“Optimization of Composite layers lay-up of an aeronautical component using an Isight-based intelligent decision advisor, iDA”

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Abstract: This paper describes the use of an Isight-based system called intelligent Decision Advisor (iDA) in the composite layer lay-up optimization problem. iDA is a frontend interface developed to use Isight's powerful explorative methods to achieve established design objectives. In this study, iDA is used to manage several hundreds of variables, and to improve the shape and positions, the orientation and the thickness of the composite plies and stack sequence of an existing wing pylon design of AleniaAermacchi. This process directly drives the design toward an immediate manufacturability with optimized stiffness, weight and cost. Finally the implications regarding the management of the whole simulation process, its multi-disciplinary aspects and its advantages to the company will be discussed.

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Keywords: Aircraft, Composites, Design Optimization, Minimum-Weight Structures, Shell Structures

1. Introduction

Composite and sandwich structures are finding increasing applications in aerospace systems mainly due to their high stiffness-strength to weight ratio, the tailoring capability and the possibility to design multifunctional components. The design of such structures may be computationally demanding in the “real-life” problem: there are an almost unlimited number of ways in which a laminate can be constructed. This is because for each composite patch it is potentially possible to vary:

i. Number of plies in a given orientation
ii. Ply orientation angle
iii. Ply stacking sequence
iv. Ply material (e.g. Tape or Fabric, honeycomb)
v. Patch position

Coupled with this, the final design is required to meet structural and manufacturability targets such as stiffness, buckling, stress & strain limits and lay-up rules. For example, if a single composite patch has three ply orientations (e.g. 0º, 45º & 90º) and 30 layers totally, the total number of available stacking sequences is over five thousand billion.

Traditional optimization methods cannot cope with problems of this scale. Indeed, a critical examination of the concepts behind it reveals some weaknesses. The main one is the idea of searching the absolute optimum of an objective function. Objectives stem from mathematical models relating design variables to performances. Often, the objective function to optimize is irregular, with numerous local optima having roughly the same value. Within this scenario, finding the “mathematical” absolute optimum can be a hard task, at the end of which there is no certainty that the optimum reached is the absolute one, therefore it can lead to a great amount of the function evaluation. Besides, from a practical point of view there is no need to have the absolute minimum/maximum. In fact, there could be many local optima with good performances and worth consideration. Another weakness of optimization is the poor manner in which boundary conditions are exploited. These conditions influence the course of the search only when they are violated. Instead, the search would be more fruitful if the boundary conditions were continuously accounted for.

iDA method has been designed to allow another approach to some optimization problem. iDA has been developed in the iSight framework in order to address complementary function: the iSight powerful workflow design and execution respect the innovative iDA approach.

An example of a wing pylon weight reduction is shown: the focus will be on the design improvement on a Carbon Fiber wing pylon structure in order to assure adequate static capability, obtain a feasible design and reduce the weight respect to the initial design. The problem involves a multidisciplinary aspect, topological carbon plies patch optimization, multi target objective, high discrete variable number (650 to 900 variables).

1.1 Introduction to the iDA method

The iDA is methodology to overcome the strictly mathematical optimization problems approach. It is not an optimizer, but rather an algorithm which looks for an improvement of the design, using efficient search strategy driven by the user expertise/experience. Objectives and constrained are not extremised, but rather are assigned targets to achieve. The iDA is based on stochastic method like Montecarlo (MCS).

Below are listed the steps implemented in the iDA method.

i. Select a starting point and perform a “local” MCS with few trials, typically around 12-16; the sampling can be done by using uniform distributions centered around the initial point, or specialized distribution, based on the user experience (like on this problem formulation).
ii. For each trial of the generated sample, evaluate the ***engineering distance*** from all the targets and constraint limits: the engineering distance is composed by two terms: limit violation and performance outcome.
iii. Select the point with the lowest distance and consider it as the centre of a new MCS.
iv. Repeat until the distance to targets is satisfactory.

The main advantage of a stochastic approach versus its deterministic counterpart is that the computational cost is not strictly related to the number of variables of the problem. This means that the engineer no longer has to make simplifying assumptions, sacrificing the realism of his model, because of the “curse of dimension”, inherent to deterministic analysis.

