# Aircraft Flight Simulation with Landing Gear Based on Multi-Domain Modeling Technology

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*Abstract*-**This paper create a full aircraft flight simulation model for accurately analyzing the performance and influence of landing gear system. The use of multi-domain modeling technology enables detailed modeling of the flight dynamic and landing gear dynamic. The simulation results show that the aircraft landing gear system mathematical model established appropriately reflects the change of force and moment in the process of taking off and landing, and it is actual in the physical process. The parameter design space is easily searched by considering a number of different landing scenarios to optimize the design.**

***Keywords-Flight simulation, landing gear system, multiple domain modeling and simulation, taking off and landing***

## I. INTRODUCTION

Airplane flight is expensive. For activities such as pilot training, flight research, and recreation, flight simulation can provide a suitable, and less expensive, alternative to real airplane flight. A key to successful employment of this process is to have a useful model of the vehicle being controlled, which is called the plant. The usefulness of the model should be judged in terms of completeness, accuracy, simulation speed, and easiness to build. Model-Based Design is a proven process for successfully developing such systems. Through the Simulink platform, physics-based tools are applied for modeling and simulating the mechanical and electrical components. The tools for mechanical components are SimMechanics and SimDriveline. The tool for electrical components is SimPowerSystems. SimMechanics enables efficient modeling and simulation of full 3-dimensional mechanical systems[1,2]. This modeling environment offers blocks for defining bodies, joints, and constraints to describe the structure of a mechanical assembly. It is based upon the principles of rigid-body dynamics and designed for general motion analysis of mechanical assemblies containing internal linkages.

This paper presents the use of multi-domain modeling technology for the study of aircraft flight simulation with landing gear system. In particular, flight dynamic, aerodynamic, landing gear dynamic and mechanical loads are designed and integrated into a comprehensive model of the aircraft flight simulation. A scenario where the aircraft lands on one wheel set first is analyzed in terms of applied forces required to perform this maneuver safely and effectively.

## II. FLIGHT DYNAMIC MODEL

The flight simulator ultimately uses the equations of motion to calculate the time derivatives of the state variables. The dynamic equations derive from Newton's Second Law and the analogous equation for angular motion[3,4]. Resolving these equations along body axes, and including terms to account for centrifugal forces due to the rotating body reference frame, yields the dynamic equations of motion. For a symmetric airplane ($I_{xy} = I_{yz} = 0$), the dynamic equations are given by:

$$\dot{u} = rv - qw + X/m$$
$$\dot{v} = pw - ru + Y/m$$
$$\dot{w} = qu - pv + Z/m$$
$$\dot{p} = \frac{I_{xz}L' + I_{xx}N'}{I_{xx}I_{zz} - I_{xz}^2}$$
$$\dot{q} = \frac{M - (I_{xx} - I_{zz})rp + I_{xz}(p^2 - r^2)}{I_{yy}}$$
$$\dot{r} = \frac{I_{zz}L' + I_{xz}N'}{I_{xx}I_{zz} - I_{xz}^2}$$

The L' and N' are given by:

$$L' = L - (I_{zz} - I_{yy})qr - I_{xz}pq$$
$$N' = N - (I_{yy} - I_{xx})pq - I_{xz}qr$$

The kinematic equations relate the velocities (angular and linear) of the airplane to the time derivatives of the position and orientation. Quarternions are more computationally efficient than Euler angles, and do not exhibit singularities. In fact, the only drawback to using quarternions is that they have no useful physical meaning.The kinematic equations for the quarternions are given by:

$$\begin{bmatrix}\dot{q}_0\\ \dot{q}_1\\ \dot{q}_2\\ \dot{q}_3\end{bmatrix} = \frac{1}{2}\begin{bmatrix}0 & -p & -q & -r\\ p & 0 & r & -q\\ q & -r & 0 & p\\ r & q & -p & 0\end{bmatrix}\begin{bmatrix}q_0\\ q_1\\ q_2\\ q_3\end{bmatrix}$$

The time derivative of the position is simply the velocity, rotated into the coordinate system of the position variables. For simulators that store the aircraft's CG position in local coordinates, the kinematic equations for position are:

