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Federal Aviation Administration Composite Manufacturing Technology Safety Awareness Course

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16. Abstract

This report documents the development of a Federal Aviation Administration safety awareness course on composite manufacturing technology. The course provides manufacturing inspectors with a technical background in composite manufacturing techniques used in aerospace and highlights specific areas that have safety implications. This course guides manufacturing inspectors in developing a suitable level of understanding to link activities on the shop floor to conditions that can lead to unacceptable defects in composite parts.

The course content is structured as a walkthrough of a typical composite manufacturing process, from raw materials manufacturing to shipping final products. Each step in the manufacturing process is represented as a module of this course. Each module introduces technical content related to industry standard techniques, discusses quality inspection techniques, and highlights the implications of the technical content for the inspector's duties. Through the course, students develop an understanding and awareness of the importance of controlling parameters that can lead to defects, which in turn become safety issues.

The course is designed to be interactive and provide the students with opportunities to learn from each other through group discussion and hands-on activities. After completing the course, the course material is made available to the manufacturing inspectors in the form of an electronic summary that they can refer to during their day-to-day work.

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LIST OF ACRONYMS

CMfgT	Composite manufacturing technology
FAA	Federal Aviation Administration
LSP	Lightning strike protection
ASI	Aviation safety inspector
NDT	Nondestructive technique
PAH	Production approval holder
UV	Ultraviolet

EXECUTIVE SUMMARY

This report documents the development of a Federal Aviation Administration safety awareness course on composite manufacturing technology. The course provides manufacturing inspectors with a technical background in composite manufacturing techniques used in aerospace and highlights specific areas that have safety implications. This course guides manufacturing inspectors in developing a suitable level of understanding to link activities on the shop floor to conditions that can lead to unacceptable defects in composite parts.

The course content is structured as a walkthrough of a typical composite manufacturing process, from raw materials manufacturing to shipping final products. Each step in the manufacturing process is represented as a module of this course. Each module introduces technical content related to industry standard techniques, discusses quality inspection techniques, and highlights the implications of the technical content for the inspector’s duties. Through the course, students develop an understanding and awareness of the importance of controlling parameters that can lead to defects, which in turn become safety issues.

The course is designed to be interactive and provide students with opportunities to learn from each other through group discussion and hands-on activities. After completing the course, the course materials are made available to the manufacturing inspectors in the form of an electronic summary, which they can refer to during their day-to-day work.

The main course content is delivered online for self-study. Students are required to read through the content of three modules over 2-week blocks. Short self-test questions are distributed with the course content; the answers are also provided. These self-tests are intended to highlight the important points of the content.

During the 2-week block, the students are required to participate in online discussion forums led by the instructors. Discussion questions are intended to encourage learning from other students’ experiences or ideas.

At the end of each 2-week block, the student must pass an assessment before moving on to the next block. The assessment is an online test consisting of true or false and multiple choice questions. The assessment is also intended to highlight important points from the module that have safety implications.

Following the online self-study is a hands-on laboratory. The laboratory consists of two days of interactive sessions. Students have the opportunity to fabricate real components using industry standard techniques. The laboratories are designed to highlight the important points of the course content that have safety implications.

1. INTRODUCTION

This report documents the development of a Federal Aviation Administration (FAA) Composite Manufacturing Technology (CMfgT) Safety Awareness course. The course provides manufacturing inspectors with a technical background in composite manufacturing techniques used in aerospace and highlights specific areas that have safety implications.

1.1 COURSE GOAL

The goal of this course is to provide FAA manufacturing aviation safety inspectors (ASIs) with a technical background of composite manufacturing at a level that allows them to better and more proactively identify deficiencies on the factory floor that have safety implications. Although targeted for FAA manufacturing ASIs, the course is also relevant to industry quality assurance inspectors, manufacturing personnel, and manufacturing and design engineers.

The course material is intended to serve as a job aid to support ASIs in their daily work. Details of the course content are made available to the ASIs for reference when needed.

After successfully completing the course, ASIs should be able to:

- provide an overview of the typical workflow in a composite manufacturing facility.
- describe important safety awareness issues associated with the different steps in composite manufacturing technologies and processes.
- describe deficiencies on the factory floor that have safety implications in composite manufacturing.
- use the technical background material presented in this course to make better decisions and be more effective in their daily work.

1.2 COURSE STRUCTURE

The course content has been divided into 12 learning modules (figure 1). There are two introductory modules. The first, Module 0.1, “Introduction to Composites,” is intended to ensure that the student’s level of background knowledge in composite materials, composite manufacturing processes, and composite structures is sufficient to successfully complete the course. The second, Module 0.2, “Composites Factory Workflow,” presents an overview of different methods of composite manufacturing and various factory workflows, with an emphasis on the fundamental processing steps that are common in various manufacturing processes.

The main body of the course describes the typical manufacturing flow in a factory, with each module representing a distinct step in the manufacturing process. The sequence of the manufacturing steps is not always the same, but the overall manufacturing flow is similar for most composite manufacturing processes:

1. Module 1: “Raw Materials Manufacturing”
2. Module 2: “Transport, Incoming QC, Storage”

3. Module 3: “Tool Prep, Cutting, Layup, Bagging”
4. Module 4: “Cure, Crystallization”
5. Module 5: “Trim, Drill”
6. Module 6: “Inspect”
7. Module 7: “Bonding, Part Assembly”
8. Module 8: “Paint, Finish”
9. Module 9: “Handling and Storage”

Each module covers one aspect of the composite manufacturing workflow and has associated online course notes, video testimonials, study aids, self-assessment, discussion questions, and laboratory components.

A final module, Module 10, “Common Manufacturing Issues,” addresses manufacturing issues that are related to one or several of the previous modules. For example, a defect such as excessive porosity may have a root cause that is a combination of several manufacturing steps: excessive moisture introduced during transport; storage or layup; and insufficient vacuum or pressure application during cure.

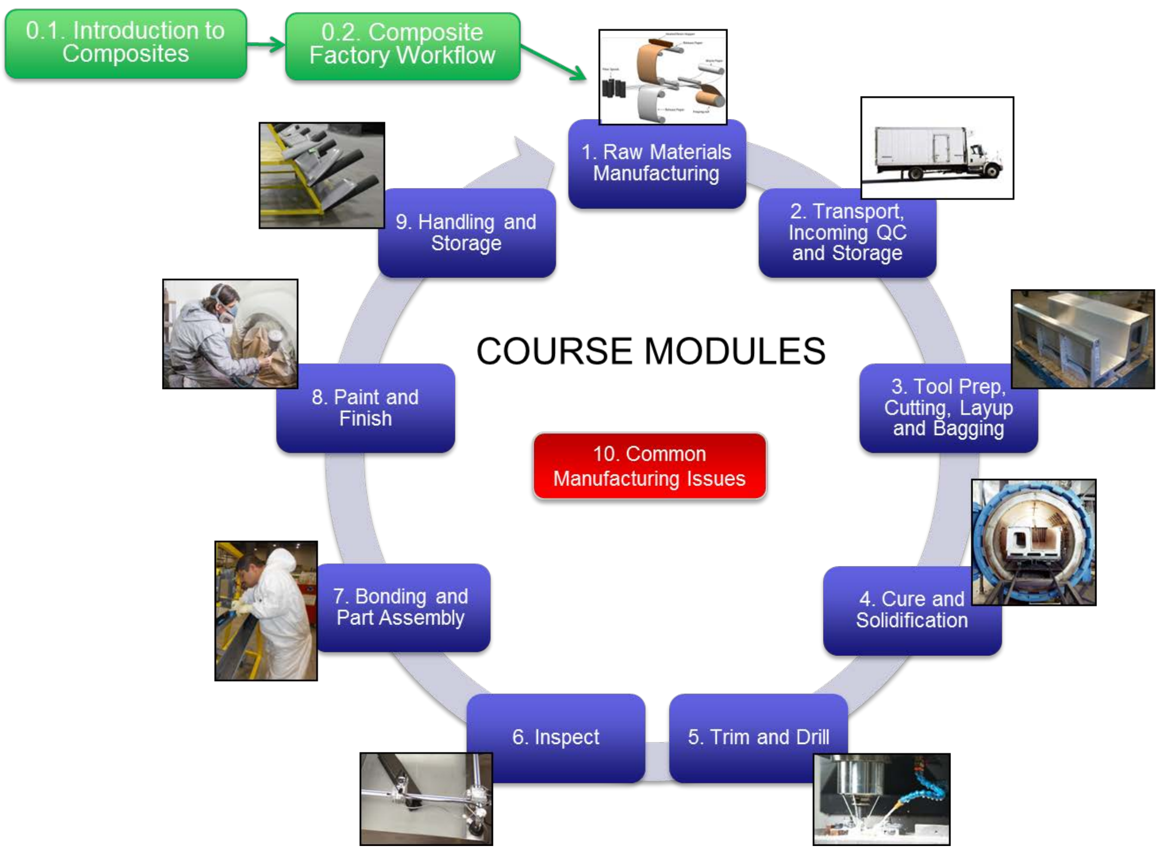

Figure 1. Composite manufacturing technology safety awareness course modules

Each learning module contains the following sections:

- Learning Objectives
- Technical Aspects
  - This section presents the technical content for the module.
- Quality Inspection Techniques
  - When appropriate, quality inspection techniques for modules are presented.
- Implications for the Inspector
  - This section summarizes the implications of the technical content on the day-to-day activities of an inspector on the factory floor.
- Summary

1.3 COURSE DELIVERY, PARTICIPATION, AND ASSESSMENT

The main course content is delivered online for self-study. Students are required to read through the content of three modules over 2-week blocks. Short self-test questions are distributed with the course content; the answers are also provided. These self-tests are intended to highlight the important points of the content modules.

During the 2-week block, the students are required to participate in online discussion forums led by the instructors. Discussion questions are intended to encourage learning from other students' experiences or ideas. Sample discussion questions, which were used during the beta trial run of the course, are listed in appendix A.

At the end of each 2-week block, the student must pass an assessment before moving on to the next block. The assessment is an online test consisting of true or false and multiple choice questions. It is also intended to highlight important points from the module that have safety implications.

Following the online self-study is a hands-on laboratory. The laboratory consists of 2 days of interactive sessions. Students have the opportunity to fabricate real components using industry standard techniques. The laboratories are designed to highlight the important points of the course content that have safety implications. Details about the laboratory from the beta trial run of the course are included in appendix B. Instructor/teaching guidelines for each module can be found in appendix C.

1.4 MODULARITY AND GENERALITY OF COURSE MATERIAL

By making the course modular and by using standard formats and software tools, the course material can easily be modified for other courses and course needs, then updated as needed in the future.

2. LEARNING MODULES

Sections 2.1–2.12 describe the learning objectives, emphasis, content, and teaching points for each module.

