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Modified Six-Degree of Freedom related to Takeoff and Landing stages of Aircraft

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Abstract: *Six degrees of freedom (6DoF) means to the freedom of movement of a rigid body (like aircraft) in three-dimensional space. Specifically, the body is free to change position as forward/backward, up/down, left/right translation in three perpendicular axes, combined with changes in orientation through rotation about three perpendicular axes, often termed yaw (normal axis), pitch (lateral axis), and roll (longitudinal axis).The development of six degrees of freedom (6-DOF) aircraft model can be used to design the longitudinal autopilot for autonomous take off and landing. Airplane can move freely in three-dimensional space, with the two horizontal axes as X and Z while the vertical axis is Y. If it needs to face up or down, it needs to change the orientation of its nose from horizontal X to Y, which is called pitch. If the plane needs to turn from the X axis to the Z axis without changing the orientation of its body, it can do a yaw by using its rudder so the wings remain horizontal while the nose starts to point to the Z axis. Finally, since it is often assumed that the X orientation is always where the nose is facing with regards to the plane, moving the plane from X to Y will make it roll, hence the term. The pilot can then combine any of these parameters of movement to execute maneuvers.*

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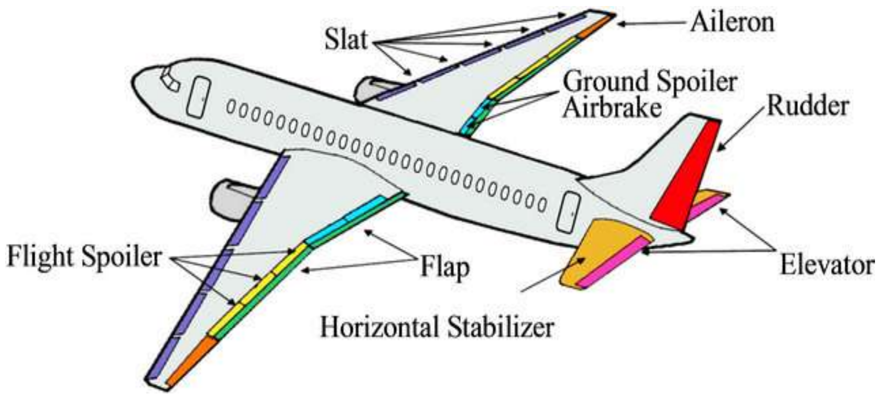
I. Introduction

Six degrees of freedom is a specific parameter count for the number of degrees of freedom an object has in three-dimensional space, such as the real world. It means that there are six parameters or ways that the body can move.

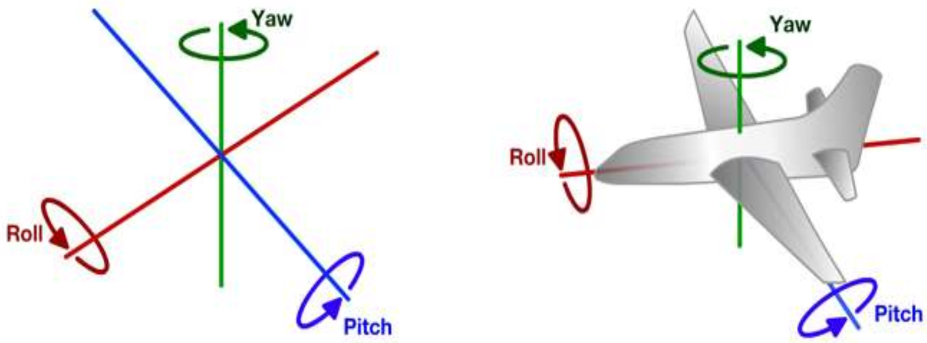
Six degrees of freedom consists of the following movement parameters:

- Translation – Moving along the different axes X, Y and Z
  - Moving up and down along the Y axis is called heaving.
  - Moving forwards and backwards along the X axis is called surging.
  - Moving left and right along the Z axis is called swaying.
- Rotation – Turning in order to face a different axis
  - Moving between X and Y is called pitch.
  - Moving between X and Z is called yaw.
  - Moving between Z and Y is called roll.

An aircraft requires control surfaces to fly and move in different directions. They make it possible for the aircraft to roll, pitch and yaw. Figure shows the three sets of control surfaces and the axes along which they tilt.



