Engineering Notes

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Dual-Phase Damping in a Landing Gear at Touch-Down

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I. Introduction

IN this paper, the application of dual-phase damping to an aircraft landing gear is investigated. The landing condition is taken into consideration. Preload and tire nonlinearities are taken into account. The purpose of employing this type of damping is to minimize the peak acceleration transmitted to the aircraft structure; the rigid body mode alone is considered here. The system is subjected to step velocity input and variations of the peak acceleration transmitted to the mass M (Fig. 1a) with respect to the four parameters which define the dual-phase damping are studied. Variations of peak acceleration with the system parameters are also determined.

A simplified representation of an aircraft with landing gear is shown in Fig. 1a, along with the dual-phase damping characteristic in Fig. 1b. Realization of the dual-phase damping characteristic is evident in the sketches of Fig. 2, where a spring-loaded ball or a return valve adapt to the changes in damping force offering the desired characteristic.[1] The four parameters A, B, ζ_1, ζ_2 could be varied by changing either the spring constant or the initial and final area of the orifice. The behavior of the system while landing is considered as follows. When the plane touches down, only the tire will start compressing and the system will behave like a single degree-of-freedom system. Once the tire force exceeds the pre-load acting on the shock strut, the latter will also compress along with the tire. Now the system behaves like a two degree-of-freedom system.

In Fig. 1a, M represents the mass of the aircraft, m-mass of the shock absorber and tire unit, K_T tire stiffness, K and C are the oleo stiffness and damping constants. In this case K_T and C are nonlinear. The tire is assumed to be straight below the shock absorber.

II. System Equations

Equation of motion, before the tire force exceeds the preload P_0 may be written as

$$(M+m)\ddot{Z}_2+K_TZ_2=K_TZ_3 \tag{1}$$

the initial condition being

$$Z_2(0)=\dot{Z}_2(0)=0$$

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Once the preload is equal to the tire force, the equation of motion of the system becomes

$$M\ddot{Z}_1+C\dot{Z}_1+KZ_1=C\dot{Z}_2+KZ_2 \tag{2}$$

$$m\ddot{Z}_2+C\dot{Z}_2+(K+K_T)Z_2=C\dot{Z}_1+KZ_1+K_TZ_3 \tag{3}$$

Initial conditions of these equations (2) and (3) are the final conditions of the previous equation (1), namely

$$Z_1(t)=Z_2(t) \text{ and } \dot{Z}_2(t)=\dot{Z}_1(t)$$

and

$$Z_3=V_mt$$

It is convenient to rewrite Eqs. (2) and (3) in the form

$$\ddot{Z}_1+2\zeta\omega_0\dot{Z}_1+\omega_0^2Z_1=2\zeta\omega_0\dot{Z}_2+\omega_0^2Z_2$$

$$\ddot{Z}_2+M/m\,[2\zeta\omega_0\dot{Z}_2+\omega_0^2Z_2+(K_T/M)Z_2]$$

$$=M/m\,[2\zeta\omega_0\dot{Z}_1+(K_T/M)Z_3+\omega_0^2Z_1]$$

where

$$\omega_0^2=K/M;\ 2\zeta\omega_0=C/M;\ \zeta=C/2(KM)^{1/2}$$

According to the characteristic shown in Fig. 1b, ζ takes values as under

$$\zeta=\zeta_1 \text{ for } |\dot{Z}_2-\dot{Z}_1|\ /V_m\leq A;$$

$$=[(\zeta_1-\zeta_2)/(A-B)]\ (X^1-A)+\zeta_1$$

where

$$|\dot{Z}_2-\dot{Z}_1|\ /V_m \text{ lies between } A \text{ and } B \text{ and}$$

$$X^1=|\dot{Z}_2-\dot{Z}_1|\ /V_m;$$

$$=\zeta_2 \text{ for } |\dot{Z}_2-\dot{Z}_1|\ /V_m\geq B$$

The nonlinear differential equations (1), (2) and (3) are solved by Runge-Kutta method using a digital computer IBM 360/44.

The purpose of employing step velocity input can be explained thus: During a landing, the airplane comes down with a constant velocity of descent v. Once the tire touches the runway, the velocity of the tire becomes zero, that is, there is a sudden fall in the velocity from v to zero. In consequence, the structure also tends to attain zero velocity. It may be said that a deceleration occurs then. The peak value of the deceleration gives the maximum force transmitted to the structure and its contents. This whole process is reversed for convenience of computation by considering a step velocity as the input (Fig.

