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SUMMARY OF DESIGN CONSIDERATIONS FOR AIRPLANE SPIN-RECOVERY PARACHUTE SYSTEMS

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A compilation of design considerations applicable to spin-recovery parachute systems for military airplanes has been made so that the information will be readily available to persons responsible for the design of such systems. This information was obtained from a study of available documents and from discussions with persons in both government and industry experienced in parachute technology, full-scale and model spin testing, and related systems.

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SUMMARY

A compilation of design considerations applicable to spin-recovery parachute systems has been made so that the information will be readily available to those responsible for the design of such systems. The information was obtained from a study of available documents and from discussions with persons in both government and industry experienced in parachute design, full-scale and model spin testing, and related systems. This survey indicated that the technology was best defined for tactical and trainer military airplanes, and was not considered applicable to other classes of airplanes, especially light general aviation airplanes. Even for the military airplanes, however, there are gaps in the technology where one must rely on the judgment of experts based on their related experience. Hence, the present paper is not a handbook for the design of spin-recovery parachute systems, but is simply a summary of the status of the technology and a discussion of approaches that have proven successful, or unsuccessful, in the past. One main conclusion evolves from this survey; that is, there are three distinct fields of technology involved: parachutes, airplane spinning, and airplane systems. Specialists in all these fields should be consulted or participate in the design of the spin-recovery parachute system from the very beginning.

INTRODUCTION

The armed services require a contractor to demonstrate by full-scale flight tests the spin and recovery characteristics of certain types of airplanes, such as fighter, attack, and trainer airplanes, as a standard part of the flight demonstration acceptance program. (See refs. 1 and 2.) During these spin demonstrations, the airplane is generally equipped with a tail-mounted spin-recovery parachute system as an emergency recovery device in case recovery from the spin cannot be effected by the airplane control surfaces. The U.S. Navy recently has added a new requirement to the full-scale spin demonstrations (ref. 2) which states that the emergency spin-recovery device must be tested in a critical spin condition during the spin demonstration tests. Although spin-recovery parachute systems have been used for many years, the technology for system design and qualification is very inadequately documented and few guidelines exist in this area. There have been, and continue to be, failures associated with spin-recovery parachute systems; many of these failures appear to be caused by the lack of understanding of the basic aerodynamic characteristics and mechanics of the spin and also to lack of experience with spin-recovery parachute systems. This situation exists because there has been little continuity in the design teams over the years with respect to spin-recovery parachute systems.

The purpose of this paper is to summarize the design considerations for spin-recovery parachute systems so that the information will be readily available to those responsible for the design of such systems. The information that is presented herein was obtained from a study of available documents (refs. 3 to 19), and from discussions with persons experienced in parachute technology, full-scale and model spin testing, and related systems. Personnel from the following organizations were consulted: (1) U.S. Air Force Flight Dynamics Laboratory, (2) U.S. Naval Air Systems Command, (3) Cessna Aircraft Company, (4) General Dynamics, Fort Worth Division, (5) Grumman Aerospace Corporation, (6) Irvin Industries, Inc., (7) Ling-Temco-Vought, Inc., (8) McDonnell Douglas Corporation, (9) M. Steinthal and Company, Inc., (10) Northrop Corporation, (11) Pioneer Parachute Company, and (12) NASA Langley Research Center.

As the information was being compiled, it became evident that in a number of areas there is no clearly defined basis for determining a best approach for insuring adequate performance of the recovery system. The present paper does not create new technology to fill these voids and does not presume to make recommendations in areas where the present technology will not clearly support such recommendations; hence, much of the paper discusses various aspects of spin-recovery parachute system design without clear-cut conclusions. It was also apparent that the technology was best defined for tactical and trainer military airplanes and was not considered to be applicable to other classes of airplanes, especially light general aviation airplanes; therefore, the present paper is limited to applications to military airplanes.

Although the primary purpose of this paper is to discuss approaches in the design of tail-mounted spin-recovery parachute systems, it was felt that a brief discussion on other spin-recovery devices, such as rockets and wing-tip mounted parachutes, would also be in order, since these devices are alternate systems for accomplishing the same purpose. This information is presented in appendix A.

SYMBOLS

Units used for the physical quantities in this paper are given in the International System of Units (SI) and U.S. Customary Units. Measurements and calculations were made in U.S. Customary Units. Factors relating the two systems are given in reference 20. A sketch of a spin-recovery parachute system with its nomenclature is presented in figure 1.

g acceleration due to gravity, 9.8 m/sec^2 (32.2 ft/sec^2)

I_X,I_Y moments of inertia about the X and Y body axes, respectively, kg-m^2 (slug-ft^2)

l_B distance between bridle attachment point and pilot parachute skirt (see fig. 1), m (ft)

l_R distance between riser attachment point and spin-recovery parachute skirt (see fig. 1), m (ft)

q local dynamic pressure, N/m^2 (lb/ft^2)

q_∞ free-stream dynamic pressure, N/m^2 (lb/ft^2)

r horizontal distance between spin axis and parachute attachment point, m (ft)

S_p area of pilot parachute based on flat diameter, m^2 (ft^2)

S_s area of spin-recovery parachute based on flat diameter, m^2 (ft^2)

V_m maximum design velocity of parachute at designated spin altitude, m/sec (ft/sec)

V_s true rate of descent in spin, m/sec (ft/sec)

X,Y,Z body axes

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

β angle of sideslip, $\tan^{-1}\frac{\Omega r}{V_s} + \phi$ where the term $\tan^{-1}\frac{\Omega r}{V_s}$ is positive in a left spin and negative in a right spin, deg

Λ angle of wing sweep, deg

ρ air density, kg/m^3 (slug/ft^3)

ϕ angle between wing span axis and horizontal measured in vertical plane, positive when right wing is down regardless of spin direction, deg

Ω angular velocity about spin axis, rps

TYPICAL CHARACTERISTICS OF SPIN AND RECOVERY

Fully Developed Spin

The fully developed spin is normally considered to be the critical design condition for a spin-recovery parachute system. Recently, however, it has become evident that it may be desirable under some circumstances to deploy the parachute during spin entry where the dynamic pressure may be higher than in a fully developed spin, and considerations for this condition are discussed in more detail in a later section of the report.

In the fully developed spin the airplane is in vertical descent in a fully stalled attitude with the angle of attack generally between 40° and 90° and is rotating about the vertical flight-path axis. A sketch illustrating the attitude angles, spin radius, and rate of rotation of an airplane in a spin is shown in figure 2. The motion may be a steady rotation or the airplane may be oscillating violently in pitch and roll. Oscillations of $\pm 30^{\circ}$ to $\pm 45^{\circ}$ are not uncommon. Any given airplane may have several different spin modes between flat or steep, fast or slow, and steady or oscillatory. In the steady-spin mode the aerodynamic forces and moments acting on the airplane are balanced by equal and opposite mass and inertia forces and moments so that an equilibrium condition exists. These mass and inertia forces and moments are produced by both the spinning rotation and the uneven mass distribution of the airplane about its body axes. As a result, an externally applied force or moment to a spinning airplane often causes the airplane to react like a gyroscope rather than in the normal manner expected in straight and level flight. The effects of these gyroscopic moments can be especially evident and important in spin recovery, as will be discussed in the following section. (Further details on spin characteristics of airplanes can be found in ref. 3.)

Spin Recovery

The fully developed spin is primarily a yawing motion and thus the most effective means of terminating it is to apply a yawing moment to oppose the rotation. Consideration must be given, however, to the gyroscopic moments which result from the application of forces or moments other than those in yaw, especially since a spin-recovery parachute applies a pitching moment as well as a yawing moment. The gyroscopic moments may be beneficial or detrimental, depending upon the mass distribution of the airplane and the direction of the applied force or moment. Because of the gyroscopic effects, applying a nose-down pitching moment, for example, to a fuselage-loaded airplane $\left(I_Y > I_X\right)$ in a spin results in a yawing moment in the direction of the spin rotation (prospin) and usually causes the spin rotation to increase rather than cause the airplane to pitch nose down. By contrast, the application of an antispin yawing moment will stop the spin rotation and simultaneously cause the airplane to nose down out of the spin from its nose-high attitude because as the spin rotation is reduced, the gyroscopic nose-up pitching moment is reduced.

