# Composite Structure Engineering Safety Awareness Course

## Similarities and Differences between Metallic and Composite materials

September 14-16, 2010

# Similarities and differences between metallic and composite materials

AGENDA

- Review of Key Terms
- Regulatory Requirements
- Expected Sources of Variation
- Other Important Considerations When Developing Design Values for Composites
- Case Studies

# Review of Key Terms

- Federal Regulations
- Documented Controls
  - Material Specifications
  - Process Specifications
  - Process Control Documents
- Material Allowables & Design Values
- Recognized Sources Material Allowables
  - MMPDS
  - CMH-17 (may require further showing)

# Federal Regulations

- The Federal Aviation Regulations are rules prescribed by the Federal Aviation Administration (FAA) governing all aviation activities in the United States. The FARs are part of Title 14 of the Code of Federal Regulations (CFR). The rules are designed to promote safe aviation, protecting pilots, passengers and the general public from unnecessary risk. For this course the focus is on those regulations which apply to the certification of specific products (aircraft, engines and propellers).
  - Part 21 – Certification Procedures for Products and Parts
  - Part 23 – Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Airplanes
  - Part 25 – Airworthiness Standards: Transport Category Airplanes
  - Part 27 – Airworthiness Standards: Normal Category Rotorcraft
  - Part 29 – Airworthiness Standards: Transport Category Rotorcraft
  - Part 33 – Airworthiness Standards: Aircraft Engines
  - Part 35 – Airworthiness Standards: Propellers

# Federal Regulations (cont...)

- Specific regulations discussed in this workshop.
  - §§ 23.603, 25.603, 27.603 & 29.603
    - Materials
  - §§ 23.605, 25.605, 27.605 & 29.605
    - Fabrication methods
  - §§ 23.613, 25.613, 27.617 & 29.617
    - Material strength properties and material design values

(more on these latter)

# Controls needed

- Material Specifications
  - Documented control established to ensure the consistency of the raw materials being purchased to manufacture products (as defined by the CFRs)
- Process Specifications
  - Documented control of the general manufacturing process being used to fabricate products
  - **Process Control Documents (PCDs)**
    - Documented controls which defines the manufacturing details of a specific manufacturing facility which is compliant with the governing Process Specification
    - Controlled “recipes” for the production of materials that conform to the requirements of material specifications.

# Allowables & Design Values

| Term | Description | Typical Use |
|---|---|---|
| ALLOWABLE | A value derived from the statistical reduction of data from a stable process. The amount of data required to derive these values is governed by the statistical significance (or basis) needed. | Forms basis of design values |
| DESIGN VALUE | A value used in analysis to compute margins-of-safety. This value most often based on an allowable adjusted to account for program criteria and actual structural conditions. Non-statistically derived design values may be used with FAA concurrence. (must meet § 2x.613) | Depending on allowable basis, used on all designs. |

# Accepted sources of Material Allowables

- The following documents are recognized by the regulatory authorities for the following purposes:
  - Metallic Materials Properties Development & Standardization (MMPDS) (Formally Military Handbook 5) is a source of allowables and methods for deriving metallic material allowables
  - Composite Materials Handbook 17 (CMH-17) (Formally Military Handbook 17) is a source of methods for deriving composite allowables (Actual values published require further showing)
    - New FAA policy to recognize NCAMP specs and data.

# Key points from AC 25.613-1

- **The A and B properties published in MIL-HDBK-5 [MMPDS] may be used without further showing**
- **Other methods of developing material design values may be acceptable to the FAA.**
- **The test specimens used for material property certification testing should be made from material produced using production processes.**
- **Test specimen design, test methods, and testing should:**
  - Conform to standards acceptable to the FAA; or
  - Conform to those detailed in the applicable chapters/sections of **MIL-HDBK-5 [now MMPDS]**, **MIL-HDBK-17 [now CMH-17]**, or other accepted equivalent material data handbooks; or
  - Be accomplished in accordance with a FAA approved test plan
- **The FAA may approve the use of other material test data after review of test specimen design, test methods, and test procedures that were used to generate the data.**

# Regulatory Requirements

- Material must be produced under Documented Control (§ 2X.603)
- Final product must be manufactured under Documented Control (§ 2X.605)

Note: In order to derive design values which satisfy the next bullet a certain "maturity" in the controlling material and processing specifications must be achieved. Values derived prior to the controlling process to provide a "stable and repeatable" product may not reflect the actual capacities of the product.

