Chapter 6 Kinematics

6.1. Introduction

Kinematics is the term applied to the design and analysis of those parts used to retract and extend the gear [2]. Particular attention is given to the determination of the geometry of the deployed and retracted positions of the landing gear, as well as the swept volume taken up during deployment/retraction. The objective is to develop a simple deployment/retraction scheme that takes up the least amount of stowage volume, while at the same time avoiding interference between the landing gear and surrounding structures. The simplicity requirement arises primarily from economic considerations. As shown from operational experience, complexity, in the forms of increased part-count and maintenance down-time, drives up the overall cost faster than weight [5]. However, interference problems may lead to a more complex system to retract and store the gear within the allocated stowage volume.

Based on the analysis as outlined in this chapter, algorithms were developed to establish the alignment of the pivot axis which permits the deployment/retraction of the landing gear to be accomplished in the most effective manner, as well as to determine the retracted position of the assemblies such that stowage boundary violations and structure interference can be identified.

6.2. Retraction Scheme

For safety reasons, a forward-retracting scheme is preferable for the fuselage-mounted assemblies. In a complete hydraulic failure situation, with the manual release of uplocks, the gravity and air drag would be utilized to deploy and down-lock the assembly and thus avoid a wheels-up landing [2]. As for wing-mounted assemblies, current practice calls for an inboard-retraction scheme which stows the assembly in the space directly behind the rear wing-spar. The bogie undercarriage may have an extra degree of freedom available in that the truck assembly can rotate about the bogie pivot point, thus requiring a minimum of space when retracted. As will be illustrated in the following section, deployed/retracted position of the landing gear, as well as possible interference between the landing gear and surrounding structures, can easily be identified using the mathematical kinematic analysis.

6.3. Mathematical Kinematic Analysis

A mathematical kinematic analysis, which is more effective and accurate than the graphical technique, was selected to determine the axis of rotation that will, in one articulation, move the landing gear assembly from a given deployed position to a given retracted position. As shown in Fig. 6.1, a new coordinate system, termed the kinematic reference frame here, is defined such that the origin is located at the respective landing gear attachment locations with the axes aligned with the aircraft reference frame. The aircraft coordinate system-based origin permits constraints established in the kinematic reference frame, *e.g.*, assembly clearance envelope, retraction path, and swept volume, be translated into the aircraft reference frame and checked for interference with surrounding structures.

6.3.1. The Pivot Axis and Its Direction Cosines

In the determination of the alignment of the landing gear pivot axis, it is assumed that the axle/piston centerline intersection is brought from its deployed position to a given location within the stowage volume. For wing-mounted assemblies, the retracted position of axle/piston centerline intersection is assumed to coincide with the center of the stowage volume. In the case of fuselage-mounted assemblies with a forward-retracting scheme, the retracted position is assumed to be at the center of the cross-sectional plane located at the forward third of the stowage length.[*]

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[*] Note: to reduce structural cut-away, many forward retracting gears have shrink mechanisms. In particular, it appears that the Airbus A 330 and A340 aircraft may have shrink struts on the main gear. This consideration is neglected in the current analysis, but probably should be considered.