Thus, in order to explain the action of the parachute for spin recovery, both the yawing moment and nose-down pitching moment applied by the parachute must be considered. The yawing moment, as previously mentioned, is the most effective means for both stopping the rotation and decreasing the angle of attack. The nose-down pitching moment however, is an undesirable byproduct of the parachute which, because of the resulting gyroscopic effects, generally will cause most tactical airplanes to spin faster and not recover, and may or may not cause the airplane to nose down or decrease in angle of attack. If the parachute is properly sized, however, the yawing moment applied by the parachute will stop the spin rotation in spite of the adverse pitching-moment effect. If, on the other hand, the parachute size is too small, it is possible that the airplane would find a new spin equilibrium condition where the spin rate is higher and the pitch attitude is steeper. This new attitude and spin rate should not be considered an improvement over the original spin mode because the airplane could continue to spin without ever recovering. Thus, a properly sized parachute that will produce a sufficiently large antispin yawing moment is required in order to effect a satisfactory spin recovery.

It also follows from the analysis of the gyroscopic effects that for airplanes with a wing-heavy loading $\left(I_X > I_Y\right)$, the nose-down pitching moment as well as the antispin yawing moment of the parachute will be favorable to spin recovery.

SPIN-RECOVERY PARACHUTE

Design Approach

There are three distinctly different branches of technology involved in the design of a spin-recovery parachute system – parachutes, spinning, and airplane systems – and persons knowledgeable in all three of these fields should be brought in on the design from the very outset. In the case of the parachute, such early coordination is particularly important because parachute technology is a very specialized branch of aeronautics. Expertise in this area is not generally available in an airplane manufacturing firm but can be obtained from government sources or from the potential parachute manufacturer.

For a given airplane, the spin-recovery parachute must be designed to recover the airplane from its worst spin condition. (The recovery of an airplane is considered to be completed when the spin rotation has been terminated and the angle of attack has decreased to below the stall.) Definition of this "worst condition" and the parachute size and riser length is generally obtained for military airplanes from tests of dynamic models in the Langley spin tunnel; these tests are discussed in more detail in a later section of the paper.

Operating Environment

The variations in the operating environment in which spin-recovery parachute systems must function for tactical and trainer-type airplanes in fully developed spins are approximately as follows:

Altitude	3050 to 10 675 m	(10 000 to 35 000 ft)
Rate of descent	37 to 153 m/sec	(120 to 500 ft/sec)
Dynamic pressure	479 to 5267 N/m^2	(10 to 110 lb/ft^2)
Mach number		0.10 to 0.50
Rate of rotation		0.10 to 1.0 rps
Airplane mass	2270 to 36 320 kg	(5000 to 80 000 lb)

There are also effects of the airplane wake which might cause the airspeed and dynamic pressures experienced by the parachute to be lower than the values given and to be quite nonuniform.

This listing of the environment is not meant to imply that one system must meet all these conditions. Although the actual spin entry of an airplane may be initiated at a higher altitude and speed than those listed, generally, several thousand feet of altitude and much of the airspeed will have been lost during the spin entry and attempted spin recovery by the use of the airplane control surfaces before the emergency spin-recovery parachute is deployed. The variations in altitude loss, rate of descent, dynamic pressure, and Mach number depend primarily on whether the spin of the airplane is steep or flat and on the wing loading of the airplane. Since the airplane is at relatively low values of Mach number in the developed spin, the parachute does not experience any appreciable Mach effects; thus, these effects are usually not considered in designing the parachute.

Wake Effects

One of the most important and least understood operating environments of the pilot parachute and spin-recovery parachute is the wake above a spinning airplane. Very little information is available on this subject, although some effort has been made with model tests in wind tunnels to determine these airflow characteristics. In general, it can be said that the wake is nonuniform, has less than free-stream dynamic pressure, and in some areas has airflow reversal. Any of these conditions may cause the parachute to have difficulty in inflating or may actually prevent inflation. In order to illustrate some of these airflow characteristics, the results of dynamic-pressure surveys conducted in the Ames 12-foot pressure tunnel on a static model in a flat spinning attitude are presented in figure 3. The test Reynolds number based on the mean aerodynamic chord of the model wing ranged from approximately 482 000 to 3×10^6, but since there was no significant effect of Reynolds number on the data, the results are presented for a Reynolds number of approximately 1.8×10^6. Figure 3 shows the wake in terms of contour and profile plots of dynamic-pressure ratios q/q_∞ of 0.25, 0.50, and 0.75. In terms of full-scale values for a fighter airplane of representative size, the contour plots (fig. 3(a)) are at elevations above the airplane of approximately 15, 22, 30, and 38 meters (50, 75, 100, and 125 ft). These results indicate that significant reductions in dynamic pressure extend 38 meters (125 ft) or more above the airplane. Reference 4 also presents some results of a wake survey conducted above a static model mounted in spinning attitudes in a wind tunnel, and the results, in general, are similar to those just discussed.

The results of smoke flow tests conducted in the Langley spin tunnel on a model similar to the one tested in the Ames tunnel, and mounted statically in a spinning attitude, are presented in figure 3(b) as arrows showing the direction of airflow. These results show a reverse airflow that can suck the parachute down on top of the airplane. Additional tests with a parachute attached to this model mounted in spinning attitudes and rotating on a spindle in the Langley spin tunnel verified the effects implied by these smoke flow tests in that if the parachute riser was too short, the parachute would be drawn down on the top of the model. Tests on full-scale airplanes also have confirmed these model tests. If the riser was made sufficiently long, however, the parachute would remain out of this reverse flow area. Thus, these results emphasize the importance of getting the parachute far enough away from the airplane to avoid adverse wake effects. There is an equally important reason, however, for not making the riser too long since excessive length will cause the parachute to aline itself on the spin axis; as a result, the parachute produces little or no antispin yawing moment while it produces an adverse nose-down pitching moment. Therefore, in such cases the parachute may be ineffective in terminating the spin. Of course, if the riser is too short, the parachute may not inflate properly or not inflate at all because of airplane wake effects. Therefore, careful consideration must be given to the selection of the riser length in order to avoid these detrimental effects.

Further information on model spin-recovery parachute testing can be found in reference 5, wherein the parachute tests were conducted in a wind tunnel on a scale model of an airplane fixed at spinning angles of attack; the effects of riser length and canopy porosity on the inflation, stability, and drag characteristics of the parachute were determined.

Parachute Requirements

Positive and reasonably quick opening (approximately 3 to 4 seconds) of the spin-recovery parachute is necessary for all operating conditions so that the spin may be terminated as rapidly as possible to minimize altitude loss. Opening characteristics are generally influenced by canopy porosity. Low porosity aids quick opening, but can result in high opening shock loads and an unstable parachute. High porosity may result in poor canopy inflation. Low snatch and opening shock loads are desirable not only from a parachute load consideration but also to reduce the loads on the airplane structure as well, since the loads are generally of such magnitude that it is necessary to reinforce the rear of the airplane. In addition, the parachute should be reasonably stable with an amplitude of oscillation of less than approximately $\pm 10^{\circ}$. A stable parachute is required so that it will tend to trail with the relative wind at the tail of the airplane in a spin and thus apply a yawing moment that is always antispin; whereas an unstable parachute because of its large oscillations may apply a yawing moment that varies from antispin to prospin, and thus hinders or prevents recovery. A canopy geometric porosity of 10 to 20 percent has generally been used to achieve the desired stability, and the degree of porosity apparently depends on the particular manufacturer's individual experience.

