

Dynamic study of the virtual prototype of the IAR-99 SOIM Aircraft

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Abstract: *This paper contains a dynamic study of the IAR-99 SOIM aircraft using ADAMS, multibody dynamic solutions. First, the analysis of the whole airplane is envisaged and then the analysis of the flight control system and the landing gear are considered. The study is performed in the idea of upgrading the IAR-99 aircraft being a continuation of a previous study concerning a flutter analysis [9] of the same aircraft, and will be followed by a paper dedicated to modern tools in the stress analysis of the aeronautical structures. Using ADAMS one can build and test complex virtual prototypes, simulating mechanical systems in a realistic manner, both visually and mathematically which is very useful before developing a real prototype. Engineers can study the dynamics of moving parts and how loads and forces are distributed throughout a complex mechanical system as an airplane. In this way multiple design solutions can be analyzed and evaluated in order to shorten the time and to reduce the cost of a new project.*

Key Words: *virtual prototype, numeric simulation, landing gear, flight control system.*

1. INTRODUCTION

Creating and analyzing virtual prototypes is a discipline based on the extraordinary development of the computing abilities. A specialized tool for creating and analyzing complex mechanical systems (as for example an airplane) is ADAMS, multibody dynamic solutions, which can be used to model, simulate, visualize 3D mechanical systems in real functioning conditions facilitating to define and optimize different projects using iterative design technique. Many CAD specialized softs are compatible with ADAMS, so the analysis performed in ADAMS can be transferred in other programs (ANSYS, NASTRAN, etc.). Building a virtual prototype should consider some aspects described in the following lines.

The solution of the virtual prototype has to be *integrated*, which means that working team must use a familiar CAD system for all the team members in order to have a simple transfer between the different design groups (mainly to the FEA groups). The solution has to be *adaptable*, in order to be able to use standard simple models in order to let less trained members of the research team to test different cases in order to optimize the considered structure. Also the solution has to be *parametric*, to permit quick changes in the whole model, to offer a good visualization of the project so that the analyzing team to be able to decide how to surpass the “sensible” points of the project. These features are decisive for those who analyze the virtual prototype and, in the same time for those who will build the

physical prototype as well. In this paper we perform a dynamic study of the IAR-99 using ADAMS for the whole aircraft, for the flight control system and for the landing gear.

2. DYNAMIC RESPONSE OF THE VIRTUAL PROTOTYPE OF THE IAR-99 SOIM AIRCRAFT

2.1 General formulation

Usually, a dynamic analysis requires the following steps:

1. Prepare the model. The analyst should:
 - a. discretize the structure by choosing the points in which we want to obtain the dynamic response,
 - b. Prescribe how the structure is loaded,
 - c. Prescribe how the structure is supported.
2. Perform the calculations.
 - a. generate the stiffness matrix k and the mass matrix m of the different parts of the considered assemble,
 - b. connect the elements together, that is assemble the element k and m matrices to obtain the global matrices K and M , and in some cases the damping matrix C ,
 - c. Assemble loads in a global vector $R(t)$,
 - d. Impose support conditions, and
 - e. Solve the global equation.

$$M\ddot{U} + C\dot{U} + KU = R(t), \quad (1)$$

where U is displacement components of the nodes.

3. Post process the information contained in U , \dot{U} , \ddot{U} .

Step 1a requires that the analyst/ exercises judgment about what type of elements to use and how coarse or refined the mesh should be in different regions of the structure. In our case we intend to use a simple 2D beam model for the plane (the so called stick model) and simple element to model the landing gear elements which takes into account the lumped mass, the stiffness and the damping characteristics. **Steps 1b** and **1c** are often more straightforward than step 1a but it is easy to do them improperly. The work in step 1 is greatly assisted by the preprocessor portion of the software.

Step 2 is carried out by the software.

Step 3 is also automatic although the analyst must instruct the program regarding the results to be presented and the format of the presentation.

