ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VI (XVI), 2007

KINEMATIC MODELLING BY MBS METHOD APPLIED TO LINKAGES USED TO AIRCRAFT CONTROL

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Keywords: mechanical systems, multibody systems, structural modeling, kinematic analysis, aircraft, Flaps

Abstract: The aim of the paper is kinematic modelling of linkages used in airplane control, on bases of the Multibody System method (MBS). In virtual prototyping of the aircraft , these linkages have to be modeled by a minimum number of bodies (MBS min). In this paper an appropiate algorithm is descriebed and also applied for concrete mechanical systems. This will be the bases for dynamic modelling of these subsystems as parts of the whole product (airplane).

1. INTRODUCTION

Generally control surfaces of an aircraft include : ailerons , rudder , elevator , tabs and flaps(see figure1). Movement of this surfaces generate roll, pitch and yaw. During the fly flaps move between "cruise posision" and "landing position" by intermediate of mechanical transmissions.

In design process of an aircraft one of the main step is virtual prototyping.
In virtual prototyping of the aircraft, mechanical systems are considered as Multibody Systems (MBS). They have to be modelled as MBS with minimum number of bodies (MBS min) to favorise obtaining real time simulation of aircraft.

The aim of this paper is kinematic modelling of linkages used for actioning of aileron as multibody systems. On bases of MBS, dynamic models could be obtained.

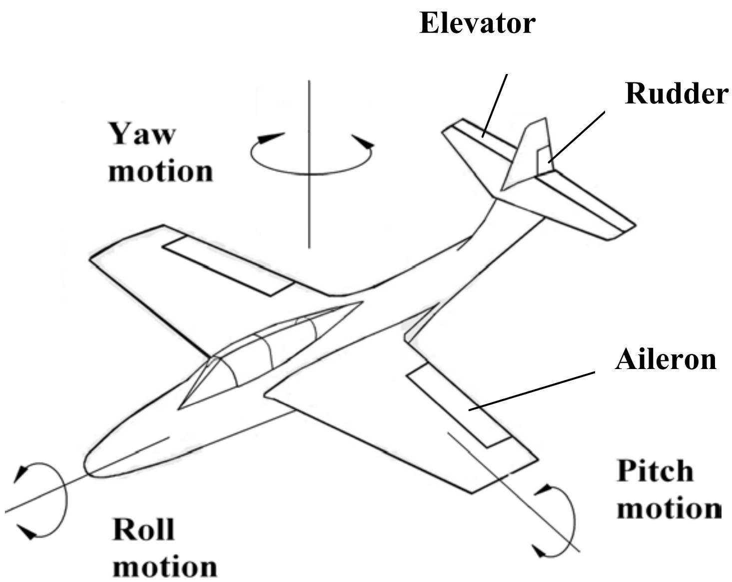

Fig 1- Aircraft controls

2. KINEMATIC ANALYSIS OF CONCRETE LINKAGE

In the paper , one linkage used for aileron control is analized.
The bases of this linkage is wing structure , that represent for the linkage – fixed body. The output body is the ailerons. The input motion is generated by pilot from control lever by intermediate of mechanical / hydraulic actuators.

