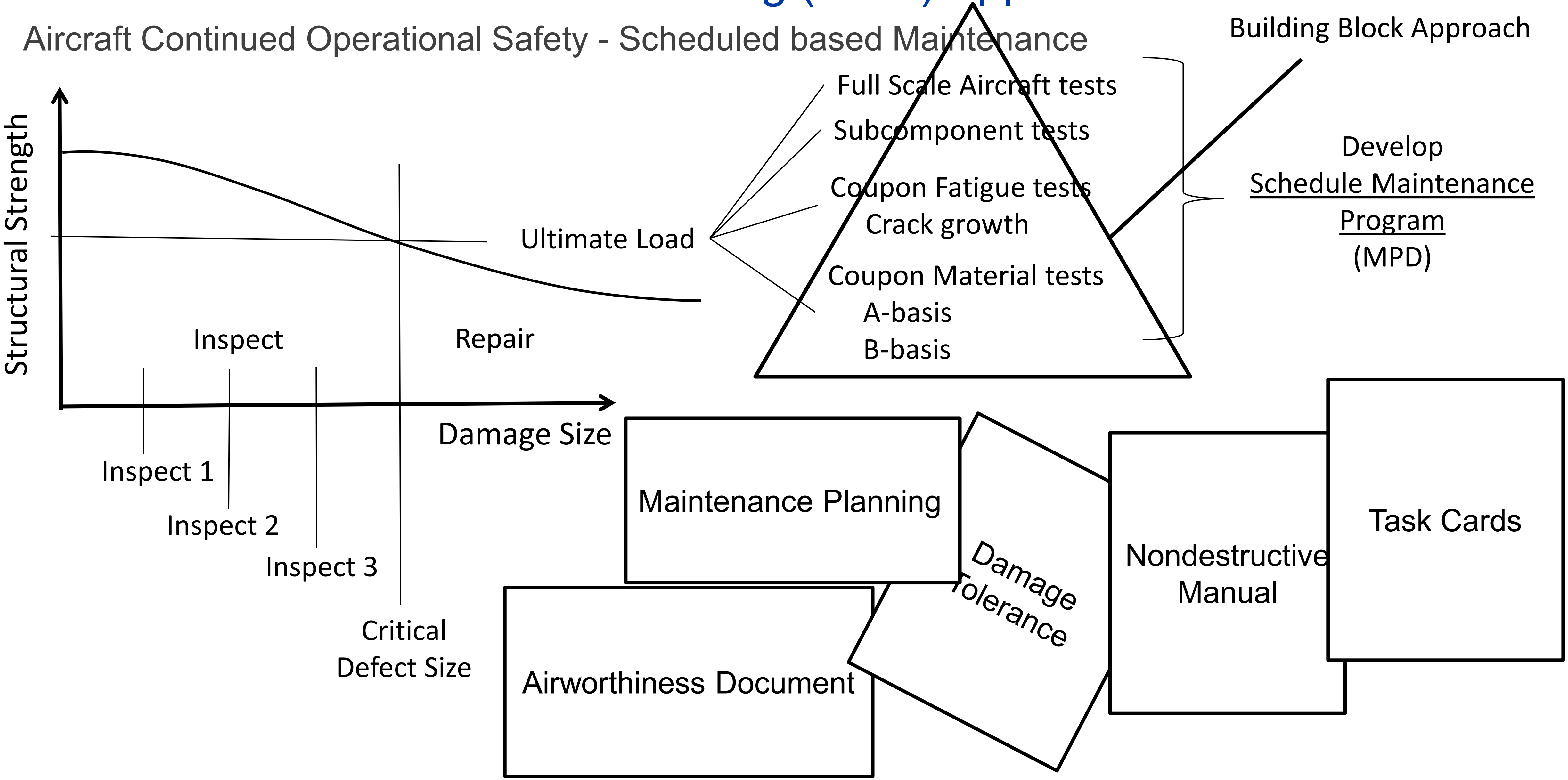
- Ultrasonic Inspection (UT) and an Detailed Inspection (DET) of external longeron and fuse skin





