Preliminary Estimation Methods for the Definition of the Landing Gear

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Abstract: *The landing gear of an aircraft is an important part of the aircraft structure. The landing and the taking off are most critical parts of a flight mission. The main goal of this paper is to provide a methodology for designing and sizing the landing gear taking into account its main three functions: to ensure the taxiing during the take-off and to ensure both the dynamic contact with the ground during landing and the taxiing required until the aircraft loses speed. This paper continues our concerns about different aspects of the complex landing phenomena. The landing gear is the component that will likely cause many problems in the aircraft design. Its design combines the best in mechanical, structural and hydraulic design. The designed landing gear should be able to meet the specifications and requirements imposed for example by CS23.*

Key Words: *landing gear, rolling equipment, tyres, wheels*

1. INTRODUCTION. NOTATIONS

The aircraft landing gear is the aircraft assembly that fulfils the following functions:

- To ensure the taxiing during the take-off until the plane takes off and gains the necessary speed for sustentation.
- To ensure both the dynamic contact with the ground during landing and the taxiing required until the aircraft loses speed.
- The movement of aircraft at the aerodrome, to and from the airport and hangars.

In all the three cases, the landing gear is the body that takes over the loads acting on the aircraft. Both during the taxiing for the take-off and especially at the first contact with the ground during landing and the corresponding taxiing, the aircraft has variable speed and therefore experiences acceleration. Consequently, the ground reactions cause shocks and the mechanical work needs to be absorbed. The landing gear must be provided with devices that absorb this mechanical work and protect the aircraft structure (fuselage or wing of which the train can be attached) from shocks. To emphasize the role of the landing gear, it is necessary to analyse the components of the landing process. In the following we define the main steps in designing the geometry and the main forces of a landing gear following [11]. The principal directions used for designing a nose wheel landing gear of a mixed civil and military air plane as basically those presented in classical texts as [1, 2, 3, 4, 5, 7, 12].

In the same time we present the main criteria for defining the components of a landing gear (wheels, dampers, etc.).

General main notations for Aircraft geometry:

G_n, M_n - Normal take-off weight, normal take-off mass,
X, Z- Aircraft GC Coordinates,
G - Maximum weight of internal fuel,
G_{at}, M_{at} - Maximum landing weight ($G_{at} = G_n - 0.25G$), maximum landing mass,
S_a - Total surface of the wing,
CMA - Mean aerodynamic chord,
X - Leading edge abscissa of the mean aerodynamic chord (MAC),
L_f - The length of the fuselage,
A_{cr} - The critical angle at landing (usually=0),
Ψ - The relief angle (usually=0),
Φ - The tail angle.

General parameters for landing gear geometry

The landing gear geometry is defined by more several parameters, some established by the aircraft design specification and shown on the standard drawing, some specific to the landing gear and calculated on the basis of the computational rules or based on the technical specialty literature.

The main landing gear geometric parameters that define the general layout of the train are shown in Fig. 1.