2.1 MODULE 0.1: INTRODUCTION TO COMPOSITES

2.1.1 Objectives

Module 0.1's objectives are as follows:

- To ensure that the student's level of background knowledge in composite materials, composite manufacturing processes, and composite structures is sufficient to successfully complete the course
- To ensure that the students are aware of the relevant regulatory requirements governing composites and their manufacturing processes
- To ensure that the students understand the role the ASI plays in manufacturing safety

2.1.2 Emphasis

In Module 0.1, the students are able to self-evaluate their knowledgebase in composite materials and their preparedness for the upcoming course content. The emphasis is to bring all students up to a standard baseline level of knowledge.

The relevant regulatory requirements and the role of the ASI are introduced in this module to give students a clear understanding of what is expected of them at the end of the course.

In addition, a glossary of common terms used in composites manufacturing is provided for the students to reference later in the course.

2.1.3 Content

This module has the following subsections:

- Composite History and Comparison to Metals

  – This section provides a background on the historical use of composite materials and a comparison to common metallic material behavior.

- Composite Material Fundamentals

- This section introduces the fundamentals of composite materials, including composite material forms and types; typical resins and fibers; laminates and sandwich structures; and common processing methods.

- Regulatory, Guidance, and Control Documents

  - This section describes national regulatory bodies and lists regulatory and guidance documents, which are relevant to manufacturing of composite materials. Material and process control documents are also described.

- The Role of the Manufacturing Inspector

  - This section provides a brief overview of the role of the manufacturing inspector in assuring safety of composite aircraft components.

- Glossary of Common Terms

2.2 MODULE 0.2: COMPOSITES FACTORY WORKFLOW

2.2.1 Objectives

The objectives of Module 0.2 are as follows:

- To introduce the students to the variety of composite manufacturing facilities based on different material forms and manufacturing processes
- To introduce the student to the fundamental processing steps that are common within various manufacturing processes

2.2.2 Emphasis

This module will give the student an overview of different forms of composite manufacturing and various factory workflows, with an emphasis on the fundamental processing steps that are common within various manufacturing processes.

2.2.3 Content

This module has the following subsections:

- Common Factory Workflows

  - This section introduces the steps that are common to all composite manufacturing facilities. These steps make up the individual modules of this course.

- Factory Workflow Examples

  - This section presents four examples of composite parts and their manufacturing workflows. These examples are intended to provide a general idea of typical manufacturing techniques used for aerospace parts. Further details on the techniques introduced here are presented later in the course.

2.2.4 Teaching Points

The following are important elements discussed in Module 0.2:

- Though the manufacturing processes and equipment required differ significantly, the resulting parts from all processes are controlled by the same fundamental concepts.
- The overall course philosophy is to understand the fundamentals that can be applied to any composite manufacturing process.
- There are common manufacturing defects that occur regardless of the process, such as porosity, warping, and non-visible damage.

2.3 MODULE 1: MATERIALS MANUFACTURING

2.3.1 Objectives

At the end of this module, students should be able to:

- describe the manufacturing processes of the individual constituents of composites and the composite forms
- explain the characteristics, advantages, and disadvantages of different fiber and resin classes of materials (thermoplastic vs. thermoset, glass vs. graphite, etc.)
- explain the characteristics, advantages, and disadvantages of different fiber forms (unidirectional, woven, chopped, etc.)
- appreciate the relationship between the quality of raw materials and the quality of the resulting composite structure

2.3.2 Emphasis

This module contains a review of the manufacturing processes of composite constituents and composite forms, with an emphasis on the effect of the initial materials and their forms on the subsequent composite properties and performance.

2.3.3 Content

Module 1 has the following subsections:

- Key Concepts in Composite Manufacturing

  - This section lists key concepts that are unique to raw materials for composites and highlights differences from metal processing

- Raw Materials

  - This section lists the raw materials used in composite manufacturing, including various material forms and the means by which they can be combined

- Fibers

  - This section introduces different fiber types (glass, aramid, and carbon) and the commonly used grades of each. The manufacturing process of fibers and the various forms available are introduced. Typical mechanical properties of raw fibers are given such that the relative advantages and disadvantages of each fiber type can be seen.

- Resins

  - This section introduces thermoset and thermoplastic resin types and the commonly used grades of each. The various resin forms are introduced and typical properties of raw resin are given such that the relative advantages and disadvantages of each resin type can be seen.

- Prepregs

  - This section discusses the prepreg form of composite raw material in more detail. Prepreg refers to a form in which the fibers are pre-impregnated with the resin so that the raw material is already a composite in its initial form.

- Core Materials

  - This section introduces core materials that are used in sandwich constructions. The common core materials (foam and honeycomb) are introduced and their relative advantages and disadvantages are discussed.

- Adhesives

  - This section introduces adhesives, which are often used in core structures, secondary cure structures, and composite to metal bonding. Adhesives are a special case of resins because their underlying chemistry is very similar.

- Consumables

  - This section introduces consumables, which are raw materials used in the production of composite parts that do not remain on the part. Consumables are critical to repeatable part production and must be appropriately controlled.

- Quality Inspection Techniques

- This section describes techniques that can be used to ensure stable material supply. The appropriate test methods and standards for different properties are discussed.

- Implications for the Inspector

    - This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification

2.3.4 Teaching Points

The following are important elements discussed in Module 1:

- The composite material and final properties are created at the same time as the part.
- Material specifications control purchased raw materials.
- The quality of the final part is directly dependent on the quality of raw materials.
- Many key characteristics of composites raw materials require statistical process control with upper and lower limits.
- Fibers:

    - Types: glass, aramid, carbon.
    - Forms: short chopped, mat, unidirectional, woven, preforms.
    - Fiber surface treatments ("sizing") improve handleability and promote fiber-resin bonding.
    - Fiber surface treatments need to be controlled.
    - Woven fabrics are orientation dependent: warp vs. weft and top side vs. bottom side.
    - Orientations of woven fabrics should be tracked from receiving to layup.

- Resins:

    - Types: thermoset, thermoplastic.
    - Forms: liquids, films, sheet, tape, pellet, powder, fiber.
    - Thermoset resins are cured by a non-reversible chemical reaction.
    - Thermoplastic resins soften when heated and harden when cooled.

- Prepregs:

    - Fibers pre-impregnated with a resin.
    - For thermoset resins, the pre-impregnation process may slightly advance cure of the resin.
    - Thermoset resin prepregs are typically stored at cold temperatures to prevent further cure of the resin.

- Core materials, adhesives, and consumables must also be controlled.
- The manufacturer's material specifications should define quality tests to be performed at the raw material supplier and those at receiving inspection.
- For qualification, test panels should use the same fabrication method as the final part.
- Visual inspection of material rolls are often performed at layup.

2.4 MODULE 2: TRANSPORT, INCOMING QUALITY CONTROL, AND STORAGE

2.4.1 Objectives

At the end of this module students should be able to:

- explain the importance of managing environmental conditions from the time of raw material manufacture to production.
- describe the appropriate packaging and shipping procedures for transportation of various raw materials.
- describe the appropriate receiving procedures for incoming raw materials.
- describe the appropriate storage procedures for raw materials.

2.4.2 Emphasis

This module covers the fundamental impact of the environmental conditions (e.g., temperature, moisture, etc.) on the quality of the materials, with an emphasis on how to control those environmental conditions so that material quality at production is consistent with design assumptions.

2.4.3 Content

Module 2 has the following subsections:

- Important Environmental Conditions

  – This section describes important environmental conditions that have an effect on the quality of composite parts. This includes temperature and moisture exposure during transport, receipt, and storage.

- Controlling Environmental Conditions

  – This section describes the techniques used to control environmental conditions from the time of raw material manufacture to production

- Receiving Raw Materials

  – This section describes typical receiving procedures for perishable materials that require cold storage

- Quality Inspection Techniques
  - This section describes techniques that can be used to ensure a stable material supply. The appropriate test methods and standards for different properties are discussed in Module 1: “Raw Materials Manufacturing.”
- Implications for the Inspector
  - This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification.

2.4.4 Teaching Points

The following are the important points discussed in Module 2:

- Important environmental conditions to control:
  - Temperature
    - Exposure of uncured thermoset resins (including prepregs and film adhesives) to temperatures above 0ºF (typically) can initiate cure.
  - Moisture
    - Excess moisture within a layup can significantly reduce the final properties of the composite part.
- Temperature and humidity recorders should be used during transportation and storage.
- Out life and shelf life are important terms defined from the date of prepreg manufacture, not the date of receipt at the production approval holder (PAH).
- The PAH should have an incoming material acceptance plan.

2.5 MODULE 3: TOOL PREP, CUTTING, LAYUP, AND BAGGING

2.5.1 Objectives

At the end of this module, students should be able to:

- explain the relationship between tool preparation, cutting, layup, and bagging on the quality of final parts.
- describe process control documents used to standardize practices leading up to cure.
- describe best practices for tool prep, cutting, layup, and bagging.

2.5.2 Emphasis

The emphasis of this module is on the relationship between tool preparation, cutting, layup, and bagging on the quality of manufactured parts. The use of process control documents to standardize practices leading up to cure will also be emphasized.

2.5.3 Content

Module 3 has the following subsections:

- Tool Preparation
  - This section describes how layup tools are defined and controlled in production. It also describes tool preparation before layup, storage, and repair.
- Ply Cutting
  - This section describes how individual plies are cut to the shapes necessary for part layup. Plies can be prepregs or dry fabrics.
- Layup
  - This section describes how plies are laid up to create a composite laminate. Plies can be prepregs or dry fabrics. The methods of defining ply orientation and manual versus automated layup techniques are described.
- Bagging
  - This section describes the assembly of a vacuum bag including definitions of vacuum bag consumables and best practices in ensuring good vacuum.
- Quality Inspection Techniques
  - This section describes techniques that can be used to ensure quality tool preparation, ply cutting, layup, and bagging.
- Implications for the Inspector
  - This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification.

2.5.4 Teaching Points

The following are the important points discussed in Module 3:

- Tooling:
  - Tool design must be defined, including the support structure under the tool surface.
  - Commonly used tool materials:
    - Invar
    - Steel
    - Aluminum
    - Composite
  - Process control documents should restrict changing the tool material and structure.
  - In general, tool preparation includes the following steps:
    - Cleaning the tool surface
    - Sealing porosity of the tool surface
    - Applying release agents
- Ply Cutting:
  - The shape of each ply should be defined as part of type design.
  - Manual ply cutting should be performed by trained technicians.
  - Automated ply cutting machines and software must be validated.
- Layup:
  - The part layup is defined by a laminate code and warp clock.
  - Manual ply layup should be performed by trained technicians.
  - Automated layup machines and software must be validated.
- Bagging:
  - Vacuum bagging is a process in which a laminate is consolidated under vacuum.
  - Bagging materials include:
    - Porous release film (or peel ply)
    - Bleeder cloth
    - Caul plate
    - Breather cloth
    - Edge dams
    - Sealant tape
    - Bag material
  - When laying up a bag, it is important to consider gas paths for entrapped air to reach the vacuum system.