A structure moves as the load is applied. If the load is cyclic, but with a frequency less than one-third of the structure's lowest natural frequency of vibration, the problem can probably be classed as static and analyzed by specific static methods. If the load has a higher frequency, or varies randomly, or is applied suddenly (as it is the case in landing) then a dynamic analysis is required. One may be interested in the large accelerations in some part of the structure, the largest stresses. The dynamic analysis requires a stiffness matrix, a mass matrix and a damping matrix. Time histories of velocities accelerations and displacements in different points of the structure are valuable information both theoretical (examples for stability studies [10, 11, 12]) and practical purposes for sizing the involved structure elements. Considering a discretization of the time interval $[0, T]$ the basic equations are described below.

$$KU_n + C\dot{U}_n + M\ddot{U}_n = R_n \quad (2)$$

where R_n is the known time dependent forcing function at the n -th instant.

We seek $U_n, \dot{U}_n, \ddot{U}_n$ at particular instants of time. Thus $n = 0, 1, 2, \dots$ corresponds to times $t = 0, t = \Delta t, \dots$ where Δt is a time increment. After calculating response at instant n time is advanced by Δt and response is calculated at instant $n+1$.

Subsequently a plot of displacement, velocity, or of acceleration at any of the d. o. f. can be constructed by connecting computed points. Direct integration methods produce an equation of the form:

$$AU_{n+1} = F(t), \text{ or } U_{n+1} = A^{-1}F(t), \quad (3)$$

where A is a nonsingular matrix, independent of time in linear problems, while F depends on quantities at instant n and perhaps at instant $n-1$. The specific forms of A and F depend on the algorithm chosen. Here we present two: central difference and Newmark.

Central Difference Method

The basis of the method is a set of finite difference formulas for the first and the second time derivative, centered at instant n . For a single degree of freedom, u we have:

$$\dot{u} = (u_{n+1} - u_{n-1}) \cdot \frac{1}{2\Delta t}, \quad \ddot{u} = \frac{\Delta u}{\Delta t},$$

For a vector U these formulas are

$$\dot{U}_n = \frac{1}{2\Delta t} (U_{n+1} - U_{n-1}) \quad \ddot{U}_n = \frac{1}{(\Delta t)^2} (U_{n+1} - 2U_n + U_{n-1}) \quad (4)$$

From equations (2), (3) and (4) we obtain:

$$A = \frac{2}{2\Delta t} C + \frac{1}{(\Delta t)^2} M \quad (5a)$$

$$F(t) = R - \left(K - \frac{2}{(\Delta t)^2} M \right) U_n - \left(\frac{1}{(\Delta t)^2} M - \frac{1}{2\Delta t} C \right) U_{n-1} \quad (5b)$$

Thus for any n U_{n+1} is calculated from known values of U_n, U_{n-1} . Velocities and accelerations, if desired, are available from equations (4). Initial displacements U_0, \dot{U}_0 are known. It may be determined from a Taylor series expansion about instant n , which for $n=0$ and a backward Δt yields $U_{-1} = U_0 - \Delta t \dot{U}_0 + (\Delta t)^2 \ddot{U}_0 / 2$, in which U_0 is determined from (2) at instant $n=0$.

The central difference method is conditionally stable: if (Δt) is too large, computed displacements become wildly inaccurate and grow without limit. To guarantee numerical stability we must use

$$\Delta t < \Delta t_{cr} \quad \Delta t_{cr} = \frac{2}{\omega_{\max}} = \frac{T_{\min}}{\pi} \quad (6)$$

where ω_{\max} is the largest undamped natural frequency of the system.

Newmark Method

The basis of the method is the following set of equations:

$$U_{n+1} = U_n + \Delta t \dot{U}_n + \frac{(\Delta t)^2}{2} [(1 - 2\beta)\ddot{U}_n + 2\beta\dot{U}_{n+1}] \quad (7a)$$

$$\dot{U}_{n+1} = \dot{U}_n + \Delta t [(1 - \gamma)\ddot{U}_n + \gamma\ddot{U}_{n+1}] \quad (7b)$$

where β , γ are numbers that can be chosen by the analyst. Substitution of (7) in (2) yields:

$$A = K + \frac{\gamma}{\beta\Delta t} C + \frac{1}{\beta(\Delta t)^2} M \quad (8a)$$

$$F(t) = f(\beta, \gamma, \Delta t, R, C, M, U_n, \dot{U}_n, \ddot{U}_n) \quad (8b)$$

\ddot{U}_0 is calculated from (2) at instant $n=0$.