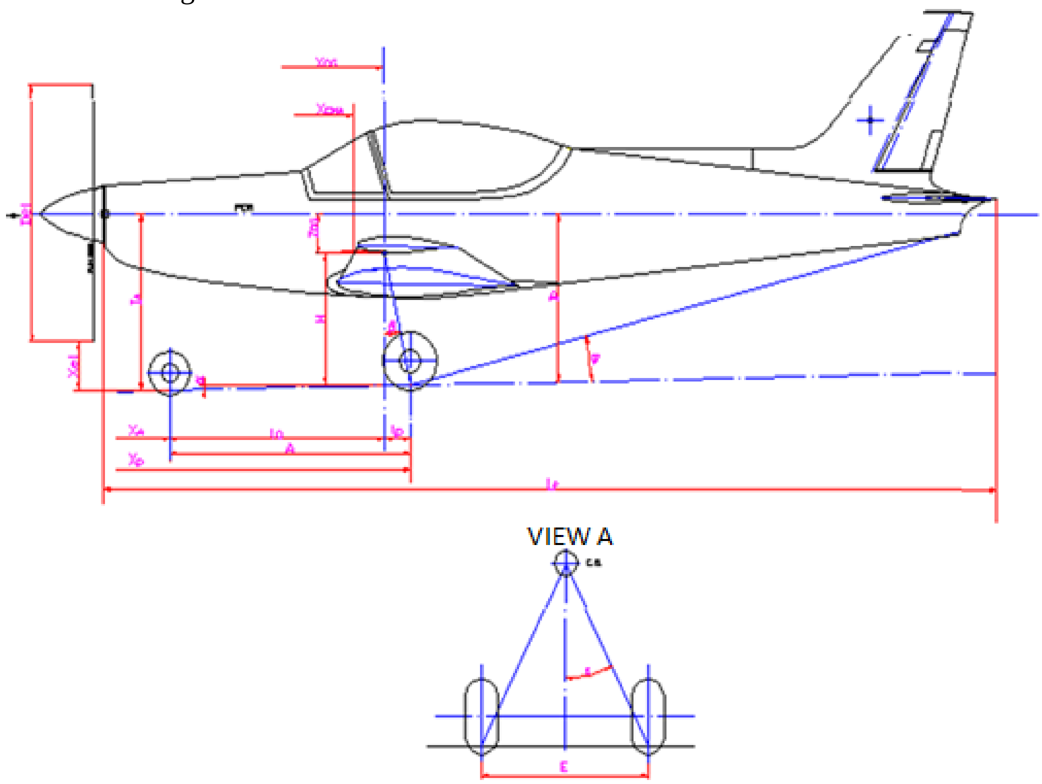

Figure 1. Landing gear geometry

The landing gear geometry parameters shown in Fig. 1 correspond to the aircraft suspended (in straight, horizontal attitude).

The terms indicate the following:

X_{CMA} - Leading edge abscissa of mean aerodynamic chord (MAC),
X_p - Abscissa of the main tire - ground contact point to the plane of reference (RP),
X_A - Abscissa of the front tire - ground contact point to the plane of reference (RP),
E - Wheel track width,
A - Landing gear wheelbase,
l_p - (distance of the main wheels) main wheels offset to the centre of gravity's projection on the ground,
l_a - (lag front wheel distance) front wheel offset to the centre of gravity's projection on the ground,
H - G. C. height from the ground,
β - Longitudinal stability angle,
ε - lateral stability angle,
D - Propeller diameter,
Y - Propeller ground clearance.

2. DETERMINATION OF THE MAIN FEATURES OF THE GEOMETRIC CHARACTERISTICS OF THE LANDING GEAR

Determining the main features of the geometric characteristics of a landing gear is an iterative process conditioned by regulatory provisions, by the values of the reactions in the wheels of the gear, by the stability conditions and by the the propeller ground clearence verification.

The process of determining the main features of the landing gear may be sinthetized in the scheme presented in figure 2.