2. Analysis and Results

An existing model of the aircraft pylon wing was analysed under a number of in flight and landing loading conditions with non-linear simulation. The iDA method has been applied in order to improvement of the wing pylon (Figure 1) actual design from the point of view of the mass reduction, keeping the same composite failure index result. The actual model FEM has some critical location (F.I., Failure Index greater than >1) on the load introduction point, due to a poor FEM and geometry model description. The optimized solution will keep the same number and position of the FEM elements with F.I.>1.

The objectives of the activity are to:

i. Use the powerful iSight workflow descriptor and iDA method approach at the concept design phase to lead the design of the plies used
ii. in the skin composite aircraft wing pylon.
iii. Save significant model set-up time & run-time compared to other optimization methods
iv. Determine the size, position & orientation of the ply patches
v. and asset a final manufacturing design
vi. with lower mass prediction and with positive Failure Index

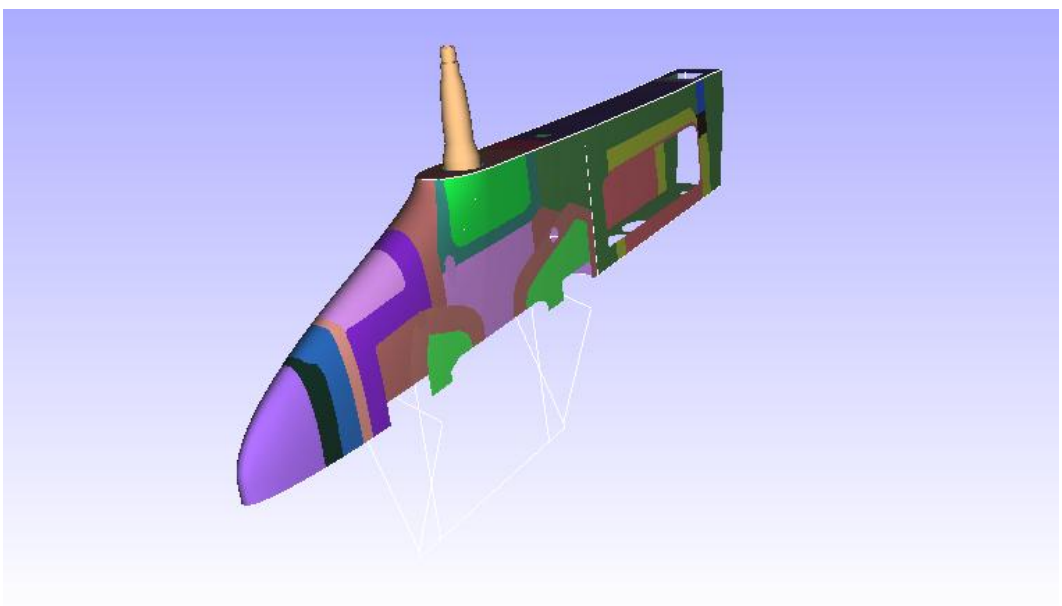


Figure 1 - the pylon actual design thickness distribution

2.1 Setup of the problem formulation

The iDA approach require a global plies geometry description: it means that to each ply, the elements group is defined.; a global ply exist on different properties region in the FEM model; changing a global ply parameter means to change all the related FEM properties where the ply is defined. The FEM model consists of 148000 nodes and 10200 shell elements.

Each global-ply thickness, material and angle becomes an iSight parameter. So the first step is to create a global ply patch model database. Based on the quite simple shape of the pylon and the needing of a reduced complexity of the ply patch, the global ply path is almost the same of the actual design region identification. Some other ply patch has been introduce where the actual design seem poor of details. Figure 2 shows the plies and the overall stacking. The shape of the plies has been defined trying to respect manufacturing constraints.