- Bagging materials, including consumable materials, should be defined and have sufficient controls.

2.6 MODULE 4: CURE, SOLIDIFICATION

2.6.1 Objectives

At the end of this module, students should be able to:

- list the various factors that affect how the material cures and consolidates.
- explain the difference between thermosets and thermoplastics in terms of cure or solidification and the critical processing parameters to control.
- explain the importance of processing on the resulting structural properties of the composite.

2.6.2 Emphasis

The emphasis of Module 4 is on the nature of cure; how it is dependent on time and temperature; and the effect on mechanical and physical properties of the finished component. The importance of consolidation with the aid of vacuum and external pressure on mechanical properties is also emphasized.

2.6.3 Content

Module 4 has the following subsections:

- Basics of Cure/Solidification

  - This section introduces the basic mechanisms of cure of a thermoset resin and solidification of a thermoplastic resin. Commercial resins used in industry today are often a complex mixture of resins and additives. Their behavior can be more complex than the basic mechanisms presented here.

- Processing Methods

  - This section introduces the most common manufacturing methods for curing and solidification of thermoset and thermoplastic resin composites. Though many other manufacturing methods exist, they are typically variations on the general methods presented here.

- Processing Parameters and Cycles

  - This section describes the most significant parameters that must be controlled for any composite manufacturing process. Process cycles are used to define and control these parameters. This section introduces typical process cycles and how they are specified in process documents.

- Part Temperature

- It is critical that all locations throughout the part achieve the specified temperature cycle. This section introduces the factors that affect the part temperature when inside an oven or autoclave. To achieve the specified temperature cycle, the heat transfer conditions of the heating system and the tool and part assembly must be fully understood.

- Quality Inspection Techniques

  - This section introduces some of the common quality inspection techniques that can be used to ensure that adequate, repeatable cure or solidification has been achieved in every part.

- Implications for the Inspector

  - This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing investigator under type or production certification.

2.6.4 Teaching Points

The following are the important points discussed in Module 4:

- Two distinct classes of resin materials based on how they react to the application of heat:

  - Thermoset Resins

    - Cure: non-reversible chemical reaction, generally triggered by heating the resin

  - Thermoplastic Resins

    - Softening upon heating, solidification upon cooling (reversible)

- Typical processing methods:

  - Vacuum bag
  - Resin infusion
  - Ovens
  - Autoclaves
  - Compression molding

- Any cure or solidification process involves controlling the same fundamental processing parameters:

  - Time

  - Pressure and vacuum (if applied)
  - Temperature

- Temperature and pressure cycles must be defined.
- All locations on the part must go through the defined process cycle to achieve the desired final properties.
- For ovens and autoclaves, the actual part temperature will deviate from the applied air temperature.
- Heating systems are not necessarily uniform and heat transfer can depend on the distribution of airflow within the heating chamber.
- The airflow in the vicinity of the part is dependent on:

  - The heating and fan system
  - The orientation of the part
  - The arrangement of tooling and fixtures

- Cure of thermoset resins is an exothermic reaction.
- If not properly controlled, the heat generated by the exothermic reaction can raise the part temperature above the limits given in the process specification.

2.7 MODULE 5: TRIM AND DRILL

2.7.1 Objectives

At the end of this module students should be able to:

- explain the differences in trimming and drilling composites versus metals.
- describe the effect of dull tools and improper trimming and drilling procedures on defects.
- describe the importance of dust control on product quality and workplace health and safety.

2.7.2 Emphasis

Module 5 emphasizes the differences between machining composites versus metals and the importance of proper techniques to avoid mechanical and heat damage in the composite. In addition, Module 5 emphasizes machining composite and metal-bonded stack ups.

2.7.3 Content

Module 5 has the following subsections:

- Trimming and Drilling Composites

  - This section describes trimming and drilling of composite materials and highlights common practices that are different than with metals. Specific topics that are covered include:

- Support structures
- Backing plates
- Rotary trimming
- Abrasive waterjet
- Cutting parameters
- Cooling methods
- Dust control

- Trimming and Drilling Defects

  – This section lists common defects of composite materials when using rotary cutting tools or waterjet cutting.

- Quality Inspection Techniques

  – This section describes inspection techniques to verify final dimensions and some cutting defects. Further details on inspection for internal defects are discussed in Module 6.

- Implications for the Inspector

  – This section describes considerations for the inspector in regard to trimming and drilling composites.

2.7.4 Teaching Points

The following are the important points discussed in Module 5:

- Trimming and drilling composites versus metals:

  – Removed composite material is fine particle dust rather than metal chips.
  – Composite surface is more abrasive, generating higher friction and heat at the cutting tool.
  – Composites are poor at conducting heat away from the cutting area.
  – Tools wear faster and become dull sooner.

- Typical trimming techniques:

  – Rotary trimming
  – Abrasive water jet

- Cooling methods:

  – Cooling fluids

    - Water based; special formulations avoid contaminating bonding surfaces

    - Liquid nitrogen
  - Cooling Gases

- Trimming and Drilling Defects

  - Delamination
  - Splintering
  - Fiber pull-out
  - Overheating
  - Oblong holes
  - Striation marks
  - Frosting

- Dust hazard:

  - Worker health and safety
  - Equipment, machinery, and electronics
  - Part in layup and assembly

- Dust control:

  - Liquid coolants
  - Vacuum ducts
  - Shrouds
  - Enclosures
  - Personnel protection
  - Ventilation

2.8 MODULE 6: INSPECT

2.8.1 Objectives

At the end of this module, students should be able to:

- identify some common defects in composite materials.
- describe nondestructive and destructive inspection methods for cured composite parts and materials.
- explain the limitations of inspection techniques with respect to laminate thickness; solid or sandwich structures; and defect size.

2.8.2 Emphasis

There is some form of quality inspection performed at each portion of a manufacturing process (visual inspection at minimum). Each module of this course covers specific inspection techniques and practices used during that portion of the manufacturing process. Module 6 discusses in more detail the inspection techniques that are used throughout the composite manufacturing process.

2.8.3 Content

Module 6 has the following subsections:

- Composite Anomalies
    - This section lists some common anomalies (as potential defects) found in composite materials. Not all anomalies can be listed here. The anomalies presented include:
        - Cosmetic anomalies
        - Cracks
        - Disbonds/delamination
        - Weak bond (a.k.a. kissing bond)
        - Voids
        - Porosity
        - Inclusion
        - Core crush
        - Fiber wrinkling or waviness
        - Ply misalignment
        - Resin rich or dry areas
        - Impact damage
- Nondestructive Inspection
    - This section describes some common nondestructive inspection techniques used for cured composite parts. There are many inspection techniques used in practice; however, they are generally small variations of the techniques presented here. Techniques presented in this section include:
        - Visual
        - Tap testing
        - Ultrasonic
        - Thermography
        - Shearography
        - Radiography
- Destructive Testing
    - This section describes destructive inspection methods for test coupons or representative parts.
- Implications for the Inspector

- This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification.

2.8.4 Teaching Points

The following are the important points discussed in Module 6:

- Some form of quality inspection is performed at each portion of a manufacturing process (visual inspection at minimum)
- Anomalies vs. defects:
  - All anomalies are considered suspected defects (i.e., non-conformity) until they are determined to be acceptable
  - Any anomalies that deviate from type design, or the tolerances thereof, that require rework or repair, are considered defects
- Nondestructive inspection:
  - Many nondestructive techniques (NDTs) involve sending a signal through a laminate and checking for any changes to the signal as it is received.
  - Changes to the signal may indicate an internal defect in the laminate.
  - No single NDT can detect all types of defects in any part.
- Destructive inspection:
  - Test coupons
    - Representative coupons
    - Traveler coupons cut from prolongation of the part
  - Full-size part
    - Can prove the quality of a group of parts
    - Used as part of first article inspection

2.9 MODULE 7: BONDING AND PART ASSEMBLY

2.9.1 Objectives

At the end of this module, students should be able to:

- describe the advantages and disadvantages of adhesive bonds, mechanical assemblies, and hybrid assemblies.
- describe important factors in ensuring high-quality bonded joints, such as surface preparation and bond line thickness.

- explain the differences in mechanical assembly of composite parts versus metal parts.
- explain the challenges in inspecting and qualifying joints.

2.9.2 Emphasis

The emphasis of Module 7 is to describe the importance of critical steps in bonding and assembly of composite components. An example point to emphasize is the importance of surface preparation on adhesive joints.

2.9.3 Content

Module 7 has the following subsections:

- Adhesives

  – This section describes the type of adhesives typically used in aerospace bonding applications.

- Bonding Techniques

  – This section describes typical bonding techniques used in aerospace.

- Surface Preparation

  – This section describes steps that are taken to prepare the surface of a composite laminate or metal for adhesive bonding. Surface preparation is one of the critical steps in adhesive bonding that has a significant effect on the subsequent bond strength.

- Mechanical Assembly

  – This section describes mechanical assembly of composite components. Emphasis is placed on special mechanical assembly considerations with composite materials compared to metals.

- Bonding Defects

  – This section describes defects that can lead to understrength adhesive bonds.

- Quality Inspection Techniques

  – This section describes inspection techniques used to ensure quality control of adhesive bonding and mechanical assembly.

- Implications for the Inspector

- This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification.

2.9.4 Teaching Points

The following are the important points discussed in Module 7:

- Advantages of adhesive bonding
  - Efficient load transfer
  - Lighter and stiffer
  - Smoother external surfaces
  - Reduce the risk of solvent and water penetration
- Advantages of mechanical assembly
  - Disassembly without damaging the part
  - Less sensitive to surface preparation and surface contaminants
  - Easier inspection and nondestructive testing
- Hybrid Assemblies
  - A combination of adhesive bonding and mechanical assembly “chicken fastener”
- Types of adhesives
  - Structural adhesives
  - Non-structural adhesives
- Forms
  - Films
  - Liquids
  - Pastes
- Initial Forms
  - One-part adhesives
  - Two-part adhesives
- Limitations on
  - Shelf life
  - Open life

- Clamp up time

- Bonding Techniques

  - Co-bonding

    - Bonding one or more previously cured components to one or more initially uncured components using an adhesive

  - Secondary bonding

    - Bonding previously cured components together using an adhesive

- Bond Line Thickness

  - Minimum and maximum bond line thicknesses should be defined in the process documents and controlled.
  - Carriers, such as knit, woven cloth, and non-woven mat, can be used to control the minimum bond line thickness or film adhesives.
  - Glass beads, thin rods, or wires can be used to control the minimum bond line thickness of paste adhesives.