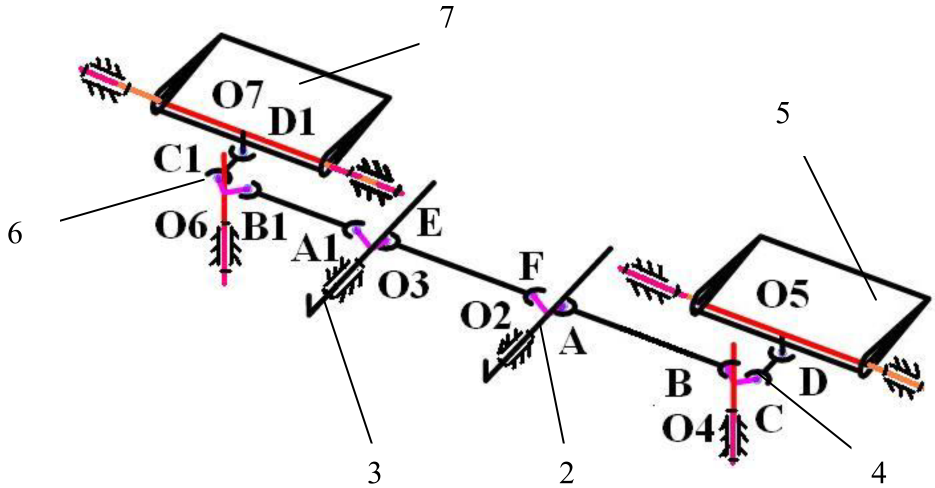

Fig 2 – Aileron controls – structural scheme

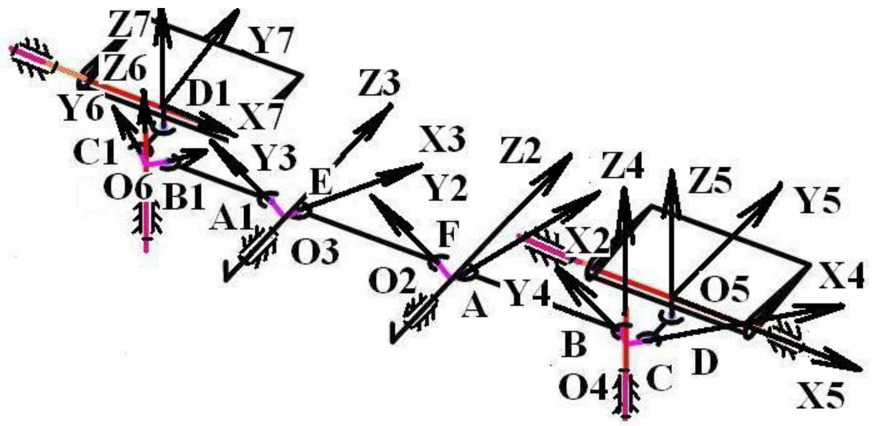

Fig 3 – Aileron controls – Kinematic scheme

The linkage from fig 2 is modeled as MBS min having 7 bodies, six geometrical constraints type R and five geometrical constraints type SS. The input body is body 2 and the output bodies are the ailerons 5 and 7. Mobility M =1 (see table1).
Figure 3 represent kinematic scheme at this aileron mechanism.

Table 1: aileron control (see fig 3)

Body i Body j	gc	Location	Number of constraints
1-2	R	O2	5
1-3	R	O3	5
1-4	R	O4	5
1-5	R	O5	5
1-6	R	O6	5
1-7	R	O7	5
2-3	SS	EF	1
2-4	SS	AB	1
2-5	-	-	-
2-6	-	-	-
2-7	-	-	-
3-4	-	-	-
3-5	-	-	-
3-6	SS	A1B1	1
3-7	-	-	-
4-5	SS	CD	1
4-6	-	-	-
4-7	-	-	-
5-6	-	-	-
5-7	-	-	-
6-7	SS	C1D1	1

$$M = S\,(n_b - 1) - \Sigma\, r$$

$$\Sigma\, r = 35 \qquad (1)$$

$$n_b = 7 \quad \text{si} \quad S = 6$$

$$M = 1$$

Between bodies “2” and “4” we have geometrical constraint AB type SS:

$$(X_A - X_B)^2 + (Y_A - Y_B)^2 + (Z_A - Z_B)^2 = AB^2$$

Where:

$$\begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} = \begin{bmatrix} X_{O2} \\ Y_{O2} \\ Z_{O2} \end{bmatrix} + M_{21} \begin{bmatrix} X_A^{(2)} \\ Y_A^{(2)} \\ Z_A^{(2)} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = \begin{bmatrix} X_{O4} \\ Y_{O4} \\ Z_{O4} \end{bmatrix} + M_{41} \begin{bmatrix} X_B^{(4)} \\ Y_B^{(4)} \\ Z_B^{(4)} \end{bmatrix} \qquad (2)$$

Rotation matrix are:

$$M_{21} = M_\gamma\ ,\ M_\gamma = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \quad \text{and} \quad M_{41} = M_\alpha = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (3)$$

Generally rotation matrix is:

$$M_i = \begin{bmatrix} \cos(X_i, X) & \cos(Y_i, X) & \cos(Z_i, X) \\ \cos(X_i, Y) & \cos(Y_i, Y) & \cos(Z_i, Y) \\ \cos(X_i, Z) & \cos(Y_i, Z) & \cos(Z_i, Z) \end{bmatrix} \tag{4}$$

Result:

$$\begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} = \begin{bmatrix} X_{O2} \\ Y_{O2} \\ Z_{O2} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} X_A^{(2)} \\ 0 \\ 0 \end{bmatrix} \text{ and } \begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = \begin{bmatrix} X_{O4} \\ Y_{O4} \\ Z_{O4} \end{bmatrix} + \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ Y_B^{(4)} \\ 0 \end{bmatrix} \tag{5}$$

Where:

$$\alpha = f(t), \beta = \mathrm{f(t)} \text{ and } \gamma = \mathrm{f(t)} \tag{6}$$

Between bodies “2” and “3” we have geometrical constraint EF type SS:

$$(X_E - X_F)^2 + (Y_E - Y_F)^2 + (Z_E - Z_F)^2 = EF^2$$

$$\begin{bmatrix} X_F \\ Y_F \\ Z_F \end{bmatrix} = \begin{bmatrix} X_{O2} \\ Y_{O2} \\ Z_{O2} \end{bmatrix} + M_{21} \begin{bmatrix} X_F^{(2)} \\ Y_F^{(2)} \\ Z_F^{(2)} \end{bmatrix} \text{ and } \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} = \begin{bmatrix} X_{O3} \\ Y_{O3} \\ Z_{O3} \end{bmatrix} + M_{31} \begin{bmatrix} X_E^{(3)} \\ Y_E^{(3)} \\ Z_E^{(3)} \end{bmatrix} \tag{7}$$

Where:

$$M_{21} = M_{31} = M_\gamma, \quad M_\gamma = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \tag{8}$$

Result:

$$\begin{bmatrix} X_F \\ Y_F \\ Z_F \end{bmatrix} = \begin{bmatrix} X_{O2} \\ Y_{O2} \\ Z_{O2} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} 0 \\ Y_F^{(2)} \\ 0 \end{bmatrix} \text{and} \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} = \begin{bmatrix} X_{O3} \\ Y_{O3} \\ Z_{O3} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} X_E^{(3)} \\ 0 \\ 0 \end{bmatrix}$$

