High-β Re-entry Vehicle Recovery

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The nosetip recovery vehicle was flown successfully on Sept. 18, 1975, from Wallops Island, Va., on a STRYPI-VII booster, which placed it at re-entry conditions of $V_E = 18{,}700$ fps and $\gamma_E = -25°$ at an altitude of 300,000 ft. Normal ballistic flight was continued until shortly after peak heating rate and peak deceleration had been experienced. The recovery process then was initiated at an altitude of approximately 28,200 ft. The recovery portion of the vehicle was soft-landed as planned and was removed from the water about 2½ hr later. This event marked the first time that a high-β re-entry vehicle had been soft-landed and recovered. The vehicle weighted 102 lb and had a ballistic coefficient of 2000 psf. The recovered portion, which weighed 40 lb, included the nosetip, most of the heat shield, and a portion of the telemetry/instrumentation. Fuzing functions for the recovery system were supplied by a dual-channel inertial fuze. The deceleration necessary to effect a soft landing was obtained by jettisoning about 60% of the vehicle mass and then deploying a two-stage parachute. A ram-air flotation bag and homing beacon on top of the main chute provided for recovery from ocean areas. Calculations indicate that this recovery technique can be applied to various test-vehicle configurations with ballistic coefficients as great as 2500 psf.

Introduction

THE severe heating and erosion environments experienced by re-entry vehicles (RV's) with high ballistic coefficients, $\beta = (W/C_DA)$, present a formidable challenge to nosetip designers. Not only must the nosetip survive these environments, but assymmetric ablation also must be minimized so that accuracy is not degraded. Development of materials and designs for high-β (>1500 psf) RV nosetips has been hampered by the difficulty of measuring performance under flight conditions and by the inadequacy of ground simulation. Telemetered data from onboard sensors can, of course, yield valuable information; however, sensor emplacement in brittle materials like graphite and carbon-carbon is difficult. Moreover, it is difficult to reconstruct nosetip shape from sensor data. Postflight recovery of some nosetip experiments provides the opportunity to compare final shape with that indicated by predictions and telemetry data.

With these objectives in mind, the Nosetip Recovery Vehicle (NRV) program was initiated in September 1973, with the goal of developing a technique for recovering high-β vehicles in the terminal portion of ICBM flight. A ballistic coefficient of 2000 psf was selected. The booster available for a flight evaluation of the technique was the STRYPI-VII. This dictated an upper limit on vehicle weight of about 100 lb and limited the demonstration flight to an entry velocity of about 19,000 fps.

In order to perform a reasonable recovery experiment, it is necessary to delay starting the recovery process until the vehicle has experienced peak heating and deceleration environments. This constraint means that normal ballistic flight should be maintained down to 20 to 25 kft, although it is desirable, of course, to delay starting the recovery process as long as is practical.

For the NRV program, the baseline altitude chosen for initiating recovery was 20 kft, a choice that insures that peak environments will be seen and that the total integrated heating will be more than 90% of that experienced if ballistic flight were continued to impact. Since, without recovery, the vehicle would impact at more than 6000 fps, and current parachute technology is limited to velocities less than 2000 fps, mass jettison was chosen to provide the additional deceleration needed to slow the RV to parachute velocity. This approach involves ejecting 60% of the vehicle mass at an altitude of about 20 kft, thereby increasing the deceleration by a factor of 1.5, after which a two-stage parachute provides the additional deceleration necessary for a soft landing. A ram-air flotation bag and a homing beacon also are incorporated to allow recovery from ocean areas.

