Table 1 Range required for the tests

Component	X, N	Y, N	Z, N	M_x, Nm	M_y, Nm	M_z, Nm
Range required: Model in center of test section	+1000	±200	+2000	±200	+1200	±100
Half-model	+1000	±2000	–	±1000	+500	±20
Drag measurement	+1000	–	–	–	+500	–
Actual range of the balance	2×500[a]	2×1000[a]	30000			

[a] See the section "Additional Equipment."

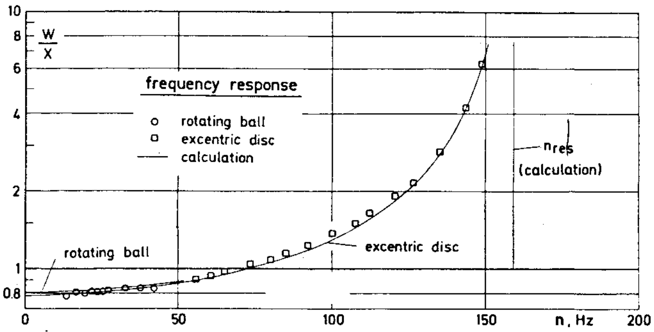

Fig. 6 Frequency response of the measuring platform in x-direction, balance hanging on ropes. X = applied load; W = indicated load.

tolerances where, during a typical measuring time of 5 min and for typical loads (e.g., $X = 10$ N), no corrections have to be made (errors <0.5% of X). Temperature variations raised no problems, as the elements are protected against air currents and are connected to a large mass which results in small temperature changes. For very accurate measurements, the drift (the rate of which remains practically constant during the measuring period) can be determined after the measurement and taken into account by correction of the error linear with time. So far, this has never proved necessary with the 9203 elements and, for the vertical transducers, only at low forces.

The linearity of the transducers, including charge amplifier, has been measured in a special program. In most cases, linearity of the elements shown in Fig. 2 remains within the boundary of 0.1% (see Fig. 5). The interferences were measured on a special turntable offering a precision of ± 0.001 deg. Calculation of the interferences predicted errors in the order of 0.01/0.05%. The tests therefore were merely checking the precision of the workmanship. If the balance is loaded strictly in one axis, the transducers not involved in the load measurement are showing signals in any case below 0.05% of the test load. The errors can be neglected in all cases. Experience showed an overall accuracy of the balance down to 10% of the required load (see Table 1) of ±0.3% of the load applied. With the analog data acquisition system, the corresponding figure is ±0.8%. Relatively high loads, however, offer an accuracy in the order of ±0.15%.

Behavior with Dynamic Loads

The dynamic response has been calculated for two conditions: 1) balance hanging on elastic nylon ropes (external forces can be neglected), turntable removed, no model; 2) balance mounted on the concrete block.

Figure 6 shows the frequency response of the balance in X-direction. The sinusoidal loads are generated by a compressed air-driven eccentric disk or steel ball. The balance shows a very low logarithmic decrement of $\bar{\delta} = 0.0178$ at 160 Hz.

The frequency response of the balance mounted on the block shows a 10% lower resonance frequency. The frequency response usually has to be measured separately for each dynamic configuration in order to detect resonances with the model and its support. This enables the measured loads to be corrected to the real aerodynamic loads up to frequencies of 100 Hz for drag and considerably higher for lift.

Conclusions

The concept of a floor-mounted six-component balance with piezoelectric force transducers has been confirmed. It offers good accuracy in a wide range of static loads, permits dynamic measurements, and enables interference-free readout of the components.

Acknowledgment

The authors express their thanks to P. Weber for his suggestions and excellent workmanship during the construction of the balance and data acquisition system.

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C80-064

Use of an Apex Drogue as a Means for Controlling Parachute Inflation

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Introduction

THE aerodynamic recovery of payloads from high speeds and high dynamic pressures usually involves the application of parachutes. It is well known that these parachutes are stressed to withstand the forces that are imposed during the relatively short, parachute inflation sequence. Immediately after the inflation, the loads imposed upon the system reduce by one or two orders of magnitude when compared to the loads during the inflation stage.

From an aeroelastic viewpoint, the mechanics of the inflation sequence are not well understood. There is generally much uncertainty in calculating the unsteady pressures and stresses in the parachute structure during this critical inflation sequence.

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The classical technique for high speed parachute recovery is to employ parachute staging. In fact, there are undoubted weight savings in employing two or more parachute stages, so that each stage is disconnected from the system immediately prior to the deployment of the next stage. Parachute staging can be used in conjunction with parachute reefing techniques in order to reduce the inflation loads further.

This latter reefing technique can be used in one or two stages to effect an increase in the overall inflation time, and also to reduce the gore and line stresses. However, there are questionable weight benefits in the wholesale, extensive use of reefing. For example, the reefed parachute must have a heavy crown area extending downward approximately one-half the length of the gore. There is, in fact, no way of relieving these high loadings in the upper gore regions, even though the lower gore regions are designed to withstand much lower dynamic pressures. A further disadvantage of reefing is that the reliability and long term storage of the pyrotechnic reefing cutters is poor, particularly in tropical areas.

