DYNAMIC ANALISYS BY MBS METHOD APPLIED TO LIGHT_SPORT_AIRCRAFT CONTROL

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

1. INTRODUCTION

The aircraft control motion (roll,pitch,yaw) during the flying by appropiate systems is made. The name and location of these systems are given in figure 1 -- for a Light_Sport_Aircraft [5].Their actioning is made from the pilot usually by intermediate of mechanical transmissions (linkages, cams, etc).
In virtual prototyping of the aircraft, mechanical syatems are considered as Multibody Systems (MBS). They have to be modelled as MBS with minimum number of bodies. (MB min) to favorise obtaining real time simulation of the whole product (aircraft).
The aim of this paper is dynamic modelling of linkage used for actioning of elevator, as multibody systems.

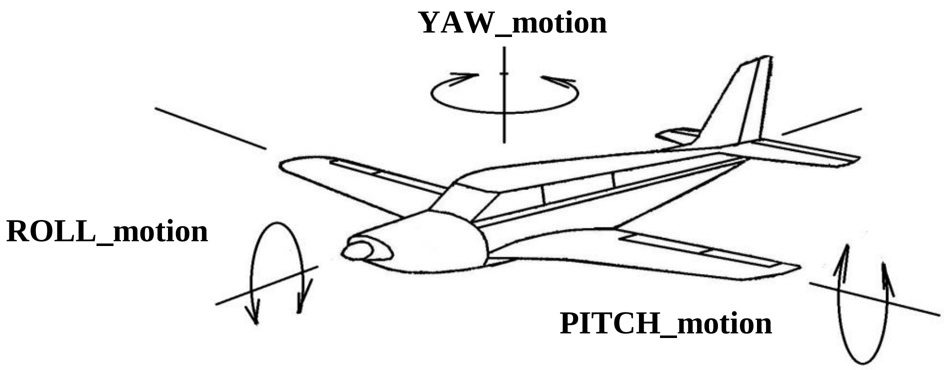


Figure 1: Light_Sport_Aircraft (LSA)

2. THEORY

According to MBS theory, a mechanical system is considered as a collection of bodies linked between them by geometrical and driving constraints[7,3].
The body is an entity which in the dynamic model will have mass and moment of inertia, and also could take over the external forces. In a concret mechanical system , a body could be fixed or moobile, input/output body, body with two or more connections.
In a linkage having "n" elements number of bodies n_b is

$$n_b \leq n \quad (1)$$

Generally

$$n_{b\,min} \leq n_b \leq n \quad (2)$$

$n_{b\,min}$ representing the minimum number of bodies for modeling a concrete linkage.

The motion of the mobile bodies is describeed in a space whose number of dimension is S . of course S=3 for planar systems and S=6 for the systems in three dimensional space.
The geometrical constraint imposes restrictions in bodies relative motion. Number of restriction is r =1 and r = 2 in the case of planar systems (S =3), respectiv r = 1…5 in the case of three dimensional systems (S = 6).
The restrictions are imposed by joints or composite joint [1,5]. In planar systems they are:
rotation R (r =2), translation T (r =2), rotation-rotation RR (r =1), rotation –translation RT (r =1)
curve –curve CC (r = 1) [7,9,11].
Driving constraints correspond to the mobility M of the system Of course $M \geq 1$.
Between number of bodies n_b, number of geometrical constraints (Σr) in a concrete space S, and mobility M , there is the relation:

$$M = S\,(n_b - 1) - \Sigma\, r \quad (3)$$

The algorithm for MBS modelling with minimum number of bodies has the following steps:

a. Identifying the bodies, in order:
   - fixed body,
   - input body (bodies),
   - output body (bodies),
   - bodies with more than two connections,
   - bodies with applied forces,
   - other bodies (if necessary).

b. Identifying geometrical constraints:
   - type
   - location,
   - number of restriction

3. CONCRETE LINKAGE

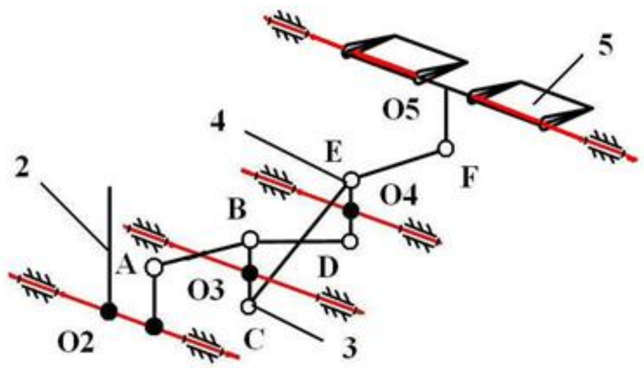


Figure 2: Elevator_control - Body Reference Frame (BRF) and Global Reference Frame (GRF)

