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Visual Environment for Structural Loads Computations for Stress Analysis of Aeronautical Structures

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Abstract

An accurate determination of flight loads represents a critical part of air vehicle design. It is a complex process and it requires skilled and experienced engineers that must integrate results from wind tunnel tests, computer simulations, historical data and empirical formulations into a number of loads cases that provide a realistic assessment of the flight vehicle's environment. Under these conditions, the vehicle must satisfy requirements imposed by regulatory agencies as part of the vehicle certification process. The main objective of this paper is to describe an environment for calculating an equivalent system of concentrated loads for a FEM analysis. In many situations in a FEM analysis the external loads are concentrated forces equivalent to given distributed pressure fields. These concentrated forces can also be used in static tests. Commercial codes provide solutions for this problem, but what we intend is to develop a code adapted to the user's specific needs.

Keywords: aircraft design; aerodynamic loads; concentrated forces; stress analysis; static tests

1. Introduction

The tools and techniques (grouped in a system) are not limited only to make the design and analysis activities of the aeronautical structures more efficient in the design process of the new aeronautical product. These tools and techniques actually support all kind of activities that are taking place during the lifecycle of a specific structure (redesign, harness, maintenance, investigation after specific events, etc). So, the costs for an aeronautical investigation are very much lowered and also the time in which it is made is shorter as the information is related and attached to the investigated object. A review of the state of art in the field [9] highlights the strengths and weaknesses of collaborative design software for particular commercial and in-house software solutions. The current

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focus is on using Virtual Reality (VR) environments (CAVE, DIVE, COVISE, ViSiCADE, etc.) for enhancing the analysis and visualization [10,11,12].

Considering, for example, an airplane wing designed with CAD tools, the database will include it as an entity with many other information attached (such as: geometric data, info about the used materials, proposed analysis method, results of a previous analysis, notes). This entity is associated with other information that may be interesting in different stages of its lifecycle. During an analysis process the user accesses a database through a visual interface that allows a better understanding of the specific structure and launch if need be, a new analysis process.

Although the collaborative environment, through the created infrastructure, ensures the communication between partners of a project and, in some cases, various tools for technical information access or transfer, the right use of them is sometimes difficult. The difficulties appear mainly because the procedures, technologies and software systems are usually implemented in different forms from partner to partner. In such cases, in order to ensure a full understanding of the information between partners, converters or other applications that may help, or notes and even re-make of some activities are used.

In [1] we described such an environment dedicated to aeronautical structures design and in [2] we developed a tool dedicated to fatigue optimization analysis. An important issue in the design process is an accurate determination of flight loads. Aerodynamic loads in a structural FEM analysis of an aeronautical structure are traditionally introduced as concentrated loads in different points of the structure see for example [6]. These concentrated loads are obtained from pressure fields in different cases and a large amount of data is handled. Although commercial FEM codes offer solutions to this problem, an in-house code adapted to user's specific needs is developed in order to take into account particular requirements. Our code offers also solutions for determining accurate loads for static tests for an aeronautical structure. If the aerodynamic pressures are given in a detailed mesh we use the same mesh to determine lumped forces and then interpolate these forces in critical stress points of our structure. Usually some commercial codes use only for points to determine the load case and there are situations in which such an approximation is inconvenient. This paper continues our efforts to create an adapted design environment for aeronautical structures [1,2].

2. Structural loads computations for aeronautical structures

The main stages of the program are:

- Reading the input data from the files of the aerodynamic data. A graphic representation of the pressure field is useful.
- Reading the input data from the files of the stress data (nodes, coordinates, elements).
- The field pressure is integrated and then distributed in the aerodynamic mesh. Using the values of the aerodynamic pressure given on the aerodynamic mesh the volume on each quadrilateral element is calculated and divided between the four nodes. Then in each node of the mesh these volumes are overlapped: for an inner node there will be four numbers, for a node situated on an edge there will be two values and for a corner only one value. In this stage we have lumped forces in the aerodynamic mesh.
- Then these values are interpolated in the stress mesh. (using this method the connections between the nodes of the stress model are not necessary). All the determined forces are then added and if the result is different from the aerodynamic total integrated pressure a correction factor shall be introduced.