The ailerons, operated by turning the control column, cause it to roll. The elevators are operated by moving the control column forward or back causes the aircraft to pitch. The rudder is operated by rudder pedals that make the aircraft yaw. Depending on the kind of aircraft, the requirements for flight control surfaces vary greatly, as specific roles, ranges and needed agilities. Primary control surfaces are incorporated into the wings and empennage for almost every kind of aircraft. Those surfaces are typically: the elevators included on the horizontal tail to control pitch; the rudder on the vertical tail for yaw control; and the ailerons outboard on the wings to control roll.



Axes of Aircraft

These surfaces are continuously checked to maintain safe vehicle control and they are normally trailing edge types.

II. Material and Methods

The primary flight controls surfaces are ailerons, elevator and rudder.

Ailerons

Movement about the longitudinal axis is controlled by the two ailerons, which are movable surfaces at the outer trailing edge of each wing. The movement is roll. If the aileron on one wing is lowered, the aileron on the other will be raised. The wing with the raised aileron goes down because of its decreased lift and the wing with the lowered aileron goes up because of its increased lift. Thus, the effect of moving one of the ailerons is complemented by the simultaneous and opposite movement of the aileron on the other wing. The ailerons are connected to each other and to the control wheel (or stick) in the cockpit by rods or cables. While applying pressure to the right on the control wheel, the right aileron goes up and the left aileron goes down. Thus, the airplane is rolled to the right as the down movement of the left aileron increases the wing camber (curvature) and the angle of attack. The right aileron moves upward and decreases the camber, what results in a decreased angle of attack. Thus, an increased lift on the left wing and decreased lift on the right wing cause a roll and bank to the right.

Elevators

The movement of the airplane about its lateral axis is controlled by the elevators. This motion is called pitch. The elevators are free to swing up and down and form the rear part of the horizontal tail assembly. They are hinged to a fixed surface; the horizontal stabilizer. A single airfoil is formed by the horizontal stabilizer and the elevators. The chamber of the airfoil can be modified by changing the position of the elevators, which increases or decreases the lift. Control cables are used to connect the elevators to the control wheel (or stick) as it happens with the ailerons. The elevators move downward when forward pressure is applied on the wheel. Thus, the lift produced by the horizontal tail surfaces is increased, what forces the tail upward, causing the nose to drop. Conversely, the elevators move upward, when back pressure is applied on the wheel, decreasing the lift produced by the horizontal tail surfaces, or maybe even producing a downward force. The nose is forced upward and the tail is forced down. The angle of attack of the wings is controlled by the elevators. When back pressure is applied on the control wheel, the angle of attack increases as the tail lowers and the nose rises. Conversely, the tail raises and the nose lowers when forward pressure is applied, decreasing the angle of attack.

Rudder

The movement of the airplane about its vertical axis is controlled by the rudder. This motion is called yaw. The rudder is a movable surface hinged to a fixed surface which is the vertical stabilizer, or fin. Its action is similar to the one of the elevators, except that it swings in a different plane; from side to side instead of up and down. The rudder is connected to the rudder pedals by controlled cables.

Secondary Control Surfaces

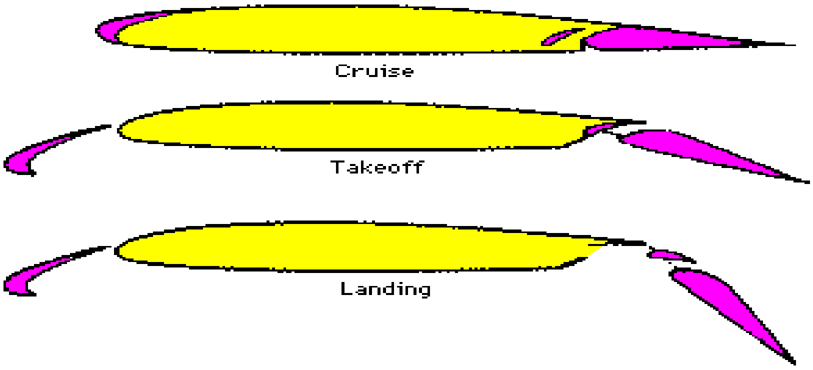
Wing Leading and Trailing edges are used to increase the aerodynamic performance of the aircraft by reducing stall speed mainly during take-off and landing speed. High lift control is provided by a combination of flaps and leading edge slats. The flap control is affected by several flap sections located on the inboard two-thirds of the wing trailing edges. The flaps are deployed during take-off or the landing approach to increase the wing camber and improve the aerodynamic characteristics of the wing.

Flaps

Flaps are mounted on the trailing edge but can also be mounted on the leading edge. They extend the edge by increasing the chord of the wing. They pivot only (simple and split flaps), extend and come down (complex and slotted flaps) or extend and camber (Krueger flaps).

