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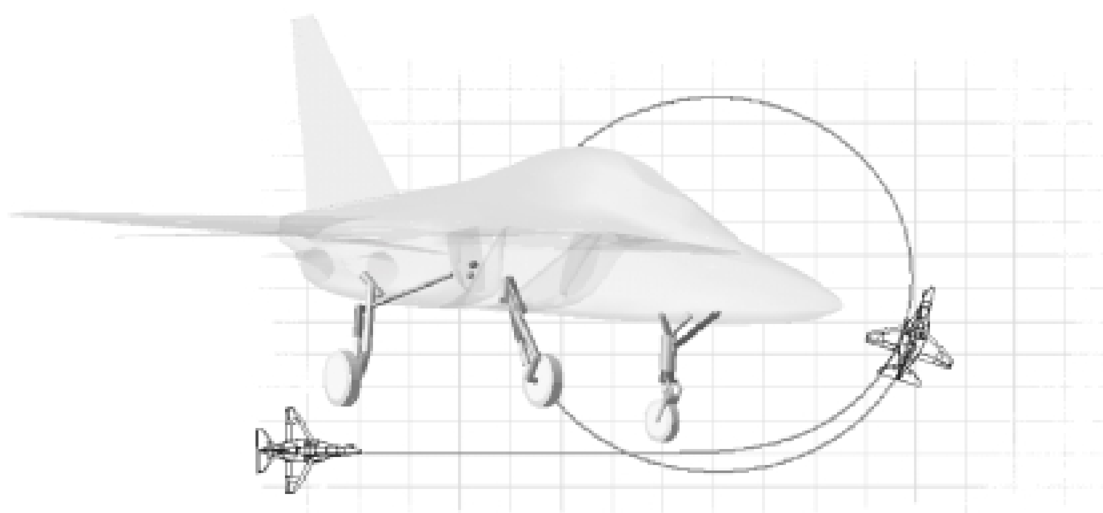

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Analysis of Landing Gear Behaviour for Trainer Aircraft

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Abstract. In the field of aircraft landing analysis, the use of a multibody code such as ADAMS has enormous potential: it allows the designer to create as complex a model as desired, with the possibility of integrating subsystems and of accounting, for example, for aerodynamics and structural flexibility. In this paper, an approach to the application of ADAMS in the analysis of landing gear behaviour and ground manoeuvring characteristics of a trainer aircraft is presented. The models developed are to be used during the design phase for the evaluation of the loads transferred to the fuselage.

The first step taken towards the implementation of the aircraft model was that of separately re-creating the behaviour of the auxiliary and main landing gear during drop-testing. In this phase, a rigid-body model was examined, along with built-in ADAMS tire models and external, user-written tire models. System components such as shock absorbers, for example, were modelled using the know-how previously acquired with a dedicated code.

After having validated the ADAMS model using the results obtained in a parallel study conducted with the dedicated code, the auxiliary and main landing gear were assembled and a complete aircraft rigid-body model was built. The model was then used to simulate the behaviour of the landing system during ground manoeuvring, using linear aerodynamics.

The model is planned to evolve, integrating flight mechanics for the approach and touch-down phase, and modelling the hydraulic subsystem.

Introduction

In the context of the development of a new advanced trainer aircraft, Aermacchi and Politecnico di Milano are co-operating on a project aimed at the evaluation of the loads transferred to the fuselage and the structural behaviour of the landing gear during impact and ground manoeuvring using dynamic and kinematic simulations. The need for integrated models as early as in the design phase, able to cater for the requirements of the different project design areas, led, during a similar cooperation in the 1980s, to the development of a dedicated code, GRAALL (Ground Roll Air And Landing Loads), used for such aircraft as AMX, S211, SF260 and MB339 [1]. As with most dedicated codes, it was relatively simple to construct and tune a model, obtaining very precise results, as long as one remained within the limits of its development: any attempt to go beyond encountered the necessity of additional, burdensome programming. In order to overcome this intrinsic, time consuming limitation, a new approach, based on the use of an industrial, multi-purpose, multi-disciplinary code was prospected. The choice fell upon ADAMS, a tool in continuous evolution, supported by a community of developers and users oriented towards similar design problems, which offers significant advantages in terms of flexibility in modelling phenomena, parameterisation, optimisation, and, last but not least, ready integration with widely used, general purpose programs.