Parachute Type

Experience has shown that either a ring-slot or a ribbon-type parachute will meet all the previously discussed requirements for a satisfactory spin-recovery parachute except the requirement for positive and quick opening. Since this shortcoming can be overcome by the use of inflation aids, these two types of parachutes are preferred for spin-recovery parachutes. The inflation aids may be used singly or in combination and the most generally used ones consist of the following: (1) pocket bands, (2) blow-out cap lightly stitched over canopy vent, and (3) additional vertical tapes sewn across slots in canopy to decrease geometric porosity. Some consideration has also been given in the past to a method which forcibly spreads the canopy skirt by ballistic means (such as used in some personnel escape systems) to aid in the inflation of spin-recovery parachutes. This approach has never been used, however, apparently because of added complexity and also because the parachute would have very high opening shock loads.

Parachute Diameter and Riser Length

Determination of the correct parachute size and riser length obviously is very important in the overall design of a recovery system. The riser length controls the position of the parachute in the wake of the spinning airplane and therefore affects the force that the parachute can apply to the airplane. The minimum parachute diameter and riser length required to terminate the spin of military airplanes must be determined by tests of a dynamically scaled model of the airplane in the Langley spin tunnel. Experimental tests are required because theoretical approaches have not been sufficiently developed to predict the correct parachute size and riser length. The model tests indicate the effectiveness of the parachute once it is fully inflated and are not intended to simulate the deployment sequence of the full-scale parachute. A cross-sectional view of the spin tunnel is shown in figure 4 and a photograph of a model in the tunnel recovering from a spin with the spin-recovery parachute deployed is presented in figure 5. A detailed description of the tunnel and its operation is given in reference 3.

Over the years a number of parachute tests have been conducted in the Langley spin tunnel, and the results of these tests in terms of parachute size and canopy distance are plotted in figures 6 and 7, respectively. Canopy distance is defined as the distance between the canopy skirt and the attachment point (approximately equal to the riser length plus the canopy suspension line length; see fig. 1). The data are presented in terms of canopy distance rather than riser length because canopy distance is the critical factor since riser length for a given canopy distance might vary slightly because of differences in the length of the parachute suspension lines. The parachute diameters and canopy distances are plotted against airplane gross weight in terms of full-scale values. The variation of parachute diameter and canopy distance with other factors was explored, but none appeared to be any more suitable than airplane weight. The parachute diameters were scaled up to full-scale values based on a drag coefficient of 0.50; and the drag coefficient itself was based on the flat planform area of the parachute canopy. The model test results that have been verified as being satisfactory by full-scale developed spin tests are noted in figures 6 and 7 by the use of solid symbols. The full-scale data are limited because few parachutes have had to be deployed under actual developed spin circumstances.

An examination of the results presented in the figures indicates that there is such a large variation in parachute size and riser length for a given airplane weight that a reasonable estimation of these factors from such empirical data is impossible. Thus, these results emphasize the point made previously that the only accurate method for the determination of the parachute size and riser length is free-spinning tests of a dynamically scaled model of the specific airplane design.

If the spin-tunnel tests of a dynamic model indicate that the model may spin flat, it would be very desirable to conduct some special wind-tunnel tests aimed at better definition of the wake characteristics behind the model because these wake effects may be very severe on parachute inflation. Very little work has been done in this area, as previously mentioned, but such tests should include deployment and inflation of a parachute with the model both fixed and rotating on a spindle at various angles of attack and sideslip which simulate spinning attitudes. It also might be desirable to supplement these tests with a wake survey with the model fixed in various spin attitudes. Data obtained from tests of these types have been very useful in establishing the wake characteristics and in determining the effect of the wake, riser length, and canopy porosity on the ability of the parachute to inflate and remain inflated.

SPIN-RECOVERY PARACHUTE INSTALLATION AND OPERATION

Parachute Compartment

A fundamental requirement in any parachute installation is to locate the compartment and the riser attachment point as far aft on the airplane as possible. This approach will reduce the possibility of the riser or parachute striking the airplane and will also give the maximum moment arm for the parachute force to act on. It should be assumed that the angle the riser makes with the fuselage longitudinal axis can be as high as 90° if a flat or a highly oscillatory spin mode exists. If the riser is likely to contact the jet exhaust because of the attachment point location, then it must be protected against heat. Additional protection of the riser might be necessary if there is a possibility of its rubbing against the airplane structure after deployment. Since the riser generally is made of fabric (for example, nylon), abrasions on or nicks in the riser while it is in tension can cause it to fail very rapidly.

The parachute compartment also should be designed so that it does not change the spin and recovery characteristics of the airplane by changing the aerodynamic and/or inertia characteristic of the airplane with the installation and thereby invalidate the tests. Recent experiences with high-performance fighter-type airplanes have shown that the type of installations shown in figure 8 have generally met these requirements. Two types of parachute compartments in current use are (1) one in which the compartment is permanently attached to the airplane and deployment is initiated by pulling the deployment bag from the compartment with a pilot parachute, and (2) one in which the compartment is pulled away and completely separated from the airplane by a pilot parachute which then pulls the compartment off the deployment bag when the riser is fully extended.

Two major requirements for a satisfactory parachute compartment are that it be designed so that (1) the extraction of the deployment bag by pilot parachute or tractor rocket or by forceful ejection can be accomplished regardless of the airplane attitude, and (2) the bag be undamaged during the deployment process. A discussion is presented in appendix B on the methods used and considered to meet these requirements.

Based on the variety of approaches used in designing parachute compartments, there should be enough good design information available so that it is not only possible but highly desirable to develop several basic types which could be adapted to any airplane configuration through the use of suitable interfaces.

Deployment Bag and Packing Methods

The deployment bag may be divided into two or three sections generally depending on the size of the parachute. If the parachute is small (diameter approximately 4.6 meters (15 ft) or less), the bag is divided into two sections with the canopy packed in one compartment and the suspension lines and riser packed in the other. For larger size parachutes, the canopy, suspension lines, and riser are packed in separate compartments within the bag. These arrangements provide an orderly and reliable method of deployment. Since the riser of a spin-recovery parachute is much longer than that used with other types of parachutes, special care must be taken in packing the riser to insure a reliable deployment. The interior of the deployment bag should be made reasonably smooth to prevent hangup or friction burns; however, it generally is not necessary to provide a special type of smooth lining in the bag to minimize friction burns because of the low extraction speed of the canopy from the bag.

Selection of a packing method for a spin-recovery parachute will depend on the size, shape, and location of the parachute compartment. The following packing methods have been used: (1) hand, (2) vacuum, (3) lace, and (4) mechanical. More detailed information on these packing techniques can be found in appendix B and in reference 6 (pp. 372-375).

Parachute Deployment Methods

The two basic methods for deploying the spin-recovery parachute from an airplane are the line-first and the canopy-first methods shown in figure 9. The line-first method is preferred for several reasons, as indicated in the discussion of the method.

<u>Line-first method.</u>- In the line-first method (fig. 9(a)), a pilot parachute extracts the deployment bag from the parachute compartment, deploying first the riser, then the parachute suspension lines, and finally, the recovery parachute by pulling the deployment bag off the parachute. The primary advantage of this method is that it provides a clean separation of the deployment bag from the airplane and also insures that the inflation of the spin-recovery parachute canopy will occur away from the airplane; thereby the possibility of parachute fouling on the airplane and the effect of the airplane wake on the parachute are minimized. Furthermore, the snatch loads will be reduced because parachute inflation will occur after the riser is fully extended.