- Design Values used in the analysis and certification of product must be Statistically Derived (§ 2X.613)

# Material Control

- § 2X.603 (Materials)
  - The suitability and durability of materials used for parts, failure of which will adversely affect safety, must –
    - Be established by experience or test
    - Conform to approved specifications
    - Take into account the effects of environmental conditions

This regulation applied to any structural elements whose failure would negatively affect safety, not just “safety of flight”

# Process Controls

- § 2X.605 (Fabrication methods)
  - The methods of fabrications used must produce a consistently sound structure
    - If a fabrication process requires close control to reach this objective, the process must be performed under an approved process specification
    - Each new aircraft fabrication method must be substantiated by a test program.

# Material Properties

- § 2X.613 (Material strength properties and material design values)
  - Strength properties must be based on testing of materials meeting approved specifications to establish design values on a statistical basis
    - Design values must be chosen to minimize the probability of structural failure.
      - Single load path structures must meet a 99% probability with 95% confidence statistics
      - Redundant load path structures must meet a 90% probability with 95% confidence statistics

# Material Properties (cont...)

- § 2X.613 (Material strength properties and material design values)
  - The effects of the operational environment must be accounted for in the design values used
  - Values greater then those computed by the above statistical means may be used if “Premium Selection” is used
    - A specimen from each **individual item** to be installed on an airplane is tested to determine that the actual strength of the item is equal or exceeds the design value used in the design.
  - (§ 25.613(f)) Other material design values may be used if approved by the Administrator.

# Summary of Regulatory Requirements

- Regulatory requirements are directly applied to actual applicants
  - Applicants are those apply to the authorities to certify products (aircraft, engines or propellers)
- Applicants are required to show that materials brought into their facilitates were purchased under documented controls
- Applicants are required to show that their processes used to fabricate regulated products are under documented control
- Applicants must show through testing in order to satisfy the statistical requirements defined in the regulations
  - Testing must account for the sources of variation introduced by both the materials and fabrication methods used to produce the product.

Note: up to this point a distinction has not been made between composite and metallic materials

# Application of the Regulations to Composite Materials

- It should be noted that the regulations themselves do not distinguish between material types
  - The underling requirement of the regulations (§§ 2x.603, 2x.605 and 2X.613) regarding material behavior is basically that the design of a product must account for the variation due to the material and fabrication used to produce that product.
- The distinguishing feature of composite construction is the ability to tailor material properties to specific structural applications
- This enhanced ability to “tailor” the mechanical behavior of the final structure require applicants to have a basic understanding of the potential sources of variability introduced by utilizing composite materials
- For materials whose mechanical behavior are influenced by processing (i.e. forgings, casting, composites) care must be taken to account for variability introduced by both the materials and the fabrication methods used to produce the final product.

# Expected Sources of Variations

- Typical metallic materials
- Special metallic materials considerations (castings, forgings, etc.)
- Composite materials

# Basic Material Types

- Materials may be divided into three basic types:
  - Stock Materials – Refers to materials whose basic mechanical behavior are not severely impacted by the manufacturing process (or at lest the impacts of manufacturing steps such as heat treatment are well understood). (Sheet, Plate, Bar, etc.)
  - Externally Engineered Materials – Refers to materials whose mechanical behavior is highly dependent on the manufacturing processes prior to being purchased. (castings, forgings, extrusions etc.)
  - Internally Engineered Materials – Refers to materials whose mechanical properties are dependent on post processing of raw material purchased. (Composites)

# Stock Materials: Typical Metallic Materials

- Typically these are the common materials with a lot of history.
- Material properties are not substantially changed during part fabrication.
- Post-purchase processes, (like heat treating) need to be well understood.
- Material Specifications directly control properties used directly in the design.
- Often design allowables meeting “A” and “B” definitions are published.

