# SIMULAND – A CODE TO ANALYZE DYNAMIC EFFECTS DURING LANDING

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*Abstract*

*The landing gear of an aircraft is part of the aircraft structure. It is the most critical part of the flight mission and also the component that will likely cause the most problems in the aircraft design. The landing gear design combines the best in mechanical, structural and hydraulic design. The designed landing gear should be able to meet the specifications and requirements imposed by the CS23. SIMULAND-01 is a program intended to analyze a reduced model (4-30 DoF) of the aircraft under transient dynamic loads during the landing phase (touchdown).*

## Introduction

The landing is a very dangerous stage of the flight - see Figure 1 [13] –therefore needing to be studied with particular care. According to statistics more than 50% of accidents occur when the aircraft is on the ground (including take-off and landing).

The landing gear is responsible for about 8 - 8.5% of the overall aircraft structural weight.

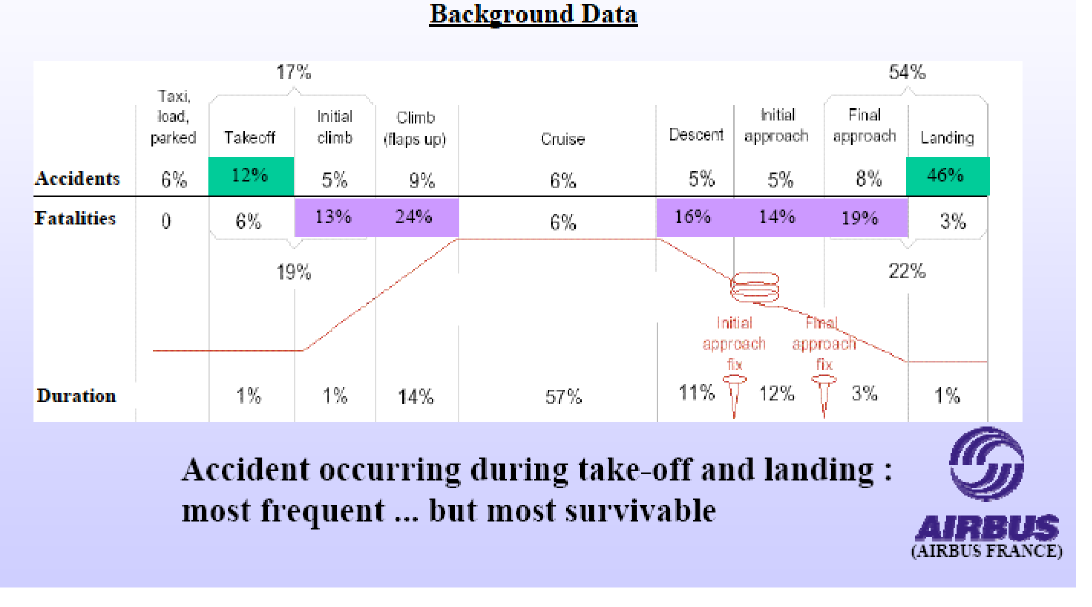



Figure 1. Accident occurring during take-off and landing [16].

During the landing process, an aircraft is exposed to a short- duration impulsive impact. The landing impact has been recognized as a significant factor which is responsible for structural fatigue damage, dynamic stress acting on the aircraft airframe, and also for the crew and passenger discomfort.

The dynamic simulation of the landing gear is used to support the engineering development process at an early stage with new aircraft programs. The simulation is focused on the prediction of loads acting on the landing gear system during the touch down (figure 2), thus allowing checking if the certification requirements stipulated in the JAR/ CS 23.473, 23. 723, 23.499 Regulations can be met. Mathematical prediction of landing gear vertical forces requires that the landing gear behavior at impact be described in equation form with a fair degree of accuracy. Models can be used to predict the loads, position, velocity and accelerations of the landing gear. Simulation provides the required insight to eliminate weak designs before making prototypes. The energy absorption during landing is of first importance. The ability of the landing gear to absorb this energy governs the value of the landing load factor.

