Aeroballistic Characteristics of 3-ft-long Parachute Decelerators

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Air drop and wind tunnel tests were conducted to verify the stability of sonobuoys with decelerators limited to a total length of 3 ft. This limitation was established for safety reasons. Existing decelerator systems are configured to a length of from 5 to 12 ft, with cross-type canopies varying in area from 1.5 to 3.5 ft^2. Testing established that 3-ft-long decelerators are suitable replacements for the existing configurations. Drag coefficient, opening load, high-altitude air descent characteristics, and stability data were determined for different types of decelerators with various area and length.

Nomenclature

B = ballistic coefficient
C_{D_0} = drag coefficient (canopy area S_0)
$C_D S$ = effective drag area
D_0 = nominal canopy diameter $= (4S_0/\pi)^{1/2}$
L_s = suspension line length
S_0 = canopy surface area
V_e = equilibrium velocity
W = weight

Introduction

SONOBUOYS are expendable electroacoustic sensors that are air deployed from Navy fixed and rotary wing aircraft. The air deployed body is blunt nosed, cylindrically shaped, 4⅞ in. in diameter, 36 in. long, and ranges in weight from 12 to 39 lb. The center of gravity varies randomly between 13 and 18 in. from the end opposite the decelerator. A ballistic coefficient (B), a ratio of weight to effective drag area ratio of 18 ± 1.0 lb/ft^2 is specified for sonobuoys weighing between 34 and 39 lb and 12.3 ± 1.0 lb/ft^2 for all other weights.

The launch angle of the sonobuoy relative to the airstream varies between fixed and rotary wing aircraft. The fixed wing orientation is down and aft 45 deg from the horizontal. Rotary wing launches are either vertical straight down or horizontal 90 deg from the direction of flight.

After launch, a decelerator system is deployed which must sufficiently stabilize the sonobuoy prior to water impact. The stability must be adequate enough so that the electroacoustic and hydromechanical systems function normally after water impact.

Currently the decelerator systems utilize cross-type parachutes which have canopy areas varying between 1.5 and 3.5 ft^2. The length-to-width ratio of the canopy is 3:1. The uninflated length of the decelerator system, i.e., the length of the fully extended uninflated decelerator from the attachment point on the buoy to the tip of the uninflated canopy, varies from 5 to 12 ft with no relation to area. Owing to a safety of flight requirement, a maximum 3-ft limitation was placed on the uninflated decelerator total length.

A program of wind tunnel and air drop testing was conducted to verify that the above performance and configuration requirements could be met. Drag and stability was evaluated to determine the influence of wake effects caused by closer coupling of the decelerator. Cross-type decelerator systems up to 12 ft in length and a variety of canopy areas in addition to rectangular-, square-, and vane-type decelerator configurations were tested. These various configurations showed the effect of change in length and the characteristics of each type.

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Wind Tunnel Testing

A test program was conducted at the NASA Lewis Research Center 10-ft Wind Tunnel to evaluate decelerator characteristics as a function of total system length. The wind tunnel test model setup is shown in Fig. 1. A full-scale model of the sonobuoy was placed in the wind tunnel parallel to the direction of flow. It was fixed to the ceiling by a strut. The parachute was stowed in the aft end of the model. A captivated windflap was released into the airstream when a dynamic pressure of 150 lb/ft^2, the wind tunnel maximum, was reached. The windflap deployed the parachute from its stowage location in the model, initiating parachute inflation. The tunnel drive was shut down and a braking system was activated to slow the tunnel.

A load cell was used in the model to measure parachute loading only. Initial load cell data were displayed on a high-speed visicorder to evaluate opening loading. Load cell data and tunnel conditions were recorded as the tunnel decelerated for further evaluation.

