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Dynamic analysis and simulation to carrier based aircraft with catapult

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Abstract
Aircraft carrier will play an important role in present and future wars as they carry most important weapons and equipment in carrier. Catapult is most commonly used in aircraft for short takeoff. It increases the takeoff velocity so that it can take off at very short runway. This paper focuses on the dynamic forces acting on nose gear of carrier based aircraft during takeoff. This paper uses ADAMS/Aircraft as simulation software which simulates the whole dynamic forces acting on nose landing gear and main gears of the aircraft. Using ADAMS software can be a very intuitive process to see the aircraft take-off posture, all kinds of real-time data after the end of the simulation through the chart data files or output to the user. Conclusively, the result from ADAMS depicted there are very slight effect on roll and yaw, while lateral axis faces slight bump due to overshoot of CG.

Keywords: Nose landing gear; catapult takeoff, dynamic process; carrier-based aircraft, Msc-ADAMS, Virtual Prototype

1. Introduction

1.1. Background

A catapult is a mechanical device, which may be used as stored muscle energy but more commonly motor coupled to the moving parts of hydraulics, steam, or an electric motor, that translates the stored energy in to a strong linear force. It consists of a track built in flight deck, below which is a larger piston or shuttle that is attached through the track to the nose gear of aircraft.

The steam catapult consists of two slotted cylinders similar in principle to those used by the Clegg & Samuda atmospheric railway. The cylinders—typically 18 inches in diameter—contain free pistons connected to a shuttle which protrudes through a slot in the flight deck. The nose wheel of the aircraft to be launched is attached to the shuttle by a launch bar.

On completion of the launch the piston is traveling at high speed and would cause damage if not stopped in a controlled fashion. This is done by a water brake, which is a horizontal dashpot into which sea water is pumped with a swirling action as fast as it can flow out of the open end. The combination of the slight compressibility of the aerated water, the restriction as the water is expelled from the dashpot and the force produced by the expelled water hitting the front of the piston assembly itself serves to absorb the energy of the piston without damage. At that point a return mechanism readies the piston and shuttle for the next launch.

Msc-Adams is the most widely used multi-body dynamics and motion analysis in the world. It helps engineers to study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and to improve and optimize the performance of their products. It also integrates mechanicals components, pneumatics, hydraulics, electronics, and control system technologies to enable engineers to build and test virtual prototypes that accurately account for interactions between these systems.

FEA is perfect for studying linear vibration and transient dynamics but way too in efficient to analyze the large rotation and other highly nonlinear motion of full mechanical systems [8].

Dynamic Analysis is operated by executing a program and observing the execution. Dynamic Analysis is precise because no approximation or abstraction is needed to be done, the analysis can examine the actual, exact run time behavior of the program. Dynamic Analysis of 3-d structural systems is a direct extension static analysis.

1.2 Literature Survey

Many researches on the carrier based aircraft takeoff have been carried out, usually specialized in their own fields with supposing and simplifying the effect of other domains.

A Simulation model was created using MABM (Multi-agent based Modeling) for carrier based aircraft launch. Here, the model is formed in two layers I) Aggregation agent layer (Ocean, Carrier, aircraft, atmosphere) II) Meta Agent layer (catapult, Landing gear, Disturbance).Each agent is involved in carrier-based aircraft catapult launch is depicted, with considering the interactions within disturbed atmospheric environment and multiple motion bodies including carriers, aircraft, and landing gears. The models of the reactive agents among them are derived on tensors, and perceived messages and inner frame work of each agent is characterized.

The Simulation and modeling of dynamic system based on Multi-agent system is of benefit to express physical concepts and logical hierarchy clearly and precisely. As conclusion, this modeling technique makes the complex integral dynamic equation of multi-bodies decompose into parallel operation of single agent and it is convenient to expand, maintain and re-use program code.

A journal which did research on Dynamic analysis of carrier based aircraft with off-center catapult launch. Here, they considered landing gear cushion (Shock Absorber) and flexible tires; a six degree of freedom mathematic model for carrier based aircraft with off-center catapult launch was established. From this research they concluded that, the roll and yaw movement are affected by initial off-center distance, while the pitch movement is slightly affected. The loss of intensity of the yaw movement is clearer than roll movement. The increase of the initial off-center distance causes the difference of 2 main landing gears which is caused by roll movement increment.

2. Methodology

The main purpose of this paper is to study the dynamic forces acting on the carrier based aircraft during catapult takeoff. Using MSC ADAMS/Aircraft and its virtual prototype, simulation will be implemented. The results are analyzed from the simulation to determine the dynamic characteristics of the Aircraft.

Methods/Tasks

1. The equation of motion of aircraft and the equation of oleo-strut compression force is generated.
2. Virtual Prototype model is used from MSC ADAMS/Aircraft and its simulation is implemented.
3. The results obtained from the simulation are analyzed to determine the dynamic characteristics of the aircraft

2.1 Components of Landing Gear

Main landing gear comprises of Strut, Shock absorbers, torque arm and set of wheel and brakes and other components. Depending on the location of components and their relation it can be further divided to following basic types 1) Steel coil spring 2) Steel leaf spring 3) Rubber 4) Oleo Pneumatic(Air/Oil)

2.2 Principle of Oleo Pneumatic

Most aircraft in present world use Oleo pneumatic shock absorbers for their landing gear. The Purpose of the shock strut is to alleviate load on the airframe and to cushion impact. With efficiency of 90% it is almost perfect device for absorbing the kinetic energy due to sink speed. The oleo Pneumatic unit not only has the highest efficiency of all types of shock absorbers, but it is also best in energy dissipation. Unlike a coil spring, it does not store energy and then release it, causing the aircraft to bounce down the runway. Instead the oil returns to its normal static condition at a controlled rate such that rebound does not occur. The ideal situation is one in which in an aircraft can make a hard landing, after which the rebound characteristics of the shuck strut will ensure that the wheels stay on the ground.