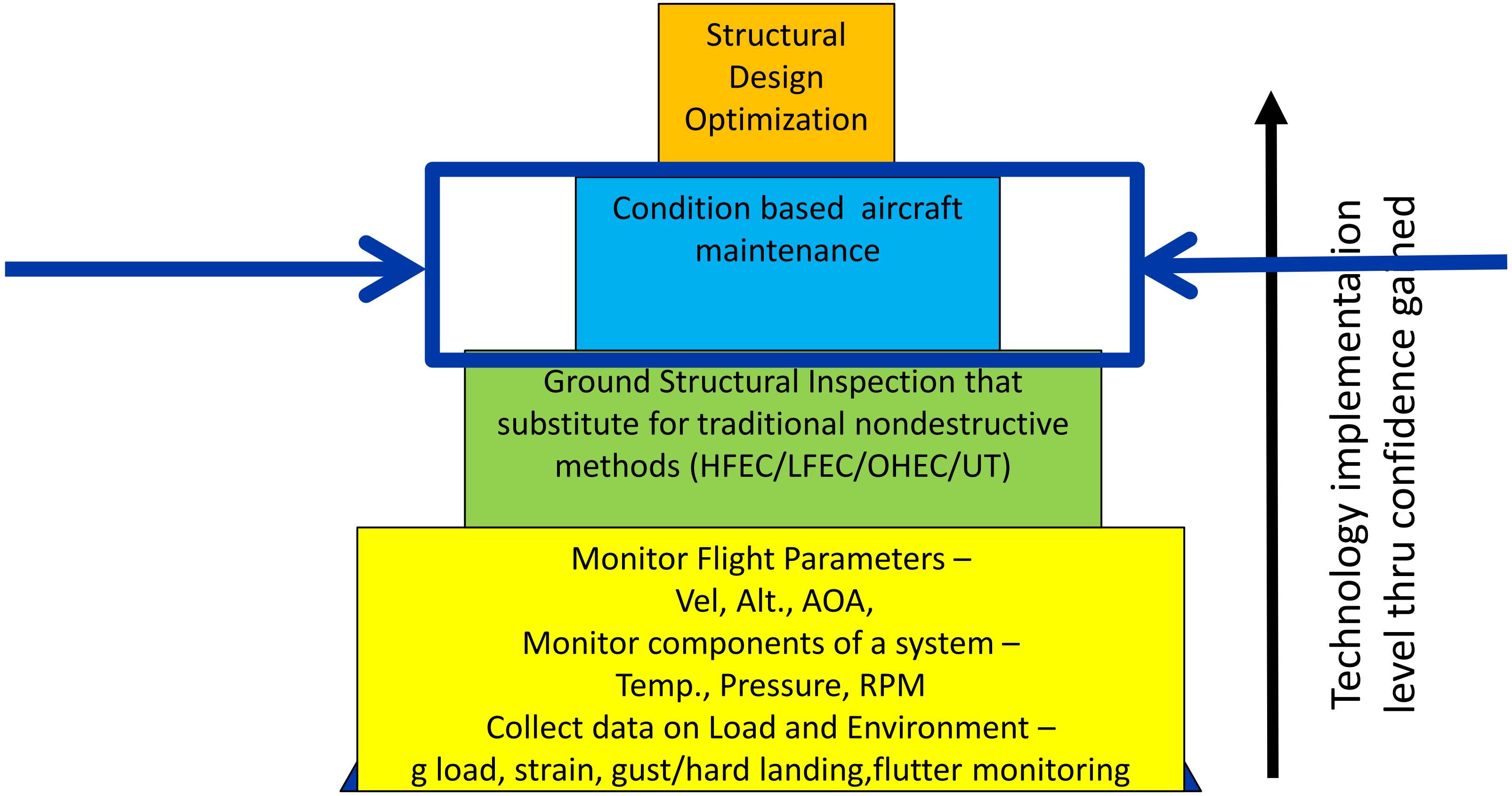
In-Service Structural Health Monitoring (SHM) Applications

