Ground loads calculation of an aircraft flexible model

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The aim of this study is to show the advantages of representing an aircraft as a flexible body completely integrated with the multibody dynamics of its landing gears and, applied to manoeuvres such as landing and taxiing, which involve great displacements.
The analyses carried out in this work show the advantages of representing a ground manoeuvring aircraft system not just as a rigid body, but as a flexible one.
The following items have been taken into account in the modelling process:

- the flexibility of the landing gear chassis;
- the flexibility of the levers;
- the shock absorber properties (gas curves, oleo damping);
- the non linear tyre (realized with an external subroutine);
- the aerodynamic forces concentrated on the vehicle centre of mass;
- the flexibility of wings (aerodynamic surfaces) and fuselage.

This model has been described using a basic ADAMS 11.0 version, specifically ADAMS Flex package has been carried out to describe the flexible parts and to integrate them to the global rigid body dynamics.
Once the complete dynamic description has been performed in terms of displacements in the several aircraft components, a procedure capable of computing the loads applied on the structure (wings and fuselage) has been set up *a posteriori*. Currently the final part of this procedure is carried out without using ADAMS, but this could, or rather should, be implemented and integrated into ADAMS environment.

Model details

- **Wing and fuselage**

The vehicle analysed in this paper is a military bi-turbo propelled high wing transport aircraft. The structure has been elastically modelled using the MSC-Nastran F.E. code (Fig.1 and Fig.2). The fuselage and wings of the aircraft are represented by a reduced stick model, i.e., its stiffness is expressed only by beam elements and equivalent stiffness connecting matrices. The aim of this representation was to have a simplified model that would reduce computational time, but was at least able to globally describe the mechanical elastic behaviour of the structure. Indeed, the model has been initially validated by comparison with the results given by experimental modal analyses, i.e., GVT (Ground Vibration Test). Further updating of the model has always been carried out taking into account the equivalence of the modal behaviour.
Since ADAMS needs the modal description of the flexible body to represent its mechanical behaviour, these have been calculated and translated into ADAMS using a modified Craig-Bampton method (Refs. [1],[3]). The inertia properties are represented by concentrated mass points.

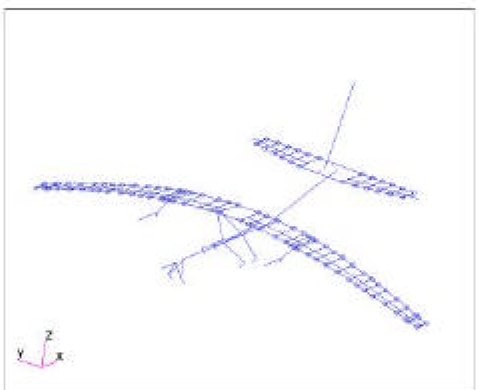

Fig. 1: first symmetrical global mode

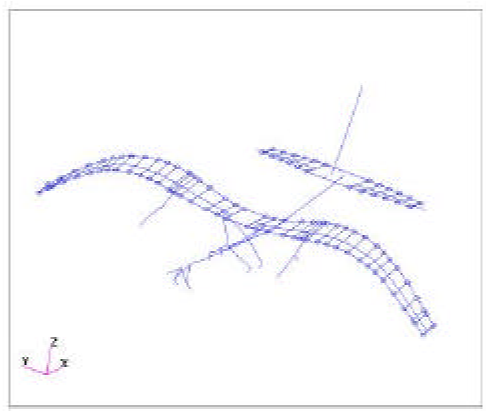

Fig. 2: second symmetrical global mode

This class of vehicles must satisfy the international requirements (Ref. [18]) in the various flight conditions. Specifically, in the critical landing and taxiing manoeuvres, the coupling between the rigid multibody and elastic motions is particularly relevant and crucial with respect to, e.g., the standard flight conditions (with load factor n=1). Indeed, in this case the unique hypothesis of single rigid body is quite satisfactory for the flight mechanic analysis, whereas the unique hypothesis of flexible body is sometimes adequate for evaluating the aeroelastic performance.
The objective of the present study arises from the above issues. The results obtained have pointed out the significant difference between these analyses and those given with the hypothesis of rigid wing and fuselage. These simulations have been useful to verify the international requirements and furthermore the comparison with experimental results, arising from the full scale model, has also confirmed and assessed the accuracy of the obtained results.