Vehicle Description

Design Concept

The basic concept (Fig. 1) provides that the high-β ballistic trajectory will be interrupted by the mass-jettison procedure. The aerodynamic force on the vehicle changes very little, since most of the drag force acts on the nosetip and forward portion of the heatshield. Thus the 60% reduction in weight results in a 150% increase in deceleration. This amount is sufficient to slow the recovery portion of the vehicle to a Mach number less than 1.5 at an altitude of 3000-6000 ft. At that time, a supersonic ribbon parachute, deployed for about 2 sec, slows the vehicle to about 400 fps. A 3-ft-diam guide-surface parachute then is deployed and slows the unit to a terminal velocity of 80 fps. A dual-chamber flotation bag is attached to the top of the guide-surface chute, where it is inflated by ram air when the chute opens. A pulse-type vhf homing beacon is attached to the flotation bag. The parachute and flotation system are shown schematically in Fig. 2.

Mechanical Design

Conceptually, NRV is made in two parts, which are held together by breakaway bolts. Figure 3 shows the parts as they would appear at the time of mass jettison. A cutaway of the assembled vehicle with recovery system in place is shown in Fig. 4. Whenever possible, conventional, proven re-entry vehicle design techniques and materials were used. The carbon phenolic/aluminum heatshield/substructure combination is similar to that used in previous designs, as is the ATJ-S graphite nosetip. The 6° cone half-angle and 1.25-in. nose radius were used to provide a vehicle length of 46 in. and a base diameter of 11.9 in.

The main structural member of the mass-jettison system is the cylindrical parachute can that is cantilevered from deep within the recovery portion of the vehicle. A concentric cylinder, which slides down over the parachute can, is capped on the aft end by a hot-gas generator. All components that are

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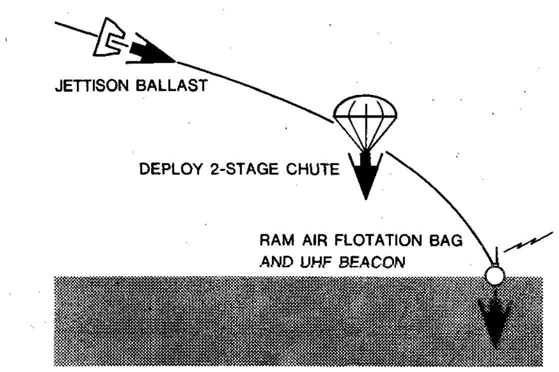


Fig. 1 Concept of re-entry vehicle deceleration and recovery.

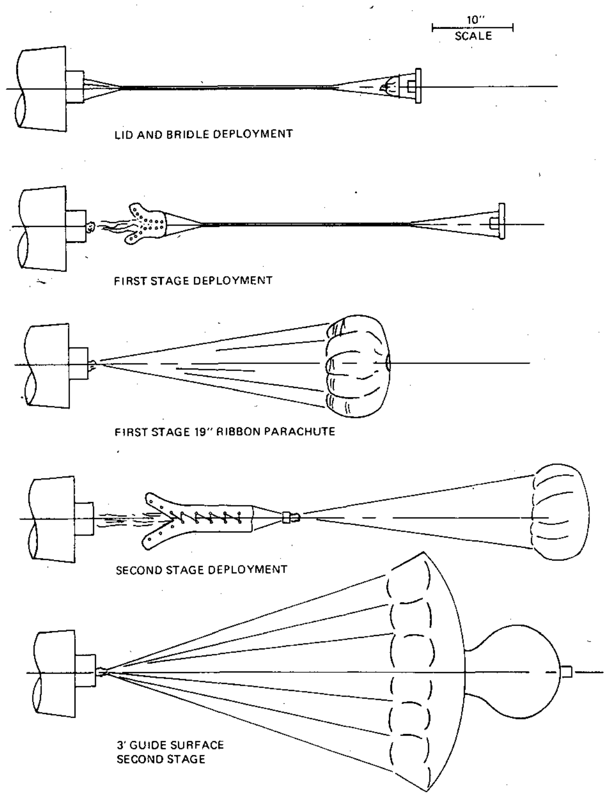


Fig. 2 Deployment sequence of NRV two-stage parachute and ram-air flotation bag.

to be jettisoned are attached to the outer cylinder. These include the aft 6 in. of heatshield, 30 lb of uranium ballast, a chemical battery, and a portion of the telemetry/instrumentation system.