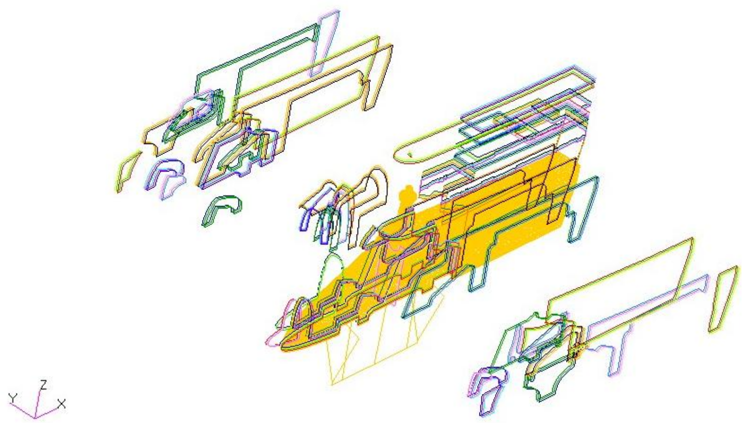
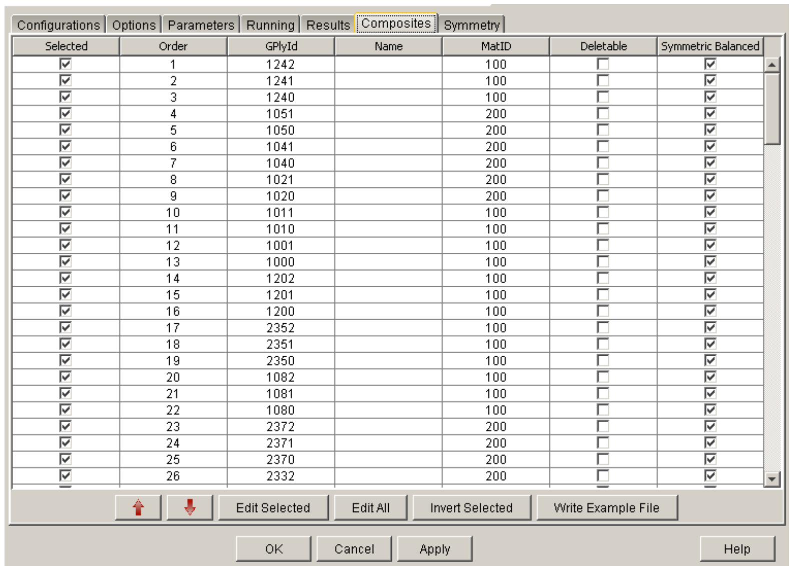


Figure 2 – Global plies definition

The global ply patch number is 200, but not all of them are independent parameters because of the final structure symmetry: the left and the right side plies are linked together.

The iDA component development has been addressed to easy setup a composite structural problem: it identify the global ply patch thickness and angle and automatically create iSight parameter, it allows to define the symmetry relationship between the plies (right side and left side of the model), deleting the slave plies from the independent parameters set. iDA can manage the composite layup constrain regarding the balanced and symmetry stack sequence through a dedicated GUI interface (see **Error! Reference source not found.**), so that the final layup is symmetric and balanced. *It is planned to introduce a parameter to control the plies stack sequence and to optimize it using iDA approach in the next project phase.*



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☑	2	1241		100	☐	☑
☑	3	1240		100	☐	☑
☑	4	1051		200	☐	☑
☑	5	1050		200	☐	☑
☑	6	1041		200	☐	☑
☑	7	1040		200	☐	☑
☑	8	1021		200	☐	☑
☑	9	1020		200	☐	☑
☑	10	1011		100	☐	☑
☑	11	1010		100	☐	☑
☑	12	1001		100	☐	☑
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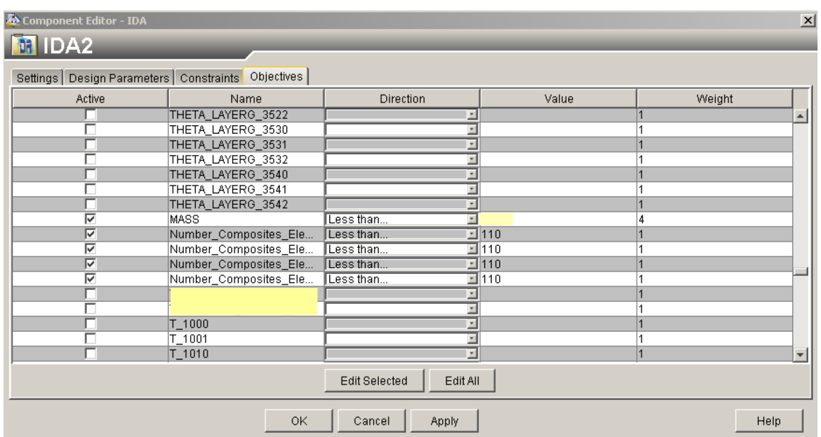
Figure 3- the iDA GUI to easy setup layup sequence constrain regarding the symmetry and the balance of the plies

The iDA automatic reads the structural simulation output results and automatic create the iSight output parameters.

