Calculating dynamic of the damper system for recovering the payload of a model carrier rocket

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Abstract

The authors study to design a physical model of carrier rocket, and a payload (include control device, parachute system…) in the missile model. For using it many times, in the testing process, the revoking system of payload by parachute and suitable damper shafts are needed. To reduce the mass of payload (and the missile) we have to calculate dynamic damper system during revoking payload. The paper presents dynamic model, method, and numerical results of the damper system during the process of bursting system shafts of dampers and the damping process when the payload connects to ground. The problem is solved by applying Matlab software. Basing in the software, the different parameters of the model are investigated and some recommend is shown in designing and manufacturing damper shaft system of the parachute.

Keywords: *dynamic damper shafts, payload, model of carrying missile*.

1. Introduction

The payload is an essential part of a launch rocket because it contains costly instruments. For research purpose, the payload is designed to be recovered by a parachute and a system of damper shafts without damaging the instruments inside. The revoking method by parachute system has been carried out for many years. The payload is designed as a cylinder, whose top is spherical; the bottom is mounted with the carrier rocket. Three damper shafts are attached to the exterior of the payload. The damper shafts are in the locked position until the parachute opens. The dampers are released for landing (Figure 1, 2).

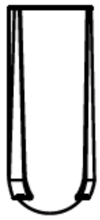


Figure 1: Dampers are in locked position

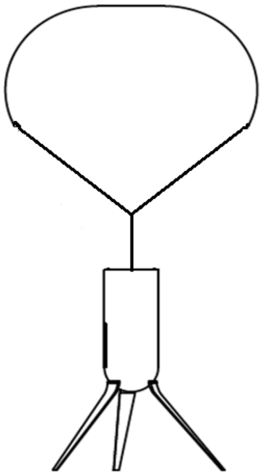


Figure 2: Dampers are released position after revoking parachute

A limited number of analytical studies of the damper system in the revoking payload process has been published [1], [2], [3], [4]. The paper focuses on the dynamic problems of the releasing damper shafts for payload as well as the damping process when the payload is landed. For recovering the payload safely, two problems need to be solved. It is necessary to know whether the damper shafts open or not while the parachute fully opened. At the beginning of releasing parachute, the velocity of the payload is considerably higher, so the aerodynamic drag acting on damper shafts is greater the inertia force. As the result, the damper shafts are pressed into the payload. When the parachute fully opens, the payload decelerates and the falling velocity decreases significantly to terminal velocity, three damper shafts might be burst themselves due to higher force of inertia. To answer the above question, forces and moments act on damper shafts during steady falling are calculated analytically. The second problem is calculating the stiffness of the damper shaft when it landed on the ground so that the load factor of the payload is not greater than 10. That maximum limit of load factor guarantees that the instruments inside the payload safe. The problem is solved by applying the law of conservation of energy. The solution provides us the stiffness coefficient of the damper shaft. Base on the stiffness coefficient, appropriate material is selected for designing and manufacturing dampers.

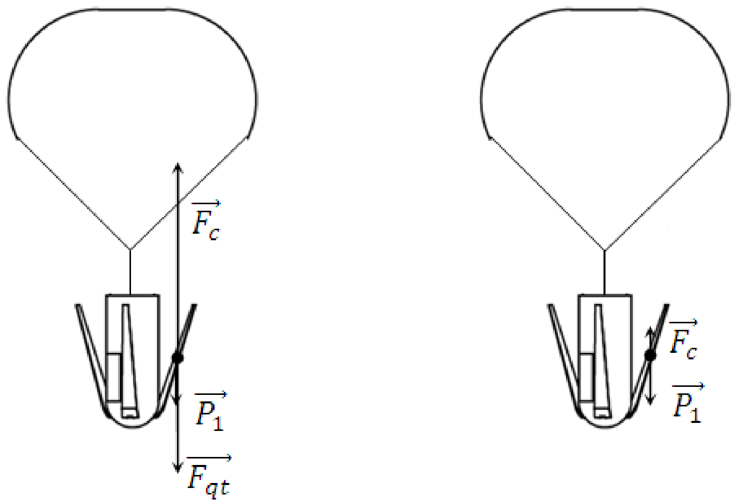
2. Method

To solve the two above problems, the equations of motion of dampers are derived. These equations are solved numerically by Matlab software. Two graphs of moments acting on each damper versus open angle of damper and two graphs of load factor versus stiffness coefficient are plotted. They help engineers to know dynamic characteristics of the bursting damper shafts in different conditions.