The final result is a set of concentrated loads applied in the stress mesh with an application point near the aerodynamic point and respecting the total pressure as given.

Remark. If the stress mesh has approximately the same size as the aerodynamic mesh one can interpolate first the pressure values in the stress mesh and then calculate the lumped forces with the procedure described below.

Noting with ndivx and ndivy the number of divisions on Ox, respectively on Oy, the matrices X(ndivx,ndivy) and Y(ndivx,ndivy) contain the values of the coordinates of the mesh, v(ndivx,ndivy) contains the parallelepiped volumes whose bases are quadrilaterals defined by the mesh . We note by $v(i,j)$ the box volume whose base is the quadrilateral with the coordinates $\big(X(i,j),Y(i,j)\big)$, $\big(X(i,j+1),Y(i,j+1)\big)$, $\big(X(i+1,j+1),Y(i,j)\big)$, $\big(X(i+1,j),Y(i+1,j)\big)$. Forces in each node are calculated by the following formulas:

$$f(i,j) = [v(i-1,j-1) + v(i-1,j) + v(i,j-1) + v(i,j)]/4$$
$$i = 2, ndivx - 1, j = 2, nidivy - 1$$
$$f(1,1) = v(1,1)/4$$
$$f(1,ndivy) = v(1,ndivy)/4$$
$$f(ndinx,1) = v(ndivx,1)/4$$
$$f(ndivx,ndivy) = v(ndivx,ndivy)/4$$
$$f(1,j) = [v(1,j-1) + v(1,j)]/4$$
$$f(ndivx,j) = [v(ndivx-1,j-1) + v(ndivx-1,j)]/4$$
$$j = 2, nivy - 1$$
$$f(i,1) = [v(i-1,1) + v(i,1)]/4$$
$$f(ndinx,1) = v(ndivx,1)/4$$
$$f(i,ndivy) = [v(i-1,ndivy-1 + v(i,ndivy-1)]/4$$
$$i = 2, ndivx - 1$$
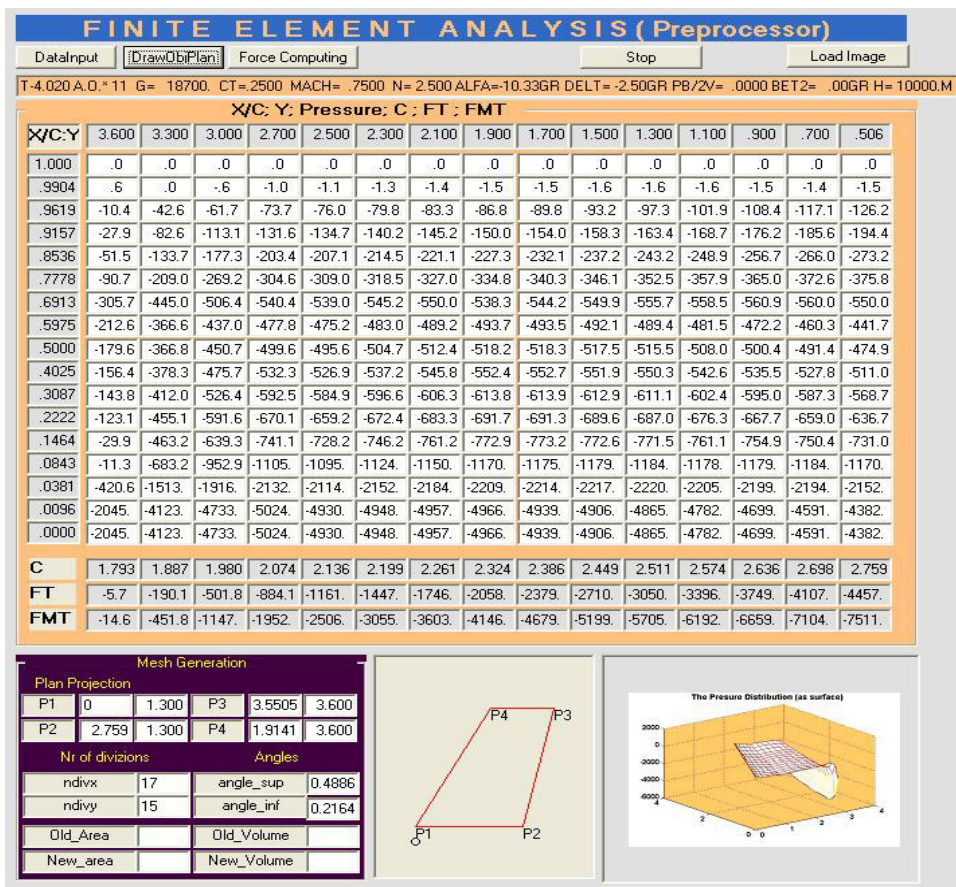$$f = \sum_{i=1}^{ndivx} \sum_{j=1}^{ndivy} f(i,j)$$