$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix} = \begin{bmatrix}q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 + q_0q_2)\\ 2(q_1q_2 + q_0q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_2q_3 - q_0q_1)\\ 2(q_1q_3 - q_0q_2) & 2(q_2q_3 + q_0q_1) & q_0^2 - q_1^2 - q_2^2 + q_3^2\end{bmatrix}\begin{bmatrix}u\\ v\\ w\end{bmatrix}$$

In traditional flight simulation[5~7] modeling tools that are based on signal flow, such as Simulink. The landing gear model for this work was elaborated upon through the use of SimMechanics. Modeling the mechanical linkages in the same environment as the aerodynamics requires an interface or connection between the two domains to be established.

The flight simulation model is shown in Figure 1. It shows that a single body block represents the aircraft and that it is connected to the landing gear system. The sensing blocks extract mechanical performance data from the simulation and make it available through numerical flow lines to traditional Simulink blocks. The actuation blocks receive numerical flow lines from traditional Simulink blocks and apply it to actuate motion through assignments for forces, torques or prescribed motions. The 6-DOF joint provides the positional reference to the world coordinate system. The properties for this body block are the mass and inertia values and key assignments for local coordinate systems. The local coordinate systems are used in a number of roles for marking critical locations on this body. Here, local coordinate systems mark the locations for the center of gravity (CG), the attachment points for the landing gear system, and the point used in the positional reference of the 6-DOF joint.

## III. LANDING GEAR MODEL

The landing gear is constructed of four links: a vertical strut, two bracing links, and a sprung extension (shock absorber). Joints are analogous to physical connections like hinges, slots, and ball and socket connections. For the landing gear, the links connect to the airframe and to each other through revolute joints, which are directly analogous to hinges. These revolute joints are all aligned to rotate about the axes parallel to the longitudinal axes of the airframe.

Modeling of mechanical systems and components often starts with CAD tools. SolidWorks offers a 3-dimensional graphical environment for defining mechanical assemblies. Figure.2 shows a SolidWorks assembly of a four-bar linkage corresponding to the described configuration of the landing gear for motion simulation.

The MathWorks, the maker of Simulink and SimMechanics, has built a translator that reads SolidWorks assembly models and creates a SimMechanics model that represents that assembly[8]. The visual context of SolidWorks is very valuable in defining joints, and the tool's ability to represent general part shapes and deliver calculations of their mass and inertia properties offers great value in the SimMechanics model building process. Once this free software is installed, it is possible to generate a textual description of the assembly that lists the mass properties for each body and the characteristics of each joint defined in the SolidWorks assembly. The modified SimMechanics model with additional accuracy by tuning the model from the actual system that contains the normal force exerted by the ground and the friction on the tires[9,10] is shown in Figure.3.

## IV. FLIGHT SIMULATION

Figure.4 shows a flight simulation model for the aircraft. An additional wind gust was modeled to inject a roll moment into the aircraft close to landing. This was achieved by simply applying a moment about the x-axis of the vehicle (roll) at a specific time and duration just prior to landing. Figure.5 shows the resulting measurements for the landing simulation.

## V. SUMMARIES

The paper presented a method for modeling aircraft systems, which include flight dynamic, landing gear dynamic, turbulent flow and ground contact. The efficiency of physics-based methods in delivering a first-principle model makes the use of these methods highly desirable for the majority of the modeling. The most useful modeling approach, however, will include mathematical and data-driven methods, also, to deliver the most accurate, complete, computationally efficient, and easily built models. The resulting model used the modified block to integrate different domain specific models and the resultant model was used to quickly search the parameter design space.

