N76-28288

A SIMULTANEOUS SPIN/EJECT MECHANISM FOR AEROSPACE PAYLOADS†

By G. Dan Palmer, TRW Systems Group
and Tom N. Banks, AVCO Systems Division

ABSTRACT

A simultaneous spin/eject mechanism was developed for aerospace applications requiring a compact, passive device which would accommodate payload support and controlled-release functions, and which would provide a highly accurate spin/ejection motion to the payload. The mechanism satisfied the requirements and is adaptable to other deployment applications.

INTRODUCTION

The simultaneous spin/eject mechanism is an important element of a recently developed system for accurate, efficient, low-cost deployment of aerospace payloads from their final booster stage (Figure 1). Although this is not the first program to employ a mechanical device to impart a simultaneous spin and eject function to a payload, the mechanism is unique because it is extremely compact and lightweight, has a highly efficient energy release, and has excellent, repeatable performance. These features have been confirmed by extensive analytical simulations and ground tests under 1-g and zero-g environments.

For this application, ease of integration with the vehicle, the supporting spacer, and the booster configuration was important; in addition, payload bumping potential and desired system accuracy called for low tipoff effects. The mechanism can be easily adapted to other aerospace deployment applications. Basic design parameters are listed in Table 1.

The successful development of this mechanism involved the joint efforts of three separate contractors: AVCO, TRW, and General Electric. AVCO was responsible for design, development, fabrication, and testing of the mechanism as a subsystem; TRW supplied design analysis, system engineering, and technical support; and GE was responsible for the integrated system (final stage booster with spin/eject mechanisms and vehicles).

†This work was supported by U. S. Space and Missile Systems Organization under Air Force Contract Numbers F04701-74-C-0325, -0326, and -0328.

SPIN/EJECT MECHANISM

The post-deployment configuration of the mechanism, Figure 2, has three basic elements: (1) a spin/eject device which imparts the desired relative separation velocity and spin rate to the vehicle; (2) a central tie-down system consisting of a structural spacer, a pyrotechnically actuated separation nut, and a high strength tie-down bolt; and (3) two in-flight disconnects (IFD's) that provide the electrical interface between the vehicle and the booster.

Spin/Eject Device

The spin/eject device consists of a spring-actuated guide housing with helical grooves and helix guidepins, with the guidepins also functioning as mechanical stops for the spring guide. The housing, which is fixed to the spacer hub, accommodates the two fixed and diametrically opposite guidepins that ride in matching helix grooves. The force of the spring pushes the spring guide against the guidepins causing simultaneous spin and longitudinal ejection. The selected helix angle determines the amount of rotation in relation to the axial translation of the spring guide and the vehicle. Ejection and spin forces are applied to the vehicle through its rear cover upon which the spring guide bears while simultaneously engaging two torque pins.

The elongated slots at the ends of the helix grooves provide low rebound and self-locking (Figure 2). During the development ejection tests, a change from a completely round pin to a semi-flat pin was made to eliminate local deformations (due to high bearing stresses) which occurred along the helix groove surfaces. These local deformations had contributed to high friction and posed a potential threat to test result repeatability. Friction was further reduced by an application of Molycoat to the guidepin and grooved surfaces. The design change and the coating permitted a reduction of friction forces by a factor of 2, resulting in a realization of 88 percent of the theoretically available energy. The redesigned pin also permitted re-use of ejector hardware without refurbishment for successive ejection tests.

Spin torque is transmitted from the moving spring guide to the vehicle through two torque pins extending aft from the vehicle rear cover to slotted grooves in the spring guide forward face (Figure 2). This interface is critical at the instant of vehicle-to-spring guide disengagement because it not only provides the torque transfer, but also supports and stabilizes the vehicle during the ejection stroke. The latter condition is facilitated by both the flat area and the conical frustum extension on the forward face of the spring guide which matches and centers the mechanism with respect to the flat area and machined indentation in the vehicle rear cover. All ejection tests demonstrated a clean, non-disturbing separation at this interface.

Central Tie-Down System

A central tie-down system was developed that utilizes a mechanical spring deployment device to impart a simultaneous spin/eject motion to the vehicle upon activation of an explosive nut. The structural spacer provides the interface transition between booster and vehicle while accommodating powered flight loads. The tie-down and release device consists of a high-strength separation bolt, under a preload of 37.8 kN (8500 lb), with an ordnance activated separation nut (SOS114196) located within the vehicle.