<u>Canopy-first method.</u>- In the canopy-first method (fig. 9(b)), the deployment bag remains attached to the parachute compartment. A pilot parachute extracts the spin-recovery parachute canopy from the bag, then the suspension lines, and finally the riser. The primary disadvantages of this method are (1) the increased possibility of the spin-recovery parachute fouling on the airplane; (2) the high snatch loads that occur because the spin-recovery parachute canopy will become inflated before the riser has become fully extended; (3) the high opening shock loads; and (4) the possibility of the canopy being

damaged, or only partly inflated, because the canopy and suspension lines become entangled. The only advantages of this method are (1) it requires a lower pilot parachute extraction force than the line-first concept because the spin-recovery parachute canopy is extracted easily regardless of the attitude of the spinning airplane; and (2) once the deployment starts, the parachute itself provides an additional force that helps complete the deployment of the canopy, suspension lines, and riser.

When the canopy-first method is used, there are several devices (listed herein) that are intended to delay the inflation of the parachute canopy and thereby minimize the previously mentioned problems. These devices however, result in additional complexity in the system for the canopy-first method.

(1) Skirt hesitator.- The skirt hesitator is a reefing line wrapped tightly around the suspension lines or the skirt of the parachute canopy. A pyrotechnic line cutter with a time delay device is used to cut the reefing line only when the riser has become fully extended. This technique will reduce the snatch loads but the possibility of canopy fouling still exists because the canopy might spread out prior to inflation.

(2) Sleeve.- The sleeve is a tapered fabric tube, approximately equal in length to the canopy gores, in which the parachute is packed. When the riser is fully extended, the sleeve is pulled away from the spin-recovery parachute canopy by a pilot parachute. This method has the same advantage as the skirt hesitator but, in addition, this method provides a protective covering for the spin-recovery parachute as it is deployed from the parachute compartment on the airplane. The canopy, however, could be burned by the heat of friction as the sleeve is removed.

(3) "Wrap-around" cloth.- The "wrap-around" cloth, attached to the parachute canopy along one seam with light stitching, is approximately equal to the length of the canopy gores and wide enough to overlap slightly when tightly wrapped around the canopy. The overlapping ends of the cloth are held together by the use of the grommet-pin method. Several cords are tied to the pins along the length of the wrap-around cloth and to the parachute compartment so that the cords will pull the pins in sequence (starting at apex of canopy) and allow the cloth to unwrap from the canopy upon deployment. This technique has the advantage of both of the previous techniques and, in addition, prevents the canopy from being burned during deployment as may be possible with the sleeve technique. The disadvantage is that as the spin-recovery parachute canopy is being extracted, the wrap-around cloth becomes free of the top part of the spin-recovery parachute canopy first while the remainder of the canopy is still in the parachute compartment. Thus, it is possible for the top of the canopy to spread or flatten out as the airstream strikes it; thus, the possibility of the canopy fouling on the airplane structure is increased. Two deployments have been made by use of this technique during full-scale spins. Although the

parachute on both flights deployed without fouling, on one flight it came very close to the airplane tail; thus, the possibility of fouling on subsequent flights was indicated.

PILOT PARACHUTE

Requirements and Types

The requirements for a satisfactory pilot parachute are similar to those for the spin-recovery parachute except that it is not necessary for the pilot parachute to be stable. Since the pilot parachute must apply only a force and not a moment to extract the deployment bag, reasonably large oscillations ($\pm 15^{\circ}$) of the parachute do not appear to be a handicap. A major factor in choosing a particular type of parachute is the size of the pilot parachute needed to produce a required force. If the diameter of the pilot parachute is no larger than 2.5 meters (8 ft), a solid flat-type parachute may be used despite its high opening shock factor because the force will be relatively small. Since this type of pilot parachute has a high drag coefficient and consequently smaller area, it requires a lower packing volume than some other types. If a larger parachute is required, then ring-slot or ribbon-type parachutes should be used because of their lower opening shock factors.

Pilot Parachute Diameter and Bridle Length

The technology for determining the size of the pilot parachute and the length of its bridle line is not well established according to reference 6 (pp. 392-393), and it has been common practice to rely on the judgment of the parachute manufacturer in this regard. A discussion of some important considerations based on past experience in applicable technology, however, may be beneficial and, therefore, this information is presented in the following paragraphs.

The size of the pilot parachute is based on a compromise between making it small enough not to exert excessive loads on the extracted item or on the parachute itself at higher speeds that might be encountered in steep spins and making it large enough to extract the deployment bag at low rates of descent that might be encountered in flat spins. Also, for the condition where the pilot parachute remains permanently attached to the recovery parachute, excessive pilot parachute size may prevent the recovery parachute from opening because of too much tension being applied to the top of the parachute canopy when the riser has become fully extended. Thus, the diameter of the pilot parachute is important for the positive and orderly deployment of the spin-recovery parachute. Past experience seems to indicate that the pilot parachute should be sized to provide an acceleration of 4g to 6g units on the deployment bag at the minimum dynamic pressure that might be expected; and, of course, it should be stressed for the highest dynamic pressure that might be encountered.

Although a size for the pilot parachute may be estimated by considering the preceding factors, table I has been prepared to indicate what has been used. This table is based on limited data and lists the pilot parachute sizes used satisfactorily in full-scale spins. The table shows that the pilot parachute area in percent of the spin-recovery parachute area varied by a factor of about 3 (from 1.3 to 4.0 percent) with the exception of airplane 8. This airplane, used a large, heavy detachable parachute compartment which would require a very large pilot parachute for proper system operation. Also it is possible that this particular parachute was sized to operate in a somewhat lower dynamic pressure environment than the other pilot parachutes.

There do not appear to be any detailed design guidelines for determining the bridle length of the pilot parachute. Available information on bridle lengths used satisfactorily on airplanes in full-scale spin demonstrations is presented in table I, and this information indicates that the bridle lengths range from 1.9 meters (6.2 ft) to 17.2 meters (56.5 ft). This wide variation in bridle lengths apparently is based on two different approaches to the problem. One approach is to make the bridle very long in an attempt to minimize wake effects of the airplane. The other approach is to make the bridle very short and assume that the deployment of the pilot parachute is a transient condition in that after the pilot parachute is deployed, it will be restrained only for an instant before it begins extracting the spin-recovery parachute package. Although the pilot parachute will be in the wake of the airplane (that is, region of reduced dynamic pressure for only an instant), there always is a possibility that the parachute may collapse during this instant if it moves into a region of reverse airflow.

Although most pilot parachute installations have been successful with a short bridle line, this approach might not work for the newer airplane configurations with broad aft fuselages and large all-movable horizontal-tail surfaces. The wake from these airplanes is large not only because of their configuration, but also because such airplanes tend to have flat spins which produce a larger wake than the steeper spins. Thus, a much longer bridle line length might be necessary in order for the pilot parachute canopy to operate in high-energy airflow, and it also may be necessary to eject the pilot parachute away from the airplane with a mortar or deployment gun to insure that it clears the wake.

Pilot Parachute Deployment Methods

To insure reliable pilot parachute deployment, regardless of the deployment method, the parachute should be ejected rearward along the fuselage axis to get it into the clean airflow away from the airplane wake in either an erect or inverted spin. There are three basic methods currently used to deploy a pilot parachute from spinning airplanes: a deployment mortar system, a deployment gun system, and a spring-loaded system.

Deployment mortar system.- In the deployment mortar system, the pilot parachute is placed in a bag which is forcefully ejected from a stowage container by a powder charge on a rubber diaphragm or a piston. (A small weight (approximately 4.45 newtons (1 lb)) is sometimes placed at the end of the bag to provide increased momentum.) When the bridle line is fully extended, the momentum of the deployment bag strips the bag from the pilot parachute. The advantage of this type of system is that the bag is ejected a considerable distance from the airplane; thus, the possibility of the parachute canopy fouling on the airplane structure and also the possibility of the canopy being in the wake of the airplane are reduced. The deployment mortars that have been used for recovery parachute systems have generally been adapted from other types of parachute recovery systems. Although there is an abundance of mortar technology available on relatively small parachutes (ranging up to approximately 4.6 meters (15 ft) in diameter), little work has been done on deployment mortars designed specially for application to spin-recovery parachute systems.