Certain choices of β, γ make the Newmark method unconditionally stable. A popular choice is $\beta = \gamma = 1/2$. This choice is called the “constant average acceleration method”.

The central difference method is best suited to wave propagation problems, while the Newmark method are best suited to structural dynamic problems, as the problem of the dynamic response during landing. In every case a Runge-Kutta integration also can be used.

2.2 Dynamic response of the IAR 99 aircraft

Using Pro/ENGINEER we build the parameterized models of the IAR-99 aircraft (figure 1) having the designs for manufacturing as input data, obtaining in this way inertial and geometric data necessary for building an ADAMS model figure 2, a) a shade model and b) a wireframe model.

This model was used to simulate the dynamic behavior of the plane.

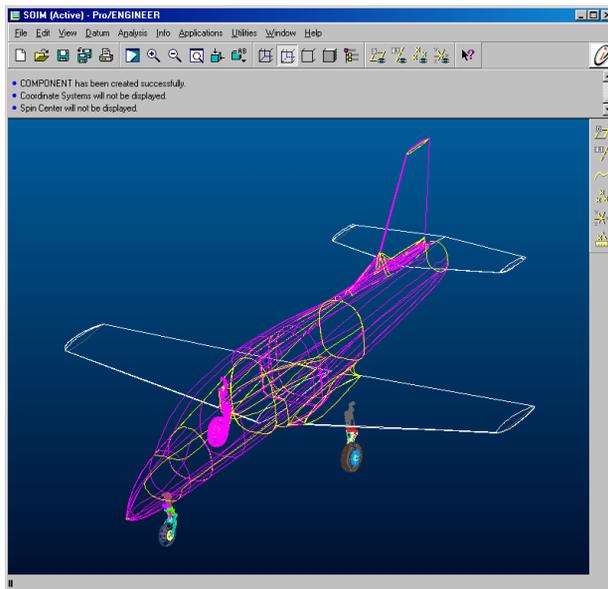


Figure 1. Pro/ENGINEER model of the IAR-99 aircraft

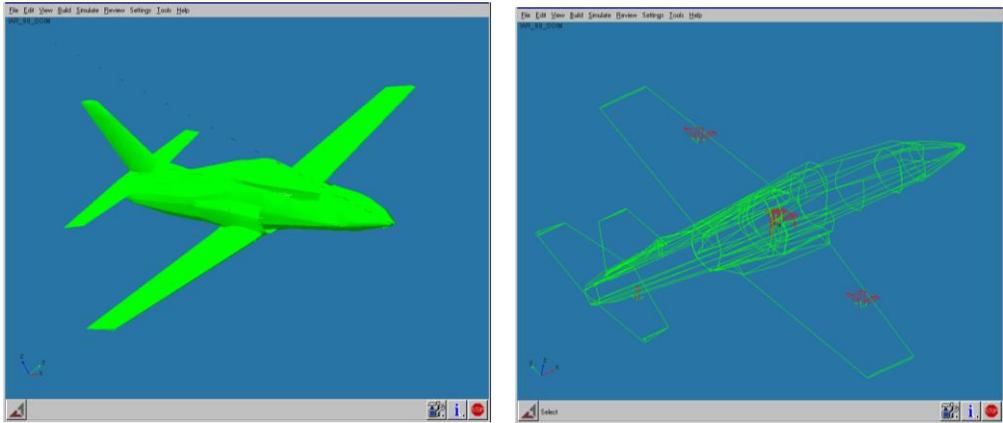


Figure 2. ADAMS model a) shade model, b) wireframe model

On this model, in key points, one introduces loads on wings, tail and on the fuselage. A time interval of 30 sec was considered for the simulations.