Table 1: Elevatot control (figure 2)

Corpul i Corpul 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
2-3	SS	AB	1
2-4	-	-	-
2-5	-	-	-
3-4	SS	BD	1
3-5	-	-	-
4-5	SS	EF	1

Number of bodies:

$n_b = 5$

Mobility M =1

$$M = S\,(n_b - 1) - \Sigma\, r \qquad (4)$$

$$M = 6(5 - 1) - 23 = 1$$

Space:

$$S = 6$$

And:

$$\Sigma\, r = 23$$

The linkage from fig 2 is modeled as MBS having 5 bodies, four geometrical constraints type R and three geometrical constraints type SS. The input body is body 2 and the output body is the elevator_5. It has mobility M =1.

The bases of these linkages is wing structure, that represent for the linkages – fixed body(GRF). Coordinate system attached to fixed body (body number_1) represent GRF (Global Reference Frame) – (see figure 2). Coordinate system attached to mobile body represent BRF (Body Reference Frame).

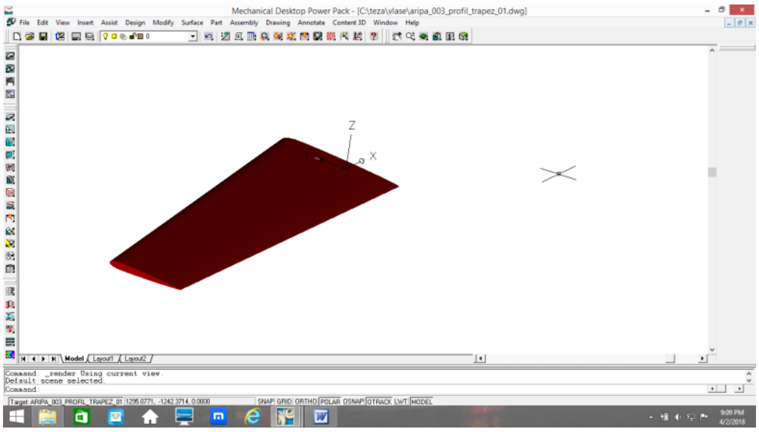


Figure 3: Wing_Structure – 3D-Model

Coordinate system attached to mobile body "i", BRF, is X_{Oi}, Y_{Oi}, Z_{Oi}.

Generalized coordinates matrix

$[qi] = [\, X_{Oi}, Y_{Oi}, Z_{Oi}, \alpha, \beta, \gamma\,]^T$

<u>Newton-Euler D'Alembert equation</u> (5)

$$[F_i^{ext}] + [F_i^{rg}] + [F_i^{in}] = 0$$

where, $[F_i^{ext}]$ represente ext forces matrix, $[F_i^{rg}]$, geometrical constraints forces matrix, $[F_i^{rg}]$, inertials forces matrix.

For body "i", and three directions, X, Y, Z, matrix form for equations are

$$\begin{bmatrix} F_i^{extX} \\ F_i^{extY} \\ F_i^{extZ} \\ M_i^{extX} \\ M_i^{extY} \\ M_i^{extZ} \end{bmatrix} + \begin{bmatrix} F_i^{rgX} \\ F_i^{rgY} \\ F_i^{rgZ} \\ M_i^{rgX} \\ M_i^{rgY} \\ M_i^{rgZ} \end{bmatrix} + \begin{bmatrix} F_i^{inX} \\ F_i^{inY} \\ F_i^{inZ} \\ M_i^{inX} \\ M_i^{inY} \\ M_i^{inZ} \end{bmatrix} = 0 \qquad (6)$$

$$\begin{cases} \sum \overline{F(i)} = 0 \\ \sum \overline{M_O(i)} = 0 \end{cases}$$

Angular acceleration

$$\varepsilon_i = \frac{\Delta\omega_i}{\Delta t} \ \ \text{rad / secunda}^2 \qquad \text{and} \qquad \omega_i = \frac{\Delta\alpha_i}{\Delta t} \ \ \text{rad / secunda} \qquad (7)$$

The tensor of inertia matrix, from Global_Reference_Frame, GRF

$$[I_i] = \begin{bmatrix} I_{XX} & I_{XY} & I_{XZ} \\ I_{YX} & I_{YY} & I_{YZ} \\ I_{ZX} & I_{ZY} & I_{ZZ} \end{bmatrix} \tag{8}$$

Where centrifugal mass moments and axial mass moments are

$I_{XY}, I_{XZ}, I_{YZ}, I_{XX}, I_{YY}, I_{ZZ}$ (9)