- **Flexible chassis**

The landing gears system of this aircraft consists of a nose gear and two main gears placed symmetrically with respect to the longitudinal plane of the vehicle (see Fig. 3 and Fig. 4). As the structure is hyperstatic, the main gear is represented by a flexible stick model too. It has been generated to accurately represent the tensional behaviour in correspondence of the jointing points to the fuselage.

During the landing manoeuvres, the role of the shock absorber is to gradually reduce the vertical speed of the aircraft by means of the deformation and dissipation performed by its components. In the case of a fully elastic system, the stored energy would be returned too sharply.

Thus, an adequate system will dissipate most of the energy held by the airplane and will stop the elastic energy release which should occur in the shortest time, in order to set the shock absorber ready for any following shock.

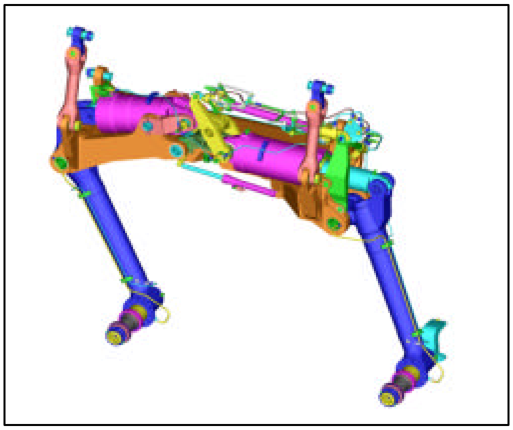

Fig. 3: CAD model of main gear chassis and components.

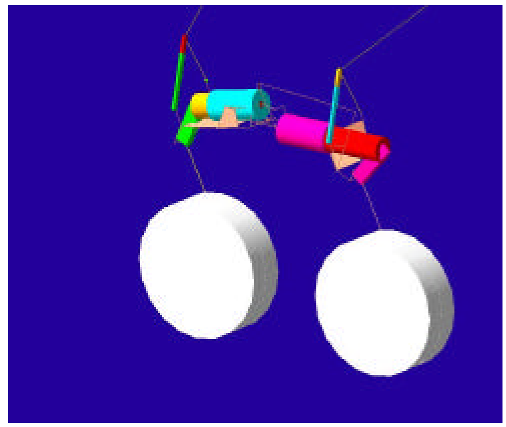

Fig. 4: ADAMS model of main gear chassis and components.

The working shock absorbers on the aircraft are typically of oleo-pneumatic type. They are composed of two chambers:

i) lower chamber, where the idraulic fluid is located, exerting the viscous behaviour;

ii) upper chamber, where the gas is located, exerting the elastic behaviour.

The shock absorber reaction can be expressed by the following equation (Refs [12], [13]):

$$R = R_e + kv^2$$

Where R_e is the elastic reaction and kv^2 is the dissipative term.

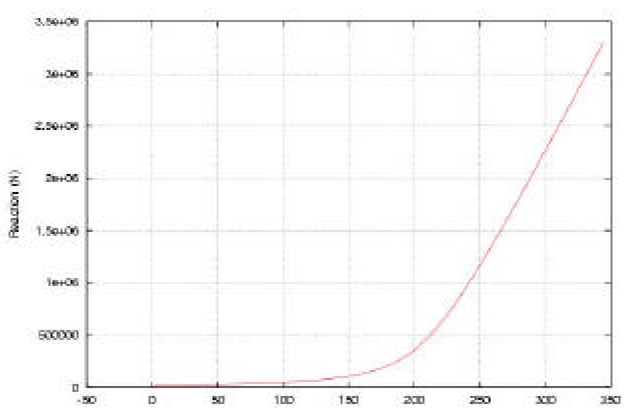

Fig. 5: Experimental politropic curve of gas in the shock absorber used in the simulation.

These laws have been constitutively implemented in ADAMS as a defined force exerting between two rigid bodies (Ref. [12]).
The elastic reaction depends on the compression of the used gas. For taxiing manoeuvres, it can be considered an isothermal transformation; for landing manoeuvres the gas follows a politropic curve, which depends on the exchange rate of heat from the gas to the surroundings.
Furthermore, in order to improve the model capability, an experimental state law curve has been also employed using the mentioned ADAMS procedure (see Fig. 5). Specifically, the dissipative coefficient k has dependencies on the idraulic fluid, the idraulic area, the coefficient and area of the orifice, and the direction of the moving stroke. In this model it has been set to two different constant values: one for the forward movement and one for the backward.