An aircraft landing gear is, by nature of its function and subsequent design, a complex multi-degree-of-freedom system.

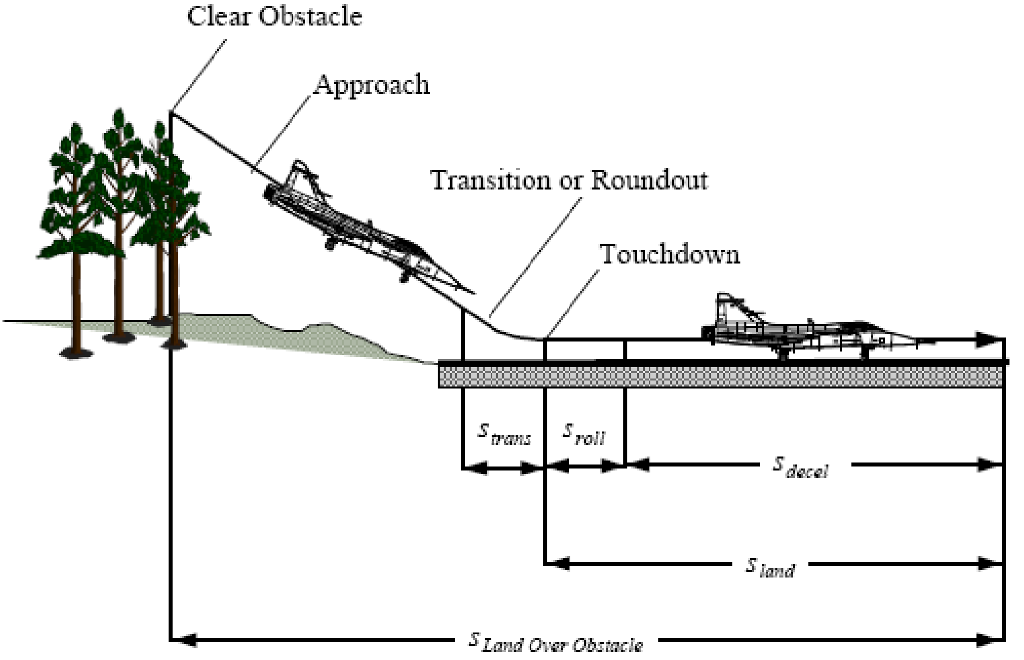



Figure 2. Landing phase

**Dynamic effects during landing**

As a recommendation, if necessary, a model, using extended case up to 30 lumped masses (4-30), can be created. In this paper, a model with 3 lumped masses is considered.

This model is shown in Figure 3.

The equations of motion, with the notations in figure 3, are:

$$\frac{mb}{2A}\ddot{x}_1 + \frac{ma}{2A}\ddot{x}_2 + c'(\dot{x}_1 - \dot{x}_3) + c''(\dot{x}_2 - \dot{x}_4) + k'(x_1 - x_3) + k''(x_2 - x_4) = 0$$
$$m'\ddot{x}_3 - c'(\dot{x}_1 - \dot{x}_3) + c'_0(\dot{x}_3 - \dot{x}_{01}) - k'(x_1 - x_3) + k'_0(x_3 - x_{01}) = 0$$

$$m''\ddot{x}_4 - c''(\dot{x}_2 - \dot{x}_4) + c''_0(\dot{x}_4 - \dot{x}_{02}) - k''(x_2 - x_4) + k_0''(x_4 - x_{02}) = 0 \tag{1}$$

$$-\frac{\rho_\alpha^2 m}{2A}\ddot{x}_1 + \frac{\rho_\alpha^2 m}{2A}\ddot{x}_2 - ac'(\dot{x}_1 - \dot{x}_3) + bc''(\dot{x}_2 - \dot{x}_4) - ak'(x_1 - x_3) + bk'(x_2 - x_4) = 0$$

with the following initial conditions:

$$\begin{aligned} &x_i(0) = 0 \\ &\dot{x}_i(0) = 3\ (m/s - touchdown\ speed) \end{aligned} \qquad i = 1,4$$