Slats

Slats are usually mounted on the leading edge. Slats extend the edge and they sit like a glove on the edge. "Slats" is an abbreviation for "slotted flaps", which means they have a nozzle like slot between the high-lift device and the wing; on the contrary, flaps do not have this slot. Figure shows the wing leading and trailing edge configurations commonly used.



Slats of Aircraft

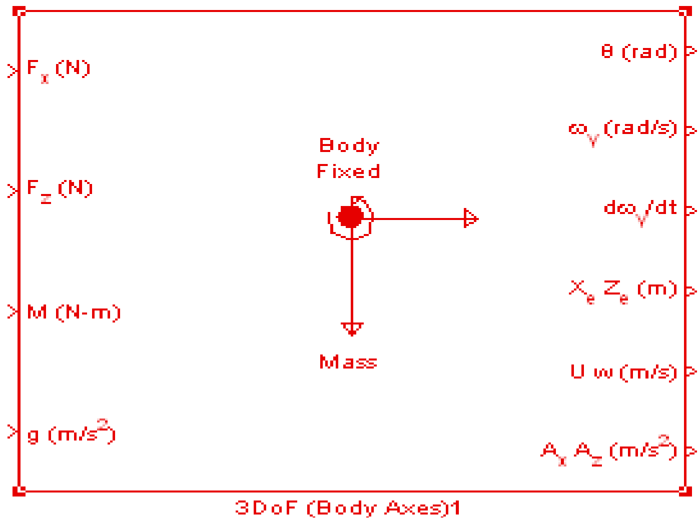
New Approach to improvement for takeoff and landing with 6 Degree of Freedom

To eliminate the accidents during takeoff and landing of aircraft, it should improve the tools of treatments of degree of freedom and equation of motion. By use advanced methods to obtain high performance and low cost in short time and in short runway. In older method longitudinal and lateral motion has discussed separately to improve. In the model of aircraft give the virtual reading near the actual reading. It has overcome the problem of the loss of control during takeoff and landing. Autopilot has ensured the takeoff and landing advanced airport but in many counties they don't have advance airport. When aircraft instruments reading is correct then no need of autopilot to safe takeoff and landing. Our research are going on to improve the passive safety of the aircraft, both in takeoff and landing by experimental methods.

Comparison of new approach of Six degree of freedom over the three degree of freedom

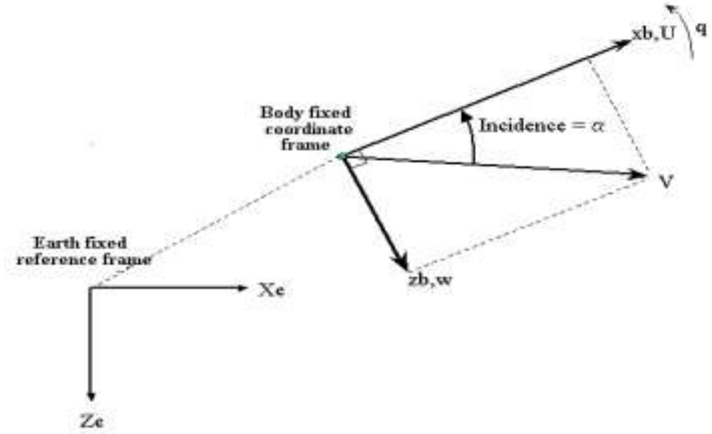
Three degree of freedom (3-DoF) Environment

In three degree of freedom the flight dynamics has one rotation and two translation axes. The older design implemented the three-degrees-of-freedom equations of motion with respect to body axes of an aircraft.



Three degree of freedom (3-DoF) Block

The 3DoF (Body Axes) block considers the rotation in the vertical plane of a body-fixed coordinate frame about an Earth-fixed reference frame.



Implementation of three degree of freedom (3-DoF)