A successful strategy on stress/strain structural problem is to define output parameters as the count of model element failing the design strain/stress condition. iDA automatic counts the failing element (element within F.I. > 1) and create appropriate iSight output parameters (see Figure 4).



Component Editor - IDA

IDA2

Settings | Design Parameters | Constraints | Objectives

Active	Name	Direction	Value	Weight
☐	THETA_LAYERG_3522			1
☐	THETA_LAYERG_3530			1
☐	THETA_LAYERG_3531			1
☐	THETA_LAYERG_3532			1
☐	THETA_LAYERG_3540			1
☐	THETA_LAYERG_3541			1
☐	THETA_LAYERG_3542			1
☑	MASS	Less than...		4
☑	Number_Composites_Ele...	Less than...	110	1
☑	Number_Composites_Ele...	Less than...	110	1
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☑	Number_Composites_Ele...	Less than...	110	1
☐				1
☐				1
☐	T_1000			1
☐	T_1001			1
☐	T_1010			1

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Figure 4 - the objective definition: mass value and the critical element number as objective to minimize

The iDA needs a problem strategy setup: in the Figure 5 the GUI is shown. The most important parameters are the iDA search steps and the number of samples per step.
The variable rate change control the amount of parameters that are changed for each sample, whereas the mutation rate control the number of parameters that violate the superimpose rules.

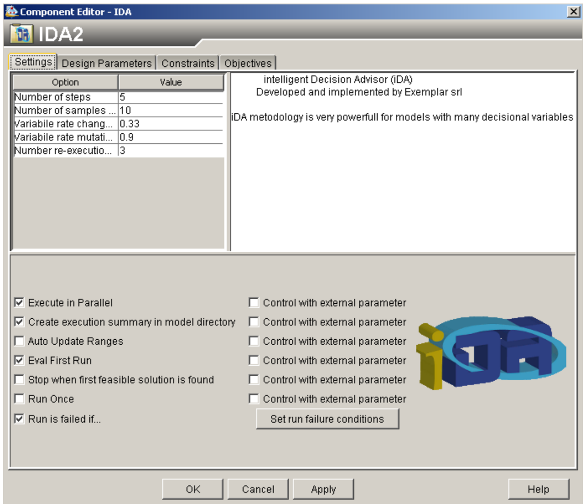

Figure 5 - the iDA main problem strategy setup

2.2 Execution of the iSight workflow

The iDA method improve the time for the response if the iSight parallel execution is enable. For this problem execution a HPC system driven by FIPER has been used. The structural non-linear simulation required about 20 minutes for the execution, so a multiple concurrent analysis is the only choice available to obtain some results on an affordable time.

The output binary result file is up to 2GB, so the VCollab binary result compression and visualization has been used during the simulation to store the result history and to quick check the convergence behavior of the solutions.

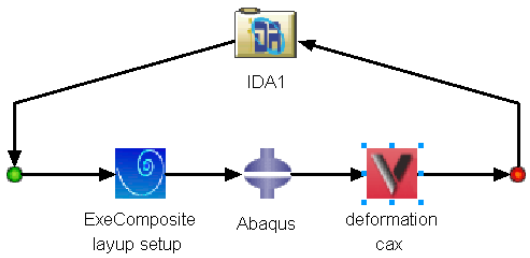

Figure 6 - the iSight workflow used: it has been dispatched through FIPER

2.3 Results

In the Figure 7 there is the mass history during the optimization run. It is possible to see a first part, the first 80 runs, which rapidly decrease the mass, than a smooth mass reduction. This is due to the constrain violation regarding the number of critical elements (number of elements within F.I. > 1.).

