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A Spin-Recovery Parachute System for Light General-Aviation Airplanes

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SUMMARY

A tail-mounted spin-recovery parachute system has been designed and developed by the NASA Langley Research Center for use on light general-aviation airplanes. The system was designed for use on typical airplane configurations, including low-wing, high-wing, single-engine and twin-engine designs. A mechanically triggered pyrotechnic slug gun is used to forcibly deploy a pilot parachute which extracts a bag that deploys a ring-slot spin-recovery parachute. The total system weighs 8.2 kg (18 lb). System design factors included airplane wake effects on parachute deployment, prevention of premature parachute deployment, positive parachute jettison, compact size, low weight, system reliability, and pilot and ground-crew safety. Extensive ground tests were conducted to qualify the system. The recovery parachute has been used successfully in flight 17 times.

INTRODUCTION

Although spin-recovery parachute systems have been used for many years when conducting spin tests on light airplanes, the design, testing, and in-flight use of these systems are not thoroughly documented. As a result of the lack of design information, test guidelines, and feedback from actual flight use, accidents continue to occur during spin evaluation tests. These accidents have been attributed to improper parachute geometry and deployment and jettison failures.

The NASA Langley Research Center is currently conducting a comprehensive research program to improve the stall/spin characteristics of general-aviation airplanes (ref. 1). As part of this program, an emergency spin-recovery parachute system was designed and developed for use on the test airplanes during spin tests. Small-scale model tests (ref. 2) have been performed to determine the parachute geometry required for spin recovery of a typical single-engine low-wing airplane. Utilizing the model data, a tail-mounted spin-recovery parachute system (fig. 1) was designed, tested, and installed on the corresponding full-scale spin-research airplane. The system incorporates many safety features and stresses simplicity to ensure high reliability without redundancy and excessive weight. The system can be adapted to various airplanes, provided the parachute size and riser lengths are varied accordingly.

Design features of the system and its components are presented. Parachute sizing, loads estimation, deployment technique, attachment and release mechanism, and cockpit controls are described. Ground and flight tests are described to provide guidelines for qualifying a spin-recovery parachute system for use on an airplane. A typical deployment load time history is presented for a flat spin recovery, and flight results are compared with qualification test results and design estimates.

TEST AIRPLANE

The NASA general-aviation stall/spin program includes spin tests of several different airplanes; therefore, a spin-recovery parachute system was designed that could be adapted to different light-airplane configurations. The single-engine, low-wing airplane shown in figure 2 was the first to be fitted with this system. This airplane has two spin modes - a moderately flat mode and a flat unrecoverable mode. The recovery system design, installation, and testing are described using this aircraft as an example.

SYSTEM DESCRIPTION AND DESIGN REQUIREMENTS

Spin-Recovery Parachute

Geometry.- A ring-slot parachute was selected for the spin-recovery parachute because it has a low opening shock, a high degree of reliability, good stability (oscillations less than ±10°), low weight, and low bulk.

The parachute geometry necessary for airplane spin recovery was determined from tests of a dynamically scaled model in the Langley spin tunnel (ref. 2). A 3.2-m-(10.5 ft) diameter parachute canopy with a drag coefficient of 0.5, suspension line length of 3.2 m (10.5 ft), and riser length of 2.9 m (9.5 ft) was selected because it provided a rapid recovery without excessive size.

Operating environment.- The conditions under which the spin-recovery parachute must function were defined by the airplane spin modes as determined from spin-tunnel model tests and the selection of 1500 m (5000 ft) as the minimum altitude for parachute deployment. These conditions were:

Deployment altitude	1500 m (5000 ft)
Descent rate	34 to 52 m/sec (112 to 170 ft/sec)
Airplane rotation rate	36°/sec to 200°/sec
Dynamic pressure	622 to 1436 Pa (13 to 30 lb/ft^2)

Loads.- The spin-recovery parachute geometry and operating environment were used to estimate the recovery-system limit loads. The direction of the force vector produced by the parachute may vary considerably due to the spin rate, descent rate, and attitude of the airplane during the deployment. Therefore, for design purposes, the limit parachute load envelope was represented by a moving force vector, the end of which described a semiellipsoid as illustrated in figure 3. For recovery system design (ultimate) loads, the limit loads were multiplied by a safety factor of 1.5.

A strain-gage load link (fig. 4) was installed in the spin-recovery parachute riser to measure the actual parachute loads during deployment and spin recovery. The link was also used to measure loads during ground and flight deployment tests. To install the load link, loops were sewn to the riser to provide a parallel but shorter path through the load link. If the link failed, the continuous riser would carry the parachute load. The link was wired to an onboard instrumentation system through a connector plug on the parachute support structure. At parachute jettison, the plug disconnects from the socket.

Deployment method.- One of the more important factors to consider when selecting the deployment method for the pilot parachute and the spin-recovery parachute is the wake effect above and behind a spinning airplane. In general, the wake is nonuniform, has less than free-stream dynamic pressure, and in some areas, has airflow reversal. Any of these conditions may cause difficulty in inflation or may actually prevent inflation of the parachute. Therefore, careful consideration was given to the selection of the parachute deployment method in order to avoid these detrimental effects.

The spin-recovery parachute is deployed by the line-first method. A pilot parachute extracts the deployment bag from the parachute support structure, deploying first the riser, then the suspension lines, and finally the recovery-parachute canopy. This method provides a clean separation of the deployment bag from the airplane and insures that inflation of the spin-recovery parachute occurs away from the airplane. The possibility of the parachute fouling on the airplane is thereby reduced, and effects of the airplane wake on the parachute are minimized. The parachute snatch load (force imposed by acceleration of canopy mass at full line stretch) is also reduced because the canopy inflates after the riser and suspension lines are fully extended.

Pilot Parachute

Geometry.- The pilot parachute must produce the force required to deploy the spin-recovery parachute from the deployment bag in a positive and orderly manner. Past experience (ref. 3) indicated that a pilot parachute should be sized to provide an initial acceleration of 39.2 to 58.8 m/sec^2 (4 to 6 g) on the deployment bag at the minimum expected dynamic pressure. Based on this, a 0.9-m-(3 ft) diameter, 8-gore, vane-type, solid, no-spring pilot parachute with low porosity canopy material and line length of 0.9 m (3 ft) was selected. This type pilot parachute has a high drag coefficient and a small area, which resulted in a small packing volume. The pilot-parachute bridle line, including an energy absorbing loop, was selected to be 8.8 m (29 ft) long to avoid effects of the airplane wake.