Deployment gun system.- Two basic approaches are generally used in designing a deployment-gun system. In one approach a canopy-first deployment is used whereas in the other approach a line-first deployment is used.

In the canopy-first deployment, a slug is permanently attached to the apex of the pilot parachute canopy by a line and is fired away from the airplane. At full bridle line extension, the parachute becomes fully inflated. The primary advantages of this approach are: (1) the parachute canopy is forcibly pulled a considerable distance from the airplane and thus the possibility of fouling and/or wake effects are reduced, and (2) a canopy-first deployment, at least for small parachutes, apparently reduces parachute malfunctions by minimizing the possibility of the line between the slug and parachute canopy becoming alternately slack and taut during deployment because of an energy exchange between the slug and parachute. The disadvantage of the canopy-first approach is that care must be taken to avoid the possibility of severe loads being applied to the parachute canopy at the instant the bridle line becomes fully extended. This approach also still creates the possibility of slug rebound which could result in damage to the pilot parachute.

In the line-first deployment, the pilot parachute is packed in a deployment bag and a slug is attached to the bag by a line. After the slug has been fired and the bridle line has become fully extended, the slug then strips the bag from the pilot parachute and the bag and slug fall free. This approach has the same advantage as the canopy-first deployment in that the bag is forcibly pulled a considerable distance from the airplane. The primary disadvantage of this approach is the possibility that the line between the slug and bag will not remain taut during deployment because the energy exchange between the two items occurs over a very short period of time relative to the canopy-first deployment.

In fact, the bag and slug have been observed, in some cases, to tumble end over end. Proper design, however, should overcome the disadvantages of either method.

The indication that either a canopy-first or line-first deployment of the pilot parachute may be appropriate appears to be contrary to the recommendation given previously in the report that a line-first deployment of a spin-recovery parachute is the most desirable. The reason for this apparent inconsistency is that the pilot parachute size is very small relative to that of a spin-recovery parachute; thus, the snatch and opening shock loads are relatively small and the possibility of the canopy fouling on the airplane structure is also small because of the forceful extraction of the canopy away from the airplane by the slug.

Experience has indicated that, as the size and consequently the weight of the pilot parachute and its bridle line increase, the successful use of the deployment gun becomes more difficult. This increase in size and weight generally is the result of the need for large spin-recovery parachutes. Unpublished information has indicated that for heavier and larger parachutes deployment gun systems function better when the bridle line and parachute canopy are packed in separate bags. There is no qualitative information relative to these considerations; therefore, if a deployment gun system is to be used, the systems development program will have to include adequate tests to insure proper operation of the system.

It appears that for a given amount of energy, the deployment gun should provide approximately the same amount of separation distance between the airplane and pilot parachute as the deployment mortar. A mortar-deployed pilot parachute, however, is believed to be the best deployment method based on overall considerations.

Spring-loaded system.- The spring-loaded method of deploying the pilot parachute generally consists of a preloaded spring that ejects the pilot parachute from its compartment directly into the airstream; a deployment bag generally is not used with this system. The pilot parachute is tied permanently to the apex of the spin-recovery parachute by a bridle. Although the spring-loaded method for ejecting the pilot parachute is one of the oldest and the simplest of the methods discussed, it also is the least forceful; and for modern airplanes a more forceful method generally is needed because a strong possibility exists that the pilot parachute may foul on the tail structure of the spinning airplane, especially in a flat spin.

DEPLOYMENT MECHANISM DESIGN CONSIDERATIONS

Basic Methods of Deployment and Jettison

Mechanical or electrical systems are used for deploying and jettisoning spin-recovery parachutes, and any given airplane may use one or a combination of these systems for the operation of the parachute. The particular choice of a system might be based on the successful use on an earlier airplane tested by the company, or that it was convenient to use a parachute system that utilized a part of another existing system of the airplane.

Emergency Power

In a fully developed spin, the airplane engine may flame out and cause a loss of the normal or primary power source. Therefore, an emergency power source is required to operate the airplane controls and spin-recovery parachute system. The emergency power source (usually a large battery pack) should have the capability of being brought into operation automatically when required. The operational time of the emergency power supply should be sufficient to allow a spin, recovery, air restart of airplane engine, if possible, or if not, a glide to a suitable landing site.

Basic Attachment Methods

The spin-recovery parachute riser is attached to the airplane by an attachment and release mechanism and this device has proven to be a critical item in the system design. For this reason, regardless of the type of mechanism used, no part of it should require such precise adjustment that lack of such adjustment could cause the mechanism to malfunction. The mechanism must perform the following critical functions: (1) attachment of the parachute riser to the airplane, (2) release of the parachute after spin recovery, and (3) automatic release of the parachute in the event of inadvertent deployment during critical phases of flight. There are two basic methods normally used:

(1) Closed-jaw method (fig. 10(a)).- The attachment of the riser to the airplane is made prior to take-off and provision is made for automatic release in the event of premature deployment.

(2) Open-jaw method (fig. 10(b)).- The attachment is not made until immediately before a spin test.

Several factors must be considered in designing the attachment and release mechanism. For example, if the shackle, or D-ring, is locked in the attachment mechanism prior to take-off, as illustrated by the closed-jaw concept of figure 10(a), it is essential from the standpoint of flight safety that provision be made so that the parachute will automatically jettison should it inflate inadvertently. This automatic jettisoning of the parachute can be accomplished by putting a weak link, such as a shear pin, in the system. Prior to the start of the spin tests, the weak link is bypassed by a locking mechanism capable of withstanding the opening shock load of the parachute. If the mechanism is left open until the start of the spin tests, however, as illustrated by the open-yaw concept of figure 10(b), the parachute will be automatically jettisoned since it would be unrestrained.

This approach does require, however, that steps be taken to insure that the shackle is in position in the mechanism when the time comes to arm the system. A low-strength bolt or safety wire can be used to achieve the proper positioning. For either of the foregoing types of systems, a light is generally used to indicate that the system has been armed by bypassing the weak link or by closing the jaws.

In both the closed-jaw and open-jaw methods, the normal procedure for releasing the parachute after it has been deployed is by mechanical means. Provisions, however, should be made for emergency jettisoning of the parachute if the primary jettison system fails to operate. This jettisoning can be accomplished through the use of explosive bolts or pyrotechnic line cutters. If explosive bolts are used, they should be of the nonfragmenting variety to insure the safety of the airplane. The pyrotechnic line cutters have a disadvantage in that the cutters and the electric wires to them are subject to damage by the slipstream and therefore might fail to function. Further information on parachute jettisoning can be found in references 7 and 8.

The most desirable method for attaching the parachute riser to the parachute attachment and release mechanism appears to be one in which the parachute riser is locked in the mechanism while the airplane is on the ground so that visual confirmation of the connection can be made. Also, it seems to be highly desirable to develop standardized parachute attachment and release mechanisms so that reliable operation can be assured.

Cockpit Control Arrangement

Experience indicates that the cockpit controls for deploying and jettisoning the spin-recovery parachute should be arranged so that the pilot can easily reach the controls while he is being subjected to the wide range of forces and attitudes that can be encountered in a spin. "Eyeballs-out" accelerations of as much as 4g have been experienced in the cockpit of some fighter airplanes because of the rate of rotation (approximately about the center of gravity) and the fact that the pilot is located a considerable distance ahead of the center of gravity. Experienced test pilots have found erect spins to be not only violent because of the oscillatory nature of some spins, but sometimes disorienting so that they become confused as to the airplane attitude and direction of rotation. The situation becomes even worse in an inverted spin where the pilot is hanging from the straps and might find it difficult to reach the emergency spin-recovery controls unless this factor is considered in positioning the controls. For further information on pilot reactions in spins, see reference 7.