Between bodies “4” and “5” we have geometrical constraint CD type SS:

$$(X_C - X_D)^2 + (Y_C - Y_D)^2 + (Z_C - Z_D)^2 = CD^2$$

$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \end{bmatrix} = \begin{bmatrix} X_{O4} \\ Y_{O4} \\ Z_{O4} \end{bmatrix} + M_{41} \begin{bmatrix} X_C^{(4)} \\ Y_C^{(4)} \\ Z_C^{(4)} \end{bmatrix} \text{ and } \begin{bmatrix} X_D \\ Y_D \\ Z_D \end{bmatrix} = \begin{bmatrix} X_{O5} \\ Y_{O5} \\ Z_{O5} \end{bmatrix} + M_{51} \begin{bmatrix} X_D^{(5)} \\ Y_D^{(5)} \\ Z_D^{(5)} \end{bmatrix} \tag{9}$$

Where:

$$M_{41} = M_\alpha = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \text{ and } M_{51} = M_\beta = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix}$$

Result:

$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \end{bmatrix} = \begin{bmatrix} X_{O4} \\ Y_{O4} \\ Z_{O4} \end{bmatrix} + \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_C{}^{(4)} \\ Y_C{}^{(4)} \\ Z_C{}^{(4)} \end{bmatrix} \text{ and } \begin{bmatrix} X_D \\ Y_D \\ Z_D \end{bmatrix} = \begin{bmatrix} X_{O5} \\ Y_{O5} \\ Z_{O5} \end{bmatrix} + \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix} \begin{bmatrix} X_D{}^{(5)} \\ Y_D{}^{(5)} \\ Z_D{}^{(5)} \end{bmatrix}$$

Between bodies “3” and “6” we have geometrical constraint A1B1 type SS:

$$(X_{A1} - X_{B1})^2 + (Y_{A1} - Y_{B1})^2 + (Z_{A1} - Z_{B1})^2 = A1B1^2 \tag{10}$$

$$\begin{bmatrix} X_{A1} \\ Y_{A1} \\ Z_{A1} \end{bmatrix} = \begin{bmatrix} X_{O3} \\ Y_{O3} \\ Z_{O3} \end{bmatrix} + M_{31} \begin{bmatrix} X_{A1}{}^{(3)} \\ Y_{A1}{}^{(3)} \\ Z_{A1}{}^{(3)} \end{bmatrix} \text{ and } \begin{bmatrix} X_{B1} \\ Y_{B1} \\ Z_{B1} \end{bmatrix} = \begin{bmatrix} X_{O6} \\ Y_{O6} \\ Z_{O6} \end{bmatrix} + M_{61} \begin{bmatrix} X_{B1}{}^{(6)} \\ Y_{B1}{}^{(6)} \\ Z_{B1}{}^{(6)} \end{bmatrix}$$

Where:

$$M_{31} = M_\gamma = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \text{ and } M_{61} = M_\alpha = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Result: (11)

$$\begin{bmatrix} X_{A1} \\ Y_{A1} \\ Z_{A1} \end{bmatrix} = \begin{bmatrix} X_{O3} \\ Y_{O3} \\ Z_{O3} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} X_{A1}{}^{(3)} \\ Y_{A1}{}^{(3)} \\ Z_{A1}{}^{(3)} \end{bmatrix} \text{ and } \begin{bmatrix} X_{B1} \\ Y_{B1} \\ Z_{B1} \end{bmatrix} = \begin{bmatrix} X_{O6} \\ Y_{O6} \\ Z_{O6} \end{bmatrix} + \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{B1}{}^{(6)} \\ Y_{B1}{}^{(6)} \\ Z_{B1}{}^{(6)} \end{bmatrix}$$

Between bodies “6” and “7” we have geometrical constraint C1D1 type SS:

$$(X_{C1} - X_{D1})^2 + (Y_{C1} - Y_{D1})^2 + (Z_{C1} - Z_{D1})^2 = C1D1^2$$

$$\begin{bmatrix} X_{C1} \\ Y_{C1} \\ Z_{C1} \end{bmatrix} = \begin{bmatrix} X_{O6} \\ Y_{O6} \\ Z_{O6} \end{bmatrix} + M_{61} \begin{bmatrix} X_{C1}{}^{(6)} \\ Y_{C1}{}^{(6)} \\ Z_{C1}{}^{(6)} \end{bmatrix} \text{ and } \begin{bmatrix} X_{D1} \\ Y_{D1} \\ Z_{D1} \end{bmatrix} = \begin{bmatrix} X_{O7} \\ Y_{O7} \\ Z_{O7} \end{bmatrix} + M_{71} \begin{bmatrix} X_{D1}{}^{(7)} \\ Y_{D1}{}^{(7)} \\ Z_{D1}{}^{(7)} \end{bmatrix} \tag{12}$$

Where:

$$M_{61} = M_\alpha = \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \text{ and } M_{71} = M_\beta = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix}$$

Result:

$$\begin{bmatrix} X_{C1} \\ Y_{C1} \\ Z_{C1} \end{bmatrix} = \begin{bmatrix} X_{O6} \\ Y_{O6} \\ Z_{O6} \end{bmatrix} + \begin{bmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{C1}{}^{(6)} \\ Y_{C1}{}^{(6)} \\ Z_{C1}{}^{(6)} \end{bmatrix} \text{ and } \begin{bmatrix} X_{D1} \\ Y_{D1} \\ Z_{D1} \end{bmatrix} = \begin{bmatrix} X_{O7} \\ Y_{O7} \\ Z_{O7} \end{bmatrix} + \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix} \begin{bmatrix} X_{D1}{}^{(7)} \\ Y_{D1}{}^{(7)} \\ Z_{D1}{}^{(7)} \end{bmatrix}$$