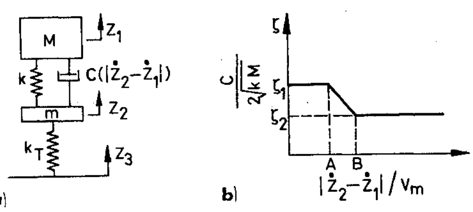

Fig. 1a) Aircraft landing gear model; b) Dual-phase damping characteristic.

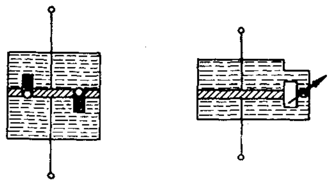

Fig. 2 Dual-phase damper.

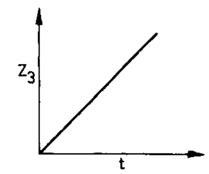

Fig. 3 Input.

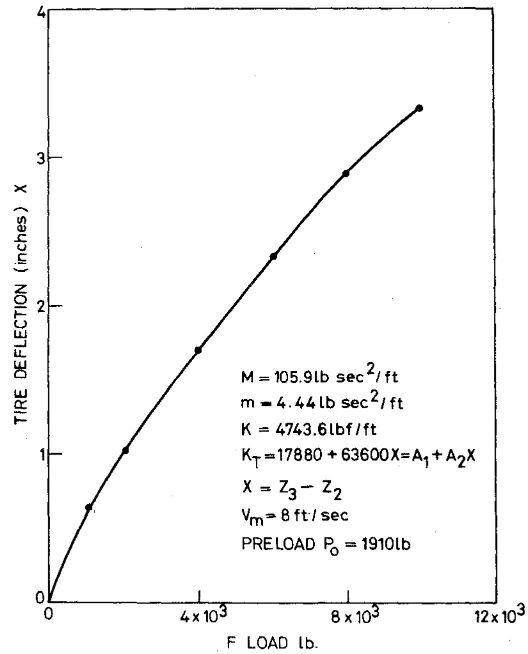

Fig. 4 Tire characteristic.

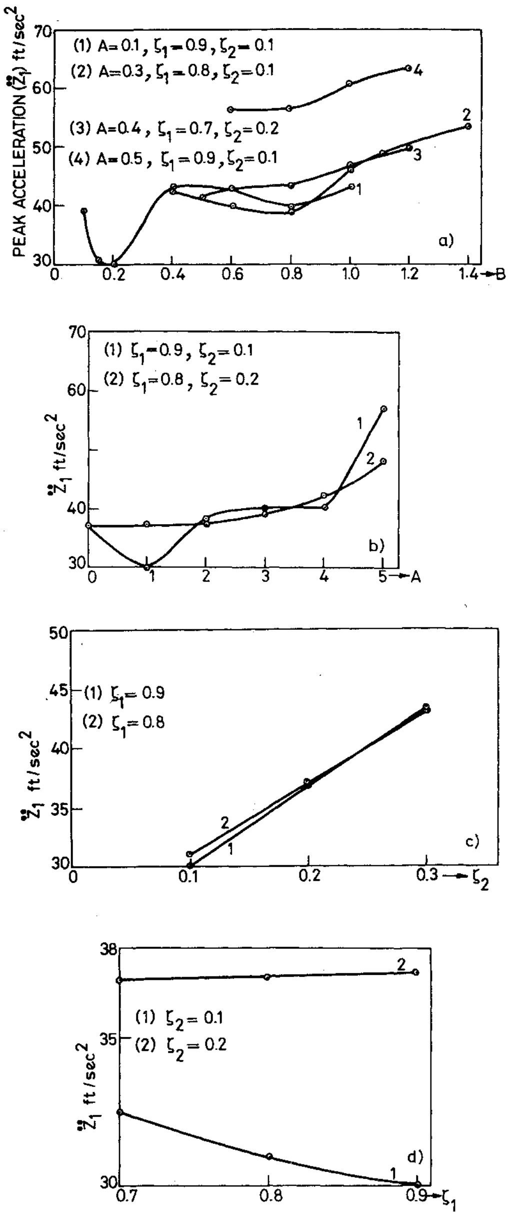

Fig. 5 System response.

