Certification Aspects of Large Integrated Bonded Structure

ASIP Conference

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Eric Nottorf – Bell Helicopter Textron Inc.

Steve Engelstad – Lockheed Martin Aeronautics Company

Michael Renieri – The Boeing Company

PRESENTATION OBJECTIVES

The objectives of this presentation are to:

1) **Illustrate several critical aspects for certification of integrated bonded structure**

2) **Present substantiation approaches that may be useful in the certification process**

3) **Present lessons learned from development of certification plans**

OUTLINE

- Introduction & Background
- Critical Certification Aspects
- Substantiation Approaches
- “Lessons Learned”

CAI OBJECTIVES

- Establish the confidence to fly integrated - bonded high performance primary composite structures
- Realize the benefits of integral bonded composite structures within acceptable levels of risk through certification for use in primary aircraft applications
- Obtain "*agreement*" from the appropriate certification authorities to provide meaningful guidance on certifying future flight worthy integrated bonded composite structures
  - Air Force, Navy and FAA

CONTENTS

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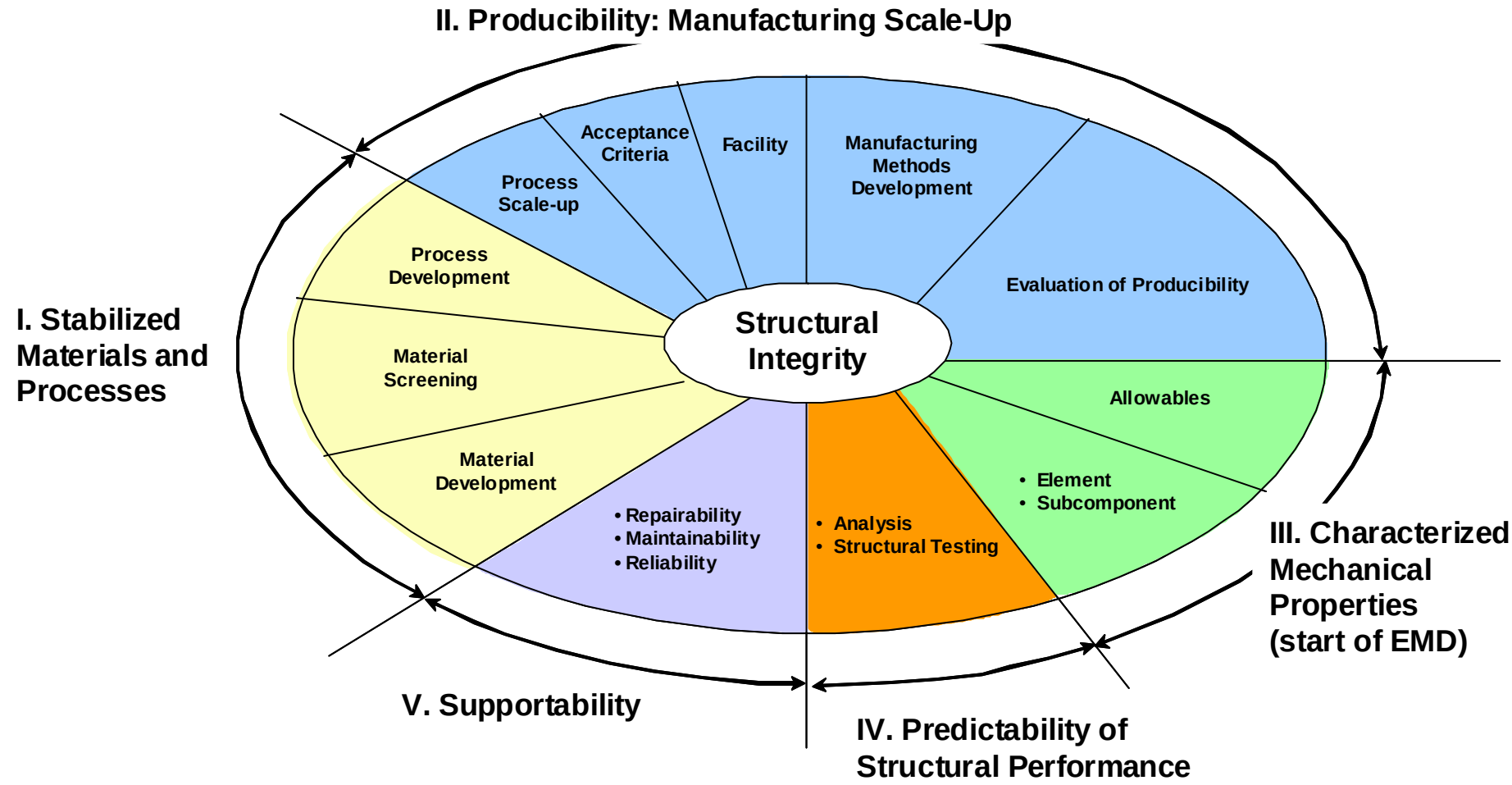
CERTIFICATION ASPECTS