Deployment method.- To insure reliable pilot-parachute deployment regardless of the deployment method used, the pilot parachute should be ejected rearward away from the airplane wake. Three deployment methods (ref. 3) were considered: a spring-loaded system, a mortar system, and a deployment-gun system. The deployment-gun method was selected for this application because it had lower reaction loads than a comparable mortar, it provided a more positive deployment of the pilot parachute than a spring system, and a reliable deployment gun was readily available from a commercial source.

The gun projectile (slug) is attached to the pilot parachute by a short retainer line (figs. 1 and 5). When the gun is fired, the projectile pulls the pilot parachute and bridle line out to its full length. Excess projectile energy is expended by tearing out stitching in a loop installed between the pilot parachute and its bridle line (fig. 6). The energy absorbing loop was added during developmental testing as a simple means of eliminating excess slug energy to prevent spring back of the slug which could foul the pilot parachute.

Deployment Gun

The parachute deployment gun (fig. 6) used in the spin-recovery system is a ballistic device used by the U.S. Air Force to forcibly deploy a personnel parachute. It has undergone extensive qualification tests, is flight qualified, and is manrated. It has proven to be highly reliable and has many ground-handling safety features. The gun is mechanically triggered by pulling on a cable with a force of 53.4 to 155.7 N (12 to 35 lb), whereby the initial cable movement cocks a firing pin and continued cable movement releases the firing pin. The firing pin impacts the primer of an explosive cartridge which ignites and fires the projectile. The 0.37-kg (0.81 lb) projectile leaves the gun barrel at a muzzle velocity of 46 to 67 m/sec (150 to 220 ft/sec), and a peak recoil force of 8967 N (2016 lb) is developed. After 10 firings the gun is completely refurbished. A safety pin is installed in the cable assembly to lock out inadvertent cable movement and insure safety of the deployment gun while on the ground.

Airplane Installation

Support structure.- The deployment bag containing the parachutes, the deployment gun, and the mechanism for attaching and jettisoning the spin-recovery parachute are mounted to the support structure, as shown in figure 1.

Overall size and projected side area of the support structure were kept as small as possible to minimize aerodynamic effects which might alter the basic airplane spin modes. A parachute riser tunnel (fig. 1) was incorporated in the design to minimize changes in the airplane inertias due to the added mass of the recovery system. The riser tunnel allowed the recovery-system center of gravity to be placed closer to the airplane center of gravity, but placed the parachute riser exit far enough aft of the empennage to keep the riser from coming in contact with the tail. This design provided the maximum moment arm through which the antispin parachute force could act during the spin recovery and used the tunnel rather than the latch to react vertical and side loads from the parachute. The support structure was designed such that when the bag mounting pins are pulled, the bag is free of the support structure and automatically separates due to the centrifugal force produced by the spin.

Deployment bag.- The deployment bag and parachute system components are shown in figure 5. The bag was designed to provide an orderly and reliable deployment of the spin-recovery parachute. The bag is constructed of 203.5 g/m^2 (6 oz/yd^2) nylon fabric reinforced with 4448-N (1000 lb) test nylon tape and is divided into three separate compartments: riser and suspension line compartment, spin-recovery parachute canopy compartment, and pilot parachute and bridle compartment.

The spin-recovery parachute canopy is stored in an accordion-fold manner in the middle compartment. Locking flaps separate the canopy from the riser and suspension-line compartment and prevent the canopy from deploying until the riser and suspension lines are fully extended. The riser and suspension lines are stowed on a line stow flap with rubber retainer bands and packed in the front compartment.

The pilot parachute and bridle are packed in the aft compartment with the bridle attached to the aft end of the bag. Two rip cords are attached to the pilot parachute bridle for mounting the deployment bag to the support structure. A 89-N (20 lb) test break cord between the bag and the apex of the spin-recovery parachute canopy provides for extension of the canopy and separation of the pilot chute and bag before canopy inflation.

Closure flaps at each end of the bag seal off the deployment bag and protect the parachutes from damage. Nylon cords laced through mouth tie loops are used to lock the ends of the bag closed. Steel knife line cutters on the projectile retainer line and parachute riser sever the cords to open the bag ends during the deployment sequence.

The packed deployment bag is 38 cm (15 in.) long and 13 cm (5 in.) in diameter and is mounted to the support structure by loops made from shock cord which are attached to the outside of the bag. The loops pass through holes in the support structure and are held in place by the mounting pins on the two rip cords attached to the pilot parachute bridle as shown in figure 7. The mounting pins are pulled when the pilot chute and bridle line are fully extended by the deployment-gun slug during the deployment sequence.

Attachment and release mechanism.- The spin-recovery parachute riser is attached to the airplane by the attachment and release mechanism shown in figure 8. This device is mounted in the forward part of the support structure with the latch at the forward end of the riser tunnel. The mechanism is mechanically operated by cables that are connected to a control handle in the cockpit. This mechanism is a critical item in the overall system design because it attaches the parachute riser to the airplane, releases the parachute after spin recovery, and automatically releases the parachute in the event of inadvertent deployment during take-off or landing.

Automatic release of the parachute is accomplished by setting the mechanism lock arm and clamp in the jettison position, while maintaining the latch in the closed position with a small shear pin as shown in figure 8(a). The shear pin provides sufficient force to prevent the latch from vibrating open in flight before it is actually locked closed prior to spinning the airplane. If the parachute should deploy inadvertently on take-off or landing, the parachute load shears the pin and the parachute automatically separates from the airplane. A tension spring provides a force of 22 N (5 lb) to hold the clamp in the jettison position until the mechanism is manually locked.

Prior to entering a stall/spin condition, the lock arm and clamp are set in the locked position by the pilot by applying tension in cable A (fig. 8(b)) thus locking the spin-recovery parachute to the airplane. A spring locking clip prevents the lock arm from opening due to vibration. The lock arm and latch each close separate microswitches when the riser shackle is properly locked to the airplane. Both switches must close to illuminate an indicator light (fig. 9) in the cockpit verifying to the pilot that the spin-recovery parachute is properly locked to the airplane.

