Parachute Cluster Dynamic Analysis

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Theme

A COMPUTER-AIDED dynamic analysis of a parachute cluster is described which models the individual parachutes in the cluster and their combined effects on the motion of an attached forebody. The complex three-dimensional motions of the forebody/parachute system are displayed using computer generated drawings and color movies. Simulated motion drawings and drop-test photographs are presented for a system consisting of a cluster of three large parachutes attached to a small forebody which experiences a rapid pitch motion. Good agreement between the actual and simulated motion is observed. The necessity of modeling each parachute individually is illustrated.

Contents

The problem of dynamically modeling parachute clusters, or multiple parachutes attached to a single forebody, has not previously been addressed in the literature. Parachute clusters are usually modeled as a single parachute using aerodynamic data for a cluster with the individual parachutes held fixed relative to one another. If a cluster system experiences rapid changes in flight-path angle, individual parachutes pitch at different rates, causing the cluster to temporarily disperse. The primary objectives of this study were to model the motion of individual parachutes in a cluster and to display the simulated motions in a meaningful way.

A dynamic model similar to that developed by Wolf[1] was used. Body axes were attached to a parachute, riser, and forebody to describe an arbitrary motion of these components in an Earth-fixed system (Fig. 1). The Earth-fixed axes were aligned with any body-axis system by a series of Euler angle rotation. By integrating velocities and Euler angle rates, one obtains the position and angular orientation of the coordinate axes as functions of time. The appropriate linear and angular velocities required were supplied by the equations of motion.

Each parachute was assumed to be a five-degree-of-freedom body with the roll degree-of-freedom about the axis of symmetry neglected. Forces on the parachute were expressed as components of the sum $\bar{F}=\bar{F}_a+\bar{F}_r+\bar{F}_i+\bar{F}_g$. Moments were calculated using appropriate lengths. The quasisteady part of the aerodynamic force, $\bar{F}_a$. was calculated using steady-state aerodynamic data and the local flow conditions at the parachute center of pressure. A simplified fluid inertia tensor was used to model unsteady fluid effects on the parachute. Elastic material properties for the parachute were used to calculate the riser force, $\bar{F}_r$, and $\bar{F}_g$ was the parachute weight. A parachute interference force, $\bar{F}_i$, was introduced to study parachute clusters. Only a very crude approximation was used in this analysis because no interference data were known to exist. The interference force was assumed to be a quasisteady force whose magnitude varied as the inverse square of the distance between the centers of pressure of a pair of parachutes. The force acted along a line through the centers of pressure (Fig. 2). Steady-state geometry data for clusters were used to adjust the magnitude to give the proper steady-state separation.

A six-degree-of-freedom axisymmetric forebody was assumed. Only a quasisteady aerodynamic force, a riser force, and a gravitational force acted on the forebody.

As discussed in Ref. 1, additional equations were needed to couple the forebody and parachutes together. These equations were obtained by equating velocity components in adjacent coordinate systems at both ends of the parachute riser. A set of forebody equations of motion, a set of parachute equations of motion and coupling equations for each parachute, a set of Euler angle time derivatives for each body-fixed coordinate system, and a set of trajectory equations for the forebody were solved using a digital computer.

The simulation of the motion of clustered parachutes attached to a forebody does not end with the computation of the motion of the coupled bodies. The engineer is still faced with the problem of presenting the results of the motion simulation in a usable form. The tabulated computer output of the

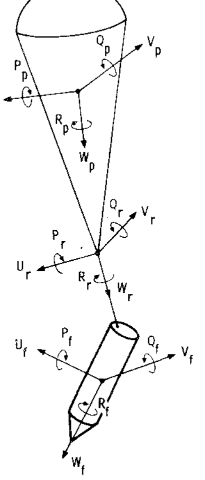

Fig. 1 Coordinate systems.

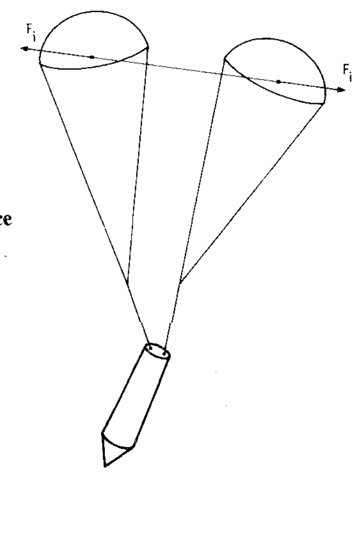

Fig. 2 Parachute interference forces.