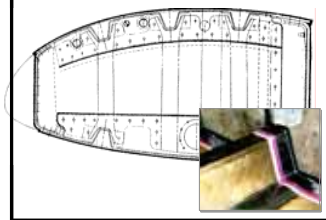
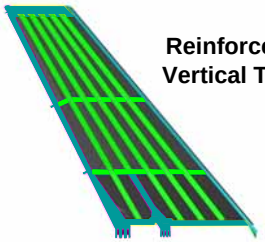
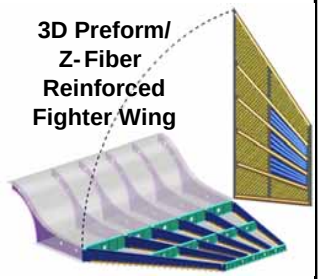
Ref. - Dr. Jack Lincoln

CERTIFICATION ASPECTS (cont)

CRITICAL CERTIFICATION ASPECTS:

- Stabilized Materials and Processes
- Producibility: Manufacturing Scale Up
- Characterized Material Properties: EMD
- Predictability of Structural Performance
- Supportability

CERTIFICATION ASPECTS (cont)
CAI "Certification" Plans

Certification Plan	Certification Characteristics			
	Design Concepts	Manufacturing Techniques	Quality Assurance Techniques	Certification Approach
Bonded Rib to Skin- Stringer Interface 	• Pre- Cured Rib Bonded to Pre- Cured Skin- Stringer Assy • Multi- cell Tiltrotor Wing Torque box • Dry Bay w/ Fuel Bag	• Co- Cured Conventional Gr/Ep Skin- Stringer Assy • Pre- Cured Conventional Gr/Ep Rib Details • Tool for Secondary Bondline	• Conventional NDI of Pre- Cured Details & Bondline • In- Line nth Article Proof Testing of Bondline	• Hybrid Progressive Certification • Cat 1 – Damage Tolerant Safe Life • Cat 2 – Damage Tolerant Slow Growth
3D Preform/ Reinforced Vertical Tail 	• Composite & metallic integration • Multi- cell torque box • Dry bay	• Bonded 3D woven Pi preforms • Close- out paste bond assembly • Co- Cured inboard assembly • Z- pinned Pi/skin bondlines	• Ultrasonic inspection of subassemblies • Borescope of paste bond squeeze out • X- ray CT of paste bond • Witness coupon proof test	• No crack growth for adhesive paste & film bonds • Fail- safe/crack arrestment for Z- pinned Pi/skin joint
3D Preform/ Z- Fiber Reinforced Fighter Wing 	• Composite & metallic integration • Multi- cell torque box • Wet bay	• Bonded 3D woven Pi preforms • Bonded Y- Pi's • Co- bonded lower assembly • Close- out paste bond assembly • Z- pinned Pi/skin bondlines	• Ultrasonic inspection of details and assemblies • LBID bond strength verification	• No crack growth for adhesive paste & film bonds • Fail- safe/crack arrestment for Z- pinned Pi/skin joint

