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Development of a Parachute Recovery System For a Reentry Nose Cone (NRV)

William B. Pepper

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DEVELOPMENT OF A PARACHUTE RECOVERY SYSTEM
FOR A REENTRY NOSE CONE (NRV)

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ABSTRACT

This report describes a two-stage parachute system consisting of a 19-in. diameter ribbon parachute and a 3-ft diameter guide surface parachute which is deployed 1.9 seconds after initial deployment. A 1.25 cubic foot ram air-filled flotation bag with radio beacon is used for ocean recovery of the 40-lb nose cone. Recovery was initiated by jettisoning 60 percent of the initial reentry mass prior to parachute deployment.

Key Words: parachute recovery, reentry vehicle recovery, recovery at sea.

SUMMARY

Sandia Laboratories has designed and developed a two-stage parachute for recovery at sea of high-performance reentry nose cones after mass jettison of 62 percent of the reentry vehicle mass. The parachute system consists of a 19-in. diameter first stage ribbon parachute and a 3-ft diameter guide-surface, second-stage parachute, with a 1.25-ft ram-air-filled flotation bag. A radio beacon on the flotation bag aids in location at sea. This study describes the results of 12 sled tests and three rocket tests conducted to develop the parachute system.

Results of an operational reentry and recovery are presented. A three-stage Strypi rocket system was launched from the NASA Wallops Island Test Range in Virginia on September 18, 1975. Reentry conditions at 300,000-ft altitude were at a velocity of about 18,700 ft/sec (Mach number 19) and a trajectory angle of -25 degrees. The 40-lb nose cone was recovered about 320 miles down range. This is the first time that a high β vehicle has been successfully recovered in an operational reentry (IRBM) environment.

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SYMBOLS

D	Parachute constructed diameter (ft)
C_{D_o}	Parachute drag coefficient based on S
F_{max}	Maximum deceleration force (lb)
g_{max}	Maximum deceleration (g's)
q	Dynamic pressure = $1/2\rho V^2$ (lb/ft ²)
ρ	Air density (slugs/ft ³)
V	Vehicle velocity (ft/sec)
S	Parachute constructed area = $\frac{\pi}{4}D^2$ (ft ²)
t	Time from release or start of inflation (sec)
W_T	Weight of test vehicle and parachute system (lb)
γ	Trajectory angle (deg)
Δ	Anticipated variations of trajectory parameters
d	Vehicle base diameter (in.)

Subscripts

c	Canopy weight	
f	Canopy filling time	
p	Total parachute pack weight	
o	Release	
T	Total	
i	Impact	} (see Table VIII)
1	First stage parachute	
2	Prior to first stage release	
3	After first stage release	
4	Second stage parachute

NRV Parachute System
FRONTISPIECE

DEVELOPMENT OF A PARACHUTE RECOVERY SYSTEM FOR A REENTRY NOSE CONE (NRV)

Introduction

With the increase of ballistic coefficient of operational reentry vehicles over the past several years, it has become of interest to develop a recovery system for vehicle nose tips. A recovered nose tip can give valuable information on material performance in various environments. The recovered nose tip can yield data for verification and improvement of analytical techniques and aid immeasurably in assessment of overall system performance.

Two-stage parachute systems¹ have been used to recover high altitude sounding rocket payloads and for the SAMS rain erosion program.^{2,3} Recovery conditions for these systems are much less severe than for a typical ICBM reentry since the parachute deployment conditions are subsonic with the payloads designed to descend in a flat spin.

The recovery system presented herein consists of an initial downstream jettison of 60 percent of the reentry vehicle mass. This allows the nose tip to decelerate to less than Mach 2, where a 19-in. diameter ribbon parachute made of nylon can be deployed. After 1.9 seconds of flight on the 19-in. ribbon parachute, its attachment is cut to deploy a 3-ft diameter guide surface second stage parachute.

