# Coordinately Modeling and Simulation of the Ejection Seat/Occupant System

**Baofeng Li * [1], Bifeng Song * [1], Sen Lei * * [1],**

*** School of Aeronautics, Northwestern Polytechnical University, Xi'an, P.R.China, 710072**
*** * China Aviation Life-Support Research Institute, Xiangfan, China, 441001**

**Kewords**: *multi-body, ejection seat, human model, Lagrange, Simulink*

## Abstract:

*The ejection seat/occupant was regarded as a multi-body system. The Lagrange equations were used to model such a system, and a visualized human model were established by VRML. By the simulation on MATLAB/SIMULINK, this model satisfies the test results very well and fairly depicts the attitude of the occupant. Such a multi-body model is helpful to design devices of crewmember protection.*

## 1 Introduction:

Computational simulation is more flexible, safety and economical, and more important in the designing of the escape system then before. Traditionally such methods treat the seat and the occupant as a whole object, and inevitably overlook the dynamic characters of the occupant. With the augment of airplane envelopes, the performance of currant ejection seats is stringent to progress. As a important research method, computational simulation needs a more accuracy model to depict the dynamic characters of the seat/occupant in the process of ejection.

For this reason, the ejection seat/occupant can't ever be regarded as a point or a single rigid body, in other words, it needs a multi-body model to represent the dynamics characters of ejection system. In such fields as robotics, biomechanics and spacecraft control, Lagrange equation is broadly used, for which is a very convenient tool to analyze the dynamics performance of multi-bodies.

In this study, we established the Lagrange equations of the seat/occupant, and human model by VRML. SIMULINK chosen as the simulation platform is very adapt to simulate dynamic system. The simulation results are verified by the sled test results, and fairly depict the action of occupant's limbs.

## 2 Reference coordinate systems

The model assumes that the coordinates of the origin of the inertial reference system are zero and all other coordinate systems are specified with respect to this system. The orientation of inertial coordinates ($o_e x_e y_e z_e$) is specified by defining which way is down by the values supplied for the components of the gravity vector. The body-axis coordinates system is fixed at the centroid of the i-th body. The relationship of coordinates systems is shown in figure 1

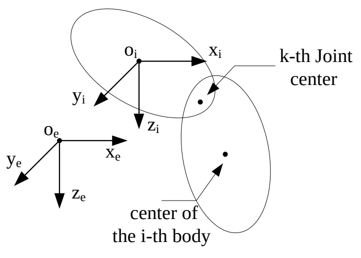


*Figure 1 reference coordinates system*

## 3 Spring-dampers-actuator to model the action between the seat and occupant

Before departure, the occupant is fastened to the seat by constraint devices, which include shoulder restraint strap, pelvic restraint strap and so on. Such devices are simplified as spring-dampers-actuators, which are shown in figure 2.

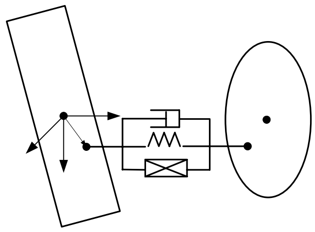

*Figure 2 Spring-dampers-actuator*

The force from spring-dampers-actuator is:

$$F_s = k(h - h_0) + c\dot{h} + f_a \qquad (1)$$

Where: $c, k, f_a$ is respectively the parameter of spring-dampers-actuator; $h = \overrightarrow{p_i p_j}$ is the distance vector of point $p_i$ and $p_j$ ; The concentrated force Fs is transformed to the generalized force by:

$$Q_i = -F_s B_i^T \hat{h} \qquad (2)$$

$$Q_j = F_s B_j^T \hat{h} \qquad (3)$$

## 4 Human and joints model

Although human body is more complex multi-body system, it can be regarded as a rigid body when the aim is to depict the kinematical characters. In this study, human body is consist of six components, which is respectively head, trunk and four limbs linked by several types of joints between each other. Human body and its components are shown in figure 3. Based on kinematical characters of the components specified above, anatomical joints are simplified as corresponding mechanical joints. For example, spherical joint for clavicle joint, Universal joint for neck (assuming that the movement of head is only in the plane of pitch.). The constraint effect on a rigid body is represented by a set of constraint equations. For a spherical joint (figure 4), its constraint equations are:

$$C = R_{0i} + A_i u_i' - R_{0j} - A_j u_j' = 0 \qquad (4)$$

$$\dot{C} = B_i \dot{q}_i - B_j \dot{q}_j = 0 \qquad (5)$$

$$\ddot{C} = B_i \ddot{q}_i - B_j \ddot{q}_j + a_{vi} - a_{vj} = 0 \qquad (6)$$

Where:

$C$ 、 $\dot{C}$ 、 $\ddot{C}$ is respectively translation 、 velocity、acceleration constraint equation. The subscript i and j implies the body of i and j; $R_{0i}$ ( $R_{0j}$ ) is the coordinates in the inertial reference coordinates system of the center of the body of i (j); $u_i', u_j'$ is the body-axis coordinates of the joint center (P and Q); $A_i$ $A_j$ is the Eular cosine Matrix. Other parameters are corresponding coefficients, more specification in [4].