Fig. 1. Aerodynamic data: pressure values, integrated values, geometry definition pressure visualization.

With these values we can calculate by interpolation all the node forces for finite element analysis.
Aerodynamic data tables with values of the pressure field (figure 1), shear forces, bending moments (figure2a),b))

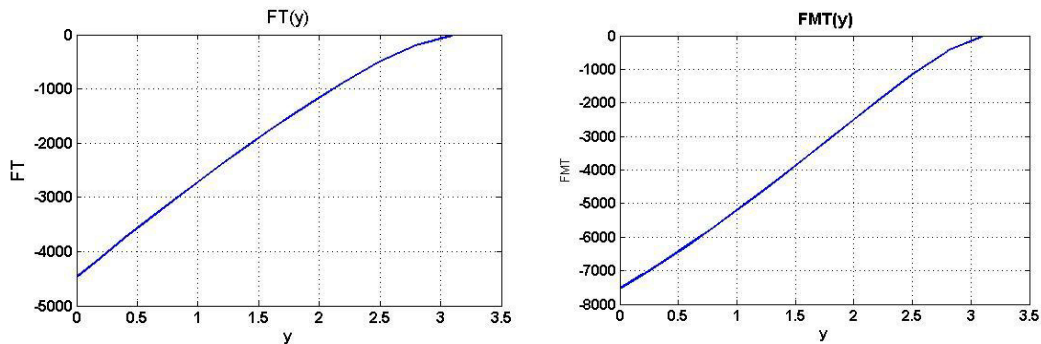and torsion moments represent the aerodynamic input data for our code.

Fig. 2. a) shear forces, b) bending moment.

The user is supposed to define whether the mesh is a uniform mesh or not, or a mesh that shall be introduced in a commercial code.

An example of stress input data is displayed in figure 3 (a plane representation) and in figure 3b) (a spatial representation) of nodes and elements of a finite element discretization of a horizontal tail of an airplane.
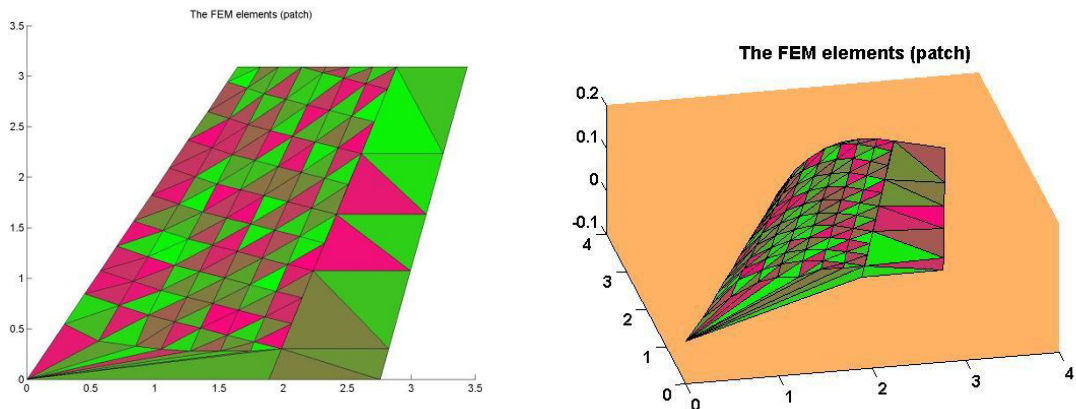

Fig. 3. a) nodes and elements-plane representation, b) nodes and elements –spatial representation.