- Surface Preparation

  - Methods:

    - Abrasion (sandpaper or grit blast)
    - Peel ply suitable for bond surface preparation

  - A rougher surface texture will wet out more and increase the surface area available for bonding.
  - Contaminants on the surface will adversely affect the bond strength.
  - There are currently no nondestructive inspection methods to determine if there is a good quality bond.

2.10 MODULE 8: PAINT AND FINISH

2.10.1 Objectives

At the end of this module, students should be able to:

- describe common painting and finishing techniques.
- explain paint thickness requirements over lightning strike mesh.
- describe appropriate environmental conditions during storage, application, and cure of finishing products.
- explain storage life and working life requirements for finishing products.

- describe common surface imperfections and subsequent repair techniques.

2.10.2 Emphasis

The emphasis of Module 8 is on ensuring that any finishing technique is properly tested and qualified against appropriate control documents and that any finishing product is properly controlled in terms of storage shelf life and proper application technique.

2.10.3 Content

Module 8 has the following subsections:

- Primers and Topcoats
  - This section introduces common primers and topcoat paints and their application methods.
- Surfacing Films
  - This section introduces surfacing films, which are commonly used as a finishing product for composite parts.
- Lightning Strike Protection (LSP)
  - This section describes LSP strategies, which are often included within finishing products.
- Surface Imperfections, Repair, and Stripping
  - This section lists some common surface imperfections after applying finishing products, appropriate repair techniques, and paint-stripping procedures for composite parts.
- Quality Inspection Techniques
  - This section describes inspection techniques to verify the quality of the finishing products.
- Implications for the Inspector
  - This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector.

2.10.4 Teaching Points

The following are the important points discussed in Module 8:

- Primers fill in surface imperfections and improve adhesion of the top coat.
- Topcoats protect the underlying part from ultraviolet (UV) light damage, rain, snow, abrasive particles, chemicals, and fluids.
- Surfacing films may be used as the final finishing layer or simply to prepare the surface for painting.
- Storage temperature and humidity should be controlled.
- Out life should be controlled.
- Personnel in close contact with primers and paints should wear appropriate protective equipment.
- LSP systems provide a conductive path from the aircraft's outer skin to a metallic "ground" (such as metal framing or ground plate).
- LSP typically involves embedding metal mesh, foil, or wire on or near the outer surface of the aircraft.

    - Materials on top of the metal mesh, foil, or wire (such as surfacing films, primers and/or topcoats) will resist electrical conductivity to the mesh, foil, or wire and risk increased damage due to a strike.

- The LSP system should provide an electrical connection across gaps.
- Metal fasteners should be either electrically insulated or electrically connected to each other and the LSP system.

2.11 MODULE 9: HANDLING AND STORAGE

2.11.1 Objectives

At the end of this module, students should be able to:

- explain the importance of safe handling and storage procedures of cured parts.
- describe sources of potential damage during handling and storage.
- describe preventative methods to avoid damage during handling and storage.

2.11.2 Emphasis

Module 9 emphasizes the importance of safe handling and storage procedures and the impact of potential damage on typical composite aircraft parts.

2.11.3 Content

Module 9 has the following subsections:

- Damage

    - This section describes the risks and procedures associated with foreign object damage on composite aircraft parts

- Handling
    - This section describes typical part handling techniques to reduce or prevent part damage.
- Storage
    - This section describes storage techniques and requirements for composite parts.
- Quality Inspection Techniques
    - This section describes inspection techniques for handling and storage damage.
- Implications for the Inspector
    - This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector.

2.11.4 Teaching Points

The following are the important points discussed in Module 9:

- A prevention program should be in place to reduce or eliminate foreign object damage during handling and storage of composite aircraft parts.
    - Foreign object impact on composite parts may lead to fracture/delamination, which may or may not be visible on the outer surface.
- If it is suspected that a part has been impacted:
    - A nonconformance record/report should be created, filed, and tracked with the part.
    - The part should be inspected for damage.
- Damage prevention
    - Thin parts may need to be structurally supported with specialized fixtures.
    - Protective devices may be placed on sensitive areas during handling and storage.
- Storage:
    - Parts should be stored in a manner to protect them from deterioration from sunlight (or UV generating artificial lights), moisture, dirt, heat, or accidental impact.

2.12 MODULE 10: COMMON MANUFACTURING ISSUES

2.12.1 Objectives

At the end of this module, students should be able to:

- understand common effects of scaling production from simple to more complex structures.
- understand engineering disposition and determine if a repair is required.
- identify defects that are associated with more than one step in the manufacturing process.
- explain the effect of those defects on the performance of a part.
- describe typical repair procedures for composite parts.
- understand the way changes should be categorized and approved.

2.12.2 Emphasis

This section exposes ASIs to practical examples of manufacturer's practices leading to defects and other safety issues with production parts, with an emphasis on understanding the root causes of the defects and the appropriate corrective actions that are required.

2.12.3 Content

Module 10 has the following subsections:

- Scaling Effects
  - This section describes common issues associated with scaling, from production of small or simple structures to larger or more complex structures
- Defect or Damage Disposition
  - This section defines the appropriate disposition process once a defect or damage has been identified
- Manufacturing Defects and Root Cause Analysis
  - This section describes defects that are associated with more than one step in the manufacturing process
  - The following defects and damage could be introduced from multiple steps in the manufacturing process:
    - Porosity
    - Disbonds/delaminations
    - Weak bonds
    - Matrix cracking
    - Broken fibers
    - Fiber waviness, wrinkling
    - Dimensional conformance

- Under cure
- Heat damage
- Resin-rich areas
- Resin-starved areas
- Fluid ingression
- Foreign object damage
- Blunt impact damage

– For each defect, the following topics are covered:

- Defect definition
- Defect effect
- Defect identification
- Potential root causes
- Repair, rework options

2.12.4 Teaching Points

The following are the important points discussed in Module 10:

- Defects are often related to scaling part size/production
  - A process that works on a small scale part or for a small production run may not translate to larger parts or larger production.
  - Careful considerations of the possibility of defect must be kept in mind when scaling up part size or production.

- Defect or damage disposition involves an engineering/manufacturing interface
  - Once a defect or damage has been identified, it must be evaluated to determine if repair, rework, or other appropriate actions are required.
  - If the defect is outside an allowable damage limit or not covered by a structural repair manual, engineering disposition is required.

- If allowed, repair of a defect typically involves removing the damaged material and applying a repair patch.
  - Repair patches may be:
    - a mechanically fastened doubler.
    - bonded repairs.
    - hybrid: bonded and mechanically fastened.
  - Types of bonded repair patches:
    - Patch

- Scarf
- Step sanded

– Patches may be cured on the part or pre-cured and applied with an adhesive.
– Uncured repair patches must be processed with an appropriate cure cycle.

- Thermal mass of the underlying structure should be considered when defining a repair cure cycle
- Changes to the manufacturing processes that do not require airworthiness approval should be viewed cautiously to ensure they do not accidentally reduce strength, durability, etc.
- Several reports published by the FAA William J. Hughes Technical Center provide guidance on how to categorize changes to materials and processes

APPENDIX A - TYPICAL DISCUSSION QUESTIONS USED FOR THE BETA COURSE

Module	Subject	Question
0.1	Please introduce yourself	Hello everyone! Please add a message to this thread to introduce yourself, including: - Your name - Your job title - Where you are from - What experience you have with composite materials (if any)
0.2	Composite factory workflow	Hello everyone, Please comment on the "composite factory workflow" presented in this module. Specifically, do you agree with the order of each manufacturing step? How could the steps be ordered differently?
	Composites versus metals factory workflows	Hello everyone, Please comment on the "composite factory workflow" presented in this module. Specifically, how does this workflow compare to a workflow you have seen for metal parts? Which steps are the same? Which steps are unique to composites?
1	Consumable material control	Consumables are materials that are used in the manufacturing process but do not end up on the final part. Examples of consumables are vacuum bag film or breather cloth. Give an example of a consumable material that should be controlled with process documents and one that should not be controlled.
	Supplier control	Controlling raw material supply is critical to ensure part quality. A production approval holder (PAH) must have processes in place to control raw materials received from a supplier. Follow up question: "to what degree must a PAH control the supplier?" Does the PAH need to control the supplier's supplier? For example, if a prepregger is supplying woven prepreg, does the PAH need to have controls in place for the prepreggers resin supplier, fiber supplier, or weaver if any of those are not done in house? As a safety inspector, is it part of your role to verify controls on the supplier's supplier?

Module	Subject	Question
2	Temperature Control	In this module, we discussed how many composite raw materials require strict temperature control during transportation and storage. Comment on the importance of temperature control. You may want to consider the following, or add your own ideas: When are raw materials at risk of prolonged elevated temperature exposure? How do we monitor raw material temperatures? What processes are typically used to control raw material temperatures?
	Moisture Control	In this module, we discussed how excess moisture exposure of composite raw materials can significantly reduce the final properties. Comment on the importance of control for moisture exposure. You may want to consider the following, or add your own ideas: What are some typical sources of moisture exposure? How do we monitor moisture levels? What processes are typically used to control moisture exposure?
3	Tool Handing	In this module, we discussed best practices for storing, preparing, and maintaining tooling for composites processing. Comment on the importance of tool quality to the quality of the final part. How do we ensure that tools are maintained to that level of quality?
	Layup	In this module, we discussed several layup techniques, including manual and automated. For either technique, layup is a critical step in the manufacturing process of a composite part because it can be easy to introduce defects. Give an example of a defect that can be introduced in the layup process. How do we avoid causing defects and ensure part quality?
4	Cure Cycles	Meeting cure cycle specifications is a critical factor in producing quality product. Cure cycles will include upper and lower limits for heating/cooling rates and hold temperatures. Comment on some of the challenges in meeting cure cycle specifications. Why is it more difficult to meet cure cycle specifications with large, thick, or complex shape parts? Give an example of how we ensure conformance to cure cycle specifications.