A major concern in the mass-jettison procedure is to push the jetison portion far enough back in the wake so that it develops substantial drag force and separates cleanly. Wind-tunnel tests indicated that a seapration distance of 4 to 6 vehicle diameters will suffice. This distance requires a relative velocity in excess of 200 fps at the time of separation. The necessary force is supplied by a high-energy, short-burn-time gas generator in conjunction with a piston-cylinder arrangement, in which the parachute can act as a piston.

When the gas generator is initiated, a pressure is developed between the end of the parachute can and the capped end of the jettison cylinder, the resultant force breaks the bolts holding the two portions of the vehicle together, and the jettison cylinder travels 18 in. over the parachute can. During this time, the resultant force reaches a maximum value of 35,000 lbf. This process, which takes 14 msec, separates the two portions at a relative velocity of approximately 250 fps.

The main portion of the telemetry/instrumentation system is packaged forward of the parachute can. A thermal battery

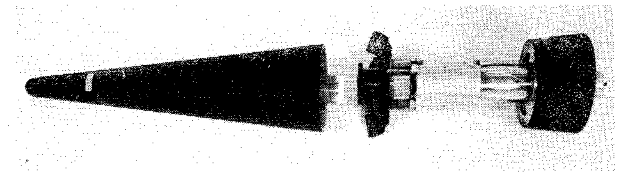


Fig. 3 Jettison portion of NRV unit shown on right with drag flaps deployed. The recovery portion is on the left.

and antenna windows also are located in this region, so that the telemetry function can be continued after mass jettison. An ultrasonic nosetip recession gage also is packaged just aft of the nosetip.

Electrical System Design

The electrical system consists of safety, fuzing, telemetry, and instrumentation components. All items not required after mass jettison are packaged in the jettison portion of the vehicle. The fuzing system is enabled during the re-entry portion of the trajectory and begins monitoring two independent axial acclerometers to determine when jettison should occur. When the deceleration exceeds 5 g, integration of one accelerometer output begins, continuing until the appropriate g-second product is accumulated. Independently, a timer is started when the deceleration on the other accelerometer exceeds 30 g. When either the integrator or timer is satisfied, the mass jettison procedure is initiated. The altitude error of this system is estimated to be ± 2500 ft. The mass jettison signal also initiates a timer; after a fixed interval (typically 7 to 9 sec), a power cartridge in the parachute can lid is fired, and the ribbon parachute is deployed. About 2 sec later, the timer provides a second signal, which fires a line cutter and allows the main parachute to be deployed. The fuzing sequence for the STRYPI flight test is shown in Fig. 5.

The fuzing system provides personnel safety through two, weapon-quality, rolamite environmental sensing devices. Also, the explosive components are isolated electrically from the firing circuits until the RV has experienced 10 g on deceleration during re-entry.

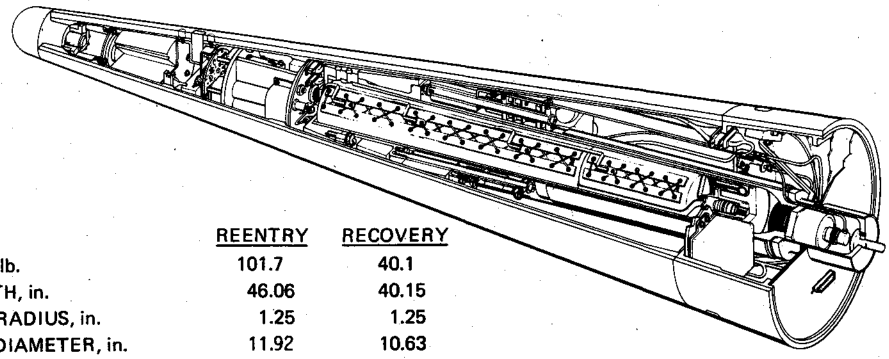
The telemetry/instrumentation system provides 31 channels of data. A 3-W, S-band transmitter, located in the recovery portion of the vehicle, is the heart of the system. Seven accelerometers and three rate gyros are used to determine flight dynamic response, whereas six thermocouples provide limited information on aerothermal response.