This reefing technique for parachute inflation control has been used with great success over the last two decades. However, the object of the present Note is to question the universal application of the reefing line technique, and to suggest that in some staged parachute systems the retention of a prior stage at the apex of the following stage has undoubted technical merit. These merits are discussed below.

Physical Resumé

Before giving any theoretical details or a practical description of the relevant rocket sled tests, it is advantageous to appreciate fully the physics of the apex attached system.

If one were to pursue a "filling time" theory for a description of the parachute inflation phenomenon, we could proceed as follows. A simple, unrestrained parachute inflates by air flowing continually into the mouth of the inflating parachute. Fluid is likewise lost from the canopy control volume through the parachute pores, crown, slots, etc. In fact, we could advance the argument that inflation is simply an application of continuity to a time-varying canopy control volume. The stresses induced in the structure are the result of a pressure differential between the inside control volume and the external fluid field.

A logical extension of the above argument is to assert that the "filling time" may be increased by introducing more porosity into the canopy. This geometric change does in fact increase the "filling time." In particular, stretch fabric, or similar devices, in the crown of the parachute have been under investigation for some time as a means of increasing a parachute's inflation time.

However, this conclusion can be entirely invalidated by the following two experiments. First, take a parachute whose inflation time is supposedly uniquely determined by the canopy porosity. In a simple deployment sequence its inflation time can be measured. Next, add a central rigging line of such a length as to draw the crown down to about the level of the skirt, and do not change the porosity of the system in any way. If the parachute is test flown, it can be seen that the inflation time is roughly halved when the central rigging line is added.

Next, do an inverse experiment. Take the basic parachute described above and attach to this parachute's apex, via a strop, another parachute or drogue. Let the drogue diameter be about 25-30% of the diameter of the original parachute. Now deploy the two-stage system by letting the drogue deploy the main, and also ensure that the drogue is attached during the whole of the inflation sequence. In this experiment it will be found that the inflation time has increased by a factor of about 3, even though there has been no change in the porosity of the main assembly.

The explanation for these tests cannot be found in a porosity or filling type argument. Instead, it should be realized that the parachute inflation process is essentially a question of the dynamic equilibrium of the canopy elements. The elements are restrained by internal canopy stresses including the rigging line tension. The unsteady pressure differential induced by the flow inside and outside of the canopy induces the canopy elements to accelerate outward from the initial or deployment configuration.

If, on the above basis, the rigging line tension is artificially increased due to the drag of the drogue parachute, then a component of the rigging line tension acts to inhibit the rate of inflation. Conversely, the central rigging introduces another load path to the store and, by so doing, reduces the tension on the outer rigging lines.

This reduction in the rigging line tension allows the canopy to inflate more rapidly, and the overall inflation time is thereby reduced.

Inflation Studies

It has been mentioned in the physical resumé that certain theoretical procedures are currently available for calculating the inflation performance of parachute assemblies. Computer procedures based upon the filling time concept are of no use in this problem. However, Wolf[1] at Sandia Laboratories has a worthwhile momentum procedure, while the current author[2] has similar programs which seem to give comparable results to Wolf's programs.

The author's programs, OPEN and PILOT, have been used to calculate the inflation performance of the apex-attached parachute system. These results can be compared with the inflation of the secondary parachute system alone, without the apex drogue attached.

No in-depth program details will be given here, except to state that the theoretical justification for the programs has been given previously in Ref. 2. The results of the current computer calculations are simply shown graphically in Figs. 1 and 2.

Figure 1 shows the predicted performance of a regular 26.5 ft. diam (SP) parachute when deployed at Mach 0.6 on the sled track using a 500 lb test vehicle. In Fig. 1 the abscissa is the independent time variable, while the four ordinates show the forebody force F, the forebody velocity V, the forebody

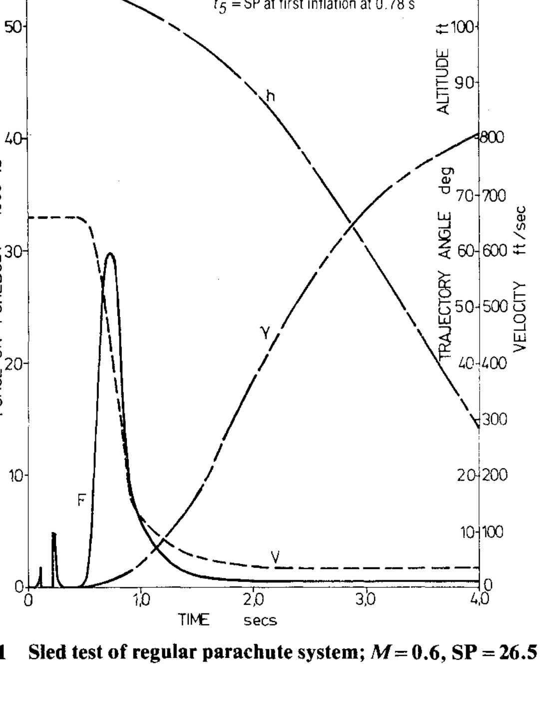

Fig. 1 Sled test of regular parachute system; $M = 0.6$, SP = 26.5 ft.