As shown in figure 2.1 oil is poured in with strut compressed. The space above the oil is then pressurized with dry air and nitrogen, when the aircraft lands, fluids are forced from the lower chamber to the upper chamber through an orifice. Although this orifice could be a merely a hole in the orifice plate, most Americans designs have a pin extending through it, and by varying the pin diameter the orifice area is varied. This variation is adjusted so that strut load is fairly constant under dynamic loading. If this could be made constant, the dynamic load curve would be rectangle, and efficiency would be 100 percent. In practice, this is never obtained and efficiencies of 80 to 90 percent are more usual. The final value is not known until the completed strut has been drop tested, and possible adjustments have been made to the metering pin size.

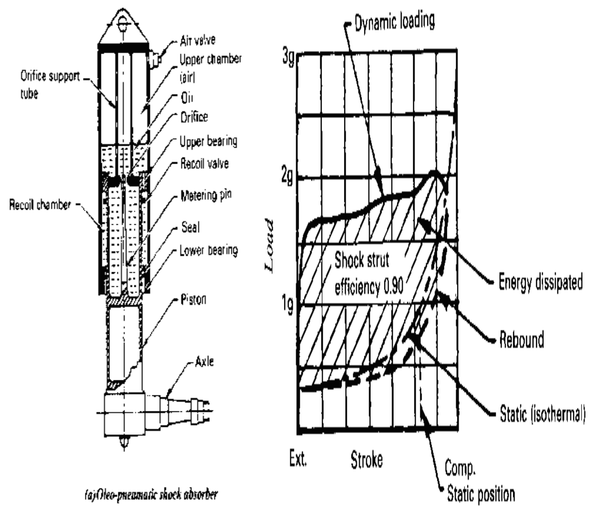


Fig 2.1: Oleo Pneumatic Shock absorbers and figure 2.2 Load vs. stroke

2.3 Mechanical Model of Nose Landing Gear

Summary of Mechanical model of nose landing gear is shown below. In nose landing gear consider two DOF of the mass-spring-damper system. The model we consider defines the movement only in vertical direction we do define the moment on horizontal direction and using the following basic assumptions [6]

1. On the front landing gear the vertical component load is acted by the mass.
2. The entire aircraft body parts (including Oleo strut, fuselage, wings, etc.) is equivalent to the landing gear shaft. The landing gear part (Strut, tires etc.) is equivalent to the wheel shaft.
3. Ignore the chamber, the damping fluid resistance, the elastic deformation of Strut.

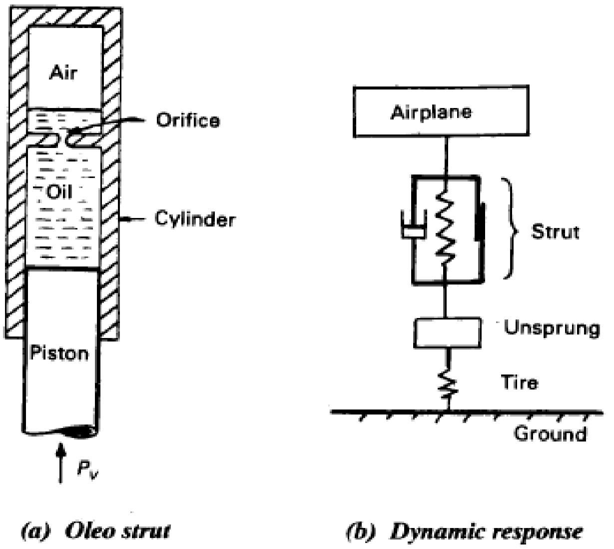


Fig 2.6: The mechanical model of Nose landing gear

Consider m_1 as Airplane weight and m_2 as unsprung and y_1 and y_2 are the vertical forces acting on m_1 and m_2.
Now listing the differential equation

$$m_1 \ddot{y}_1 = Y_n + F_n - F_h - f - m_1 g$$

$$m_2 \ddot{y}_2 = Y_t - F_n + F_h + f - m_2 g$$

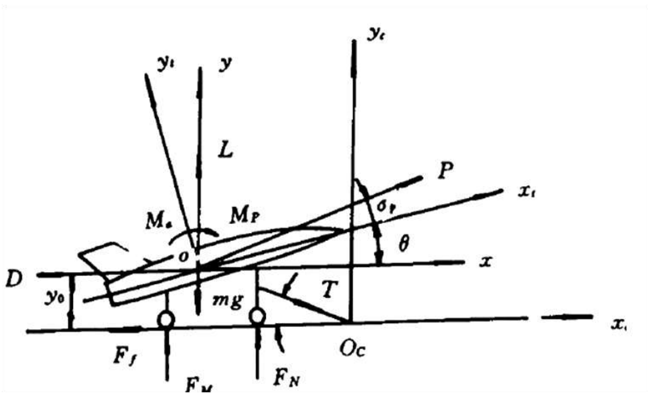
Initial Condition, $y_1 = y_2 = 0$

$$\dot{y}_1 = \dot{y}_2 = 0$$

Y_n= Equivalent Lift
F_n= Oleo Strut shock absorber
F_h= Oleo strut fluid Resistance
f= friction
The above equation is for two degree of freedom for Mechanical Model of Nose Gear.