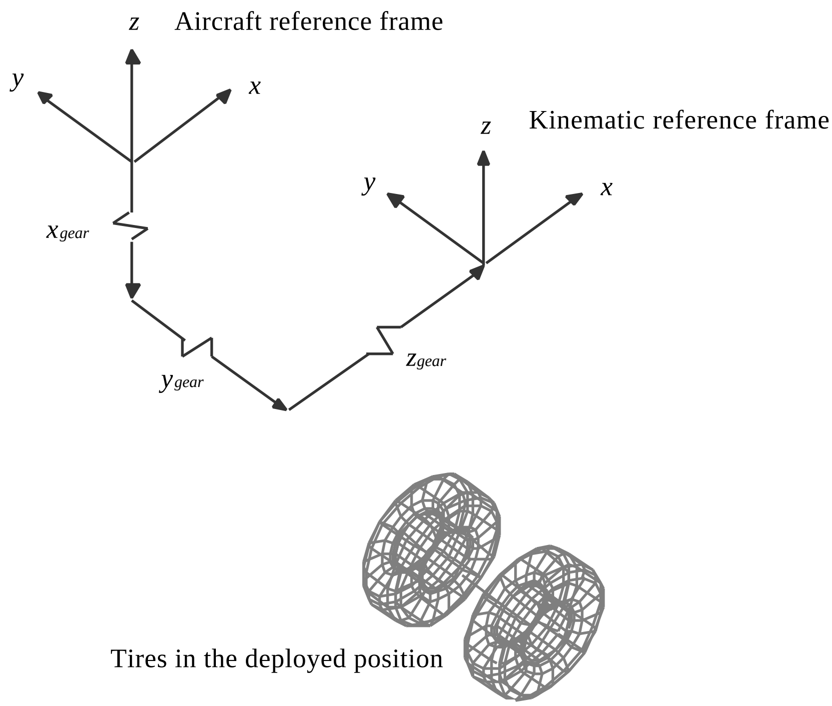

Figure 6.1 Relationships between the aircraft and kinematic reference frames

6.3.1.1. The Fuselage-mounted Assembly

For fuselage-mounted assemblies with a forward retracting-scheme, the pivot axis is defined by the cross product of the space vectors corresponding to the deployed and retracted position of a point location on the truck assembly. As shown in Fig. 6.2, the cross product of two vectors ($\mathbf{V}_1$ and $\mathbf{V}_2$) representing the deployed and retracted positions of a given point location, here taken as the axle/piston centerline intersection, is orthogonal to both vectors, *i.e.*, in the direction of the pivot axis. Thus,

$$\mathbf{V} = \mathbf{V}_1 \times \mathbf{V}_2 \tag{6.1}$$

From standard vector operation, the direction cosines of the fuselage-mounted assembly is given as

$$l = \frac{X}{\sqrt{X^2 + Y^2 + Z^2}} \qquad m = \frac{Y}{\sqrt{X^2 + Y^2 + Z^2}} \qquad n = \frac{Z}{\sqrt{X^2 + Y^2 + Z^2}} \tag{6.2}$$

and the angle between the two vectors, *i.e.*, the angle of retraction (ϕ_{full}) in this case, is calculated using the expression

$$\cos\phi_{full} = l_1 l_2 + m_1 m_2 + n_1 n_2 \quad (6.3)$$

where l_i, m_i, and n_i are the respective direction cosines of the deployed and retracted space vectors.

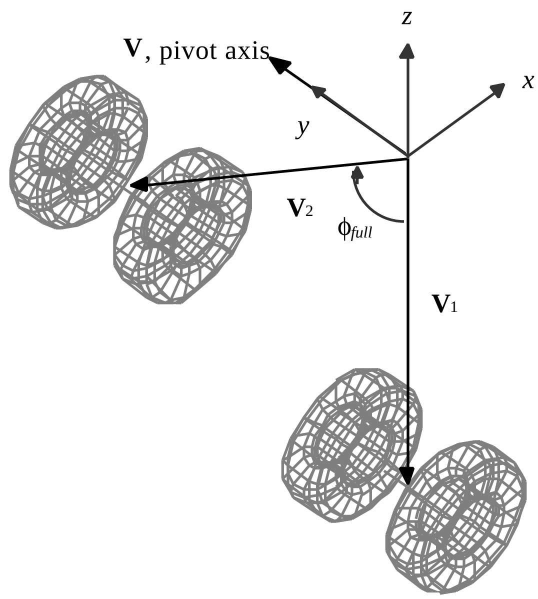

Figure 6.2 Fuselage-mounted assembly pivot axis alignment

6.3.1.2. The Wing-mounted Assembly

The determination of the wing-mounted assembly pivot axis involves the deployed and retracted positions of two points on the assembly. Essentially, the problem consists of bringing the line segment between the two points from its deployed position to its retracted position [31]. For ease of visualization, a twin-wheel configuration is used here to illustrate the procedure involved in determining the alignment of the desired pivot axis. Identical procedure is used for other configurations as well.

As shown in Fig. 6.3, the axle/piston centerline intersection is selected as the first point (point A), while the second point (point B) is conveniently located at a unit distance along the axle, inboard from the first point location. retracted positions of the first and second points are given as point A' and B', respectively.