The experience acquired with the previous code has proved to be very useful for the construction of landing gear multi-body models in ADAMS. The versatility of the latter has in fact allowed an easy implementation of the dedicated software equations, reducing the conversion time between the two calculation procedures. For example, the oleo-pneumatic shock absorber model was developed following the method already implemented in the dedicated code, which allows for both conventional orifice and variable diameter metering pins. Analogously, the FIALA tire used for the simulations with ADAMS was tuned using both experimental data and simulations with the GRAALL tire model applied in ADAMS as a user-defined subroutine. Furthermore, the first validations on the multi-body model were carried out by comparing the results obtained on the corresponding models built and simulated with the previous method.

Model construction

The first step taken towards the construction of the complete model for the new advanced trainer aircraft was the separate implementation in ADAMS of the main and auxiliary landing gear with rigid body models, designed on the basis of an existing undercarriage with similar performance requirements. Experimental drop test results and previously developed models were therefore available for validation of the basic model. Successive modifications, either geometric or functional, corresponding, for example, to variations of the shock absorber metering pin geometry or initial pressure value, could then be carried out on the basis of the validated model.

The basic parts considered for each gear were the attachment braces (the actual interface towards the fuselage), the structural cylinder, the shock absorber, the fork, and the wheel. For the nose gear, an additional part representing the steering cylinder was introduced.

Various tire models were examined and in particular two were chosen for comparison: the built-in FIALA tire and the GRAALL tire, implemented as a GFOSUB. The principal difference between these models resides in the calculation of the vertical force: the FIALA model treats the tire like a beam on elastic foundation, with a linear vertical stiffness coefficient, while the GRAALL model adopts a geometric approach, with the vertical force calculated using a polytropic compression based on the intersection volume of a torus with the ground, thus equivalent to a non-linear vertical stiffness. The FIALA model implies an elaboration of test data prior to the implementation in order to determine the stiffness coefficient, while the GRAALL tire parameters correspond to physical quantities, such as inflation pressure, polytropic exponent, tire initial internal volume.

Once all the parts had been defined and their mass characteristics assigned, the single-acting oleo-pneumatic shock absorber with its force components was implemented, using the model developed for GRAALL. The hypotheses behind this model are of gas polytropic compression and fully turbulent oil flow through the orifices, which lead to the following well-known force expressions [2]:

1.) elastic force: $$F_{elastic} = p_0 \cdot A_{gas} \cdot \left(\frac{l}{l - c_{\text{int}} \Delta l} \right)^{\gamma}$$

p_0 initial pressure
A_{gas} gas chamber reference area
l gas chamber initial length
c_{int} oil-gas interaction coefficient
Δl shock absorber stroke
γ polytropic exponent

2.) viscous force: $$F_{viscous} = \frac{1}{2} \cdot \rho \cdot \frac{A_s^3 \cdot \dot{s} \cdot |\dot{s}|}{\left(A_{tr} \cdot C_d\right)^2}$$

ρ hydraulic oil density
A_s oil chamber reference area
$\dot{s}$ shock absorber stroke velocity
A_{tr} orifice area
C_d flow coefficient

3.) frictional force: $$F_{friction} = c_{friction} \cdot F_{elastic} \cdot \left[Tanh\left(\frac{\dot{s}}{v_{ref}} \right) \right]$$

$c_{friction}$ friction coefficient
$\dot{s}$ shock absorber stroke velocity
v_{ref} reference velocity

An IMPACT force was implemented in order to limit the shock absorber fully extended length.