After deployment and spin recovery, the parachute is jettisoned by moving the lock arm to the jettison position by applying tension in cable B (fig. 8(c)). The parachute load severs the shear pin and pulls the latch open. As the shackle pulls out of the latch, the parachute load causes a rapid acceleration of the latch, swinging it against a lead stop that deforms to dissipate the latch energy. This energy absorber was required to reduce the large inertia load imposed on the leg of the latch by the rapid deceleration of the latch when it contacts the mechanism housing. The lead energy absorber is replaced after each system deployment.

Cockpit Controls

Arrangement.- Two separate and distinct cockpit controls, a deployment handle and arm/jettison handle (fig. 9), are used to operate the spin-recovery parachute system. A "D-ring" deployment handle is located between the pilot's legs at the front of his seat, and a spherical arm/jettison handle is located immediately to the right of the pilot. The controls are positioned so that they can be reached and operated easily by the pilot under all spin conditions.

Deployment handle.- The deployment handle is similar to that used for actuating aircraft ejection seats. It can be reached with either hand and requires a pull force of 27 to 31 N (6 to 7 lb) and a travel of about 5.3 cm (2.1 in.) to fire the deployment gun. The handle is connected through a bell crank to the deployment gun by means of cables. The bell crank was sized to provide an acceptable deployment-handle travel and pull force. Metal tubing was used as a cable guide to route the cable from the bell crank through the fuselage to the deployment gun. A safety pin is installed to lock out the deployment handle during take-off, landing, and when on the ground.

Arm/jettison handle.- The arm/jettison handle is connected to the attachment and release mechanism by cables A and B in figure 8. The handle moves in a fore-and-aft direction. For take-off, landing, and ground operations, the handle is positioned aft in the jettison position. This unlocks the attachment and release mechanism so the spin-recovery parachute will separate from the airplane if inadvertently deployed.

Prior to initiating a spin maneuver, the arm/jettison handle is moved forward and to the left into a locking detent. This arms the system by locking the attachment and release mechanism which is verified by illumination of an "armed" indicator light on the instrument panel. If the spin-recovery parachute is used to recover the airplane, jettison is accomplished by pushing the arm/jettison handle forward and to the side to clear the detent and then pulling rearward with a force of 22 to 44 N (5 to 10 lb).

System Deployment Sequence

Prior to spin entry, the parachute is locked to the airplane by putting the arm/jettison handle (fig. 9) in the "armed" position. The spin-recovery parachute system (fig. 1) is activated by pulling the deployment handle (fig. 9) in the cockpit. This mechanically triggers the deployment gun (fig. 5), firing the projectile which starts the system deployment sequence. The spin recovery parachute-system deployment sequence is shown in figure 10.

SYSTEM TESTING AND QUALIFICATION

To assure system reliability, a comprehensive qualification test program was performed which included static load, ground deployment, airplane taxi deployment, and flight deployment tests.

Static Load Tests

The parachute support structure, along with the attachment and release mechanism, was statically loaded to verify that they would withstand the limit loads and function properly under such loads. The parachute attachment and release mechanism was operated under load to determine the forces required of the pilot to operate the mechanism and to verify proper jettison operation up to the limit design load on the riser shackle. Both the magnitude and direction of the spin-recovery parachute loads (fig. 3) were simulated.

Ground Deployment Tests

Deployment tests from a moving truck provided a check of the deployment sequence with dynamic pressure acting on the parachutes. To avoid the wake area behind the vehicle, the recovery system was suspended 2.4 m (8 ft) from the side of the vehicle by means of a boom, as shown in figure 11. Tests were performed at dynamic pressures of 294 Pa (6.1 lb/ft^2) to 919 Pa (19.6 lb/ft^2), the maximum attainable with the vehicle moving into the wind. Time, dynamic pressure, and parachute load were recorded onboard the truck. High-speed cameras on the truck and in a chase helicopter filmed the deployment sequence for review of the test in slow motion.

The first two deployments from the moving truck showed that after the projectile stretched out the pilot parachute bridle line, it sprang back with the potential of fouling the pilot parachute. Additional tests were defined to develop a method of expending excess projectile energy through a smooth, slow deceleration to eliminate the spring back. This led to the incorporation of the previously described stitched energy-absorber loop. Several combinations of thread size, stitching pattern, and loop length were tested. The final configuration (fig. 12) was tested four times from the moving truck. In two of these tests, the system was deployed rearward parallel to the direction of travel, and for the last two tests, the system was deployed pointed upward at a 45° angle and perpendicular to the direction of travel. The system functioned properly in all deployments.

Airplane Taxi Test

An airplane taxi test provided the first operational checkout of the complete spin-recovery parachute system and controls and provided pilot familiarization with the system prior to flight test. The system was deployed with the airplane taxiing down a runway at a speed that produced the minimum design dynamic pressure (622 Pa (13 lb/ft^2)). The deployment was filmed by wing-tip cameras and from a chase helicopter. An instrumentation system onboard the airplane was used to record parachute load and airplane response. Results duplicated those of deployments from the moving truck.

Flight Deployment Test

As the final step in qualifying the spin-recovery system for flight use, the system was deployed twice in level flight. These tests provided the opportunity to check system deployment at minimum design dynamic pressure and to check system integrity near maximum design dynamic pressure. Parachute deployment loads and airplane response were recorded onboard the airplane. The deployments were filmed from wing-tip cameras and from a chase helicopter. Both level flight deployments exhibited opening loads similar to those experienced in ground tests.

OPERATING EXPERIENCE

Deployment in a Spin

To date, the spin-recovery system has been used 17 times to recover the airplane from otherwise unrecoverable spins. Sixteen of these were recoveries from a flat spin; one was a recovery from a steep spin.

After the first deployment of the parachute to recover the airplane from a spin, the attachment and release mechanism latch fractured when the parachute was jettisoned. The failure did not effect the jettison function of the parachute, but replacement of the broken latch was necessary. This failure was duplicated in ground tests by unlocking the latch with a dead weight suspended from the riser and shackle that was equivalent to the parachute load at the time of jettison. When the latch was unlocked, the riser shackle pulled the latch open and swung it against the body of the attachment and release mechanism, causing the latch to fracture. Previous load and jettison tests had utilized a hydraulic jack to apply the load, resulting in different loading because the force accelerating the shackle was rapidly reduced to zero after the latch was unlocked. Use of a less brittle material for the latch and addition of the previously described lead energy absorber in the attachment and release mechanism eliminated the fracture problem.