Most of the decelerators tested were made of medium weight nylon material, MIL-C-7350, 2.25 oz/yd^2. Ten percent of the canopies were made of lightweight nylon material, MIL-C-7020, 1.1 oz/yd^2. Air permeability for the above materials is from 100 to 150 and from 80 to 120 ft^3/min/ft^2, respectively. Previous wind tunnel tests were conducted[1] comparing material weight which varied from 1.1 to 4.75 oz/yd^2 for a given canopy configuration. The results showed that the drag coefficient varied by from only 0.02 to 0.03 at a velocity of from 100 to 120 ft/s, which corresponds to the required B. Since these results show that varying the material does not significantly affect C_D, there was no effort to identify the material of specific decelerator types in this paper.

The four decelerator types tested (cross, rectangular, square, and vane) are shown in Fig. 2. The rectangular type has been in service for a few years. The square configuration was explored as a low-cost option. The vane type is used as a pilot chute in many large decelerator systems. In all cases the parachutes were packed in a deployment bag, and a line first deployment method was used. To achieve higher effective drag area ($C_D S_0$) for cross-type parachutes, the number of suspension lines was varied from two to three per panel and evaluated. The total quantity of runs made in the wind tunnel was approximately 100 including a combination of decelerator lengths, canopy area, and type.

Since the total decelerator length requirement is a unique design constraint, a more conventional parameter will be

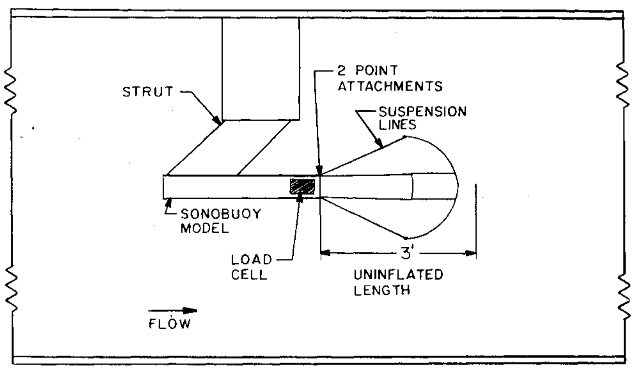

Fig. 1 Wind tunnel test configuration.

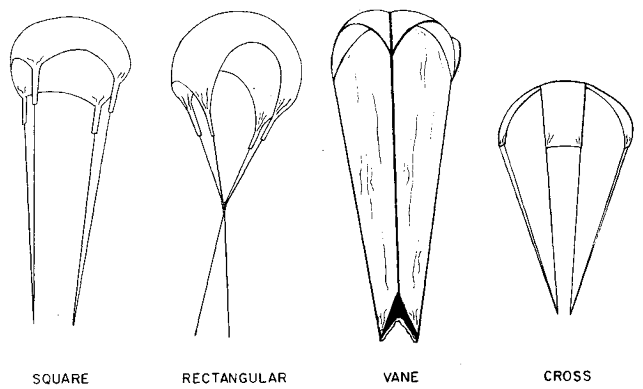

Fig. 2 Various parachute types.

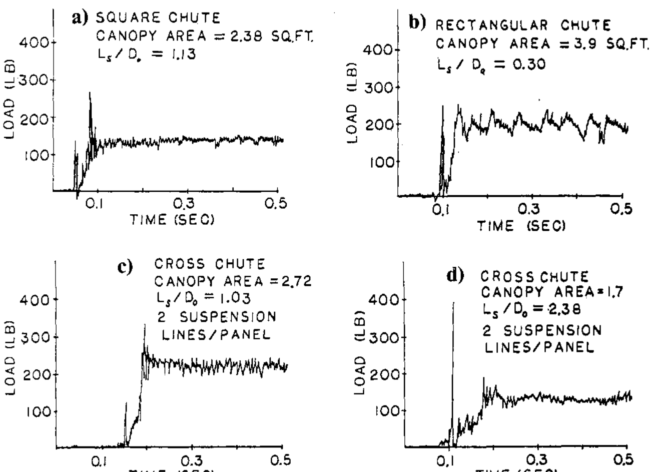

Fig. 3 Opening load history.

specified. Suspension line length/canopy effective diameter (L_s/D_0) is introduced at this time and will be included in the data.

