Appendix E-2

Outline
Proposal AG29 Workpackages

by

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GARTEUR

STRUCTURES AND MATERIALS

PROPOSAL FOR ACTION GROUP

DEVELOPMENT OF A PROBABILISTIC METHODOLOGY FOR RAPID INTERCHANGE OF COMPOSITE MATERIALS IN THE DESIGN OF COMPOSITE STRUCTURES

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1. INTRODUCTION

High qualification costs for interchanging composite materials has limited the number of qualified materials for use. A large proportion of the high qualification cost is associated with the extensive mechanical testing programme that is required to generate design databases of material properties.

A larger amount of testing is required for composite materials compared with isotropic materials due to its relatively larger variability in mechanical properties. This variability results from the heterogeneous nature of the materials' microstructure and dimensional variations due to manufacturing. Additional factors such as the materials' batch-to-batch and operating conditions would also contribute to the mechanical property variability.

The mechanical property variability is accounted for in the design allowable generation process, by the use of safety factors or by the use of a semi-empirical statistical design allowable. Use of the former would result in over-designed structures, whilst the latter (i.e. design allowable), would not yield information on the reliability of the structure.

Therefore, the development of a probabilistic methodology, which permits the assessment of composite materials interchangeability effects on structural reliability, is proposed. The probabilistic methodology permits rapid theoretical predictions of stochastic material properties (such as strength). Structural reliability is then predicted from the strength distribution and actual loading data.

In addition to its ability for predicting reliability, information from its probabilistic sensitivity factors (by-products from the probabilistic analysis) could be interpreted for identifying the less dominant material properties. Test reduction for these less sensitive material properties could then be suggested from the probabilistic analysis. Conversely, an increased amount of test could be suggested for the more sensitive material properties.

Due to the inability in reliability validation, reliability predictions from any advanced probabilistic code have not been trusted with much confidence. This is often the case since validation at a given reliability level could demand data generation from a relatively large number of tests (ranging from thousands to millions).

Therefore, we propose the use and validation of a commercially available probabilistic code linked to a Finite Element Analysis (FEA) as the principal activity within this GARTEUR Action Group. Within this, a low complexity and small-sized test element (possibly at sub-element level in the qualification hierarchy) would be selected for analysis. A large number of these elements would be tested in order to validate the theoretical reliability predictions.

Upon validation of the probabilistic code, another larger structure (henceforth denoted as test structure) would be designed probabilistically and its reliability predicted. In parallel to this, the same test structure would also be designed deterministically using design allowables. The reliability of the deterministic design is then compared against the probabilistic equivalent.

The reliability and sensitivity information from a validated code would enable designers to improve existing structures and reduce the development cost of future structures, through predictive designs. In addition, the potential for reducing the materials qualification and structural certification costs using the probabilistic approach within this exercise could be evaluated and if successful, suggested to the relevant certification authorities.

2. OBJECTIVES

1) Establish the confidence in using an available probabilistic code for analysing composite structures.

2) Establish the significance of batch-to-batch and manufacturer's variability effects on laminate strength variability.

3) Establish the suitability of using simplified strength predictive models for probabilistic analysis.

4) Development of statistical models accounting for batch-to-batch and manufacturer's variability for the random variables considered.

5) Establish the reliability of deterministically designed structures and investigate the potential gains of the probabilistically designed equivalent.

3. STATEMENT OF WORK

The main objective of this work is to develop a probabilistic methodology for predicting the reliability and sensitivity of a composite structure under uniaxial compression loading. The exact response parameter to be investigated is to be specified in defining WP2.

A simple test element will be manufactured and tested for validating the reliability predictions. Although the current work will only focus on the analysis and validation of small test elements, the methodology could be extended at a later stage for investigating a different test element of a different material.

The tasks within this GARTEUR Action Group will be divided into the following work packages (WP);

WP 1: Review of current probabilistic codes for the analysis of composite structures

This review will identify the strengths and weaknesses of commercially available and in-house codes. The review should conclude by recommending a suitable code and analysis method for composite structures. The method should be capable for accounting the spatial variability observed in composite structures.