- **Aerodynamic force**

The aerodynamic forces acting on the vehicle during the landing manoeuvre have been modelled with a lift force (L) and a drag force (D), applied to the centre of mass of the vehicle. The lift is given by:

$$L = \frac{1}{2} r V^2 S C_L(a)$$

where $C_L(a)$ is the lifting coefficient defined as follows:

$$C_L(a) = 2p(a + a_0)$$

where a is the attack angle of the vehicle and a_0 is the attack angle corresponding to zero lift.

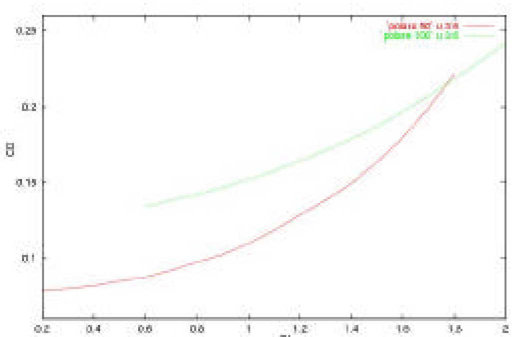

Fig. 6: polar curves relative to full and partial extension of flaps

The drag force is given by:

$$D = \frac{1}{2} r V^2 S C_D(a)$$

and $C_D(a)$ is evaluated starting from the polar curves. These curves differ if the total (Fig. 6, green line) or partial (Fig. 6, red line) extension of flaps are considered:

$$C_D(a) = C_{D_0} + k C_L^2(a)$$

where C_{D_0} is the drag coefficient corresponding to zero lift and k is the parameter controlling the flap extension.

- **Tires**

The tire model used for these simulations is a user defined one. It is possible to evaluate the forces and torques exchanged between the tires and ground (Ref. [19]). The information inserted in the tire properties file are the geometric and elastic properties necessary to initialise the forces and torques evaluation. These are the undeformed internal and external radius of the wheel, vertical and longitudinal stiffness, lateral stiffness due to the slip angle, friction coefficient for zero and unit slip.

Consideration on the elastic interaction

During landing manoeuvre, the impact of the vehicle with the ground results in an intense force applied for a short period of time compared with the natural periods of the structure. This force, known as *shock*, could excite some of the undesired frequencies of the structure and cause local damage.
Considering the global linearized dynamics given by the multibody chain composed by the rigid and elastic members that model the landing vehicle, one can lead to the identification of such critical frequencies by means of the identification of the so called *shock spectrum* (Ref. [15]).
An example of *shock spectrum* identification is reported in Fig. 7 showing two pick values in the lower range of frequency and a decreasing behaviour for the upper values. This dimensionless curve has been obtained using a direct simulation performed by ADAMS V11. It has been achieved by imposing an impulsive reaction force at tires/ground contact points as given by a previous analysis. The acceleration of the centre of mass has been chosen as the output of the system.

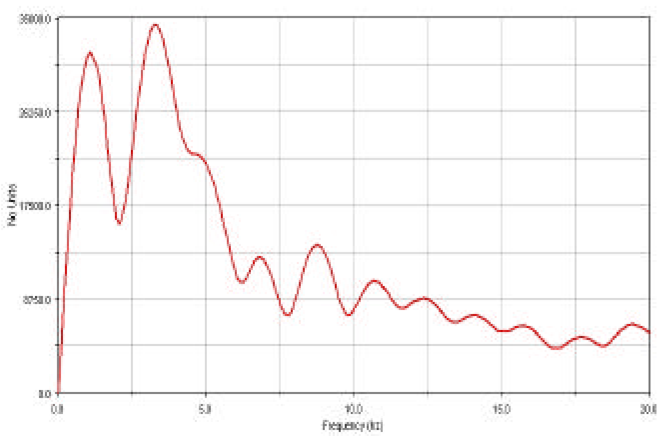

Fig. 7: Shock spectrum for the ground reaction as input to the system.