The results are presented in figures 3 and 4 – aerodynamic loads on the left wing and on the tail. We also obtained some animations.

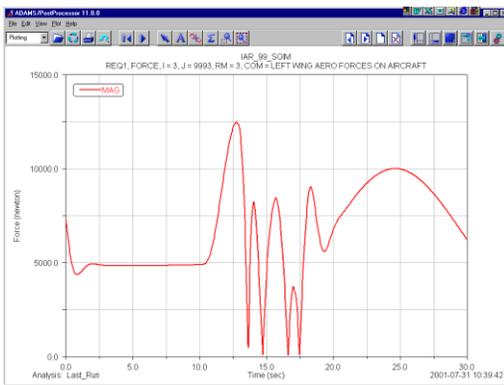


Figure 3. Aerodynamic load on the left wing

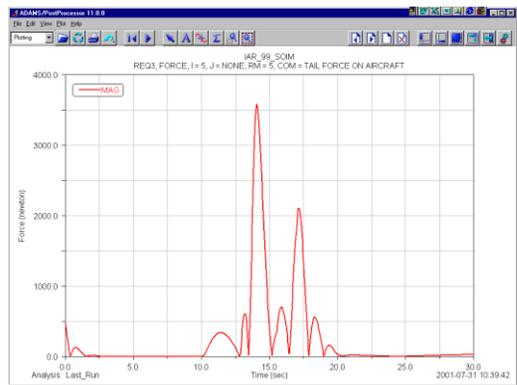


Figure 4. Aerodynamic load on the tail

2.3 Analysis of the flight control system

Using geometrical and inertial data of the flight control system as input data, an ADAMS model was built up (figures 5 and 6) considering also the joints on the fuselage.



Figure 5. Geometric model of the flight control system

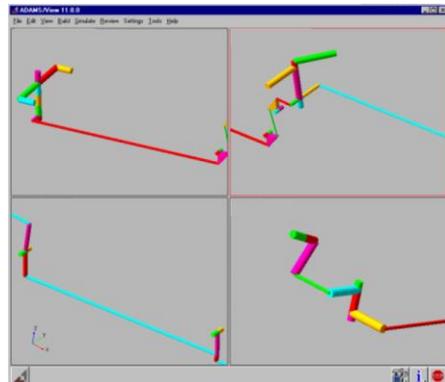


Figure 6. Geometric model of the flight control system (details).

Using assemble designs one defines the way that the movement is transmitted in the kinematic chain (figure 7). As an external load a rotatory movement was prescribed. Some results are illustrated in figures 8, 9, presenting time histories of forces and moments in different points.

