DYNAMIC SOLUTION BY MBS METHOD APPLIED TO AIRCRAFT CONTROL

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Abstract: *The aim of the paper is dynamic 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 the 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.*
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 small airplane [5]. Their actioning is made from the pilot usually by intermediate of mechanical transmissions (linkages, cams, etc).
In design process of an aircraft (very complex product) one of the main step is virtual prototyping, whose aim is analysis and dynamic behavior optimization by using software. That means a unitary modelling of all the subsystems of the aircraft.
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 aileron, as multibody systems. On bases of MBS, kinematic and dynamic models could be obtained.

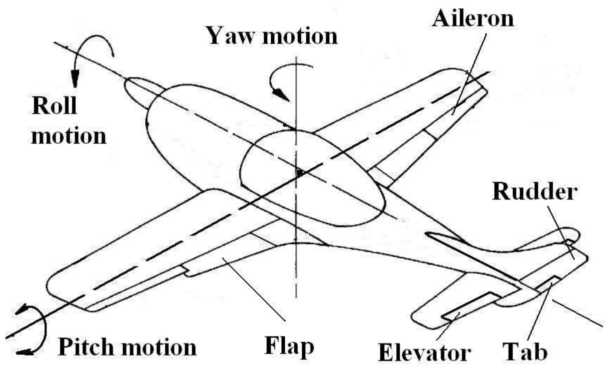

Figure 1 Small aircraft

2. THEORY

According to MBS theory , a mechanical system is considered as a collection of bodies linked between them by geometrical and driving constraints[7,3,9,11].
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 concrete 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 :

(1)

$n_b \leq n$

Generally

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

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

The motion of the mobile bodies is descriebed 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 [1,5,9,11]. 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) [7,9,10].

Driving constraints corespond 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:

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

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 connection,
- bodies with applied forces,
- other bodies (if necessary).

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

3. CONCRETE LINKAGE

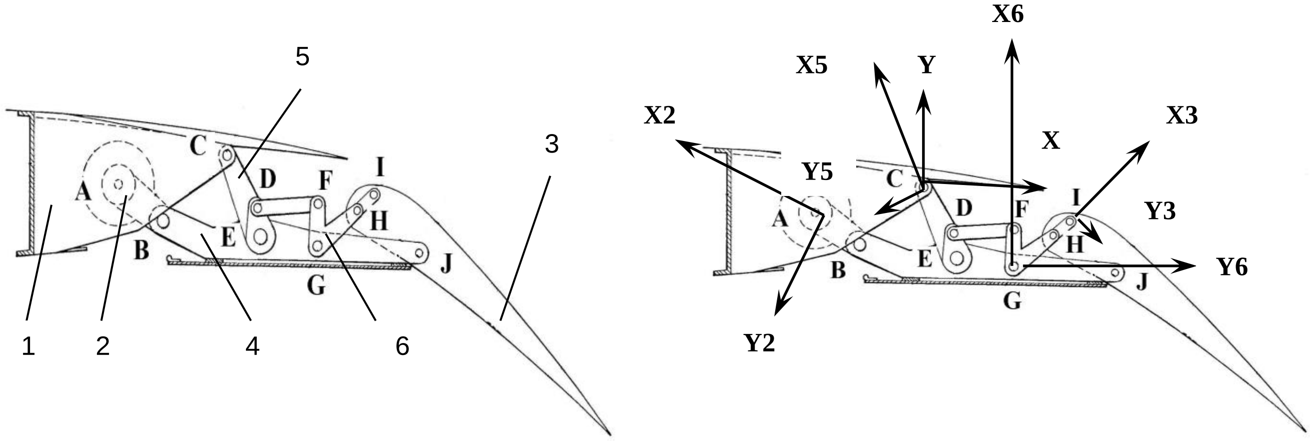

Figure 2. Aileron control - Body Reference Frame (BRF) and Global Reference Frame (GRF)

Table 1: Aileron control **(figure 2)**

Body i Body j	gc	Location	Number of constraints
1-2	R	A	2
1-3	-	-	-
1-4	-	-	-
1-5	R	C	2
1-6	-	-	-
2-3	-	-	-
2-4	R	B	2
2-5	-	-	-

2-6	-	-	-
3-4	R	J	2
3-5	-	-	-
3-6	RR	HI	1
4-5	R	E	2
4-6	R	G	2
5-6	RR	DF	1

Number of bodies:

$n_b = 6$

Mobility M =1

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

$$M=3(6-1) - 14 = 1$$

Space:

$S = 3$

And:

$\Sigma\, r = 14$

The linkage from fig 2 is modeled as MBS having 6 bodies, six geometrical constraints type R and two geometrical constraints type RR. The input body is body 2 and the output body is the flap3. 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).