# Externally Engineered Materials : Castings, Forgings, etc...

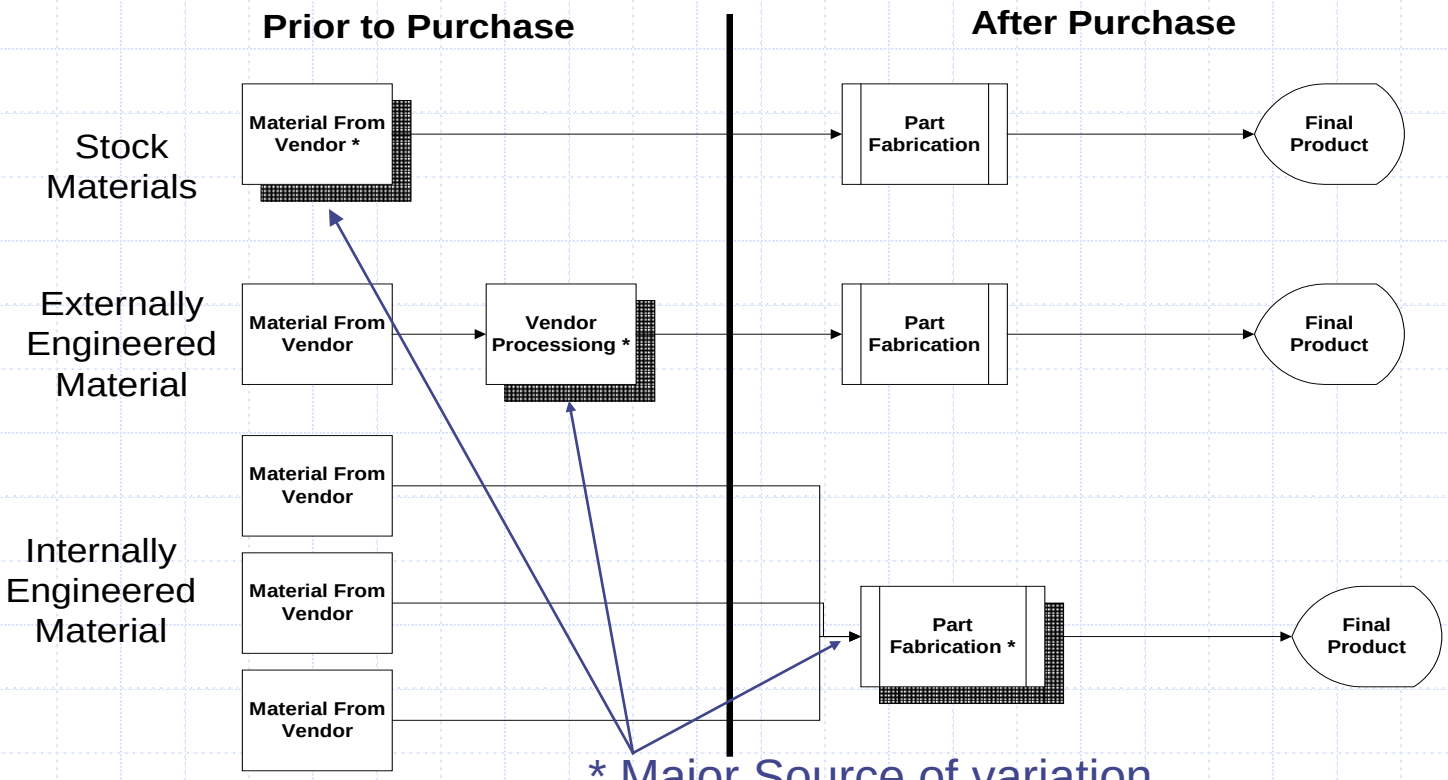
- High variability typically seen in the creation of these materials.
- Baseline material properties are controlled by material specifications, but provisions are made to verify properties of individual Parts (first part cut-ups.).
- Typically only Specification minimum values (“S”) are published due to the variability of the material.
- Often in design a large reduction factor is applied to account for material variability.

# Internally Engineered Materials: Composites

- Material is actually created during part fabrication.
- Material Specifications controls raw material being purchased, not the material in it's final state.
- The key design properties are dependent on the fabrication process used to produce the product.
- Design allowables are tied to both the material's) and process used to fabricate parts.
- What material properties which require allowables to be develop depend on the analytical methods used in design. (No one generally accepted industry approach for composite design.).

# Major Sources of Variation

- **Controlled by Material Specification**
- **Controlled by Process Specification**




* Major Source of variation.