3) given at the tire and the peak acceleration transmitted to the mounted mass is calculated.

III. Parametric Study

The values assumed for M, m, K, and K_T are shown in Fig. 4. For conducting a parametric study of the system (Fig. 1a), the values of M, m, K, P_0, A_1, A_2, and V_m are changed by $\pm 10\%$ and the variations of the peak acceleration with respect to these changes are also studied; here, P_0 is the preload for the shock absorber, A_1 and A_2 are constants defining tire characteristics and V_m, velocity of descent.

Parameters like K, P_0, and K_T are calculated from the shock absorber and tire characteristics. The details of the shock absorber considered in the analysis are as follows:

Piston inner diameter = 2.74 in. Area = 5.89 in^2.
Piston outer diameter = 3.12 in. Area = 7.65 in^2.
Cylinder inner diameter = 3.55 in. Area = 9.88 in^2.
Air charging pressure = 250 psi.
Initial air volume = 108.2 in^3.
Ratio of travel of separator to stroke = 1.295
Load at which the oleo starts closing = 250 × 7.65 lb.
Preload = 1910 lb.

Spring constant K is calculated under the assumption that the polytropic constant γ is 1.0.[2]. Knowing the initial pressure, the initial and final volume of air, the final pressure of air is calculated. From the initial and final air pressures and the stroke, the spring constant K can be calculated. For the tire stiffness curve shown in Fig. 4, a theoretical curve is fitted having the relation

$$F = 17880x + 63600x^2$$

IV. Results

From the data computed, it is found that the peak acceleration of M exhibits a variation with A, B, ζ_1 and ζ_2 as typified in the graphs, Fig. 5. The peak acceleration (*i*) decreases, then increases and after that decreases and again increases with increase in B for $A = 0.1,0$ and $\zeta_2 = 0.1$. For other values of A greater than 0.1, the peak acceleration either decreases and then increases or increases with B (Fig. 5a). (ii) The minimum or the least value obtained in case (i) decreases and then increases with increase in A (for $\zeta_2 = 0.1$) or increases with A (for $\zeta_2 \geq 0.2$) (Fig. 5b). (iii) The minimum obtained in case (i) increases with ζ_2 (Fig. 5c). (iv) The least or minimum value obtained (with $\zeta_2 = 0.1$) decreases with increase in ζ_1. For $\zeta_2 > 0.1$, it increases with increase in ζ_1 (Fig. 5d).

From the parametric study for sensitivity considerations, the following observations emerge: a) If M is increased, the peak acceleration drops and if M is decreased, the peak acceleration goes up. b) If K is increased, the peak acceleration of M increases and if K is decreased, it drops down. c) If preload is decreased by 10%, there are variations in the peak acceleration. But if it is increased by 10%, the variations are not considerable. d) If the tire stiffness is increased, the peak acceleration goes up and if it is reduced, it comes down. e) When the velocity of descent is reduced, the peak acceleration drops down. f) In the case of m, if m is increased to 200% or decreased by 50% there is a variation in the peak acceleration; it drops down in the first case and increases in the second case.

V. Comparison

The dual-phase damping is better than constant or nonlinear orifice damping. The least value of the peak acceleration obtained is 30 ft/sec^2 for dual phase damping with the values of the parameters as $A=0.1$, $B=0.2$, $\zeta_1=0.9$ and $\zeta_2=0.1$. For constant damping, the least value is 36.9 ft/sec^2 where $\zeta=0.2$. With nonlinear orifice damping (where $F=C|\dot{x}|\dot{x}$) having C as 140 lbf/(ft/sec)^2, the peak acceleration is 114 ft/sec^2.

VI. Conclusion

From the previous results, it is observed that dual-phase damping serves better than constant or nonlinear orifice damping.

References

[1] J. C. Snowdon, "Isolation from Mechanical Shock with a Mounting System Having Nonlinear Dual-phase Damping," *The Shock and Vibration Bulletin*, Bulletin 41, Pt. 2, Dec. 1970.

[2] B. Milwitzky and F. E. Cook, "Analysis of Landing Gear Behavior," NACA Rept. 1154, 1953.