Examples of recorded opening load histories are shown (Fig. 3) for system total lengths equal to and greater than 3 ft. These curves represent some of the most severe loading measured. A summary of opening loads is shown (Table 1). Snatch loads two to three times the average load were observed and appeared not to be related to decelerator length. The longer decelerator systems exhibited high snatch loads more frequently than the short types. At least half of the snatch loads observed were less than the average load measured. The opening load factor for the cross type varied between 1.3 and 1.5 and appeared to be independent of length for L_s/D_0 ranging from 0.6 to 3.0. Limited testing of other decelerator types showed opening load factors as high as 1.9 for the square type and as low as 1.0 for the rectangular type.

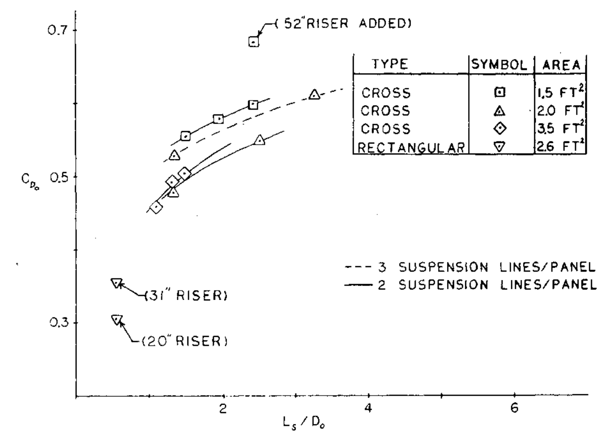

Fig. 4 Decelerator C_D vs L_s/D_0.

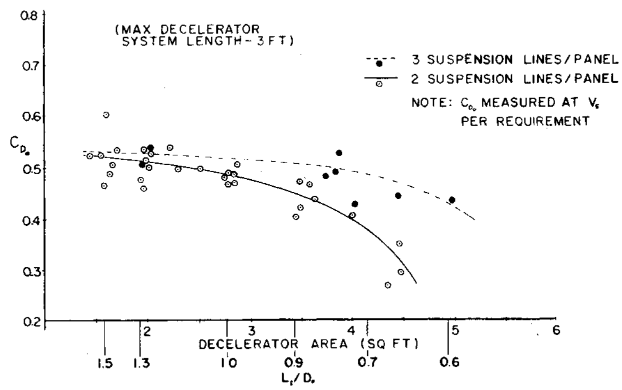

Fig. 5 Cross-type chute C_0 vs area characteristics.

Although line first deployments were used in every test, it appears that the loading measured was not typical. Careful review of high-speed film taken during parachute inflation showed that the deployment bag was coming off before the suspension lines were fully extended. The amount of snatch loading that occurred depended on the amount of canopy inflation at line stretch.

Drag coefficient (C_{D_0}) data were then computed based on drag measured at equilibrium velocity (V_e) for the specified ballistic coefficient. Figure 4 shows the relationship between the cross-type chute C_{D_0} and L_s/D_0 area and the number of suspension lines for cross- and rectangular-type parachutes. Figure 5, which applies to the 3-ft maximum decelerator length requirement, shows how C_{D_0} varies as a function of decelerator area and number of suspension lines per panel. The L_s/D_0 relationship is also shown to comply with poplar design practices. Figure 6 shows the C_D and L_s/D_0 for rectangular, square-, and vane-type parachutes. Reviewing the wind tunnel data confirmed that the difference in parachute material weight had no appreciable effect on C_D.

High-Altitude Testing

A series of high-altitude air drop tests from 25,000 ft was conducted at NASA Wallops Flight Center to determine how air descent time is related to the sonobuoy weight to effective drag area ratio. A variety of sonobuoy weights and weight to effective drag area ratios were tested. The altitude of the drop aircraft and the altitude/time history of the buoy air descent were determined by radar. Ten samples of each configuration were tested and the average time for that sample was used for C_{D_0} computation. All systems dropped complied with the 3-ft maximum length requirement.