The following basic principles should be considered in the arrangement of the cockpit for deploying and jettisoning the spin-recovery parachute: (1) the controls should be positioned so that they can be reached and operated easily under all spin conditions;

(2) the controls should be guarded against inadvertent operation; and (3) the sequence of operation of the controls should be such that it is impossible to jettison the parachute by mistake before it has been deployed.

SPIN-RECOVERY PARACHUTE LOADS

In order to design properly the spin-recovery parachute and associated lines, the maximum design load of the parachute must be determined. This parachute drag load is estimated from the following quantities: (1) parachute diameter and drag coefficient, (2) parachute opening shock factor, (3) air density ρ at spin altitude, and (4) maximum design velocity V_m of parachute at the designated spin altitude. (This velocity is greater than that expected in a fully developed spin of a given airplane and is attained during the level-flight checkout tests of the parachute operation.) The parachute diameter and drag coefficient generally are obtained from dynamic model tests in the Langley spin tunnel, and ρ and V_m are selected by the airplane manufacturer; the determination of the parachute opening shock factor is discussed in the following paragraph.

The spin-recovery parachute operates under an infinite mass condition as defined in reference 6 (p. 149), and the opening shock factor under these conditions for standard-type parachutes as defined by the U.S. Air Force can be found in reference 6 (p. 164). This reference indicates that for infinite mass conditions, the opening shock factor does not change with altitude. Some limited unpublished results from level-flight checkout tests of parachutes, however, indicate that the opening shock factor apparently does increase with an increase in altitude. Thus, since there seems to be some disagreement as to the effect of altitude, it would be desirable to check the opening shock load of the parachute in level-flight tow tests at the highest altitude at which it is expected to be opened.

The parachute industry generally uses a safety factor of 1.5 for hardware design. Since fabricating and multiple reuses of the parachute cause a decrease in the ultimate strength of the material, design factors of about 2.3 to 2.5 are used for the parachute design.

FUSELAGE LOADS

The fuselage of the test airplane usually must be strengthened to withstand the large loads exerted on it by the deployment of the tail-mounted spin-recovery parachute. If external members are required for reinforcement, they should be configured to avoid aerodynamic effects that could alter the stall and spin behavior of the airplane. In order to minimize structural modifications and increases in weight of the fuselage, the direction and magnitude of the parachute load should be estimated as accurately as possible for the critical loading conditions. The loads during four different flight conditions that should be considered in analysis of the fuselage strength requirements are

(1) Deployment during level flight for system checkout tests, which has not generally been a critical condition since the loads are applied along the fuselage axis

(2) Deployment during the fully developed spin, which has in the past been the critical design condition because large lateral bending loads are applied to the fuselage axis

(3) The dive following recovery, which is generally not a critical condition because of the axial direction of the load

(4) Deployment during the spin entry, which is a condition that has recently come up for consideration as a recovery procedure during a stall test program for an airplane that is considered to have poor spin characteristics.

There is little or no precedent for analysis of this fourth condition, but it might provide the most critical design condition, especially if accelerated stalls are considered wherein the dynamic pressure might be considerably higher than that in the developed spin and the riser might be at a large angle relative to the fuselage axis. In any event, all these load conditions should be considered by the system designers, but only the condition of deployment from a fully developed spin is discussed in further detail herein because it has, in the past, generally been the critical condition and because the design methods have proven to be satisfactory.

Experience indicates that the critical fuselage loading condition during the developed spin occurs at the time of the maximum opening shock load of the parachute. Therefore, in order to estimate the direction and magnitude of the applied load to the airplane fuselage, the following quantities should be known: (1) parachute drag load, and (2) the angular position of the parachute riser relative to the fuselage. The parachute drag load is obtained by the method presented in the preceding section entitled "Spin-Recovery Parachute Loads." The following techniques may be used as an aid in estimating the riser angle relative to the fuselage. The angle can be obtained directly from motion pictures of tests of the dynamic model with an attached parachute in the Langley spin tunnel. A supplementary means of determining the riser angle is to calculate it by use of data obtained from the spin-tunnel tests. In this approach the riser angle is considered to be a function of the fuselage pitch angle and the sideslip angle at the tail of the fuselage $\left(\beta = \tan^{-1} \frac{\Omega r}{V_s} + \phi\right)$. By using these quantities, a load envelope can be approximated. In general, the applied load is assumed to act in a cone-shaped envelope, the included angle of the cone being dependent on the type of spin predicted for the full-scale airplane based on dynamic model tests. When the fuselage strength requirements are calculated, generally a safety factor of 1.5 is applied to the estimated parachute loads.

If there is some concern about the magnitude of the parachute opening shock load and/or the possibility of overinflation, then the parachute might be reefed for about 1 or 2 seconds. Reefing would, of course, add some further complexity to the system.

QUALIFICATION AND MONITORING OF RECOVERY SYSTEMS

In order to insure maximum reliability of the parachutes and systems prior to actual use for a spin recovery, a systematic series of buildup tests from laboratory to flight tests should be performed. (The U.S. Navy, as previously mentioned, requires the parachute to be deployed in a critical spin condition.) These systematic tests normally are as follows: free-drop tests, laboratory tests, airplane ground tow tests, inflight deployment tow tests, deployment tests in a developed spin, parachute drag measurements, and photographic records.

Free-Drop Tests

The minimum opening speed of the spin-recovery parachute can be determined by the use of the outdoor free-drop testing technique which consists of dropping the parachute with an attached weight preferably from a helicopter and deploying it when the desired altitude and airspeed are reached. By having the helicopter move forward at a low airspeed, a partial cross-wind deployment can be obtained which provides a slightly better simulation of a deployment during an actual spin. Although the minimum opening speed of the parachute ordinarily is not determined, it is believed that it would be very desirable to do so since this characteristic would indicate the ability of the parachute to inflate in a low-dynamic-pressure environment such as might be encountered in the wake of the airplane. The main limitation of this technique is that the effect of the wake of the spinning airplane on the operation of the parachute is not simulated and must be estimated.

Laboratory Tests

A checkout or bench test of the deployment system should be made in the laboratory to provide an early indication of the operation and possible mechanical or electrical shortcomings of the system. This system checkout should include tests to determine the operation of the parachute attachment and release mechanism while a simulated maximum parachute drag load is being applied. Also under similar conditions, the force required by the pilot to operate the attachment and release mechanism should be determined. These checkout tests should include not only simulation of the magnitude of the parachute loads that might be expected during a spin and recovery but also the directions of these loads. This simulation is a particularly important consideration since, as will be seen later, these are the only tests in which the operation of the system can be checked while applying the parachute loads at various angles up to the perpendicular to the fuselage axis, except tests in an actual spin.

Airplane Ground Tow Tests

Ground tow tests with the airplane taxiing at speeds just below lift-off conditions are desirable in that a checkout of the system can be made under dynamic conditions. The primary advantage of these tests is that they provide a means for checking out the operation of the complete recovery system under reasonably safe conditions.

The limitations of the techniques are (1) in general, this technique cannot be used with detachable parachute compartments because they will fall and strike the ground during the deployment sequence, (2) the wake of the spinning airplane is not simulated, (3) the angle at which the parachute is extracted and the loads applied during a spin and recovery are not simulated, and (4) the maximum dynamic pressure required cannot be achieved.

Inflight Deployment Tow Tests

Airplane inflight deployment tow tests are used to check the recovery system at higher speeds and dynamic pressures, and therefore at higher loading conditions than can be obtained on the ground. These tests also provide an opportunity to check the parachute drag and opening shock loads. In these tests the parachute is deployed at increasingly higher dynamic pressures until the maximum design dynamic pressure is reached to determine whether any failures in the system might result.