2.4 The Equation of Motion of Aircraft

The Equation of Motion of the aircraft are as follows [6]



$$m\frac{dV_x}{dt} = Tcos\theta_t + Pcox(\theta + \sigma_p) - R_x - f(F_n + F_m)$$

$$m\frac{dV_y}{dt} = Psin(\sigma_p + \theta) - Tsin\theta_t + R_y + F_n + F_m - mg$$

$$I\frac{d^2\theta}{dt^2} = M_a + M_p + M_t + M_n + M_n$$

$$\frac{dm}{dt} = -m_c$$

$$\frac{dH}{dt} = V_y$$

$$\frac{dX}{dt} = V_x$$

P = Thrust
T = Catapult Tension
θ_t = Angel Between Catapult and Nose gear
R_x, R_y = Reaction force in X-Component and Y-Compnent
F_n = Force acting on Nose gear
F_m = Force acting on Main Landing Gear
f = Co-efficient of friction
m = mass of Carrier based Aircraft
I = Moment of Inertia
M_a = Momentum due to Aerodynamic Center
M_p = Momentum due to thrust
M_t = Momentum due to catapult takeoff
M_n = Momentum due to Nose landing gear
M_m = Momentum due to Main landing gear

3. Simulation Using ADAMS/Aircraft

3.1 Virtual Prototyping

Virtual prototyping is a technique in the process of product development. It involves using computer-aided design (CAD) and computer-aided engineering (CAE) software to validate a design before committing to making a physical prototype. This is done by creating (usually 3D) computer generated geometrical shapes (parts) and either combining them into an "assembly" and testing different mechanical motions, fit and function or just aesthetic appeal. The assembly or individual parts could be opened in CAE software to simulate the behavior of the product in the real world. ADAMS (Advanced Dynamic Analysis of Mechanical Systems) was originally the company by the United States MDI (Mechanical Dynamics Inc.) Development, ADAMS / Aircraft software module is an extension module, including standard models, template models and custom models; you can create, analyze, and assemble wheel, landing gear and full machine model. Using ADAMS / Aircraft can create and modify the aircraft landing gear model, and then analyze it separately, or as part of the whole machine to get the landing gear and the whole machine static, dynamic.

For the standard model, any user can edit in this mode, the assembly of the aircraft landing gear model or virtual prototype. Users can use the existing template to create new subsystems to achieve the new assembly. But for the model change is limited. In the template model, expert users can enter, in this mode, you can create a new template for a standard interface to use, and can be controlled to create, modify all the features of the model. Users can shortcut key F9 to switch to each other in two modes. Figure 3.1 for the use of ADAMS / Aircraft Simulation module flow chart.

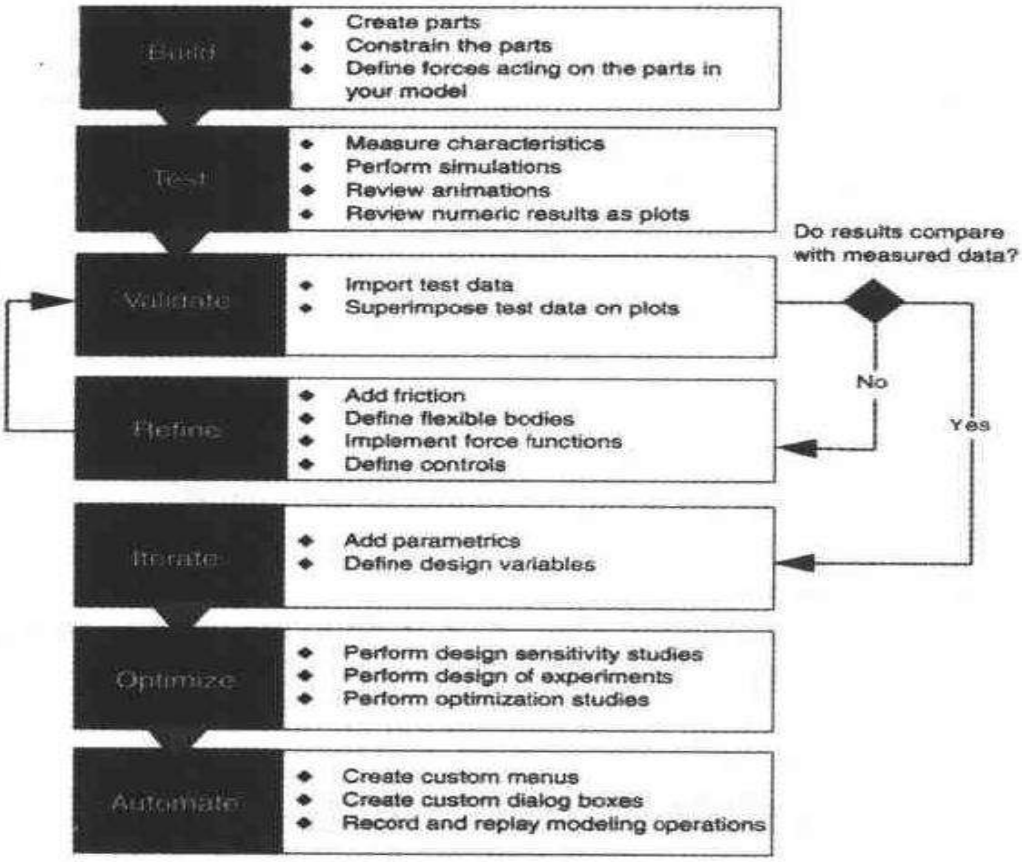


Fig 3.1: ADAMS/Aircraft simulation module flow chart

3.2 Simulation Using ADAMS/Aircraft

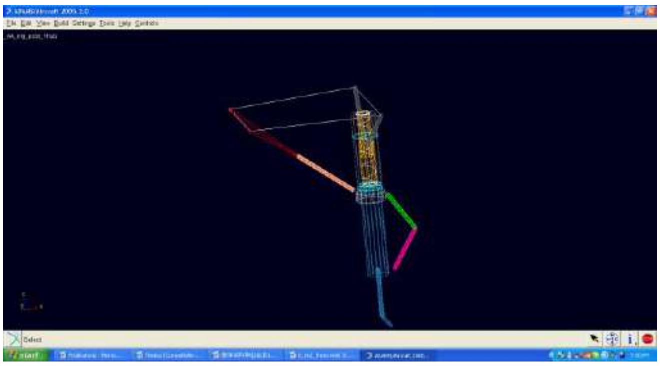
3.2.1 Virtual Prototype of Landing gear

This section describes the process of building virtual prototype landing gear and full military aircraft from ADAMS/Aircraft template and doing its simulation. In this section we discuss how we established the templates, subsystems and assembly models.