Note on Stability in Decelerating Flight

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It is well known that the angle-of-attack oscillation of a re-entering space vehicle is very dependent upon whether the dynamic pressure q is increasing or decreasing. This effect is discussed, for example, in Refs. 1-7. The same type of phenomenon is observed when a bomb is dropped, or an escape system is ejected from an aircraft. In the latter case, a body which is found to be statically stable in the wind tunnel, and to have a positive aerodynamic damping, may appear to be unstable when launched from a rocket sled or an aircraft. That is, it experiences an angle-of-attack oscillation, the amplitude of which increases with time.

This particular problem can be explained by what is essentially a single-degree-of-freedom analysis which yields a closed-form solution. Consider the horizontal motion of a bluff body which has: a) no coupling out of the plane of oscillation, b) negligible variation of drag with angle-of-attack α, and c) negligible forces developed normal to its flight path. Assumption b) uncouples the velocity equation, which becomes

$$m\dot{u}+(C_DS)\ \tfrac{1}{2}\rho u^2=0$$

or

$$\dot{u}+\gamma u^2=0 \tag{1}$$

where C_DS is the drag area, assumed constant; ρ is the mass density of the air and is assumed constant; u is the body's velocity; m is the body's mass; and $\gamma=(\rho C_DS/2m)$, a ballistic coefficient having units of length^{-1}. Integration of Eq. (1) gives

$$\frac{u}{u_o}=\frac{1}{1+\tau} \tag{2}$$

where the nondimensional time parameter $\tau=u_o\gamma t$ and u_o is the initial velocity.

The equation for pitching motion for the angle of attack is

$$I\ddot{\alpha}-C_{m_{\dot{\alpha}}}(\dot{\alpha}\ell/u)S\ell\tfrac{1}{2}\rho u^2-C_{m_\alpha}S\ell\tfrac{1}{2}\rho u^2\alpha=0 \tag{3}$$

where the symbols all have their usual meaning. This simplifies to

$$\ddot{\alpha}-\psi_1u\dot{\alpha}-\psi_2u^2\alpha=0 \tag{4}$$

where

$$\psi_1=(C_{m_{\dot{\alpha}}}S\ell^2\rho/2I)\quad(\text{length}^{-1})$$

$$\psi_2=(C_{m_\alpha}S\ell\rho/2I)\quad(\text{length}^{-2})$$

Substituting Eq. (2) for u, and expressing $\dot{\alpha}$ and $\ddot{\alpha}$ in terms of the nondimensional time parameter τ

$$\frac{d^2\alpha}{d\tau^2}-\frac{\psi_1}{\gamma}\frac{1}{(1+\tau)}\frac{d\alpha}{d\tau}-\frac{\psi_2}{\gamma^2}\frac{1}{(1+\tau)^2}\alpha=0 \tag{5}$$

The transformation $\eta=\log(1+\tau)$ leads to

$$\frac{d^2\alpha}{d\eta^2}-(1+\psi_1/\gamma)\frac{d\alpha}{d\eta}-\frac{\psi_2}{\gamma^2}\alpha=0 \tag{6}$$

This is a linear second-order differential in η, for which all the solutions are known. The lightly damped oscillatory solution will generally occur in practice, and for this case, the roots of the characteristic equation associated with Eq. (6) are

$$\lambda=m\pm in$$

where

$$m=\frac{1}{2\gamma}(\gamma+\psi_1)$$

$$n=\frac{1}{2\gamma}\sqrt{-[(\gamma+\psi_1)^2+\psi_2]} \tag{7}$$

$$\therefore\ \alpha=e^{m\eta}[A\cos n\eta+B\sin n\eta] \tag{8}$$

The arbitrary constants, A and B, are determined by the initial conditions at $\tau=0=\eta$; namely

$$\alpha=\alpha_0$$

$$\left[\frac{d\alpha}{d\eta}\right]_0=\left[\frac{d\alpha}{d\tau}\right]_0$$

which leads to

$$\frac{\alpha}{\alpha_0}=e^{m\eta}\left\{\cos n\eta+\frac{1}{n}\left[\frac{1}{\alpha_0}\left[\frac{d\alpha}{d\eta}\right]_0-m\right]\sin n\eta\right\} \tag{9}$$

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