Output data are lumped forces, diagrams of the shear force, bending and torsion moments, calculated from the equivalent concentrated forces. Comparing these diagrams with the initial ones one can evaluate the accuracy of the load computations.

Remark. The code provides concentrated forces in a mesh obtained using a finite element code and/or a mesh definite by the user.

The code is a Visual Basic program using also MATLAB capabilities in an effort to create a user friendly interface [8].

The Visual Basic [7] facilities allow to create an interface for aerodynamic data and to define a new stress mesh or a set of arbitrary nodes where the lumped forces are needed. The MATLAB processor is mainly used to handle surfaces and grids in graphical representation. Also, with the MATLAB "griddata" function, based on Delaunay triangulation, we can interpolate the pressure values and the concentrated forces in the stress mesh.

The application is developed in Windows. It can be used with Visual Basic (at least V6) and MATLAB (at least Release 13).

3. Examples

3.1. Example-Horizontal tail

For the horizontal tail described in figure 1 subjected to a pressure field using the method described above one obtains the following distribution of forces. The length of the marker is proportional with the value of the force.

The main results are presented in table 1 and there are the Id of the node its coordinate and the value of the lumped force. The marker representation (figure 4) is slightly different from that of the PATRAN representation (figure 6b) because it takes into account the value of the force. The value of the resultant force and its application point is in a good relation with the aerodynamic data.
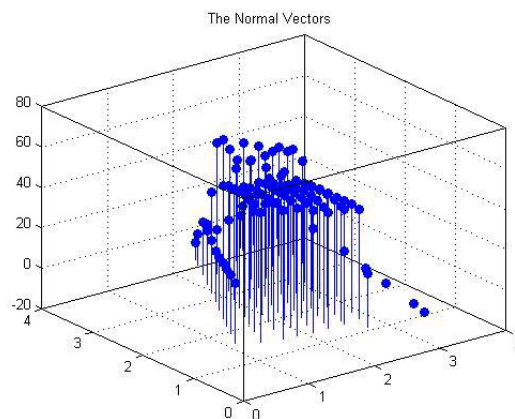

Fig. 4. Calculated forces in stress points.

Table 1. Lumped forces on a horizontal tail of an airplane.

Node_id	Node_Coordinates (m)			Force (daN)
1	0.949	0.637	0.094	-43.761
3	0.719	0.733	0.065	-22.18
5	1.049	0.879	0.096	-43.043
7	0.829	0.969	0.068	-22.164
9	1.152	1.129	0.099	-41.528
11	0.944	1.215	0.072	-21.91
17	1.37	1.657	0.105	-37.681
….	…	…	…	…
256	1.888	0	0.115	-18.1
257	0	0	0	-0.231
Xg_Rez= 2.05 Yg-Rez=1.49			F=	-4416.72

3.2. PATRAN Examples

Using PATRAN for a similar aeronautical structure we obtain a distribution of the pressure field presented in figure 7 which can be used directly in a FEM analysis.

The aerodynamic data may have the following EXCELL representation (figure 5).
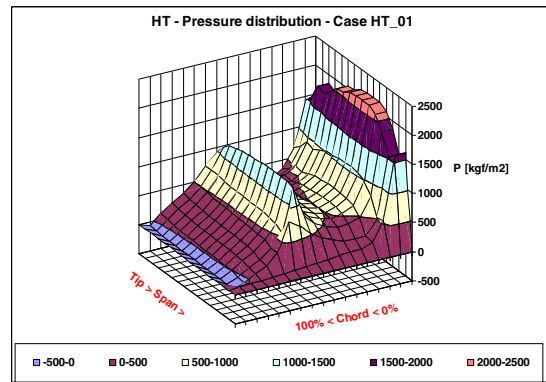
Fig. 5. EXCELL representations of aerodynamic data.