Taking the Fourier transform of such an output one can have an idea of the first natural frequencies of the global system (tires plus landing gear system plus fuselage and plus wing) which has been considered as linearized in the vicinity of impact configuration. This analysis, compared with the shock spectrum information obtained by the special nature of the input, can lead to useful indication in order to evaluate the maximum stress condition reached by the global structure during its operative conditions. Specifically, as a relevant result, the flexible model of the aircraft presents a stiffness matrix which is slightly different from its rigid representation. Indeed, the response calculation using a flexible model of the aircraft, which has a different stiffness, may lead to relevant differences compared to the rigid model.

Multibody simulation of landing and taxiing manoeuvres

In accordance to the conditions imposed by the JAR requests (Ref. [18]), simulations of landing and taxiing have been computed. The results of these analyses confirm the advantage of using a total flexible model. By evaluating the results that have been obtained, one can conclude that the strain energy absorbed by the flexible aircraft reduces the maximum value of ground reactions and loads at the fuselage-gears jointing points.

- **Spin up and spring back conditions for the main landing gear**

Another important result achieved by this study has been the determination of the spin up and spring back conditions, which are critical conditions for the general design and assessment of the aft and forward fuselage respectively.

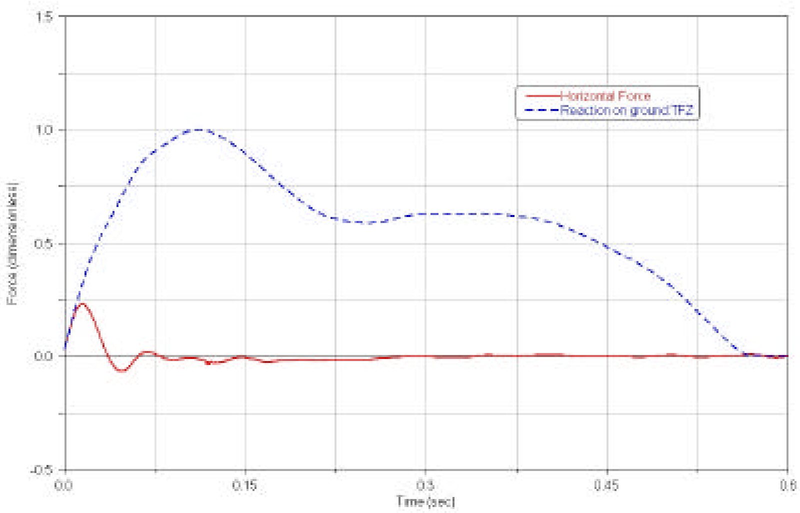

Fig. 8: Spin up and spring back conditions compared with ground reaction

In landing manoeuvres, when the aircraft touches the ground, the wheel axle has a horizontal speed equal to that of the aircraft's, while the pneumatic, in its contact point, has zero speed. This is the cause of a sudden deceleration on the wheel. Its maximum value, multiplied by the *unsprung* mass (the mass that reacts with the air spring of the shock absorber, i.e., the wheel, break system on it, and the pneumatic) represents the spin up condition.

The elastic representation of the main gear chassis, allows the identification of the forward acceleration of the wheel, due to the return of energy stored on the chassis undergoing elastic deformation. In the same way as that of the spin up condition, the multiplication of its maximum value with the unsprung mass leads to the spring back condition.

In Figure 8 the reactions representing spin up and spring back are reported by the solid line. As physically expected, both values occur largely before the reaction on ground (dashed line) reaches its maximum value. The frequency of this dumped oscillation should represent the natural frequency including the all system of the main landing gear plus the chassis.

- **Tire reaction on ground**

Another significant estimate performed by ADAMS multibody/elastic simulation is given by the maximum value of the reaction on ground. In Figure 9 the rigid model (dashed line) and flexible model (solid line) are compared. This shows that the flexible model experiences a lower pick value but the reaction lasts for a longer period, representing the greater energy absorbed during landing.