2.1. Dynamic Analysis of the damper shafts in flight

The parachute is designed to open at an altitude of 200m above the ground. The locking pins which retain the damper shafts are free. We consider two stages: the first stage is calculated from parachute started to revoke until the payload gets terminal velocity. In this step, the velocity of the payload is high and the bursting time is small (1s, [4]), so the inertial and aerodynamic drag force of the damper shaft are high. In the second stage, the payload falls steadily at a lower terminal velocity of 3.65 m/s, [4], the aerodynamic force acting on damper shaft are small in comparison to their gravitational force.

The forces acting on damper shafts during bursting parachute and during its steady fall are shown in figure 3 (a, b).



a) Parachute bursting *b) Steady fall of parachute*

Figure 3: The forces acting on damper shafts during bursting parachute (a) and during its steady fall (b)

Where: $\vec{F}_{qt}$ - Inertial force; $\vec{F}_c$ - Air drag; $\vec{P}_1$ - Gravity.

The forces are given as follows:

+ Gravity of the damper:

$$P_1 = m_1 g \tag{1}$$

Where: m_1 - is the mass of the damper shaft, it is located in the centre of gravity.

+ Aerodynamic force acting on damper shaft:

$$F_c = C_c \cdot \frac{\rho \cdot V_c^2}{2} \cdot S \tag{2}$$

Where C_c - drag coefficient of the damper shaft; V_c - falling velocity of the damper shaft; S - frontal area of the damper shaft.

+ Inertial force acting on the damper shaft when bursting parachute:

$$F_{qt} = - m_1 a \quad (3)$$

Where, a - is the acceleration of the damper shaft.

Base on the forces act on damper shaft, we manage to calculate moments of these forces relatively about hinge of the damper shaft.

+ Moment of the gravity.

$$M_1 = ½.L.\sin\varphi.P_1 = ½.L.\sin\varphi.m_1 g \quad (4)$$

Where L is the length of the damper shaft, φ – opened angle of the damper shaft.

+ Moment of the inertial force:

$$M_{qt} = ½.L.\sin\varphi.F_{qt} = ½.L.\sin\varphi.\ m_1 a \quad (5)$$

+ Moment of the aerodynamic drag:

$$M_c = ½.L.\sin\varphi.F_c = ½.L.\sin\varphi.C_c \cdot \frac{\rho \cdot V_c^2}{2} \cdot S \quad (6)$$

Comments:

- When bursting parachute, there are only three types the moment due to inertial force, aerodynamic drag force and gravity.;
- When payload falls steadily, there are only two types of moment due to gravity and aerodynamic drag force.

2.2. Dynamic Analysis of the damper shafts at moment of touch down

Forces acting on dampers at time of landing are shown in figure 4.

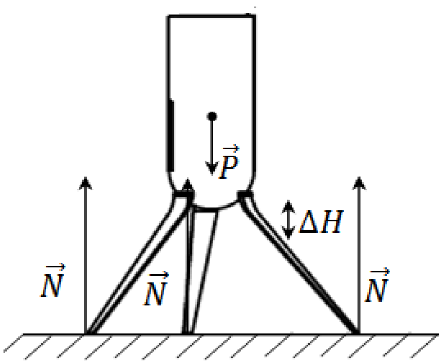


Figure 4: Forces impacting on damper shafts during connecting to ground

When payload touches ground, the reactive force starts acting on the shaft of the damper. The value of the force increases as the deformation of damper increases. To calculate the deformation of the damper shafts we apply the law of conservation of energy for damping process. Set maximum deformation is ΔH.

The work of the mean deformation force F_{tb} in the distance ΔH overcomes sum work of gravity and kinetic energy:

$$F_{tb}.\Delta H = \frac{m \cdot V_y^2}{2} + mg\Delta H \quad (7)$$

Where, $F_{tb} = F_{max}/2$ (we assumed that the elastic force of the dampers depends linearly on the deformation) is the mean reactive force of the ground impacting on damper shafts when they connects to ground.

V_y is a vertical velocity of the payload when it connects to the ground; m is the mass of payload, g = 9,8m/s^2 gravity acceleration; ΔH is deformation of the center of payload's gravity.

$F_{max} = C.\Delta H$, where C is the hardness coefficient of the damper shaft.