In these equations the mass matrix, the stiffness matrix, the damping matrix, and the load vector have the following forms:

$$M = \begin{bmatrix} \frac{mb}{2A} & \frac{ma}{2b} & 0 & 0 \\ 0 & 0 & m' & 0 \\ 0 & 0 & 0 & m'' \\ -\frac{\rho_\alpha^2 m}{2A} & \frac{\rho_\alpha^2 m}{2A} & 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} c' & c'' & 0 & 0 \\ -c' & 0 & c'' & 0 \\ 0 & -c'' & 0 & c'' \\ -ac' & bc'' & 0 & 0 \end{bmatrix} \quad K = \begin{bmatrix} k' & k'' & -k' & -k'' \\ -k' & 0 & -k' & 0 \\ 0 & -k'' & 0 & k'' \\ -ak' & bk'' & ak' & -bk'' \end{bmatrix} \tag{2}$$

$$R(t) = \begin{bmatrix} 0 \\ c'_0\,\dot{x}_{01}(t) - k'_0\,x_{01} \\ c''_0\,\dot{x}_{02}(t) - k''_0\,x_{02}(t) \\ 0 \end{bmatrix} \tag{3}$$

To solve this system we transform (1) in the standard form:

$$\dot{y}_1 = y_2,$$

$$\dot{y}_2 = \frac{\rho_\alpha^2 - ab}{\rho_\alpha^2 + b^2}\dot{y}_4 - \frac{c'}{m(\rho_\alpha^2 + b^2)}(y_2 - y_6) - \frac{k'}{m(\rho_\alpha^2 + b^2)}(y_1 - y_5),$$

$$\dot{y}_3 = y_4,$$

$$\dot{y}_4 = \frac{\rho_\alpha^2 - ab}{\rho_\alpha^2 + b^2}\dot{y}_2 - \frac{c'}{m(\rho_\alpha^2 + b^2)}(y_4 - y_8) - \frac{k''}{m(\rho_\alpha^2 + b^2)}(y_3 - y_7),$$

$$\dot{y}_5 = y_6, \tag{4}$$

$$\dot{y}_6 = \frac{c^{'}}{m^{'}}(y_2 - y_6) - \frac{c_0^{'}}{m^{'}}(y_6 - \dot{x}_{01}) + \frac{k^{'}}{m^{'}}(y_1 - y_5) - \frac{k_0^{'}}{m^{'}}(y_5 - x_{01}),$$

$$\dot{y}_7 = y_8,$$

$$\dot{y}_8 = \frac{c^{''}}{m^{''}}(y_4 - y_8) - \frac{c_0^{''}}{m^{''}}(y_8 - \dot{x}_{02}) + \frac{k^{''}}{m^{''}}(y_3 - y_7) - \frac{k_0^{''}}{m^{''}}(y_7 - x_{02})$$

$$x_{01}(t) = \gamma(1 - e^{-\gamma t}(1 + \gamma t)),\ x_{02}(t) = \gamma(1 - e^{-\gamma t}(1 + \gamma t))$$

with the following initial conditions

$$y_i(0) = 0, (\ i = 1,...,8)$$
$$\dot{y}_i(0) = 3, (i = 1,.....,8)$$

In order to take into account the nonlinear effects two parameters $\varepsilon_1$, $\varepsilon_2$ are introduced to represent the elastic and damping functions:

$$k(x) = kx + k\varepsilon_1 x^3$$
$$c(\dot{x}) = c\dot{x} + c\varepsilon_2 \dot{x}^2$$