Inertial massic moment from one axe, is

$I = m_i \, r_i^2 \; (\mathrm{g} * \mathrm{mm}^2)$

Mass matrix is

$$[m_i] = \begin{bmatrix} m_\mathrm{i} & 0 & 0 \\ 0 & m_\mathrm{i} & 0 \\ 0 & 0 & m_\mathrm{i} \end{bmatrix}, \quad \text{and} \quad \begin{bmatrix} F_i^{inX} \\ F_i^{inY} \\ F_i^{inZ} \\ M_i^{inX} \\ M_i^{inY} \\ M_i^{inZ} \end{bmatrix} = -[\mathrm{m_i}][\ddot{q}_i] \tag{10}$$

Where

[qi] = [q1, q2, q3, q4, q5, q6 $]^T$ = [X_{Oi} , Y_{Oi} , Z_{Oi} , α , β, γ $]^T$

Final system from geometrical constraint is

[F (X_{Oi} , Y_{Oi} , Z_{Oi} , α , β, γ)] = 0

From kinematic constraints we are (11)

γ = f (t)

Generalized velocities matrix

$$[\dot{q}] = [\,\dot{\mathrm{q}}_1\; \dot{\mathrm{q}}_2\; \dot{\mathrm{q}}_3\; \dot{\mathrm{q}}_4, \dot{\mathrm{q}}_5, \dot{\mathrm{q}}_6]^\mathrm{T} \text{ where } \dot{\mathrm{q}} = \frac{\mathrm{dq}}{\mathrm{dt}} \tag{12}$$

Generalized accelerations matrix

$$[\ddot{q}_i] = [\,\ddot{\mathrm{q}}_1\; \ddot{\mathrm{q}}_2\; \ddot{\mathrm{q}}_3\; \ddot{\mathrm{q}}_4, \ddot{\mathrm{q}}_5, \ddot{\mathrm{q}}_6]^\mathrm{T} \text{ where } \ddot{\mathrm{q}} = \frac{\mathrm{d^2q}}{\mathrm{dt^2}}$$

Primary target from this dynamic solution by MBS method, is bodies motion with all forces and weights.

$$\begin{bmatrix} F_i^{inX} \\ F_i^{inY} \\ F_i^{inZ} \\ M_i^{inX} \\ M_i^{inY} \\ M_i^{inZ} \end{bmatrix} = -\begin{bmatrix} m_\mathrm{i} & 0 & 0 \\ 0 & m_\mathrm{i} & 0 \\ 0 & 0 & m_\mathrm{i} \end{bmatrix} [\,\ddot{\mathrm{q}}_\mathrm{i}\,]^\mathrm{T} \quad \text{and} \quad \begin{bmatrix} F_i^{rgX} \\ F_i^{rgY} \\ F_i^{rgZ} \\ M_i^{rgX} \\ M_i^{rgY} \\ M_i^{rgZ} \end{bmatrix} = -[J_i]^T[\lambda_i] \tag{13}$$

Jacobian matrix from geometrical constraints is $[J_i]$.

Column matrix from Lagrange multiplier is $[\lambda_i]$.

From <u>Newton-Euler D'Alembert equation , equilibrium of forces</u>

$[F_i^{ext}] + [F_i^{rg}] + [F_i^{in}] = 0$ (14)

We have

$[\mathrm{m_i}][\ddot{q}_i] + [J_i]^T[\lambda_i] = [F_i^{ext}]$

From $[J_i]$, numbers of rows is equal to numbers of equqtions from geometrical constrainta.

From $[\lambda_i]$, numbers of terms is equal to number of equqtions from geometrical constraints.