Module	Subject	Question
	Thermal Profiling	Thermal profiling is a characterization of a heating system with a part and tool loaded inside. The goal is to achieve uniform, controlled, and consistent heating of the part. Give an example of a factor that can affect the thermal profile of the part.
5	Trimming and drilling composites versus metals	It is common for an operator with metal working experience to have difficulty trimming or drilling composite parts. Give an example of an adjustment that must be made when trimming or drilling composites versus metals.
	Dust control	Dust from cutting composites is very different than chips from cutting metal. Give an example of the implications of fine composite dust on product quality and workplace health and safety. What is an example of a strategy used to manage dust exposure to parts, equipment, or personnel?
6	Anomalies versus defects	All anomalies in a part are considered suspected defects until they are determined to be unacceptable. Give an example of a common anomaly in composite parts and comment on the process of evaluating if the anomaly is acceptable and, if not, how the defect might be repaired.
	Inspection limitations	There is no nondestructive technique (NDT) that can detect all flaws. Each technique has its own inspection limitations. Give an example of an NDT commonly used with composite parts and discuss what the limitations of that technique are to detecting certain defects.
7	Adhesive Bonding	While auditing a manufacturer, you discover a part that failed along a bonded joint after that part had previously passed an ultrasonic (pulse echo) test. Explain how such a failure could occur. Discuss how we ensure the quality of bonded joints and how such failures can be avoided?
	Part Assembly	A prototype of a helicopter nose cowling made of composite material is being considered to replace a metal equivalent. The production supervisor tells you that for assembly of the metal nose cowling, many of the built-up tolerances are taken out by “adjusting” the detail part (he illustrates by producing a rubber mallet). Discuss concerns you may have with the composite nose cowling or how those concerns may be overcome.
8	Primers and Topcoats	The role of primers and topcoats is beyond aesthetic appearances. Give an example of an environmental hazard to composite parts and discuss where the application of primers and topcoats has safety implications on the airworthiness of a composite part.
	Lightning Strike Protection	What factors should be kept in mind when installing lightning strike protection materials and adjacent finishing products (surfacing films, primers, and topcoats) to ensure that lightning strike protection systems work effectively?

Module	Subject	Question
9	Handling and storage of composite parts versus metals	You have been asked to develop training programs for technicians in your factory so that they better understand handling and storage of composite parts. They have been working with metal parts for years, but the newest aircraft in your fleet has some composite parts and they need to understand the differences. What points would you emphasize in the training content?
	Handling and storage of easily damaged parts	Are there certain composite structures that are more easily damaged during handling and storage than others? What methods may be used to help prevent damage while handling or storing these sensitive parts?
10	Scaling effects	A small aircraft part manufacturer, located in western New York state, has many years of experience producing small- to medium-scale composite parts. The parts are mostly solid laminate spars and ribs. They win a new contract to produce larger scale aircraft parts, again solid laminate spars and ribs. The contract requires the manufacturer's production rates to double. The manufacturer plans to open a new large scale production facility in southern Texas. They plan to use the same manufacturing process and the same suppliers as they already have experience with. They also plan to transfer experienced personnel to the new facility to ensure that the manufacturing processes are consistent with their best practices. What challenges may this manufacture face when scaling both their part sizes and production rates? What effect could scaling have on the presence of and recurrence of defects?
	Defect disposition	If you have witnessed or have experience with any of the composite defects listed in this module, describe, in general terms without naming companies or individuals, how the defect was identified, the root causes, and any changes that were made to the process as a result. If you do not have experience with these defects, how could you use what you learned in this class to ensure that the potential composite defects listed in this module are properly addressed when discovered by technicians or inspectors? Your tasks in dealing with these defects likely involve different communications with inspectors, manufacturing engineers, and structural engineers, depending on instructions contained in approved documentation. Along these lines, what should you do when you discover a potential defect that has never been discussed in any of the manufacturing instructions, specifications, or training you have seen?

APPENDIX B - BETA LAB

The laboratory session was conducted at the National Institute for Aviation Research (NIAR) and was formatted to align with the educational discussions and teachings that were presented in the online portion of the Composite Manufacturing Technology safety awareness class. The lab consisted of a two-and-a-half-day, hands-on opportunity that covered the following course modules:

1. Module 1: “Raw Materials Manufacturing”
2. Module 2: “Transport, Incoming QC, Storage”
3. Module 3: “Tool Prep, Cutting, Layup, Bagging”
4. Module 4: “Cure, Crystallization”
5. Module 5: “Trim, Drill”
6. Module 6: “Inspect”
7. Module 7: “Bonding, Part Assembly”
8. Module 8: “Paint, Finish”
9. Module 9: “Handling and Storage”

A representative from Cytec began the lab by providing a thorough presentation concerning prepreg manufacturing and transport. Topics covered included raw materials; resin and fiber differences; fiber forms; resin impregnations; and the manufacturing process to ensure repeatable and reproducible products. Ample time was provided for questions and answers.

A transition was made from the classroom setting to the shop floor setting; handling and storage of prepreg materials at NIAR were discussed. Hands-on lay-up then occurred. Participants had the opportunity to make a honeycomb core part along with composite rulers that the participants could take with them. During this process, the students witnessed the cutting of prepreg on a Gerber cutter and discussed proper tool preparation and core handling considerations. Other course objectives included nondestructive inspection techniques, which allowed for hands-on opportunities with A-Scan and Phased Array hardware. Concluding the course modules consisted of fastener installation, part bonding using paste adhesive, and a paint and finishing discussion in which participants were allowed to use a virtual paint booth, mix paint, and apply it to a part.

APPENDIX C – INSTRUCTOR/TEACHER GUIDELINES

The teaching guidelines for each module of the course are summarized in this section. The guidelines elucidate on the teaching points presented in the main body of the report. The teaching guidelines may be used to develop course notes/content with emphasis on specific areas outlined in the following paragraphs.

C.1 MODULE 0.1: INTRODUCTION TO COMPOSITES

- Composite History and Comparison to Metals

  In this section, illustrative examples of historical usage of composites in aircraft structures and structural components must be presented. The examples should include general aviation, commercial, and military applications. The increasing use of composites structural components in commercial aircraft must be emphasized.

  A succinct comparison between metals and composites must be presented with emphasis on the directional dependence of properties in composites. The advantages and disadvantages of orientation dependence of properties as applied to tailorability and presence of weak directions should be stated. From an aircraft application perspective, the highlighted advantages must include the potential for large integrated structures, corrosion, and fatigue resistance. An illustration of a metallic stiffened panel with fasteners compared with a composite skin-stringer panel with adhesive bonding may be used to drive the idea of weight savings and lower part count. The discussion on the disadvantages of composites must include their sensitivity to environmental conditions such as UV exposure and moisture absorption. Unlike metals, the composite materials are created at the same time as the part. This fundamental difference in composite and metal part fabrication must be explained along with the safety message of controlling the manufacturing process for composites to ensure quality of finished products.

- Composite Material Fundamentals

  In this section, the fundamental aspects of composites which are specific to airframe applications must be discussed. They should include the definition of composites, the constituents and their roles, the constituent types specific to aircraft applications, description of the widely used composite forms, and an overview of the common manufacturing methods.

  The definition of composites for this course must emphasize the immiscibility of the constituents and their synergistic action to create an enhanced product. The role of the individual constituents: reinforcement and matrix must be explained along with illustrative examples. The classification of composites based on reinforcement types (particulates, flakes, short fiber and continuous fibers) and matrix types (polymers, metals, ceramics) should be presented with examples of typical fiber-matrix combinations.

The description of polymeric matrices should clearly differentiate the characteristics of thermoset and thermoplastic resins at a high level. Examples and applications of typical thermoset resins (epoxy, phenolic, Polyimide, etc.) used in aircraft structures must be presented as part of the course notes. The different types of fiber materials (carbon, Aramid and glass) along with their assemblages (unidirectional, woven and braided) must be discussed.

A brief introduction to the definition of lamina and laminates, tailorability of laminate properties by controlling the position and orientation of plies must be presented. A description of sandwich construction along with illustrative examples of sandwich core materials, and design details such as edge close out must be presented.

A high level description of the wet lay-up and prepreg layup must be included in the course content. The key steps involved in the wet layup process and the significance of correctly mixing the resin and hardener must be discussed. The discussion on prepreg material must include the partially cured state (B-stage) of the resin, the shelf life of the prepreg, and their tackiness at room temperature. A brief summary of the importance of tooling in composite part fabrication, tooling types (single/double sides, male/female) and common tooling materials must be presented. The key steps involved in any manufacturing process and a listing of the common manufacturing methods (Vacuum bag molding, autoclave molding, pultrusion, etc.) must be presented. The importance of controlling the manufacturing process and its relevance to the final part quality must be stressed.

- Regulatory, Guidance, and Control Documents

This section should present a listing and brief description of the FAA and other key aviation regulatory bodies worldwide. An outline highlighting the purpose of the regulatory documents including the Code of Federal Regulations, Airworthiness Directives, Advisory Circulars, Policy Statements, FAA Orders, FAA Technical Reports must be presented. Other reports of significance including EASA AMC, SAE AIR Reports and CMH-17 Composites Materials Handbook must be briefly discussed. To provide the students with a perspective of the regulatory documents relative to the contents of the course, a table listing some of the regulatory documents related to composites and their correspondence with the different modules of the course should be provided.

The regulations and documents related to Material Specifications, Material Control, Process Specification and Process control must be enumerated. The formal definitions of material and process specifications as stated in AC20-107B and AC21-26A should form the basis of this section. The course notes should emphasize the intent of the material and process specifications which are to ensure that the materials and processes for manufacture of composite structures produce safe aircraft. The roles and responsibilities of the raw material suppliers and the composite part manufacturers in establishing the material specifications must be described in detail. The establishment of material specification limits, and acceptable evidence for conformance to the specification must be discussed. The finer aspects of the quality control used to manage the incoming material quality, which include types of testing, documentation, need to test both prepreg and cured laminates, frequency of testing and retest criteria, must be enumerated.

- The Role of the Manufacturing Inspector

  This section provides a brief overview of the role of the manufacturing inspector in assuring safety of composite aircraft components. The inspector's role in composite type certification and composite production must be outlined. The challenges faced by the inspector during type certification and production must be briefly described.

C.2 MODULE 0.2: COMPOSITES FACTORY WORKFLOW

This module will give the student an overview of different forms of composite manufacturing and various factory workflows, with an emphasis on the fundamental processing steps that are common within various manufacturing processes. The module provides composite part manufacturing examples where the workflow is described and the commonality in the fundamental processing steps are highlighted.