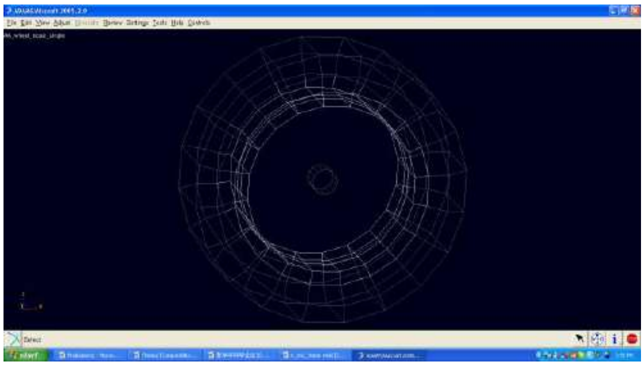
1. Creating a template system.

A Nose landing gear assembly model is created in ADAMS/Aircraft. The whole assembly can be found on the shared folder of this software including the wheel of the gear assembly and military aircraft.

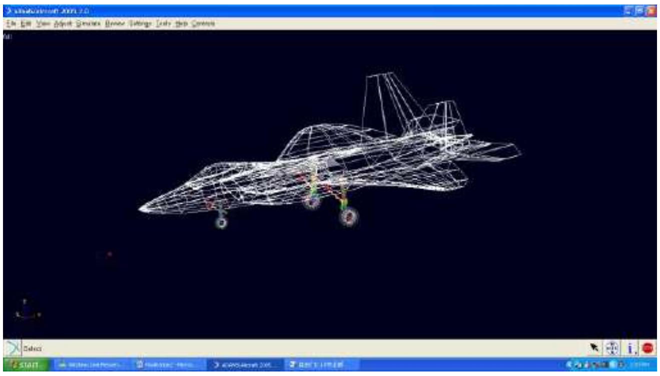
i) ADAMS/Aircraft is set to standard interface and the working unit is set to IPS System, length as Inch, Mass as pound and Time as second. From the file menu open is selected, by right clicking the mouse button we go to shared templates where we pick the file _AA_nlg_post_1hub after clicking the above file we get the following figure.



ii) Same process is done for the wheel.



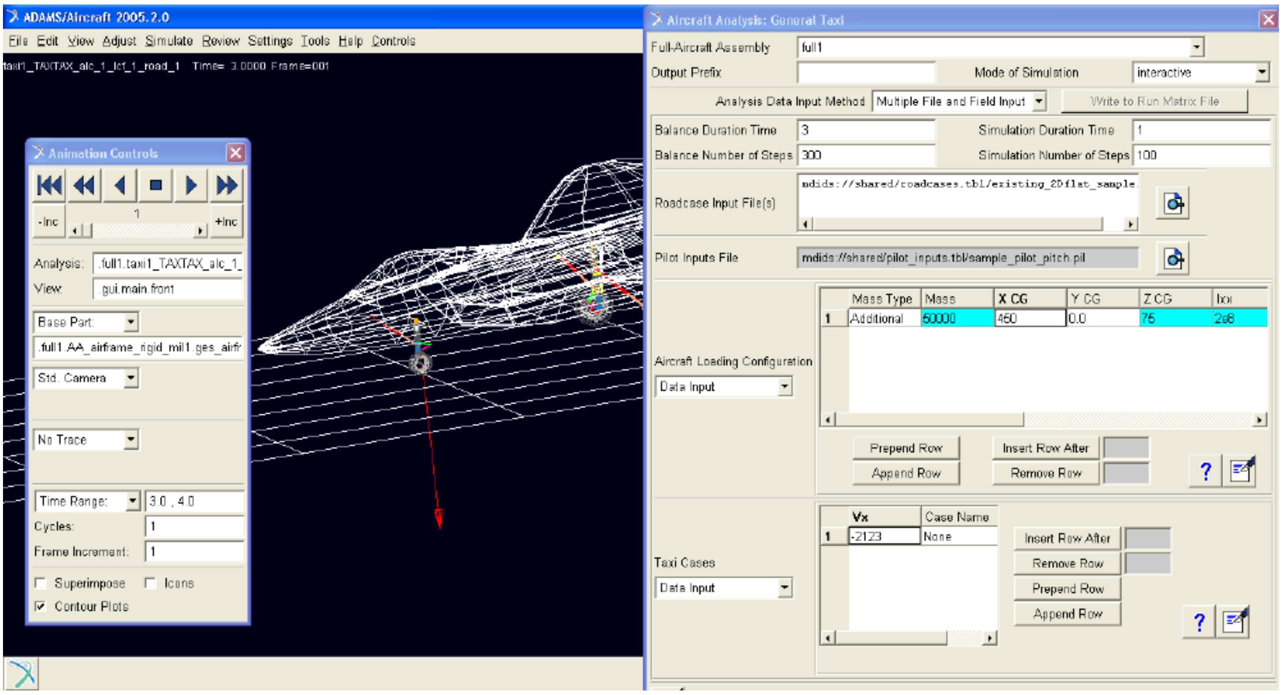
iii) Applying force to Nose landing gear. It is the most important part of the simulation; a force is applied to the nose landing gear which is parallel to the global X-axis of the software and acts as a catapult force. To give a force on oleo strut we go to template builder of ADAMS/Aircraft and open a shared file of Nose landing gear. Then a marker is created at oleo strut of nose gear which is a reference point for the force. After creating marker a force function is given in X-axis which is, if (time-3:0, 0, if (time-3.2:-2238, -2238, 0)). Its main purpose is to define force as 0 until 3 seconds but in between 3 to 3.2 seconds the force rises 2238. Now the force is applied on the template, we call the template in standard interface to make it a subsystem and assemble it with a full aircraft.



3.2.2 Simulation Parameters

Simulation main parameters.