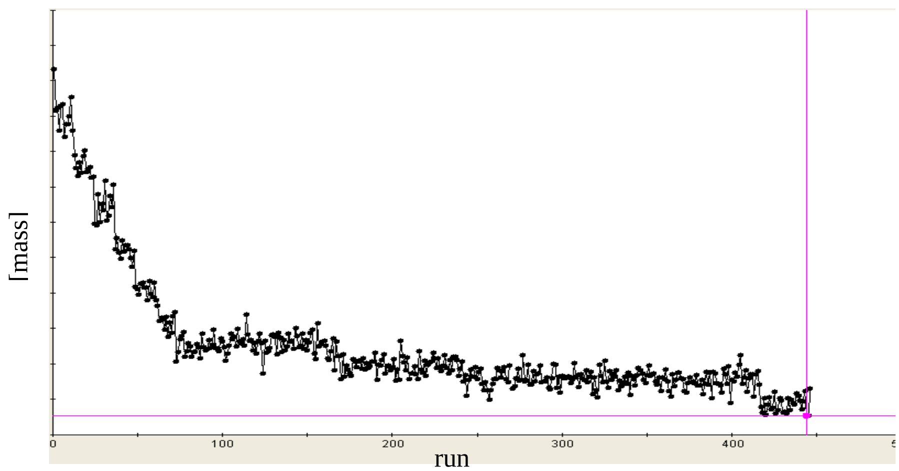

Figure 7 - Pylon mass history

In the Figure 8 there are plotted the mass versus the critical element number for the 4 loadset analyzed. The 4th graph in the Figure 8 describes a predominant behavior of the loadset called B116 on the constrain violations: these mean that, if the loadset constrains B16 is respected, than all the others loadset are respected too. In the Figure 9 there is a scatter plot of the critical element number violation between the loadset B16 and the loadset B13: the correlation line is above the diagonal, this means that the B16 is critical respect to the loadset B13. Similar diagram can be creates for the others loadset B14 and B15. In order to reduce the analysis time should be possible to limit the non-linear analysis only to the loadset B16.

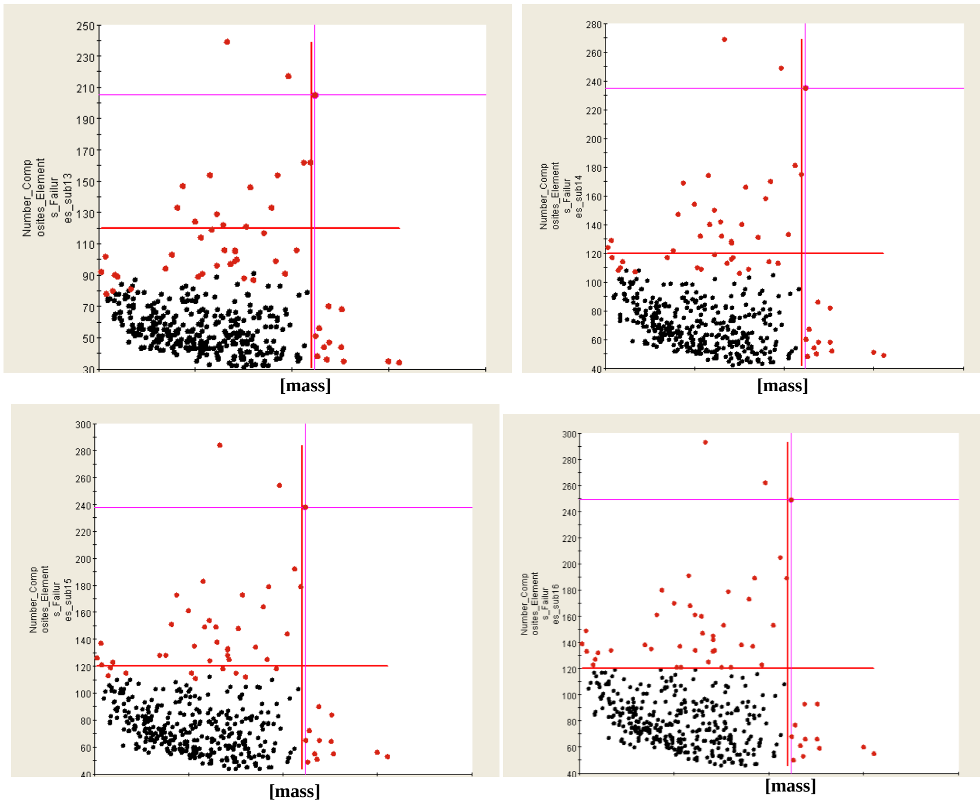

Figure 8 - the scatter plot regarding mass vs the element critical number for each loadset