# Design Values (Allowables) Considerations

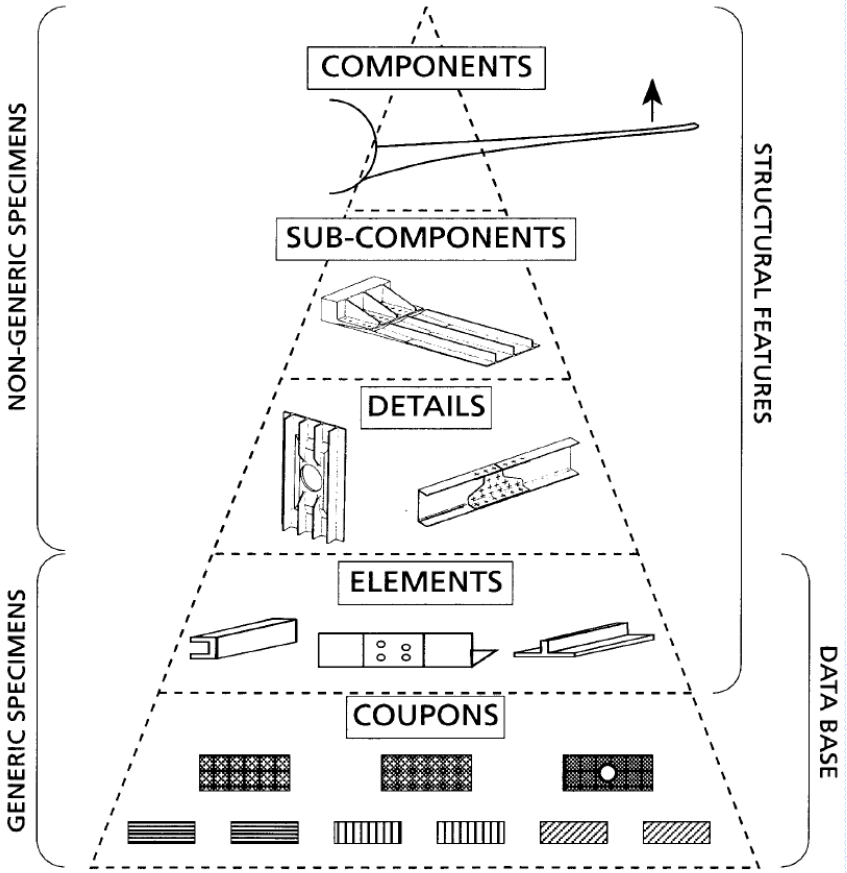
- Stock Materials – Common processes and procedures may be followed (such as MMPDS).
- Externally Engineered Materials – Variability is generally introduced during vendor processing and may vary depending on the part the vendor is producing.
- Internally Engineered Materials – The final material form is actually produced on-site with most of the variability being introduced during part fabrication. (Sources such as CMH-17, AGATE, NCAMP supplemented with applicant validation testing during the part fabrication phase)

# Other Important Considerations When Developing Design Values for Composites

- Brief description of Building Block Approach (BBA)
- Ties to higher levels of BBA when developing Design Values for certification basis