A drag coefficient was computed based on air descent time, altitude, decelerator size, and sonobuoy weight. The drag coefficient was varied in a computer program which modeled air descent until the average time measured was achieved.

Table 1 Opening load summary

Run	Type	System length, in.	Snatch load factor	Opening load factor
A	Square	36	1.0	1.9
B	Rectangular	36	1.25	1.0
C	Cross	36	0.54	1.5
D	Cross	52	3.0	1.48

Table 2 Low-altitude test points

Altitude, ft	Airspeed, kias
1500	300
500	350
200	300
150	200
100	45

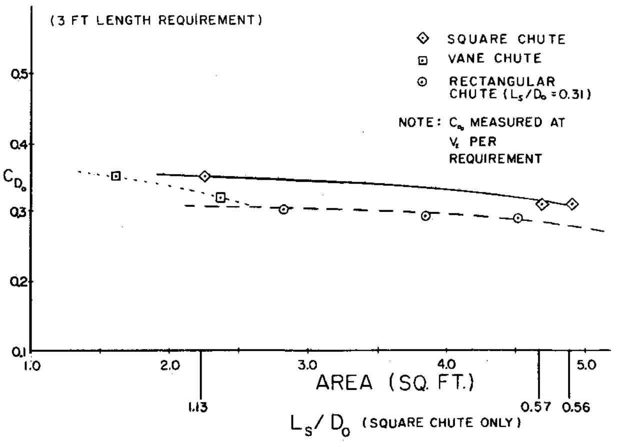

Fig. 6 Various decelerator C_D vs area characteristics.

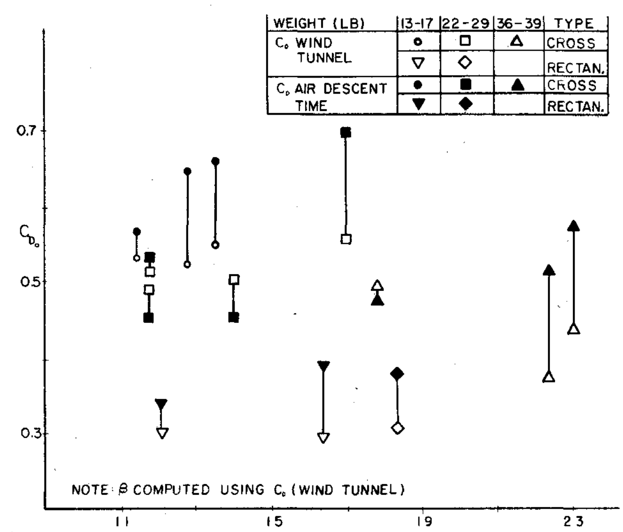

Fig. 7 Decelerator C_D vs B.

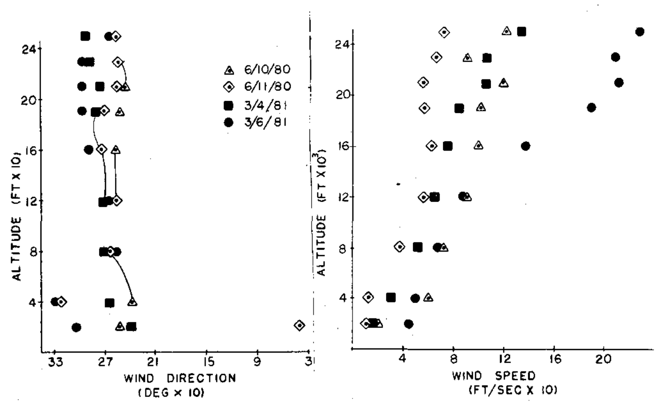

Fig. 8 Wind profiles.