The equations of motion are

$$\dot{u} = \frac{F_x}{m} - qw - g\sin\theta$$

$$\dot{w} = \frac{F_z}{m} + qu + g\cos\theta$$

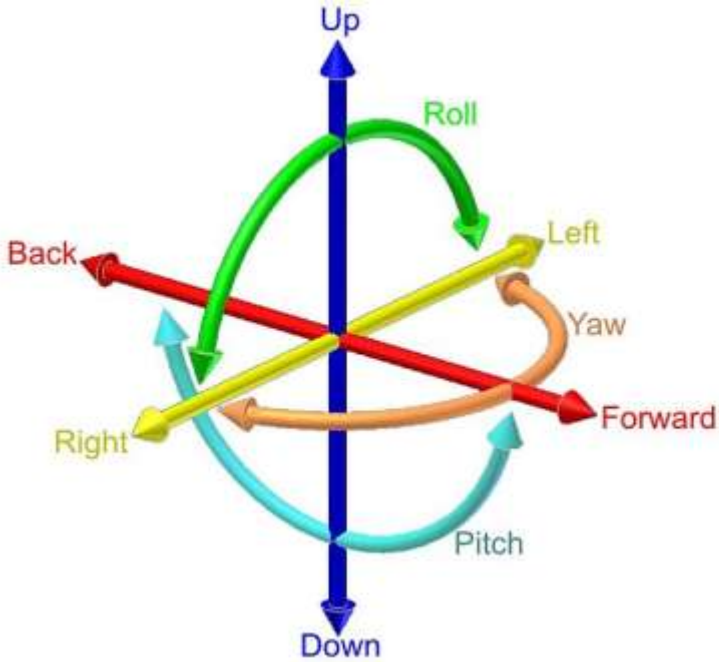
$$\dot{q} = \frac{M}{I_{yy}}$$

$$\dot{\theta} = q$$

Where the applied forces are assumed to act at the center of gravity of the body of aircraft.

Six degree of freedom (6-DOF) Environment with new approach

Six degrees of freedom (6DoF) refers to the freedom of movement of an aircraft body in three-dimensional space. Specifically, the body is free to change position as forward/backward (surge), up/down (heave), left/right (sway) translation in three perpendicular axes, combined with changes in orientation through rotation about three perpendicular axes, often termed pitch, yaw, and roll.



Six degree of freedom (6-DoF) of an aircraft

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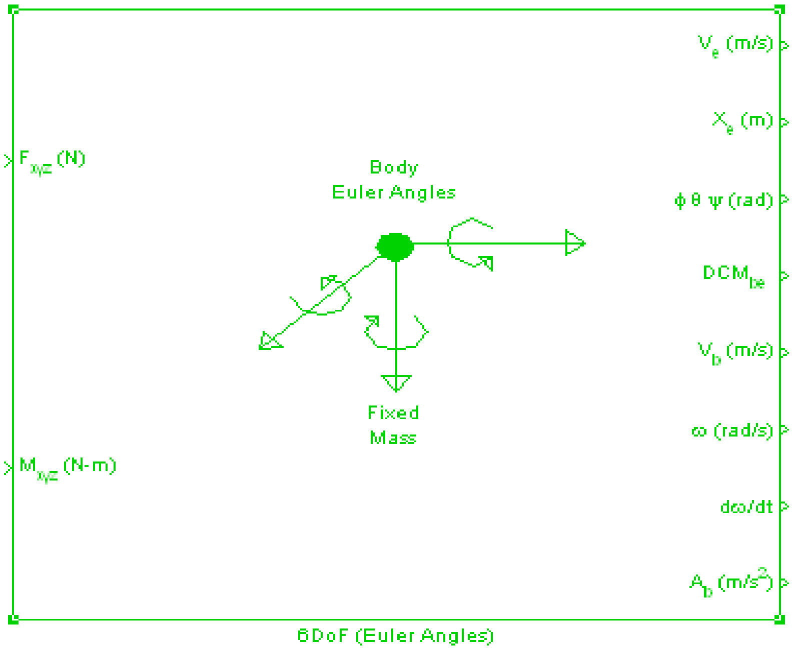
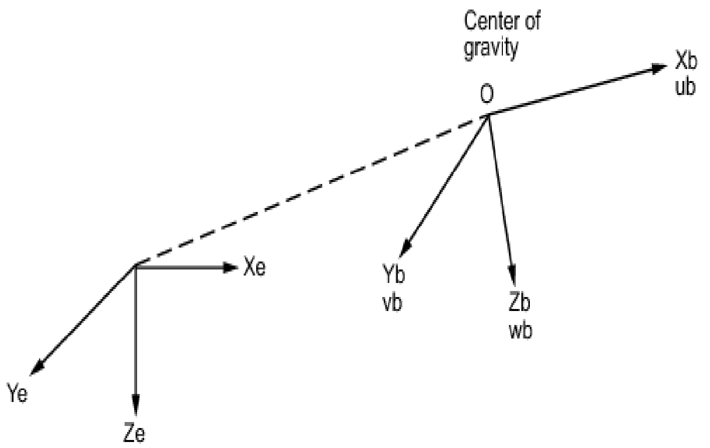
In new approach of 6-DoF, dynamics of aircraft works with three rotations and three translation axes. The implementation of Euler angle representation the six-degrees-of-freedom equations of motion.