Velocity of "A"and"B" points represente derivate vs.(versus) time:

$$\begin{bmatrix}\dot{X}_A\\ \dot{Y}_A\\ \dot{Z}_A\end{bmatrix}=\begin{bmatrix}\dot{X}_{O2}\\ \dot{Y}_{O2}\\ \dot{Z}_{O2}\end{bmatrix}+\dot{M}_{21}\begin{bmatrix}X_A^{(2)}\\ Y_A^{(2)}\\ Z_A^{(2)}\end{bmatrix}\text{ and }\begin{bmatrix}\dot{X}_B\\ \dot{Y}_B\\ \dot{Z}_B\end{bmatrix}=\begin{bmatrix}\dot{X}_{O4}\\ \dot{Y}_{O4}\\ \dot{Z}_{O4}\end{bmatrix}+\dot{M}_{41}\begin{bmatrix}X_B^{(4)}\\ Y_B^{(4)}\\ Z_B^{(4)}\end{bmatrix}$$

Where:

$$\dot{M}_\gamma=\frac{d}{dt}\begin{bmatrix}1&0&0\\0&\cos\gamma&-\sin\gamma\\0&\sin\gamma&\cos\gamma\end{bmatrix}=\dot{M}_{21}\text{ and }\dot{M}_\alpha=\begin{bmatrix}\cos\alpha&-\sin\alpha&0\\ \sin\alpha&\cos\alpha&0\\0&0&1\end{bmatrix}=\dot{M}_{41}\qquad(13)$$

Result:

$$\begin{bmatrix}\dot{X}_A\\ \dot{Y}_A\\ \dot{Z}_A\end{bmatrix}=\begin{bmatrix}\dot{X}_{O2}\\ \dot{Y}_{O2}\\ \dot{Z}_{O2}\end{bmatrix}+\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\begin{bmatrix}X_A^{(2)}\\ Y_A^{(2)}\\ Z_A^{(2)}\end{bmatrix}\dot{\gamma}\text{ and }\begin{bmatrix}\dot{X}_B\\ \dot{Y}_B\\ \dot{Z}_B\end{bmatrix}=\begin{bmatrix}\dot{X}_{O4}\\ \dot{Y}_{O4}\\ \dot{Z}_{O4}\end{bmatrix}+\begin{bmatrix}-\sin\alpha&-\cos\alpha&0\\ \cos\alpha&-\sin\alpha&0\\0&0&0\end{bmatrix}\begin{bmatrix}X_B^{(4)}\\ Y_B^{(4)}\\ Z_B^{(4)}\end{bmatrix}\dot{\alpha}$$

Velocity of "E"and"F" points represente derivate vs.(versus) time:

$$\begin{bmatrix}\dot{X}_F\\ \dot{Y}_F\\ \dot{Z}_F\end{bmatrix}=\begin{bmatrix}\dot{X}_{O2}\\ \dot{Y}_{O2}\\ \dot{Z}_{O2}\end{bmatrix}+\dot{M}_{21}\begin{bmatrix}X_F^{(2)}\\ Y_F^{(2)}\\ Z_F^{(2)}\end{bmatrix}\text{ and }\begin{bmatrix}\dot{X}_E\\ \dot{Y}_E\\ \dot{Z}_E\end{bmatrix}=\begin{bmatrix}\dot{X}_{O3}\\ \dot{Y}_{O3}\\ \dot{Z}_{O3}\end{bmatrix}+\dot{M}_{31}\begin{bmatrix}X_E^{(3)}\\ Y_E^{(3)}\\ Z_E^{(3)}\end{bmatrix}$$

Where:

$$\dot{M}_\gamma=\frac{d}{dt}\begin{bmatrix}1&0&0\\0&\cos\gamma&-\sin\gamma\\0&\sin\gamma&\cos\gamma\end{bmatrix}=\dot{M}_{21}=\dot{M}_{31}\qquad(14)$$

Result:

$$\begin{bmatrix}\dot{X}_F\\ \dot{Y}_F\\ \dot{Z}_F\end{bmatrix}=\begin{bmatrix}\dot{X}_{O2}\\ \dot{Y}_{O2}\\ \dot{Z}_{O2}\end{bmatrix}+\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\begin{bmatrix}X_F^{(2)}\\ Y_F^{(2)}\\ Z_F^{(2)}\end{bmatrix}\dot{\gamma}\text{ and }\begin{bmatrix}\dot{X}_E\\ \dot{Y}_E\\ \dot{Z}_E\end{bmatrix}=\begin{bmatrix}\dot{X}_{O3}\\ \dot{Y}_{O3}\\ \dot{Z}_{O3}\end{bmatrix}+\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\begin{bmatrix}X_E^{(3)}\\ Y_E^{(3)}\\ Z_E^{(3)}\end{bmatrix}\dot{\gamma}$$