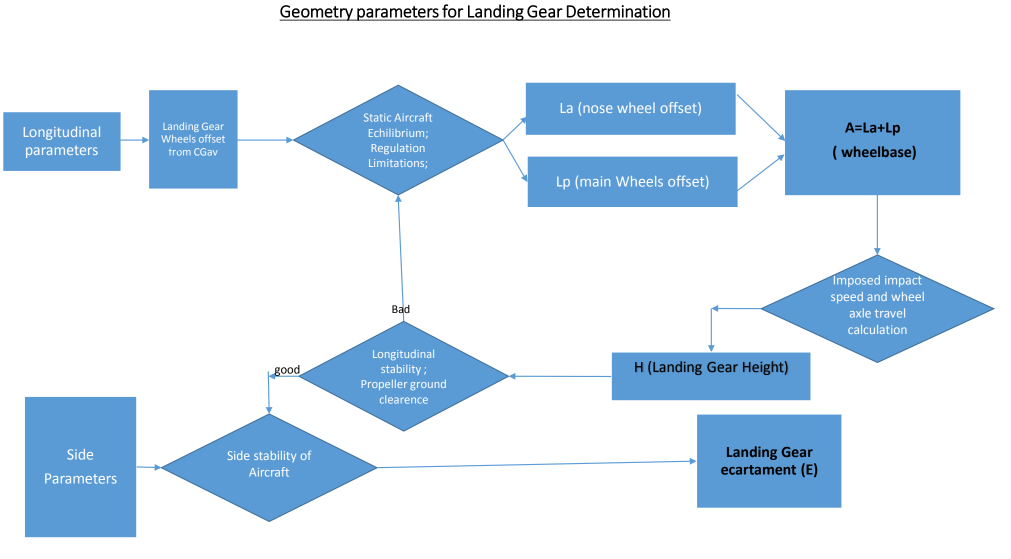

Figure 2. The iterative process of determining the main features of the geometric characteristics of a landing gear

2.1 Determining the initial longitudinal geometrical parameters based on static forces

These initial parameters will be used to define other geometrical parameters of the landing gear.

To define the actual values of the main wheels offset to the centre of gravity's projection on the ground and the landing gear wheelbase one has to take into account the following three relations:

$$l_p \in [0.15CMA, 0.20CMA],$$

$$A \in \left[0.3L_f, \right), 0.4L_f],$$

$$F_A = \frac{l_p}{A} \times G_{max},$$

where: $G_{max} = M_n * g$, g is the gravitational acceleration, F_A is the load on the front wheel, and the last equation is an equilibrium equation. Another important condition is that the front wheel loading must ranging

$$F_A \in [0.08G_{max}, 0.15G_{max}].$$

Usual good values are:

$$F_A = 0.115G_{max}, F_P = 0.885G_{max},$$

where F_p is the load on the main landing gear.

For the final force repartition we use the equation:

$$F_{AS} = F_A + \frac{M_{max} * g}{10} * \frac{a * H}{A}$$

where a=0.3g (as in [10]), and F_{AS} is the final force on the front wheel.

2.2 Determination of the parameters of the selection of the wheels, dampers, and the height of the gear

The next step is the selection of the rolling equipment, wheels and tires.

Taking into account the above calculated efforts and the low tire pressure requirement to ease aircraft ground maneuverability including on improvised runways the GOODYEAR tire catalogue (for example) offers the most suitable aircraft tires. The wheels of the landing gear are selected from specialty catalogues so that they are size compatible with the selected tires.

The process of defining and sizing a land gear continues with the calculation of the landing vertical impact speed needed for vertical travel of wheels axles determination. According to CS23 regulations, the vertical impact speed must range between the following limits:

$$V_Z \in [2.134{,}3][\frac{m}{s}]$$

The calculation formula given by CS23 is:

$$V_Z = 0.9\sqrt[4]{\frac{G_{at}}{S_a}}$$

In accordance with regulations the maximum recommended value is admitted.

V_z= 3 [m/s] – the vertical impact landing speed of the aircraft with a normal landing weight.

Using the maximum value of the recommended impact speed one can determine the total vertical travel of shock dampers. Total vertical travel of wheels axles (figure 3) are computed using the equation that expresses the energy balance in the most critical case which is the landing. The landing gear wheel contact with the landing strip is rough, equivalent to the airplane falling with a vertical speed of V_z = 3 [m/s]. Shock is absorbed by dampers and partially tires because of their elastic characteristic. The energy balance, accounting for the considerations above, is:

$$M_{at} \times \frac{V_Z^2}{2} = M_{at} \times n_r \times g(S_d + \delta_p \times n_p)$$

where FAR 23.1001 recommends:
$n_r \geq 2$ –ground reaction factor considering lift,
$n \geq 2.67$ – inertia factor.