Figure 13 presents a typical load time history of a deployment to recover the airplane from a flat spin. The spin-recovery parachute stopped the spin within two turns after the deployment gun was fired. Most notable from the load plot is the absence of the large opening load peak that characterized the ground and level flight deployment tests. The maximum load occurred just prior to jettison, with the airplane and parachute moving at terminal velocity. The maximum vertical and side loads produced by the parachute during deployment and recovery did not exceed the vertical and side loads produced by the parachute oscillations in the terminal velocity dive prior to jettison. Loads measured during steep and flat spin recoveries were found to be much lower than the estimated load values used to design the system. The open parachute was very stable in the wake of the airplane, providing a smooth stable glide.

CONCLUDING REMARKS

A highly dependable spin-recovery parachute system has been developed and qualified for light general-aviation airplanes. The design, testing, and use of the system have been described. The system has been used to recover a general-aviation research airplane from 1 steep and 16 flat spins that were otherwise unrecoverable. The deployment-gun method used to deploy the pilot parachute was effective in avoiding the airplane wake and provided positive pilot-parachute inflation. The ring-slot parachute proved satisfactory for spin recovery, had low deployment loads, and was very stable in the wake of the airplane. Due to high dynamic pressure and parachute oscillations, the maximum normal and longitudinal parachute loads occurred just prior to jettison. The flight deployment data indicated that the spin-recovery parachute limit loads used for design purposes were conservative.

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3. Burk, Sanger M., Jr.: Summary of Design Considerations for Airplane Spin-Recovery Parachute Systems. NASA TN D-6866, 1972.

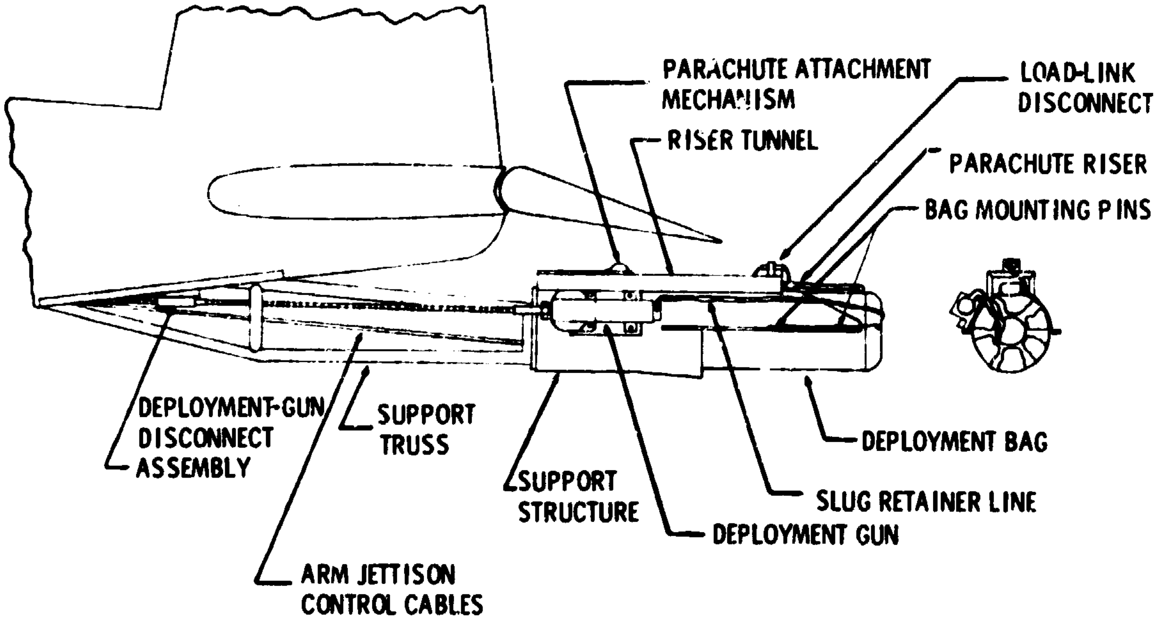

Figure 1.- Spin-recovery parachute system.