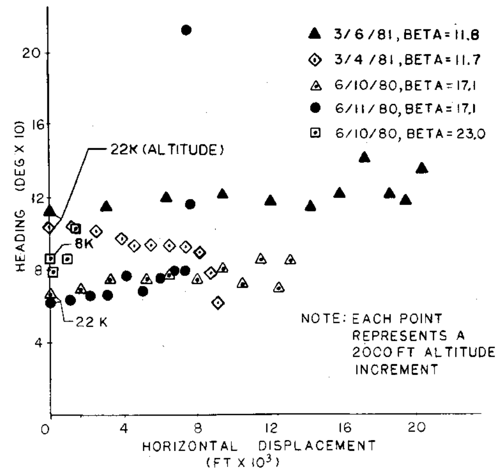

Fig. 9 Wind induced trajectory.

Figure 7 shows a comparison of the C_{D_0} computed based on air descent time and the C_{D_0} measured in the wind tunnel for the same B configuration. This B is computed using wind tunnel C_{D_0}. The data show that for a given sonobuoy weight, as the ballistic coefficient is reduced, the sonobuoy is more stable. The closer the computed and measured C_{D_0} compare, the greater the stability.

Wind induced drift is of interest when placement accuracy is a requirement. During the high-altitude tests, wind profiles (Fig. 8) and sonobuoy wind induced trajectories (Fig. 9) were measured. The wind profiles display the direction and heading of the winds as a function of altitude for specific test days. The profiles were measured approximately at the time of drop. The trajectory shows heading and displacement as a function of altitude for different B. The data are organized to show the effect on displacement of varying winds for a given B and varying B for a given wind profile. It appears that the sonobuoy trajectories match the heading of the wind. The displacement measured compares to a distance computed by multiplying the velocity of wind for some altitude increment by the air descent time for that altitude increment.

Low-Altitude Test

Air drop tests at low altitude were conducted to evaluate flight stability. The launch points used for this testing are shown in Table 2.

This matrix of test points provides a variety of performance conditions. The lower-altitude points allow only a minimum time for stabilization. The maximum altitude was selected since equilibrium velocity and vertical descent will be achieved from any altitude equal to or greater than 1500 ft for the B configurations tested. A number of air drops were made at each of the launch points to observe the functioning of the sonobuoy internal systems. Stability was adequate if sonobuoy system functioning was normal after water impact.

The test buoys dropped ranged in weight from 14 to 39 lb, configured to the required B. Rectangular-type parachutes were used only on sonobuoys under 22 lb. Cross-type chutes were used on all weight sonobuoys. The weights of the test samples were 13, 18, 23, 29, 36, and 39 lb. Ten samples of each weight were dropped at the above launch points. The 100-ft altitude launch point was from a rotary wing aircraft. The sonobuoy was dropped vertically decelerator end last. All the other test drops were from a fixed wing aircraft.

The results of the tests showed that decelerators sized within the established constraints could provide sufficient stability. The shallowest water entry angle that the buoys were exposed to was 35 deg relative to the water surface. The stability was such that the sonobuoy body oscillations about the trajectory angle varied by no more than 5 deg. The sonobuoy in-water functioning was not affected.

Conclusions

1) The data contained in this paper clearly show the effect of wake on a close coupled parachute. Considering these results, blunt nose stores ranging in weight from 12 to 39 lb can be adequately stabilized with a cross- or rectangular-type parachute sized to the ballistic coefficient and total length requirements previously outlined.

2) The effect of B on stability for various weight stores can be determined by comparing the C_D's for a particular B configuration shown in Fig. 7. The C_D measured in the wind tunnel and the C_D computed from air descent time will approach equality as stability improves for a given B.

3) Useful design information is compiled within that addresses drag coefficient, opening load, and high-altitude descent characteristics.

Reference

[1]Ludtke, W.P., "Effects of Canopy Geometry on the Drag Coefficient of a Cross Parachute in the Fully Open and Reefed Conditions for a W/L Ratio of 0.264," Naval Ordnance Laboratory, White Oak, Silver Spring, Md., NOLTR 71-111, Aug. 1971.