The results of 12 sled tests and three rocket tests are presented. The system is qualified for deployment over a dynamic pressure range of 800 to 2700 lb/ft² (Mach number 0.8 to 1.5).

Final proof of the recovery system was verified by a Strypi rocket system^{4,5} launched from the NASA Wallops Island Test Range in Virginia on September 18, 1975. Reentry conditions at 300,000 ft altitude were at a velocity of about 18,700 ft/sec (Mach 19) and a trajectory angle of -25°. The 40-lb nose cone was recovered about 320 miles down range.

Recovery System Concept

The recovery design was based on a reentry vehicle weighing 102 lbs with an initial velocity of 18,700 ft/sec at a trajectory angle of 25 degrees below the horizontal at 300,000 ft. Recovery was desired to commence at an altitude of about 28,200 ft after the vehicle had passed through the peak heating and maximum stagnation pressure environment.

Because of the high dynamic pressure of 75,000 lb/ft² at the desired recovery initiation altitude, no known parachute could be used. Therefore, for a first stage deceleration it was proposed to eject the aft 60-percent (62 lb) of the reentry vehicle with a telescoping tube powered by a hot gas generator. In 8.3 seconds the dynamic pressure decays to 1600 lb/ft² (Figure 1) at

which time a nylon ribbon parachute could be deployed (Figure 2). After 1.9 seconds of deceleration the ribbon parachute would extract a 3-ft diameter guide surface second-stage parachute, which was chosen to produce a survivable (75 ft/sec) impact of the 40-lb nose cone at sea level. The parachute functioning sequence is illustrated in Figure 2.

Figure 1. Dynamic Pressure Range at Parachute Deployment for the NRV Strypi Test

Figure 2. Sketch of the NRV Parachute System Operation

Parachute System Design

First Stage Parachute

The initial design was a 2-ft diameter ribbon parachute with reefing to 50 percent of the full open drag area for 0.5 sec. The diameter was reduced to 19 in. for the final design, with no reefing used. The 20 degree conical design has 12 suspension lines of 750-lb cord and 14 horizontal continuous ribbons of 250-lb strength. Detailed specifications are given in Table I. The variation in first-stage parachute weight with size is shown in Figure 3. The final design 19-in. diameter ribbon parachute weighs 7 ounces.

TABLE I

Nylon-Parachute Specifications for the NRV Recovery System

	<u>First Stage</u>	<u>Second Stage</u>
Type of Parachute	Ribbon (Continuous)	Guide Surface
Constructed Dia (in.)	19	36
Cone Angle (deg)	20	0
Number of Gores	12	12
Suspension Line Strength (lb)	750	220
MIL Spec.	C-5040 B/IV	C-7515, Type 15
Length (in.)	30	36
Number of Horizontal Ribbons [†]	14	--
MIL Spec.	T5038E	--
Strength (lb)	250	--
Number of Verticals per Gore	3	--
MIL Spec.	C-5040 B/I	--
Strength (lb)	100	--
Canopy Cloth Strength (oz/yd ²)	--	1.6
Vent Dia (in.)	2.5	7.64
Skirt and Vent Band*	2 x 250	
Sounding Line Strength (lb)	--	1500
MIL Spec.	--	C-4232A/Type III
Flotation Bag (1 ft ³)	--	
Diameter (ft)	--	1.25

NOTES:

[†]2' diameter ribbon chute used on tests prior to 3/1/75 had 18 horizontal ribbon.

*Same as horizontal ribbons

First-Stage Bridle and Swivel

The 19-in. diameter ribbon parachute is attached to the vehicle by a two-leg bridle made from a spliced loop of 6780-lb tensile strength Kevlar-29 as shown in Figure 4. The parachute is connected to the bridle by a specially designed swivel shown in Figure 4. The swivel and bridle have been tested dynamically to a peak load of 5875 lb with no failure. The rated strength of the swivel is 5400 lb. A dynamic load analysis of the first-stage parachute and bridle indicated a load peak of 4100 lb in the Kevlar bridle and 3500 lb in the suspension lines of the 19-in. ribbon parachute for a deployment at 2000 lb/ft² dynamic pressure.

