**Course ES-2**
***Composite Laminate Analysis***

## Course Summary

ES-2 provides the backbone for designing and analyzing composites with a thorough understand of classical laminate plate theory and failure criteria. The ES-2 course is perfect for engineers who did not take composite courses during their university education, or who recognize that their university courses were too theoretical and did not provide enough practical understanding. ES-2 goes well beyond university level composite courses by using real-world mechanical property data for modern composite materials that are currently available and evaluating these materials on existing composite configurations. The course is 80% analysis and 20% hands-on. The shop work involves manufacturing unidirectional and woven fabric panels at the lamina and laminate level as well as mechanically loading test coupons to failure. The course performs the analysis with a highly evolved Excel spreadsheet. Additionally, it introduces the students to composite analysis using FEA. ES-2 is a prerequisite for ES-3/ES-4 unless the students have an extensive background with laminate analysis through their past work experience or university education. ES-2 is also recommended as an intermediate prerequisite between ER-1 and ER-2 for engineers performing repairs and modification who have access to load data.

## Introduction

Engineers involved in the design and repair of composite structures are often required to analyze and develop a unique lamination sequence. This requires an understanding of the relationships between ply materials and their effects on the properties of the overall composite laminate. ES-2 presents composite laminate analysis in way that is well beyond the methods used by most university courses. In a single week, student become thoroughly knowledgeable of both classical laminated plate theory (CLPT) and failure criteria, which are usually covered in two semester-long courses. Mathematical skills in matrix algebra and basic calculus are utilized.

The ES-2 course requires only a basic understanding of engineering loads, moments, and deformations. The generalized stress-strain relationships for homogenous, isotropic materials are used to develop the stiffness and strength for an orthotropic, fiber-reinforced composites. The analysis unfolds into lamination theory to study the results of lamination sequence and the requirements for ply orientation. Students will develop and perform stress, strain and stiffness analysis using laminated plate theory, as well as fabricate and perform structural testing on actual composite laminates. The mechanical testing will be compared with the computer analytical predictions.

This course will also enable the engineer to determine the mechanical behavior of a laminated fiber-reinforced materials by understanding the interaction between the fiber and the matrix and the effects of the stacking sequence on a laminate for both axial loads and bending moments. The course develops all the necessary equations to understand the effects of resin content, fiber volume and material density. Simple Excel files are provided and used to demonstrate the effects of different configurations of the ABD matrix on the mechanical properties of a complete composite laminate. Thermal and moisture expansion characteristics are evaluated along with mechanical strain to determine the total strain on the laminate.  Then, common industry failure criteria are presented in thorough detail and applied to the composite laminate to finalize the design process.  Throughout the week, the analytical methods

discussed in the course are also represented in FEA.  The final analysis is compared to both the analytical calculations and the FEA results.

# Topics

## Key Lecture Topics:

- Axis and coordinate systems for both the material and laminate.
- Basic engineering loads, moments, and deformations.
- Stress and strain relationships.
- Composite material properties, Data requirements and Industry databases.
- Constitutive equation based on the stiffness and compliance matrices.
- Off-axis, in-plane and transverse loading.
- The effects of core material on laminate stiffness.
- The significance of symmetric and unsymmetric laminates.
- Interpretation of the A, B and D matrices.
- ABD matrix effects on the physical properties for various lamination sequences.
- Computer laminate analysis using the ABD matrix.
- The effects of ply coefficients of thermal and moisture expansion on the overall laminate characteristics.
- Both theoretical and practical laminate failure criteria.

## Workshop Exercises:

- Direct application of ply materials and lamination sequence is brought from the theoretical understanding to the classroom and shop environment.
- Computer design and simulation using both Excel spreadsheets and Femap NASTRAN FEA.
- Prepreg woven fabric and unidirectional laminate fabrication.
- Structural testing to failure; comparison between actual and theoretical calculations and analysis.

## Course Benefits

Attendees will learn how to develop and perform stress, strain and stiffness analysis using Laminated Plate Theory and to perform structural testing/validation on composite laminates.

## Prerequisites

ES-1 Composite Essentials for Engineers and Managers

or

ER-1 Aerospace Repair Analysis and Substantiation

or

*M-1/R-1 Composite Structures: Fabrication and Damage Repair-Phase 1

* Must have engineering degree or design/analysis skills with M-1/R-1 to qualify

## Teaching Method

Active classroom lecture and workshop exercises

## CEU

3.6