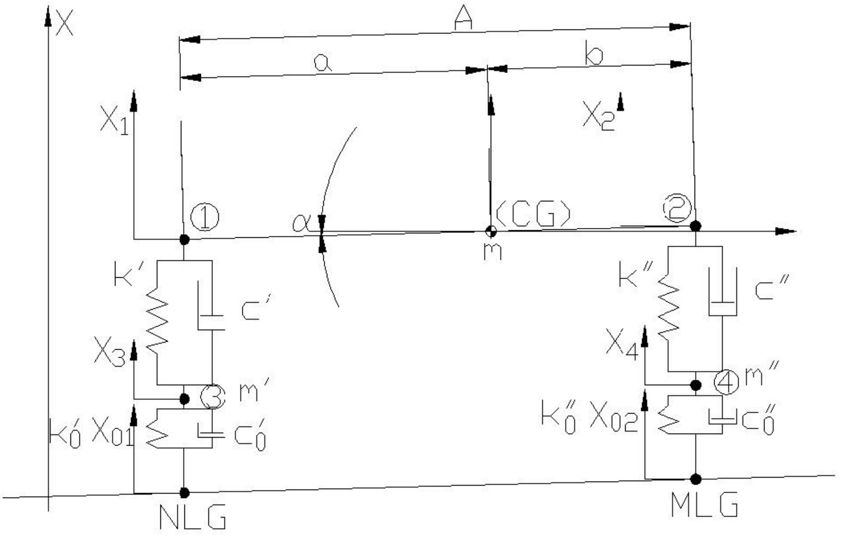



Figure 3. Four degrees of freedom model

We developed a C++ code “SIMULAND” to integrate and analyze the dynamic response of the aircraft during the torch-down stage of the landing phase. Within this program there are two options to integrate the motion equations (4). These options are: the forth order Runge-Kutta method and a predictor-corrector method. Using “SIMULAND” one can get plots of selected displacements, velocities and accelerations in different points of the structure and also exceedance curves.

The limitations of the model refer to the following:

- Lumped masses are located only in vertical plane of symmetry of the a/c;
- A symmetric landing is considered;
- The aerodynamic lift is assumed equal to the weight during the initial impact;
- Applicability on a vehicle with a tricycle landing gear;
- Dry runways (no icy, no flooded runway);
- The wheels don't spin before touchdown;
- It is assumed that landing gear elastic legs remain in upright vertical position and do not change their orientation during landing
- Ground effect is being neglected;
- Airframe deformation at impact starts from undeformed "0 g" state not from the pre-stressed "+1g" state

**Numerical results**

Some numerical results obtained with SIMULAND are shown in the following paragraph.

The input data for the model described in figure are:

| | |
|---|---|
| $\rho_\alpha = 1.6279$ m | radius of inertia (pitch) |
| $a = 3.72$ m | LG geometry (see fig. 6.1) |
| $b = 0.47$ m | LG geometry (see fig. 6.1) |
| $m = 3356$ Kg | a/c weight ( = M LW - m' – m" ) |
| $m' = 43.3$ Kg | NLG weight |
| $m'' = 172.4$ Kg | MLG weight |
| $c' = 1158$ Nm/s$^2$ | NLG viscous constant (oleo strut) |
| $c'' = 1638$ Nm/s$^2$ | MLG viscous constant (oleo strut) |
| $c_0' = 1.$ Nm/s$^2$ | NLG viscous constant (tire) |
| $c_0'' = 1.$ Nm/s$^2$ | NLG viscous constant (tire) |
| $k' = 10000$ N/m | NLG elastic (spring) constant (oleo strut) |
| $k'' = 20000$ N/m | MLG elastic (spring) constant (oleo strut) |
| $k_0' = 30000$ N/m | NLG elastic (spring) constant (tire) |
| $k_0'' = 30000$ N/m | MLG elastic (spring) constant (tire) |
| $\gamma = ).2 - 10.$ | Is a parameter which describes the shock intensity |
| ☞ $m_i$ (i =1,2,3………) | Component masses and their locations - for calculation of moment of inertia (in pitch) |
| $\varepsilon_1$ | elastic function for nonlinear approach (0 for the linear case) |
| $\varepsilon_2$ | elastic function for nonlinear approach (0 for the linear case) |

We have the following window to launch the program.