The inflight tow tests have the same limitations as the ground tow tests except that of achieving the maximum required dynamic pressure; and the risk is greater than that for ground tow tests.

Deployment Tests in Developed Spin

The U.S. Navy, as previously mentioned, requires the spin-recovery parachute system to be tested in a critical spin condition during the stall and spin demonstration tests. Determination of this condition by the U.S. Navy generally is based on the results of model spin tests in the Langley spin tunnel. A critical spin condition probably would be one wherein the model results indicated that recoveries from certain spins may be difficult or impossible by use of the airplane control surfaces.

The flight test program should consist of a series of buildup tests ranging from spin conditions wherein recovery is possible by the use of the airplane control surfaces to the worst spin condition from which recovery may or may not be possible. For each of these conditions the spin-recovery parachute is deployed to determine whether the recovery system operated properly and whether the parachute terminated the spin satisfactorily.

Parachute Drag Measurements

The installation of a drag link or strain gage to measure the drag of the parachute during deployment and inflation is very desirable. Such a drag link is usually a single-axis gage attached to the riser so that it pivots with the riser, but it could be a three-axis gage fixed to the airplane. The drag link is used to measure the opening shock load and steady drag load of the parachute in level flight. The measured steady drag load is used to determine whether the parachute produces the proper force as required by the design specifications. This qualification test is important in that if the parachute force is less than that required by the specification, the parachute may not effect a satisfactory spin recovery. During a spin demonstration the measurement of the parachute force may be used to determine whether the parachute is operating in or near free-stream air or in the wake of the spinning airplane where the parachute is less effective.

Photography

Motion pictures of spin-recovery parachute operation are highly desirable every time the parachute is used, as an aid in analysis of the operation of the system, particularly if there should be a malfunction. Although the importance of motion pictures is well recognized, photographic coverage for the entire spin test program by ground-to-air, air-to-air, and onboard cameras is not always made. Such motion pictures generally are taken during level-flight checkout tests, but there is seldom adequate coverage if the parachute should have to be used for emergency recovery during the actual spin tests. The following paragraphs discuss the application and usefulness of each type of photography.

Ground to air.- Ground-to-air motion pictures are frequently taken of the spin demonstration flights to record the behavior of the airplane during spin entry, in the developed spin, and during the recovery. Detailed analysis of the pictures with regard to the operation of the parachute recovery system is difficult, however, because of the frequently poor resolution of the pictures due to the atmospheric disturbances and the long distance between the camera and airplane.

Air to air.- Air-to-air motion pictures generally are taken of the level-flight check tests of the parachute system by a chase airplane. Since this operation can be done at fairly close range, the functioning of the parachute system can be seen in reasonably good detail. Motion pictures of the spin demonstration tests also can be obtained from a chase airplane although they are not always made. The technique consists of the chase airplane circling the descending spinning airplane at a sufficient distance so that the g-forces generated by the chase airplane do not become so great as to hamper the airborne photographer in tracking the spinning airplane. Thus, because of this low g-force requirement, this technique results in the motion pictures being taken at a relatively long distance from the spinning airplane (approximately 457 to 610 meters (1500 to 2000 ft)). Because of this distance, the resolution of the pictures, in many cases, may not be entirely adequate. This photographic technique, however, apparently can be improved by the selection of a suitable chase airplane (one that has good visibility and a small turning radius without excessive g-forces) and a properly trained chase aircrew which has previously worked together as a team.

Onboard.- A camera attached to the test airplane is used in many cases to record the operation of the parachute system in the level-flight checkout tests. This camera, however, usually is not oriented to record the deployment sequence of the parachute during spin tests, although the use of such an arrangement would appear to be highly desirable because, in several cases, a spin-recovery parachute has failed to function properly, and there has been no record from which its operation could be analyzed and used as a basis for corrective action. In order to achieve this capability the onboard installation would probably require two cameras with wide-angle lenses aimed differently to provide coverage of the entire area of the deployment sequence. The cameras should start automatically upon initiation of parachute deployment. Such a system would provide motion-picture records with sufficient detail for study of the normal parachute deployment or, more importantly, to determine why a malfunction occurred. Experience with parachutes has shown that, as an aid in the analysis of the parachute operation, it is desirable to have contrasting colors on the parachute canopy and lines. Provision should be made to prevent damage to the cameras during an airplane crash. One approach is to encase the cameras in a shockproof and fireproof container to insure their survival; and another approach is to jettison the cameras during the emergency and lower them to the ground by parachute.

CONCLUSIONS

The following conclusions were drawn from the foregoing summary of technology applicable to spin-recovery parachute systems which was obtained from a study of available documents and discussions with persons experienced in parachute technology and related fields:

1. There are three distinctly different branches of technology involved in the design of a spin-recovery parachute system – parachutes, spinning, and airplane systems – and persons knowledgeable in all these fields should be brought in on the design from the very outset. In particular, parachutes are a very specialized branch of aeronautics; so it is very important that parachute technologists be consulted on the design of the overall system from the outset.

2. It is essential that the parachute size and riser length be determined from free-spinning tests of dynamically scaled models such as are conducted in the Langley spin tunnel.

3. Ring-slot and ribbon parachutes are most often used for spin-recovery parachutes.

4. The parachute attachment point should be located at the extreme rear of the airplane fuselage or rearward of it on a boom to provide the maximum moment arm for the parachute force to act on, and to prevent parachute riser damage caused by contact with the airplane structure.

5. A line-first deployment is generally considered to be the best method of deploying the spin-recovery parachute.

6. A mortar-deployed pilot parachute is considered to be the best deployment method.

7. No definite method or criterion has been established to determine accurately the required pilot parachute diameter and bridle line length for extracting or deploying the spin-recovery parachute. In view of this situation, it has been common practice to rely on the judgment of the parachute manufacturer in this area.

8. From the standpoint of reliability, two completely independent systems should be used to operate the parachute; each system would serve as an emergency backup system for the other.

9. The most desirable type of attachment and release mechanism for the spin-recovery parachute appears to be one wherein the shackle, or D-ring, of the parachute is locked to the mechanism while the airplane is on the ground so that visual observation may be made of the connection. A shear pin, or similar device, may be used so that the parachute will be jettisoned automatically in case of inadvertent deployment.

10. Basic principles which should be considered for the proper arrangement of the cockpit controls for deploying and jettisoning of the spin-recovery parachute are as follows: (1) the controls should be positioned so that they can be reached easily and operated, and yet they should be designed so that they are guarded against inadvertent operation; and (2) the sequence of operation of the controls should be such that it is impossible to accidentally jettison the parachute before it has been deployed.

11. Installations of onboard movie cameras which are capable of recording the entire deployment and inflation sequence of the spin-recovery parachute during the spin tests as a means of analysis, particularly of malfunctions, should be made mandatory. The cameras should start automatically upon initiation of parachute deployment, and should be designed to be recoverable after a crash and fire.

12. Standardized parachute attachment and release mechanisms should be developed as well as several basic types of parachute installations which could be adapted to any airplane configuration through the use of suitable interfaces.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 29, 1972.

APPENDIX A

ALTERNATE SPIN-RECOVERY DEVICES

Although tail-mounted spin-recovery parachutes are used almost exclusively in full-scale spin demonstrations, rockets and wing-tip-mounted parachutes have sometimes been given consideration. Antispin rockets have been used occasionally, but wing-tip mounted parachutes have been used apparently only once. Thus, the characteristics of the rockets will be discussed in more detail than the parachutes in the following sections of this appendix.

Rockets

Background and system setup.- Rockets are generally used for spin recovery in special cases where the use of a parachute involves unusual problems. Tail-boom airplane configurations or tailless configurations with a very short tail moment arm might provide such unusual problems. Rockets, however, have many disadvantages when compared with tail-mounted parachutes as will be discussed later.

