The development of a software for processing simulation on the missile ejection system based on ADAMS 9.1 platform

YU Jingjun GUO Weidong
Beijing University of Aeronautics and Astronautics, Beijing, P.R.China, 100083
E-Mail:yujingjun@263.net
ZHANG Shiwei QIN Bingcai
014 Center Luoyang, Henan Province, P.R.China, 471000

Abstract: *Aimed at simulate the detachment between the missile and the plane caused by some ejection mechanisms, a software based on ADAMS 9.1 platform are developed In this paper. Firstlyboth the architecture of the whole software system and function of each component are described. As the most important parts of this paper, some key techniques in the software system such as the parametric modeling and solution of mechanisms and dynamics analysis for complex pneumatic system are studied in detail. Finally, by applying this developed software and taking one concrete missile ejection system for example, the whole ejection procedure is simulated. The result shows that this software plays a very important part in designing the real missile ejection system. In addition, it demonstrates that ADAMS is a strong tool used for designing virtual prototype.*

1 Introduction

Up to date, a specified software suitable for analyzing the kinematic and dynamic performances in the procession of missile ejection has not been developed in China. Especially when taking the air-actuated setting as the source of driving power. Indeed, it is urgent for an aeronautic industry to have such a specified software. This is why we set out developing the software which is used for analysis and simulation for the missile ejection system.

In order to simulate the detachment between the missile and the plane actuated by some ejection mechanisms, to analyze the kinematic and dynamic characteristics of the missile during the ejection, what is more important, to help designing the real missile ejection system, a software for processing simulation on the missile ejection system is developed. The software development is based on ADAMS 9.1 platform. With making a second development, it can be acted as an independent and convenient software.

In this paper, firstly both the architecture of the whole software system and function of each component are described. As the most important parts of this paper, some key techniques applied in the software system such as the parametric modeling and solution of mechanisms and dynamics analysis for complex pneumatic system as an air-actuated setting are studied in detail. Finally, by applying this developed software and taking one concrete missile ejection system for example, the whole ejection procedure is simulated. The result of simulation is also given.

2 The overall architecture of the software system

According to the task requirement, the overall functions of the missile ejection system are presented as follows: by selecting one type from each of the model libraries including the mechanism library, power system model library, missile model library, plane model library, a missile ejection system can be made up, then the real-time kinematic and dynamic analysis and simulation can be made with the help of ADAMS9.1, a software with a strong function of making a solution and simulation. The kinematic and dynamic characteristics of both and mechanism and missile can also be given by means of charts or sheets, these characteristics include that how the displacement, velocity and acceleration of the mass center of the missile and those of each component of the mechanism vary with time, and also include that those of the mass center of each hinge point vary with time. Thus the motional status of the missile in the process of ejection may be gained easily, what is more important, it can bring a great convenience for designing a real missile ejection system.

The components of this software are numbered in detail as follows:

a The software system architecture

The function of this part is to manage and call other function parts and to coordinate with them. This architecture, which is a friendly human-machine interface desired for engineering application, is constructed by using ***MENU DIALOGUE BOX ICON*** etc. provided by ADAMS. Fig. 1 has shown this structure.

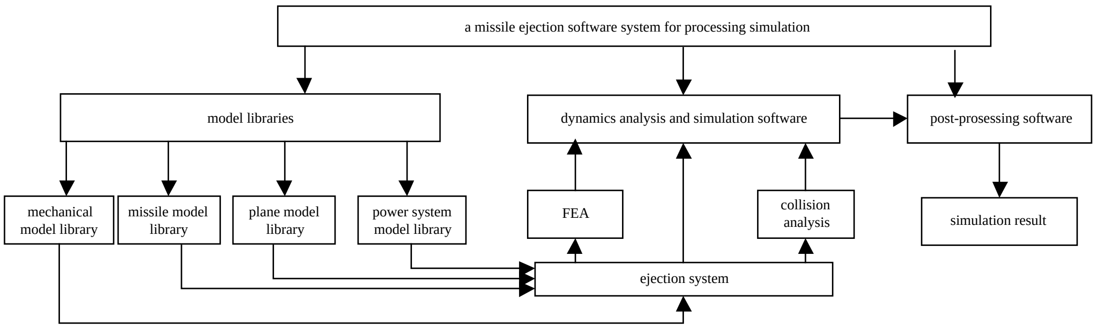


Fig 1 The system architecture

b Model library part

There are four model libraries: ejecting mechanism model library, power system model library, missile model library, plane model library. These four libraries make up the most important part of the whole missile ejection system, and each component is independent each other. One of their function is to frame up a complete system to be analyzed by calling the relevant elements of these libraries. In addition, all these libraries has several advantages such as easy to watch, easy to call, easy to expand and change.