Figure 3. Variation of First Stage Parachute Weight with Size

Figure 4. First Stage Bridle Arrangement

Interstage Cutter

By using the unusual bridle/lug arrangement shown in Figure 4, it was possible to release the first-stage parachute by firing a single* cutter. The cutter was fired electrically by a signal from a timer 1.9 seconds after the parachute can cover was fired initiating a first stage deployment. The cutter was potted in an aluminum housing attached to the forward load plate face. The housing protected the cutter from impact damage which might result from the second stage swivel movement during mass jettison and insured proper position of the cutter. The cutters were subjected to over 1100 g's in a 5.5-in. diameter air gun for a pulse length of about 11 ms to simulate the mass jettison shock pulse. They were shock-tested twice longitudinally and twice laterally and then electrically initiated. The tests are listed in Table II. All Halex cutters cut the 2250 lb nylon successfully. The cutter was also tested twice using the 5875-lb Kevlar-29 bridle material. To insure complete cutting of the Kevlar, it was necessary to roll the 1-in. -wide webbing, tie/wrap with E thread, and wax-coat a 2-in. long segment which was positioned in the cutter to insure a complete clean cut.

Second-Stage Parachute

The second-stage parachute shown at the bottom of Figure 2 is a lightweight 3-ft diameter ribless guide surface design having 12 suspension lines of 220-lb breaking strength and a canopy made of 1.6 oz/yd² nylon cloth. Detailed specifications are given in Table I. The parachute weighed 10.5 oz.

TABLE II

NRV Cutter Shock Tests

Test No.	Cutter	Max. g's	Pulse Length Δt (ms)	Delay	Character of 2250 lb, Line Cut
1	C-413	1250	12	1.62 sec	not complete
2	C-413	750	12.5	2.01 sec	2 lb pull to ext.
3	Halex No. 5801	1250	12	3.57 ms	good
4	Halex No. 5801	1200	10	3.45 ms	good
	Lot A				
5	Unadyn SN 18	1150	10.8	1.84 sec	not complete
	Lot A				
6	Unadyn SN 16	1130	11.5	1.84 sec	good
7	Round Half Moon	1100	12	2.0 sec	anvil broke, good
8	Halex No. 5801	1150	11.4	3.91 ms	good
9	Halex No. 5801	1140	13	3.17 ms	good

*Halex Model No. 5801 cable cutter.

Sounding Line

The suspension lines of the second-stage 3-ft diameter guide surface parachute are only 3-ft long; hence there was not sufficient travel in the water for the relatively sharp nose cone to slow down sufficiently after water impact to prevent suspension line failure. A 12-ft long 1500 lb braided nylon "sounding line" was connected to the swivel and to the attachment loops of the flotation bag to support the vehicle should the lines fall. The excess line was accordion folded and tacked with 5 cord to the inside of the canopy and in two places along one of the 220 lb parachute suspension line.

Radio Location Beacon

A radio beacon* was attached to the top of the flotation bag to aid in locating the payload after impact at sea. The beacon range is about 50 miles with a life of at least 48 hours. The battery† powering the beacon was located in a nylon pocket sewn to the upper portion of the 3-ft guide surface canopy.

In order to insure that it could withstand the expected 1000-g shock pulse at mass jettison, the beacon was tested on the Hi-Gee Accelerator along three axes under an acceleration pulse of 700 g's (17 ms half sine pulse length) and 1000 g's (1.6 ms pulse length). After these six shocks the beacon continued to operate successfully.

Deployment Method

The mass jettison system described in Ref. 4 was designed especially for the NRV. The system consisted of a piston/cylinder shown in Figure 5. The cylinder was part of the tail cover. The piston was a machined part of the thrust cup which had three flanges extending to the outside diameter of the parachute can. A PC 40-007 power cartridge was screwed into the forward end of the cup and protected by an aluminum cap. Two "O" rings on the piston provided a pressure seal.