Generally, the specialty literature recommends greater factors for aircraft, so in accordance with reference [9] we admit: n_r = 3. Obviously, that would reduce the computed shock absorbers travels but we must expect somewhat higher dynamic loads.

From the formula above the wheel axles travels can be computed, and considering the landing gear struts are telescopic we have implicitly determined the shock absorber travels:

$$S_d = \frac{V_Z}{2\eta_r \eta_a} - \frac{\eta_p \delta_p}{\eta_a}$$

where V_z = 3 [m/s] – vertical impact speed,
g = 9.81 [m/s^2]- acceleration of gravity,
n_r = 3 – ground reaction factor,
η_a = 0.8- the filling coefficient of the energy absorbtion diagram of the oleopneumatic damper,
η_p = 0.46 -the filling coefficient of the energy absorbtion diagram of the tire,
δ_p = 0.75 $\delta_{p\ total}$ –tire flattening upon impact (from the tire catalogue).

To maintain conformity with CS23 requirements for overloaded landing (at the maximum admissible landing weight) with a vertical speed increased by a factor of 1.2 as in $V_{zc} = 1.2 \times V_z$, the total wheel axle travel increases by at least 10%.

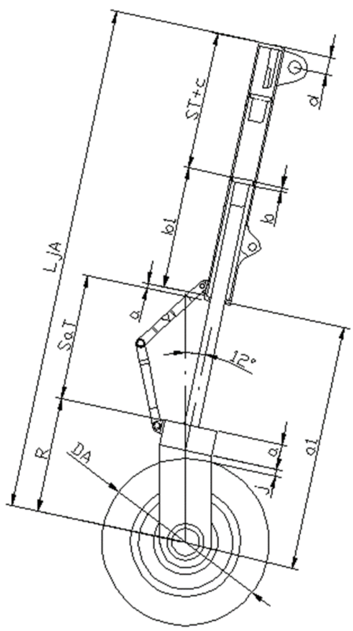

Figure 3. Geometric parameters of front wheel strutand axial travel of the front wheel strut damper

The following step in the process of sizing the landig gear is estimating the extended wheel strut length and reassessing the aircraft to ground clearence.

The main parameters defining wheel strut length are represented in Fig 2 for the front strut and in figure 4 for main gear wheel struts. The base dimensions defining strut length are total travel of shock dampeners and selected tire diameters- which are known. If, based on experience and recommendations in specialty literature, we admit the clearances between the tire and strut fork, the general sizes of guiding and fastening elements, we can have a very precise estimation of the total strut lengths.