Aircraft Continued Operational Safety - Scheduled based Maintenance



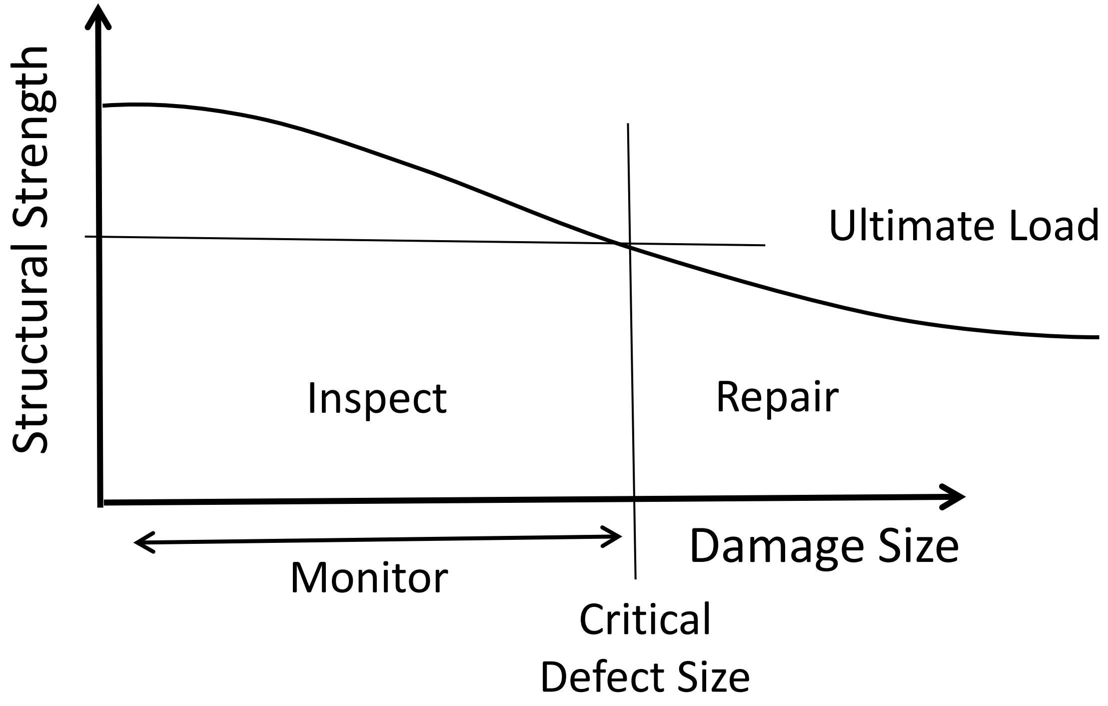
In-Service Structural Health Monitoring (SHM) Applications

