Course ER-2
Advanced Aerospace Repair Analysis and Substantiation

Course Summary

ER-2 should not be considered a mere expansion of the concept already presented in ER-1. ER-2, is in fact, significantly much more. It is the direct result of over 10 years of specific R&D and thousands of hours of effort to develop an advanced repair analysis methodology that is applicable to the modern application of heavily loaded composite primary structure. When ER-1 was developed, composites were found primarily on surface panels, cowlings, landing gear door, and fairing panels - all secondary structure that did not necessarily require the most rigorous analysis. However, in modern aviation applications, composite materials are found on wings, stabilizers, flight controls and pressurized fuselages. These Damage Tolerant primary structures demand a more advanced analysis method than ER-1, of which is the central focus of ER-2. This is an advanced level course designed for degree-qualified aerospace and mechanical engineers who are responsible for the design analysis and substantiation of repairs to both primary and secondary composite structures. All students are required to have completed the ER-1 Aerospace Repair Analysis and Substantiation course to be prepared to explore a more in-depth analysis of repairs to primary structures. Although the focus is still on stiffness, strength, and composite joints, the analysis presented addresses the full in-plane and bending stiffness of composite laminates as well as a detailed representation of the most common industry used composite failure criteria. The most unique topic is the extremely in-depth analysis that is presented for evaluating the stress concentrations caused by both unrepaired damage (Allowable Damage Limits - ADLs) as well as those caused by application of different repair configurations (stiffness induced stress concentrations). This evaluation allows the determination of both the Design Limit Load (DLL) for ADLs and the Design Ultimate Load (DUL) for Damage Tolerance. This analysis meets the requirements for FAA and EASA Bonded Repair Size Limits (BRSL) and existing DoD composite repair guidelines. The ER-2 joint analysis offers solutions that are beyond any university course or professional training by presenting advanced calculations for determining the adhesive shear stress and strain across the full length of the bonded joint as well as multi-row mechanically fastened joints. Then, expanding upon the shop exercises and coupon testing in ER-1, the ER-2 workshop projects creates full circular repairs in the class panels and mechanically tests the completed repair in its entirety, without cutting the repair into test coupons. An example repair is then evaluated with FEA and mechanically tested with Digital Image Correlation (DIC).

Introduction

ER-2 is an extremely advanced analysis course that presents the stringent requirements for designing and approving composite repairs to primary structure. It is assumed that the students have gained an understanding of composite materials and processes for both the original structure and the repair from taking ER-1. Thus, 80% of the ER-2 course is analysis and the remaining 20% is shop exercises and mechanical testing. Just as ER-1 focused on stiffness, strength, and repair joint, ER-2 is centered around the same subjects, but at a much more advanced level. The full [ABD]-matrix is presented to evaluate both the in-plane and flexural stiffness of both the original laminate and the repaired laminate. To complete a full understanding of Classical Laminate Plate Theory (CLPT), hygrothermal expansion and common industry failure criteria are also discussed. The CLPT and failure criteria discussions are fairly fast paced which is why ER-2 students may consider taking the ES-2 Composite Laminate Analysis course if a more in-depth understanding of these topics is desired.

A major focus of ER-2 is an evaluation the load redistribution around the cleaned-up damage to determine if it is structurally acceptable to allow the damage to go unrepaired. This determination is what is often referred to as allowable damage, where the maximum extend of acceptable unrepaired damage determines the allowable damage limits or ADLs. The primary issue with allowable damage is that stress concentrations are created at the edge of the damage. Therefore, an in-depth discussion is presented on stress concentrations in composite laminates and how these stress concentrations vary based on laminate material and ply orientations. However,

most significant about the ER-2 analysis is the method presented for analytically determining the full redistribution of stresses around the hole based on the application of far-field applied loads. This analysis is performed with a special modification of the Lekhnitskii Method, called the Complex Boundary Displacement method, which was specifically developed by the Abaris Training Engineering instructor based on complex stress potential equations.

