DISTRIBUTED LOADS DISCRETIZATION IN COMPOSITE MATERIALS STRUCTURES TESTS

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Abstract

Development of a tool for the calculus of discrete loads which allows the reproduction of distributed loads in composite structures tests.

This tool aims to calculate those punctual loads which best reproduce during component tests the stress/strain distributions originated by the action of distributed loads.

The tool uses as main input the solutions from the finite element models for those loads cases which are expected to be reproduced during the test. It also allows the introduction of restraints like the maximum number of loading points and jacks to be used during the test or the relations between the different loading points when they are connected to a whiffletree.

As an output the tool calculates the best mechanical solution based on whiffletrees for the maximum number of jacks stated which best fits the finite element solutions used as an input for the different load cases selected. The solution is based on a error function which can be adapted by the user when a part of the solution should be prioritized.

This paper presents a tool developed for a particular test on an airplane structure, but it also described a systematic approach which can be generally applied to obtain test loads to be applied during the test of a structure submitted to distributed loads in service.

1. Introduction

1.1. Scope of the work

When testing composite structures submitted to distributed loads in their surface during its in-service operation the first question that normally arise during the test conception is related to the simulation of that kind of loads during the test.

In some cases when the load distribution is quite simple *e.g.homogeneus* and approximate solution can be found quite easily. But unfortunately those loads tend to have complex distributions and moreover, as a function of the different scenarios that the same structure can face during its in-service life it could be of interest to simulate different load cases which can have different loads distributions associated.

The simple way to apply those distributed loads will be to a find a solution to the same problem based on discrete loads which reproduce as much as possible the original problem/situation.

Traditionally loads are applied to big structures during testing by mean of servocontrolled jacks *usuallyhydraulics* using close loop controller. So, in a first approach the aim of the designer will be to include as much jacks and then load introduction points as possible. Based on this first questions to be answered when designing the load introduction would be: where it is necessary to apply the loads?, how many load introduction points are necessary? how many jacks are available?

There are also some technical and economical aspects which also act as a restriction when trying to simulate the effect of a distributed load on a structure being tested. There are examples of different approaches not suing jacks for the load introduction ([2]).

A good example of composite structures submitted to distributed loads are those which are assembled into an aircraft. Extensive experience in the field of testing this kind of components is available due to the important safety requirements and those the though certification process associated to the development of a new transport aircraft. These structures can be considered as a good example to begin to explain the traditional approach to this problem.

- First question would be, where to apply those discrete loads which best simulate the real distribute load? Semi-monocoque structures still represent the basic structural concept in aerospace structures, which means that usually we will find thin covering shells which could not be able to withstand a local load introduction which magnitude will be high enough to act as the resultant force of the distributed load applied in the surrounded area. This is the main reason why in those structures the location of the loading points is usually very restrictive, as they can only be installed in the those points of the structure where stiffeners members exist usually known as *hard points*. As an example, when testing a wing, the preferred loading points to simulate distributed loads will be ribs sections.
- Once the location of the possible loading points is known it is necessary to make a selection of those which are going to be used during the test. This is basically constrained by the number of jacks available.

For those structures like a wing the main source of distributed load would be the lift generated by itself which will produce a bending moment around the root joint to the fuselage and a torsion moment around the longitudinal axis due to the pressure distribution along a wing section. The classical way to face this problem is to find a number of loads applied in the ribs in order to simulate the bending moment and the adjust rib by rib the necessary loading between two jacks in each one of them to adjust the torsion moment. Both problems, the one related to the bending and the one related to torsion have analytical solution, so a good approach to the distribute load can be found after some iterations.

Unfortunately not all structures can be idealized as a beam and the analytical solution to the problem is not possible. This happens in components where the ratio between characteristic lengths does not fulfil beam hypothesis, in areas where the curvature could not be disregarded, etc.

1.2. Motivation

In the field of aerospace structures testing and certification is a common issue to find out the necessity to calculate discrete loads which accurately reproduce distributed loads.

The aim was to create a systematic approach which helps to calculate those loads with independency of the structure under consideration.

2. Tool

2.1. Fundamentals

The systematic approach described in this document is based on the following guidelines:

- The load application points are known and fixed
- There is a F.E.M. of the structure available which can be used to generate one solution for an unitary load applied in each one of the load application points.