The preload magnitude is based on static and dynamic loads and vibration environments associated with the boost phase, and is designed to preclude vehicle-to-spacer "gapping." A simple assembly and preload procedure was developed for integrating the spin/eject mechanism with the spacer and vehicle.

The tapered seat at the aft end of the spring guide housing prevents rebound of the ejected separation bolt. The bolt is trapped in its rearward position prior to spring guide movement providing a protuberance-free interface with the vehicle.

Inflight Disconnects

Electrical requirements for the subsystem were met by providing two IFD's (18-pin standard Bendix connector) at the rear cover/spacer interface (Figure 2). These connections provide checkout, monitoring, and control functions from the launch facility, as well as transmission of the activation current on inflight command to fire the pyrotechnics of the separation nut.

To preclude pin binding during extraction, AVCO designed and developed a connector support device. This device allows three-dimensional adjustment during assembly and adequate freedom for rotation which permits the pin connector to be separated with little or no side load upon preload release and during the initial spin/eject motion. This "floating nut-plate" (Figure 3) prohibits relative motion prior to the separation event and accommodates the rotation required up to the time of IFD physical separation.

SPIN/EJECT REACTIONS

Booster control system capability limits dictate the maximum axial and angular (roll) impulses to the booster at 75.6 Ns (17 lb-sec) and 13.6 Nms (10 ft-lb-sec). Booster component responses to the separation nut ordnance shock and to off-center deployments were of concern; however, ground test results verified that the induced environments were within acceptable limits.

Although the deploying vehicle is supported at the forward face of the spring guide, very little transverse moment capability exists at this interface. Consequently, the vehicle tends to hinge, or tip, relative to the moving spring guide if the reaction moments on the booster stage yield overturning moments to the vehicle greater than the restoring moment capability. Off-axis deployments, i.e., where the ejection force line of action does not coincide with the combined booster-vehicle c.g., are susceptible to this tendency. The degree of hinging is a function of the deployment reaction moments and the booster-vehicle mass properties.

Because the existing design has limited moment capability at the vehicle-spring guide interface, and because the booster is relatively massive for the initial vehicle deployments, only the last few vehicles in multiple deployments experience significant hinging.

DESIGN EVALUATION

The mechanism's flight performance was verified through extensive analytic simulations and ground tests. Functional performance specifications required a separation velocity of 1 ± 0.1 m/sec (3.24 ± 0.3 ft/sec) and a vehicle spin rate of 450 ± 72 deg/sec with a tipoff rate less than 3 deg/sec, while not exceeding the booster reaction impulse limits. Further, contact with adjacent equipment or vehicles during boost and deployment was to be avoided.

Analytical Simulation

Both closed-form and computerized solutions were utilized in the functional performance analyses. These simulations involved single-body ejections (the ejector spacer cantilevered from an infinite mass) and two-body ejections (the ejector spacer rigidly attached to the booster). Closed-form terms satisfactorily describe the kinematics of the mechanism because the helix proportions the ejection energy between spin and axial translation. The closed-form solution was used in the mechanism parameter/performance tradeoffs and for support of the early development tests.

To include booster control system and ejector flexibility effects (e.g., torque pin/rear cover and guide pin/groove compliances), however, a more extensive computerized simulation was developed. The simulation was used in establishing the pre-test predictions and post-test evaluations for both the system separation tests (zero-g drop) and actual flight tests. Critical areas of deployment clearance, optimum deployment order and sequence for multiple deployments, and trajectory inputs (targeting biases) were evaluated based on the computerized simulation. This simulation included two six-degree-of-freedom bodies (one with a complete control system and logic), clearance envelope geometry, flexible ejector effects, and provisions for an approximation to the hinging effect.

Ground Test

Development and verification of the simultaneous spin/eject mechanism, both as a subsystem and as part of a missile system, comprised a major portion of the overall program testing activity. The ground ejection testing history is briefly summarized in Figure 4.

Ejection Tests (1-g)

Early design verification of the mechanism concept was obtained from a series of fixed-base vehicle downward ejection tests. Several tests were run using a conservative simulation of the hinging environment; a 10-degree vertical tilt induced a transverse moment on the vehicle during the ejection stroke caused by the 1-g gravity vector. Several test configurations underwent preconditioning (shock and vibration) prior to testing. The vehicle was a mass simulated model with actual rear cover hardware; the spacer and the mechanism were full-scale development, or flight-type, hardware configurations.