Aircraft Gross weight (m) = 50000 P
Aircraft Centre of Gravity X (G) = 450 inches
Aircraft Centre of Gravity Y (G) =75 inches
Moment of Inertia X-axis = 2E8
Moment of Inertia Y-axis = 2E8
Moment of Inertia Z-axis = 2E8
Aircraft Velocity = 2123 inches/sec



For simulation, we go to simulate menu from toolbar click ground analyses and to taxi we input the parameters of the aircraft and give the takeoff velocity. The simulation runs for 5-15 seconds and to see its animation we go to review menu from toolbar and click animation controls and see its animation. For good results, the simulation is done numerous time changing the catapult force and take off velocity.

4. Results and Discussion

4.1 Simulation Results

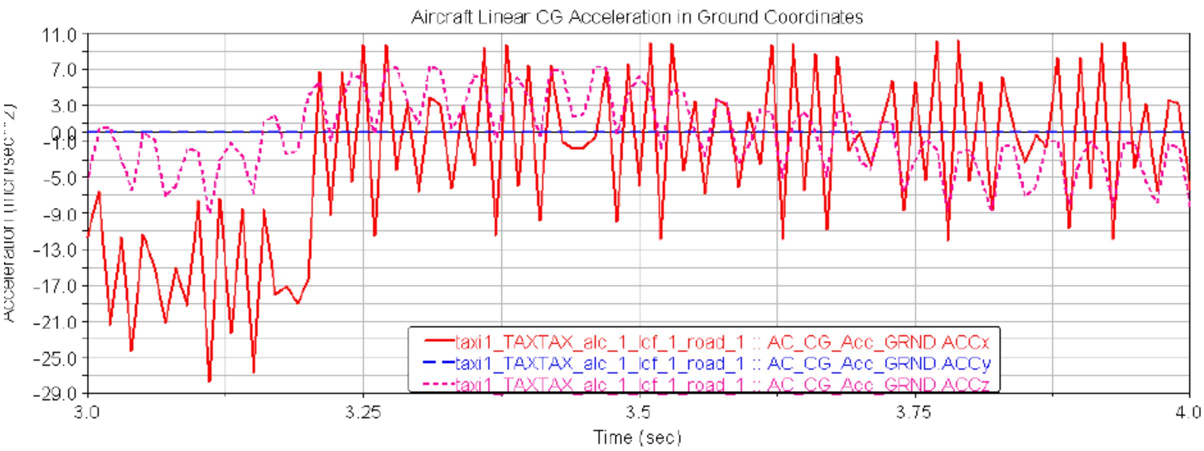


Fig 4.1: Aircraft linear CG displacement in Ground Coordinates

When the force is applied at 3.0 seconds the Aircraft linear CG acceleration in Ground coordinates along the X-axis increases at first and shows a non-linearity and then after 3.2 seconds the force applied in the nose landing gear is removed the non-linearity finally appears to be constant till takeoff. Now if we look in Z-axis at first we find same result as shown in X –axis but after 3.2 seconds instead of coming to its normal position it overshoot.

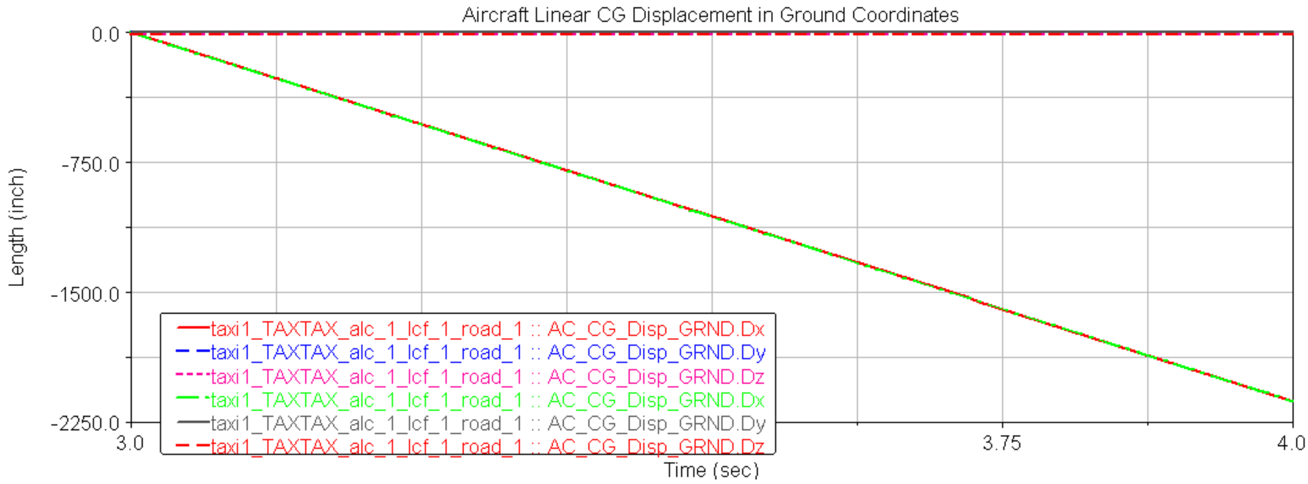


Fig 4.2: Aircraft linear CG displacement in Ground Coordinates

From the figure at 3.0 seconds the aircraft thrust and the catapult force is applied due to which we can notice that there is an increment in the length with respect to time.