c System modeling analysis part

System modeling analysis refers to select the corresponding model from above four model libraries by means of the human-machine interface and link them up according to some requirements. These requirements include that the positions of these child models and their linking ways are easy to change and modify.

d System simulation part

The system simulation part is used for analyzing the kinematic and dynamic characteristics of missile ejection system. If necessary, you can set some parts of the mechanism model are flexible or consider solving the collisions between the parts.

e Post-processing part

The function in this part is to provide the analysis and simulation results of the ejection system. The kinematic and dynamic characteristics of both and mechanism and missile can also be given by means of charts or sheets, these characteristics include how the displacement, velocity and acceleration of the mass center of the missile and those of each component of the mechanism vary with time, and also include that those of the mass center of each hinge point vary with time.

3 Parameterization modeling and solution to the mechanism model

The ejecting mechanism model library is made up of about 50 mechanism models. After finishing modeling, a mechanism model with new parameter values can be easily built by changing the lengths of the mechanism members, the position of each hinge point is also changed with the modification of the lengths value. While it is impossible to achieve above work directly owing to the limit current function in ADAMS, which you can only modify the mechanism by changing the coordinates of signing point such as the hinge point etc.

3.1 Determination of each the mechanism hinge point coordinate

Using the method of building the design variables, the expressions reflecting the relationship between the member lengths and the hinge point coordinates can be given. Each point coordinate is the function of the length value of the mechanism members, thus the parametric modeling of the mechanism can come true. Now take the mechanism shown as fig. 2 for example, this modeling method is introduced in detail. But the first thing to do is to build the expressions reflecting the relationship between the member lengths and the hinge point coordinates.

Such conditions have been known: the length of each member, including L_3 L_{4BD} L_{4DF} L_5 L_6 L_7 L_{8GH} L_{8HI} L_{8JH} L_{8HK} L_{JM} L_{KL} L_{9NP} H_9,and $x_{A,}$,y_A ,x_B ,y_B ,x_C ,y_C,,x_E ,y_E , representing the coordinate of the hinge point A, B, C, E, both of which are shown in fig.2.

The solve requirements: the coordinate of the hinge point D F G H I L M, and the id point J K N P Q R.

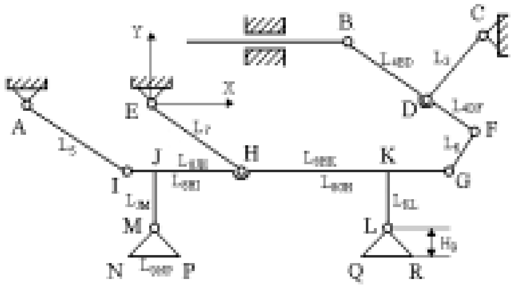


Fig. 2 Modeling of an ejection mechanism

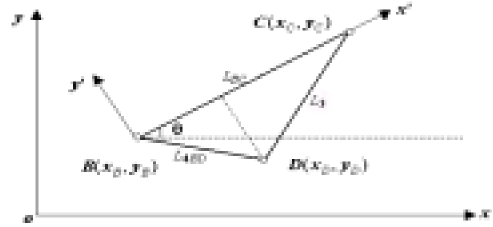


Fig. 3 The sketch map of solving the hinge point D

3.1.1 Determination of hinge point D and F coordinates

The coordinate of hinge point D is located in the focus of between the circle whose center is point B and the value of its radium is L_{4BD} and the circle whose center is point C and the value of its radium is L_3. At this time, the point D coordinate has two possible values from the view of mathematics. In fact, considering the above mechanism model, The position coordinate of point D with smaller y coordinate is the real solution. The relationship of these points is shown in fig.3.