AVCO developed and employed a computerized data reduction technique for use with the high-speed (400 frames/sec) film coverage. Markings were made on the vehicle model, and the relative positions of these markings and changes in dimensions were measured, frame by frame, using a Vanguard film analyzer. Appropriate geometric relationships and camera optics coded into a computer program were input with measured data from the Vanguard analyzer; velocity, spin rate, and tipoff data were output.

For this test phase, eleven subsystem ejection tests were performed: three checkout tests of early design hardware; five development tests, one with the semi-flat pin reference design; and three engineering demonstration tests, all with design reference hardware (Figure 4).

In addition to verifying the simultaneous spin/eject concept and design approach, the tests were used to: (1) demonstrate functional operational and performance capabilities, (2) determine repeatability, and (3) establish final design performance parameters and compliance with design requirements.

Separation Tests (Zero-g)

The system-level separation tests utilized the mechanism to deploy a vehicle from a booster model under a zero-g environment. The zero-g environment was obtained by simultaneously dropping the vehicle and the booster model prior to initiating the ejection event, and continuing free-fall beyond end of stroke (Figure 4). As part of the flight-proof testing, an additional separation test was conducted with the flight-proof vehicle and spin/eject subsystem in the zero-g environment.

The configurations tested represented different mass properties of the booster, as well as different offsets for the ejection impulse reaction with respect to the system c.g. Corresponding results were predicted for each test from analytic simulations that accounted for specific mass and offset parameters. The correspondence was excellent between predictions and measurements.

Deployment data for the separation tests from the vehicle and booster model rate gyros and accelerometers were hard-wired to the data acquisition system. For the flight-proof test, the dynamics portion of the flight instrumentation system (rate gyros, accelerometers, and PCM telemetry) was utilized.

Results of the four demonstration separation tests and the flight-proof separation test data, including the effects of new hardware and environmental exposure, indicate oustanding agreement with predictions and an excellent degree of repeatability (Table 2).

CONCLUSION

The final design hardware and functional performance of the simultaneous spin/eject mechanism fully meets the subsystem and system requirements as verified by analyses, ground tests, and successful flight tests. Specifically,

- The electrical inflight disconnect design, which accommodates simultaneous rotation and translation, is functionally adequate; no adverse effects were observed.
- The ordnance-activated separation nut is a reliable device for initiating the spin/eject process. The shock environments produced by separation nut activation and spin/eject process are within acceptable limits.
- The mechanism provides predictable, acceptable, and repeatable performance; tipoff effects were consistently less than the 3 deg/sec requirement.
- Deployment reactions generated by the operation of the mechanism were accommodated by the booster without detrimental effects.

The design latitude of this mechanism can readily accommodate a practical range of vehicle mass properties by modification to the helix angle, ejector spring rate, and/or stroke. The design ensures adaptability to future aerospace vehicle or spacecraft deployment subsystem applications.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the contributions and assistance of R. A. Winje of TRW Systems Group and S. J. Terani, Jr. of AVCO Systems Division.

Table 1. Mechanism basic design data

Parameter	Nominal Magnitude
Mechanism	
Ejection spring rate	26.62 kN/m (1824 lb/ft)
Spring free length	16.6 cm (6.55 in.)
Spring compressed length	9.1 cm (3.59 in.)
Active stroke	5.1 cm (1.99 in.)
Initial spring force	2.13 kN (480 lb)
Torque radius	2.4 cm (0.9488 in.)
Helix angle	9.963 deg
Displacement ratio, angular to linear	4.18 deg/cm (10.608 deg/in.)
Friction coefficient	0.12
Exterior size	6.6 cm (2.6 in.) diameter, 14.0 cm (5.5 in.) height
Weight (including spring)	1.45 kg (3.19 lb)
Spacer	
Spacer size	25.4 cm (10.0 in.) diameter, 20.3 cm (8.0 in.) height
Spacer weight (including separation bolt, nuts, and cable assemblies)	2.97 kg (6.54 lb)