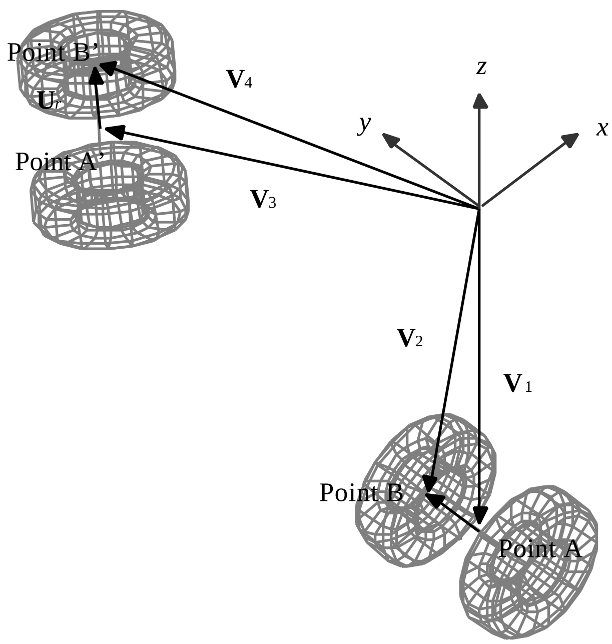

Figure 6.3 Vector representation of the wing-mounted landing gear

Of the four point positions required in the analysis, the positions of point A and A' are readily determined from the geometry of the landing gear and the stowage volume, respectively. From simple vector algebra

$$\mathbf{V}_2 = \mathbf{V}_1 + \hat{j} \tag{6.4}$$

where subscripts 1 and 2 denote the space vector corresponding to the deployed positions of points A and B, respectively. Similarly,

$$\mathbf{V}_4 = \mathbf{V}_3 + \mathbf{U}_r \tag{6.5}$$

where subscript 3 and 4 denote the retracted positions of point A and B, respectively, and $\mathbf{U}_r$ defines the orientation of the unit vector in its retracted position and is unknown.

To solve for $\mathbf{U}_r$, it is assumed that no devices are used to shorten the length of the strut during the retraction process, *i.e.*, that the magnitudes of $\mathbf{V}_2$ and $\mathbf{V}_4$ remain constant,

$$X_1^2 + (Y_1 + 1)^2 + Z_1^2 = (X_3 + X_U)^2 + (Y_3 + Y_U)^2 + (Z_3 + Z_U)^2 \tag{6.6}$$

and that the magnitude of the retracted unit vector remains at unity

$$X_U^2 + Y_U^2 + Z_U^2 = 1 \tag{6.7}$$

The angle of inclination (θ) of $\mathbf{U}_r$ in the *yz*-plane, which is one of the design variables that can be used to position the retracted truck assembly to fit into the available stowage space, is given as

$$\tan\theta = \frac{Y_U}{Z_U} \tag{6.8}$$

The vector components of $\mathbf{U}_r$, and subsequently $\mathbf{V}_4$, can then be determined by solving Eqs (6.6), (6.7), and (6.8) simultaneously.

As shown in Fig. 6.4, the pivot axis that will permit the achievement of the desired motion is defined by the cross product of the space vectors between the deployed and retracted positions of the two point locations, in this case points A and B,

$$\mathbf{V} = \mathbf{V}_B \times \mathbf{V}_A \tag{6.9}$$

where

$$\mathbf{V}_A = (X_3 - X_1)\hat{i} + (Y_3 - Y_1)\hat{j} + (Z_3 - Z_1)\hat{k} \tag{6.10}$$

and

$$\mathbf{V}_B = (X_4 - X_2)\hat{i} + (Y_4 - Y_2)\hat{j} + (Z_4 - Z_2)\hat{k} \tag{6.11}$$

Thus, the direction cosines of the wing-mounted assembly and the angle of rotation can be determined using Eqs (6.2) and (6.3), respectively. Note that the subscripts in Eq. (6.3) will be 1 and 3 in this case, *i.e.*, the vectors corresponding to the deployed and retracted positions of point A, respectively.