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SUBSTANTIATION APPROACHES

CRITICAL CERTIFICATION ASPECTS:

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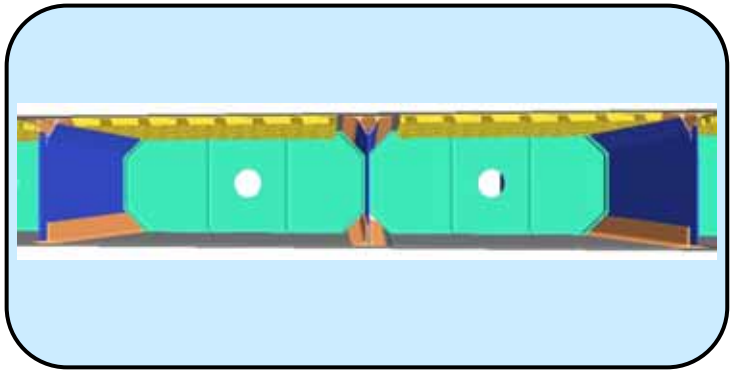
- Supportability

SUBSTANTIATION APPROACHES (cont)

STABILIZED MATERIALS & PROCESSES

- Tooling control
  - Form, Fit & Function
- Material Control
  - Precured Details
  - Adhesive
  - Consumables
- Area control
  - Temperature & Relative Humidity
  - Dust Particle Count & Contaminants
  - Vehicles & Storage & Handling of Details
  - Work Surface
- Surface preparation
  - Solvents
  - Cleaning
  - Abrasive Blast
- Bond process
  - Pressure, Temperature & Cure Cycle



SUBSTANTIATION APPROACHES

(cont)

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SUBSTANTIATION APPROACHES (cont)

PRODUCIBILITY (cont)

QA Inspection methods must be able to detect any defects in Subassemblies and in the Final Assembly

Acceptable QA techniques include:

- Travelers or test coupons
- A-Scan
- C-Scan/Laser UT
- Borescope
- X-Ray
- Laser Bond Inspection Device (LBID)

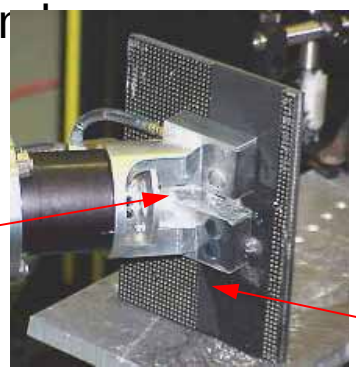
The size and frequency of allowable defects is established by both analysis and element testing

SUBSTANTIATION APPROACHES (cont)

PRODUCIBILITY (cont)

Example QA/Inspection Process for Bonded Joints

- QA pre and post bonding sampling of the adhesive for hardness testing. Surface validation processes include roughness and surface energy
- Bondline feature detection using ultrasonic NDE is required over 100% of the bond to validate that adhesive is present, no unbonds and no inclusions
- Laser Bond Inspection (LBI) is used on a low frequency sampling basis to validate the surface preparation, adhesive application and curing processes were performed to a level that results in a strong bon



SUBSTANTIATION APPROACHES (cont)

MANUFACTURING SCALE-UP

- Provide sufficient lead time for tooling and fabrication of subscale components prior to fabrication of the first production article
- Identify and resolve potential problems using subscale components prior to production
- Select available materials and reliable suppliers for now and in the future
- Utilize planned production materials, tooling and processes from coupon fabrication to subcomponent fabrication
- Utilize planned production facilities from coupon fabrication to subcomponent fabrication
- Demonstrate unique tooling or process methods at subscale level with sophistication of production level

SUBSTANTIATION APPROACHES

(cont)

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SUBSTANTIATION APPROACHES (cont)

MATERIALS & MATERIAL PROCESS

"Certification" approaches assume materials for structural components have been qualified