* Made by Micro Electronics, Inc., 911 Commercial Ave., Anacortes, Washington 98221, Model No. 181 Transmitter with steel case and frequency set at 248.6 megahertz.

† Micro Electronics, Inc., Battery Module Model No. 198-36-M, 1-1/4" x 1-1/4" x 2-7/8" with initiation plug at one end and 3-ft coax cable exiting from opposite end.

a) Assembled tail cover

b) Tail cover, thrust cup, and pressure cartridge cover

Figure 5. Tail Cover Deployment System

The firing cable passed through a steel tube with an elliptical cross-section cemented to the inside wall of the parachute can and through a sharp cut knife screwed to the tail cover/cylinder. The knife severed the fire cable as the tail cover moved aft, and the three-leg bridle attached to lugs on the tail cover (Fig. 2) picked up the thrust cup extracting it from the parachute can, leaving a smooth can wall for clean parachute extraction. The lid was held in place before deployment by six No. 6 brass screws which required 2000 lb force to shear and deploy the lid. The lid velocity measured during static test was 70 ft/sec.

Packing and Rigging

Both parachute bags are of the two-leaf design with 375-lb/lacing cord along each side. Material strengths used in packing and rigging are given in Table III. After the initial bag lacing and tightening by a hydraulic bag lacer, the packs were wrapped in a 0.065-in.-thick piece of leather used as a spacer. The pack was placed between two metal "clam shells" of 3.25-in. I.D. and 0.5-in. wall thickness and placed in a packing press overnight with five tons pressure. This brought the packs down to a smooth cylindrical shape, and they could be installed by hand in the parachute can.

TABLE III

Rigging Specifications for NRV Parachute System

	Breaking Strength (lb)
<u>First Stage (19 in. Ribbon)</u>	
Vent Break Cord	100
Canopy Locking Spider	--
Line Ties: 5 ea x 4 cord	36
Bag Lacing	375
<u>Second Stage (3 ft. Guide Surface)</u>	
Vent Break Cord FF	16
Canopy Tie: 1 x 3 cord	24
Line Ties: 8 ea, 1 x 3 cord	24
Beacon Cover Removal Cord	100
Battery Arming Lanyard	550
Lid Bridle (3 leg)	1500
Second Stage Bridle (2 leg)	1500
Lid Bridle Ties: 7 x E cord	8.5
Lazy Leg for Pack Extraction (2 leg x 8 in.)	1500

Parachute System Weight and Volume

The first-stage parachute pack weighed 1.37 lb and was packed to an unusually high density of 48.8 lb/ft³ (without considering the swivel weight). The second-stage parachute pack weighed 4.1 lb and was packed to 50 lb/ft³ density. The concentrated weights of the battery, swivel, and Hoxex cutter make this density figure abnormally high. Component weights are listed in Table IV. The total parachute system for the Strypi rocket test weighed 5.47 lb which was 5.3 percent of the 102 lb total reentry vehicle weight.

Pack Storage Effects

The pack for the NRV-12 sled test was stored for 12 days and the parachute packs were then drawn out of the parachute can to determine any increase in extraction force attributable to pack expansion. A 15-lb load was measured in pulling the first stage pack out and a 25-lb load was required to pull out the second-stage pack, as compared to 12-lb and 15-lb, respectively, prior to storage. The extraction forces measured for the Strypi pack (see section on Strypi Rocket Test) were 5-lb to start the first-stage pack out, and 3.5-lb to pull the second-stage pack out.