Substitution of $F_{max} = C.\Delta H$, F_{tb} into (7) yields:

$$\frac{C.\Delta H}{2}.\Delta H = \frac{m \cdot V_y^2}{2} + mg\Delta H \quad (8)$$

Or $$C.\Delta H^2 - 2mg\Delta H - m \cdot V_y^2 = 0 \quad (9)$$

Solving the above quadratic equation, we receive ΔH.

After that we find:

$$F_{max} = C.\Delta H \tag{10}$$

With values F_{max} we manage to define the maximal vertical overload during the process in which payload connects to ground.

$$n_{ymax} = F_{max}/mg. \tag{11}$$

We have to limit the value of ΔH to guarantee that the payload does not touch ground. In the design of damper, the length of damper shaft L = 0,457m, the angle of the damper with horizontal plane when payload connects to ground is 45^0, and when it stops, it is $\leq 30^0$. As the result, we know $\Delta H_{max} \approx 0{,}07$m = 7cm.

3. Results and discussion

The initial data for calculation.

The mass of payload m= 7kg, mass of one damper shaft m_1 = 0,3kg; area of damper shaft S = 0,0147m^2; coefficient aerodynamic drag $C_c \approx 0{,}9$; the gravity of acceleration g = 9,8m/s^2; length of the damper shaft L = 0,457m; air density ρ=1,225 kg/m^3; acceleration of payload a = 100m/s^2, [4]; steady speed of payload V_y = 3,65m/s = V_c , [4].

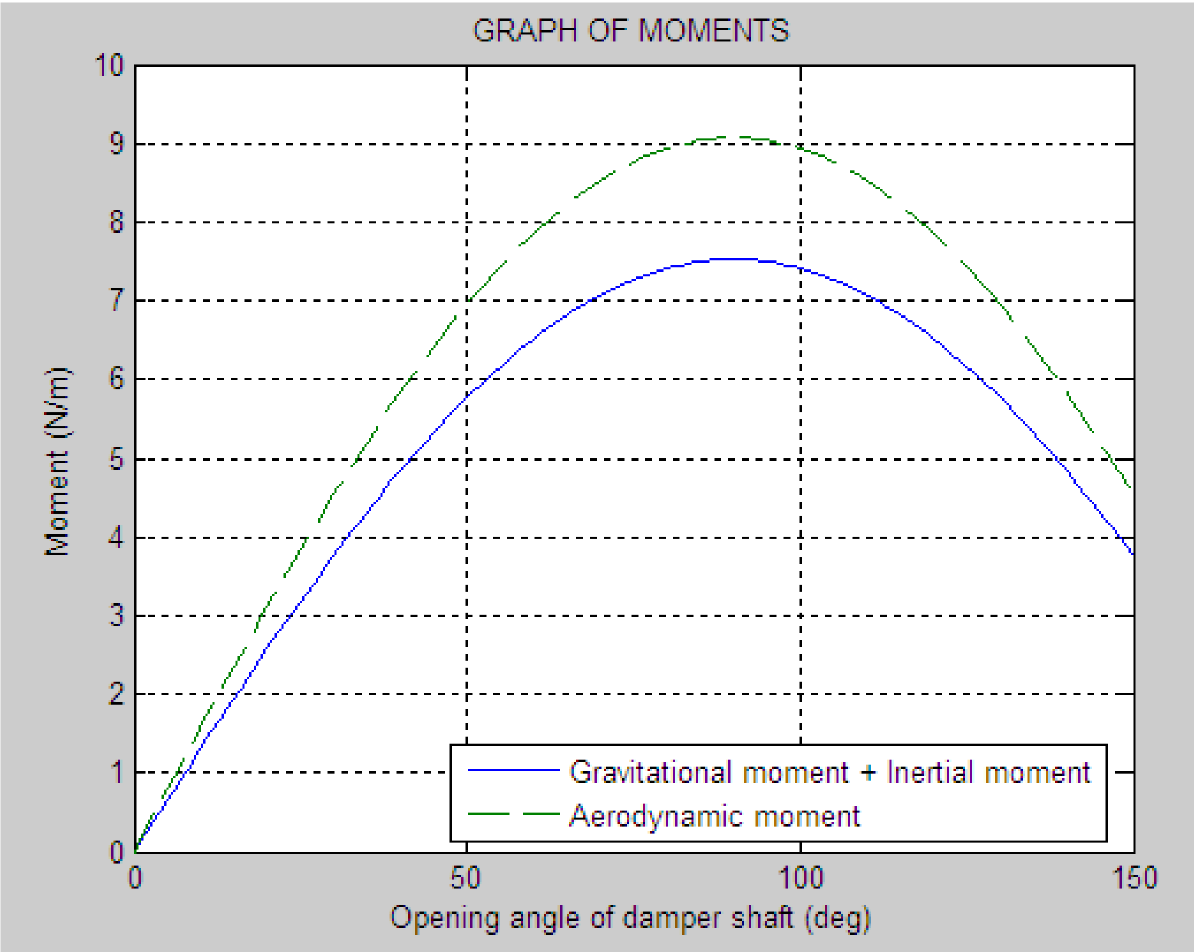
With these data, we calculated, follow the formula (1) ÷ (6):