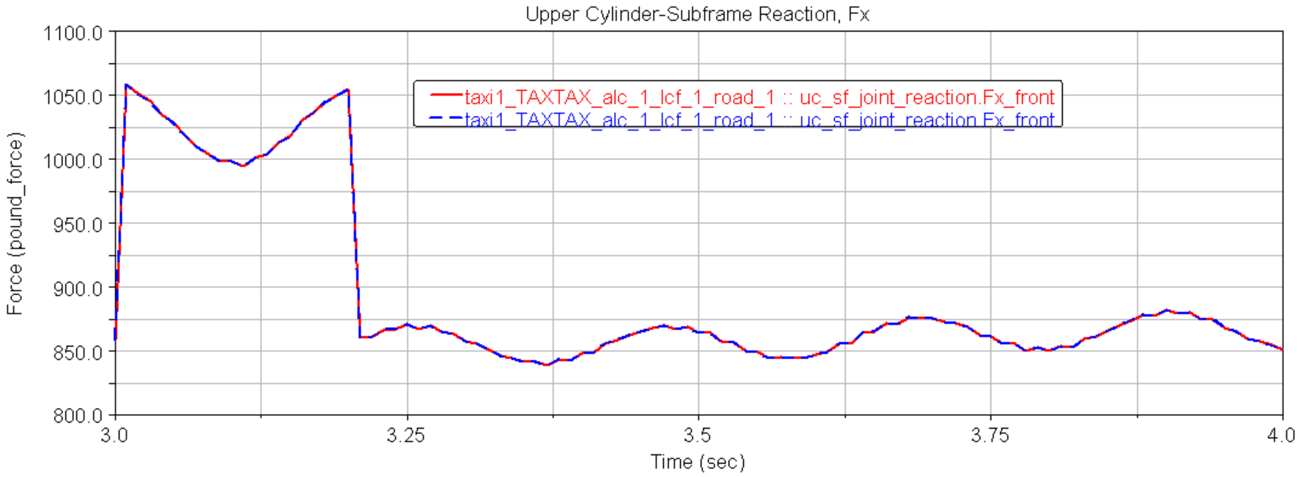


Fig 4.3: Upper Cylinder sub frame reaction in Y axis

The figure above shows that when catapult force is applied in 3.0 seconds there is a sudden increment in force of upper cylinder of the oleo strut of nose landing gear but after some seconds there is a reaction force of upper cylinder which tends it to come back to its normal position but due to the catapult force it drags the upper cylinder to certain weight. After 3.2 seconds the catapult force is removed and we can see that the upper cylinder tends to come back to its normal position. This phenomenon is also shown in figure given below.

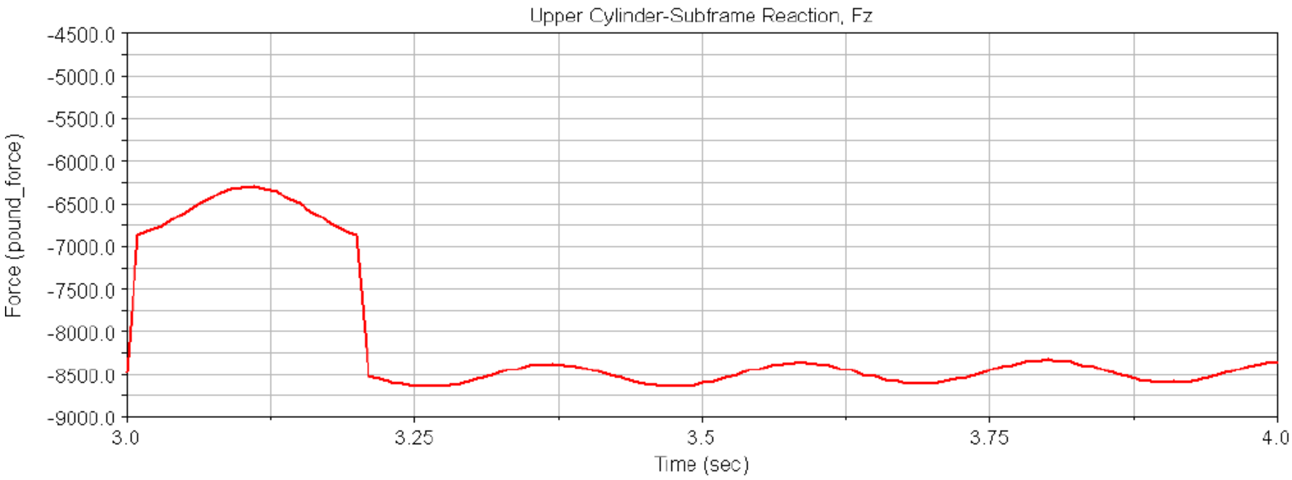


Fig 4.4: Upper Cylinder sub frame reaction in Z axis

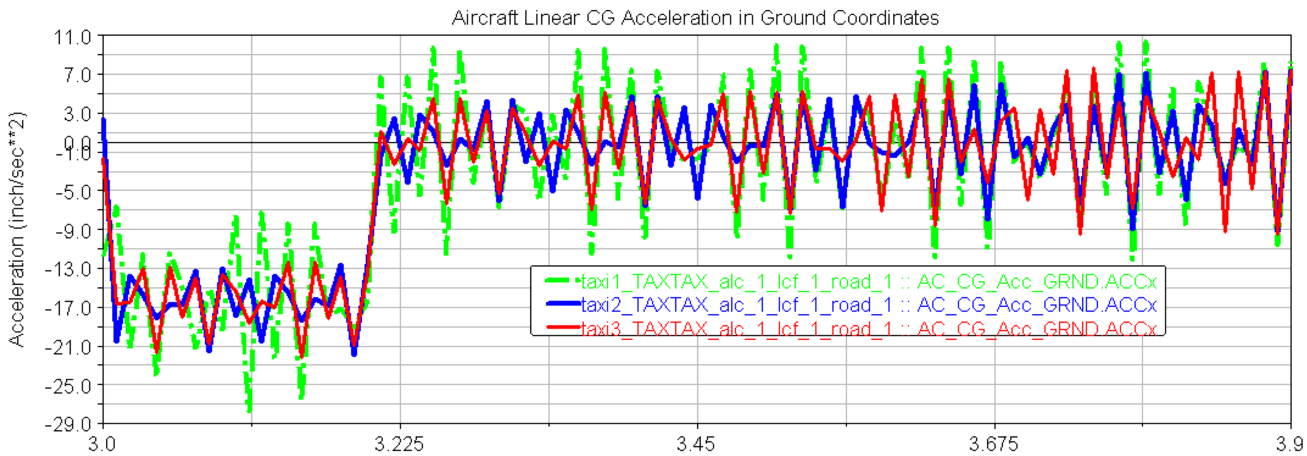


Fig 4.5: Aircraft CG Acceleration in Ground Co-ordinates

Looking at figure 4.1 we see many non-linearity's in the figure but if the velocity is increased then the graph tends to be more stable which is very good as shown in figure 4.5.