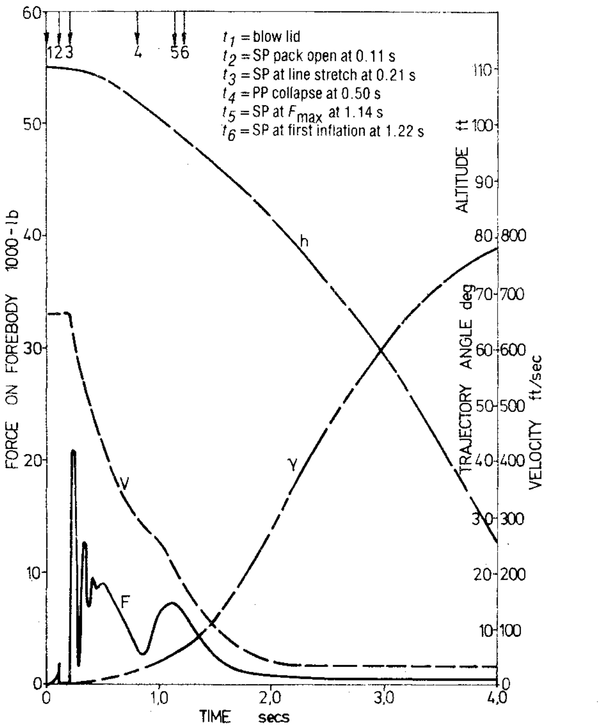

Fig. 2 Sled test of apex-attached parachute system; $M=0.6$, PP = 8 ft., SP = 26.5 ft.

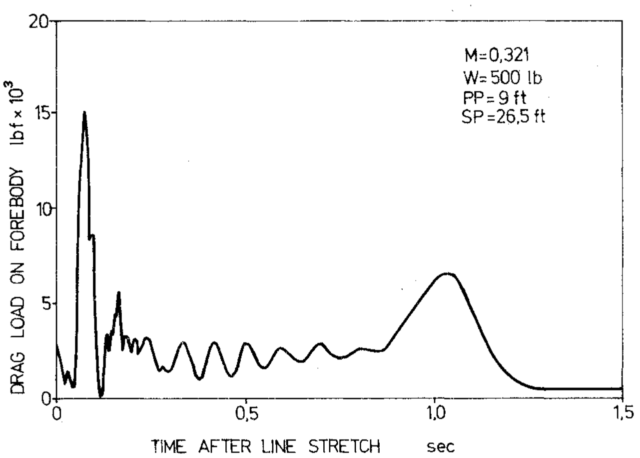

Fig. 3 Experimental result of test 726.

height h, and the trajectory angle of the forebody γ. Captions t_1 through t_5 are the event markers where $t=0$ is taken as the instant of tail can separation.

Figure 2 refers to the apex attached parachute system with the 8 ft diam primary parachute (PP) attached to the 26.5 secondary parachute (SP). Here the inflation time is 1.01 s. compared to 0.56 previously. The altitude loss has increased to 13 ft compared to 9 ft., while the peak force has fallen to 9100 lb compared to 29,700 lb previously. In principle, the force-time curves are of double peaked form for the apex-attached system, while there is only one large peak for the regular system.

Experimental Result

A number of test firings have been made on the rocket sled facility at Sandia Laboratories, Albuquerque. The object of these tests was to confirm the performance of the system described in Figs. 1 and 2. The trials undertaken so far are still in the "work-up" stage at Mach numbers around 0.3.

A typical experimental result is shown in Fig. 3 for test 726 at Mach 0.321. Here the longitudinal accelerometer record is directly related to the drag force on the forebody. The inflation time was measured at 1.25 s with a peak inflation load of only 6000 lb. The primary parachute load peaked at 15,000 lb during the initial snatch.

It should also be noted that the primary parachute tended to "breathe" at about 10 Hz in the period given by 0.3-0.8 s after the initial line stretch.

The tests conducted so far have confirmed that the large increases in the inflation time of the secondary parachute can be achieved by use of an attached apex parachute.

Conclusions

In short, it is believed that the apex attached parachute system should be investigated further. The following benefits should accrue:

1) The peak inflation loads can be reduced by a factor of 2 or 3.

2) Eliminates the use of fixed-time, conventional pyrotechnic reefing cutters.

3) The main or secondary parachute is inertially and aerodynamically reefed over the full deployment q range.

4) The canopy strength requirements are dramatically reduced. This reduction in strength should allow a replacement of ribbons by regular fabric.

5) The overall system weight should be about 40% less than the weight of a conventionally reefed ribbon parachute system. This statement takes due account of the extra weight involved in the primary parachute system.

6) No severe altitude penalty is incurred in the overall deployment.

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Note on the Yawing Moment Due to Side Slip for Swept-Back Wings

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Introduction

IN Ref. 1, Babister has presented the following expression for yawing moment coefficient due to side slip for swept-

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