TABLE IV

NRV Parachute System Component Weights

(Strypi Test)

	Weight oz.
<u>19 in. Ribbon Parachute</u>	7.0
Deveney Swivel	7.0
Bag (4-in. long) } 33.18 in. ³ volume	6.17
Lid Bridle	1.83
Static Cutters, Lanyards, Lacing	22.0
Packed 2' Ribbon Parachute	1.37 lb
<u>Deployment System</u>	
Tail Cover (with 3 lugs)	12.3
Thrust Cup	1.1
Gas Generator	0.5
Aluminum Cap	0.1
	14.0
<u>3' Guide Surface</u>	10.5
Bag (17-in. long) 141 in. ³ volume	16.0
Swivel	5.0
Sounding Line, 1500-lb Braided (12 ft long)	5.0
1.25-ft Dia Flotation Bag	11.6
Beacon Transmitter, Micro Electronics Model 181 (248.6 MHZ)	3.71
Battery, Micro Electronics Model 198-36-M	5.33
Antenna Cover, Plastic	0.45
Static Cutters (6 ea) and Lacing	2.0
Holex #5801 Cutter	1.0
Cutter Housing and Potting	2.91
Bag Lacing	0.31
Micarta Disk	1.76
	65.57
Packed 3-ft Guide Surface	4.10 lb
Total (19-in. R & 3-ft GS)	5.47 lb
Packing and Rigging (40 hrs)	

Drop Tests on Water

Two (over water) drop tests of the NRV vehicle at Conchas Lake, New Mexico, were conducted in the fall of 1974. The unit was released about 1000 feet above the 4100-ft msl water target from the Beaver airplane at a speed of about 60 knots TAS. The suspension lines of the 3-ft guide surface parachute failed at water impact, which led to incorporation of a sounding line (see section on Sounding Line). The second test using the sounding line was successful, even though the suspension lines failed, because the sounding line was present, connecting the flotation bag to the vehicle.

Environmental Tests

Prior to sled launched free-flight tests, the parachute system installed in the can was first subjected to a simulated mass jettison then to 50 g's longitudinal acceleration in the direction encountered during sled track runs and 55 g's in the opposite direction to simulate NRV vehicle deceleration after mass jettison. X-ray photographs taken before and after the tests were used to determine any damage or movement of the parachute packs and components. No detrimental effects were noted applicable to the pack for the Strypi rocket test.

Wind Tunnel Tests

The 2-ft diameter ribbon parachute, Figure 6, 3-ft diameter guide surface parachute, Figure 7, and tail cover with bridle, Figure 8, were tested⁶ in the Vought Systems Division 7 x 10-ft low-speed wind tunnel at LTV Aerospace Corporation, Grand Prairie, Texas, in June 1974. The test results are presented in Table V.

Figure 6. 2-ft Diameter Ribbon Parachute
Full-Open in Wind Tunnel

Figure 7. 3-ft Guide Surface Parachute and Flotation Bag in Wind Tunnel

Figure 8. Tail Cover on Bridle in Wind Tunnel

TABLE V
Wind Tunnel Tests of NRV Parachute System

Run	q lb/ft ²		D (lb)	C_{D_0}	S_{O_2} (ft ²)	Remarks
10.1	35	3' Guide Surface with 1 ft ³ Flotation Bag	190	0.77	7.06	Stable
10.2	50		280	0.79	7.06	"
10.3	75		434	0.82	7.06	"
11.1	100	2' Ribbon, Reefed, L = 28 in.	110	0.35	3.14	Stable
11.2	100	2-ft Ribbon Full-Open	199	0.63	3.14	10° Trim
12.1	35	3-3/8 in. Dia. Tail Cover	2	0.94	0.0621	Stable
12.2	50		no data			Coning 45°

Sled Tests

The one-mile long dual rail sled track⁷ at Sandia Laboratories, Albuquerque, was used to develop the parachute recovery system for the NRV. Figure 9 shows the sled prior to launch. The test vehicle is boosted to the desired velocity by one or two solid fuel rockets. The desired velocity variation with dynamic pressure at lid fire is shown in Figure 10 for high speeds and in Figure 11 for testing at the minimum dynamic pressure.