A lifting surface is a trapezoidal flat plate that has inboard and outboard edges aligned with the X-axis of the aerodynamic coordinate system as shown in the sketch below.
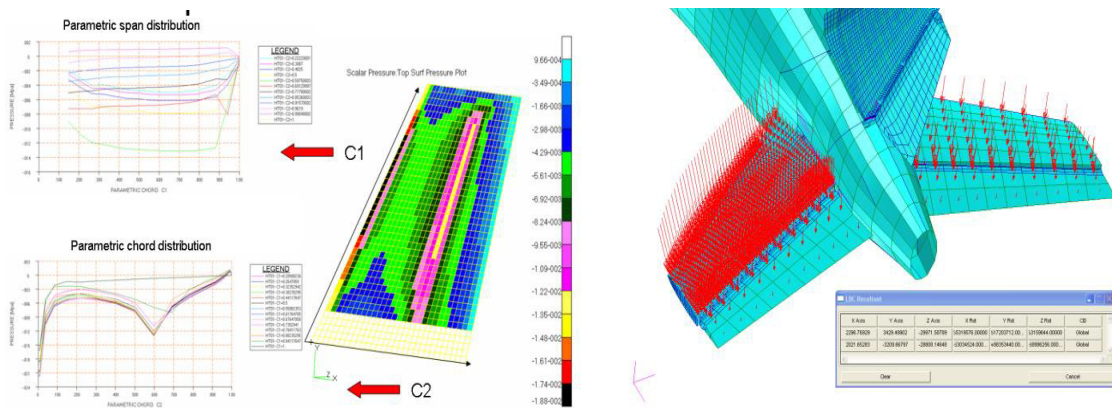

Fig. 6. PATRAN method a) main steps, b) results.

In order to follow the steps used in PATRAN (figure 6 a)) we present how the distributed field pressure for a FEM analysis is obtained. The considered structure is an inner aileron with the geometry defined below (Table 2). The results can be seen in figures 7, and 8.

Table 2. Inner aileron.

	x(m)	y(m)	Pressure (daN/m^2)
Point 1	15.3	22.7	1261
Point 2	315.82	25.710	6384
Point 3	15.97	22.710	417
Point 4	16.38	25.710	272

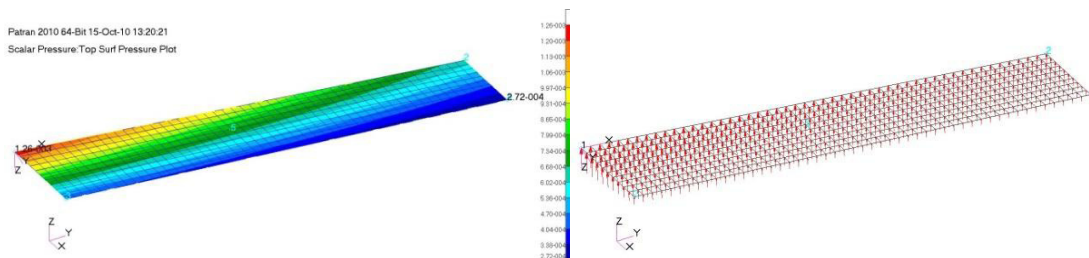*Daniela Baran et al. / Procedia Engineering 69 (2014) 1430 – 1436*

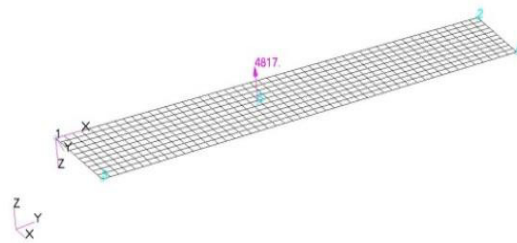Fig. 7. Presure distribution a) contur plot, b)marker plot

Fig. 8. Pressure distribution resultant force (4817daN) application point (x=1373.066, y=259, z= 0) in local coordinate system

4. Conclusion

This program provides a useful tool for any aerospace engineer interested to obtain concentrated loads for a finite element analysis from distributed pressures. It is user friendly, allowing the analysis of many cases in a short time. It can also be used in static tests and operates as commercial codes as we presented in the last example.

As future work, we intend to develop the flexibility of our load calculation interface including some sizing operations following [3,4,5] in order to proper understand the defined aeronautical structure and to be able to take some quick decisions concerning it.

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