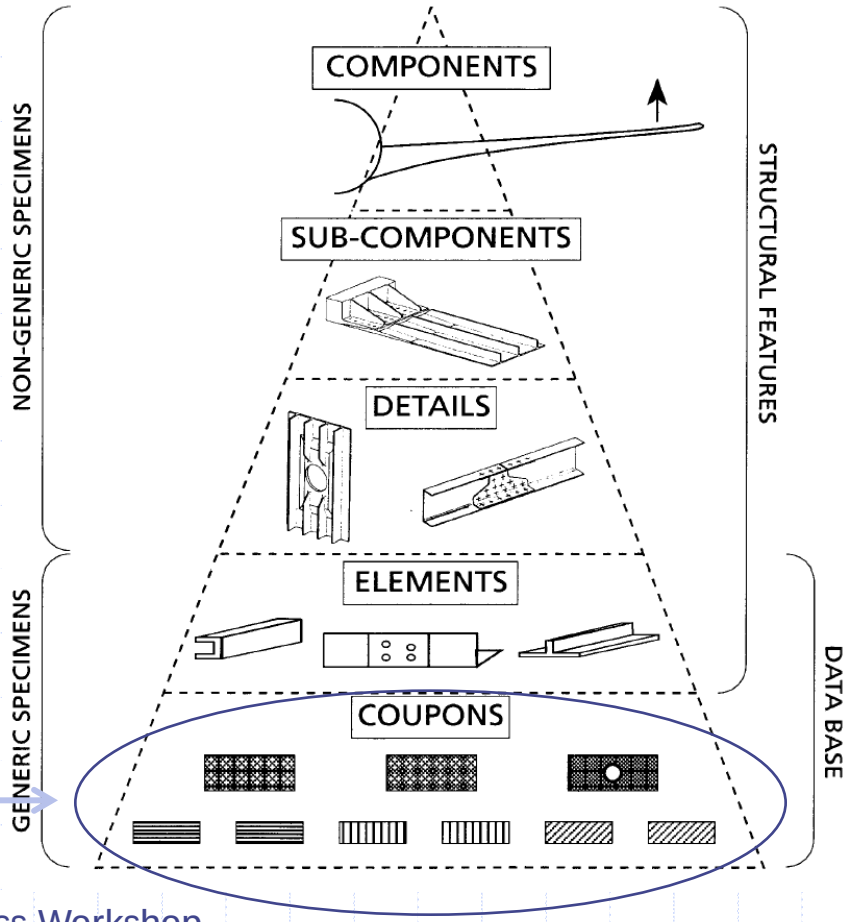
# Building Block Approach

- The Building Block Approach is a means of linking knowledge gained from elemental testing to more complex structures and ultimate to product being certified.
- Details of the BBA depend on the analytical methods used.



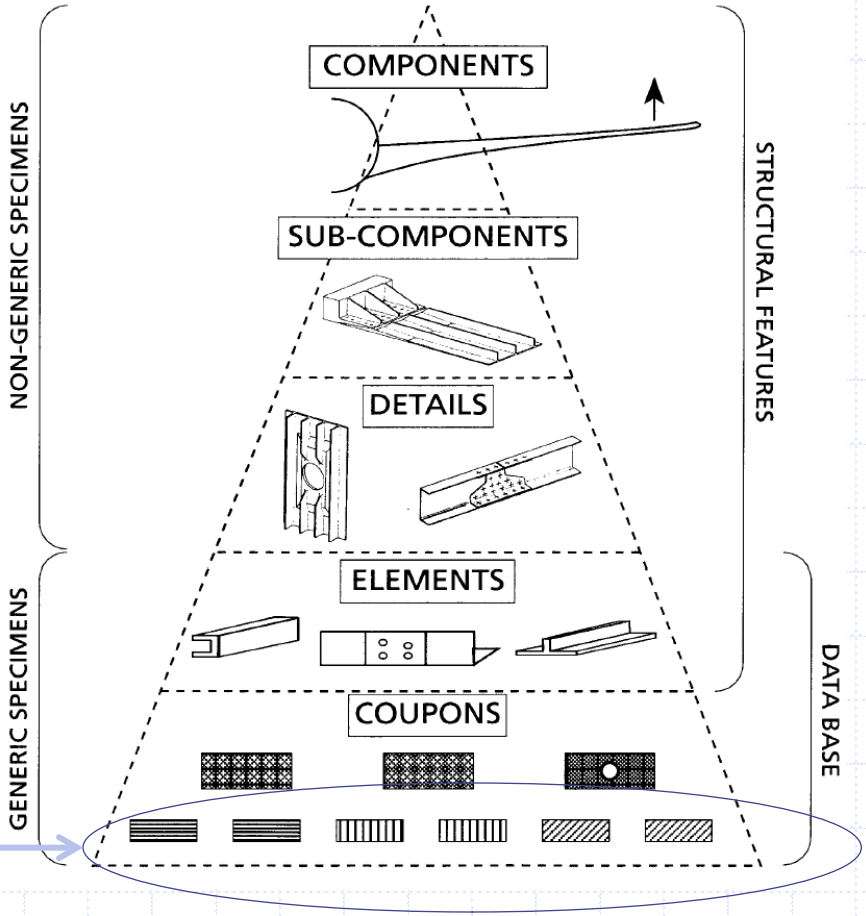
# Building Block Approach

- Data from sources like CMH-17 and NCAMP data at the coupon level, and may not provide all the coupon level data needed to support a specific design.



