Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Modular Asymmetric Parachute for Wind Tunnel Testing

P. C. Klimas,* H. E. Widdows,† and R. H. Croll‡
Sandia National Laboratories, Albuquerque, New Mexico

Introduction

RECENTLY, Sandia National Laboratories has been examining systems in which gliding or lifting parachutes play an important role. The parachute applications being considered here typically call for deployments at high speeds ($M_\infty \lesssim 1.2$) and high dynamic pressures ($q_\infty \lesssim 2200$ psf) with staging times on the order of 1 or 2 s. These boundary conditions have suggested developing an asymmetrical canopy which was based upon a conventional ribbon parachute and which would hopefully retain many of that type of canopy's favorable strength and stability characteristics. The lack of analytical capability in the area of asymmetrical parachutes implied an experimental program. This Note details the construction and wind tunnel testing of one such class of parachutes. The testing itself is unique because it uses parachutes built to a modular design.

Model Construction

Recent experience at Sandia National Laboratories showed that lifting parachutes with lift-to-drag (L/D) ratios of 0.5-0.7 were readily achievable by lining several gores of a symmetrical ribbon parachute with a nonporous fabric. The L/D depended upon 1) what percentage of the total number of gores were lined, 2) what portions of the gores were lined, 3) line lengths, 4) total porosity, and 5) suspension line geometry (flat, round, flat rolled, etc.). These factors also affected two other important areas of parachute operation: inflation loads and stability in yaw, roll, and pitch. With such complexity involved, it was felt that the only reasonable way to sufficiently understand this class of lifting parachutes was to conduct a series of parametric wind tunnel studies.

General load requirements and earlier efforts strongly suggested fixing the total number of gores at 24 and the number of lined gores at seven. (In normal horizontally deployed operation, these lined gores would be uppermost and are referred to as the "top" gores.) Four of these fully lined seven-gore segment geometries were considered. The first of these was a conventional 20-deg conical panel (panel B in Fig. 1). The remaining three were nominally built in the same way but had varying amounts of material removed from the skirt region. The postulate for removing this material was that skirt luffing and its undesirable effects could be avoided by deleting fabric which might be sustaining a negative pressure differential. The material removed from the top gores extended inward from the unmodified skirt to a circular arc defined by two endpoints and a midpoint. The two endpoints of the arc terminate at the ends of the unmodified boundary zipper/radials (outer ends of upper radials A in Fig. 1). The radial distance to the midpoint of the arc for each of the three modified top panels was then either 5, 10, or 13% less than the unmodified conical radius.

This left 17 gores whose porosity could be varied. These were divided into two groups, "side" and "bottom." The bottom gores were intended to provide differential porosity for the lined gores and so were also seven in number. The remaining ten gores were considered in pairs of five gores each and separated the bottom and top seven-gore panels. The top and bottom panels were thought of as working together primarily to produce lift, while the two side panels were envisioned as primarily providing directional stability.

Specifically, five combinations of side porosity and five bottom porosities were of interest. Those on the five-gore side pairs were 33, 25, 42/17, 33/17, and 25/0% λg. (In the dual designations, the skirt half of the gore has the first value for λg while the second number refers to the vent half.) The five bottom seven-gore panels had λg's of 50, 42, 33, 50/33, and 42/17%. Coupled with the four seven-gore lined top panels, these combinations implied a total of 100 different lifting canopies.

Construction of 100 separate canopies was felt to be prohibitively expensive. In what proved to be a viable alternative, a modular construction scheme was devised. This scheme's salient feature was gore panels which fit together with nylon zippers. This type of zipper was sufficiently strong, flexible, and narrow enough to closely approximate conventionally constructed radials. Each canopy comprised four "zip-in" panels, two seven-gore (top and bottom) panels, and two five-gore (side) panels (see Fig. 1). This type of construction required ten, five, and nine seven-gore panels to make the 100 different canopies. The total of 19 represents approximately a 20-fold savings in gore panels over conventional construction. Additional modular/quick-change

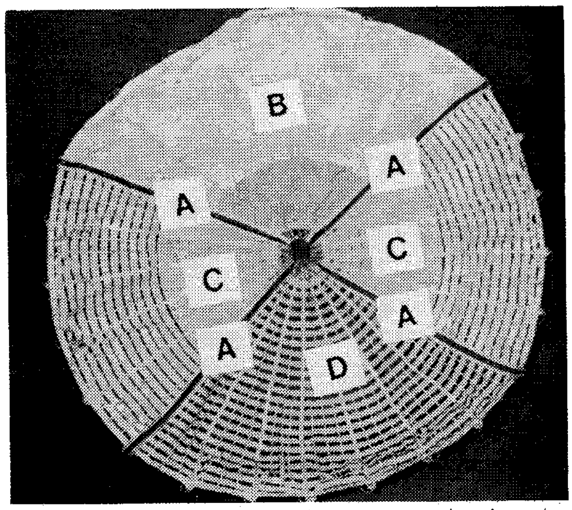

Fig. 1 Layout of modular parachute canopy; A—zipper/radial, B—top gores, C—side gores, D—bottom gores.

Received Oct. 14, 1981; presented as Paper 81-1933 at the AIAA 7th Aerodynamic Decelerator and Balloon Technology Conference, San Diego, Calif., Oct. 21-23, 1981; revision received June 9, 1982.