A series of simulations aimed at reproducing drop test experimental results brought to the proper tuning of the model components, namely tire and shock absorber parameters. The existing simulation results, tuned on the basis of experimental data, were used as validation material. Comparative testing of the two tire models brought to the conclusion that, at least for this particular case, the FIALA tire model could be used for the development of the landing gear ground manoeuvring model with an acceptable margin of error. In fact, under the loads examined, the tire does not present an exasperated non-linear behaviour, but can be reputed fairly linear, as can be seen in figure 1 graphic 4. The hysteresis loop is somewhat different, but in the case under examination, as can be seen in the other graphics of figure 1, the repercussions on the gear behaviour are minor.

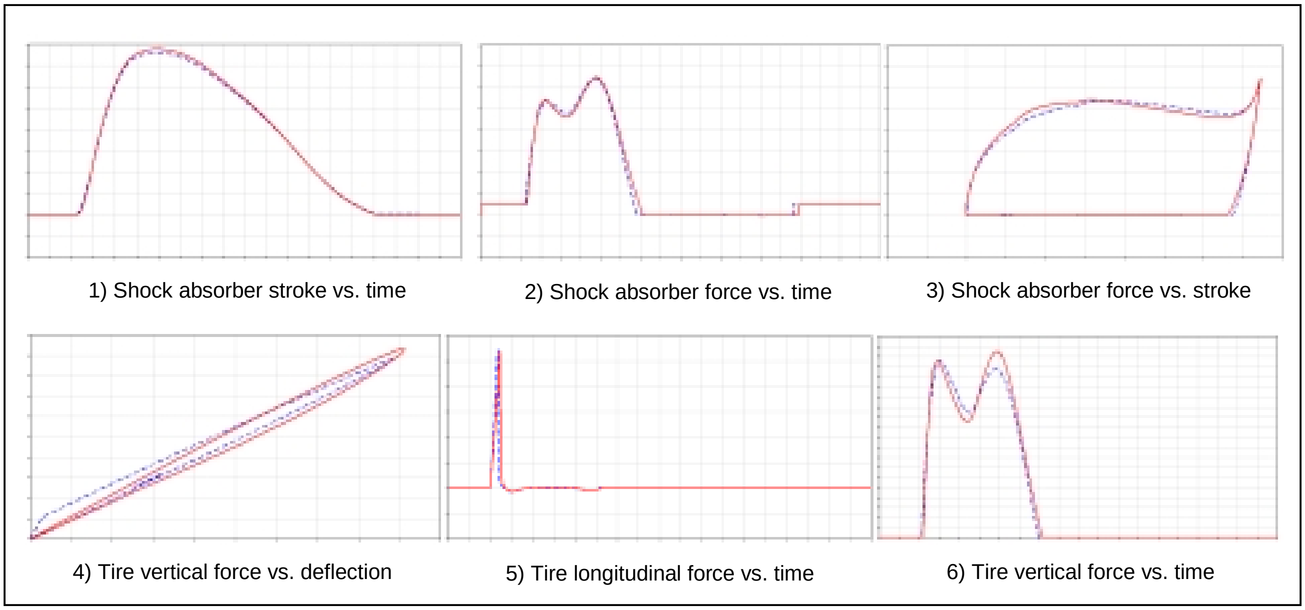


Figure 1: Simulation results for the MLG drop tests: GRAALL continuous line, ADAMS dotted line

Once the separate components were tuned, the rigid body model of the complete undercarriage was assembled and the fuselage mass characteristics were assigned to a part reproducing the aircraft centre of gravity, constrained to the main and nose gear via spherical joints and very stiff bushings.