- "B" Basis material characterization as a function of temperature, moisture, damage, defects, and fatigue
  - Material properties
  - Strength properties
  - Durability properties
  - Acceptance criteria
- "B" Basis adhesive characterization as a function of adherend, surface preparation, bondline thickness, temperature, moisture, damage, defects, and fatigue
  - Material properties
  - Strength properties
  - Durability properties
  - Acceptance criteria

SUBSTANTIATION APPROACHES (cont)

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  - Analysis
  - Testing
- Supportability

SUBSTANTIATION APPROACHES (cont)

EXAMPLE STATIC STRENGTH REQUIREMENTS

- Sufficient static strength shall be provided including the effects of:
  1. Repeated loading
  2. Environmental exposure
  3. Material and process variability
  4. Defects or service damage that are not detectable or are acceptable by QC
  5. Manufacturing acceptance criteria
  6. Maintenance
- Detrimental deformations, including delaminations shall not occur below 115% DLL (without structural failure at ultimate loads)
- Bonded structure shall be capable of sustaining the residual strength loads without safety of flight failure

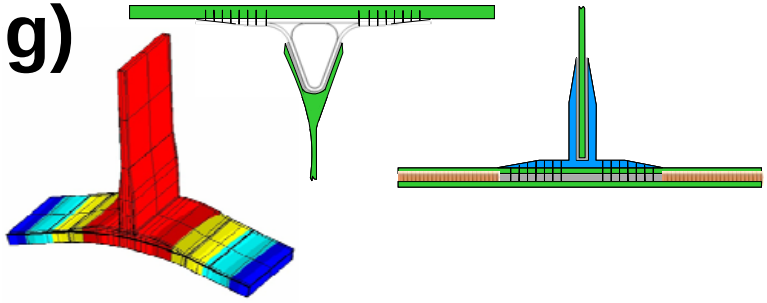
SUBSTANTIATION APPROACHES

(cont)

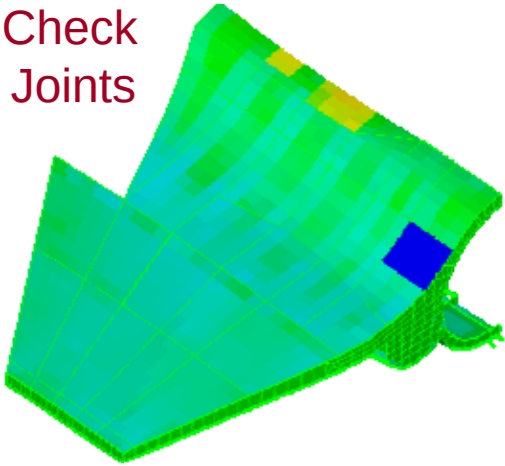
ANALYSIS - STATIC STRENGTH

Static Analysis (Fighter Wing)

- **A NASTRAN finite element model will be utilized for internal loads computation**
- **Skins will be optimized for stability and damage tolerance strength**
- **Critical location joint strength sizing utilizing StressCheck analysis**