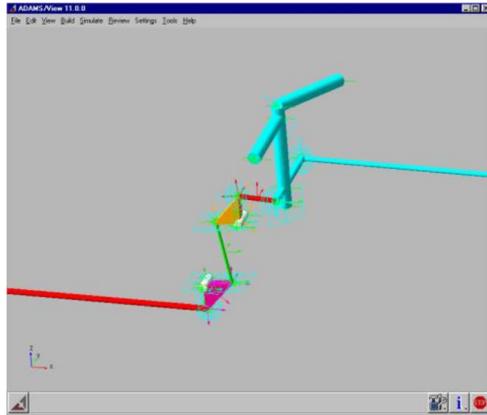


Figure 7. Key points in the kinematic chain

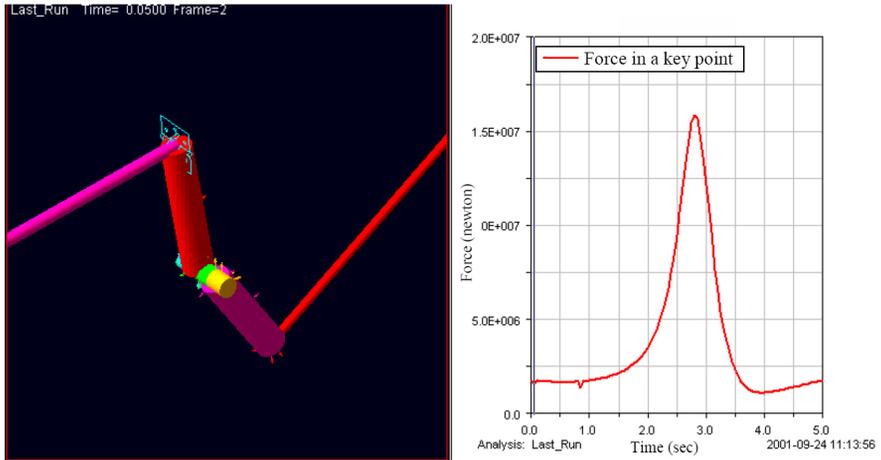


Figure 8. Force in a key point

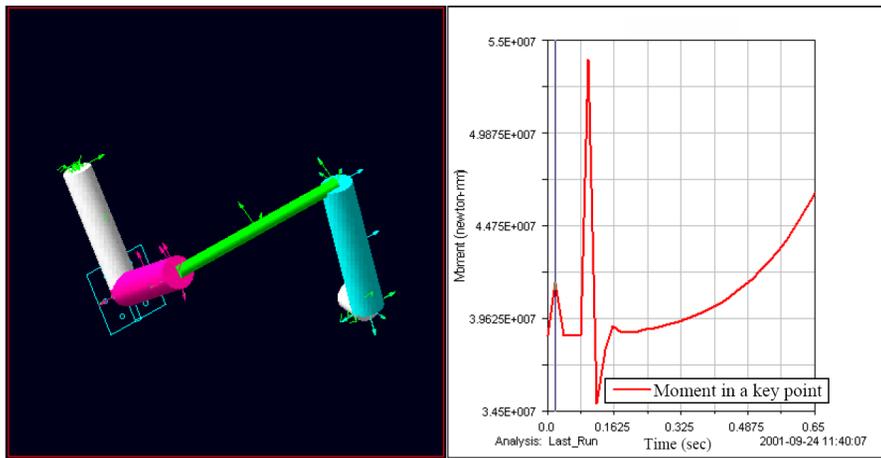


Figure 9. Moment in a key point

2.4. Dynamic response of the landing gear

As before, from the manufacturing designs of the landing gear we build Pro/Engineer models and these models were transferred in ADAMS (figures 10, 11) and some key points where loads were defined (fig. 12, 13).

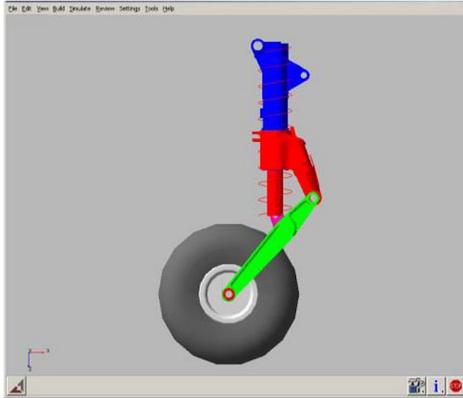


Figure10. Nose gear (ADAMS model)

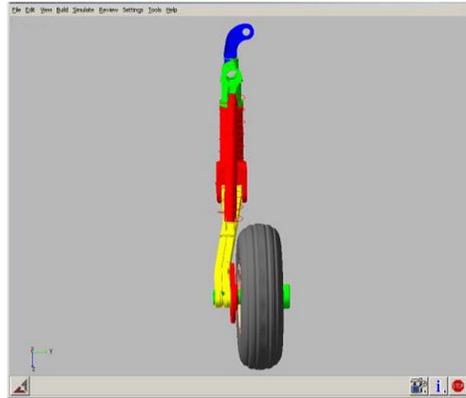


Figure 11. Main gear (ADAMS model)

Two cases were considered for each gear: taking off and landing. Using ADAMS we obtained simulations of these cases (figure 14 and 15 represents retracted gears) and graphic representations of time histories of some of the involved forces (fig16, 17).