In term of some theories about the coordinate transformation, the point D coordinate in XOY coordinate frame is as follows:

$$\begin{cases} x_D = x_B + \dfrac{L_{4BD}^2 - L_3^2 + L_{BC}^2}{2L_{BC}}\cos\theta + \sqrt{L_{4BD}^2 - \left(\dfrac{L_{4BD}^2 - L_3^2 + L_{BC}^2}{2L_{BC}}\right)^2}\sin\theta \\ y_D = y_B + \dfrac{L_{4BD}^2 - L_3^2 + L_{BC}^2}{2L_{BC}}\sin\theta - \sqrt{L_{4BD}^2 - \left(\dfrac{L_{4BD}^2 - L_3^2 + L_{BC}^2}{2L_{BC}}\right)^2}\cos\theta \end{cases} \tag{1}$$

Where:

$$L_{BC} = \sqrt{(x_B - x_C)^2 + (y_B - Y_C)^2} \tag{2}$$

$$\theta = arctg\frac{y_C - y_B}{x_C - x_B} \tag{3}$$

The position of hinge point F is located on the line determined by point B and point D, so it is very easy to solve the coordinate of point F. The relation expression is shown as follows:

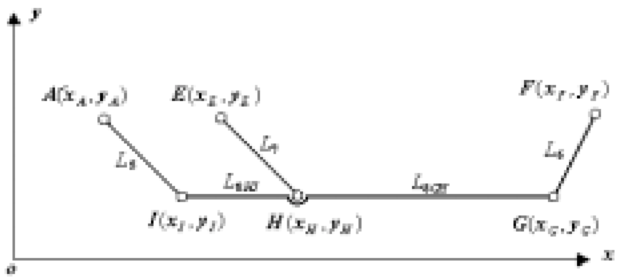
$$\begin{cases} x_F = x_B + \dfrac{L_{4BD} + L_{4DF}}{L_{4BD}}(x_D - x_B) \\ y_F = y_B + \dfrac{L_{4BD} + L_{4DF}}{L_{4BD}}(y_D - y_B) \end{cases} \tag{4}$$

3.1.2 Determination of hinge point G, H and I coordinates

Both the position of hinge point G, H, I and their relations are shown in fig.4. In term of machine and mechanism theory, the part 5, 6, 7, 8 make up a III rod group, it is impossible to describe their coordinates by means of some expressions directly. So an optimization method based on single variable is applied in order to solve all these point coordinates.

Here take the x coordinate of the hinge point I as the optimized variable. According to the position relationship of point I and point A, y coordinate y_I of point I about its x value x_I is expressed as follows:

$$y_I = y_A - \sqrt{L_5^2 - (x_A - x_I)^2} \tag{5}$$



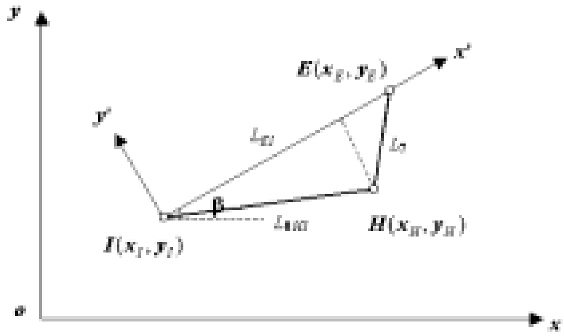


Fig. 4 The position of the hinge point G, H, I

Fig. 5 The scheme of solving the hinge point H

The coordinate of hinge point H is located in the focus of between the circle whose center is point I and the value of its radium is L_{8HI} and the circle whose center is point E and the value of its radium is L_7. Considering the above mechanism model, The position coordinate of point H with smaller y coordinate is the real solution. Fig. 5 shows the sketch map of solving the hinge point H, and its coordinate is:

$$\begin{cases} x_H = x_I + \dfrac{L_{8HI}^2 - L_7^2 + L_{EI}^2}{2L_{EI}}\cos\theta + \sqrt{L_{8HI}^2 - \left(\dfrac{L_{8HI}^2 - L_7^2 + L_{EI}^2}{2L_{EI}}\right)^2}\sin\beta \\ y_H = y_I + \dfrac{L_{8HI}^2 - L_7^2 + L_{EI}^2}{2L_{EI}}\sin\theta - \sqrt{L_{8HI}^2 - \left(\dfrac{L_{8HI}^2 - L_7^2 + L_{EI}^2}{2L_{EI}}\right)^2}\cos\beta \end{cases} \tag{6}$$