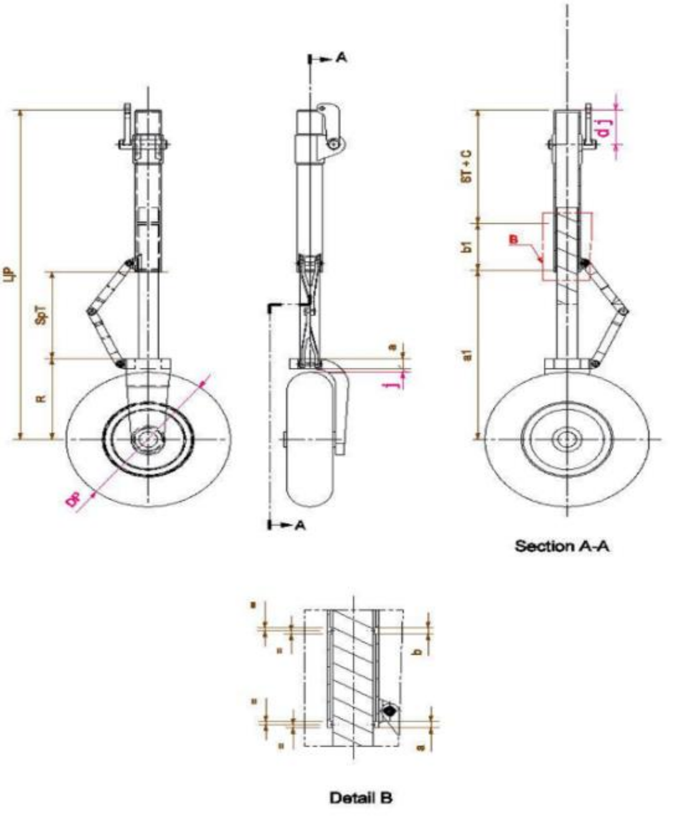

Figure 4. Parameters of main wheel strut

To calculate the length of front wheel strut initial known data are: D_A and S_{aT} (figure 3). Initial calculation data based on experience and specialty literature recommendations are a, b,c, *j (a=b)* and the ratio a_1/b_1.

With the notations in figure 3 we can calculate a_1:

$$a_1 = R + S_{aT} + \frac{a}{2} = \left(\frac{D_a}{2} cos\alpha + j + a\right) + S_{aT} + a/2$$

The total estimated length of the front strut will be:

$$L_{jA} = a_1 + b_1 + \frac{b}{2} + S_{aT} + c$$

Length of main wheel strut (figure 4).

Initial known data: $D_{P,}$ S_{pT}, *a*, *b*, *c*, *j* (*a*=*b*).

Using the notations in figure 4 we can write :

$$a_1 = R + S_{pT} + \frac{a}{2} = \left(\frac{D_p}{2} + j + a\right) + S_{pT} + \frac{a}{2}$$

Total estimated length for the main landing gear wheel strut will be:

$$L_{jP} = a_1 + b_1 + \frac{b}{2} + S_{pT} + c$$

Using data obtained during the flow presented above, one can represent the final updated view of the landing gear geometry (figure 5).