The 40-lb nose cone is ejected upward from the sled at a vertical velocity of 125 ft/sec. One-half second after upward ejection the tail cover is ejected deploying the first-stage parachute. The unit after impact is shown in Figure 12. The results of 12 sled tests are given in Table VI. The vehicle velocity was determined by a laser tracker and is shown for the last two sled tests in Figures 13 and 14. A telemetry system in the vehicle was used to obtain longitudinal acceleration as shown in Figures 15 and 16 for Sled Tests 11 and 12.

Figure 9. NRV Test Vehicle on Rocket Sled

Figure 10. Velocity and Dynamic Pressure Variation with Time from Sled Launch

Figure 11. Variation of Dynamic Pressure at Deployment with Velocity at Upward Ejection for NRV Sled

Figure 12. 3-ft Guide Surface Parachute and Flotation Bag at Impact

TABLE VI																		
Sled Tests										Test Results								
Test No.	Test Date	W _T (lb)	V _{ej} (ft/sec)	V _o (ft/sec)	q _o (lb/ft ²)	g _{max} (g's)	q ₁ (lb/ft ²)	g ₁ (g's)	g ₂ (g's)	w _p (lb)	V _i (ft/sec)	P (slugs/ft ³)	Δt ₁	Δt ₂	Δt ₃	t ₄	Δt ₅	Comments
1	2/28/74	36.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Vehicle didn't eject, bird hit fire cable
2	4/11/74	36.2	1900	-	-	-	-	-	-	4.87	-	-	-	-	-	-	-	Double 1500 lb lid bridle failed
3	5/8/74	36.2	1900	-	-	-	-	-	-	4.81	-	-	-	-	-	-	-	2 ft Chute bridle failed at Atlas Cutter
4	6/6/74	36.0	1920	1673	2800	-	-	-	-	-	180	-	-	-	-	-	-	Safety pins in 2 sec. cutters not removed
5	6/19/74	38.6	1936	1673	2800	130	176	7	28	-	92	0.001810	0.040	0.040	0.01	0.060	0.060	Successful. 2 ft ribbon chute was reefed until release (2 sec cutters used)
6	7/18/74	40.0	2231	1886	3557	-	-	-	-	-	705	0.001900	0.036	0.034	0.01	-	-	Bridle to 2 ft chute failed due to twist
7	8/15/74	40.0	1804	1568	2283	110	81	7	-	5.56	92	0.001857	0.072	0.06	0.02	0.15	0.11	Successful
8	1/10/75	42.45	1755	1542	2447	-	-	-	-	5.94	689	0.002058	-	-	-	-	-	No lid deployment. Fire cable broke.
9	2/20/75	44.0	1887	1640	2690	100	242	6	-	5.9	131	0.001937	-	-	-	-	-	3 ft chute not deployed, too tight in can.
10*	3/20/75	44.3	1722	1443	2082	190	-	-	-	5.95	656	0.001937	0.0425	0.0425	0.0175	-	-	2 ft bridle failed due to pack movement.
11	3/28/75	44.2	1607	1383	1992	75	165	10	18	5.07	100	0.002083	0.060	0.060	0.0133	0.120	0.10	Successful.
12	5/20/75	44.0	968	906	776	24	79	3	12	5.3	100	0.001893	0.065	0.075	0.015	0.123	0.057	Successful.

*C. G. = 31.7-in. from theoretical cone apex

- = no data
Δt₁ = time from lid fire to lid bridle line stretch
Δt₂ = time from lid bridle line stretch to 19" chute line stretch
Δt₃ = 19 in.chute filling time
Δt₄ = 3 ft guide surface chute deployment time
Δt₅ = guide surface chute filling time

First stage chutes were 2' dia ribbon on sled tests #1 through 9 and rocket test #1 and 19 in.dia on tests #10 through 12 plus rocket tests #2 and 3

○ Theoretical Point Mass Trajectory

Figure 13. Velocity/Time for NRV-11 Sled Test

Figure 14. Velocity/Time for NRV-12 Sled Test

Figure 15. Longitudinal Acceleration for Sled Test-11

Figure 16. Longitudinal Acceleration for Sled Test-12

Rocket Boosted Tests

Two rocket tests were conducted at the Sandia Laboratories Tonopah Test Range, Nevada, to evaluate parachute performance coupled with actual mass jettison. No parachute data were obtained from either test because the parachute system failed soon after lid fire on the first test. The cause of failure was premature firing (due to mass jettison shock) of the cutter used to sever the bridle holding the first stage to the vehicle. The adapter between the NRV vehicle and second-stage rocket failed on the second test, and all electrical power was terminated. The parachute lid power cartridge was never fired.