Using the solutions to the unitary load cases a transfer matrix can be created which links the loads applied to the solution of the problem, which will be normally in terms of strain, stress, displacements or any other magnitude which can be obtained as a result from the F.E.A.

2.2. Formulation

The previously described process can be formulated as follows:

$$\begin{pmatrix} k_{11} \\ k_{21} \\ ... \\ k_{m1} \end{pmatrix} = \begin{pmatrix} k_{11} & k_{12} & k_{13} & ... & k_{1n} \\ k_{21} & k_{22} & k_{23} & ... & k_{2n} \\ ... & ... & ... & ... & ... \\ k_{m1} & k_{m2} & k_{m3} & ... & k_{mn} \end{pmatrix} \begin{pmatrix} \\ 0 \\ ... \\ 0 \end{pmatrix} \tag{1}$$

Using all those *solutions* (right side of the equation) from the F.E.A. the the original transfer matrix can be created:

$$\begin{pmatrix} S_1 \\ S_2 \\ ... \\ S_m \end{pmatrix} = \begin{pmatrix} k_{11} & k_{12} & k_{13} & \cdots & k_{1n} \\ k_{21} & k_{22} & k_{23} & \cdots & k_{2n} \\ \vdots & ... & ... & ... & \vdots \\ k_{m1} & k_{m2} & k_{m3} & \cdots & k_{mn} \end{pmatrix} \bullet \begin{pmatrix} F_1 \\ F_2 \\ \vdots \\ F_m \end{pmatrix} \tag{2}$$

With the previous expression the solution to any combination of load applied into the known loading points can be obtained. From this point a it is possible to find a approximate solution to the real problem without the necessity to interact with the F.E.M. which has lot of advantages in terms of computational cost and time.

Once the transfer function is known the solution obtained from the real problem should be calculated from the F.E.M. This will be an input for the tool developed.

After this an optimization tool is created in order to minimize errors between the real loading state to be reproduced (S_i) and the simplified loading state generated. A global error R can be defined as a function f based on the individual errors of each component F_i of the loading state vector.

2.3. *Optimization*

An optimization process could be defined as the methodology of making something as fully perfect as possible, to measure that perfection it is necessary to measure the *goodness* by a function f (objective function). In our case it will be an error function based on the differences from S and F, a correct definition of that function will be critical to achieve a good solution.

2.4. *Restrictions*

Until now the basic procedure has been described but there are some limitations that should be considered and which act as restrictions during the optimization process: number of jacks, maximum load of each jack, different load cases to be simulated, loading points which can not be loaded simultaneously...

2.5. *Composites*

All the process followed leads to some punctual loads to be applied into the structure, when working with metal structures that could lead to local plastifications which will not affect the global behavior of the structure. But when working with composites special care should be taken when sizing and checking this load introduction points. Uncorrect sizing of the load introduction joints could produce local failures like delaminations, due to the out of plane loading, which can growth during a fatigue test creating a premature failure of the structure.

2.6. *Options*

The basic approach where one jack is connected to a single introduction point is not always feasible due to number of jacks or controllers limitations, this can be solved, partially, by using mechanical links between the loading points and applying loads to those links using the jacks.

This relation between the loads applied to each loading point can be considered into the optimization problem directly in such a way that even the basic geometry of that link can an output of the optimization tooling. That is, usually that kind of links act as lever arms, so there is a direct relation between the loads transmitted by each point and the loads applied by the jack through the relative lengths from the point where the load is applied and the load application points.

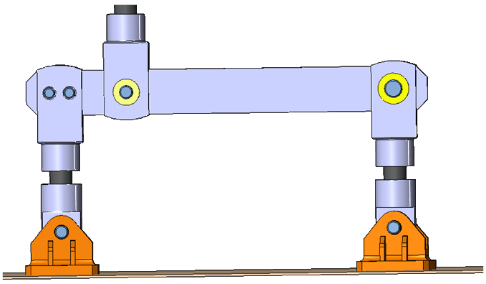

Figure 1. Typical mechanical link between two loading points

The mechanism used to apply various punctual loads using one jack based on lever arms is usually known as whiffletree.