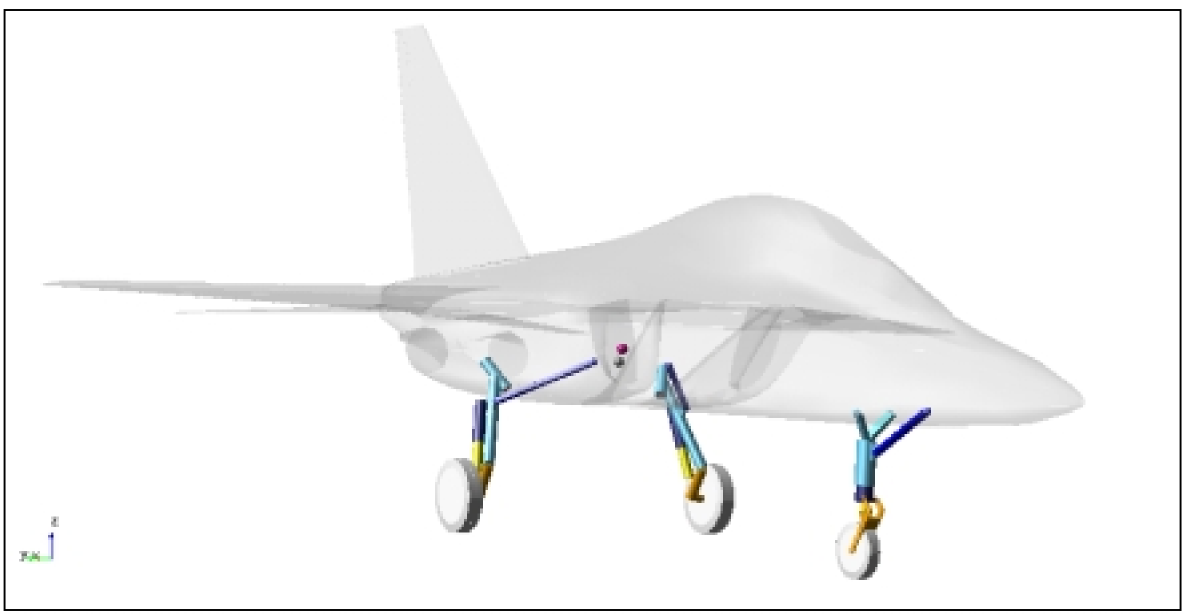


Figure 2: Complete aircraft model

Linearised aerodynamic forces, dependent upon the aircraft pitch and yaw angles, were then applied at the aerodynamic centre. This represents a large step forward with respect to the possibilities offered by the previously developed dedicated code and allows a simulation of the aircraft behaviour which is far more adherent to reality, as will be discussed further on. Some difficulties were encountered in the correct determination of the aircraft attitudes, that is model pitch and yaw angles relative to the trajectory, necessary for a correct evaluation of the aerodynamic forces (relative wind direction): mathematical models were used to overcome the problem.

At this point, the model was ready to be used in the simulation of ground manoeuvres. To start with, two basic cases were approached: symmetrical braking and steering.

Ground manoeuvre simulations: symmetrical braking

For the symmetrical braking manoeuvre model, the hypothesis of an ideal ABS system, able to constantly maintain the maximum allowable tire-ground friction coefficient, was made, thus guaranteeing the maximum braking effect and consequently maximising the longitudinal load. Under this assumption, the FIALA tire was used with built-in tire-ground friction disabled while the braking forces were implemented as forces and couples acting directly on the axle:

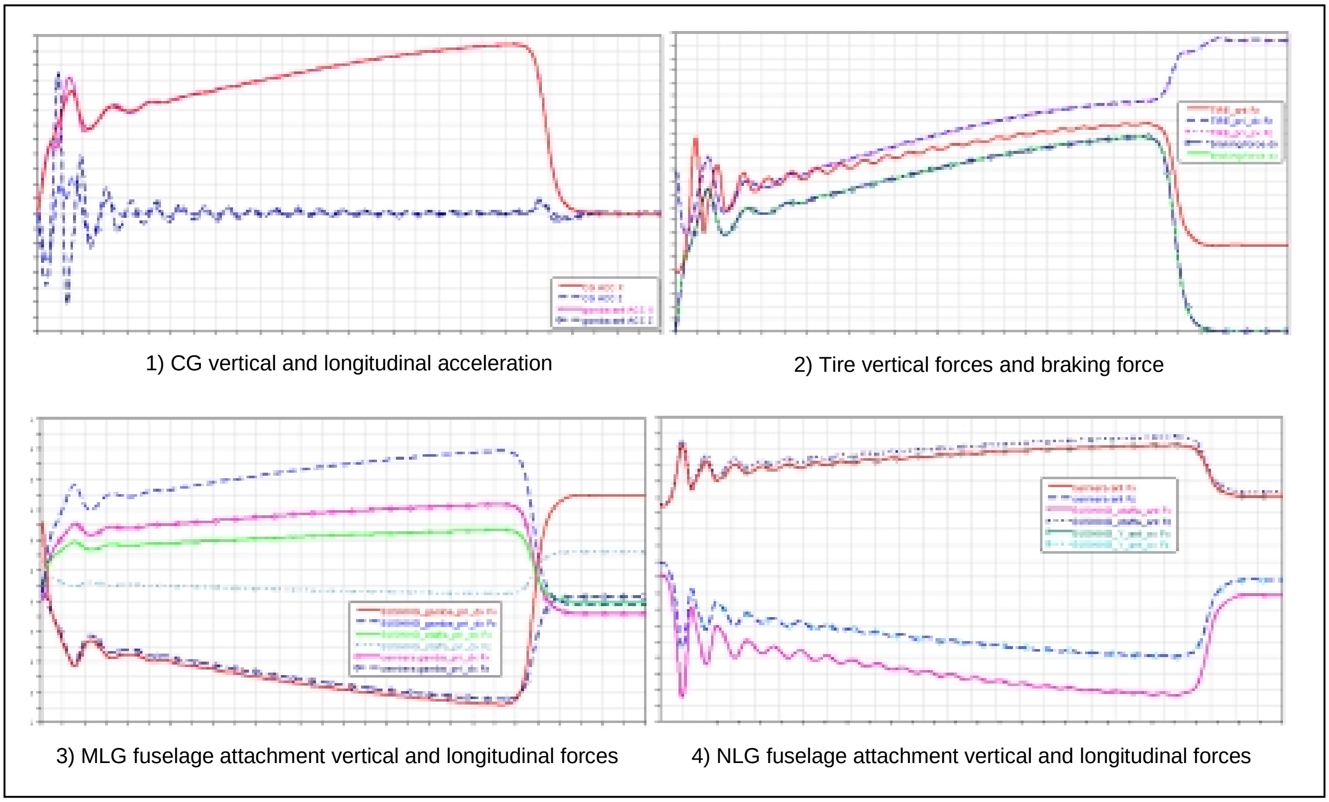
$$F_{braking}=\mu(v)\cdot F_{ztire}$$

$$M_{braking}=R_{rolling}\cdot F_{braking}$$

$\mu(v)$	ground friction coefficient (varies with aircraft forward speed)
F_{ztire}	tire vertical force (FIALA model)
$R_{rolling}$	tire rolling radius

Being a symmetrical manoeuvre, no lateral tire forces were taken into account. This was possible thanks to the particular choice of landing gear geometry, in which the axles only undergo vertical and longitudinal movement during gear deflection.

Various mass distributions and initial velocities were examined. An example of the output obtained can be seen in figure 3, where the presence of the aerodynamic forces yields a realistic evolution of the manoeuvre: as the aircraft speed decreases, the vertical load on the landing gear increases, thus augmenting the available braking force.



1) CG vertical and longitudinal acceleration

2) Tire vertical forces and braking force

3) MLG fuselage attachment vertical and longitudinal forces

4) NLG fuselage attachment vertical and longitudinal forces

Figure 3: Braking simulation results

The results obtained in the different configurations were then compared to those obtained with a simplified program based on the MIL specifications and to those obtained through theoretical studies. The outcome was deemed satisfactory, especially considering the fact that the MIL-based program does not include the effects of aerodynamics or of a varying tire-ground friction coefficient [3], and, more important, it does not consider the transient behaviour. The simplicity of the model leads, in fact, to a conservative envelope for steady loads; there is no guarantee that transient loads are encompassed, as can be seen in the case of the nose landing gear in figure 3 graphic 4. In the specific case, a cosinusoidal braking transient was applied, bringing the braking force to full value in 0.2 seconds.