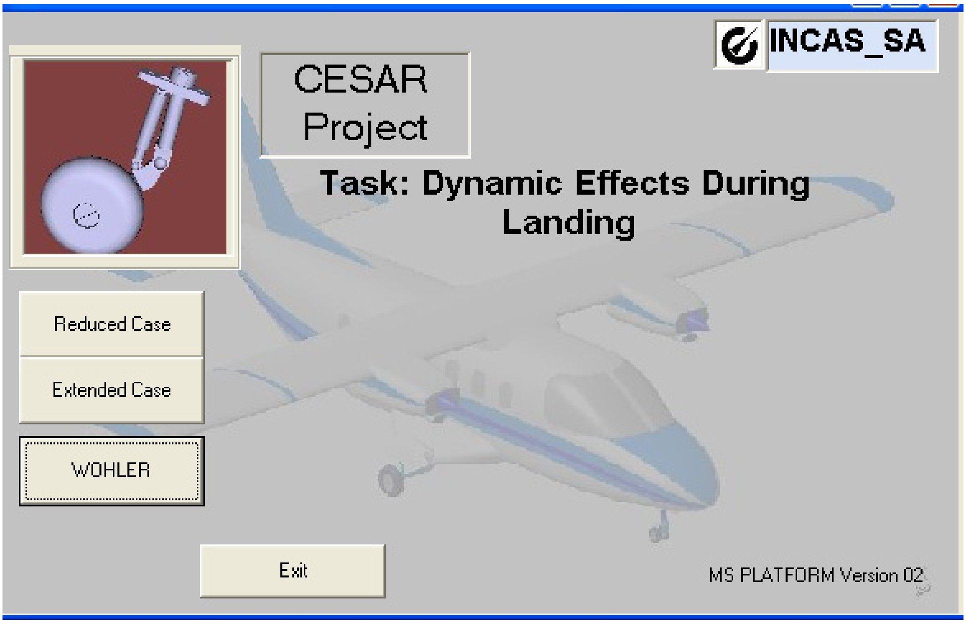



Figure 4. First window

Then, using the button Reduced Case we switch on the second window presented in figure 5. By pushing the button ***“Data Input”*** one can find a preseted set of values; for the input parameters these values can be changed with the appropriate values.

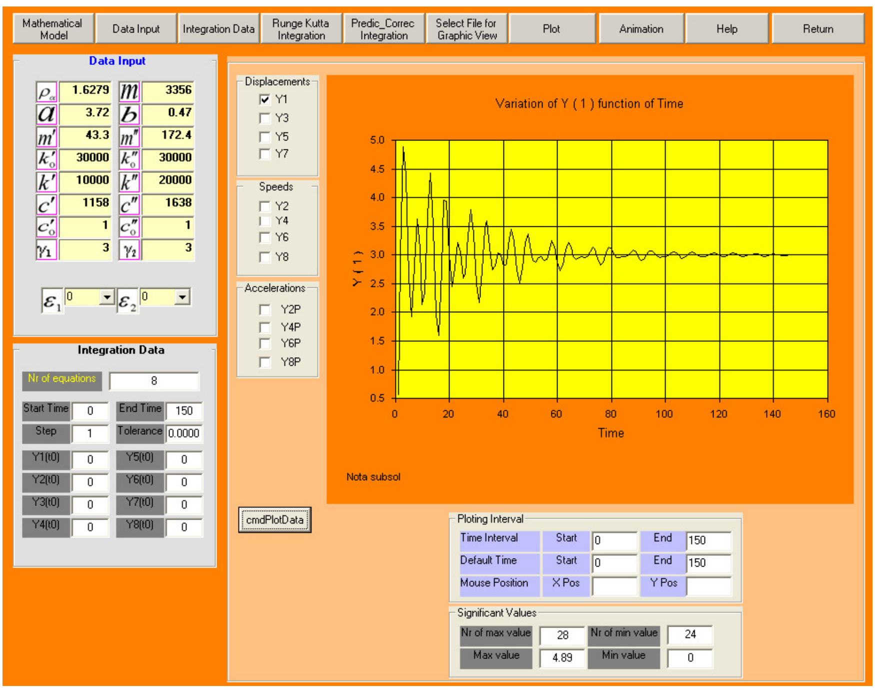



Figure 5. Second window (displacements)