2.7. Load cases

The procedure described is valid for one single load case but can also be generalized to a situation where for a number of jacks fixed around the structure and with fixed links geometry the best solutions for a group of different load cases is desired.

3. Application to a component test: A350 XWB S19.1 Full Component Test

The tool developed was first used in the test loads calculation for the A350 XWB S19.1 Full Component Test (Figure 2). Briefly in number this test has 19 jacks servocontrolled and about 1500 strain gauges.

In this test various loads needed to be simulated (aerodynamic, inertia loads, etc). This was a good example because there are various loads forces with different characteristics but instead of trying to adjust any of them one by one the aim will be to find those punctual loads which best fits the behavior of the component when submitted to those loads.

The same process described in this document was followed in order to calculate those loads to be applied and the basic geometry characteristics that describe the mechanical link to be used to distribute the load (Figure 3).

4. Conclusions

A systematic approach to the load calculation procedure to be applied to reproduce in-service distribute loads when testing structures has been described. The procedure is totally independent of the structure being tested as it is basically an optimization problem which inputs are the results from a Finite Element Model. Based on the experience the definition of a correct error function to be minimized is critical to achieve a good solution, and for that reason is desirable a minimum knowledge about the structure being tested and the results from the F.E.M.

Normally the error function will include different weights for different groups of variables in the F vector, by using these weights the importance of one variable against other can be prioritized,

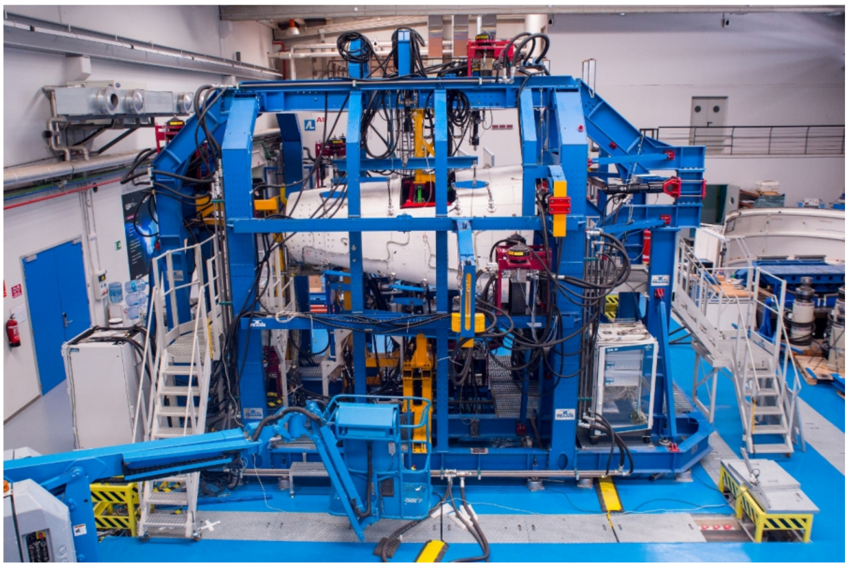

Figure 2. General view of A350 XWB S19.1 Full Component Test

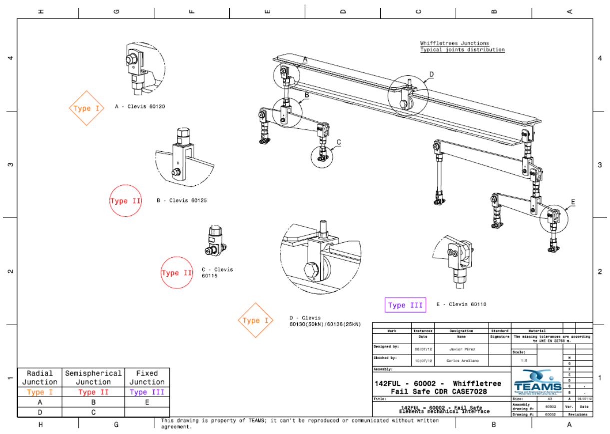

Figure 3. Load introduction mechanism

e.g. strain at a certain critical location can be more important than displacements in a non critical area.

The results from the tool has demonstrate to be consistent and a good approximation to the real load cases to be simulated, in any way engineering judgement can not be obey as the optimization problem could lead to mathematical solutions with no physical sense.

References

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