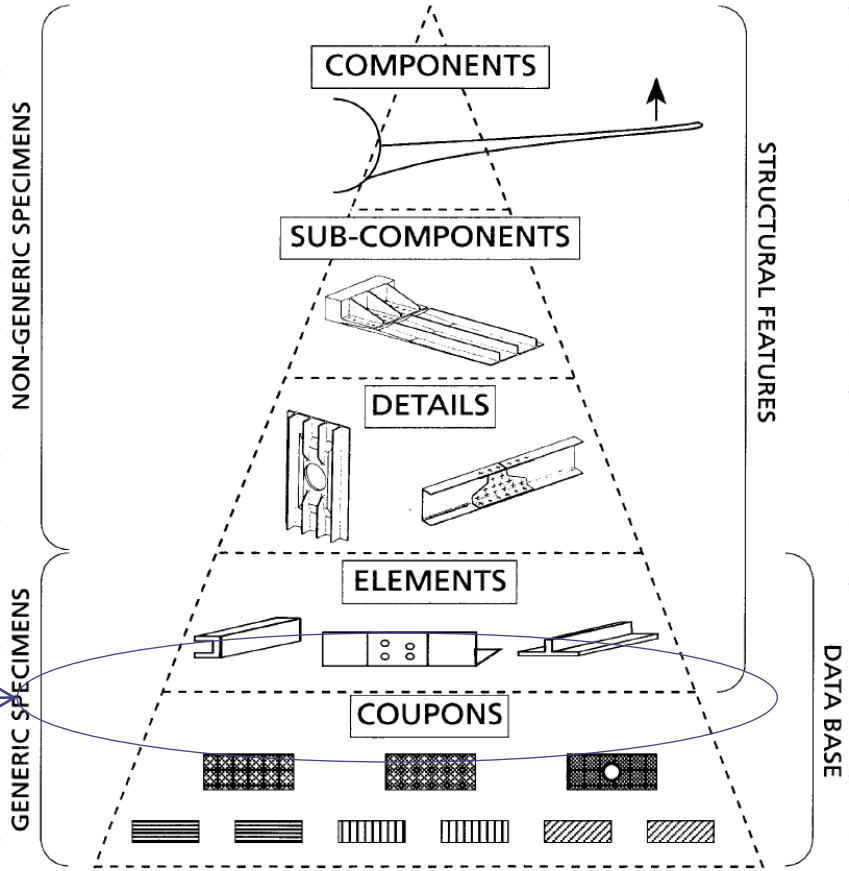
# Building Block Approach

- Testing at the lowest levels are vital for the development and validation of material specifications, but may be of limited use for deriving design values