Velocity of "C"and"D" points represente derivate vs.(versus) time:

$$\begin{bmatrix}\dot{X}_C\\ \dot{Y}_C\\ \dot{Z}_C\end{bmatrix}=\begin{bmatrix}\dot{X}_{O4}\\ \dot{Y}_{O4}\\ \dot{Z}_{O4}\end{bmatrix}+\dot{M}_{41}\begin{bmatrix}X_C^{(4)}\\ Y_C^{(4)}\\ Z_C^{(4)}\end{bmatrix}\text{ and }\begin{bmatrix}\dot{X}_D\\ \dot{Y}_D\\ \dot{Z}_D\end{bmatrix}=\begin{bmatrix}\dot{X}_{O5}\\ \dot{Y}_{O5}\\ \dot{Z}_{O5}\end{bmatrix}+\dot{M}_{51}\begin{bmatrix}X_D^{(5)}\\ Y_D^{(5)}\\ Z_D^{(5)}\end{bmatrix}$$

Where:

$$\dot{M}_\alpha=\begin{bmatrix}\cos\alpha&-\sin\alpha&0\\ \sin\alpha&\cos\alpha&0\\0&0&1\end{bmatrix}=\dot{M}_{41}\text{ and }\dot{M}_{51}=\begin{bmatrix}\cos\beta&0&\sin\beta\\0&1&0\\-\sin\beta&0&\cos\beta\end{bmatrix}=\dot{M}_\beta\qquad(15)$$

Result:

$$\begin{bmatrix}\dot{X}_C\\ \dot{Y}_C\\ \dot{Z}_C\end{bmatrix}=\begin{bmatrix}\dot{X}_{O4}\\ \dot{Y}_{O4}\\ \dot{Z}_{O4}\end{bmatrix}+\begin{bmatrix}-\sin\alpha & -\cos\alpha & 0\\ \cos\alpha & -\sin\alpha & 0\\ 0 & 0 & 0\end{bmatrix}\begin{bmatrix}X_C{}^{(4)}\\ Y_C{}^{(4)}\\ Z_C{}^{(4)}\end{bmatrix}\dot{\alpha} \text{ and } \begin{bmatrix}\dot{X}_D\\ \dot{Y}_D\\ \dot{Z}_D\end{bmatrix}=\begin{bmatrix}\dot{X}_{O5}\\ \dot{Y}_{O5}\\ \dot{Z}_{O5}\end{bmatrix}+\begin{bmatrix}-\sin\beta & 0 & \cos\beta\\ 0 & 0 & 0\\ -\cos\beta & 0 & -\sin\beta\end{bmatrix}\begin{bmatrix}X_D{}^{(5)}\\ Y_D{}^{(5)}\\ Z_D{}^{(5)}\end{bmatrix}\dot{\beta}$$

Velocity of “A1”and”B1” points represente derivate vs.(versus) time:

$$\begin{bmatrix}\dot{X}_{A1}\\ \dot{Y}_{A1}\\ \dot{Z}_{A1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O3}\\ \dot{Y}_{O3}\\ \dot{Z}_{O3}\end{bmatrix}+\dot{M}_{31}\begin{bmatrix}X_{A1}{}^{(3)}\\ Y_{A1}{}^{(3)}\\ Z_{A1}{}^{(3)}\end{bmatrix} \text{ and } \begin{bmatrix}\dot{X}_{B1}\\ \dot{Y}_{B1}\\ \dot{Z}_{B1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O6}\\ \dot{Y}_{O6}\\ \dot{Z}_{O6}\end{bmatrix}+\dot{M}_{61}\begin{bmatrix}X_{B1}{}^{(6)}\\ Y_{B1}{}^{(6)}\\ Z_{B1}{}^{(6)}\end{bmatrix} \tag{16}$$

Where:

$$\dot{M}_\gamma=\frac{d}{dt}\begin{bmatrix}1 & 0 & 0\\ 0 & \cos\gamma & -\sin\gamma\\ 0 & \sin\gamma & \cos\gamma\end{bmatrix}=\dot{M}_{21}=\dot{M}_{31} \text{ and } \dot{M}_\alpha=\begin{bmatrix}\cos\alpha & -\sin\alpha & 0\\ \sin\alpha & \cos\alpha & 0\\ 0 & 0 & 1\end{bmatrix}=\dot{M}_{61}$$

Result:

$$\begin{bmatrix}\dot{X}_{A1}\\ \dot{Y}_{A1}\\ \dot{Z}_{A1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O3}\\ \dot{Y}_{O3}\\ \dot{Z}_{O3}\end{bmatrix}+\begin{bmatrix}0 & 0 & 0\\ 0 & -\sin\gamma & -\cos\gamma\\ 0 & \cos\gamma & -\sin\gamma\end{bmatrix}\begin{bmatrix}X_{A1}{}^{(3)}\\ Y_{A1}{}^{(3)}\\ Z_{A1}{}^{(3)}\end{bmatrix}\dot{\gamma} \text{ and } \begin{bmatrix}\dot{X}_{B1}\\ \dot{Y}_{B1}\\ \dot{Z}_{B1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O6}\\ \dot{Y}_{O6}\\ \dot{Z}_{O6}\end{bmatrix}+\begin{bmatrix}-\sin\alpha & -\cos\alpha & 0\\ \cos\alpha & -\sin\alpha & 0\\ 0 & 0 & 0\end{bmatrix}\begin{bmatrix}X_{B1}{}^{(6)}\\ Y_{B1}{}^{(6)}\\ Z_{B1}{}^{(6)}\end{bmatrix}\dot{\alpha}$$