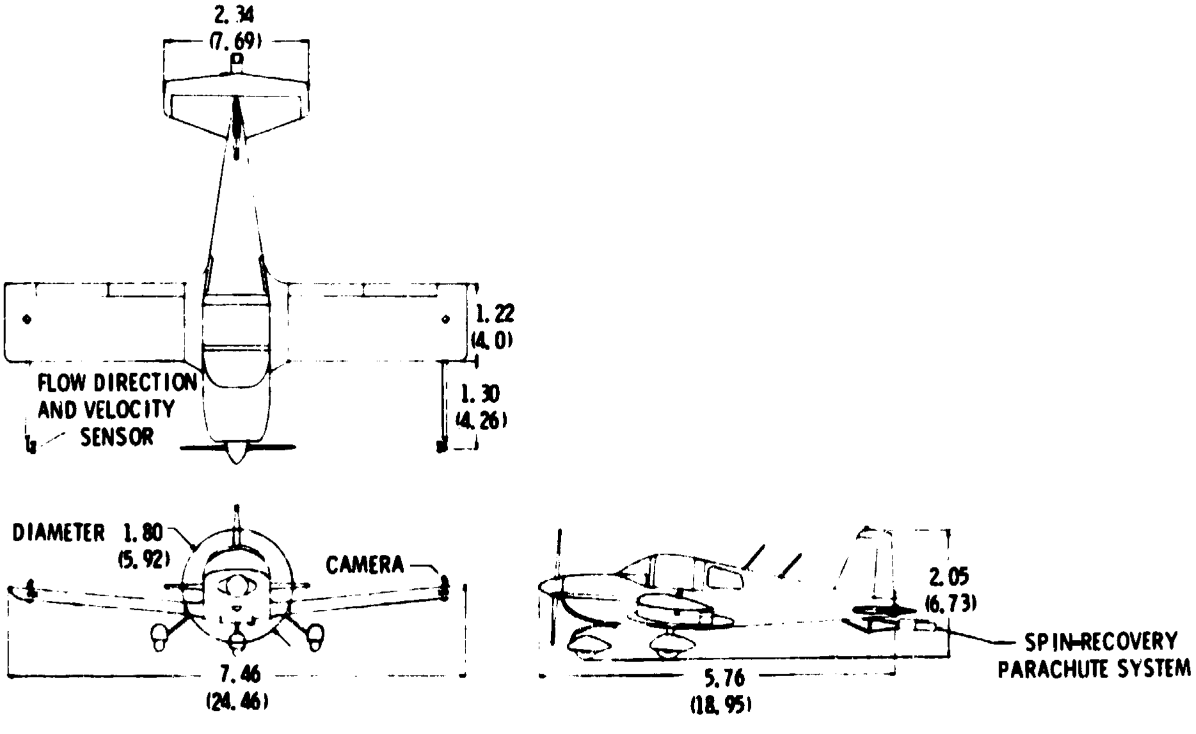

Figure 2.- Spin research airplane. Dimensions are in m (ft).

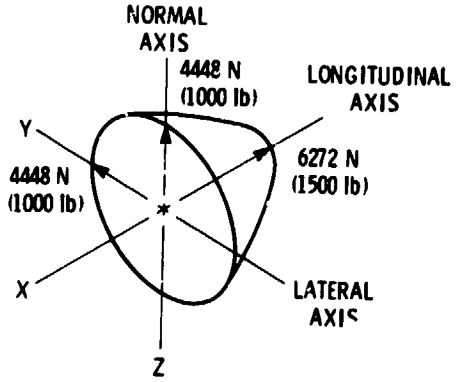

Figure 3.- Spin-recovery parachute limit-load envelope.

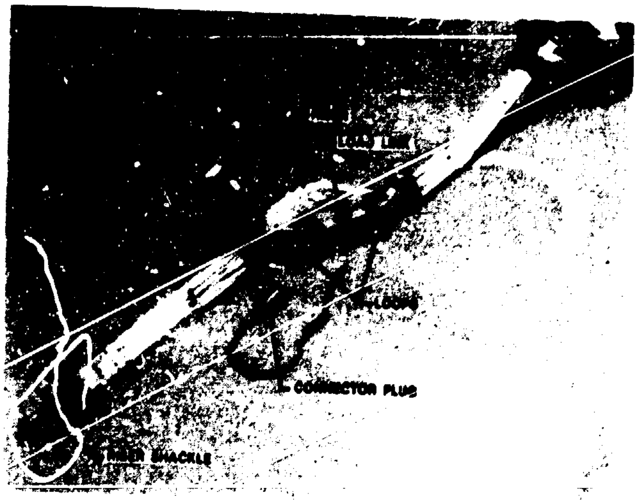

Figure 4.- Strain-gage load-link installation.

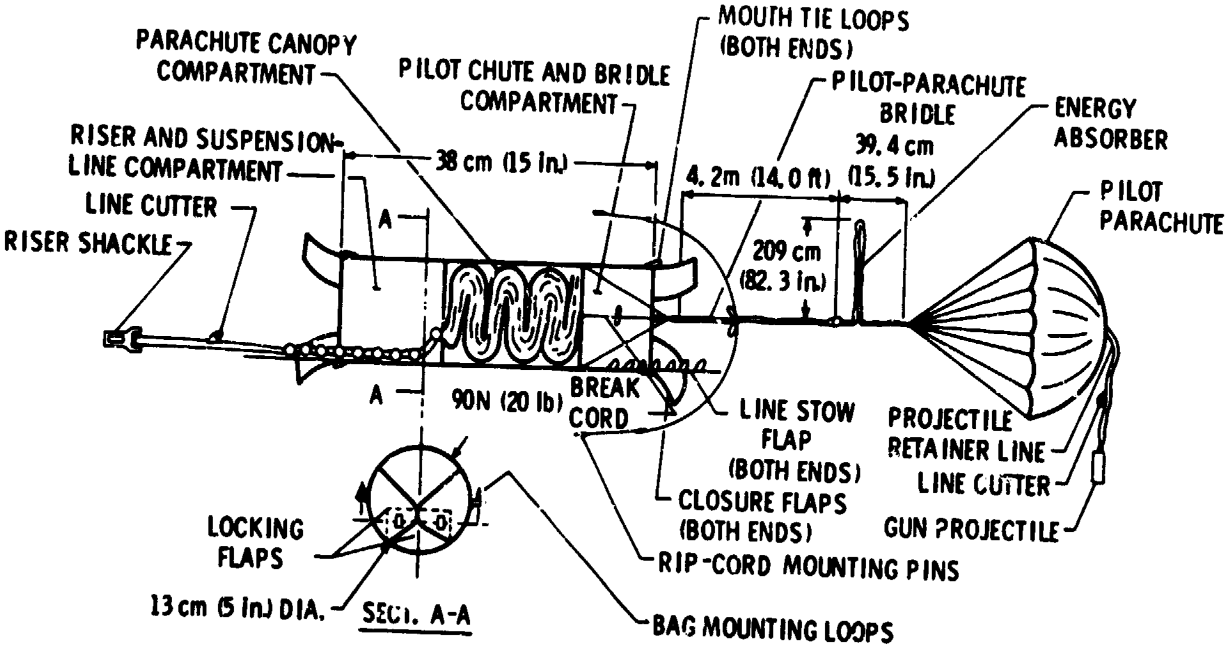

Figure 5.- Deployment bag and parachute system components. (Not to scale.)