3-D StressCheck Models of Joints

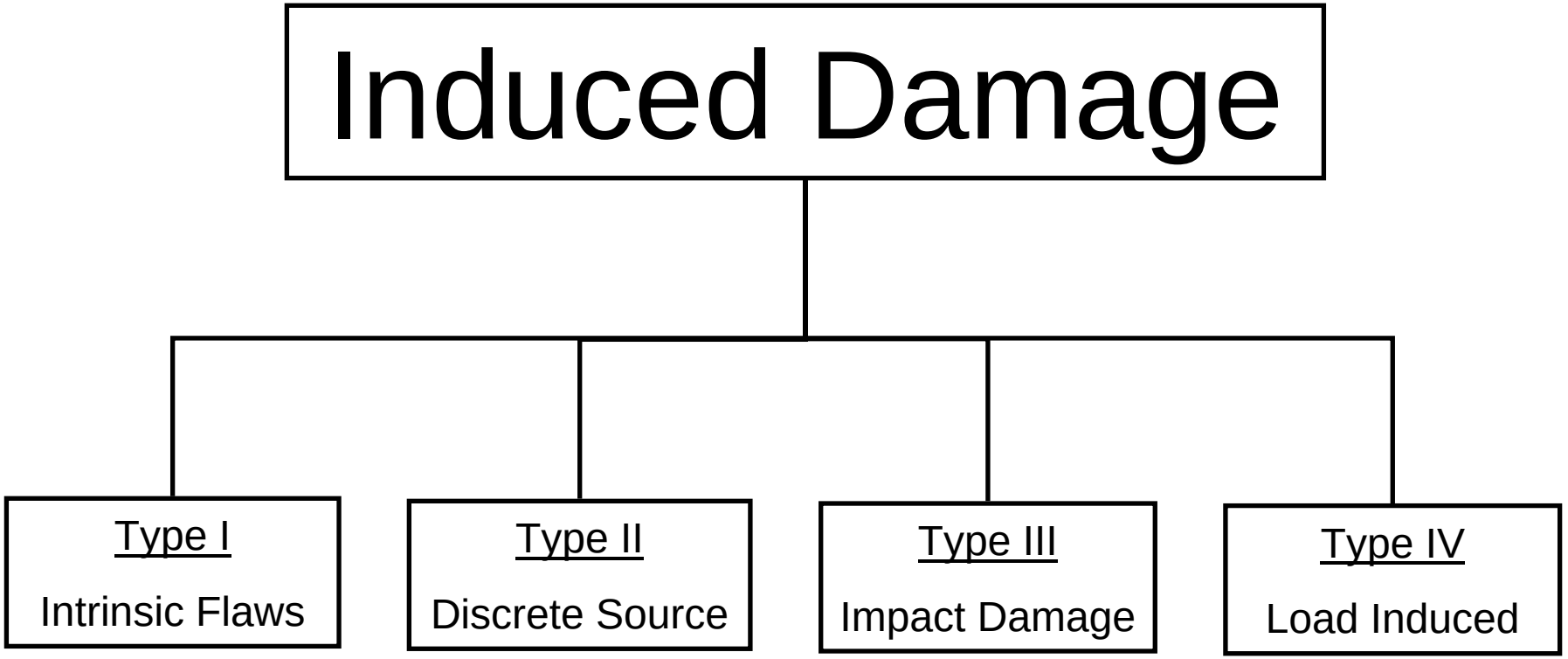


Detailed NASTRAN Internal Loads Model

SUBSTANTIATION APPROACHES

(cont)