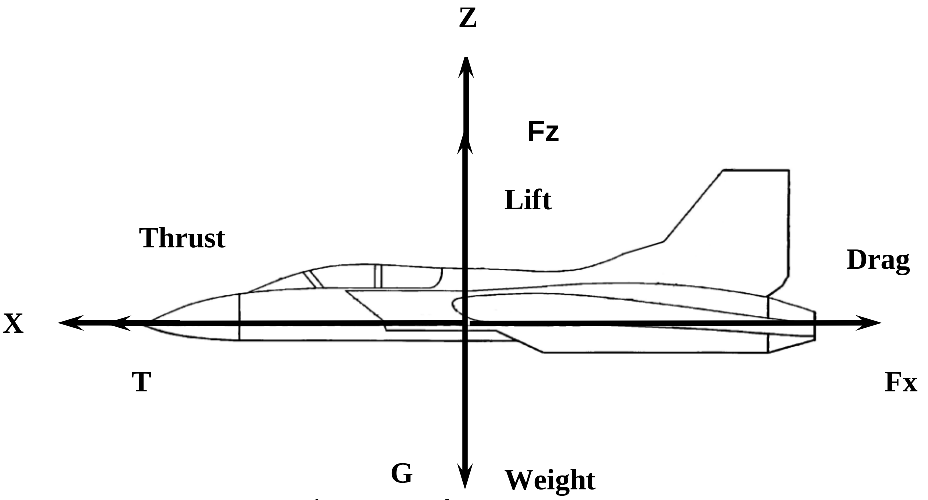


Figure 4. Light_Sport_Aircraft - Forces

Wing aircraft, and tail surfaces from, Light_Sport_Aircraft, represente two most important lifting surfaces. From subsonic flight, (v. Figure 5), speed a pressure, are

$$p_\infty + \frac{\rho V_\infty^{\ 2}}{2} = p_{loc} + \frac{\rho V_{loc}^{\ 2}}{2} \tag{15}$$

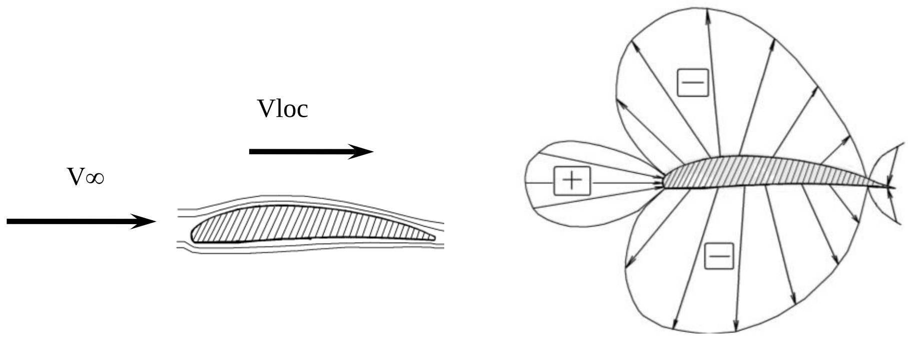
And

$$\Delta p \ = \frac{\rho V_\infty^{\ 2}}{2}\left(1 - \frac{\rho V_{loc}^{\ 2}}{V_\infty^{\ 2}}\right) \tag{16}$$

Where

p_{loc} and V_{loc} , represent local wing parameters into disturbed area, and

p and V represente parameters from un-disturbed area, ρ is density of the fluid.



Laminar_subsonic_flow from wing section Distribution of pressures from wing surfaces

Figure 5: Light_Sport_Aircraft – Subsonic and Laminar Flow

We define,

Pressure_Coefficient (see Figure 6)

$Cp \ = \dfrac{\Delta p}{p_d}$ where $\mathrm{p_d} \ = \dfrac{\rho V^2}{2}$ is dynamic pressure

So (17)

$$Cp \ = \left(1 - \frac{V_{loc}^{\ 2}}{V_\infty^{\ 2}}\right)$$

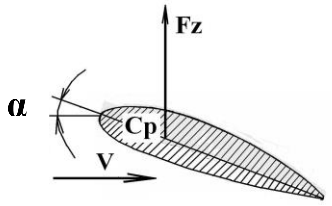


Figure 6: Pressure_Coefficient

We define Lift_Force

$$F_Z = (\Delta \mathrm{p}_{\mathrm{extrados}} - \Delta p_{\mathrm{int}\ rados})S \quad where \quad \Delta \mathrm{p} = \frac{\mathrm{C_P} \rho V^2{}_{\infty}}{2}$$

$$F_Z = \left(C\mathrm{p}_{\mathrm{extrados}} - Cp_{\mathrm{int}\ rados}\right)\frac{\rho V^2{}_{\infty}}{2} S \qquad (18)$$

Final

$$F_Z = \mathrm{C_Z} \frac{\rho V^2{}_{\infty}}{2} S \quad \text{where} \quad \mathrm{C_Z} = \left(C\mathrm{p}_{\mathrm{extrados}} - Cp_{\mathrm{int}\ rados}\right)$$

Where "Cz" is Lift Force coefficient.
We define Total Aerodinamic Force, R (see Figure 7).

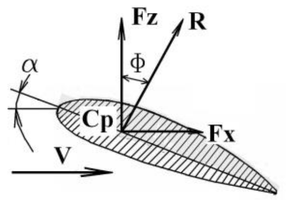


Figure 7: Total Aerodinamic Force

$$\vec{F}_Z + \vec{F}_X = \vec{R}, \quad \text{where} \quad \text{Fx is Drag Force} \qquad (19)$$

4. 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 equations 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.

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