The three-stage Strypi rocket system test of the NRV recovery system, described in detail in Reference 4, was launched from the NASA Wallops Island Test Range in Virginia. Apogee was 108 miles. Reentry conditions at 300,000 ft altitude were at a velocity of about 18,700 ft/sec ($M \sim 19$) and a trajectory angle of -25° . The 40-lb nose cone was recovered about 320 miles down range. The payload was sighted by the Coast Guard search ship Cherokee 2.5 hours after impact and was brought aboard 10 minutes later. The sea state was glassy smooth with 5 knot winds, and this was a great help to recovery. The 3-ft guide surface parachute and flotation bag were undamaged. The suspension lines did not fail at water impact as was expected (see section on Drop Tests on Water) probably because of the lower impact velocity of 75 ft/sec at sea level. The carbon nose plug had considerable erosion with a "tektite-like" appearance. The heat shield over the nose cone was severely cracked but intact. The telemetry record is shown in Figure 17.

Figure 17. Longitudinal Deceleration During NRV/Strypi Reentry

System Performance

First-Stage Loads

The maximum first-stage loads measured on the sled tests are shown in Figure 18 as a function of dynamic pressure at the time the lid was fired. The suspension lines of the 19-in. diameter ribbon parachute should withstand a 5000-lb load (900-lb rated strength divided by a design factor of 1.8), as is borne out by test number 5. The 3.0σ spread in loads expected for the operational Strypi rocket test are shown to be well within the proven limits of the first-stage parachute.

Figure 18. First Stage Parachute Loads

Disconnect Loads

The 19-in. parachute load available for extracting the second-stage pack is shown in Figure 19. The upper curve for vehicle plus 19-in. chute is obtained from onboard telemetry accelerometers. The lower curve is derived by subtracting the vehicle drag from the upper curve. For the Strypi test there was at least a 126-lb force available to extract the second stage and bench tests after storage demonstrated that a 25-lb force was required. The factor of safety for extraction is therefore 5.

Parachute System Drag

The nominal parachute system drag-area time function given in Table VII was used to compute point mass for the extreme initial conditions listed in Table VIII. All trajectories indicate successful recovery. The lowest extraction force at first stage release is 126 lb and the highest extraction force necessary was 25 lb giving a factor of safety of 5. The lowest altitude above mean sea level at which a suitable terminal velocity is reached is 823 ft, which is an adequate margin of safety.

TABLE VII

Drag Area/Time Function for the Final Design NRV Recovery System

Time from Lid Fire (sec)	$C_D S$ (ft ²)
0	0.23
0.12	0.23
0.255	1.30
1.90	1.30
1.91	0.30
2.0	0.30
2.10	6.0
1000.0	6.0

TABLE VIII

Theoretical Trajectory Results for the NRV Strypi Rocket Test

Traj.* No.	h_o (ft, msl)	v_o (ft/sec)	q_o (lb/ft ²)	g_1 (g's)	g_2/g_3 (g's)	ΔF (lb)	q_2 (lb/ft ²)	g_4 (g's)	$h_{(v=85)}$ (ft, msl)	v_i (ft/sec)	t_i (sec)	R_i (ft)
1	5000	1549	2458	58	5.6/1.3	159	174	21	3800	75	54	1676
2	5000	1265	1639	41	5.1/1.17	145	157	19	3900	75	56	1517
3	5000	1000	1024	27	4.4/1.0	126	137	17	4000	75	57	1346
4	9000	1050	1000	27	4.7/1.1	133	146	18	7822	75	105	1478
5	1800	1190	1597	40	4.7/1.1	133	147	18	823	75	15	1392

NOTES: Initial trajectory angle was -33° for all trajectories.