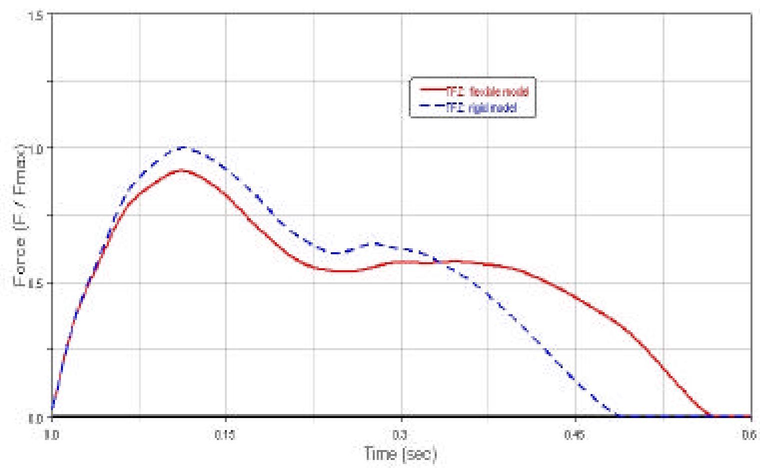

Fig. 9: Comparison between rigid model (dashed line) and elastic model (solid line).

- **Loads at jointing points**

As mentioned before, since the main chassis is a hyperstatic structure, which is only linked to the fuselage in four points, the load distribution results as being extremely difficult to guess. In Figures 10 and 11 rigid (dashed line) and elastic (solid line) models are compared in terms of reactions at jointing points. A similar result to the reaction on ground is obtained here. The rigid model presents higher pick values and undergoes a more oscillating behaviour.

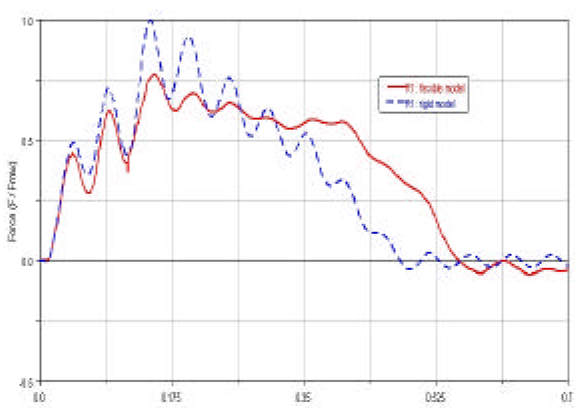

Fig. 10: vertical load at forward joint

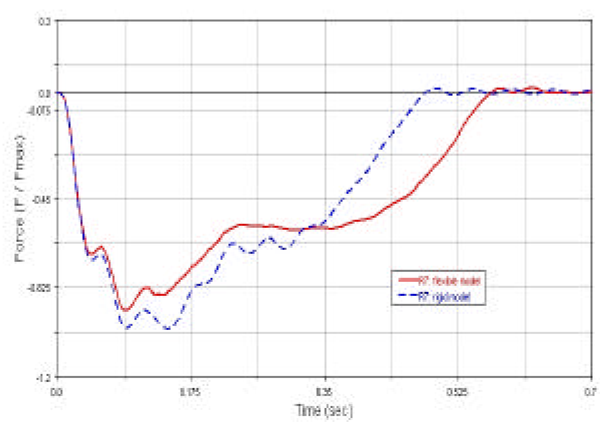

Fig. 11: vertical load at aft joint

- **Taxiing results**

Taxiing simulations have been computed using a landing field model which has been realised from experimental data. Reactions at jointing points have been taken into account in order to represent the difference between rigid and flexible model. In Figures 12 and 13 one can see that these results are extremely similar.
Another way of evaluating the mechanical behaviour of the aircraft could be obtained analysing the solution of the linearized system around the equilibrium position.