Example of integration data**:**

- Start 0
- End length (steps) [number of system periods]
- Step 1
- Tolerance 0.0000001
- Y1(0)…………Y8(0)
- Y2(0) = Y4(0) = Y6(0) = Y8(0) = 3.0 (m/s)

Example of output data:

- Table with the input data (TEMP_R_Case.txt) ;
- Results file (name.txt ; characters length)
- Displacements of the ondes (Y1,Y3,Y5, Y7) ;
- Speeds of the nodes (Y2,Y4,Y6,Y8) ;
- Accelerations of the nodes(Y2P,Y4P,Y6P, Y8P) (in figure 6 one can see accelerations of mass 1 and in figure 7 acceleration of mass 2);
- Plots of the values (PLOT.exe) ;
- Significant values : No. of max value and Max max value
  No. of min value and Min min value

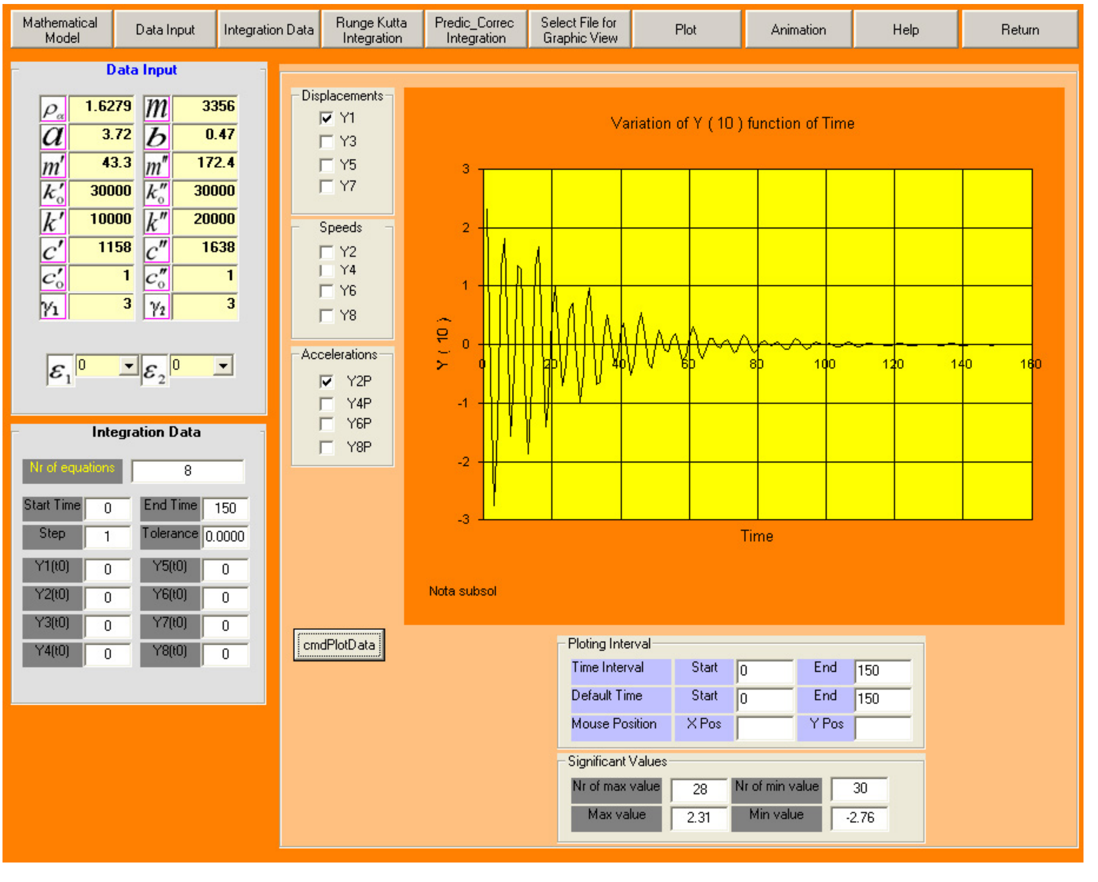
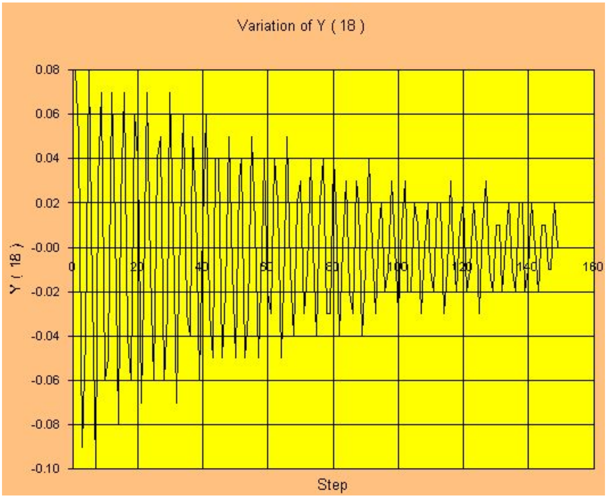
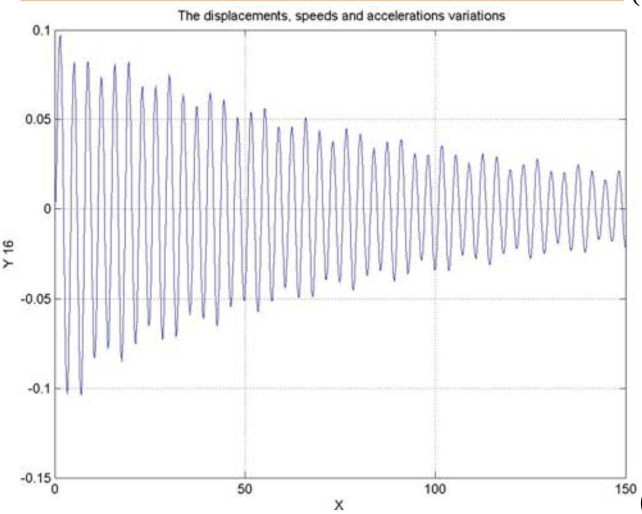