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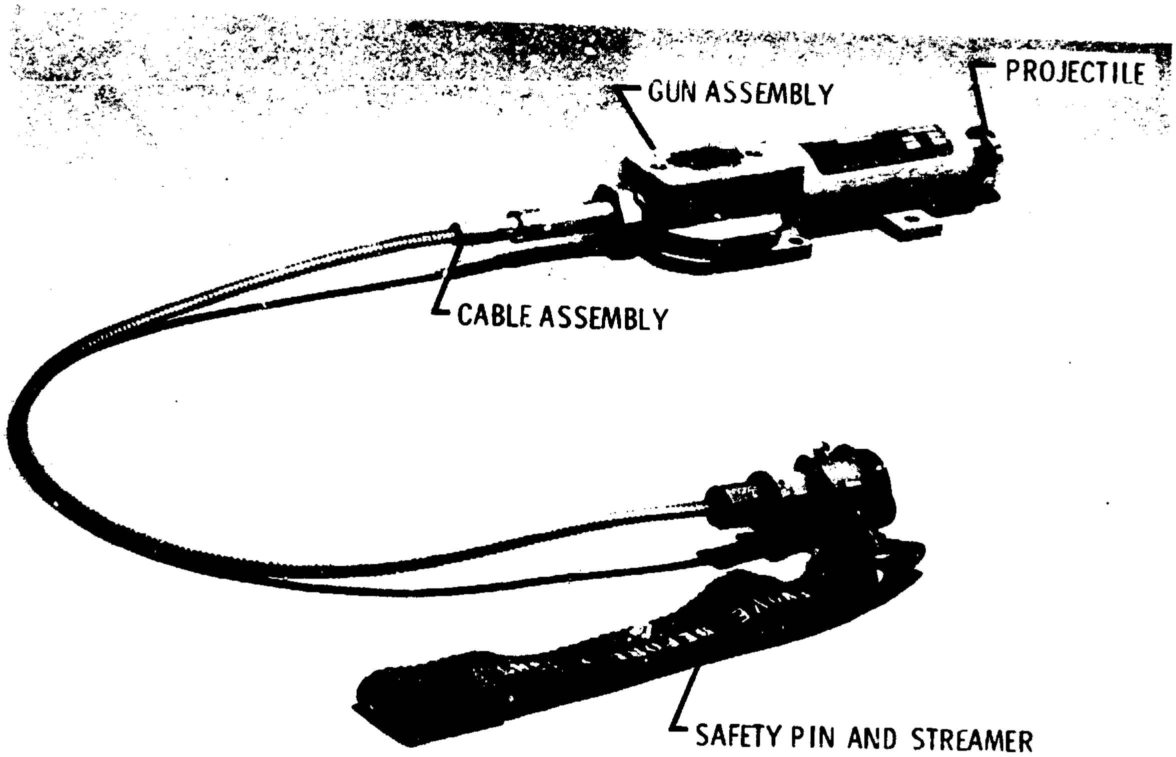

Figure 6.- Parachute deployment gun.

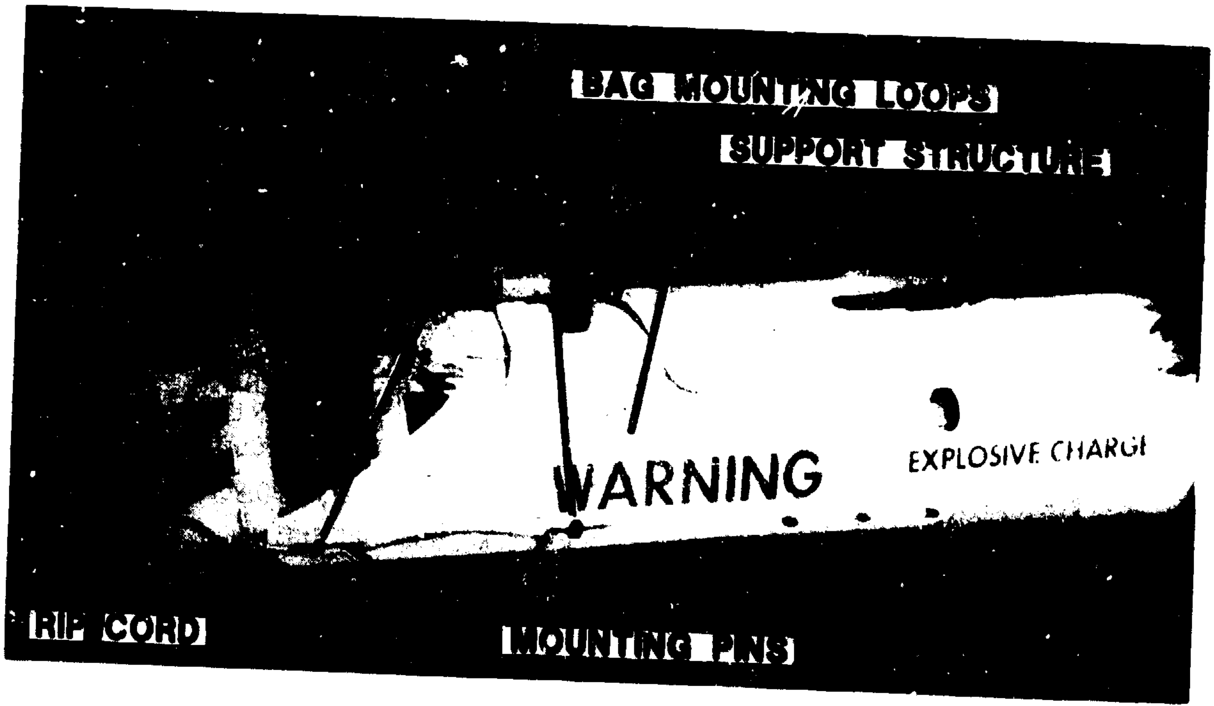

Figure 7.- Deployment bag mounted support structure.

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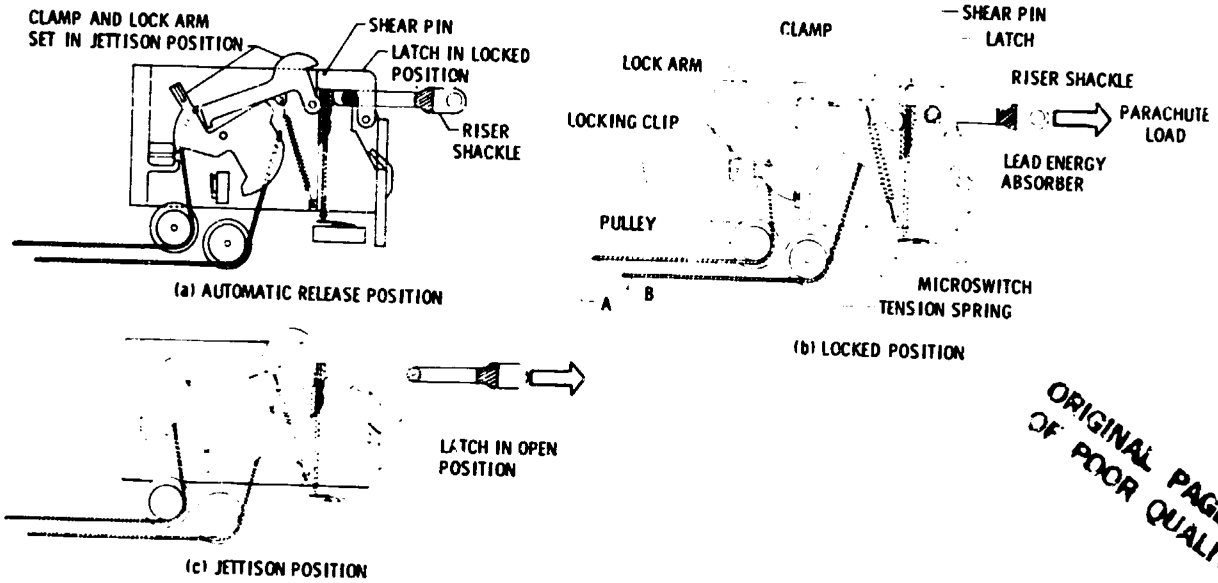