Table 2. Zero-g separation results

Parameters	Test Designation				
	1	2	3	4	Flight-Proof
Axial Velocity, m/sec					
measured	0.98	1.07	1.04	0.94	0.85
predicted	0.95	1.01	1.01	0.88	0.82
Axial Velocity, ft/sec					
measured	3.2	3.5	3.4	3.1	2.8
predicted	3.1	3.3	3.3	2.9	2.7
Angular Rates, deg/sec					
measured pitch	-5.0	-0.1	0.5	-3.0	-3.3
predicted pitch	-3.6	0.1	1.8	-5.2	-5.2
measured yaw	3.2	0.2	-1.1	3.2	2.8
predicted yaw	3.1	0.2	-0.5	3.0	2.4
measured roll	478	483	472	475	472
predicted roll	465	453	456	469	458
Tipoff Rates,† deg/sec	1.4	0.2	1.4	2.2	1.9

†Mechanism induced, based on vector difference of test and predicted transverse rates

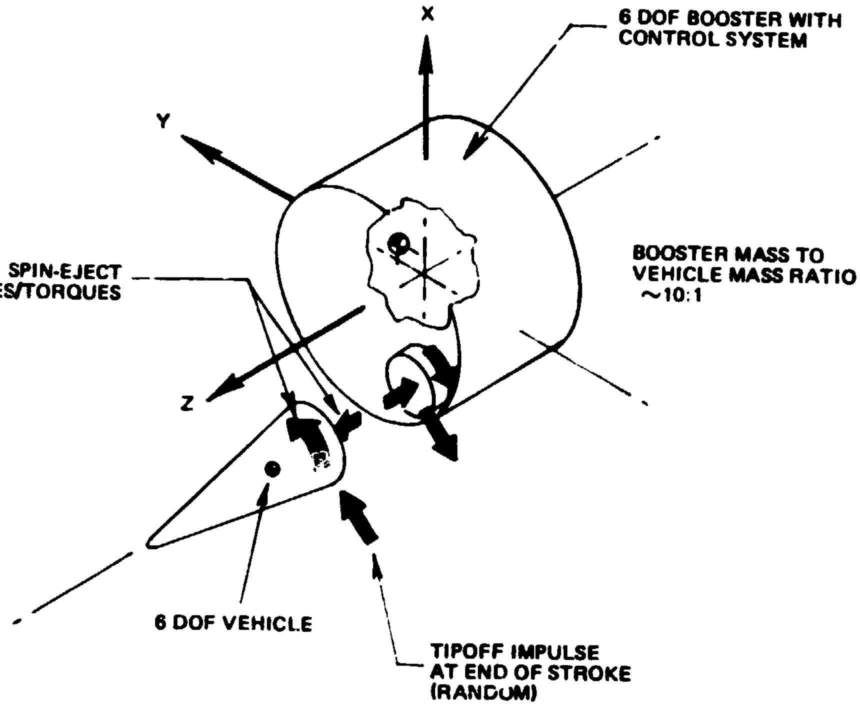


Figure 1. Schematic representation of vehicle deployment

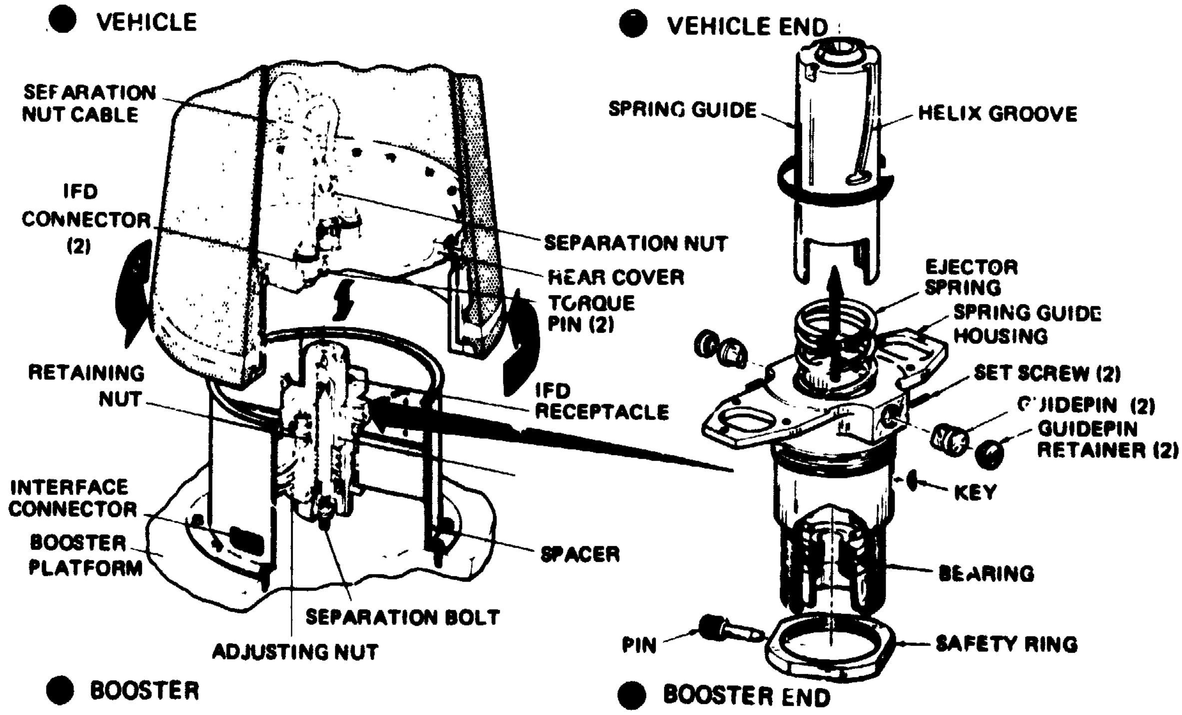
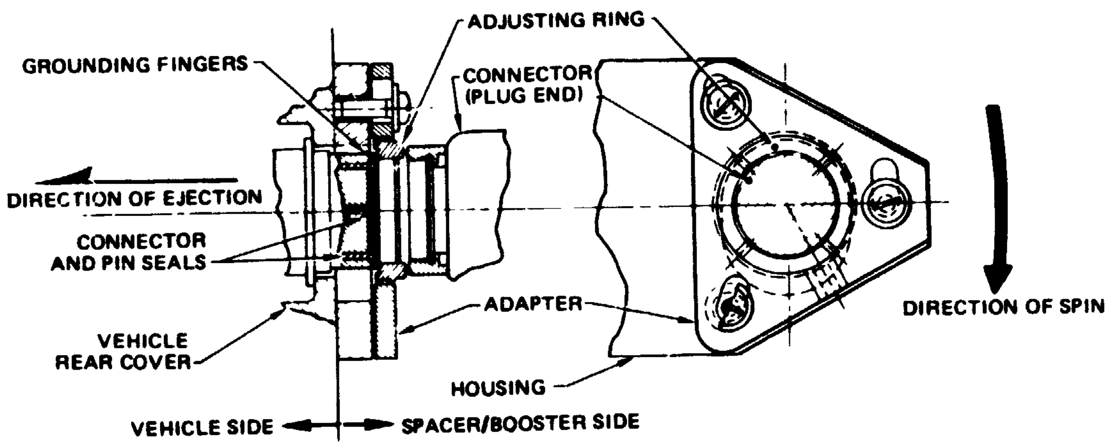