Where

$$L_{EI} = \sqrt{(x_E - x_I)^2 + (y_E - y_I)^2} \tag{7}$$

$$\beta = arctg\,\frac{y_E - y_I}{x_E - x_I} \tag{8}$$

The position of hinge point G is located on the line determined by point H and I, so it is very easy to solve the coordinate of point G. The relation expression is shown as follows:

$$\begin{cases} x_G = x_H + \dfrac{L_{8GH}}{L_{8HI}}(x_H - x_I) \\ y_G = y_H + \dfrac{L_{8GH}}{L_{8HI}}(y_H - y_I) \end{cases} \tag{9}$$

Now we have obtained the position coordinates of the hinge point G, H, I. Clearly they are all the functions about variable x_I, but the objective function has not been built up to date. Maybe you have noticed that the known value L_6 is not used, so the objective function can be defined as follows:

$$F(x) = \left|\sqrt{(x_F - x_G)^2 + (y_F - y_G)^2} - L_6\right| \tag{10}$$

According to the theory of optimization, a suitable design variable value need be sought to assure the minimum value of objective function $F(x_I)$. If we can't do this, the precise positions of hinge point G, H, I may not be found.

At the first time, we used a method based on multi-variable optimization, i.e. take all the coordinates of G, H, I (x_G ,y_G ,x_H ,y_H ,x_I ,y_I)as the design variables and build several functions for optimization. Owing to multi-variables, the problem of multi-crest happened. As a result, an optimized solution is hard to gain unless the beginning values of the design variables are very suitable. In general, the error is too large to satisfy our design need. After many trials, we finally found the method introduced above. And a desired result has been taken.

3.2 Parametric modeling of the mechanism by using ADAMS

The operation process on parametric modeling of the mechanism by using ADAMS is specified in detail as follows.

1. Define the known conditions (the length of each mechanism members: L_3 L_{4BD} L_{4DF} L_5 L_6 L_7 L_{8GH} L_{8HI} L_{8JH} L_{8HK} L_{JM} L_{KL} L_{9NP} and the coordinate of the point A, B, C, E: $x_{A,}$,y_A ,x_B ,y_B ,x_C ,y_C,,x_E ,y_E)as the design variable; On the other hand, set the beginning value and the variance range of the optimized variable x_I . When setting its beginning value, the layout of the mechanism model need be considered to make the beginning value close to the optimum value as possible and be convenient with optimization. In addition, the beginning value is set directly as defining design variable. While the variance range of x_I need be set within an available value range. For example, In fig. 1, the maximum value of x_I is x_A+ L_5, and its minimum value is x_A- L_5 .
2. Use tool ***Point*** and build the hinge points and the signing points J, K. Define them as Point_A, Point_B, Point_C, Point_D, Point_E, Point_F, Point_G, Point_H, Point_I, Point_J, Point_K, Point_L, Point_M.
3. Construct the mechanism members with ***2 Bodies-1 Loc*** mode in the tool ***Link***. For example, build member Part_AI between point A and point I, build member Part_BF between point B and point F, build member Part_CD between point C and point D, build member Part_GI between point G and point I, while unit the members between G and I, between J and M, between K and L into one member by using ***BOOL*** operation.
4. Build the motion relationship between each member of the mechanism. Here they all have the motions rotated with fixed axis.
5. Build the objective function and solve it by using the optimization method. To specify in detail, From the ***Build*** menu, point to ***Measure***, point to ***Function***, point to ***New***, input the expressions into ***Function Builder*** click ***OK***. From Simulate menu, select ***Design Study, DOE*** **,Error!** then click start and begin the optimization for x_I. When a suitable value has been found, the optimization ends, the positions of some unknown points are also found. If some parameters need to be modified, input these values into a self-defined dialog and click ***OK***. Thus the parametric modeling of the mechanism has also been done. Fig. 6 shows the interface and the dialog for modifying the mechanism parameters.