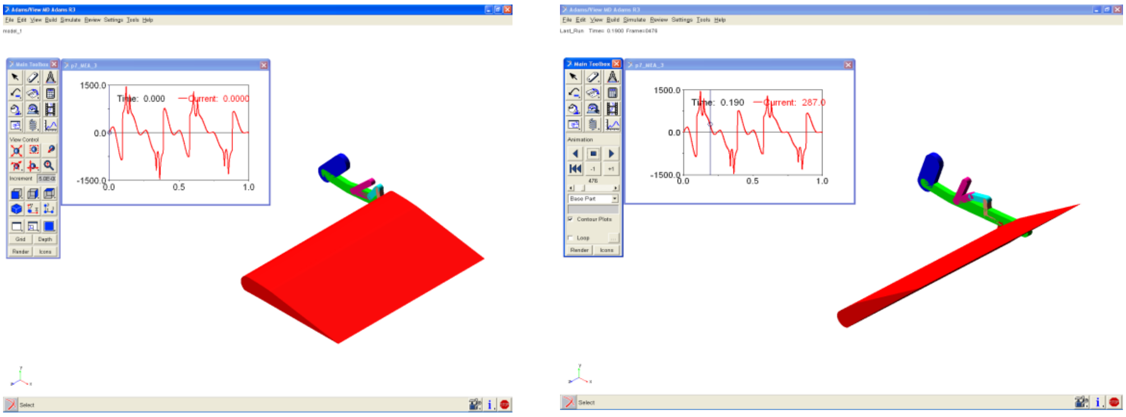

Figure 3 Aileron control – 3D-Model- Simulated by ADams

VERIFY MODEL: aileron_1

-8 Gruebler Count (approximate degrees of freedom)
7 Moving Parts (not including ground)
10 Revolute Joints
1 Degrees of Freedom for .aileron_1

There are 9 redundant constraint equations.
This constraint: unnecessarily removes this DOF:
.model_1.JOINT_1 (Revolute Joint) Rotation Between Zi & Yj
.model_1.JOINT_2 (Revolute Joint) Rotation Between Zi & Xj
.model_1.JOINT_3 (Revolute Joint) Rotation Between Zi & Xj
.model_1.JOINT_4 (Revolute Joint) Rotation Between Zi & Xj
.model_1.JOINT_5 (Revolute Joint) Rotation Between Zi & Xj
.model_1.JOINT_6 (Revolute Joint) Rotation Between Zi & Yj
.model_1.JOINT_7 (Revolute Joint) Rotation Between Zi & Xj
.model_1.JOINT_7 (Revolute Joint) Rotation Between Zi & Yj

.model_1.JOINT_10 (Revolute Joint) Rotation Between Zi & Xj

Model verified successfully

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

Generalized coordinates matrix

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

<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

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

The tensor of inertia matrix, from Global_Reference_Frame, GRF

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

Where centrifugal mass moments and axial mass moments are

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

Inertial massic moment from one axe, is

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

Mass matrix is

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

Where

$[qi] = [q1, q2, q3, q4, q5, q6]^T = [X_{Oi}, Y_{Oi}, Z_{Oi}, \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}]^T$

Final system from geometrical constrainta is

$[F(X_{Oi}, Y_{Oi}, Z_{Oi}, \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma})] = 0$

From kinematic constraints we are (11)

$\gamma = f(t)$

Generalized velocities matrix

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

Generalized accelerations matrix (12)

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

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

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

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

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

From Newton-Euler D’Alembert equation , equilibrium of forces

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

We have (14)

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

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

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

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.

REFERENCES

[1] Brine, Gerald, T. **Flap System for Short Takeoff and Landing Aircraft**, United States Patent US4784355,1988

[2] Frans Willem de Haan., Cornelis Adrianus., **Aircraft fitted with wing trailing edge flaps actuated by six-bar mechanisms,** In: UK Patent Aplication GB 2079688 A, 1982

[3] Haug, J.E., **Computer Aided Kinematics and Dynamics of Mechanical Systems**, Allyn and Bacon,U.S.A., 1989

[4] Klose, A, J., **Airplane Aileron System**, In: United States Patent US2369832, 1945

[5] Lawrence,Y,Lam., Michael,Lam.,**Aileron For Fixed Wing Aircraft**, In: United States Patent US6554229B1,2003

[6] Lee, Norman. **Aircraft Flap System**, United States Patent US3785594, 1972

[7] Shabana, A., **Dynamics of Multibody System**s, A Wiley Interscience Publication, 1989

[8] Stephenson, M, F., Wash, Issaquah., Wing Flap Mechanism, In: United States Patent US4605187, 1986

[9] Visa,I., Alexandru,P., Alexandru,C.,Talaba,D., **Proiectarea functionala a mecanismelor ,Metode clasice si moderne**, Editura Lux Libris ,Brasov 1998

[10] Visa,I., Antonya,Cs.,**Structural synthesis of planar linkages as multibody systems**, Proceedings of the Eighth IFToMM International Symposium on Theory of Machines and Mechanisms Bucharest,Romania Syrom,2001

[11] Visa,I.,**Mechanical Systems Modeling as Multibody Systems in Product Design**, Brasov,Romania,PRASIC 2002

[12] Wang, Timothy., **Variable camber leading edge flap**, United States Patent US4189120, 1980

[13] Westburg,P.W.,**Aircraft flap supporting and operating mechanism** United States Patent US3013748