WP 2: Definition of experimental programme

The composite material, lay-ups and number of specimens to test are to be defined within this work package. The input parameters (coupon data) to be characterised should depend on the probabilistic model inputs for the response parameter of interest. Laminate manufacture and material selection should be such that they would include the batch-to-batch and manufacturer's variability.

In addition, the methods for characterising the input parameters (ply angles, ply thickness, dimensional variability) are also to be defined within this WP.

Currently, a uniaxial compression load case and a flat rectangular panel for the test element are being considered for the reliability validation exercise. Geometry of the test element will be defined through an initial sizing exercise such that the laminate would not fail under a specified level of applied loading.

Two sets of test elements, differing in geometry and weight would be separately designed to survive the specified load level. One set would be designed deterministically using the allowable-factor approach and the other designed probabilistically (i.e. designed to have a given level of reliability) based on the actual distribution parameters.

WP 3: Definition and development of simplified deterministic models

The suitability of available deterministic models for the response under the loading case considered will be investigated. A simplified model will be defined within this WP for incorporation into the probabilistic analysis.

WP 4: Manufacture and test of coupons and elements

Test coupons (for material properties) and test elements (for reliability validation) are to be manufactured and tested in this WP. In order to capture the manufacturer's variability, parent laminates should be manufactured by the different partners but tested at only one facility using one test standard.

Two sets of tests are to be conducted in this WP. The first set of test is the materials characterisation tests (coupon) to obtain the model's material input parameters (ply properties) and the second set is the test (element) to obtain the test element's response parameter.

Two sets of test elements (for the two different designs in WP 2) are to be tested using the same test standard to obtain the test element response.

WP 5: Numerical assessment of probabilistic code

A numerical assessment of the test elements defined in WP 2 will be conducted in this WP. The probabilistic method from WP 1 and the Adaptive Directional Importance Sampling (ADIS) will be benchmarked against a direct Monte-Carlo Simulation (MCS). Accuracy and efficiency of these methods will be validated using test data for response parameters from WP 4.

WP 6: Code/Method validation

Reliability of the element designed probabilistically and deterministically in WP 4 is to be checked against actual reliability data from tests.

WP 7: Probabilistic design vs. deterministic design

Once the validation in WP 6 is completed, the reliability of an allowable-factor design against a probabilistically designed test structure will be investigated. A weight/reliability trade-off analysis is then conducted for these designs.

No code validation is to be conducted for the test structure within this GARTEUR.

4. MEMBERSHIP

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The monitoring responsible will be **Prof. Paul Curtis** (DSTL ,UK)

5. DIVISION OF WORK

Each of the participating companies has substantial facilities for the manufacture, testing and analysis of composite materials. These include autoclaves, presses, servo-hydraulic test machines and computer workstations.

The contribution of participating organisations to the programme is as follows:

Participant	Main Contribution	Work Package
QINETIQ	Assessment of available probabilistic code	1,2,5,6,7
INTA	Manufacture and test of coupons and elements	2,4
CIRA	Development of simplified delamination model	2,3
SENER-BOREAS	Manufacture and test of test element	4,5,6
NLR	Probabilistic analysis using in-house probabilistic tool (RAP)	1,5,6,7

6. TIMESCALES

The timescales for carrying out the work and target dates for meetings and reporting are indicated in the following bar chart.

Date	04/ 2004	06/ 2004	09/ 2004	12/ 2004	03/ 2005	06/ 2005	09/ 2005	12/ 2005	03/ 2006	06/ 2006	09/ 2006	12/ 2006
Objective												
Proposal submission												
Kick-off meeting												
WP 1												
WP 2												
WP 3												
Review Meeting 1												
WP 4												
Review Meeting 2												
WP 5												
Review Meeting 3												
WP 6												
WP 7												
Review Meeting 4												
Production and distribution of final report												

7. REPORTING

The final report will be GARTEUR “Limited” and the distribution will be as follows:
All members of GARTEUR council
All members of XC
All members of S&M GoR
All members of Action Group

The AG will propose additional nominations for limited distribution of the final report, if requested.