Moment of inertial force: $M_{qt} = 6{,}855.\sin\varphi$ (Nm)

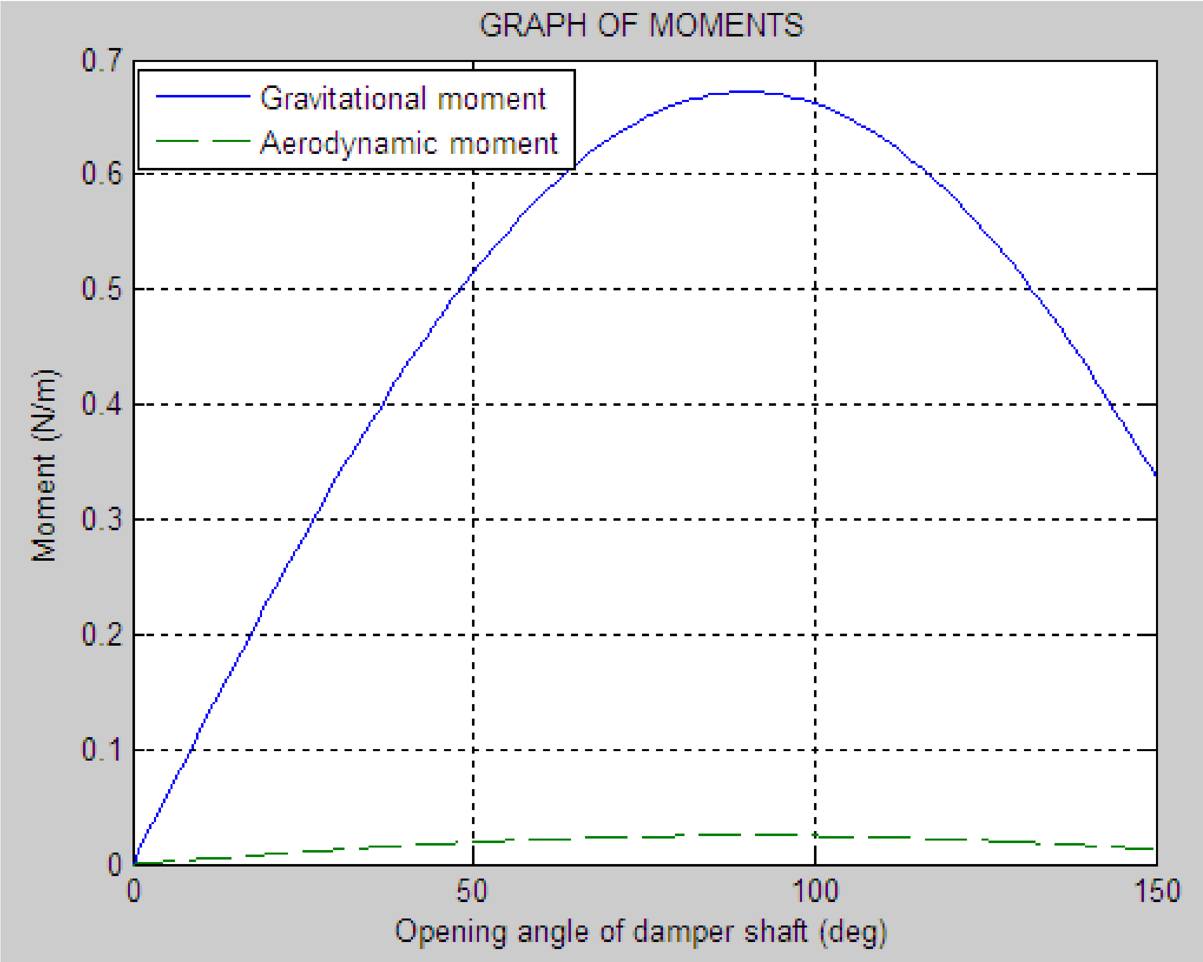
Moment of gravity: $M_1 = 0{,}672.\sin\varphi$ (Nm)

Moment of aerodynamic drag: $M_c = 9{,}073.\sin\varphi$ (Nm) (When a parachute starts to open V_y = 70m/s); $M_c = 0{,}025.\sin\varphi$ (Nm) (When a parachute falls steady with speed V_y = 3,65m/s)

Using Matlab software we could build the diagram of moment which depends on opened angle of damper shaft:



a) Parachute Opens



b) Parachute falls steadily

Figure 5: Moments impact on damper shaft versus opening angle of damper shaft.