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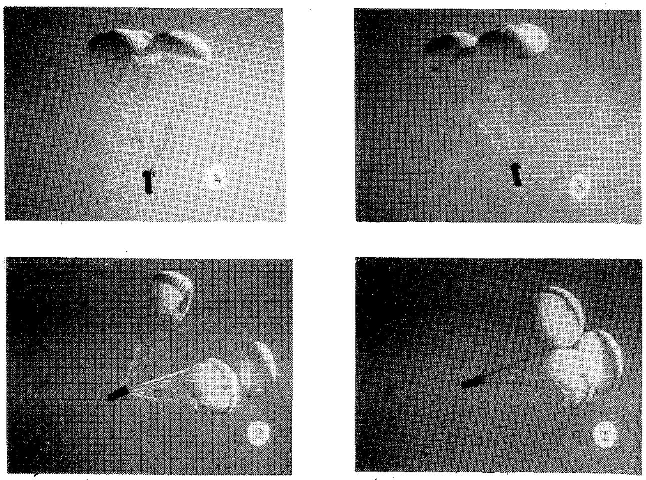

Fig. 3 Motion of cluster of three 48-ft diam ribbon parachutes and forebody.

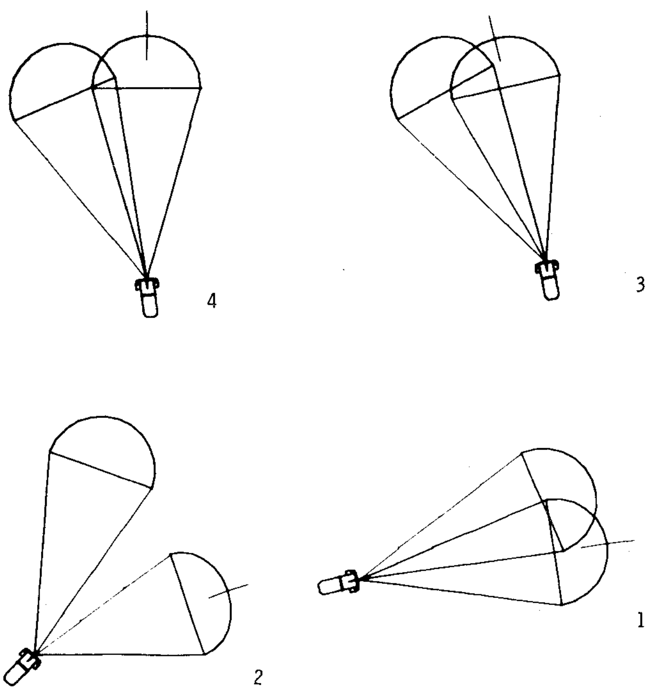

Fig. 4 Computer simulated motion of cluster of three 48-ft diam ribbon parachutes forebody.

positions and orientations of the clustered parachutes and forebody was replaced by a graphic presentation. A "theoretical tracking telescope, with movie camera," provided computer-generated movies and drawings similar to those obtained during full-scale drop tests of parachute test units. The computer-generated visual documentation system used the MOVIE 2 computer program. This computer program, developed at Sandia by Spahr,[2] used a CDC 6600 computer to generate a magnetic tape of plot commands for an off-line modified DatagraphiX 4020 plotter. Output media available on the modified DatagraphiX 4020 were 7½ × 7½-in. black and white drawings (hard copy), 16 mm color and black and white movies, 35 mm color and black and white slides, and 35 mm color and black and white movies.

The system chosen for computer simulation consisted of a cluster of three 48-ft ribbon parachutes attached to an 8500-lb forebody. Some dispersion of the parachutes in the cluster occurred after full inflation because the parachutes were deployed at high speed in a horizontal trajectory. During the resulting deceleration and pitch over, the parachutes pitched at different rates and in different directions, causing a temporary dispersion of the cluster. The actual pitch over is illustrated in the photo sequence of Fig. 3. When inflation is completed, the three chutes are in a compact, nearly symmetrical cluster while the entire system is still nearly horizontal. The top chute pitches over rapidly while the two bottom chutes pitch outward and lag considerably. The entire system is seen to overshoot the vertical and eventually stabilize in a steady descent. Figure 4 shows the computer simulated motion illustrated with still pictures generated at approximately the same times as the actual photos. The two lower parachutes are shown as one in the simulation picture because one parachute is directly behind the other. An apparent shortening of the lower two parachutes occurs in the second frame because the two parachutes are tilted toward and away from the viewer. Reasonably good qualitative agreement between the actual and simulated motion is observed. Copies of the color movie used in the paper presentation are available on loan from the authors.

Acknowledgment

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References

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[2] Spahr, H.R., "Computer Generated Visual Documentation of Theoretical Store Separation Analyses," *Aircraft/Stores Compatibility Symposium Proceedings*, Sacramento, Calif., Vol. 2, Jan. 1974, pp. 208-235.