Flight Test Results

The NRV flight test unit was launched from Wallops Island, Va., on Sept. 18, 1975, on a STRYPI-VII, three-stage, solid-propellant rocket system (Fig. 6). The first stage carries the system to an altitude of about 600 kft. The first stage is separated during exoatmospheric flight, and an attitude-control system orients the remainder of the rocket to the desired re-entry angle. The second- and third-stage motors then boost the payload to the desired re-entry velocity. On this test, the NRV test unit was separated from the third stage at an altitude of 300 kft, at which point the velocity and flight path angle were 18,700 fps and $-25°$, respectively.

From 300 to 40 kft, the vehicle was well behaved. The initial roll rate of 3.3 rps gradually decreased to about 3 rps. The initial angle of attack of about 4° damped well. A slight angle-of-attack increase was noted in the 70-85-kft region, but damping continued until about 38 kft. At this point, the windward meridian stabilized, and the trim angle of attack increased rapidly (Fig. 7) until the excursion was interrupted by the jettison process.

Mass jettison occurred at an altitude of 28.2 kft, and the first-stage parachute was deployed 8.3 sec later at 11.5 kft. Impact occurred 312 n. mi. southeast of Wallops Island. After 2½ hr in the water, the unit was recovered by the Coast



	REENTRY	RECOVERY
MASS, lb.	101.7	40.1
LENGTH, in.	46.06	40.15
NOSE RADIUS, in.	1.25	1.25
BASE DIAMETER, in.	11.92	10.63
CONE ANGLE, DEGREES	6.00	6.00
BALLISTIC COEFFICIENT, psf	-2000	-750

Fig. 4 Cutaway of the nosetip recovery vehicle (NRV) with the parachute system shown in the center surrounded by the jettison system, fuze, and telemetry components.

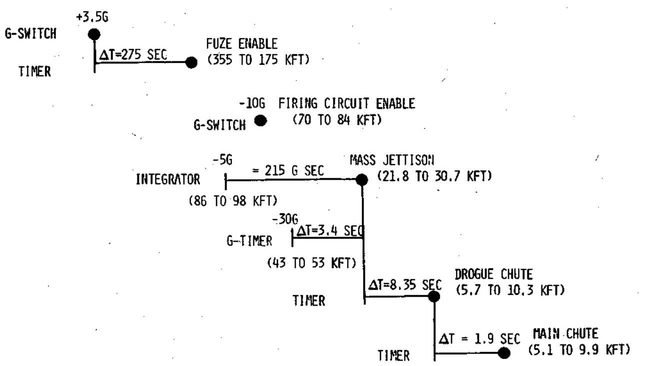


Fig. 5 NRV recovery fuzing sequence showing dual-channel concept.

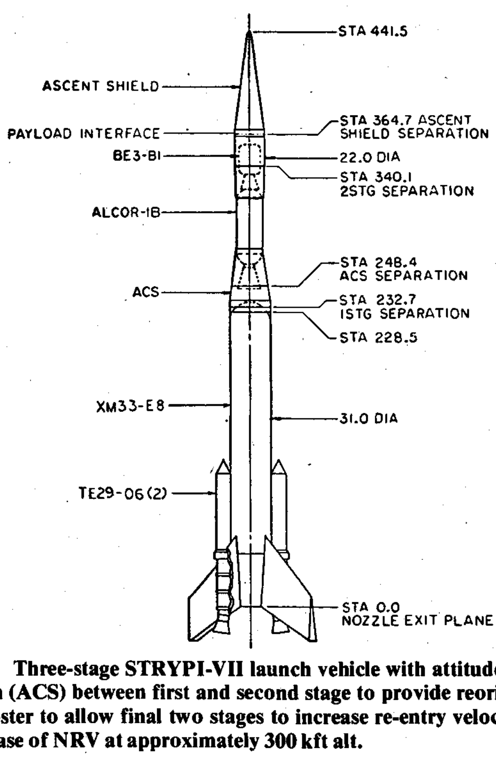


Fig. 6 Three-stage STRYPI-VII launch vehicle with attitude control section (ACS) between first and second stage to provide reorientation of booster to allow final two stages to increase re-entry velocity prior to release of NRV at approximately 300 kft alt.