Having included aerodynamics and modelled the transient certainly results in a more realistic model behaviour, but this is costly in terms of complexity and requires the tuning of a greater number of design variables. This can render the application of the detailed model impractical in the early stages of the design.

A non-symmetrical braking model is planned to be implemented in the near future; of course, in this case the lateral tire force becomes an important issue, thus the FIALA model will be used with tire-ground friction enabled and an ideal ABS system will be implemented as a PID controller on the braking torque, this time applied directly on the tire body.

Ground manoeuvre simulations: steering

In the steering manoeuvre model, the FIALA tire was used with the tire-ground friction enabled. The steering motion was applied as a PID controlled torque and not as an imposed joint motion, thus allowing a more realistic approach to the actual steer-by-wire mechanism. Moreover, the over-constraining imposition of the joint motion would have altered the lateral stability of the system.

A first series of simulations, conducted with constant velocity on the trajectory, guaranteed by a PID controller traction force applied in the centre of gravity, allowed the determination of the limit steering angles and turning radii for each rolling speed.

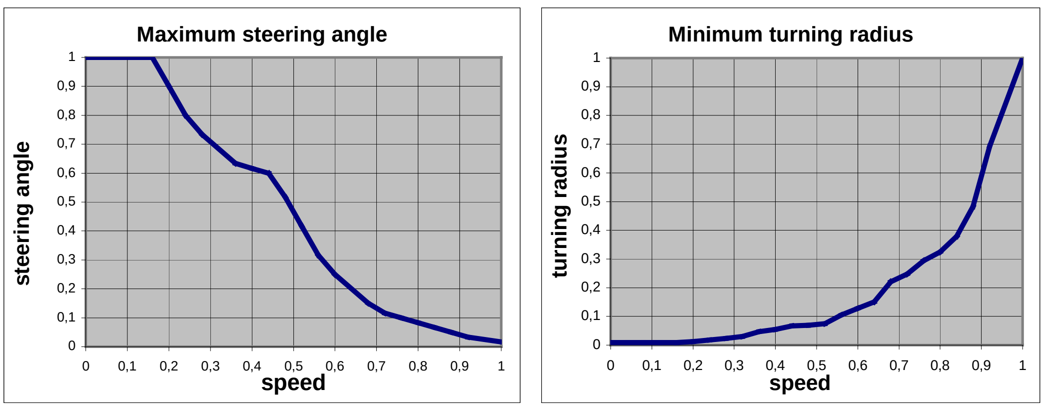
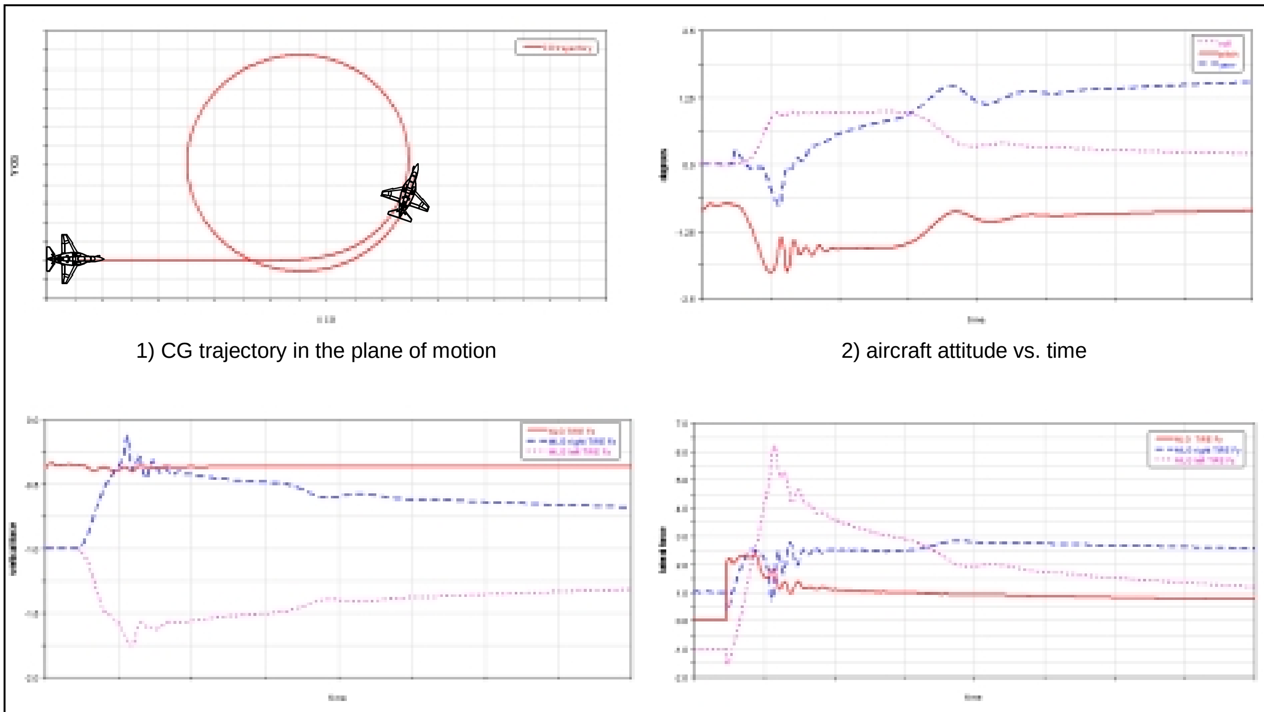