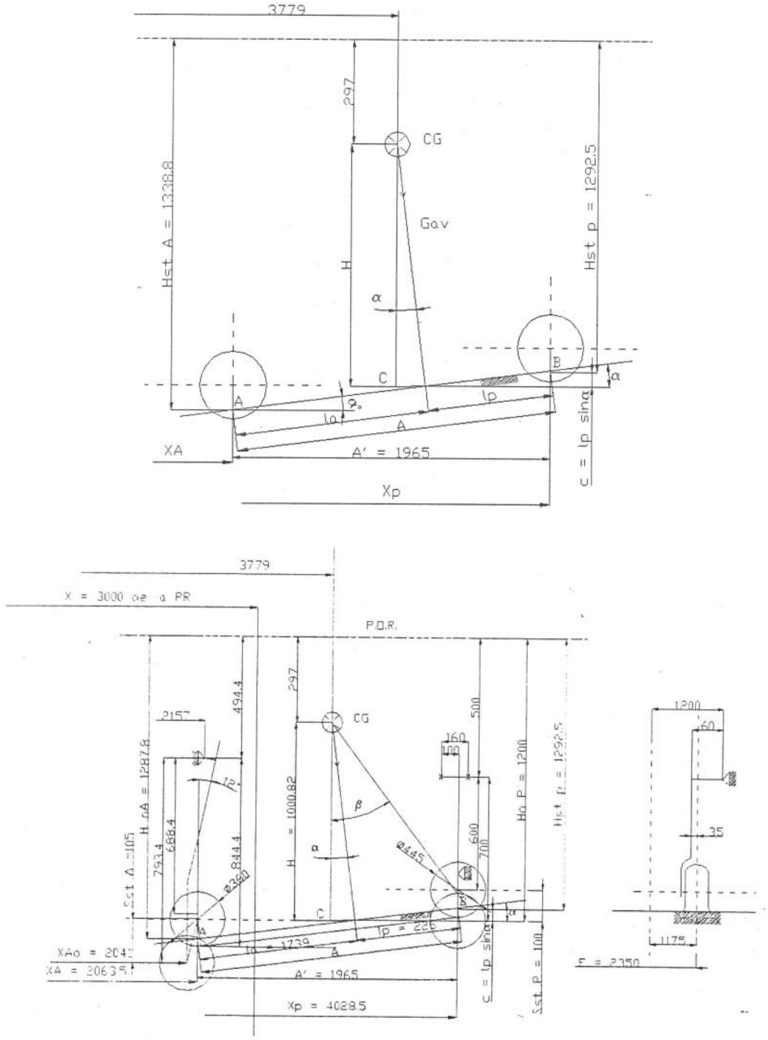

Figure 5. Updated geometry of the landing gear

The new updated parameters are presented below. The ground attitude angle (α):

$$\alpha = atan\left(\frac{H_{stA} - H_{stA}}{A'}\right)$$

The landing gear wheel base referrenced to ground:

$$A = A'/cos\alpha$$

The main gear offset and anterior wheel offset referenced to ground established above remain valid as in the ground-referenced system they were taken into account in wheel loading calculations. The height of the aircraft's gravity center in aircraft-reffereced and ground-refferenced systems, respectively:

$$H_{av} = H_{stP} + c - Z_{CG}$$
$$H_{sol} = H_{av}/cos\alpha$$

Main wheel offset in aircraft - referrenced system:

$$CB = l_p cos\alpha + H_{av} tan\alpha$$

Abscissa of main wheel tire contact to ground:

$$X_p = X_{CG} + CB$$

Abscissa of front wheel tire contact to ground:

$$X_A = X_p - A$$

2.3 Verification of the longitudinal stability and the propeller ground clearence

The next step is to verify the longitudinal stability during aircraft taxiing. Using the notations presented above, the longitudinal condition for the aircraft is expressed by the following relation:

$$\beta \geq \alpha_{cr} \quad or\ \varphi$$

The smaller value between α_{cr} and φ is considered to avoid aircraft tail impact on landing (when the main wheels hit the ground) at a critical incidence (α_{cr}),or at the limit incidence for tail clearance (φ).
It is noteworthy that usually $\varphi > \alpha_{cr}$, so the longitudinal taxiing aircraft stability becomes:

$$\beta \geq \alpha_{cr}$$

The last step presented in this paper is the propeller ground clearence verification. As specified in CS 23 the propeller ground clearence for a maximum take-off weight shall be:

a) Under normal circumstances (tires and shock absorbers compressed accordingly for unoperated position): $g_{el} \geq 7 inches\ (178\ mm)$.
b) Under the most critical condition (tires and shock absorbers totally compressed) $g_{elcr} \rangle\ 0$ meaning positive and adapted to terrain, lower on concrete runways and higher on improvised and rough runways.

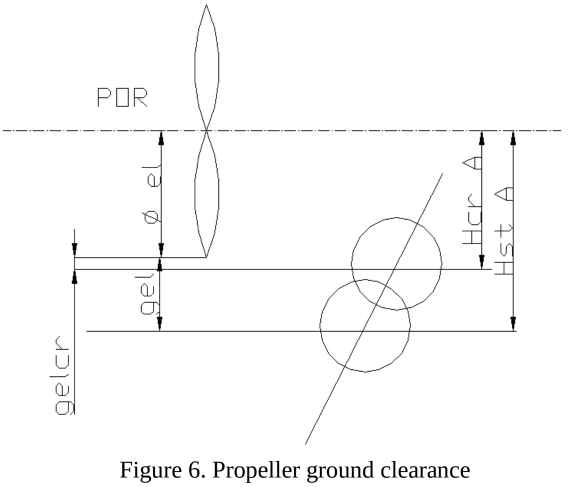

Figure 6. Propeller ground clearance

With the notations in figure 6 and the calculated data in the paper we can write:

a) $g_{el} = H_{stA} - \Phi_{el}/2$

b) $g_{elcr} = H_{cr} - \Phi_{el}/2$

2.4 Determination of the track gauge (E) of the landing gear

The landing gear track gauge (E) (figure 7) is determined from the condition of lateral stability during landing [11]. It depends on the following characteristics: the landing gear wheel base A, the height of the landing gear (H_0), and the coordinates of the center of (X and Z).