Figure 2. Simultaneous spin/eject mechanism, post-deployed

● ASSEMBLED VEHICLE AND SPACER



● DISENGAGED VEHICLE AND SPACER

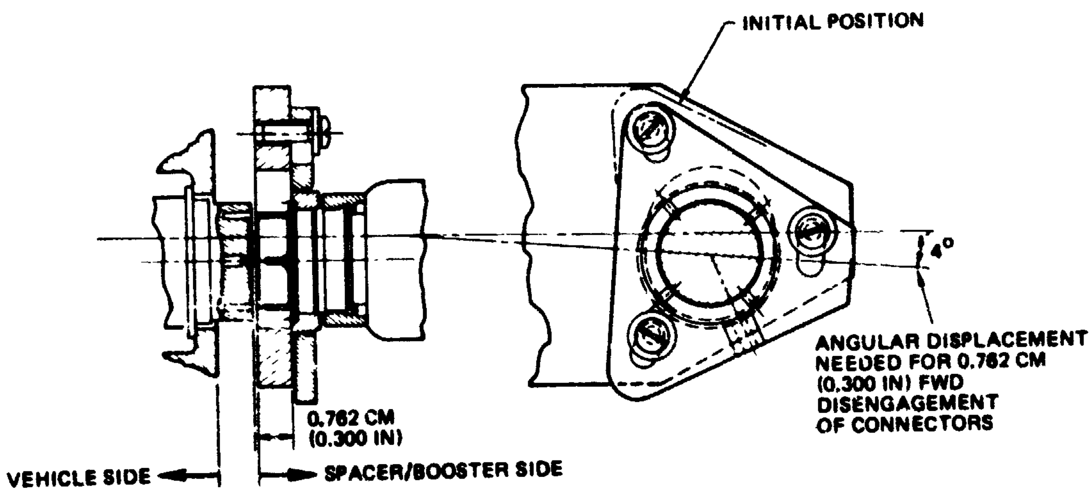
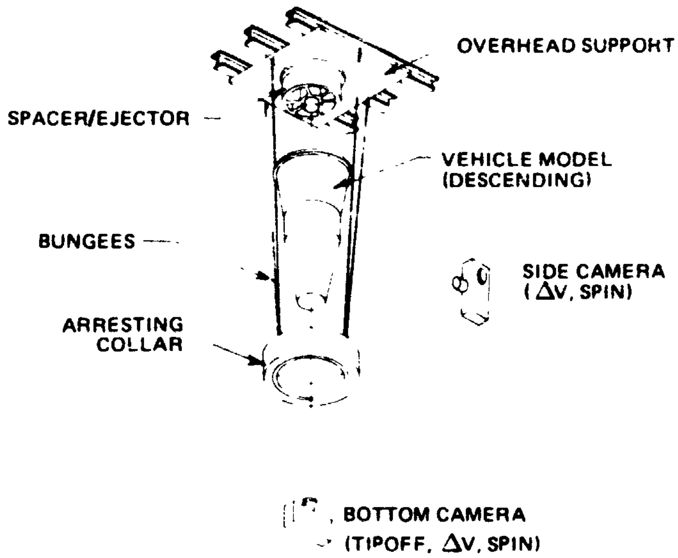


Figure 3. Basic design, inflight disconnect

- EJECTOR TEST SETUP, 1-g



- TEST TYPE:

  Fixed base, downward ejection in 1-g field

- NUMBER OF TESTS AND MECHANISM HARDWARE CONFIGURATION:

  3 Checkout (early design hardware)

  5 Development (1 with final helix pin design)

  3 Engineering demonstration (design reference hardware)

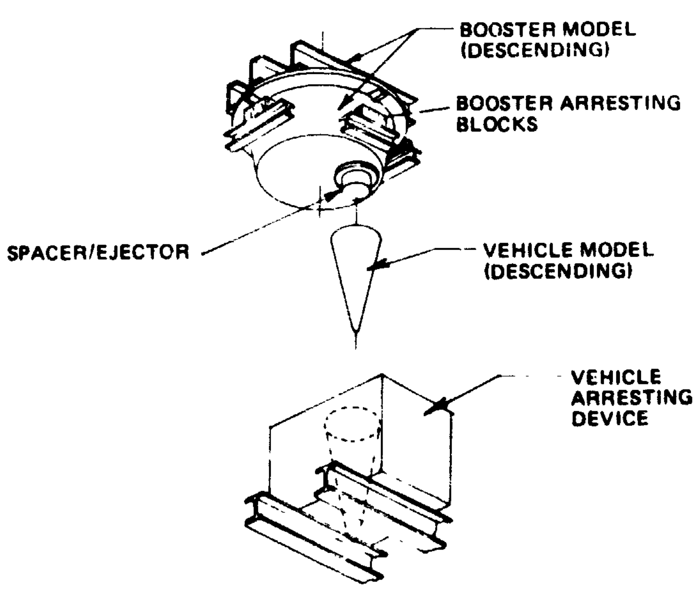
RESULTS

- 16 Successful deployments; results and repeatability allowed reduction of planned test program
- Hinging effects predictable and acceptable
- Friction determination:

  $\mu = 0.124$ (7 tests)
- Tipoff rate:

  < 3 deg/sec (10 tests)
- Spin-rate and velocity predictions confirmed: (5 0-g tests)

- SYSTEM SEPARATION TEST SETUP, 0-g



- TEST TYPE:

  Two body separation, free-fall in 0-g field

- NUMBER OF TESTS AND MECHANISM HARDWARE CONFIGURATION:

  4 Engineering demonstration (design reference hardware)

  1 Flight proof (flight configuration)

Figure 4. Ejector and system separation tests