Figure 4: Example of steering model output

A second series of simulations was conducted at each limit steering angle, without traction forces applied, thus allowing the speed along the trajectory to decay. An example of the simulation results can be seen in figure 5, where the importance of the transient behaviour in determining the maximum loads can be appreciated.

Once again the results were compared to those obtained with the simplified MIL-based program, which considers steady state loads without aerodynamic effects and without modelling the transient. The same considerations expressed earlier for the braking model apply: in order to correctly define the transient, the model complexity increases, thus making it difficult to use for preliminary calculations.



1) CG trajectory in the plane of motion

2) aircraft attitude vs. time

3) Tire vertical force vs. time

4) Tire lateral force vs. time

Figure 5: Steering simulation results

Conclusions

The outcome of this experience can be summarised as follows: the models available at present are far more adherent to the actual operating conditions than those previously developed with the dedicated code. ADAMS in fact has the advantage of allowing the user to properly take into account most of the major factors influencing the physical behaviour with a relatively low modelling time expenditure, if compared to the elaboration of a dedicated code. This does not mean that additional programming is not necessary: some of the applied forces have to be defined through external, user-written subroutines, since their implementation using built-in ADAMS functions is extremely complex if not nearly impossible in some cases. The complexity of the model itself, thus the large amount of work required in order to implement it in ADAMS, corresponds though to a much greater versatility and ease in defining different simulation conditions, resulting in a more efficient design procedure, able to follow all of the typical design-phase evolutions, but, due to its complexity, being less efficient in the preliminary steps.

The project is planned to evolve with the introduction of flexible elements, for example the attachment braces, which are the primary source of dynamic oscillations present in the landing gear-fuselage attachments. A more detailed aerodynamic force description will be added to the model and ADAMS will also be linked with an external subroutine that will generate the flight mechanics during approach, in order to trim the aircraft and simulate the whole landing manoeuvre in various flight conditions. This will for example permit the realistic simulation of non-symmetric touch-down configurations. Another aspect that will be developed is the parallel study of the hydraulic system using ADAMS Hydraulics and linking ADAMS with AMESim, which will allow the simulation, for example, of the retraction kinematics, of the braking system and of the steering system.

This evolution will eventually lead to the integration and synergy with other projects under development both at Aermacchi and at Politecnico di Milano: the reconstruction and simulation of accidents involving aircraft landing gear failure, the verification of the kinematic behaviour of aircraft flight command systems in various operating conditions, nose gear shimmy simulation, just to name a few.

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