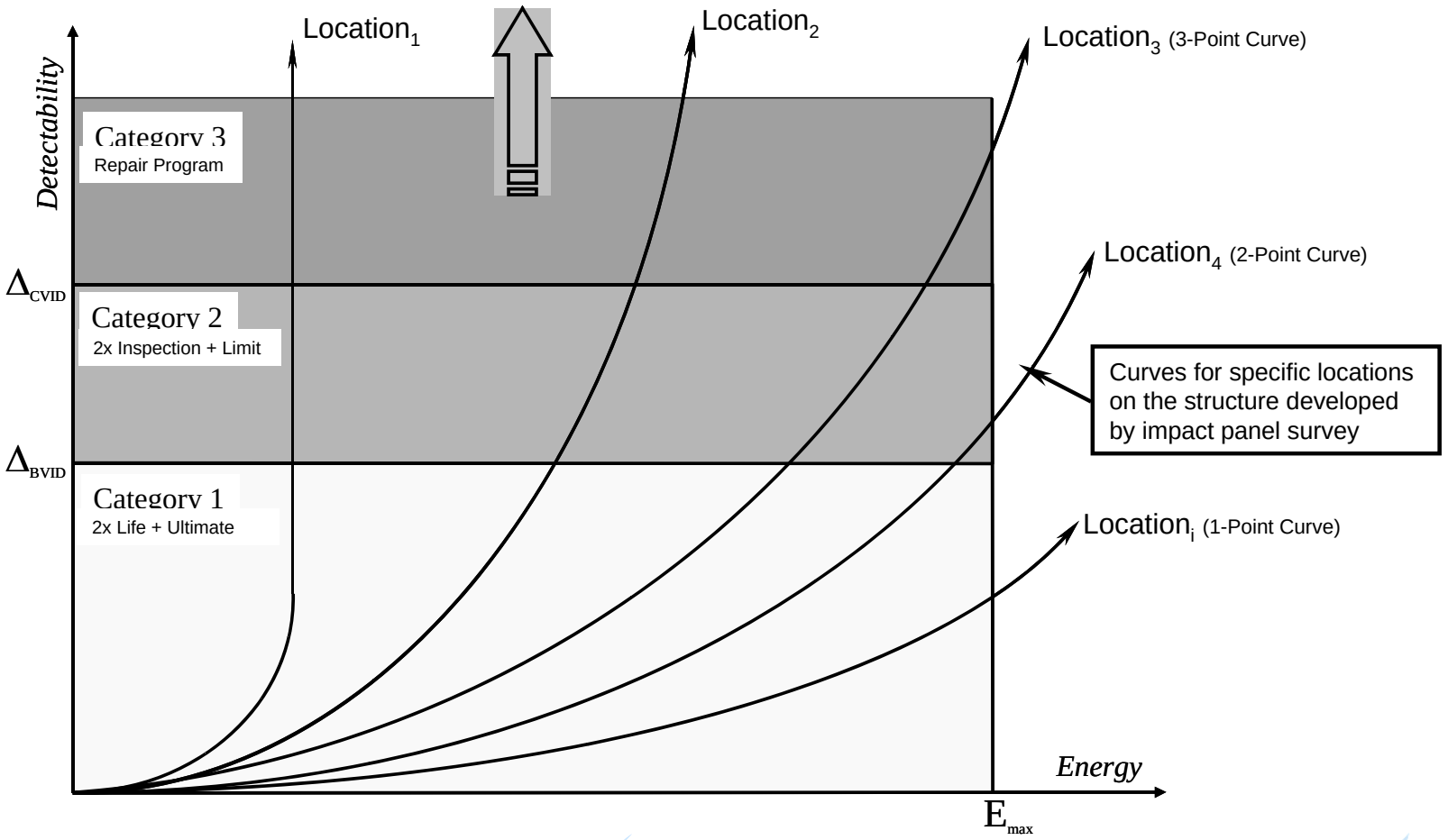
DAMAGE ASSESSMENT



SUBSTANTIATION APPROACHES

(cont)

DESIGN PHILOSOPHY FOR DAMAGE EFFECTS



SUBSTANTIATION APPROACHES

(cont)