Velocity of “C1”and”D1” points represente derivate vs.(versus) time:

$$\begin{bmatrix}\dot{X}_{C1}\\ \dot{Y}_{C1}\\ \dot{Z}_{C1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O6}\\ \dot{Y}_{O6}\\ \dot{Z}_{O6}\end{bmatrix}+\dot{M}_{61}\begin{bmatrix}X_{C1}{}^{(6)}\\ Y_{C1}{}^{(6)}\\ Z_{C1}{}^{(6)}\end{bmatrix} \text{ and } \begin{bmatrix}\dot{X}_{D1}\\ \dot{Y}_{D1}\\ \dot{Z}_{D1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O7}\\ \dot{Y}_{O7}\\ \dot{Z}_{O7}\end{bmatrix}+\dot{M}_{71}\begin{bmatrix}X_{D1}{}^{(7)}\\ Y_{D1}{}^{(7)}\\ Z_{D1}{}^{(7)}\end{bmatrix}$$

Where:

$$\dot{M}_\alpha=\begin{bmatrix}\cos\alpha & -\sin\alpha & 0\\ \sin\alpha & \cos\alpha & 0\\ 0 & 0 & 1\end{bmatrix}=\dot{M}_{61} \text{ and } \dot{M}_{71}=\begin{bmatrix}\cos\beta & 0 & \sin\beta\\ 0 & 1 & 0\\ -\sin\beta & 0 & \cos\beta\end{bmatrix}=\dot{M}_\beta \tag{17}$$

Result:

$$\begin{bmatrix}\dot{X}_{C1}\\ \dot{Y}_{C1}\\ \dot{Z}_{C1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O6}\\ \dot{Y}_{O6}\\ \dot{Z}_{O6}\end{bmatrix}+\begin{bmatrix}-\sin\alpha & -\cos\alpha & 0\\ \cos\alpha & -\sin\alpha & 0\\ 0 & 0 & 0\end{bmatrix}\begin{bmatrix}X_{C1}{}^{(6)}\\ Y_{C1}{}^{(6)}\\ Z_{C1}{}^{(6)}\end{bmatrix}\dot{\alpha} \text{ and } \begin{bmatrix}\dot{X}_{D1}\\ \dot{Y}_{D1}\\ \dot{Z}_{D1}\end{bmatrix}=\begin{bmatrix}\dot{X}_{O7}\\ \dot{Y}_{O7}\\ \dot{Z}_{O7}\end{bmatrix}+\begin{bmatrix}-\sin\beta & 0 & \cos\beta\\ 0 & 0 & 0\\ -\cos\beta & 0 & -\sin\beta\end{bmatrix}\begin{bmatrix}X_{D1}{}^{(7)}\\ Y_{D1}{}^{(7)}\\ Z_{D1}{}^{(7)}\end{bmatrix}\dot{\beta}$$

Acceleration represente 2 – th order derivate vs. time
Acceleration for A and B points:

$$\begin{bmatrix}\ddot{X}_A\\ \ddot{Y}_A\\ \ddot{Z}_A\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O2}\\ \ddot{Y}_{O2}\\ \ddot{Z}_{O2}\end{bmatrix}+\frac{d}{dt}\left\{\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\dot{\gamma}\right\}\begin{bmatrix}X_A^{(2)}\\Y_A^{(2)}\\Z_A^{(2)}\end{bmatrix} \text{ and } \begin{bmatrix}\ddot{X}_B\\ \ddot{Y}_B\\ \ddot{Z}_B\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O4}\\ \ddot{Y}_{O4}\\ \ddot{Z}_{O4}\end{bmatrix}+\frac{d}{dt}\left\{\begin{bmatrix}-\sin\alpha&-\cos\alpha&0\\ \cos\alpha&-\sin\alpha&0\\0&0&0\end{bmatrix}\dot{\alpha}\right\}\begin{bmatrix}X_B^{(4)}\\Y_B^{(4)}\\Z_B^{(4)}\end{bmatrix}$$

Where:

$$\ddot{M}_{41}=\ddot{M}_{61}\frac{d}{dt}\left\{\begin{bmatrix}-\sin\alpha&-\cos\alpha&0\\ \cos\alpha&-\sin\alpha&0\\0&0&0\end{bmatrix}\dot{\alpha}\right\}=\begin{bmatrix}-\cos\alpha&\sin\alpha&0\\-\sin\alpha&-\cos\alpha&0\\0&0&0\end{bmatrix}\dot{\alpha}+\begin{bmatrix}-\sin\alpha&-\cos\alpha&0\\ \cos\alpha&-\sin\alpha&0\\0&0&0\end{bmatrix}\ddot{\alpha} \quad (18)$$

$$\ddot{M}_{21}=\ddot{M}_{31}=\frac{d}{dt}\left\{\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\dot{\gamma}\right\}=\begin{bmatrix}0&0&0\\0&-\cos\gamma&\sin\gamma\\0&-\sin\gamma&-\cos\gamma\end{bmatrix}\dot{\gamma}+\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\ddot{\gamma}$$