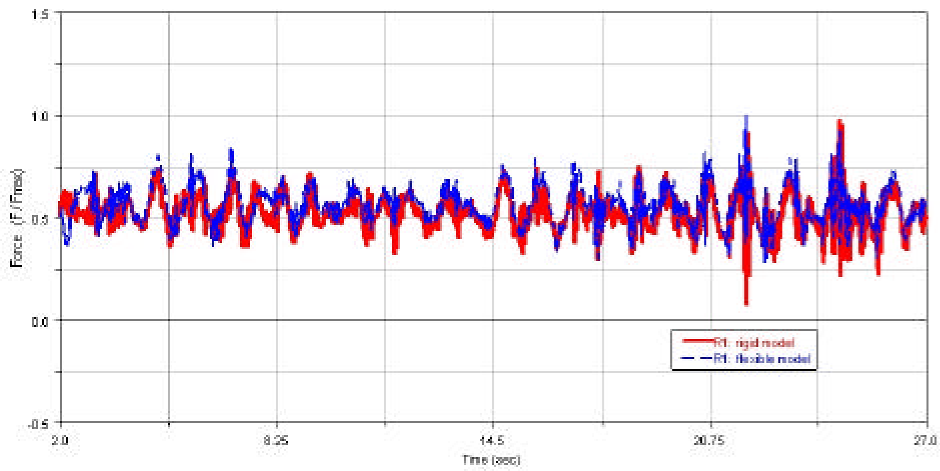

Fig. 12: vertical load at forward joint

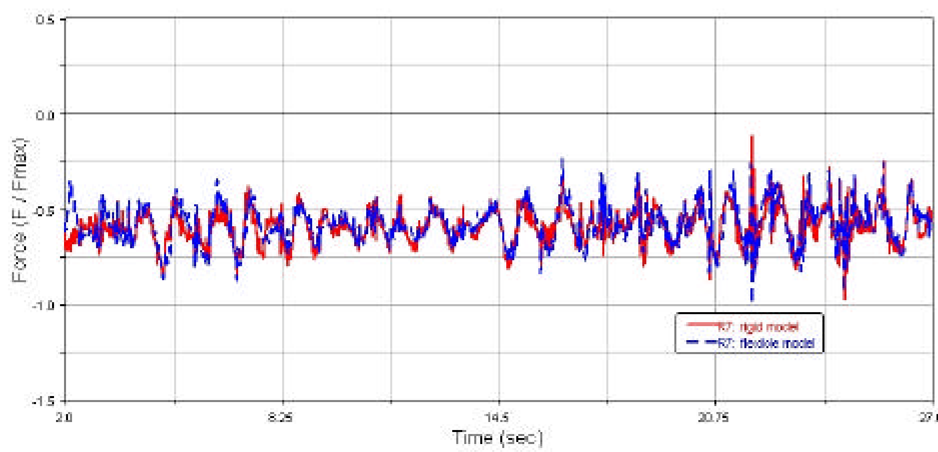

Fig. 13: vertical load at aft joint

Concluding remarks

A multi-body representation has been performed using the standard *ADAMS* package (V11) including the elastic description of some elements whose elastic deformation has a crucial role in landing and taxiing manoeuvres of an aircraft.

The structure of *ADAMS* computational environment has allowed a very positive interaction with other possible pre- and post- processor packages and this issue has heightened the possibility of implementing a very automatic and user-friendly procedure for loads evaluation during these manoeuvres.

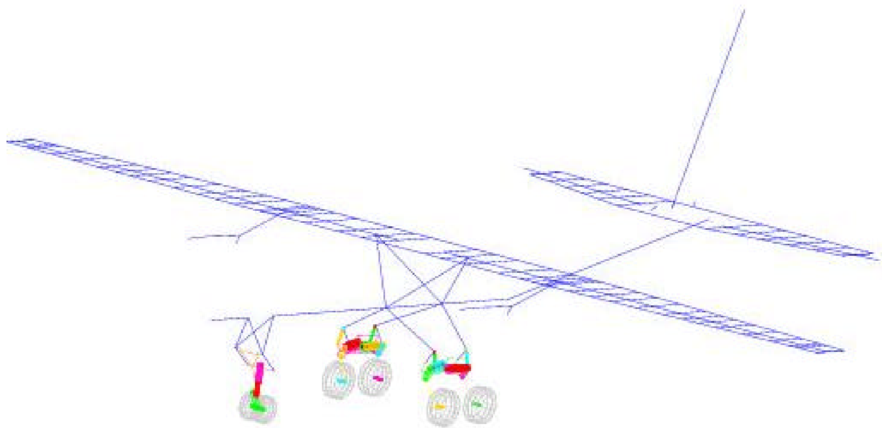

Fig. 14: View of the full multibody elastic model

The comparisons between rigid and elastic analyses have shown the relevance of the elastic description when emphasizing some special critical phenomena as the so-called *spin-up* and *spring-back*. Furthermore, comparisons with experimental modal test data on the full scale model have confirmed an adequate level of assessment of the multi-body elastic description.

The developed *ADAMS* computational environment will allow further enhancements of the present modelling. In other words, a development of this model would result in a more accurate representation of the aerodynamic force by way of a modal force distributed over the lifting surfaces, the effect of flexibility on the mechanics of flight at different operative conditions, and the possibility of more accurate descriptions of the internal loads using *ADAMS* enhanced versions.

Acknowledgements

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