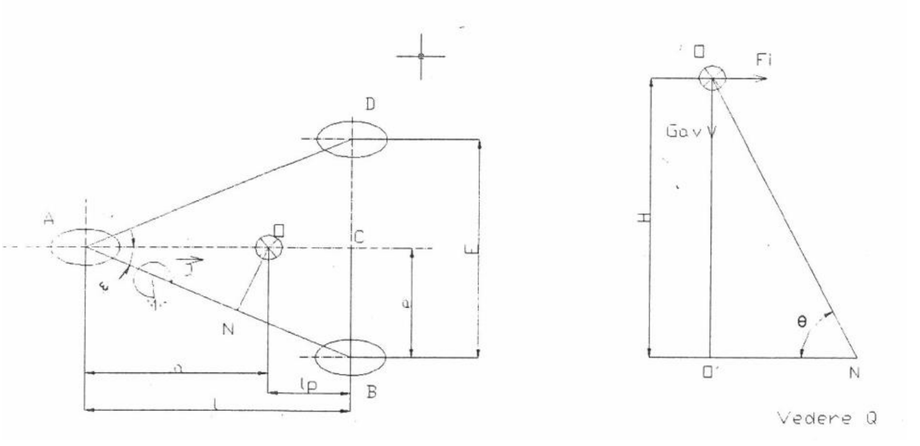

Figure 7. The landing gear track gauge (E)

The basic equations are:

$$M_r = G_{av} * ON \geq F_i * H \geq G_{av} * \mu * H \text{ sau } G_{av} * l_a * \sin\varepsilon \geq G_{av} * \mu * H$$

where: $G_{av}$is the plane weight,; F_i is the lateral inertia force; μ is the friction coefficient between the tire and the ground, and H is the height of the center of gravity from the ground.

Finally we have:

$$\frac{E}{2} \geq \frac{l * \mu * H}{\sqrt{l_a^2 - \mu^2 * H^2}}$$

3. NUMERICAL EXAMPLE

For the landing gear presented in figure 1, representig the landing gear of a primary training aircraft with dual military and civilian use using the flow described in chapter 2 we obtain the following values for its characteristics [11]:

$$l_p = 226.152\ mm$$
$$A = 1965.22\ mm$$
$$F_A = 152.73\ daN$$
$$F_P = 586\ daN$$
$$V_Z = 3.067 m/s$$
$$S_{dA} = 0.1595\ m$$
$$S_{dP} = 0.1514\ m$$
$$L_{jA} = 856\ mm$$
$$L_{jP} = 840\ mm$$
$$E = 2350 mm$$

3. CONCLUSIONS

This study emphasise the basic procedure steps for designing the landing gear main geometric characteristics and is useful in landing gear design. It can be utilised by both researchers and aeronautics students. The study is not complete, other chapters complete the task such as: design of front and main wheel strut shock absorber system, design and sizing of shock absorbers for main and front wheel struts, study of the ground support triangle, aircraft taxiing, minimum turn radius, checking lateral stability in taxiing manoeuvers. This paper continues our concerns about the problems encounter during landing and will be further completed with studies presented in [8]. In this paper [8] we discussed the possibility of using ADAMS in defining some aspects of the landing gear structure (such dynamic loads on struts) (figure 8).