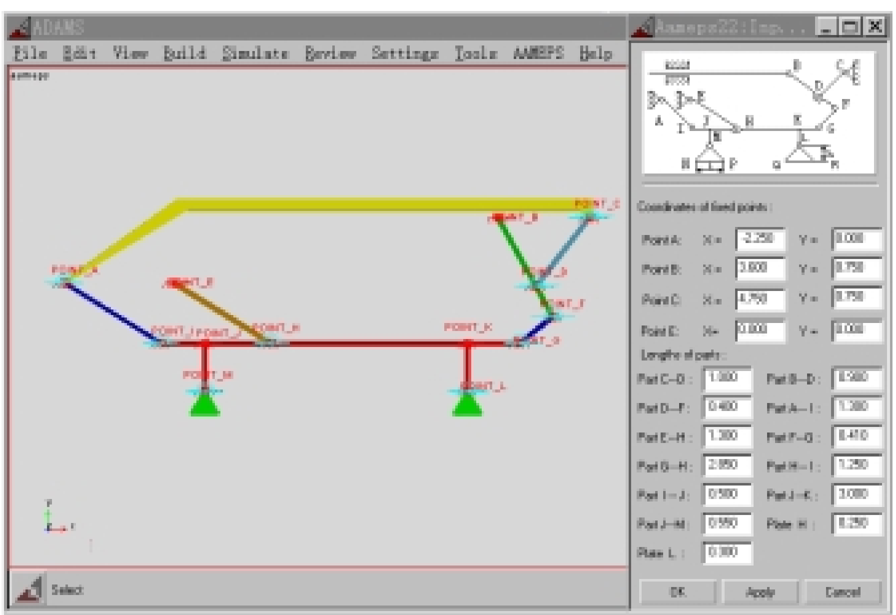


Fig. 6 The interface and the dialog for modifying the mechanism parameters

4 Parametric modeling and solution to the power system

In general, the air-actuated setting or the gas-fired actuated setting is taken as the power resource of the missile ejection mechanism. Although ADAMS have a very strong function in making the kinematic and dynamic analyses for a mechanical system, it lacks making an auto-modeling and a analysis for some power setting especially for air-actuated setting. In view of the difficulties of auto-modeling for air-actuated setting, we used a convenient way to realize the modeling for the power setting of the missile ejection mechanism. This method is based on using the functions provided by ADAMS, and what we have done is to make a second development.

To describe it in more details, the modeling of the power system can be divided into two parts: building a geometry and making a solution. The former can be finished by using some basic geometry elements provided by ADAMS, while the latter is a key to solving the modeling of power system. In order to realize it, firstly mathematics modeling process becomes very necessary if gaining some expressions, then define the relevant parameters of this power system as some design variables, Thus some functions expressed by these variable and some constant value are built and solved by ADAMS /Solve, finally an expression about the power output value is derived. A force expressed by these functions is defined and is attached to the output part of the power system. Thus the modeling of power system is finished. In order to modify the parameters more conveniently, a dialog for parameter inputting is built. Now take a differential cylinder for example, the method of power system modeling is introduced as follows.

4.1 Modeling of the power system

4.1.1 Differential cylinder model

Here take the air-actuated setting as a research objective, which is used in the ejecting mechanism as the power source of the missile ejection system. The structure of a real air-actuated setting is very complicate, but in the need of analysis easily, we can simplify it to a physical model shown as fig. 7. In fact this model is a differential cylinder which is made up of gas bottle 1, cylinder 2 and piston 3. The pressed gas flows between these three cavities, at the same time, the difference of the gas pressure value on either side of the piston 3 has developed. Thus the existence of this value makes the piston 3 propel the ejecting mechanism.