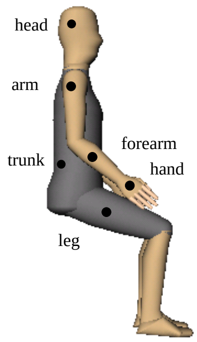


*Figure 3 human model and components*

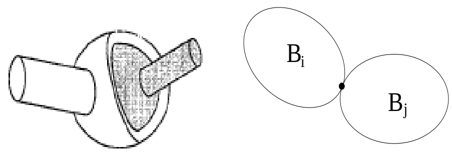


*figure 4 spherical joint*

## 5 Lagrange dynamics equations for multi-body system and its simulation platform Description

For a multi-body system, the Lagrange equations of first kind equations have the form as:

$$M\ddot{q} + C_q^T \lambda = Q_e + Q_v \qquad (7)$$

Where:

$q$ , $\lambda$ , $M$ , $Q_v$ and $Q_e$ are respectively generalized coordinates, Lagrange multiplier, mass matrix, generalized active force and generalized inertial force; $C_q^T$ is partial derivative matrix of constraint equations with $q$ , which has the form as:

$$C_q^T = \begin{bmatrix} \frac{\partial C_1}{\partial q_1} & \frac{\partial C_1}{\partial q_2} & \cdots & \frac{\partial C_1}{\partial q_n} \\ \frac{\partial C_2}{\partial q_1} & \frac{\partial C_2}{\partial q_2} & \cdots & \frac{\partial C_2}{\partial q_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial C_s}{\partial q_1} & \frac{\partial C_s}{\partial q_2} & \cdots & \frac{\partial C_s}{\partial q_n} \end{bmatrix}^T \quad (8)$$

In this study, we choose Matlab/Simulink as the simulation platform. Among others the main reasons for that are its capabilities of solving problems with matrix formulations and easy extensibility. As an extension to MATLAB, Simulink adds many features for easier simulation of dynamic systems, e.g. graphical model and the possibility to simulate in real time. The Simulink program and VRML model are shown in figure 5 and 6.

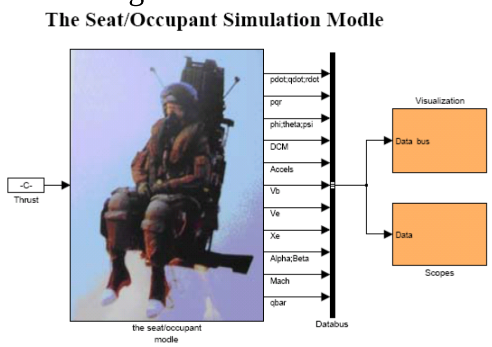

*Figure5.simulation program*

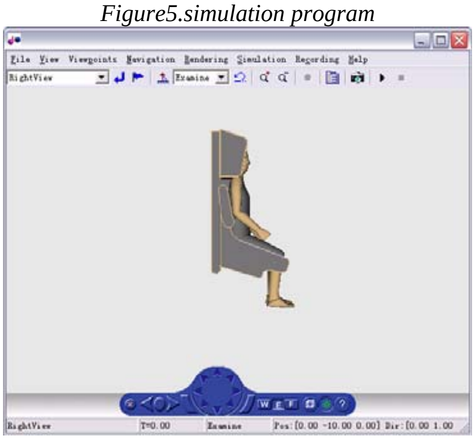
*Figure 6 seat/occupant model*

## Simulation and conclusion

In the study, we chose several typical conditions of ejection to verify the model. Some of simulation results are shown in figure 7-11. From the figure 7, it is seen that the curve of simulation is satisfied the test results very well. Figure 8、9 show the seat\occupant attitude and MDRI. The adduction angle of pilot's clavicle joint varies with the velocity of ejection, which relation is shown in figure 10. Figure 11 shows the history of time from ejection to seat\occupant departure.

Computational simulation as a flexible, safe and economical research method is more and more important to the researchers. In the field of ejection, this method has been progressing for about thirty years. Regarding the seat/occupant as a multi-body and coordinately modeling is convenient to depict the occupant kinematical characters and design the effectual devices to protect the pilot against high air pressure.

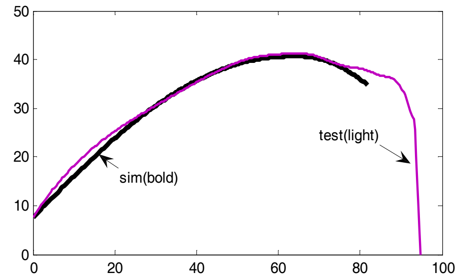

*Figure 7 Altitude VS Downrange distance (0-200km/h)*

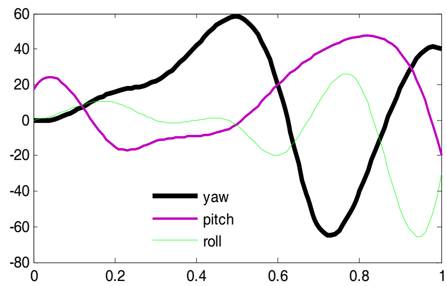

*Figure 8 Attitude-time curve (0-800km/h)*

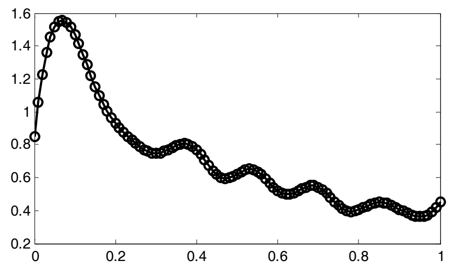
*Figure 9 MDRI-time curve (0-800km/h)*

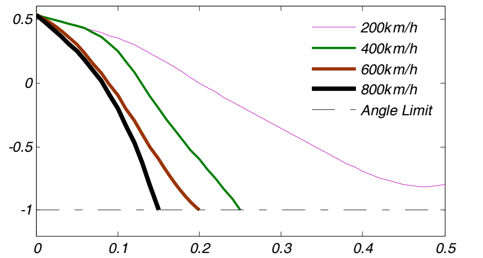

*Figure 10 Flexion angle time curve with velocity*

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*Figure 11 the 0-200 history of time (interval time 80 ms)*

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