Same results were obtained when I made the takeoff velocity constant and made variation in Catapult force as shown in figure 4.6. The effect on nose landing gear was same as shown above in figure 4.3.

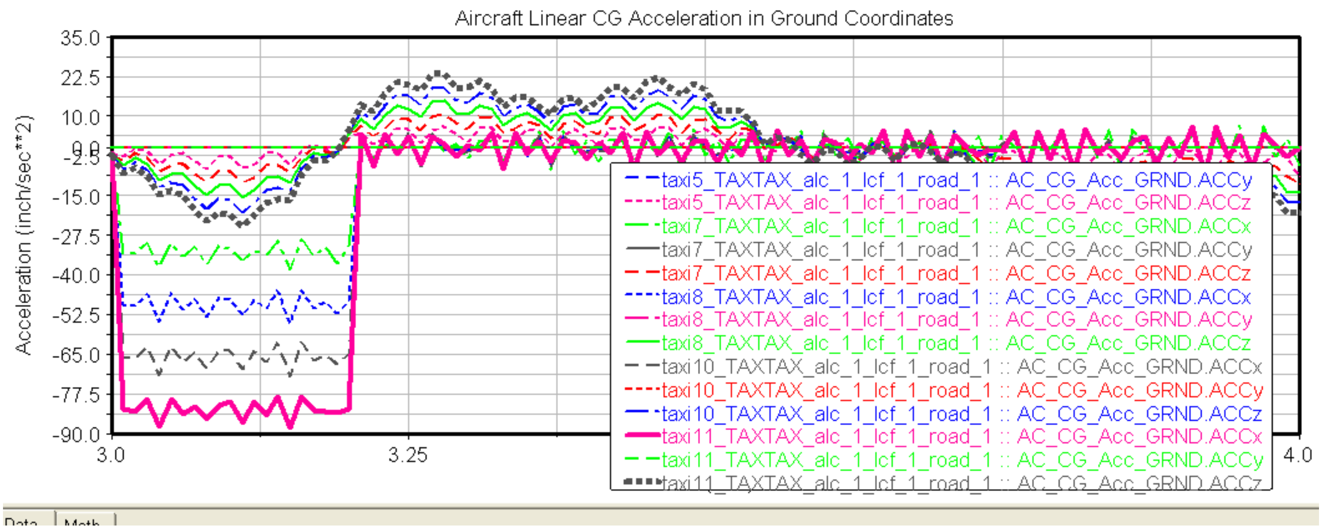


Fig 4.6: Aircraft Linear CG Acceleration in Ground Co-ordinates

Now if we look at figure 4.7 we see the Torque acting on Upper Cylinder Sub-frame in Z-axis, which means the rate of trunion while takeoff, now as velocity increases the rate of trunion becomes more stable. At low velocity the rate of trunion is very high.

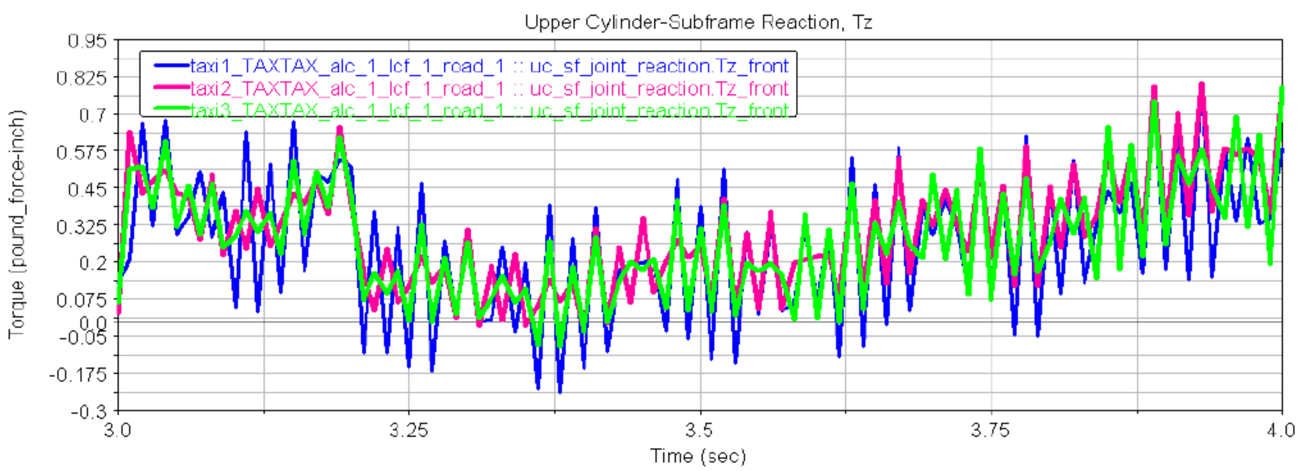


Fig 4.7: Torque acting on Upper Cylinder sub frame of Nose landing gear in Z-axis

Figure 4.8 and 4.9 shows the torque acting on Upper Cylinder Sub-frame of Nose landing gear in Y-axis, which means the pitching of the Upper cylinder sub frame. Figure 4.8 shows the graph where the catapult force acting on nose landing gear is made constant and the velocity of the aircraft is varied where it shows that a lift is being induced (taxi2 graph at figure 4.8) at a very high rate.