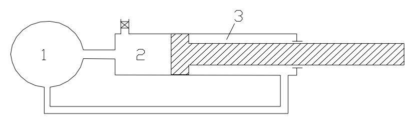


Fig. 7 The physical model of air-actuated setting

4.1.2 Mathematics modeling of the gas drive setting

We can describe the parameter variance in the cavity gas by using the state function of ideal gas, the first law of thermodynamics and Newton theorem about motion. The varying rate of gas volume, pressure, temperature and the heat emitting rate which exist in each cavities of the air-actuated setting can be expressed by 12 differential functions as follows.

$$\begin{cases} \dot{V}_1 = 0 \\ \dot{V}_2 = S_2 \dot{x} \\ \dot{V}_3 = -S_3 \dot{x} \end{cases} \tag{11}$$

$$\begin{cases} \dot{T}_1 = \dfrac{T_1}{P_1 V_1}[kR(T_3 G_{31} - T_1 G_{12}) - RT_1(G_{31} - G_{12}) - (k-1)\dot{Q}_{T1}] \\ \dot{T}_2 = \dfrac{T_2}{P_2 V_2}[kRT_1 G_{12} - RT_2 G_{12} - (k-1)\dot{Q}_{T2}] \\ \dot{T}_3 = \dfrac{T_3}{P_3 V_3}[-kRT_3 G_{31} + RT_3 G_{31} - (k-1)\dot{Q}_{T3}] \end{cases} \tag{12}$$

$$\begin{cases}\dot{Q}_{T1} = \sigma_0 \dfrac{P_1}{RT_1} F_1 (T_1 - T_a) \\ \dot{Q}_{T2} = \sigma_0 \dfrac{P_2}{RT_2} F_2 (T_2 - T_a) \\ \dot{Q}_{T3} = \sigma_0 \dfrac{P_3}{RT_3} F_3 (T_3 - T_a)\end{cases} \tag{13}$$

$$\begin{cases}\dot{P}_1 = \dfrac{RT_1}{V_1}(G_{31} - G_{21}) + \dfrac{P_1}{T_1}\dot{T}_1 \\ \dot{P}_2 = \dfrac{-RT_2}{V_2} G_{12} + \dfrac{P_2}{T_2}\dot{T}_2 - \dfrac{P_2}{V_2}\dot{V}_2 \\ \dot{P}_3 = -\dfrac{RT_3}{V_3} G_{31} + \dfrac{P_3}{T_3}\dot{T}_3 - \dfrac{P_3}{V_3}\dot{V}_3\end{cases} \tag{14}$$

Where:

$$G_{ij} = \mu A P_i \sqrt{\frac{1}{RT_i}} \sqrt{\frac{2k}{k-1}} \sqrt{\left(\frac{2}{k+1}\right)^{\frac{2}{k-1}} - \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \qquad \frac{P_j}{P_i} < \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \tag{15}$$

$$G_{ij} = \mu A P_i \sqrt{\frac{1}{RT_i}} \sqrt{\frac{2k}{k-1}} \sqrt{\left(\frac{P_j}{P_i}\right)^{\frac{2}{k}} - \left(\frac{P_j}{P_i}\right)^{\frac{k+1}{k}}} \qquad \frac{P_j}{P_i} \geq \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \tag{16}$$

Hence, The force acted in the piston is

(17)

The parameters used in expression 11-17 are explained as follows:

$V_i, \dot{V}_i$ —the volume value and the varying rate of the volume of the cavity i $\dot{T}_i, T_i$ —the temperature value and the varying rate of the temperature of the cavity i $x, \dot{x}$ —the movement velocity rate of the piston T_a, P_a —the temperature and pressure of the atmosphere S_i —the contacting area between the piston and the cavity i P_i —the pressure of the cavity i $\dot{Q}_{Ti}$ —the heat emitting rate of the cavity i G_{ij} —the flowing quantity of the gas from cavity I to cavity j F_i —the area of transferring heat in the burning room **R—**gas constant **k—**the heat cavity ratio σ_0 —the coefficient of transferring heat.

4.2 Making a solution to the air-actuated setting

As far as this air-actuated setting as a power system is concerned, its solving process is actually to make a combined solution for a series of differential function group. With the help of ADAMS, this problem has become very easy.