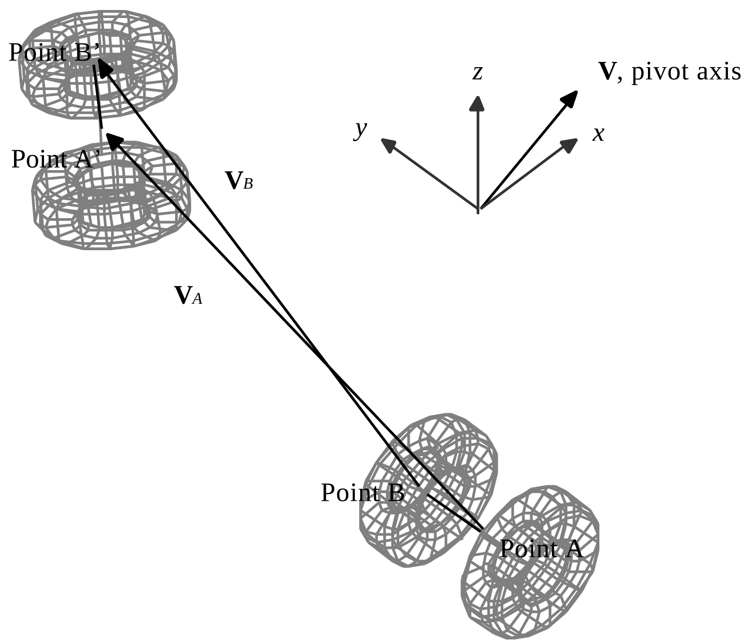

Figure 6.4 Wing-mounted assembly pivot axis alignment

6.3.2. Retracted Position of a Given Point Location

In addition to determining the required pivot axis and angle of retraction, the analytic method is used to establish the retraction path and the stowed position of the landing gear assembly. Note that the drag and side struts are excluded in the analysis since the retraction of these items involves additional articulation, *e.g.*, folding and swiveling, that cannot be modeled by the analysis.

Define point A as an arbitrary point location on the landing gear assembly. Given the angle of rotation and the direction cosines of the pivot axis as determined above, the retracted position of point A, denoted here as **A'**, can be determined by solving the following system of linear algebraic equations [2, pp. 193-194]

$$\begin{bmatrix} X_{A'} \\ Y_{A'} \\ Z_{A'} \end{bmatrix} = c_1 \begin{bmatrix} l(lX_A + mY_A + nZ_A) - X_A \\ m(lX_A + mY_A + nZ_A) - Y_A \\ n(lX_A + mY_A + nZ_A) - Z_A \end{bmatrix} + c_2 \begin{bmatrix} mZ_A - nY_A \\ nX_A - lZ_A \\ lY_A - mX_A \end{bmatrix} + \begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} \qquad (6.12)$$

where

$$c_1 = 1 - \cos\phi \qquad c_2 = \sin\phi \qquad 0 < \phi < \phi_{full} \qquad (6.13)$$

Similarly, the retraction path and swept volume of the assembly, as shown in Fig. 6.5, can be established by calculating several intermediate transit positions at a given interval of degrees. The above information can then be used to identify possible interference between the landing gear and surrounding structures during deployment/retraction.

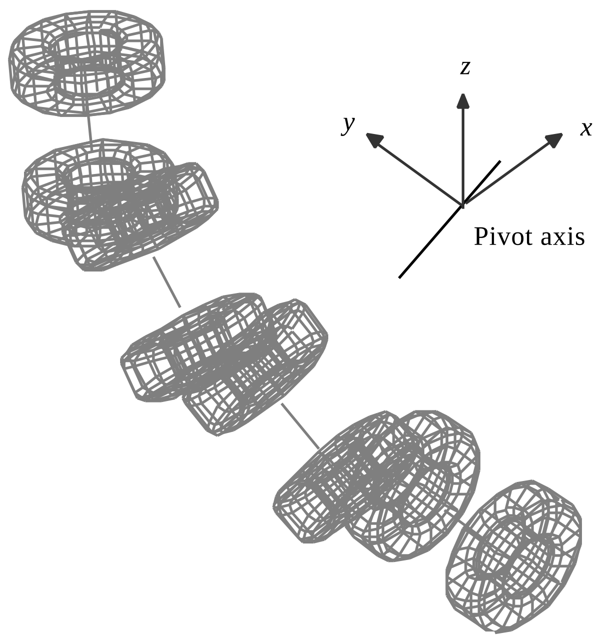

Figure 6.5 Retraction path and swept volume of the landing gear

6.4. Integration and Stowage Considerations

For future large aircraft, interference between the landing gear assembly and the surrounding structure is one of the more important considerations in the development of kinematics. With the large number of doors required to cover the stowage cavity on such aircraft, a complex deployment/retraction scheme for both the landing gear and doors is required to ensure that no interference will occur under all conditions. Additionally, the availability of stowage volume can become a major integration problem as the number of tires increases with aircraft takeoff weight. Given the conflicting objectives between maximizing the volume that can be allocated for revenue-generating cargoes and providing adequate landing gear stowage space, a trade-off study involving crucial design parameters, *e.g.*, pivot axis alignment, angle of retraction, and bogie rotation, is needed to arrive at a satisfactory compromise with surround structures.