Total vehicle weight was 40 lb.

* These trajectories represent the deployment velocity/altitude window for start of lid deployment due to the expected 3σ errors in predicting the reentry trajectory.

Figure 19. 19-in. Diameter Ribbon First Stage
Parachute Loads at Disconnect

Second-Stage Loads

The 3-ft diameter guide surface second-stage parachute opening loads are shown in Figure 20 as a function of dynamic pressure at lid fire. The expected loads of 300 to 800 lb over the 3σ operational range are well within the design limit of 1050 lb for this parachute.

Figure 20. Second Stage 3-ft Guide Surface Peak Opening Loads

Vehicle Drag Coefficient

Since success of a recovery operation such as NRV is highly dependent upon knowledge of vehicle drag, significant effort was expended in developing the NRV drag prediction methods.⁸ First efforts included estimations of NRV drag using the Hypersonic Arbitrary Body (HABS) and CONECD computer codes and comparison with flight test data from the MINT, SAMAST-01, SAMAST-01A, SAMAST-02, RCTV and three Mk-4 flights. The theoretical results agreed with the flight data to within 16 to 18 percent from 100,000 feet to impact. Estimates of error bounds on C_A were obtained by observing how well HABS predicted C_A for the flight data. Drag predictions were improved by considering the physical phenomena appropriate to an ablating RV entering the earth's atmosphere. Inviscid forebody drag was determined by the NASA-AMES Flow Field (NAFF) code and the effects of nosetip shape change were obtained using modified Newtonian pressure

distributions for the ablated nose configuration. Base drag was determined as a function of Mach number modified by base pressure measurements for the MINT reentry vehicle. Viscous drag was calculated for the ablating heatshield by use of the standard BLUNTY, Charring Material Ablation (CMA) and Boundary Layer Integral Matrix Procedure (BLIMP) aerothermodynamic analysis codes. The induced drag component was provided by CONECD. The first vehicle drag was then compared with flight data and final error bands established (Figure 21). An optimization study was conducted to determine the combinations of vehicle drag (before and after mass jettison) that would produce the maximum range of dynamic pressure at chute deployment; finally a systems parametric study including the effects of changes in time of mass jettison and timer set, reentry angle, and reentry velocity was conducted to define the bounds of dynamic pressure and altitude (Figure 22) appropriate for successful parachute deployment. In Figure 23 the deceleration time/history during reentry shows reasonable agreement between predicted and measured values.

Conclusions

The results of a 1.5-year program to develop a parachute system to recover a high performance reentry vehicle by parachute are presented. Twelve sled tests and 3 rocket tests were conducted to perfect the system. The final design consisted of a 19-in. diameter ribbon first-stage parachute and a 3-ft diameter guide surface second-stage parachute with 1.25-ft diameter flotation bag and radio beacon for location.

Conclusions drawn from this study are

1. The parachute system is capable of being deployed over a dynamic pressure range of 800 to 2400 lb/ft².
2. The 5.5 lb parachute system weighs 5.3 percent of the total reentry vehicle weight (103 lb).
3. The parachute system successfully recovered a 40-lb nose cone after a simulated operational reentry trajectory.

Recommendations

If it is deemed desirable to lighten the recovery system weight or make the pack less dense, Kevlar-29 material could be substituted for the nylon components to save 25 percent or 1.4 lb. The Kevlar development would take about one year.

(a) High Mach Number Range

(b) Intermediate Mach Number Range

(c) Low Mach Number Range

Figure 21. Predicted Recovery Drag Coefficient

Figure 22. Predicted Parachute Deployment Conditions

Figure 23. Reentry Deceleration

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