Open ADAMS/View, click ***Build*** in the main menu and select ***Differential Equation*** in the option of ***System Elements***, build 12 DIFF functions(differential functions shown as 10-13). To avoid existence of the function with too many words, divide it into several parts, then express them with some variable expressions, i.e. click ***Build*** in the main menu and Select ***State Variable*** in the option of ***System Elements***. Notice that it is necessary to call some functions and expressions in ***ADAMS/View Function Builder***, such as DIF, DIF1, VARVAL, IF etc. in the process of building up all above functions and expressions.

In order to make the users convenient in doing such work, the parametric method is also used when making a solution for the power system, i.e. define each parameter of the setting as a variable and build a dialog for parameter inputting to modify the parameters in term of the changed conditions(shown as fig. 8). After clicking ***OK***, a new solution can be gained.

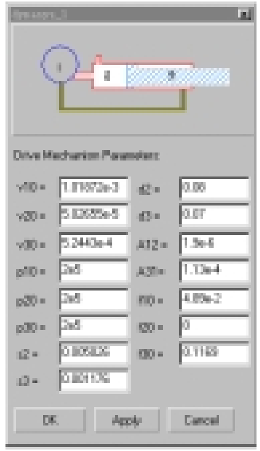


Fig. 8 A dialog for modifying the parameters of power system

5 processing simulation on the missile ejection system

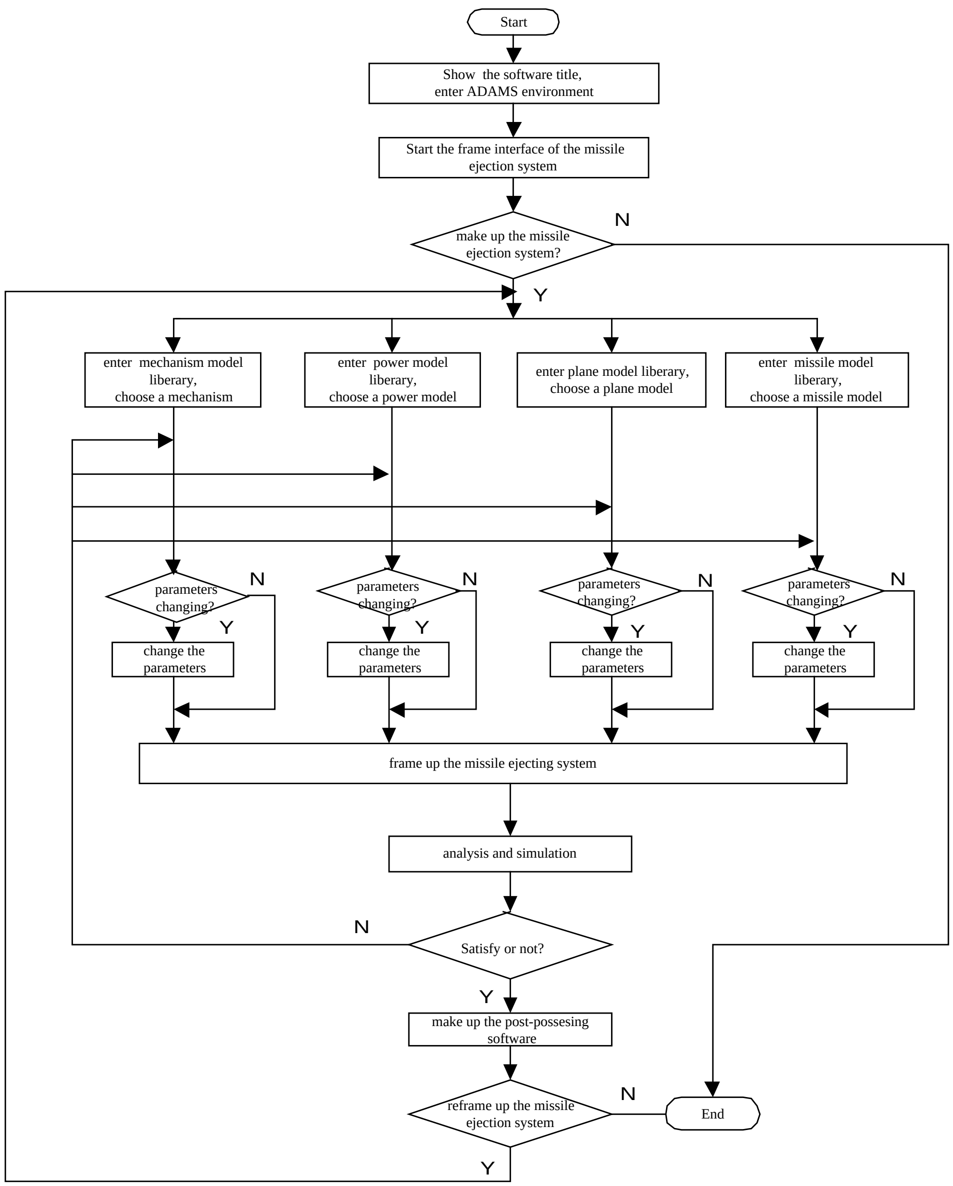


Fig. 9 The flow chart of processing simulation

5.1 The simulation process of the missile ejection system

The operating steps of analysis and simulation for the missile ejection process are numbered as follows.

1 Call ejection mechanism model from the mechanism library and the dialog for inputting the mechanism parameters;
2 Call air-actuated setting model from the power system library and the dialog for inputting the setting parameters. In addition, link it with the above ejection mechanism;
3 Call the missile model from the missile model library, suspend it on the linking slider of the ejection mechanism, thus an integrated missile ejection system is formed;