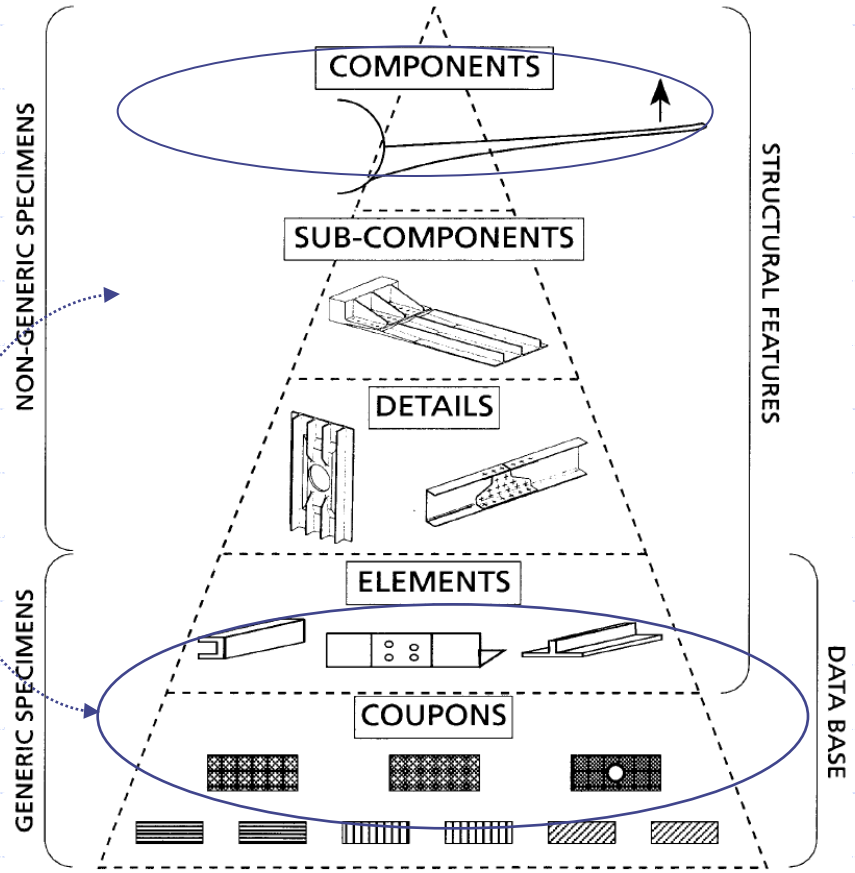
# Building Block Approach

- In order to encompass the variations introduced by both the materials and fabrication processes used, design values must be determined from testing of coupons which sufficient complexity to reflect the sources of variation.

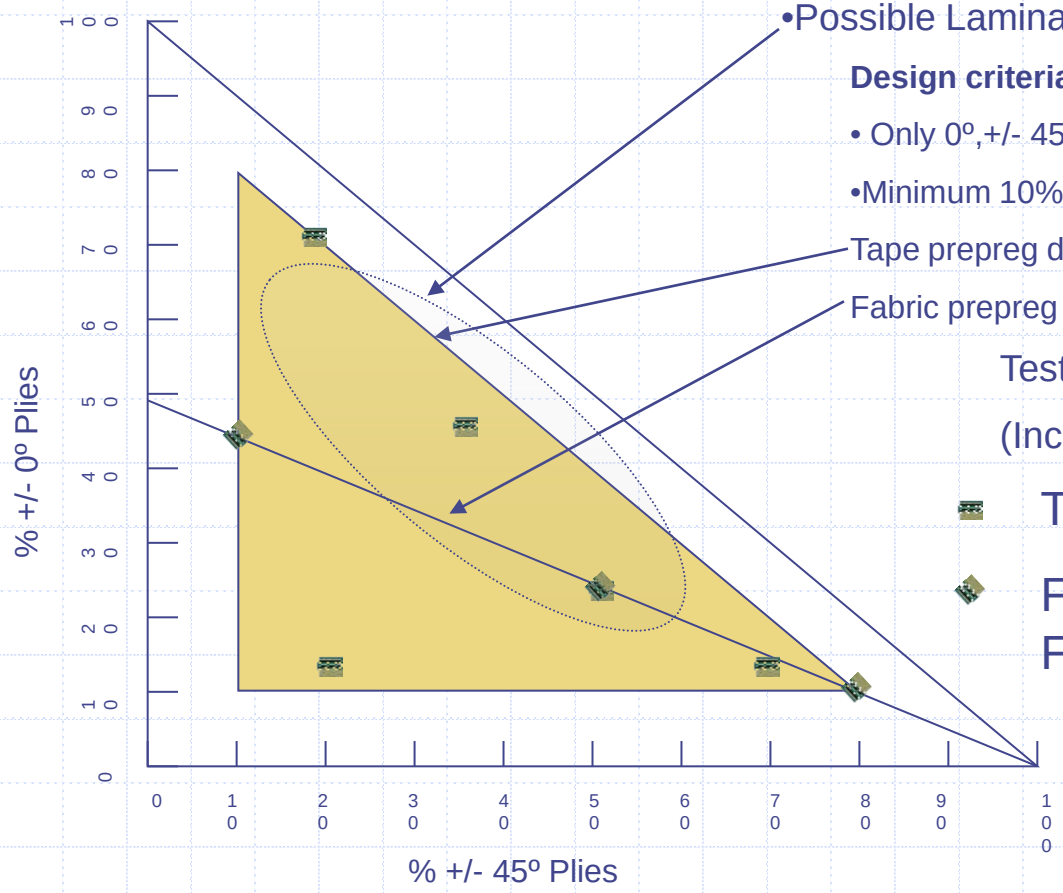


# Building Block Approach

- Final selection of coupons needed to derive design values must take into account values needed by the analytical tools used in the design of actual details and components.