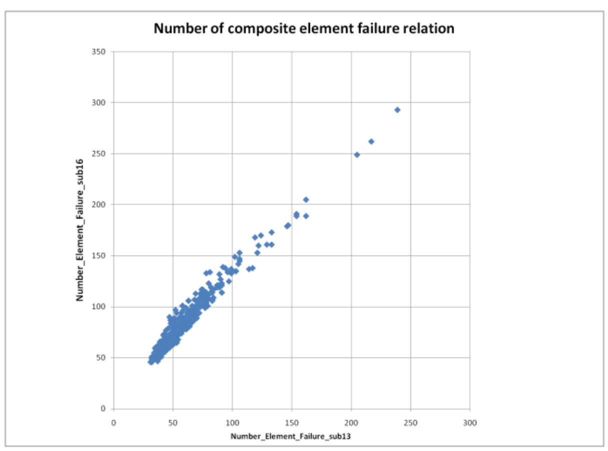

Figure 9 - the relation between the critical element number on the loadset B13 *vs* the critical element number on the loadset B16

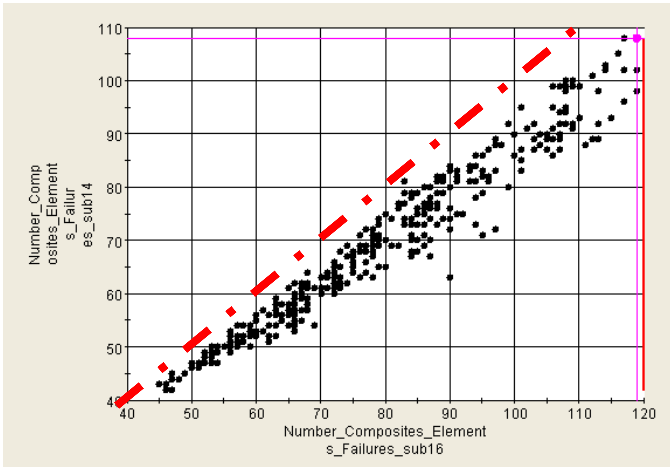

Figure 10 - the relation between the critical element number on the loadset B14 *vs* the critical element number on the loadset B16

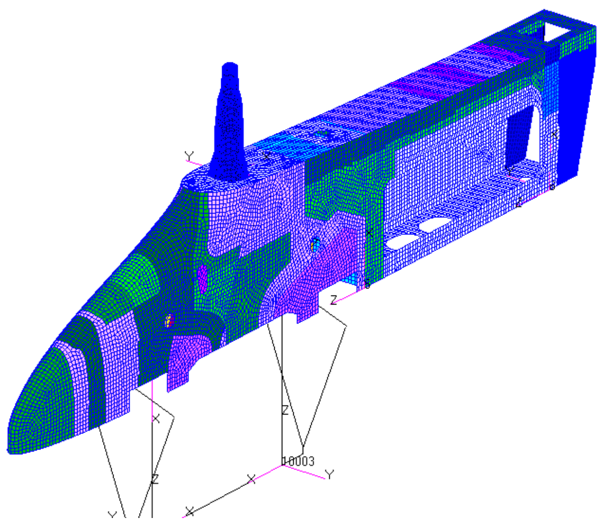

Figure 11 - the resut thickness distribution

3. CONCLUSIONS

The capabilities of the proposed methods were illustrated with this test-case, namely a pylon wing. All the relevant relationships between system variables, the hubs of the system, the strongest couplings and the modes of behaviour are provided to the analyst in a graphical manner. Based on these results, the designer can perform comprehensive composite design and optimization, in that all the possible modes of behavior of the system are obtained, together with the corresponding probability of occurrence.

The optimum locations of the ply patches are typically along the load paths although this was shown to change significantly when required to resist to the torsion loads as well as bending. This shows that the optimum location for the plies cannot be determined from the loading conditions alone; an optimum design is dependent upon a combination of the applied loads and the design constraints. The stresses, strains and failure indices in the plies can be assessed for the optimised design. The strains in the new design were found to be within the required limits.

An automatic interpretation procedure was used to determine the optimum ply patch locations and also estimated the required number of orientation in each patch. This will allow the ply patches to be designed in the best possible locations. The orientation percentages in each patch can also be assessed. A minimum feasible mass value for the composite design was determined, although this is likely to increase after applying constraints to meet additional targets for lay-up rules, strains and failure indices.

4. Acknowledgment

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