4 Carry out the simulation for the system, and measure the relative data and compared them with the data which the design requirement;
5 Modify the system, and then carry out the simulation for this new system. Try it again and again, until satisfy the design requirement.
6 Finally, gain the kinematic and dynamic characteristics of the mechanism and the missile by means of curves or charts from the post-processing software.

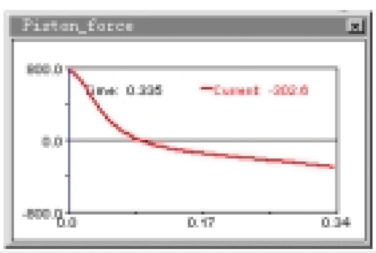
The flow chart of processing simulation for this system is shown as fig. 9.

5.2 The result analysis of simulation

From the ***main toolbar*** of **ADAMS**, select ***Simulation*** Set the simulation time(0.34s) and simulation step(200). From ***Plot Builder***, select the measure items you need. The relative curves can appear on ***Plot Window***.

Fig. 9 and fig. 10 show parts of the curves. The unit of horizontal axis is sec, the unit of vertical axis use “m,kg,N,s,deg”.

1. The curve of piston force



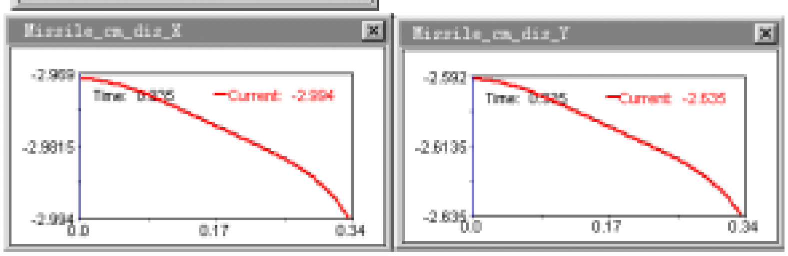


Fig. 9 The curve of piston force

Fig. 10 The curves reflecting the position of missile mass center

From Fig. 10, we can conclude: initially the force applied in the cylinder is large enough to cause the mechanism move forward, but the force value becomes small gradually, and the decline velocity of the missile is controlled. When it becomes a negative value, the velocity begins to decline. When the simulation time equals to 0.34s, the piston has a maximum displacement.

2 *the curves reflecting the position of missile mass center*

From fig. 10, we can conclude: the missile can keep horizontal and stable status during its declining motion.

6 Conclusion

The result shows that this software plays a very important part in designing the real missile ejection system. In addition, it demonstrates that ADAMS is a strong tool used for designing virtual prototype.

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