Figure 8.- Spin-recovery parachute attachment and release mechanism.

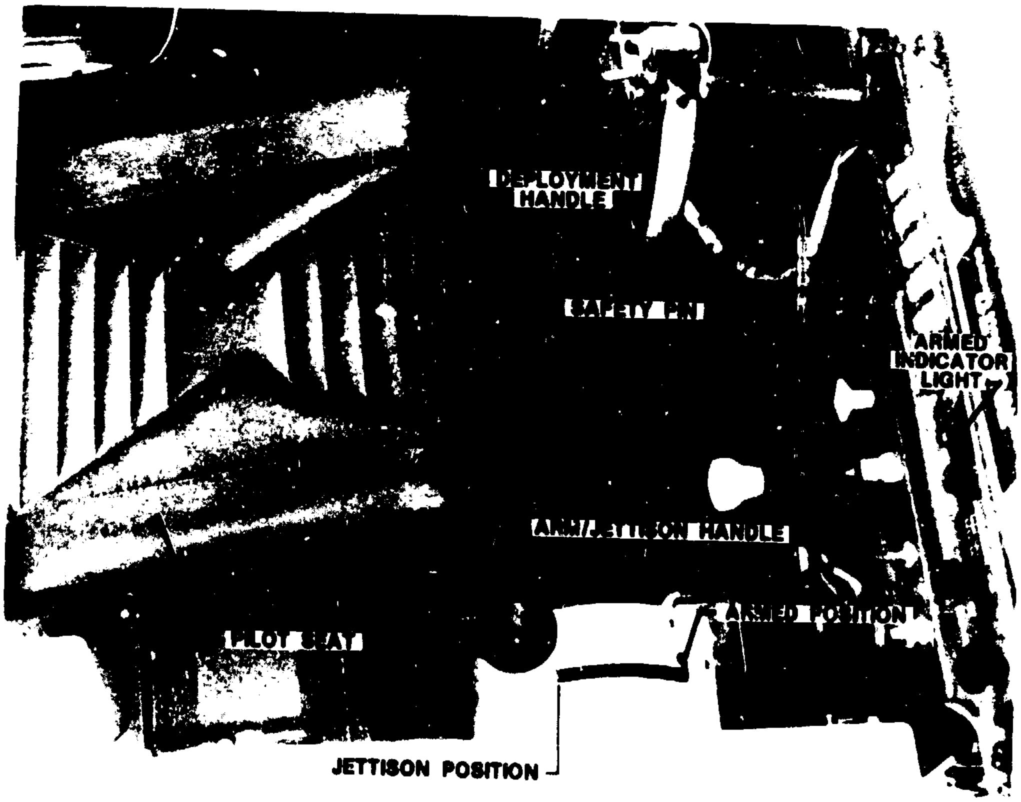

Figure 9.- Arrangement of cockpit controls.