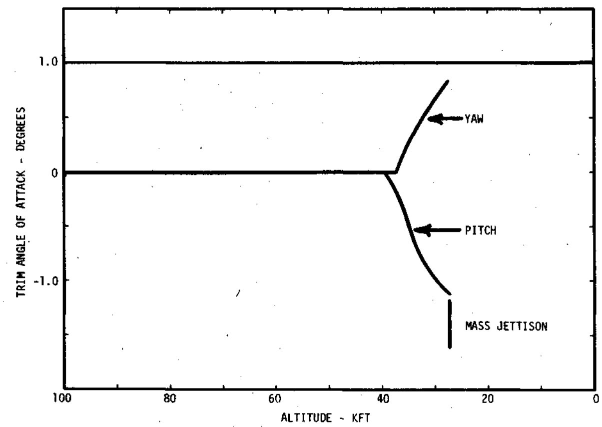


Fig. 7 Trim angle of attack as a function of altitude.

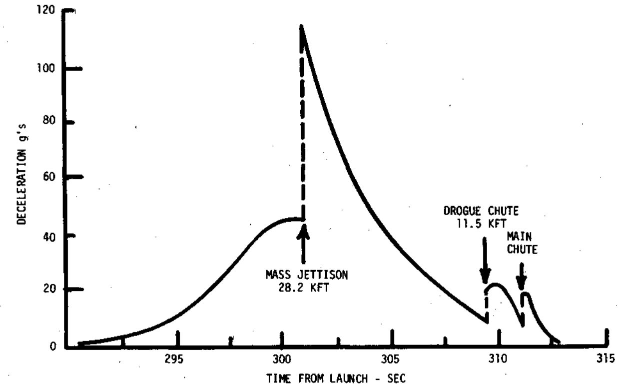


Fig. 8 NRV flight deceleration history showing large step increase at mass jettison and at both stages of parachute deployment.

Guard cutter Cherokee. Telemetry data were acquired successfully from launch until impact, and photographic coverage also was obtained by the terminal radiation program (TRAP) aircraft between the altitudes of 112 and 28 kft.

A large variation among a number of separate drag predictions made in preparation for the flight test prompted an increase in the nominal altitude for mass jettison from the design value of 20 to 26.5 kft. Flight results showed that this degree of conservatism was not required; however, the change did not compromise the objectives of the flight. As Fig. 8 illustrates, mass jettison did not occur until after peak deceleration.

As a profile of the recovered nosetip (Fig. 9) shows, the recession in the stagnation region is 0.336 in., a value that agrees well with pretest predictions of 0.29-0.35 in. The asymmetric nature of the ablation (the three-dimensional aspect of which is shown in Fig. 10) tends to explain the rapid angle-of-attack excursion just before mass jettison. The effect of this shape on aerodynamic forces presently is being studied. A more detailed description of this experiment, along with a complete set of onboard data and reconstructed post-test trajectories, is given in Ref. 1.

Potential Applications

The NRV capability envelope for a Vandenberg-to-Kwajalein reference trajectory is shown in Fig. 11. In the latter trajectory, experiments can be done with peak

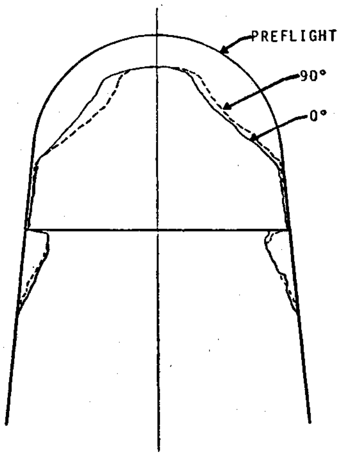


Fig. 9 Postflight profile of NRV nosetip relative to preflight configuration. Note asymmetry, especially in the 0° -180° profile.