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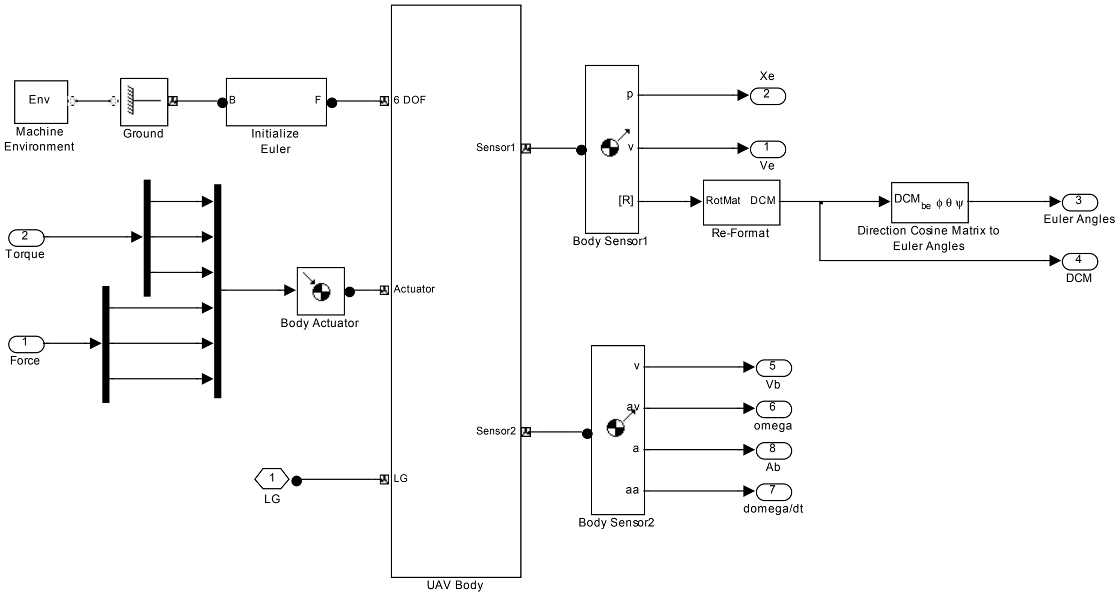


Figure 1. Aircraft flight simulation SimMechanics model with landing gear linkage