Acceleration represente 2 – th order derivate vs. time.Acceleration for E and F points:

$$\begin{bmatrix}\ddot{X}_F\\ \ddot{Y}_F\\ \ddot{Z}_F\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O2}\\ \ddot{Y}_{O2}\\ \ddot{Z}_{O2}\end{bmatrix}+\frac{d}{dt}\left\{\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\dot{\gamma}\right\}\begin{bmatrix}X_F^{(2)}\\Y_F^{(2)}\\Z_F^{(2)}\end{bmatrix} \text{ and } \begin{bmatrix}\ddot{X}_E\\ \ddot{Y}_E\\ \ddot{Z}_E\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O3}\\ \ddot{Y}_{O3}\\ \ddot{Z}_{O3}\end{bmatrix}+\frac{d}{dt}\left\{\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\dot{\gamma}\right\}\begin{bmatrix}X_E^{(3)}\\Y_E^{(3)}\\Z_E^{(3)}\end{bmatrix}$$

Where: (19)

$$\ddot{M}_{21}=\ddot{M}_{31}=\frac{d}{dt}\left\{\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\dot{\gamma}\right\}=\begin{bmatrix}0&0&0\\0&-\cos\gamma&\sin\gamma\\0&-\sin\gamma&-\cos\gamma\end{bmatrix}\dot{\gamma}+\begin{bmatrix}0&0&0\\0&-\sin\gamma&-\cos\gamma\\0&\cos\gamma&-\sin\gamma\end{bmatrix}\ddot{\gamma}$$

Acceleration represente 2 – th order derivate vs. time. Acceleration for C and D points:

$$\begin{bmatrix}\ddot{X}_C\\ \ddot{Y}_C\\ \ddot{Z}_C\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O4}\\ \ddot{Y}_{O4}\\ \ddot{Z}_{O4}\end{bmatrix}+\ddot{M}_{41}\begin{bmatrix}X_C^{(4)}\\Y_C^{(4)}\\Z_C^{(4)}\end{bmatrix} \text{ and } \begin{bmatrix}\ddot{X}_D\\ \ddot{Y}_D\\ \ddot{Z}_D\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O5}\\ \ddot{Y}_{O5}\\ \ddot{Z}_{O5}\end{bmatrix}+\ddot{M}_{51}\begin{bmatrix}X_D^{(5)}\\Y_D^{(5)}\\Z_D^{(5)}\end{bmatrix}$$

Then:

$$\begin{bmatrix}\ddot{X}_C\\ \ddot{Y}_C\\ \ddot{Z}_C\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O4}\\ \ddot{Y}_{O4}\\ \ddot{Z}_{O4}\end{bmatrix}+\frac{d}{dt}\left\{\begin{bmatrix}-\sin\alpha&-\cos\alpha&0\\ \cos\alpha&-\sin\alpha&0\\0&0&0\end{bmatrix}\dot{\alpha}\right\}\begin{bmatrix}X_C^{(4)}\\Y_C^{(4)}\\Z_C^{(4)}\end{bmatrix} \quad (20)$$

$$\begin{bmatrix}\ddot{X}_D\\ \ddot{Y}_D\\ \ddot{Z}_D\end{bmatrix}=\begin{bmatrix}\ddot{X}_{O5}\\ \ddot{Y}_{O5}\\ \ddot{Z}_{O5}\end{bmatrix}+\frac{d}{dt}\left\{\begin{bmatrix}-\sin\beta&0&\cos\beta\\0&0&0\\-\cos\beta&0&-\sin\beta\end{bmatrix}\dot{\beta}\right\}\begin{bmatrix}X_D^{(5)}\\Y_D^{(5)}\\Z_D^{(5)}\end{bmatrix}$$

Where:

$$\ddot{M}_{51} = \frac{d}{dt}\left\{\begin{bmatrix} -\sin\beta & 0 & \cos\beta \\ 0 & 0 & 0 \\ -\cos\beta & 0 & -\sin\beta \end{bmatrix}\dot{\beta}\right\} = \begin{bmatrix} -\cos\beta & 0 & -\sin\beta \\ 0 & 0 & 0 \\ \sin\beta & 0 & -\cos\beta \end{bmatrix}\dot{\beta} + \begin{bmatrix} -\sin\beta & 0 & \cos\beta \\ 0 & 0 & 0 \\ -\cos\beta & 0 & -\sin\beta \end{bmatrix}\ddot{\beta}$$

$$\ddot{M}_{41} = \frac{d}{dt}\left\{\begin{bmatrix} -\sin\alpha & -\cos\alpha & 0 \\ \cos\alpha & -\sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\dot{\alpha}\right\} = \begin{bmatrix} -\cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & -\cos\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\dot{\alpha} + \begin{bmatrix} -\sin\alpha & -\cos\alpha & 0 \\ \cos\alpha & -\sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\ddot{\alpha} \quad (21)$$

Acceleration represente 2 – th order derivate vs. time. Acceleration for A1 and B1 points:

$$\begin{bmatrix} \ddot{X}_{A1} \\ \ddot{Y}_{A1} \\ \ddot{Z}_{A1} \end{bmatrix} = \begin{bmatrix} \ddot{X}_{O3} \\ \ddot{Y}_{O3} \\ \ddot{Z}_{O3} \end{bmatrix} + \frac{\mathrm{d}}{\mathrm{dt}}\left\{\begin{bmatrix} 0 & 0 & 0 \\ 0 & -\sin\gamma & -\cos\gamma \\ 0 & \cos\gamma & -\sin\gamma \end{bmatrix}\dot{\gamma}\right\}\begin{bmatrix} X_{A1}^{(3)} \\ Y_{A1}^{(3)} \\ Z_{A1}^{(3)} \end{bmatrix} \text{ and } \begin{bmatrix} \ddot{X}_{B1} \\ \ddot{Y}_{B1} \\ \ddot{Z}_{B1} \end{bmatrix} = \begin{bmatrix} \ddot{X}_{O6} \\ \ddot{Y}_{O6} \\ \ddot{Z}_{O6} \end{bmatrix} + \frac{d}{dt}\left\{\begin{bmatrix} -\sin\alpha & -\cos\alpha & 0 \\ \cos\alpha & -\sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\dot{\alpha}\right\}\begin{bmatrix} X_{B1}^{(6)} \\ Y_{B1}^{(6)} \\ Z_{B1}^{(6)} \end{bmatrix}$$