*Member of Technical Staff, Advanced Energy Projects Division 4715.

†Technical Staff Associate, Parachute Systems Division 5632.

‡Member of Technical Staff, Experimental Aerodynamics Division 5634.

Table 1 Lift/drag and axial force coefficient, $C_A \equiv F_A/\frac{1}{2}\rho V_\infty^2 S$, 1.0-diameter (40-in.) suspension line lengths, no top panel leading-edge cutback

Five-gore side panels	Seven-gore bottom panels									
	50		42		33		50/33		42/17	
Porosity, %	L/D	C_A	L/D	C_A	L/D	C_A	L/D	C_A	L/D	C_A
33	0.64	0.61	0.65	0.63	0.64	0.63	0.64	0.61	0.65	0.65
25	0.68	0.62	0.68	0.64	0.68	0.64	0.68	0.62	0.67	0.65
42/17	0.64	0.60	0.64	0.62	0.63	0.62	0.64	0.60	0.64	0.62
33/17	0.65	0.60	0.65	0.63	0.65	0.62	0.65	0.61	0.65	0.64
25/0	0.67	0.64	0.67	0.63	0.67	0.65	0.67	0.61	0.66	0.66

Table 2 Roll and yaw damping coefficients, ζ_ϕ and ζ_β, and inflation load factors, $C_{A\max}/C_{A\text{steady}}$, 1.0-diameter (40-in.) suspension line lengths, no top panel leading-edge cutback

Five-gore side panels		Seven-gore bottom panels				
Porosity, %		50	42	33	50/33	42/17
33	ζ_ϕ			5.3		
33	ζ_β	...	...	4.2	...	...
Load factor				1.69		
25	ζ_ϕ	5.35	4.1		5.9	4.1
25	ζ_β	...	4.3	...	5.6	3.3
Load factor		1.54	1.71		1.58	1.57
33/17	ζ_ϕ		4.2			
33	ζ_β	...	3.8	...	...	...
Load factor			1.48			
25/0	ζ_ϕ	4.9	4.8	4.8		4.0
33/17	ζ_β	4.0	2.8	2.5		1.3
Load factor		1.75	1.85	1.64		1.71

features were the use of fishing tackle snaps for both suspension line attachment and pocket bands at zipper radials. Each of the 40-in. constructed diameter canopies could have been tested at three different suspension line lengths: 30, 40, and 60 in., for a total of 300 separate parachute configurations.

Model Testing and Results

The modular parachutes were subjected to three types of testing in the Vought Corporation 7×10-ft Low Speed Wind Tunnel. The first type was making static force and L/D (trim angle) measurements. The parachutes streamed behind a strut-mounted projectile-like forebody at a freestream dynamic pressure of 35 psf. Axial force was measured by a load cell and trim angle via a potentiometer/rod system. The triaxial potentiometer was set in the base of the forebody and attached to a square cross-section rod which was free to slide in a fixture sewn to the parachute's vent. The rod deflected the potentiometer in pitch, roll, and yaw. Of the possible 300 combinations cited, 123 were flown. The use of zipper radials does not appear to significantly compromise canopy shape. The measured L/D's and axial force coefficients for the 1.0-diameter suspension line length, no top panel leading-edge cutback models are given in Table 1 as examples of typical data for the static phase. The average test time for each parachute was less than 15 min. This represents a three- to fourfold saving in actual tunnel occupancy time over that for conventional models.

A second testing phase examined the pitch, roll, and yaw motions of the parachute about the canopy's nominal mean values. Here, the parachute was substantially displaced in pitch (α), and/or roll (ϕ), and/or yaw (β) from the trim values by means of strings secured to the vent region of the canopy and run outside of the tunnel to reels. After the strings were severed by pyrotechnic cutters, the ensuing motion was measured by the triaxial potentiometer/rod device. Recorded were forces, moments, and angular positions (α,ϕ,β) as a function of time. Only selected configurations which in phase 1 had shown high L/D and/or high degrees of directional stability underwent this dynamic testing. Tunnel dynamic pressure was again 35 psf.

The last type of testing involved the measuring of inflation loads. As in the second phase, only canopies showing promise from earlier testing were considered. The canopies were streamed reefed (15-in. reefing line) behind a streamlined shape cable mounted in the center of the test section. Axial loads were measured before, during, and after disreef at a tunnel dynamic pressure of 25 psf. This lower value was dictated by the strength of the suspension line fishing tackle snaps.

Table 2 gives the results of the second and third phase testing of the same representative family discussed above. The phase 2 results are tabulated in terms of damping coefficients, ζ, which were extracted by roughly fitting the angular histories with curves of the form

$$\Delta\phi = (\phi_0 - \phi_{\text{trim}})\exp(-\zeta_\phi t)\cos\omega_\phi t$$

$$\Delta\beta = (\beta_0 - \beta_{\text{trim}})\exp(-\zeta_\beta t)\cos\omega_\beta t$$

Initial displacements measured from the trim values were zero except in the plane whose damping coefficient was sought.

Summary

The construction of a series of asymmetrical wind tunnel model parachutes designed to a modular concept is described. These parachutes proved very economical from both the construction and testing points of view. The static force, inflation force, and dynamic force and motion time history wind tunnel testing of these models is described. Typical results for one representative family of canopies are presented.

Acknowledgment

This work supported by the U.S. Department of Energy under Contract No. DE-AC04-76DP00789.