Comment:

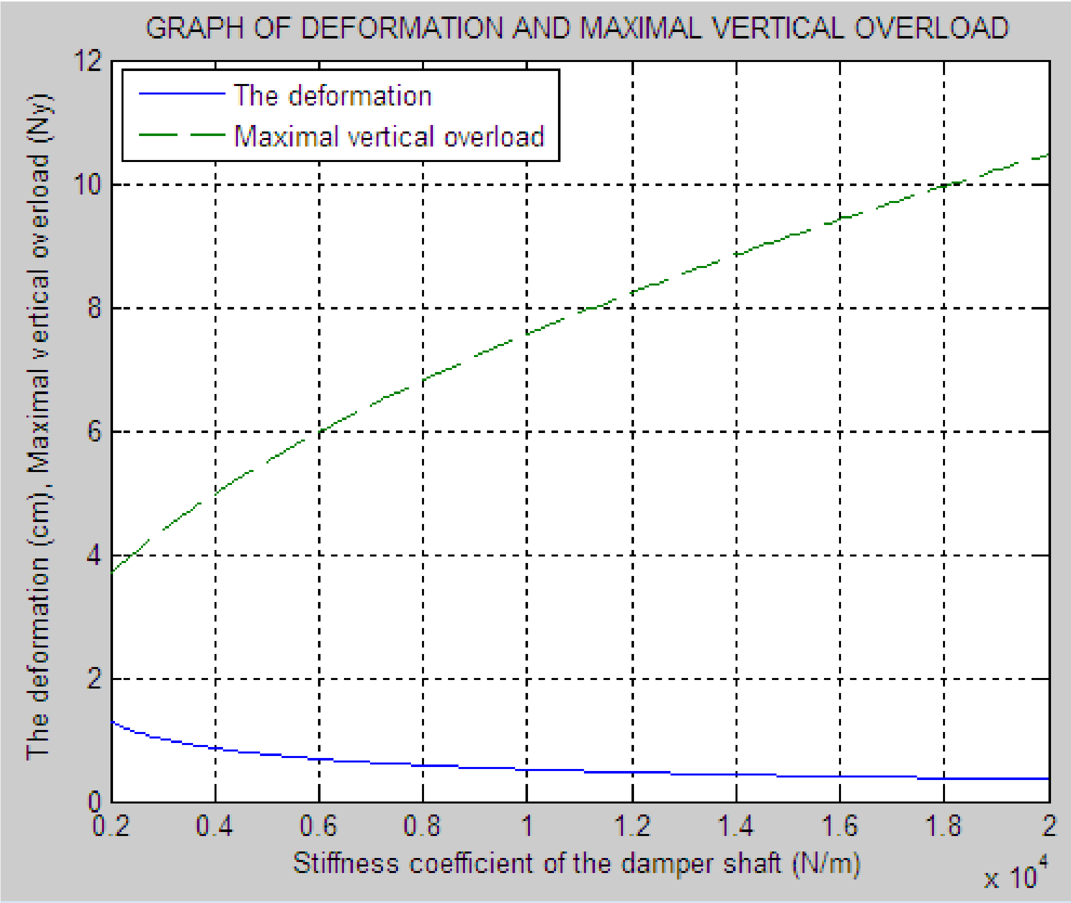
- When bursting parachute, the moments of the aerodynamic drag forces of the damper shafts significantly exceed the sum of moments of the gravity and inertial forces (Figure 5.a), so the damper shafts could not open.

- When payload falls steadily, the moment of gravity exceeds the moment of the aerodynamic forces (Figure 5.b), so the damper shafts will open definitely.