Where:

$$\ddot{\mathrm{M}}_{31} = \frac{\mathrm{d}}{\mathrm{dt}}\left\{\begin{bmatrix} 0 & 0 & 0 \\ 0 & -\sin\gamma & -\cos\gamma \\ 0 & \cos\gamma & -\sin\gamma \end{bmatrix}\dot{\gamma}\right\} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & -\cos\gamma & \sin\gamma \\ 0 & -\sin\gamma & -\cos\gamma \end{bmatrix}\dot{\gamma} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & -\sin\gamma & -\cos\gamma \\ 0 & \cos\gamma & -\sin\gamma \end{bmatrix}\ddot{\gamma} \quad (22)$$

$$\ddot{M}_{61} = \frac{d}{dt}\left\{\begin{bmatrix} -\sin\alpha & -\cos\alpha & 0 \\ \cos\alpha & -\sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\dot{\alpha}\right\} = \begin{bmatrix} -\cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & -\cos\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\dot{\alpha} + \begin{bmatrix} -\sin\alpha & -\cos\alpha & 0 \\ \cos\alpha & -\sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\ddot{\alpha}$$

Acceleration represente 2 – th order derivate vs. time. Acceleration for C1 and D1 points:

$$\begin{bmatrix} \ddot{X}_{C1} \\ \ddot{Y}_{C1} \\ \ddot{Z}_{C1} \end{bmatrix} = \begin{bmatrix} \ddot{X}_{O6} \\ \ddot{Y}_{O6} \\ \ddot{Z}_{O6} \end{bmatrix} + \ddot{M}_{61}\begin{bmatrix} X_{C1}^{(6)} \\ Y_{C1}^{(6)} \\ Z_{C1}^{(6)} \end{bmatrix} \text{ and } \begin{bmatrix} \ddot{X}_{D1} \\ \ddot{Y}_{D1} \\ \ddot{Z}_{D1} \end{bmatrix} = \begin{bmatrix} \ddot{X}_{O7} \\ \ddot{Y}_{O7} \\ \ddot{Z}_{O7} \end{bmatrix} + \ddot{M}_{71}\begin{bmatrix} X_{D1}^{(7)} \\ Y_{D1}^{(7)} \\ Z_{D1}^{(7)} \end{bmatrix}$$

Where:

$$\ddot{M}_{61} = \frac{d}{dt}\left\{\begin{bmatrix} -\sin\alpha & -\cos\alpha & 0 \\ \cos\alpha & -\sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\dot{\alpha}\right\} = \begin{bmatrix} -\cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & -\cos\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\dot{\alpha} + \begin{bmatrix} -\sin\alpha & -\cos\alpha & 0 \\ \cos\alpha & -\sin\alpha & 0 \\ 0 & 0 & 0 \end{bmatrix}\ddot{\alpha} \quad (23)$$

$$\ddot{M}_{71} = \frac{d}{dt}\left\{\begin{bmatrix} -\sin\beta & 0 & \cos\beta \\ 0 & 0 & 0 \\ -\cos\beta & 0 & -\sin\beta \end{bmatrix}\dot{\beta}\right\} = \begin{bmatrix} -\cos\beta & 0 & -\sin\beta \\ 0 & 0 & 0 \\ \sin\beta & 0 & -\cos\beta \end{bmatrix}\dot{\beta} + \begin{bmatrix} -\sin\beta & 0 & \cos\beta \\ 0 & 0 & 0 \\ -\cos\beta & 0 & -\sin\beta \end{bmatrix}\ddot{\beta}$$

3. CONCLUSION

Present research in the multibody dynamics has been developed by computer techniques. Modern industrial design use computer for analyzing rigid multibody systems. Automatic process in this case offer many solution in short time.

For aircraft design many equation needs simultaneous solutions. Many mechanical aircraft systems work together in different conditions. Performance analysis of this used a new applications software. MBS is a modern method for dynamic simulations and virtual prototype.

Mechanical systems analysis software MBS automatically formulate and solve the motion equations[2].

Using this soft a new type of study can be defined – Virtual Prototyping[2].

Structural and kinematic analysis are bases for dynamic models.

Dynamic model of this linkages is MultiBody spatial mechanical system connected with geometric constraints, driving constraints, complaint joints and forces[2].

Global Reference Frame (GR**F)** is a coordinate system represented three orthogonal axes fixed in time. This coordinate system is rigidly connected to fixed body - ground [2,4,7,8].

Body Reference Frame (BRF) is a coordinate system formed by three orthogonal axes connected to each mobile body component to the MBS system[2,4,7,8].

The solid model of this spatial mechanism
was created using CAD software.The geometry was imported in ADAMS using the STEP file format [2]

ADAMS/Exchange read the CAD file and convert the geometry into ADAMS geometric elements[2].

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