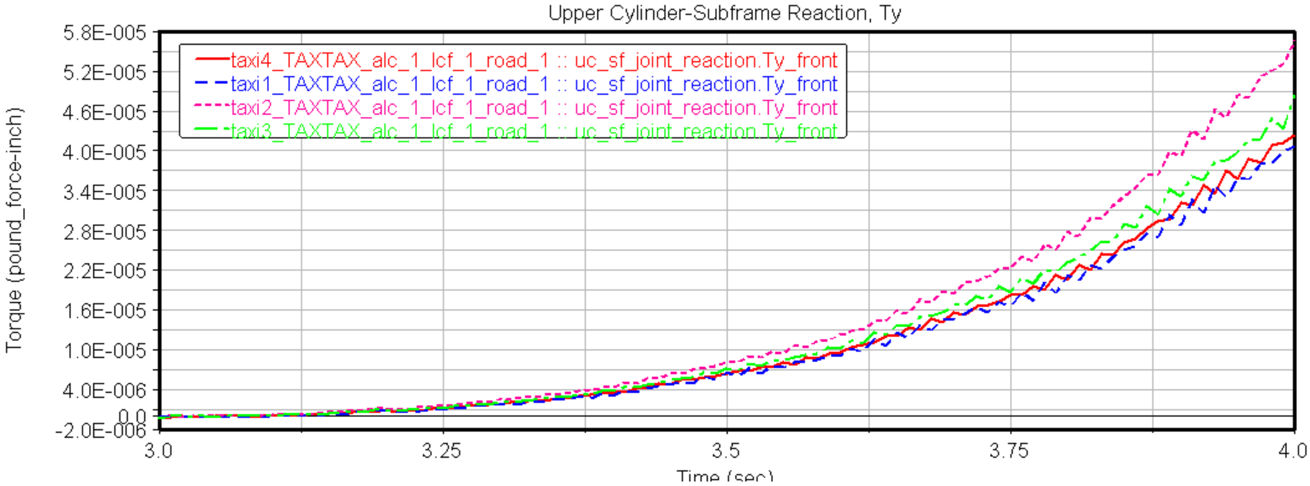


Fig 4.8: Torque on Y-axis on nose landing gear where catapult force is made constant

But if we look at figure 4.9 where the catapult force is varied and the velocity of aircraft is made constant the rate of torque in Y-axis is increased at the end of the simulation. This means the lift is produced at high rate at the end of catapult takeoff when the catapult force acting on nose landing gear is made constant.

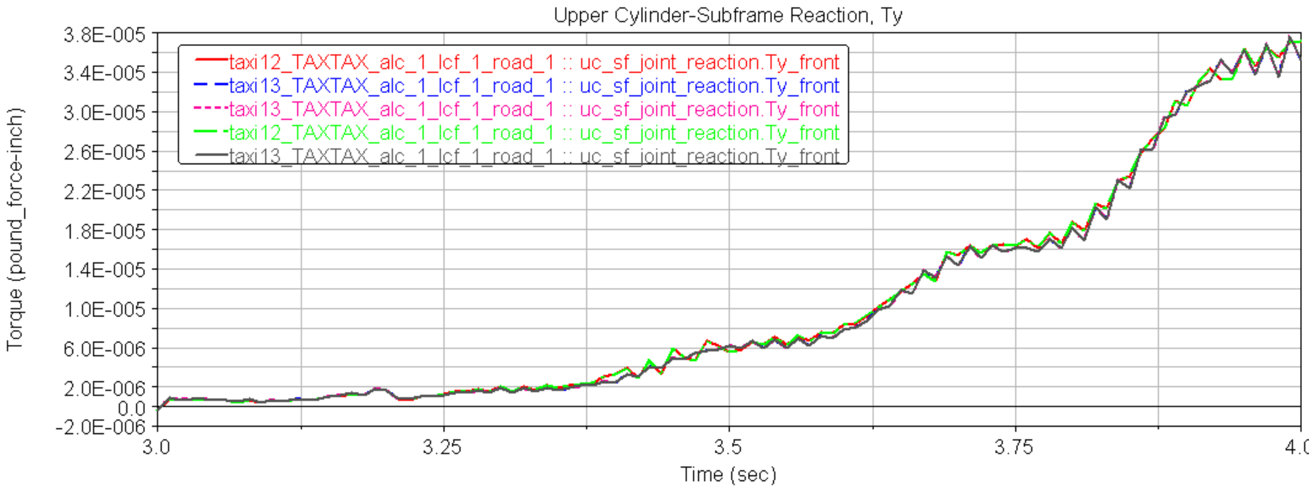


Fig 4.9: Torque on Y-axis on nose landing gear where the catapult force is varied.

5. Conclusions

After designing landing gear structure, establishing two DOF mass-spring-damper model and then entire carrier based aircraft on ADAMS/Aircraft with landing gear as rigid mass dynamic analysis was carried out on the aircraft. The CG of aircraft increases when the catapult force is applied, and tries to remain constant till takeoff after the catapult force is removed. In another case when the catapult force is applied on the aircraft, the aircraft nose points down due to the shift of CG of aircraft towards the front side but after 3.2 seconds when the catapult force is remove, the CG tries to come back to its normal position but unfortunately it overshoots due to which aircraft bumps slightly during takeoff. During takeoff, thrust and the catapult force acts at a same time due to which there is a constant increment on the displacement of the aircraft till takeoff speed reaches.

Now focusing on the nose landing gear, when the catapult force is applied on nose landing gear there is a sudden increment in the force, for some seconds it tries to synchronized with the motion of catapult force but due to aircraft parasite drag and friction due to tire it cannot synchronize totally with the catapult force due to which there is again an increment on the force of nose landing gear till 3.2 seconds but after 3.2 seconds the catapult force is released and the aircraft moves with its normal velocity till take off. The catapult force on nose landing gear on certain angle so we can resolve into 3 different axes i.e. X,Y and Z, we mainly consider X and Z figure 4.4 shows the upper cylinder sub frame reaction in Z direction. Initially as the catapult force is applied the reaction of the upper cylinder increases linearly (straight line on graph) and as catapult force continues it enters a nonlinear region (curved line in graph) as the load factor increases it reaches its critical value for the single chamber of the oleo strut then the dual chamber becomes active to absorb the remaining catapult force.

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