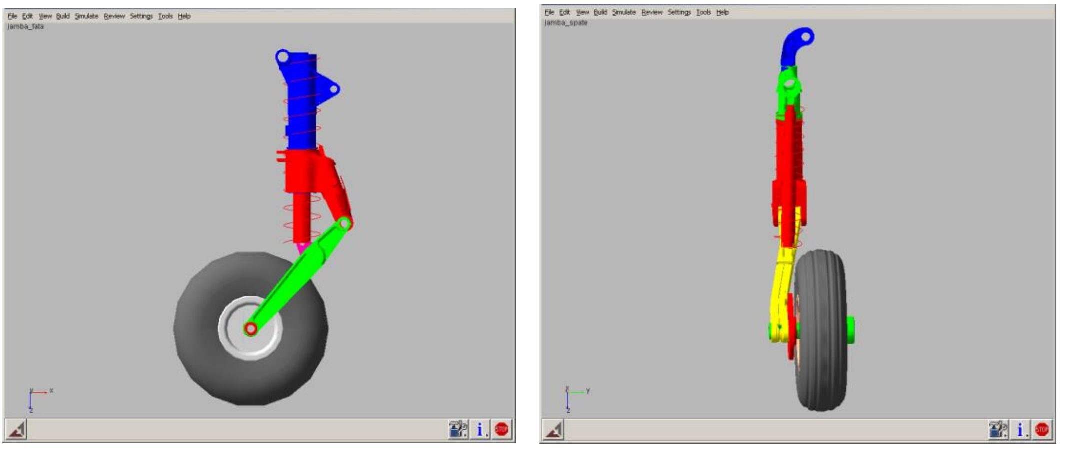

Figure 8. Nose gear and main gear (ADAMS models)

Using ADAMS we obtained simulations of these cases and representations of time histories of some of the involved forces (figure 9).

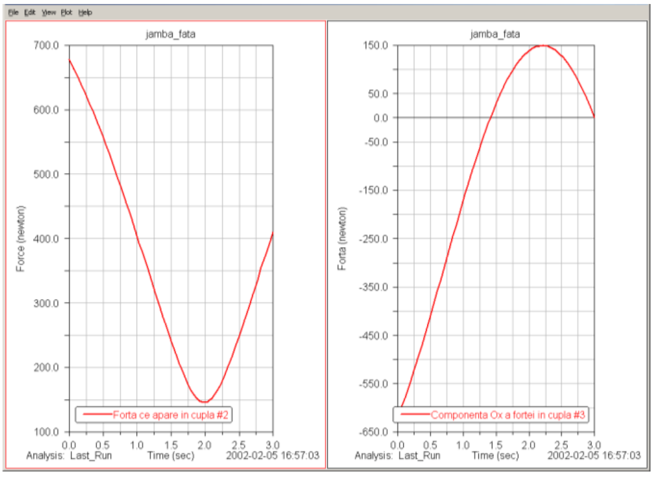

Figure 9. Forces – main gear

Another direction followed in studying the landing phenomena was that to develop simplified models and corresponding analysis programs as presented in [6] SIMULAND and a window of this program can be visualized in figure 10.

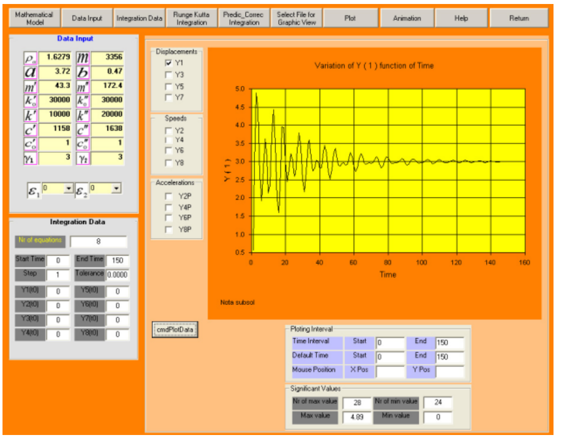

Figure 10. Displacements calculated with the SIMULAND code

The importance of the present paper is that it presents a syntesis of a more realistic and pragmatic abordation of different aspects of the landing gear design.

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