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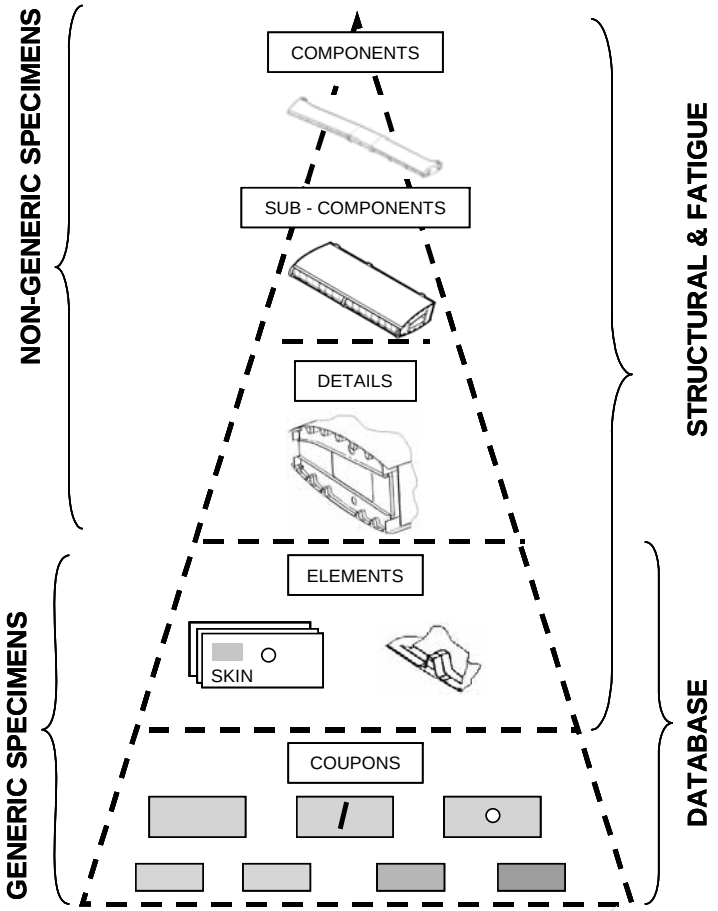
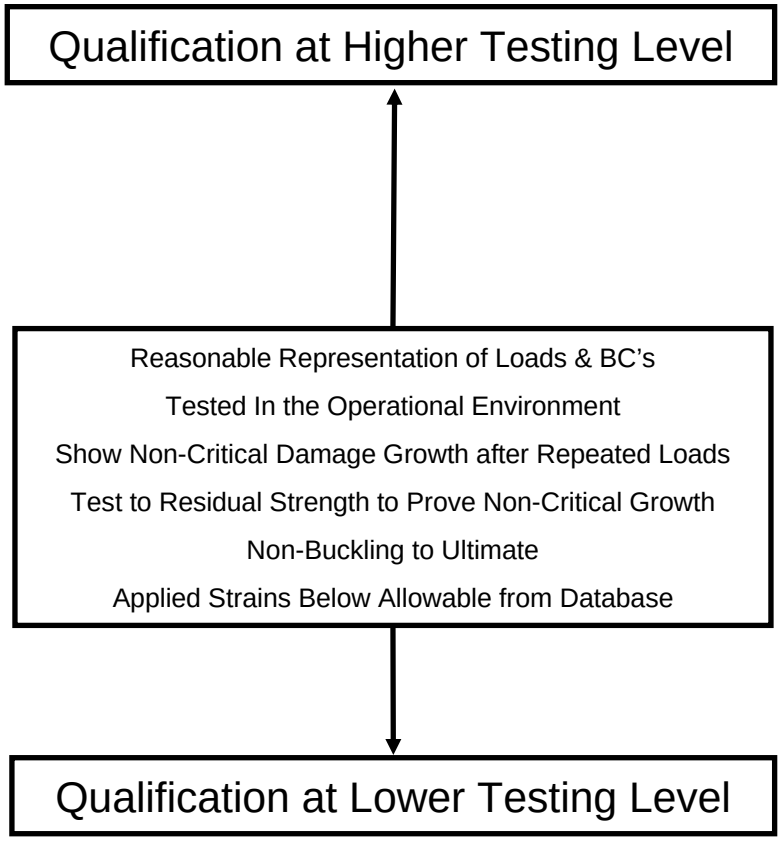
SUBSTANTIATION APPROACHES

(cont)

TESTING (cont) – BUILDING BLOCK APPROACH



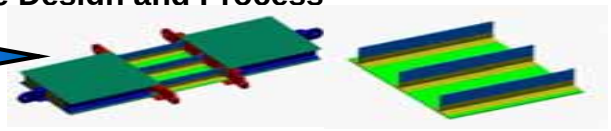


SUBSTANTIATION APPROACHES

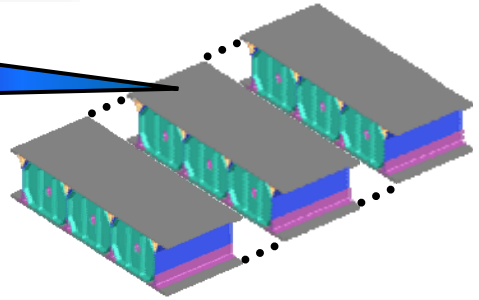
(cont)