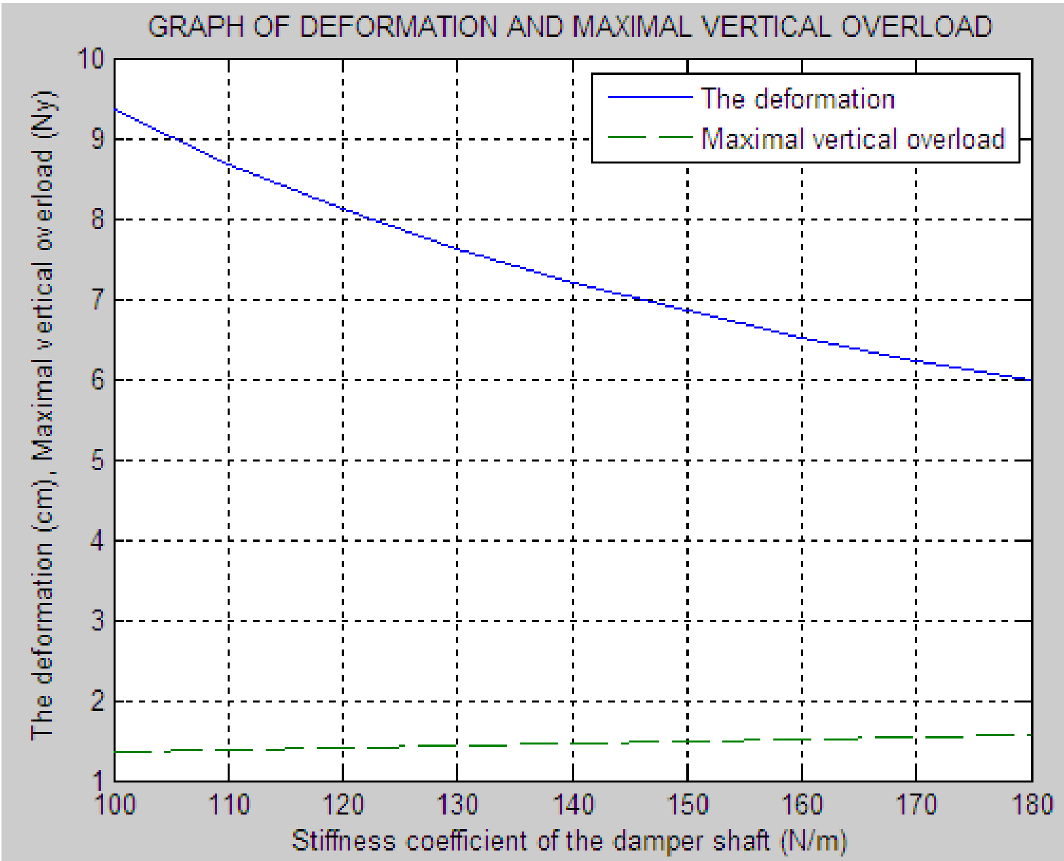
With a different hardness coefficient of the damper shaft, we will receive different deformation. As the result, we could define the vertical overload and the maximal deformation, by using the formulas (9) - (11). The calculated results are shown in the figure 6 (a, b).

Comments:

- The diagram indicates that: when the hardness coefficient of the damper shaft increases, the maximal overload also grows up, but the deformation decreases;
- To guarantee the overload coefficient of the payload $n_{ymax} \leq 10$ during the time of grounding, the hardness coefficient of the damper shaft will be $C \leq 1{,}81.10^4$ N/m and the deformation is $\Delta H \geq 0{,}395$cm (figure 6a);
- With the result of the figure 6b, to guarantee $\Delta H \leq \Delta H_{max} = 7$cm, the hardness coefficient of the damper shaft will be $C \leq 1{,}81.10^4$ N/m. As the result, he maximum overload will be $n_{ymax} \geq 1{,}48$



a)



b)

Figure 6: Diagram of deformation and maximum overload

Conclusion

In the first stage, when parachute starts to open, the moment of aerodynamic force is higher than the total moments of inertia force and gravity force of the damper shaft, so the damper shaft could not burst. To guarantee that the damper shafts will open themselves, we could design a twisted spring in the hinge of the damper shafts. However, in the second step, when the parachute falls steadily at low terminal velocity, the moment of gravity is higher than the moment of aerodynamic force, so the damper shafts open automatically, the twisted spring is not necessary.

To reach the maximum of the vertical overload and deformation when the parachute connects to ground, the hardness coefficient of damper shaft is $145 \leq C \leq 1{,}81.10^4$ N/m. It is a foundation of choosing the materials and designing the structure of the damper shaft.

The investigated result is the base for to perform experiments.

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