The common industry composite repair techniques presented in ER-1 require the application of one or more extra repair plies to ensure that a positive margin of safety is achieved for the repair. However, these extra repair plies also result in added stiffness in the repair. This additional stiffness will draw load into the repair area and cause a stiffness induced stress concentration. To address these stress concentrations, the next application of the Complex Boundary Displacement method takes the same equations used to analysis the stress redistribution around a hole, and with a slight modification uses the same approach to determine the load redistribution caused by the repair. After years of research and development, this analysis method is being presented in the ER-2 course for the first time as it has been revealed to the industry. This method does not use FEA, but both an FEA example and an actual full-scale repair is tested with Digital Image Correlation (DIC) to demonstrate how the Complex Boundary Displacement method provides identical results with a fraction of the time and effort spent by using an Excel spreadsheet.

Continuing with an expanded discussion on stiffness, strength, and composite joints initially presented in ER-1, the ER-2 course presents the most in-depth analysis technique for the bonded joint used in the industry, which were derived from the well know (but often elusive) Hart-Smith Method presented in a series of 1970s NASA reports. This analysis method calculates the full adhesive shear stress and shear strain along the length of the bonded joint and is presented in methodical format that makes it easily understood, that when combined ease of the spreadsheet allows bonded joint calculations to be performed in minutes.

Often, BRSL regulations will require that mechanical fasteners be used with thick repair to primary structure. To address this requirement, advanced bolted joint calculations for composite repairs with multiple fastener rows are presented which address the unique concept of bearing/bypass (ASTM D7249) in composite mechanically fastened joints.

The workshop exercises in ER-2 also build upon the test panels created in ER-1. To address the advanced allowable damage concepts of ER-2, ASTM D3039 unnotched tension and ASTM D5766 open hole tension tests are performed to determine the characteristic dimension for Whitney-Nuismer Point Stress Criterion. Then full width panels are tested with cleaned up holes and allowable sized holes to evaluate both DLL and DUL. Unique full circular repairs are applied to each group’s shop panel and the repairs are tested in their full width to validate the advanced repair analysis techniques discussed throughout the week.

Topics

Classroom Topics:

- Axial and flexural stiffness in a composite repair.
- Max Stress, Max Strain, Tsai-Hill, and Tsai-Wu Failure Criteria.
- Evaluation of allowable damage to composite structure.
- The relationship between unnotched tension & compression, open hole tension & compression, BVID, the characteristic dimension, allowable damage, and design values.
- The calculation of Design Limit Load (DLL) and Design Ultimate Load (DUL).
- Damage Tolerance, Durability, and Damage Resistance for composite aircraft structures, and how these principles are evaluated in developing a composite repair.
- Stress redistribution in the surrounding structure caused by a cleaned-up damage hole and a disbonded taper sanded repair.
- Stress concentrations in the surrounding structure caused by a repair stiffness that is too low or too high.
- Adhesive bonded joint analysis to calculate the bond between the original structure and the repair for both secondarily bonded doublers and scarf repairs.
- The rapid evaluation of a repair configuration using a modified Lekhnitskii Method uniquely developed by the Abaris Training instructor.

Workshop Exercises:

The workshop topics involve fabricating, repairing, and testing composite test coupons and full-width panels comprised of:

- ASTM D3039 un-notched tension
- ASTM D5766 open hole tension
- ASTM D7136/D7137 compression after impact
- Disbonded taper sanded repair per BRSL.
- Disbonded non-taper sanded repair per BRSL.
- Cocured taper sanded full-width repairs.
- Precured doubler full-width repairs.

Course Benefits

Students attending this course will gain advanced knowledge and enhanced skills in repair analysis and substantiation necessary in the implementation of repair design instructions for heavily loaded composite structures.

Prerequisites

ER-1 Aerospace Repair Analysis and Substantiation course.

ES-2 Composite Laminate Analysis course is a suggested prerequisite but not mandatory.

Teaching Method

Active classroom lecture and workshop exercises

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