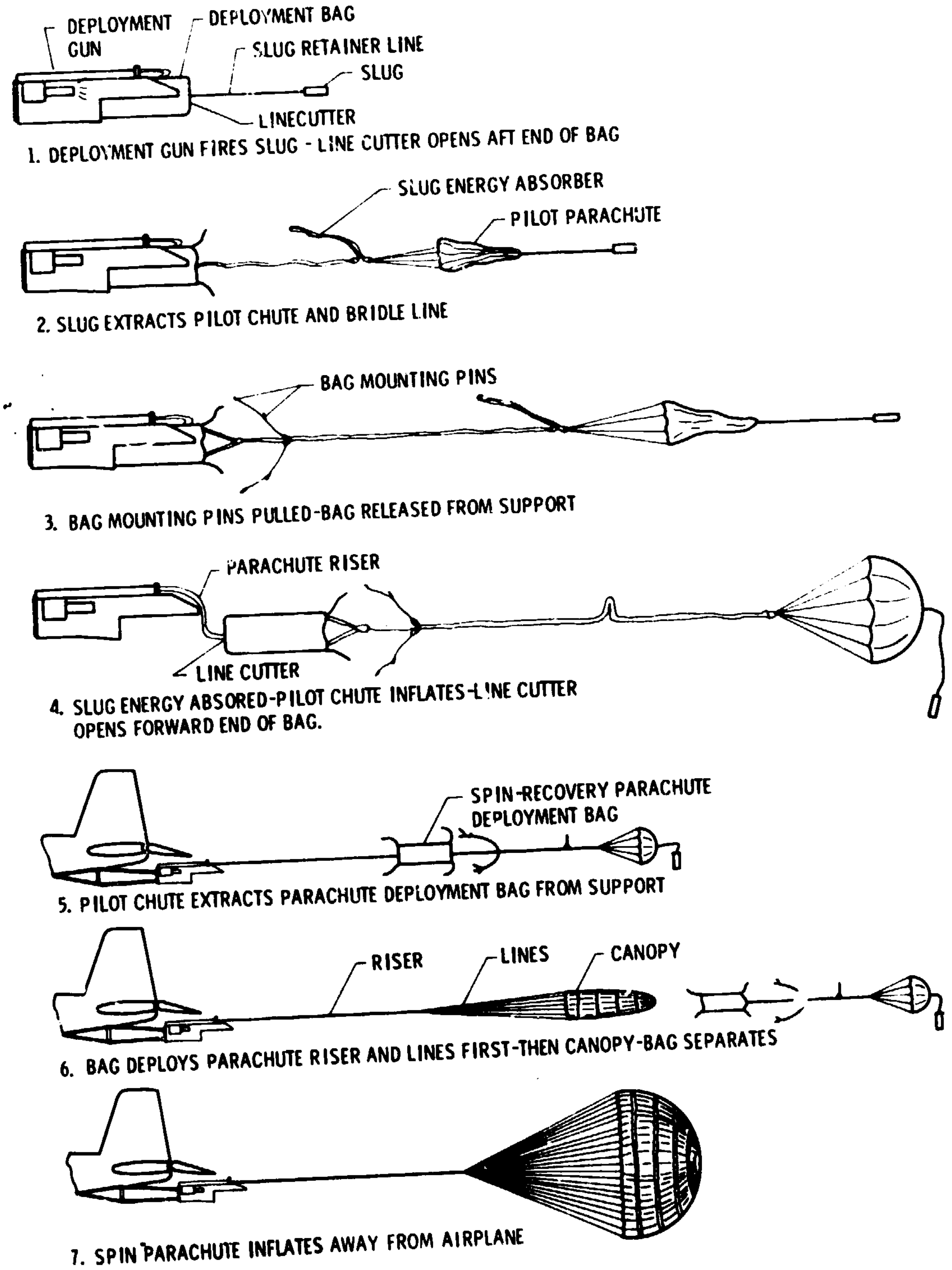

Figure 10.- Spin-recovery parachute system deployment sequence.

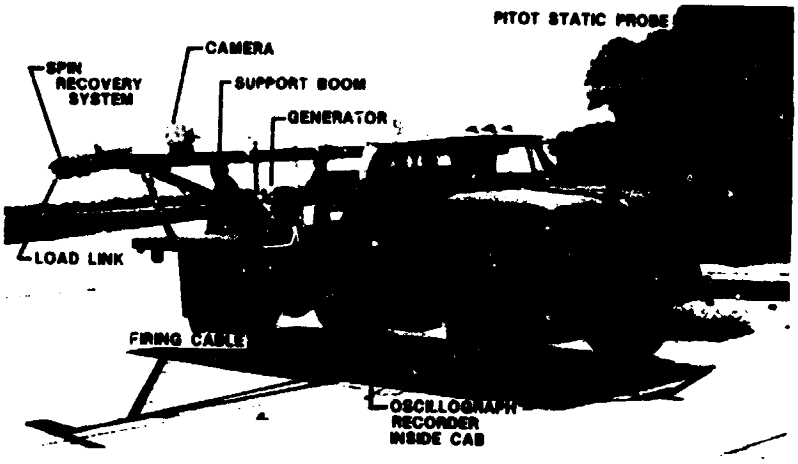

Figure 11.- Truck used for deployment tests.

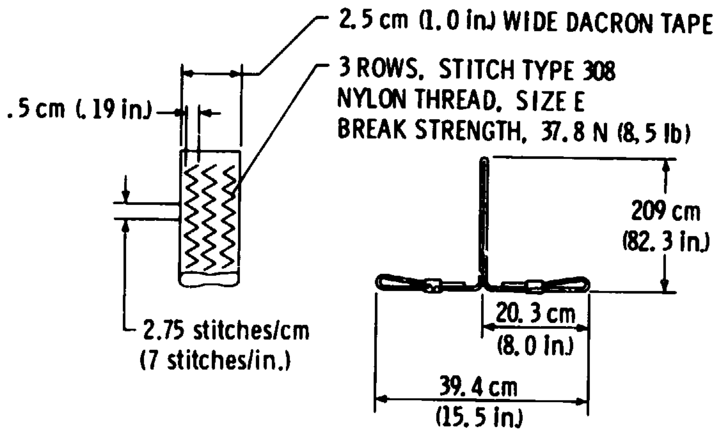

Figure 12.- Projectile energy absorber detail. (Not to scale.)

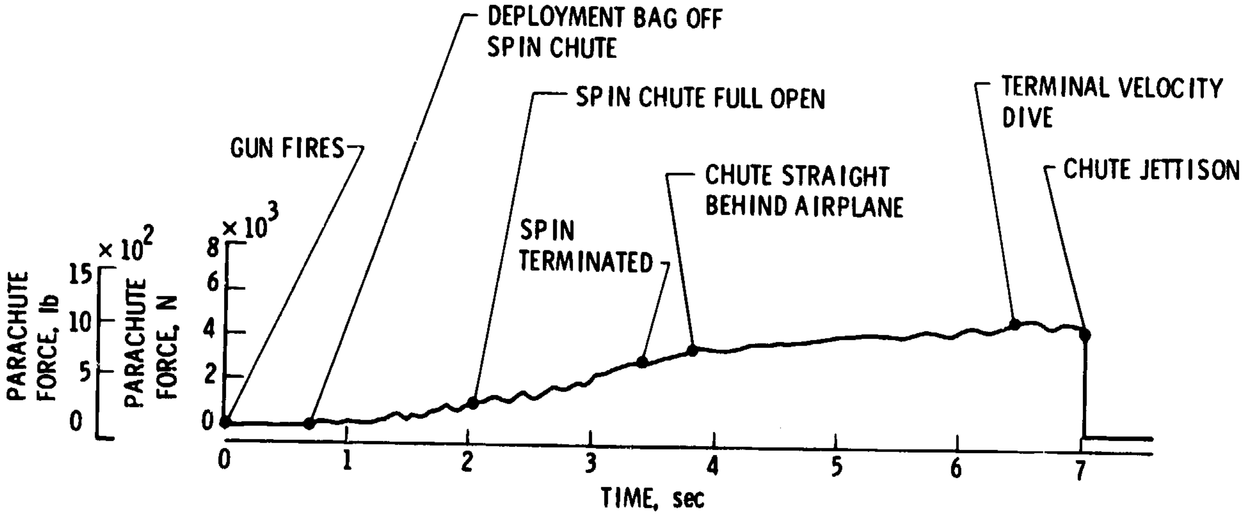

Figure 13.- Typical parachute load time history for recovery from flat spin.