- Common Factory Workflows

  The basic processing steps common to the different processing techniques for composite parts are listed and a high level description of each step is provided. The processing steps described in this module are treated in greater depth/detail in the subsequent individual modules of the course. The processing steps to be discussed are

  1. Raw Materials Manufacturing
  2. Transport Incoming QC and Storage
  3. Tool Preparation, Cutting, Layup and Bagging
  4. Cure and Solidification
  5. Trim and Drill
  6. Inspect
  7. Bonding and Part Assembly
  8. Paint and Finish
  9. Handling and Storage

  The discussion on each processing step should be an overview along with an emphasis on how they affect the final part quality. For each processing step, the issues that affect the final part quality must be listed and discussed in brevity. For the raw materials manufacturing, a listing of the material types (fibers, resins, etc) and the simultaneous formation of material and the part must once again be stressed. Illustrations of typical processing methods for the raw materials may be used. The control of environmental conditions during transport and storage of raw materials, use of sealed bags to prevent moisture absorption during storage, quality control of incoming material must be outlined under Transport, Incoming QC and Storage. The section of Tool preparation, Cutting, Layup and Bagging must briefly discuss the need for process control documents, tool quality, standard practices for cutting and layup, bagging materials and bagging. A brief outline of the cure process in thermosets and crystallization in thermoplastics must be presented with appropriate illustrations. The need for thermally activating the cure of thermosets and the control of the cure cycle per the process specification must be mentioned. The key aspects of machining composites and the tooling used should be covered under the discussion on Trimming and Drilling of composites. The section on Inspection of composites must include a listing of the most common inspection methods (Visual, Tap testing, Ultrasound) with illustrations. The limitations of the NDI methods and the dependence of pass/fail criteria on the NDI equipment, its settings and the part itself, must be emphasized. A brief discussion on the use of traveler coupons and the need to control their processing and conditioning history to reflect that of the actual part must be stressed. The advantages, disadvantages and limitations of mechanical assemblies and adhesive bonding must be outlined in the discussion on Bonding and part Assembly. Common finishing operations such as the use of surfacing films and painting and typical imperfections associated with their applications must be outlined in the section on Paint and Finishing of composite parts. A brief outline on the common practices used for handling and storage of finished parts along with an emphasis on the flaws that could be introduced by not following the procedures must be highlighted in the section on Handling and Storage.

- Factory Workflow Examples

  This section should include illustrative examples of different manufacturing processes for typical aircraft components. The examples should be specific to aircraft structural parts such as stiffened skin panels, spars, skins, propeller shafts, etc. These examples are intended to provide a general idea of typical manufacturing techniques used for aerospace parts. In each example, the previously discussed key steps must be enumerated specific to the manufacturing technique being used. After the examples are presented, a flowchart or other illustration must be used to draw parallels between the distinct manufacturing methods discussed in the examples. The key messages to be delivered here are the existence of common fundamental concepts for the significantly different manufacturing processes, and the common defects that may be inherent to all processing methods.

C.3 MODULE 1: MATERIALS MANUFACTURING

In this module, the different raw materials used for composites, their classification and types, and the manufacturing methods used for the raw materials are discussed in detail. The raw materials include resin, fiber, fiber assemblages, prepreg, core materials for sandwich, adhesives and consumables. The quality inspection techniques and the implications for the inspector are also discussed in detail. The depth of content for each topic is discussed in the following paragraphs

- Key Concepts in Composite Manufacturing

  This section reiterates the fact that the composite material and part are created at the same time and thus the resulting material properties are dependent on the fabrication process. The need for material and process specifications is emphasized. This section outlines the similarities and differences in raw materials from different sources and the implications of following a material specification. The need for a statistical process control which is able to identify the drift in the process as opposed to a pass/fail criterion must be specified. The goal of such a process should be to ensure a stable material supply in terms of repeatable properties.

- Raw Materials

  This section provides an overview of the two major options for combining fiber and matrix to make composite parts. A flowchart is used to outline the making of dry fabric and prepreg beginning from the precursor suppliers for resin and fibers. A definition of material batch is provided and the sources of batch to batch variability are listed

- Fibers

  This section introduces different fiber types (glass, aramid, and carbon) and the commonly used grades of each. The typical range of diameters in which these fibers are available, their trade names, and popular suppliers (if available) are listed. The precursor materials for the fibers, manufacturing process of fibers, and the various grades available are introduced. The advantages/disadvantages of each fiber material type and their typical applications are listed. A brief overview of the fiber surface treatments used to promote fiber handleability and promotion of fiber-resin bonding is presented. A clear distinction between the two main components of sizing which include “former” and “coupling agent” must be made.

  The different fiber forms or assemblages including short chopped fibers, random fiber mats, Unidirectional forms, woven fabric types and 3D forms are classified and elucidated. The description of each fiber assemblage is accompanied by illustrations, their advantages and limitations in terms of usage for composite parts of different geometrical shapes and structural requirements, suitability for specific manufacturing methods, etc., are outlined in this section. Illustrative examples of woven fabrics should include plain weaves, satin weaves, twill weaves and multi-axial fabrics.

- Resins

  This section discusses the two key resin types – thermosets and thermoplastics in detail. A clear distinction between the two in terms of how they react to application of heat, their raw forms, recyclability, and microstructure is made. A listing of common aerospace resins is provided. The different additives present along with the base thermoset resin are listed and enumerated in this section.

- Prepregs

  A formal definition of prepreg, common materials used for making prepreg for aerospace applications are discussed in this section. The hot-melt impregnation method and the solvent impregnation method for producing prepreg are discussed using illustrations.

- Core Materials

  This section describes the use of cores in sandwich structures and the mechanics associated with the high bending stiffness in sandwich structures. The common core material types (foam, honeycomb, and isogrid), their advantages in terms of formability, bondability to facesheets, and mechanical performance are discussed. The different methods of bonding facesheets and core (co-cure co-bond with/without adhesive and secondary bonding) are discussed in this section. The different types of honeycomb cores in terms of cell wall materials and cell wall shapes are presented with illustrative examples.

- Adhesives

  This section introduces adhesives, which are often used in core structures, secondary cure structures, and composite to metal bonding. Adhesives are a special case of resins because their underlying chemistry is very similar. The typical applications of adhesives and the various forms (films, liquids, pastes, sprays) in which they are available are listed. The further description of film adhesive is provided with emphasis of the carrier film used and its purpose.

- Consumables

  This section introduces consumables, which are raw materials used in the production of composite parts that do not remain on the part. A listing of the common consumables used in part manufacture (vacuum bag, breather cloth, peel ply, surfacers, etc.). Consumables are critical to repeatable part production and must be appropriately controlled.

- Quality Inspection Techniques

  This section describes the quality inspection techniques for ensuring stable material supply for aircraft applications. Guidance documents published by the FAA (AC 21-26A, AC 21-31, DOT/FAA/AR-06/10, DOT/FAA/AR-07/03) and CMH-17 (Volume-I) and their scope in terms of manufacturing quality systems and material tests is outlined. The need for an incoming material acceptance plan, the definition of quality inspection tests in the material specifications, and the availability of PCD’s for FAA audits are outlined.

  The quality inspection tests used for raw materials and cured composites are discussed in detail in this section. The raw material tests discussed are Visual inspection, Chemical Tests (resin composition, degree of cure), Physical tests (resin viscosity, gel time), and Thermal tests (glass transition temperature, heat of reaction). The details of individual tests including the measurand and the required equipment/apparatus are discussed. The quality inspection techniques for cured specimens include chemical, thermal and mechanical tests. A high level description of the mechanical tests which include tension, compression, flexural, short beam shear, in-plane shear, flatwise tension and climbing drum peel tests are presented along with illustrations.

- Implications for the Inspector

  A brief listing of the items to consider when evaluating the materials are is presented. These include material specifications, final material properties, supplier PCD's, inclusion of Statistical Process Control

C.4 MODULE 2: TRANSPORT, INCOMING QUALITY CONTROL, AND STORAGE

This module covers the fundamental impact of the environmental conditions (e.g., temperature, moisture, etc.) on the quality of the materials, with an emphasis on how to control those environmental conditions so that material quality at production is consistent with design assumptions. The content of individual sections in this module are discussed in the following paragraphs

- Important Environmental Conditions

  This section describes important environmental conditions that have an effect on the quality of composite parts. This includes temperature and moisture exposure during transport, receipt, and storage. The effects of temperature on uncured resin in terms of cure advancement and loss of tack is highlighted. The effects of moisture absorption including increased porosity levels and strength reduction are discussed with illustrative examples.

- Controlling Environmental Conditions

  This section describes the techniques used to control environmental conditions from the time of raw material manufacture to production. Formal definitions of storage, shelf and tack lives along with their typical values are provided. The shelf lives at different storage temperatures are further discussed. The requirement for defining the storage temperature, shelf life, out life and tack life in the material specifications is emphasized. The use of electronic temperature loggers for recording temperature history during transport and storage along with a perishable material storage record is discussed. The need for storing prepreg in air tight enclosures (polyethylene bag), typical thaw durations, control of humidity levels in storage and working rooms, seasonal variability of humidity are discussed. The calibration of recording (temperature and moisture) instruments are also emphasized.

- Receiving Raw Materials

  This section describes typical receiving procedures for perishable materials that require cold storage. The best practices for receiving perishable materials requiring cold storage are listed. These include reading the MSDS, precautions about not opening air tight bagging containing material and the need for recording data such as material name, batch, roll number, data and time of shipment arrival, temperature, etc.

- Quality Inspection Techniques

  This section provides an overview of the quality inspection techniques discussed in module 1. The references for sample material specification (DOT/FAA/AR-02/109) are cited. The requirement of the Production Approval Holder (PAH) to have a incoming material acceptance plan and the details of the material specifications specific to the quality tests are discussed.

- Implications for the Inspector

  This section provides an exhaustive list of items to be considered by the Inspector when evaluating Material Acceptance and Receiving Inspection. The items cover the requirements for prepregging within shelf life of fiber sizing, compliance of receiving inspection tests with specification acceptance limits, disposition of ‘TBDs’ in the material specification, preparation of test panels and specimens, evaluation of specification for fabrics (weave styles, yarn size), review of certificate of conformance from vendors, evaluation of honeycomb core relative the specification, evaluation of storage and recording methods/instruments used for temperature and humidity.

C.5 MODULE 3: TOOL PREP, CUTTING, LAYUP, AND BAGGING

The emphasis of this module is on the relationship between tool preparation, cutting, layup, and bagging on the quality of manufactured parts. The details covered under each topic are discussed in the following paragraphs.

- Tool Preparation

  This section discusses the various aspects of tooling which include tool design and preparation, tooling materials, tooling control, maintenance, repair and storage. Using illustrative examples, the requirement for defining tooling design (in terms of drawings, solid models, etc.) and the need to include tooling sub-structure in the design are discussed. The common tooling materials (steel, invar, etc.) are discussed and compared in terms of their durability, dimensional stability, thermal expansion, thermal conductivity, and ease of fabrication. The need for restricting the change of tooling material and structure through PCDs is discussed in reference to changes in thermal expansions, heat transfer, etc. The discussion on tooling preparation address cleaning of tool surface, sealing surface porosity, application of release agents, and the requirement of defining the appropriate procedures in the PCDs. The maintenance and repair of tooling address both structural aspects leading to distortion, as well as resurfacing issues. A brief discussion on tooling storage and inspection is also presented with emphasis on both mechanical and UV light damage.

