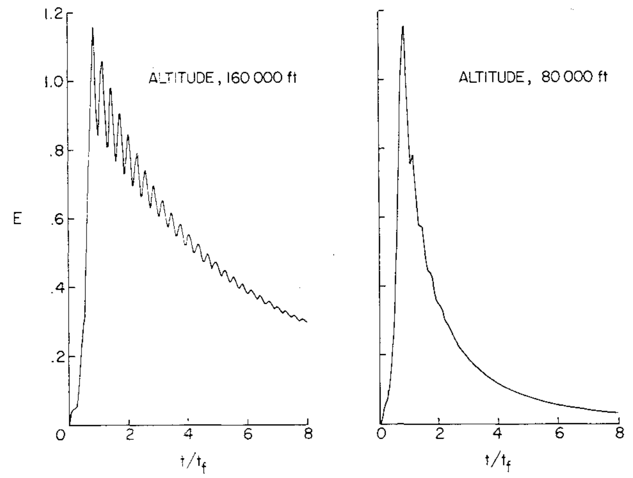

Fig. 3 Normalized force histories, E, for different depolyment altitudes.

The force on the payload can be obtained by multiplying Eqs. (3) by $-k$. This force can be expressed as $(-kq_sC_DS_o/m_1\omega^2)E$, which reduces to $-q_sC_DS_oE$ for $m_2 \gg m_1$. E is then a force normalized to the steady load and can be obtained from Eqs. (3), once the exponent n is specified and the integration is performed. Table 1 lists expressions for E with n varying from 1–4. The maximum value of E (or the load amplification factor, M) can be determined after setting $dE/dt = 0$ and obtaining those maximizing values of t for various values of t_f. This has been done for the cases in Table 1 and it was found that M occurs shortly after full inflation (at approximately $t_f + T/4$). The load amplification factors are presented in Fig. 2 as a function of the ratio of filling time to the natural oscillation period of the elastic system. From Fig. 2 it is seen that M varies between 1 and 2 and is generally decreasing with increasing t_f/T. For $t_f/T > 2$ and $n > 1$, M varies approximately as $1 + (nT/2\pi t_f)$. Therefore, when the filling time is very short or when the natural period of oscillation is relatively long (i.e., low value of k), elasticity can result in significant opening load amplification. (Although the present analysis indicates that suspension lines with a higher spring constant can reduce opening load amplification, Ref. 1 indicates that stiffer lines increase snatch force. Hence, both opening load and snatch force should be considered, when designing a parachute system for a specific application.)

Another interesting result obtained from the elastic model is the character of the load history immediately following full inflation. Here the assumption of $\dot{x}_1$ (or $\dot{x}_2$) being nearly constant cannot be made since the system will be rapidly decelerating due to the drag provided by the fully inflated canopy. Instead, one can now assume that the drag area maintains a constant value. By setting $\dot{x}_2/\dot{x}_1 = (1 + \varphi)$, where $\varphi \ll 1$ a dimensionless parameter, Eqs. (1) can be combined to yield

$$\ddot{\xi} - (C_DS_o\rho\dot{\xi}/2m_1\varphi^2)\dot{\xi} + \omega^2\xi = 0 \qquad (4)$$

Hence, this change in assumptions produces an equation different from Eq. (2). For $\dot{\xi} < 0$, the parachute is closing on the payload and the second term in Eq. (4) represents nonlinear damping of the spring-mass system. For $\dot{\xi} > 0$, the parachute is increasing its separation distance from the payload and energy is being put back into the system. For any single cycle oscillation, energy is added and then dissipated. The net result is an oscillation about the steady drag loading history. The amplitude of oscillation will depend on the "damping" term. One obvious consequence of this is that for a given parachute system the amount of "damping" decreases as the density decreases. Hence, one could expect oscillating load histories initiated by the inflation process to persist at high altitude even when the parachute drag area remains steady. Numerical solutions of Eqs. (1) were obtained for identical parachute systems, operating under nearly infinite mass conditions, at the same dynamic pressure but different altitudes. The resulting payload force histories were normalized to the steady load and are presented in Fig. 3 as a function of the ratio of time to filling time. Note for both cases that the opening load is amplified, as predicted by the earlier analysis. Also, note that the load oscillation following full inflation for the higher altitude case has less "damping" than the lower altitude case, as predicted by the later analysis. This altitude or density effect can be noteworthy above about 80,000 ft. For parachute tests at lower altitudes, the elastic system will have high "damping." And load oscillation due to suspension line elasticity would not be expected.

In general, when the drag area does not remain constant following full inflation, load oscillations can be much more severe than that indicated in Fig. 3. This was the case for the flight test reported in Ref. 2, where it was shown that the elastic model could provide a good reproduction of the payload force time history.

Conclusions

Using a two-body spring-mass system to analyze parachute loads, the following conclusions can be stated:

1) For infinite mass parachute deployments, suspension line elasticity can result in an amplification of the opening load. For those cases where the growth in drag area during inflation is proportional to $(t/t_f)^n$, the magnitude of the effect can be approximated by $1 + (nT/2\pi t_f)$.

2) For parachute deployments at high altitude (above about 80,000 ft), oscillating load histories initiated by the inflation process will persist as a result of reduced "damping" due to the small value of atmospheric density.

References

[1] "Performance of and Design Criteria for Deployable Aerodynamic Decelerators," ASD-TR-61-579, Dec. 1963, U.S. Air Force, pp. 164, 143.

[2] Eckstrom, C. V. and Preisser, J. S., "Flight Test of a 40-Foot-Nominal Diameter Disk-Gap-Band Parachute Deployed at a Mach Number of 2.72 and a Dynamic Pressure of 9.7 Pounds Per Square Foot," TM X-1623, 1968, NASA.

[3] Jacobsen, L. S. and Ayre, R. S., *Engineering Vibrations*, Chap. 4, McGraw-Hill, New York, 1958.

Technical Comment

Erratum: "Solar Deflection of Thin-Walled Cylindrical, Extendible Structures"

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αT^4 and $\alpha T^4{}_{av}$ in Eqs. (6) and (10) should read σT^4 and $\sigma T^4{}_{av}$, respectively. σ is the Stefan-Boltzmann constant. Similarly, the α in Eq. (15) should be σ. The same error occurs in the example; thus, $\sigma T^4{}_{av} = 233.43$ and $\sigma T^3{}_{av} = 0.384$.

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