# Design Considerations (generalized simplified example only)




•Possible Laminates for specific application

**Design criteria:**

• Only 0º,+/- 45º, 90º fiber orientations used.

•Minimum 10% fibers in each direction

Tape prepreg design space

Fabric prepreg design space

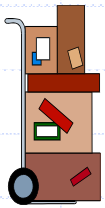
Testing required for each laminate

(Including multiple batches (3 min)

- Tape UNT,UNC, OHC, FHT
- Fabric UNT,UNC, OHC, FHT

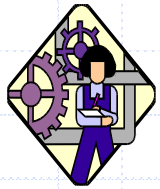
# Product & Design Connection

**•Manufacturing Processes**



•Material Purchased

•+



•Internal Manufacturing Processes

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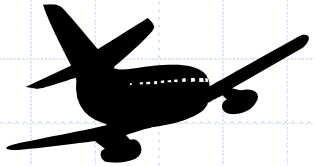


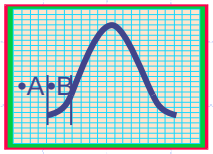
•Product

**•Material & Processing Standards**

•Material Specification

•Process Specification

**•Engineering Processes**




•Prediction of Material Behavior

•(Design Values)

•+

•Prediction of Structural Behavior

•(Design Analysis)

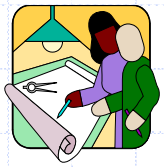
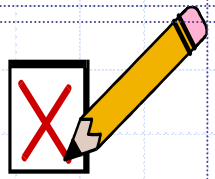
•+

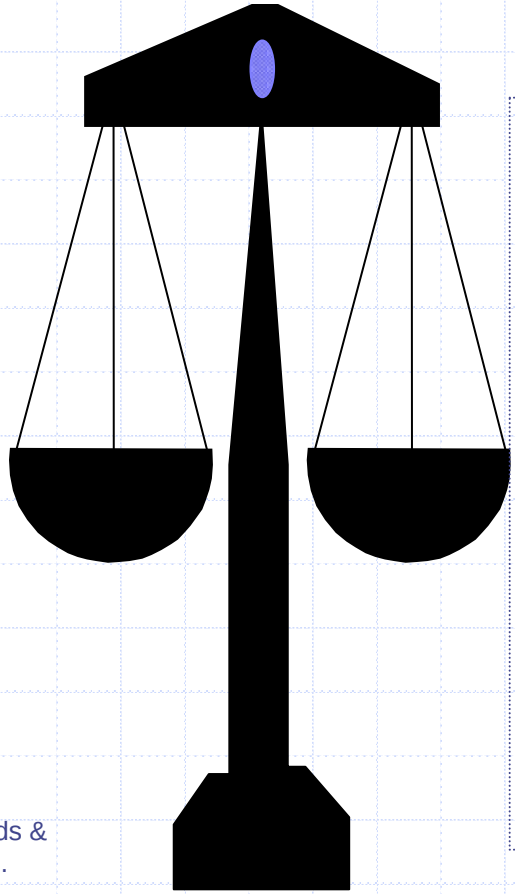
•Verification & Certification Tests

•=

•Certification Basis

# Certification Balance

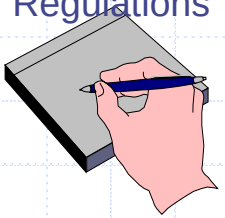
| | •Premium Selection<br>•or<br>•Point Design | | • Spec Controls<br>• and<br>•Allowables & Analysis Methods<br>• in place |
|---|---|---|---|
| •Material & Process Specifications |  | |  |
| •Methods & Allowables |  | •OR |  |
| •Testing Requirements |  | |  |



• Certification
•Requirements

•Performance Goals

•FAA/EASA Regulations



•Criteria

•The more the materials and processes are under control and Methods & Allowables understood, the less testing is required for certification.

# Case Studies

- Composite “material allowables” vs. “Design Values”
- Key Differences taken by manufacturers in certification approaches (manufacturer’s perspective)
- Observed differences between metallic and composite structures
- Examples of environment protection schemes

•Presenters will provide slides