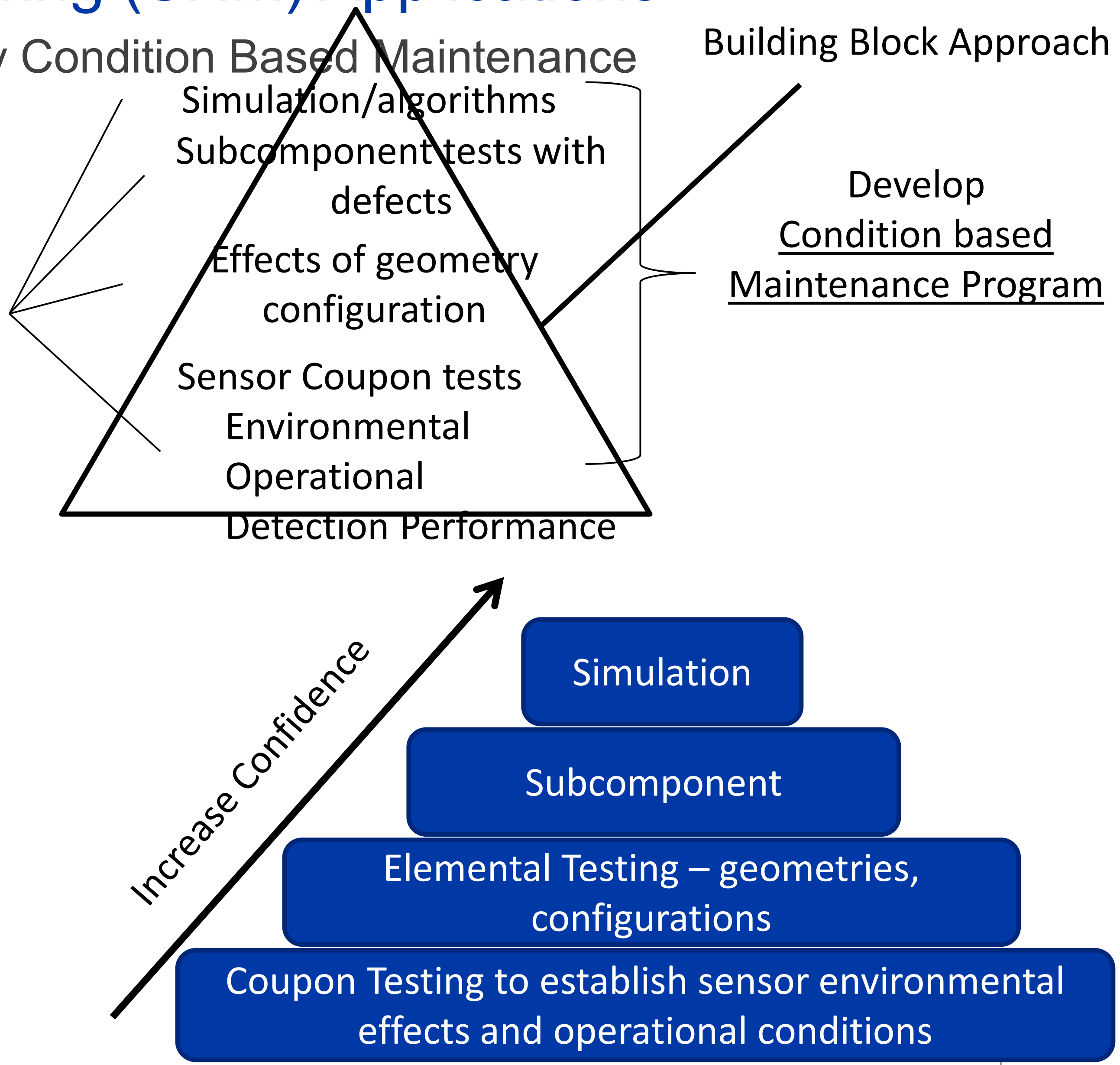
Building Block Approach



In-Service Structural Health Monitoring (SHM) Applications

Future - Aircraft Continued Operational Safety Condition Based Maintenance





In-Service Structural Health Monitoring (SHM) Applications

Future Implementation Approach and Benefits

- Faster inspections / indications
  - In-situ detection with less access/restoration
  - Reduce accidental damage associated with access/restoration
  - Solution for inspections not aligned with scheduled maintenance (C/D checks)
- Faster assessment of structural damage and size and maintenance decision
  - Expedite repair planning with remote diagnosis
- Early flaw detection
  - Monitor crack growth/damage size (Passive/Active)
  - Enhance safety and allow for less drastic and less costly repairs
- Eliminate removing airplane from service

Equivalent or better continued airworthiness, safety and reliability level

In-Service Structural Health Monitoring (SHM) Applications

Shared Data

- Build industry structured data collection between OEM/Airline/Sensor Supplier
  - Model
  - Flight Hours/Cycles
  - Number of Inspection
  - Inspection results
  - Detectable crack length required
  - Sensor type
  - Other(s)
- Structured data collection enables:
  - Reduces testing/development costs
  - Condition Based Maintenance

In-Service Structural Health Monitoring (SHM) Applications

Summary

- Cultivate use of data science for Aircraft Continued Operational Safety
- Build upon the Issue Paper thru strategic applications sensors (CVM/PZT/others) at known areas of interest representing multiple environments
- Develop a down select approach/criteria that provides ‘best value’ benefits to customer
- Shared Boeing applications under future consideration
- Develop standard CVM/PZT application configurations with developed Lndi (crack detectable length)
- Shared data required to move to next level

Thank You

Walter.J.Jarecki@boeing.com
Zeb.Tidwell@boeing.com
Jeong-Beom.Ihn@boeing.com

Questions?