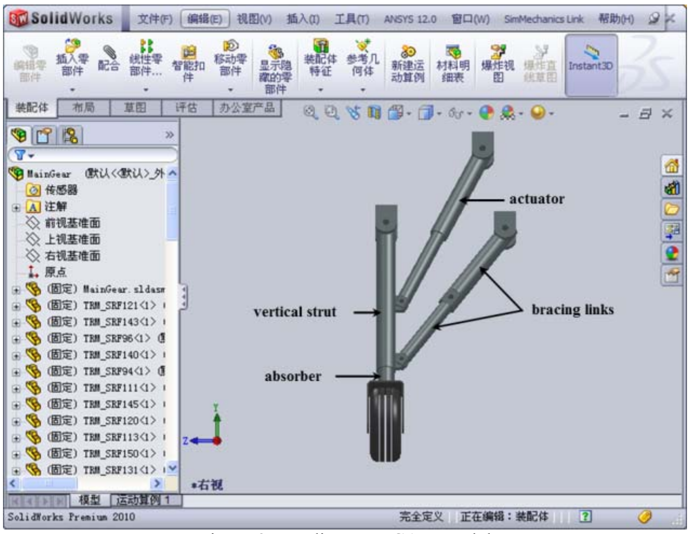


Figure 2. Landing gear CAD model

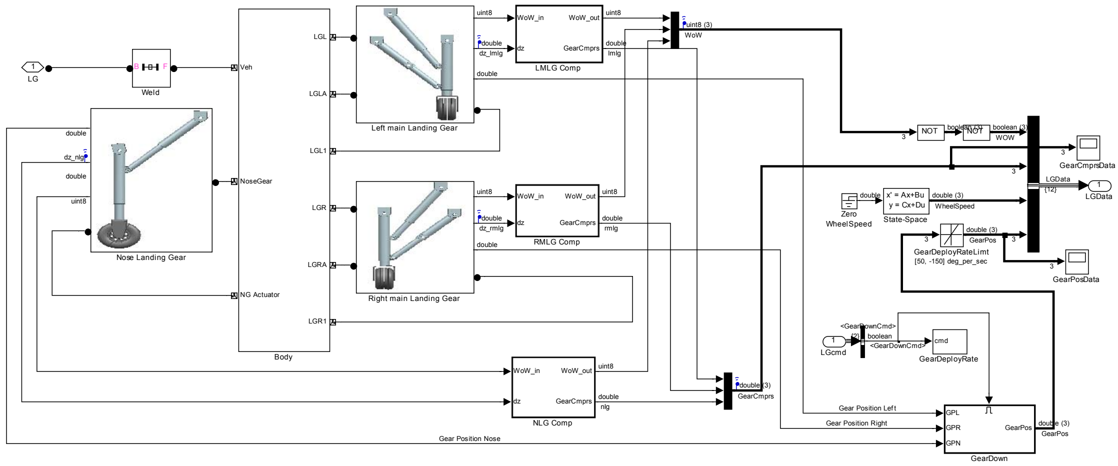


Figure 3. Landing gear SimMechanics model

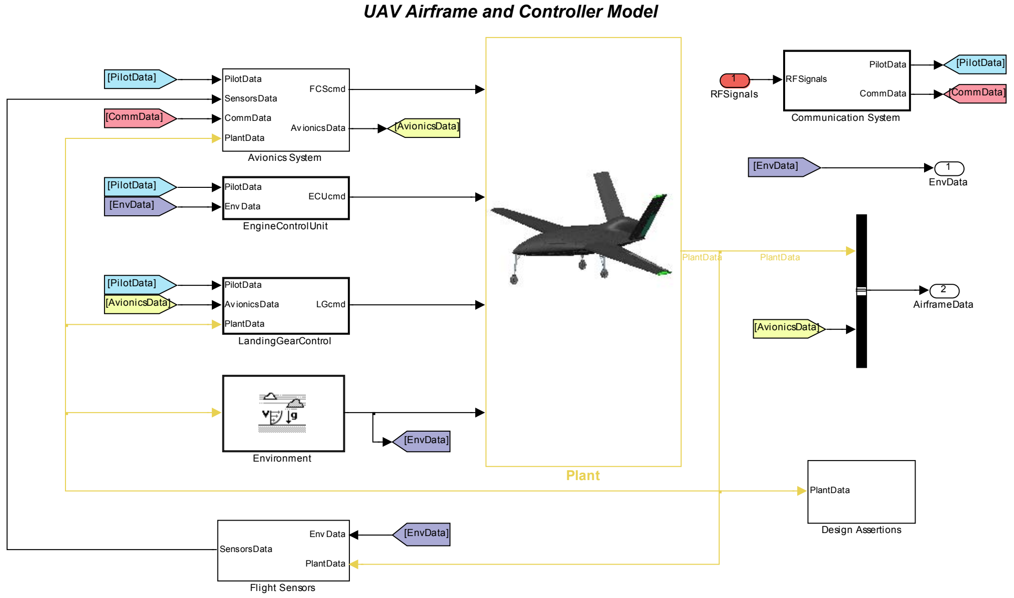


Figure 4. Flight simulation model for the aircraft

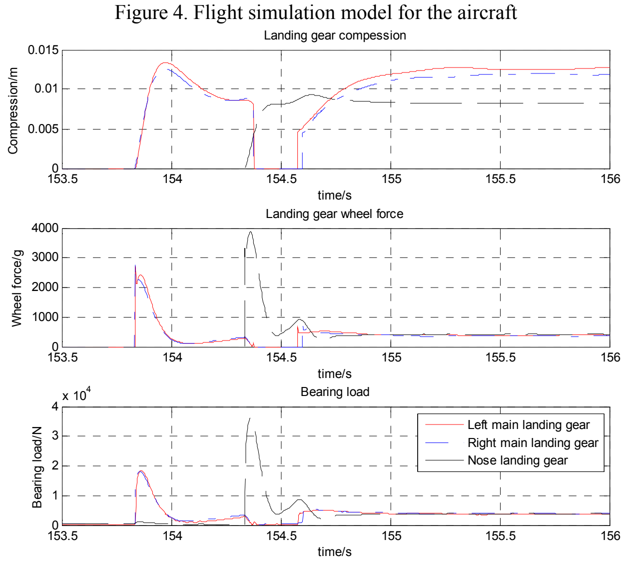


Figure 5. Results for landing gear simulation