- Ply Cutting

In this section, the different ply cutting methods, preparation of ply kits, cutting tools and equipment are discussed using illustrations. The ply cutting methods discussed in detail include the manual ply cutting and the use of automated ply cutting machines. This section emphasizes the need for trained technicians for manual ply cutting and the best practices which include use of sharp cutting tools, cutting surfaces, use of cutting guides /templates, cleanliness of work area. The cross-contamination of prepreg occurring due to use of same cutting tools for different materials is emphasized. The different cutting methods used by automated cutters (reciprocating knives, ultrasonic knife, water jet) are discussed along with the need for controlling the cutter's software to ensure conformity to type design.

- Layup

  In this section, definition of laminate codes for laminates using unidirectional and fabric plies are described using simple examples. The use of warp clock to define the +ve and –ve orientations during layup on a tool and during repair are discussed. The precautions associated with layup of fabric plies to account for the inherent ply asymmetry is highlighted using illustrations. The section provides a step-by-step procedure for placing plies on a tool while emphasizing that the manual layup should be performed by trained technicians. The use of optical layup templates during manual layup is discussed using illustrative examples. Detailed examples of prepreg layup, wet layup, resin infusion, use of cores, and complex structures are presented. The use of core splices and potting during layup of sandwich structures are also discussed.

- Bagging

  This section describes the vacuum bagging process and the various components and consumables used. The functions of porous release films, bleeder cloth, caul plate, breather cloth, edge dams, sealant tape, bagging material and vacuum ports are discussed with appropriate illustrations. The best practices associated with the use of above consumables and leak detection methods are presented in detail.

- Quality Inspection Techniques

  This section describes techniques that can be used to ensure quality tool preparation, ply cutting, layup, and bagging. The different types of defects in fabrics (baggy cloth, broken warp or fill yarns, wrinkles, fuzzball, nep, slub, etc.) are outlined using illustrations.

- Implications for the Inspector

  This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification. A list of items to be considered by the inspectors when evaluating the tool preparation, ply cutting, layup and bagging are presented. Some of the key items include inspection of tool surface for visible imperfections, availability of documentation for calibration of tooling, record of tool rework/repair, tracking of tooling usage in terms of cure cycles, cutting and placement methods for plies, specification of core and ply splice locations in drawings, training of layup technicians to disposition ply defects, control of ply and trim waste, control of layup environment, etc.

C.6 MODULE 4: CURE, SOLIDIFICATION

The emphasis of this module is on the nature of cure; how it is dependent on time and temperature; and the effect on mechanical and physical properties of the finished component. The importance of consolidation with the aid of vacuum and external pressure on mechanical properties is also emphasized. The details of the individual topics covered in this module are outlined in the following paragraphs

- Basics of Cure/Solidification

  This section introduces the basic mechanisms of cure of a thermoset resin and solidification of a thermoplastic resin. The key stages in the cure of a thermoset resin and the concept of degree of cure are introduced. The evolution of cure during a typical cure cycle is illustrated. The effects of heating rates on the progression of cure, the changes in viscosity during cure, gelation and vitrification are discussed briefly. The different forms of raw thermoplastic materials are listed and the basic steps involved in processing thermoplastics are outlined. The microstructural changes in thermoplastics from being amorphous above melting temperatures to crystallization to various degrees during cooling are discussed briefly. The effects of cooling rates and challenges associated with processing thermoplastics with reinforcements are discussed.

- Processing Methods

  This section introduces the most common manufacturing methods for curing and solidification of thermoset and thermoplastic resin composites. The use of vacuum in wet and dry layups for consolidating layers and removing entrapped air and volatiles is discussed. The advantages and disadvantages of using vacuum compaction are discussed along with a mention of pressure dependence on altitude above sea level. The key steps involved in the resin infusion methods (RTM, VARTM, VARI, LRTM) are outlined along with a summary of the advantages and disadvantages of these methods. The curing of parts using ovens and autoclave are discussed with illustrative examples. The steps involved in compression molding and their advantages/disadvantages are briefly discussed. Alternative processing technologies such as electron beam curing, microwave ovens, and use of heat transfer fluids are also outlined.

- Processing Parameters and Cycles

  This section describes the most significant parameters: time, temperature, pressure and vacuum, that must be controlled for any composite manufacturing process. The need for tracking time during curing of thermoset and thermoplastic resins with specific reference to closing of voids and evacuation of gases is discussed. The need for application of pressure and temperature during cure are enumerated. Process cycles are used to define and control these parameters. This section introduces typical process cycles and how they are specified in process documents. The effects of incorrect process cycles and lack of control over process parameters on the resulting defects in the part are discussed. The cumulative nature of thermoset resin cure and the need to track accumulation of cure during post cure and secondary bonding is emphasized.

- Part Temperature

  It is critical that all locations throughout the part achieve the specified temperature cycle. This section introduces the factors that affect the part temperature when inside an oven or autoclave. To achieve the specified temperature cycle, the heat transfer conditions of the heating system and the tool and part assembly must be fully understood. The airflow around the tooling/part in ovens and autoclaves are discussed with emphasis on part placement, tooling design and placement of baffles to improve heat transfer and thus uniformity of temperature. The effects of exothermic heat during the cure of thermoset resins are discussed with reference to tooling material, part thickness and heating rates. A comparison of part temperatures and lag relative to air temperature with different tooling material is made to illustrate the effects of the heat capacity of the tooling material. The placement of thermocouples, definition of cure cycles based on lead or lag thermocouple reading and calibration of thermocouples are discussed.

- Quality Inspection Techniques

  This section introduces some of the common quality inspection techniques that can be used to ensure that adequate, repeatable cure or solidification has been achieved in every part. The methods discussed (optional) are the use of thermal maps, cure records, dynamic scanning calorimetry (DSC), measurement of glass transition using DSC or dynamic mechanical analysis (DMA), short beam shear tests and measurement of void content using micrographs. An overview of these methods along with applicable standards and specialized equipment are presented as optional course material.

- Implications for the Inspector

  This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing investigator under type or production certification. An exhaustive list of items to be considered by the inspector when evaluating cure and solidification are presented. The items addressed include definition of cure cycle requirements in process specifications, means of recording process parameters, locations of parts, thermocouples and other sensors in an autoclave/oven, methods to detect exotherms, certification and calibrations of ovens, post cure inspections, changes to cure cycles, provisions for tracking additional cure cycles experienced by parts due to secondary operations such as repair and rework, etc.

C.7 MODULE 5: TRIM AND DRILL

In this module, the fundamental differences between machining composites versus metals and the importance of proper techniques to avoid mechanical and heat damage in the composite are discussed. An overview of different drilling/trimming methods, the defects arising due to machining of composites, inspection methods, and implications for the inspector are presented in detail. The content of individual sections in this module are summarized in the following paragraphs

- Trimming and Drilling Composites

  In this section, the typical machining operations (trimming, drilling, surface finishing, etc.) on the "near net shape" composite parts are discussed. The fundamental differences in removal of material during machining operations on composites and metals are presented. This section describes trimming and drilling of composite materials and highlights common practices that are different than with metals. The need for support structures and backing plates are emphasized along with best practices. The surface ply(ies) delaminations during drilling without backing plates is illustrated and the need to specify and control the backing plate material is emphasized. The rotary trimming operation is discussed in detail, specifically the type of tools and coatings (solid carbide, diamond coated carbide), tool geometry (tip angle, number of flutes, flute twist angle), etc. A brief summary of the waterjet cutting and its advantages over other machining methods are discussed.

  The low thermal conductivity (relative to metals) of composites poses a challenge in terms of managing the heat arising during the machining process. A summary of the different methods of cooling (cooling fluids, cryogenic machining, cooling gases) are presented. Another important aspect of composites machining is the control of dust emanating from the machining process. The implication of the composites dust to worker health and safety, equipment, machinery, electronic, parts in layup/assembly are discussed in detail. The different methods of dust control at the source/cutting location, personnel protection, work area, are elucidated with appropriate illustrations.

- Trimming and Drilling Defects

  This section lists common defects of composite materials when using rotary cutting tools or waterjet cutting. The defects discussed in this section include delaminations occurring due to dull tools, splintering in unsupported plies, fiber pull-out due to tool catching, overheating due to friction, imperfect hole geometries, and defects due to waterjet cutting. The physical characteristics of the defects and their root causes are discussed.

- Quality Inspection Techniques

  This section describes inspection techniques to verify final dimensions and some cutting defects. A brief overview of the machining defects which can be detected using visual inspection and the best practices are outlined. A detailed discussion on the defects and inspection methods will be covered in module 6. The measurement and verification of part dimensions using coordinate measuring machines (CMM's), the different probe types, and best practices during measurement of composite parts are outlined.

- Implications for the Inspector

  This section describes considerations for the inspector in regard to trimming and drilling composites. The requirement for defining the machining parameters (cutting speeds, etc.), use of backup blocks, methods of cooling, tooling types, in the material specifications is discussed. The defect types to consider during inspection of machined parts are also outlined.

C.8 MODULE 6: INSPECT

There is some form of quality inspection performed at each portion of a manufacturing process (visual inspection at minimum). Each module of this course covers specific inspection techniques and practices used during that portion of the manufacturing process. Module 6 discusses in more detail the inspection techniques that are used throughout the composite manufacturing process.

- Composite Anomalies

  This section lists some common anomalies (as potential defects) found in composite materials. Not all anomalies can be listed here. The anomalies presented include Cosmetic anomalies, Cracks, Disbonds/delaminations, Weak bond (a.k.a. kissing bond), Voids, Porosity, Inclusion, Core crush, Fiber wrinkling or waviness, Ply misalignment, Resin rich or dry areas, Impact damage. etc. For each composite anomaly, their physical nature is described along with illustrations wherever possible. The source(s) of some of these anomalies are also cited. A brief outline on the disposition of the anomalies is presented using a flowchart.

- Nondestructive Inspection

  This section describes some common nondestructive inspection techniques used for cured composite parts. There are many inspection techniques used in practice; however, they are generally small variations of the techniques presented here. Techniques and their brief specifics presented in this section include:

  - Visual (overview of method, training of personnel, use of optical aids, work area lighting)

- Tap testing (description of manual and automated tap testing, dependence of operator skill, limitations of use on composite part type and defect types that can be detected)
- Ultrasonic (fundamental principle, definition of pulse-echo and through transmission, A-scan and C-scan modes, use of couplants)
- Thermography (principle of operation, limitations)
- Shearography (principle of operation)
- Radiography (principle of operation, detectable flaw types, computed tomography)

- Destructive Testing

  This section describes destructive inspection methods for test coupons or representative parts. A brief discussion on traveler coupons and best practices is presented. The different types of destructive testing (mechanical, chemical, impact, micrography) and their use are outlined.

- Implications for the Inspector

  This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification. The items include calibration and maintenance of NDI equipment, development and use of defect standards, specification of tools for certain NDI tests (tap test), and environment under which NDI. The need for NDI inspectors to be qualified by a procedure defined by design approval holder and approved by the FAA is discussed. The roles of level I, II and III inspectors are also outlined.