Figure 6. Acceleration of mass 1

Figure 7 displays a comparison of SIMULAND and MATLAB results. One can notice that they are similar. Figure 8 shows an example of an exceedance curve.




(SIMULAND)




(MATLAB)

Figure 7 Comparison between SIMULAND and MATLAB (acceleration of mass 2)

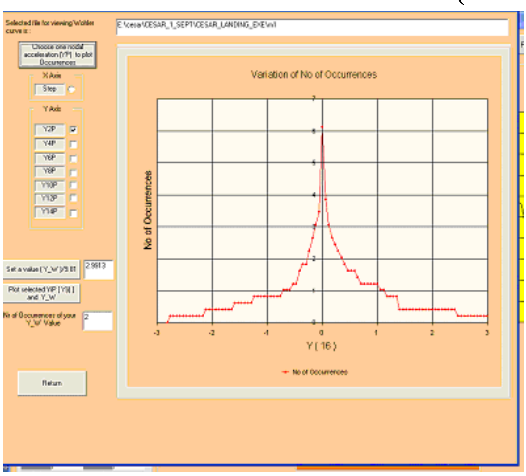



Figure 8 Acceleration exceedance curve for mass 1

## Conclusions

The main benefits of SIMULAND are: the possibility of analyzing in a short time of an unlimited number of load cases and landing gear configurations, a simplified method for obtaining a model able to produce useful information, the accuracy of the analysis which can be defined by the user and the simplified models that are easier to create.

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