New block of six degree of freedom (6-DoF)

The 6DoF (Euler Angles) block considers the rotation of a body-fixed coordinate frame (X_b , Y_b , Z_b) about a flat Earth reference frame (X_e , Y_e , Z_e). The origin of the body-fixed coordinate frame is the center of gravity of the body, and the body is assumed to be rigid, an assumption that eliminates the need to consider the forces acting between individual elements of mass.



Implementation of six degree of freedom (6-DoF)

The translational motion of aircraft body-fixed coordinate frame is given below, where the applied forces [F_x $F_y F_z$]^T are in the body-fixed frame, and the mass of the body m is assumed constant.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m\left(\dot{\bar{V}}_b + \bar{\omega} \times \bar{V}_b\right)$$

$$\bar{V}_b = \begin{bmatrix} u_b \\ v_b \\ w_b \end{bmatrix}, \bar{\omega} = \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

The rotational dynamics of the body-fixed frame are given below, where the applied moments are $[L\ M\ N\ ]^T$, and the inertia tensor I is with respect to the origin O.

$$\bar{M}_B = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}} + \bar{\omega} \times (I\bar{\omega})$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

The relationship between the body-fixed angular velocity vector, $[p\ q\ r]^T$, and the rate of change of the Euler angles, $[\theta\ \Phi\ \varphi\ ]^T$, can be determined by resolving the Euler rates into the body-fixed coordinate frame.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting J then gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi\tan\theta) & (\cos\phi\tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

III. Result and Discussion

The important uses of Six-Degree of Freedom over Three-Degree of Freedom in aircraft field, it to give the more accurate data for instruments reading to reduce the mistake in landing and takeoff. So the development of Six-Degree of Freedom is necessary to find the suitable takeoff and landing.

Advantage of six degree of freedom over three degree of freedom is given in the following table.

3-DoF	Existing 6-DoF	Proposed 6-DoF
The three rotational motions, Pitch, Yaw were not supportedthe linear translations.	It supports the all six degree of freedom eventually. Thus supporting all 6 degrees of motion.	The thing with the first three is Euler angular *velocity*. Taking only 1 derivative of that input to create a position is fairly clean, plus it has added the gravity (accelerometer) as a reference point to prevent drift over time.
A 3DoF manufacturing device (aircraft) can get a lot of useful work done without ever needing to do any amount of rotating,	6DOF device uses three separate blocks to generate all motions. It has no new block to support complete the process together.	When linear translations become a problem then linear accelerometers detect acceleration instead of velocity.
It contains the velocity of the body resolved into the body-fixed coordinate frame, (u, w).	It contains the velocity in the body-fixed frame.	It contains the velocity, angular rates in body-fixed axes, in radians per second.
It contains the acceleration of the body resolved into the body-fixed coordinate frame, (Ax, Az).	It contains the accelerations in body-fixed axes.	It contains the accelerations, angular accelerations in body-fixed axes, in radians per second.
It contains the location of the body, in the Earth-fixed reference frame, (Xe, Ze).	It contains the Euler rotation angles [roll, pitch, yaw], in radians.	It contains the coordinate transformation from flat Earth axes to body-fixed axes.

IV. Conclusion

An aircraft in flight is free to rotate in three dimensions: pitch, nose up or down about an axis running from wing to wing; yaw, nose left or right about an axis running up and down; and roll, rotation about an axis running from nose to tail. The axes are alternatively designated as lateral, vertical, and longitudinal. These axes move with the vehicle and rotate relative to the Earth along with the craft. These rotations are produced by torques (or moments) about the principal axes. On an aircraft, these are intentionally produced by means of moving control surfaces, which vary the distribution of the net aerodynamic force about the vehicle's center of mass. Elevators (moving flaps on the horizontal tail) produce pitch, a rudder on the vertical tail produces yaw, and ailerons (flaps on the wings that move in opposing directions) produce roll.

The dynamic model to represent the target aircraft is 6 degrees of freedom model, describing the ascending and descending movement, the velocity variation in the vertical movement and the altitude change as a function of the aircraft climbing or descent. The longitudinal dynamic model is characterized by the pitch angle. The reference value of the pitch angle depends on the desired values of the aircraft altitude and velocity.
The aim to use six degree of freedom in aircraft is to maintain a safe and economic operation. Thus, the desired flight missions can be accomplished even under unexpected events. In the early days of flight, safety was the main concern of a flight control system. Since the number of flights and number of people using planes for travel has increased, safety is even more important.

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