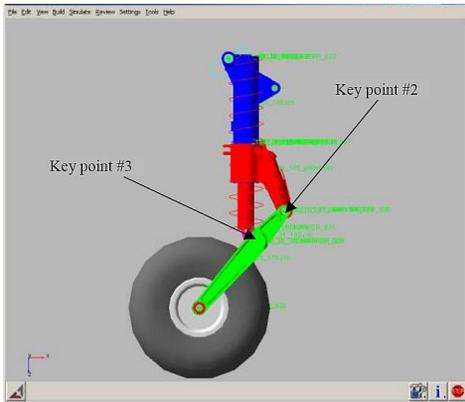


Figure 12. Nose gear

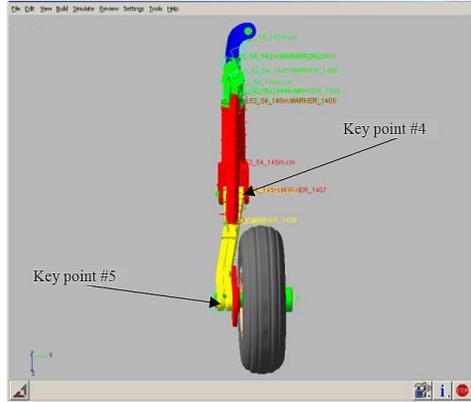


Figure 13. Main gear

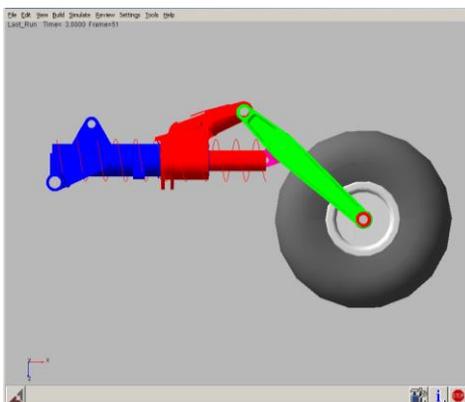


Figure 14. Retracted nose gear

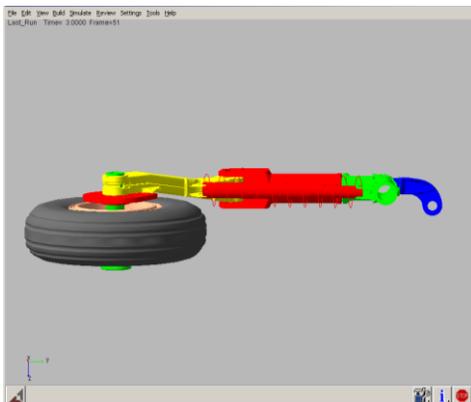


Figure 15. Retracted main gear

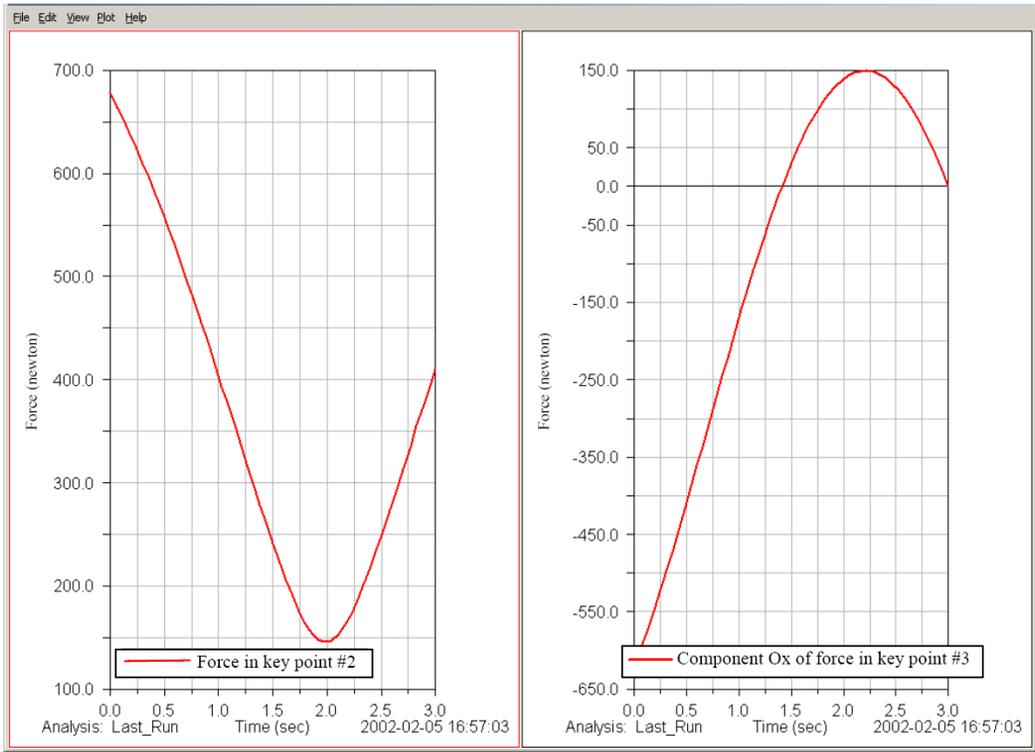


Figure 16. Forces- nose gear

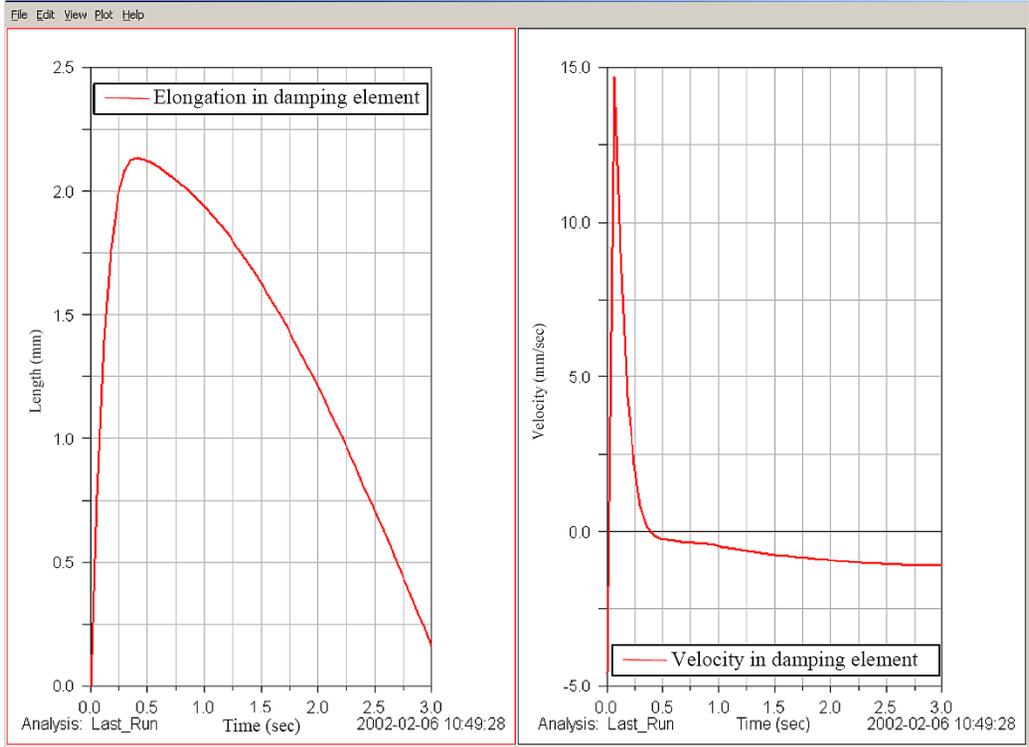


Figure 17. Damping characteristics – main gear

3. CONCLUSIONS

This study illustrates how modern design tools (as ADAMS) can contribute to improve an existing aeronautical project by simulating the dynamic response in different situations. Using real data the virtual prototypes are well calibrated and can offer valuable information to design physical prototypes.

Using the virtual prototypes, a team can analyze faster many design variants, reducing costs, not replacing the physical prototype, but making the whole design process more efficient.

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