TESTING (cont) - CERTIFICATION APPROACH

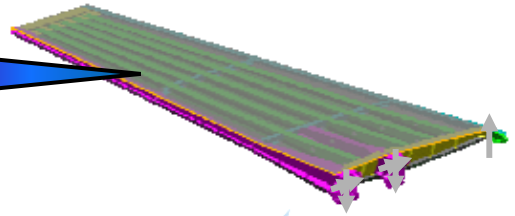
- **Point Design Coupon Tests**
  - Information Required to Support/Validate Design and Process
- **Element Tests**
  - Allowable
  - Effects of Defects



- **Subcomponent Tests**
  - Validate Design Under Complex Loading (Static & DaDT Requirements)
  - Minimize the Risk for Full-Scale Test article
  - Evaluate Sensitivity to Damage Levels (manufacturing & in-service)
  - Evaluate Sensitivity to Spectrum
  - Evaluate Residual Strength after Fatigue
  - Validate Analytical (FEM) Models



- **Detailed Analysis and Correlation at Element and Subcomponent Levels under Simple and Complex Loadings**
  - Essential to gain confidence



- **One Full-Scale Test Article**
  - Validate Durability, Damage Tolerance and Static Strength

SUBSTANTIATION APPROACHES

(cont)

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SUBSTANTIATION APPROACHES

(cont)

SUPPORTABILITY - REPAIR

- Designed into the Structure Wherever Feasible
- Bondlines Sized to Accept Fastener Repair
  - Appropriate skin thickness for CS fastener if required on OML
  - Appropriate flange widths for necessary edge distance
  - Appropriate thickness for bearing/bypass failure before shear failure

SUBSTANTIATION APPROACHES

(cont)

SUPPORTABILITY (cont)

Inspection and Access

- Access to bondlines through features in structure

Reliability

- Develop a structure that will not fail during the lifetime of the system through a combination of:
  - Process Control
  - Proof Testing
  - Structural Testing

Force Management Data Package

- Final Analysis Reports (loads, stress, fatigue, etc.)
- Logistics Support Analysis
- Data Tracking Tools

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“LESSONS LEARNED”

“Certification” Plans

- Plans must have a combination of QA, process controls, manufacturing controls, and analytical tools to fully address compliance.

Assessment of Bondline Integrity

- The ability of assess Bondline Integrity through adequate process and procedure with existing NDE methods depends on the situation that is being evaluated including structure, experience, database, and application.
- New techniques like the LBI method are a significant advancement in assessment capability

Proof Testing

- The proof test serves as a confidence booster test that loads the structure to limit load and thus does check the quality of the joint. It is not a necessary step in the certification process if there are sufficient controls in the production process, and appropriate certification analysis and testing is performed. The LBI NDE method addresses the “kissing bond” concerns.

"LESSONS LEARNED" (cont)

Laser Bond Inspection

- Laser Bond Inspection (LBI) technique is an enabling technology for integrated bonded design and should be a proactive design tool to optimize designs, rather than an inspection tool after the fact.

Energy Based Impact Criteria

- Correlation between strain reduction and impact energy for composite materials is usually quite good.
- There are often questions about the confidence of probabilistically derived upper energy bounds since this method requires significant data to develop acceptable upper bounds.

Analytical Validation is Key

- Validation of the models is the key issue in certification.
- Key analytical toolsets have been implemented by the CAI contractors.

“LESSONS LEARNED” (cont)

One Full-Scale Article

- Plan would work for this wing box (specific component of aircraft), but we can’t sell it programmatically (full aircraft).
- The test program will vary from program to program. What you can help us with is tackling the roadblocks that have kept composites off airframes and you can help by developing a universally accepted system of process controls.

SUMMARY

Summary

This presentation has:

- Illustrated several critical aspects for certification of integrated bonded structure
- Presented substantiation approaches for several critical certification aspects
- Presented “lessons learned” from the development of certification plans

Large Integrated Bonded Structure has additional features including bondlines and repair that require additional certification consideration

Certification plans must have a combination of QA, process controls, manufacturing controls, and analytical tools to fully address compliance

Certification of Large Integrated bonded Structure is possible when a comprehensive approach to certification is taken

The certification approach that should be taken depends on the specific structural configuration - approaches should be tailored to meet each individual application