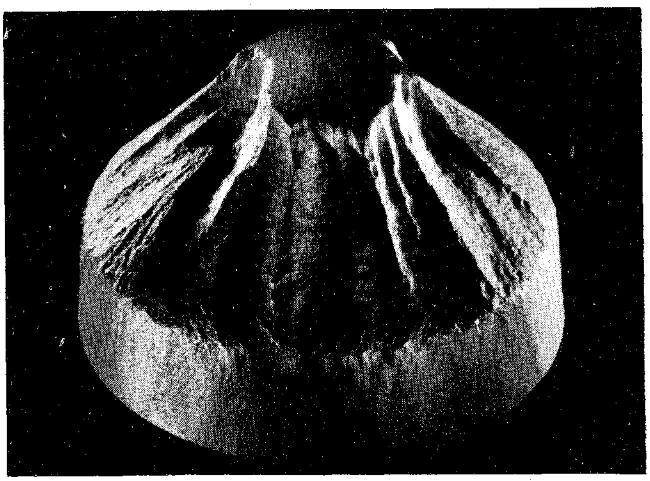


Fig. 10 Recovered nosetip showing erosion pattern that developed outside of the stagnation region.

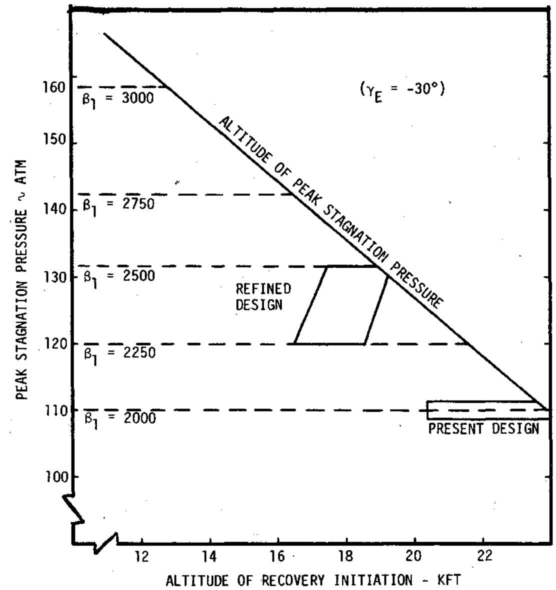


Fig. 11 NRV capability envelope showing increased capability proposed for refined vehicle design.

stagnation pressures of about 110 atm, and calculations indicate that rather simple refinements of the existing design can extend this capability to approximately 130 atm. The recovery initiation altitude can be lowered to 12 to 14 kft at a re-entry angle of $-25°$, if desired, and would provide an opportunity to fly through various types of clouds and precipitation.

A separate investigation[2] has shown that the recovery technique developed for the NRV program could be applied to both the Navy MK4 and the Air Force MK12 re-entry vehicle external configurations. In both cases, for normal trajectories, the recovery process need not be started until after peak heating rates and peak stagnation pressure have been experienced.

Conclusions

A technique for recovering high-β re-entry vehicles have been developed and flight-demonstrated at IRBM conditions. This technique can be used to aid in the evaluation of both experimental and operational re-entry vehicles. Design studies indicate that experiments requiring peak stagnation pressures as high as 130 atm can be soft-landed and recovered by this technique. Vehicles also can be recovered after flights through high- and middle-level clouds and precipitation.

Acknowledgment

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References

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[2]Clark, R.E., English, E.A., Henderson, G.W., and Otey, G.R., "Recovery of Operational Re-entry Vehicles," Sandia Lab., Livermore, Calif., SAND76-8014, April 1976.