6.4.1. Truck Assembly Clearance Envelope

Clearances are provided to prevent unintended contact between the tire and the adjacent parts of the aircraft during operation, particularly in the case when the tire is damaged and continues to spin when stowed. As shown in Fig. 6.6, the maximum grown outside diameter (D_G) and section width (W_G) are determined using the expressions [25, p. 8]

$$D_G = D + 2(1.115 - 0.074\,AR)H \tag{6.14}$$

and

$$W_G = 1.04\,W \tag{6.15}$$

where D is the specified rim diameter, H is the maximum section height, W is the maximum section width, and AR is the tire aspect ratio defined as

$$AR = \frac{H}{D} \tag{6.16}$$

The values for the radial and lateral clearance, *i.e.*, C_R and C_W, respectively, are calculated using the expressions [25, p. 9]

$$C_R = \begin{bmatrix} 0.073 \\ 0.060 \\ 0.047 \\ 0.037 \\ 0.029 \end{bmatrix} W_G + 0.4 \qquad at \quad \begin{Bmatrix} 250\,MPH \\ 225\,MPH \\ 210\,MPH \\ 190\,MPH \\ 160\,MPH \end{Bmatrix} \tag{6.17}$$

and

$$C_W = 0.019 W_G + 0.23 \tag{6.18}$$

The constant coefficients found in Eqs (6.14), (6.15), and (6.16) are based on the maximum overall tire dimensions, plus growth allowance due to service and the increase in diameter due to centrifugal force.

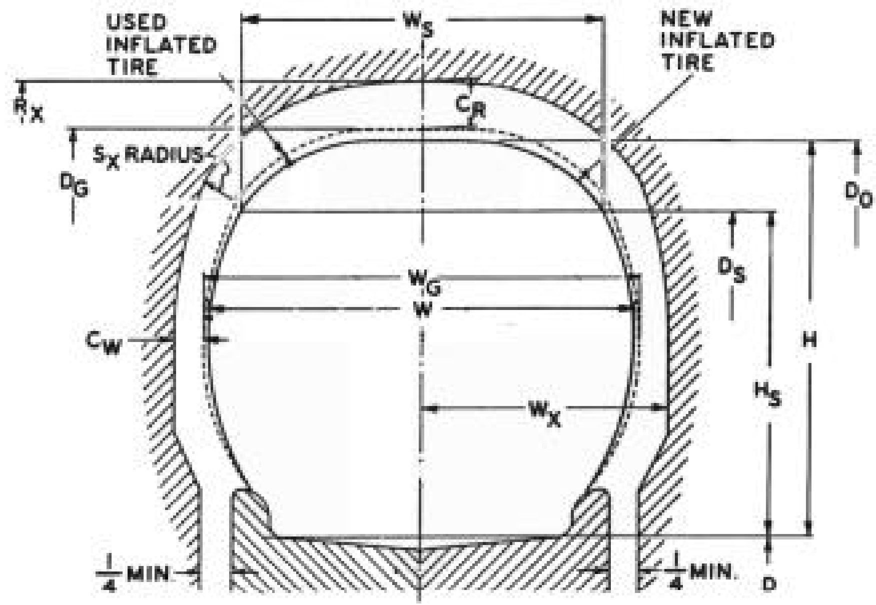

Figure 6.6 Clearance envelope for aircraft tires [25]

Based on the clearance as determined above, the minimum radial and lateral distance between the tire and surrounding structures are calculated as follows [25, p. 9]

$$R_x = \frac{D_G}{2} + C_R \tag{6.18}$$

$$W_x = \frac{W_G}{2} + C_W \tag{6.19}$$

$$S_x = \frac{C_W + C_R}{2} \tag{6.20}$$

Given the minimum allowable distances obtained using Eqs (6.18), (6.19), and (6.20), a clearance envelope is established around the truck assembly. Then, using the kinematic analysis as outlined in the previous section, the boundary of the envelope is re-established in the retracted position. Note that the envelope is represented in the kinematic coordinate system, while the boundaries of the landing gear wheelwell are in the aircraft coordinate system. Recall that the origin of the kinematic reference frame is defined in the aircraft coordinate system. Thus, simple algebraic manipulation would bring both sets of data under the same coordinate system, whether it be the airframe or the kinematic reference frame. Stowage boundary violations can then be identified by comparing both sets of data for discrepancies.