C.9 MODULE 7: BONDING AND PART ASSEMBLY

In this section, the advantages of adhesive bonding, mechanical assembly, hybrid assembly are outlined. A brief discussion on the composite part fit-up and best practices are also presented. In this module, the important factors in ensuring high quality bonds, adhesive materials, bonding techniques, mechanical assembly, defects arising due to bonding, inspection techniques and implications for the inspector are discussed. The details of the individual sections of this module are summarized in the following paragraphs

- Adhesives

  This section describes the type of adhesives typically used in aerospace bonding applications. Typical structural adhesives (epoxies, BMIs, phenolics, cynate esters) and non-structural adhesives (acrylics, silicones, etc.) are listed. Different adhesive forms (films, liquids, pastes) are discussed with emphasis of ease of handling, storage, bondline thicknesses, etc. The differences between one part and two part adhesives along with their advantages, usage and storage are enumerated. The typical shelf life, open time and clamp-up time for adhesives are also discussed.

- Bonding Techniques

This section describes typical bonding techniques used in aerospace. The details of the co-bonding, secondary bonding, and co-curing of composite parts are enumerated using illustrations and the key differences are highlighted. The control of bondline thickness and adhesive fillets are discussed. The need for clamping pressure during cure of adhesive and different methods of applying the pressure is presented.

- Surface Preparation

  This section describes steps that are taken to prepare the surface of a composite laminate or metal for adhesive bonding. Surface preparation is one of the critical steps in adhesive bonding that has a significant effect on the subsequent bond strength. The surface preparation using abrasion and peel ply are discussed in detail. The abrasive surface preparation methods using sandpaper and light grit blasting are discussed with emphasis on best practices. A brief discussion on the use of peel ply for surface bond preparation is presented. The different types of peel ply materials, their qualification and control, and peel ply material substitution considerations are outlined. The contamination of bonding surfaces, cleaning, and activation of bonding surfaces (metallic) are also discussed.

- Mechanical Assembly

  This section describes mechanical assembly of composite components. Emphasis is placed on special mechanical assembly considerations with composite materials compared to metals. The different fastener types commonly used in composite assemblies, consideration of galvanic corrosion during selection of fastener material, hole tolerances, need for clearance fit, cleaning of debris from hole surfaces , etc., are discussed in this section. The use of inserts and bushings to protect the laminates and special considerations for their usage are also discussed.

- Bonding Defects

  This section describes defects that can lead to understrength adhesive bonds. The physical nature of kissing bonds, their detectability using NDI, and root causes for their formation are presented in detail. Amine blush, a chemical contamination leading to kissing bonds is further discussed along with best practices for their removal.

- Quality Inspection Techniques

  This section describes inspection techniques used to ensure quality control of adhesive bonding and mechanical assembly. The inspection techniques covered in this section include assembly inspection methods (Surface preparation inspection, visual inspection), non-destructive and destructive inspection methods of parts. A strong emphasis is made on lack of non-destructive methods for quantifying the quality of the bond. An overview of Verifilm™ testing used to verify the fit of mating parts and the bondline thickness is also presented in this section.

- Implications for the Inspector

  This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector under type or production certification. The discussion on the implications focus on surface preparation methods, cleaning of surfaces, evaluation of surfaces prepared for bonding (e.g., using water break testing), preparation of test specimens, issues related to secondary bonding and co-bonding, mixing of adhesive and bonding.

C.10 MODULE 8: PAINT AND FINISH

The emphasis of Module 8 is on ensuring that any finishing technique is properly tested and qualified against appropriate control documents and that any finishing product is properly controlled in terms of storage shelf life and proper application technique. In this module the common painting and finishing techniques are described. Discussions on paint thickness requirements, lightning strike mesh, environmental conditions during storage, storage and working life requirements, common surface imperfections and repair techniques are also presented. The individual sections of this module are summarized in the following paragraphs.

- Primers and Topcoats

  In this section, the need for primers (to fill in surface imperfections) and topcoats (to protect part from UV exposure, rain, chemicals, fluids, etc.), their storage, application and cure, shelf life, and a listing of common materials is presented. A detailed discussion of the best practices during application of primers and topcoats, and personnel protection is also presented.

- Surfacing Films

  This section introduces surfacing films, which are commonly used as a finishing product for composite parts. The role of surfacing films, their usage during layup, compatibility with composite resin, their storage and shelf life are briefly discussed.

- Lightning Strike Protection (LSP)

  In this section, the need for LSP in composite airframes is explained with reference to metallic airframes. The role of LSP systems in providing a conductive path between the outer skin of aircraft to a metallic “ground” is explained. The typical LSP methods using and embedded layer of mesh/foil/wire are explained. The different LSP material forms, materials, application methods and alternative technologies are discussed. The need for LSP systems to provide electrical connection across gaps and across metallic fasteners are also discussed.

- Surface Imperfections, Repair, and Stripping

This section lists some common surface imperfections after applying finishing products, appropriate repair techniques, and paint-stripping procedures for composite parts. A brief discussion of imperfections such as pinholes, print-through, tooling surface mirroring, resin ridges and surface layer micro-cracks is presented. The best practices during surface repair of the aforementioned imperfections are listed. The details of paint stripping and precautions to be taken during paint stripping are briefly discussed.

- Quality Inspection Techniques

  This section describes inspection techniques to verify the quality of the finishing products. The inspection techniques address control of liquid paint viscosity, surface visual inspection for pin-hole, print through defects, and destructive testing for paint thickness and primer/topcoat adhesion, micro-cracking, and testing of lightning protection material.

- Implications for the Inspector

  This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector. The list of items to be considered during evaluation of surface finishing, painting, etc., include provisions in type design for surfacing materials; control of surfacing materials, primer, paint; control of working time for primers; control of primer and paint thickness; use of protective gear by personnel; control of environment during priming and painting.

C.11 MODULE 9: HANDLING AND STORAGE

In this module, the importance of safe handling and storage procedures for cured parts are outlined. The potential sources of damage during handling and storage, and preventative methods for avoiding damage are described. The details of the individual sections of this module are summarized in the following paragraphs.

- Damage

  In this section, the formal definitions of "Foreign Object", "Foreign Object Damage", and Foreign Object Elimination are presented. The morphology of foreign object impact damage under high energy, medium energy and low energy impacts are discussed with illustrations. The sources of low energy impact damage during handling and storage, disposition of damage, typical indicators of damage (gouges, scratches, etc.), damage reporting, investigation of root cause, and formulation of preventive actions to eliminate future repetitions are discussed in this section.

- Handling

  This section describes typical part handling techniques to reduce or prevent part damage. The establishment of procedures for handling and storage, training of personnel, service and maintenance of equipment, use of support structures are briefly discussed under the section on handling. Under the section on damage prevention, the use of protective devices (edge protectors, caps, plugs, etc.), visual inspection of the same, removal of loose objects when entering critical areas, identification of no-step areas, FOD control area are discussed.

- Storage

  This section describes storage techniques and requirements for composite parts. Emphasis is placed on protection from UV sources, moisture, heat, stacking of multiple parts, and contamination by packaging material, and training of personnel in packaging, storing and shipping requirement.

- Quality Inspection Techniques

  This section describes inspection techniques for handling and storage damage. The best practices for visual inspection are outlined. Other inspection methods discussed in module 6 are referenced. The need for verification of required protective devices prior to storage, verification of removal of protective devices during assembly and periodic review of FOD programs and procedures are emphasized.

- Implications for the Inspector

  This section describes the implications of the information presented in this module to the tasks and objectives of the manufacturing inspector. A list of items to be considered when evaluating the handling and storage requirements are presented. These include availability of documented procedures for storage and handling, procedure to report FOD, procedures for inspections, and limits on storage duration prior to assembly.

C.12 MODULE 10: COMMON MANUFACTURING ISSUES

This section exposes ASIs to practical examples of manufacturer’s practices leading to defects and other safety issues with production parts, with an emphasis on understanding the root causes of the defects and the appropriate corrective actions that are required. The issues addressed in this module include scaling, defect disposition, manufacturing defects and root cause analyses, repair and approval changes. The details of the individual sections are summarized in the following paragraphs.

- Scaling Effects

  This section describes common issues associated with scaling, from production of small or simple structures to larger or more complex structures. A distinction between scaling associated with part size and scaling associated with production is made. The typical deviations from the nominal and resulting defects from the two types of scaling are listed. The best practices for mitigating the scaling effects including qualification of production limits, inclusion of final production process parameters and tooling methods during process development and certification, need for and validation of modeling approaches used for process design are discussed in this section.

- Defect or Damage Disposition

  This section defines the appropriate disposition process once a defect or damage has been identified. The need for engineering/manufacturing interface, review of source documentation to determine the NDI method, determination of appropriate action after detection of defect are briefly outlined in this section.

- Manufacturing Defects and Root Cause Analysis

  This section describes defects that are associated with more than one step in the manufacturing process. The morphology of the defects, their detectability using standard NDI methods, their effects on mechanical properties, potential root causes, applicable repair and rework are discussed in detail for each defect listed below. The defects and NDI methods are illustrated in most cases. A detailed discussion (optional) on porosity, its detection using different methods, test standard for its measurement and quantification, root causes, specifically bridging, manufacturing related issues, are discussed in detail.

  - Porosity
  - Disbonds/delaminations
  - Weak bonds
  - Matrix cracking
  - Broken fibers
  - Fiber waviness, wrinkling
  - Dimensional conformance
  - Under cure
  - Heat damage
  - Resin-rich areas
  - Resin-starved areas
  - Fluid ingression
  - Foreign object damage
  - Blunt impact damage

- Repair

  In this section, the three common repair methods – Mechanical, Bonded and Hybrid, are outlined based on their load carrying capabilities. The bonded repair workflow is listed and the different types of bonded repair (patch, scarf, step sanded) are enumerated using illustrations. Best practices for each repair types are also discussed. A detailed discussion of the repair equipment including heated blankets, vacuum bags, pressure clamps, portable autoclaves is also presented. The basic roles of each equipment in the repair process, their limitations, calibration and maintenance requirements are listed. The recent developments in repair technologies highlighting the use of automated equipment for 3D digital scanning of damaged/scarf area, CNC milling of scarf surfaces, automated layup. CNC milling of procured patches.

- Changes

  This section describes the FAA guidance on approving changes to composite materials or processes. The typical changes to manufacturing processes (consumable materials, oven loading, cure cycle tolerance), best practices, categories of changes (minor, major) are described in this section. Reference to reports published by the FAA William J. Hughes Technical Center provides guidance on how to categorize changes to materials and processes is also made in this section. The challenges associated with moving production facilities or changing part manufacturers are also discussed.