Some testing of rockets which apply an antispin yawing moment has been done in the Langley spin tunnel on dynamic models, and similar testing has also been done on several occasions with full-scale airplanes. Investigations to determine the effectiveness of rockets in terminating spins by the application of a pure rolling or pitching moment to a dynamic model, however, have been brief and only exploratory; thus, no valid conclusions can be made regarding these types of moment applications. Some typical investigations in the Langley spin tunnel using rockets on dynamic models as spin-recovery devices are reported in references 21 to 26; results from full-scale tests of rockets used for spin recovery are presented in references 27 and 28.

Rockets generally have been installed on or near each wing tip but there have been cases where the rocket was installed at the nose or the tail of the airplane. When the rockets are installed on the wing tips, their thrust is applied in a forward direction. Depending on the direction of the spin which should be determined by a sensor, the left or right rocket is fired to apply an antispin yawing moment (for example, in a right spin the right rocket would be fired).

When spin-recovery rockets are added to the airplane, care should be taken that the rocket installation does not alter the spin and recovery characteristics of the airplane by altering the aerodynamic and/or inertia characteristics of the airplane and thereby invalidate the tests.

Thrust orientation.- The effectiveness of the applied yawing moment produced by rockets mounted on the wing tips depends on the orientation of the rocket thrust line with respect to the principal axis of the airplane. In order to avoid a rolling moment that might be adverse, depending on the mass distribution of the airplane (ref. 3, pp. 22-23), the rocket thrust should be alined as closely as possible with the principal axis of the airplane.

Rocket impulse.- On the basis of past experience with model spin-recovery rocket investigations, certain conclusions can be drawn regarding the nature of the rocket impulse required, rocket impulse being the product of the average value of the thrust and the time during which it acts. The rocket must not only provide a sufficient yawing moment for recovery, but the rocket must provide this moment for as long as the spin rotation is present. Rockets that have the same impulse but different amounts of thrust and thrust durations may or may not produce satisfactory spin recoveries depending on the magnitude of the thrust and the thrust duration. For example, after it has been found that a rocket which provides a certain thrust for a certain period of time affords satisfactory recoveries, it has also been found that a rocket which provides the same impulse in the form of a smaller thrust over a longer period of time may not provide satisfactory recoveries; and one which provides the required impulse in the form of a larger thrust over a shorter period of time also may not provide satisfactory recoveries. Thus, the correct rocket impulse must be determined from model spin-recovery rocket tests in the Langley spin tunnel.

Advantages.- The primary advantages of a rocket-recovery system are as follows:

(1) Definite known yawing moment is applied.

(2) Applied yawing moment is not affected by wake of airplane.

(3) Rockets do not have to be jettisoned after use.

(4) Fuselage or wing has to be strengthened only to withstand the yawing moment produced by the rockets.

Disadvantages.- The disadvantages of rockets may be summed up as follows:

(1) Some type of sensor must be used to determine the direction of spin so that the proper rocket is fired.

(2) Duration of rocket thrust is limited.

(3) If duration of rocket thrust is too long and pilot does not terminate it when recovery is complete, the airplane may enter a spin in the opposite direction; conversely, if the rocket thrust is terminated prematurely, the airplane may not recover from the spin.

(4) If the pilot does not regain control of the airplane following recovery by use of a rocket and the airplane enters a second spin there is no further emergency recovery

system; whereas, with a tail-mounted recovery parachute, he can retain the stabilizing effect of the parachute until he is sure he has recovered control.

(5) Two installations are necessary if rockets are mounted on wing tips.

Wing-Tip-Mounted Parachutes

Tests were conducted until 1952 in the Langley spin tunnel on dynamically scaled models using wing-tip-mounted parachutes. (See refs. 29 to 33.) Full-scale airplane tests with wing-tip parachutes have apparently been made on only one airplane in the past 20 years (ref. 34). Wing-tip parachutes apply an antispin yawing moment to the airplane to effect a spin recovery; they also apply a rolling moment and, if the airplane has a swept wing, a pitching moment will be applied.

Even though wing-tip parachutes generally need be only about 50 to 60 percent as large as a tail parachute in order to effect a spin recovery, they have all the disadvantages of rockets. In addition if the mass of the airplane is distributed along the wing, the rolling moment produced by the parachute will retard spin recoveries (ref. 3, pp. 22-23).

APPENDIX B

ADDITIONAL CONSIDERATIONS WITH REGARD TO THE SPIN-RECOVERY PARACHUTE

Design of Parachute Compartment

The parachute compartment serves as an enclosure for the deployment bag and may or may not serve as an enclosure for the pilot parachute if one is used. The parachute compartment is generally mounted externally on the airplane fuselage (although not a preferred arrangement) because of limited space within the fuselage and is usually made of metal to withstand the aerodynamic forces, and in some cases high temperatures, acting on it. The compartment should be designed so that the walls are parallel; or an expansion of the compartment walls toward the opening is even more desirable. The compartment should have a smooth interior, and the edges at the opening should be rounded and smooth. If there is a potential heating problem because of the compartment location relative to heat from the tail pipe, some provision may have to be made to insulate the compartment.

Attached parachute compartment.- The permanent attachment of the parachute compartment to the airplane is a desirable arrangement in that the pilot parachute size required to extract the deployment bag is smaller than that used to pull a detachable compartment and deployment bag combined away from the airplane. The force required to extract the parachute from the attached compartment, however, could be high, especially when the airplane is in a flat spin where the pilot parachute force may be acting at approximately right angles to the compartment axis. Four basic methods for extracting the bag from an airplane in both erect and inverted spins are discussed in the next paragraphs. Method 2 has been used successfully to recover an airplane from a spin; the other methods have never been used for spin recovery although they have been given serious consideration based on parachute technology proven in other applications. The four methods are:

(1) Open a door in the parachute compartment equal to the maximum length and width of the deployment bag. When such a door is used, the pilot parachute can then easily extract the bag regardless of the angle the pilot parachute bridle makes with the compartment axis. In such a system, the compartment door should be hinged so that it is retained on the airplane, since releasing the door might allow it to strike the airplane and/or endanger personnel and property on the ground. Tying the door to the parachute bridle line might result in the door tangling in the system or severing the line.

(2) Immediately after deploying the pilot parachute, mortar out the deployment bag at a velocity sufficient only to clear the airplane and allow the pilot parachute to remove the bag from the spin-recovery parachute.

(3) With a larger mortar charge and no pilot parachute, mortar out the deployment bag at a considerably higher velocity than in the previous method so that the bag is stripped off the spin-recovery parachute by momentum.

(4) Use a small spin-stabilized tractor rocket connected to the deployment bag by a short line to extract the bag at a sufficient velocity to insure a clean separation between it and the airplane. At full riser extension the bag is removed from the parachute by continuing force of the rocket. A variation of this method is currently being used on one type of manned escape system called the "Yankee" escape system (ref. 18, pp. 36-56), which uses a tractor rocket connected by a line to the personnel seat to rescue the aircrew.

A further discussion of deployment methods based on theoretical approaches is presented in reference 19.

Detachable parachute compartment.- With a detachable parachute compartment, the attitude of the spinning airplane is no longer a consideration during the extraction of the spin-recovery parachute from the compartment because the compartment leaves the airplane and thus the compartment attitude is completely independent of the airplane. A problem for consideration with this approach, however, is that the compartment may have severe oscillations because of insufficient line tension if the pilot parachute is too small. These oscillations could cause burning or tearing of the parachute canopy and associated lines during deployment. Although this problem also could occur when only the deployment bag is extracted by the pilot parachute, the problem is aggravated by the greater weight of the parachute compartment. Thus, a larger pilot parachute is needed for a detached parachute compartment than for an attached compartment. In this type of system, the pilot parachute remains with the detached compartment and, generally, it is large enough to recover the compartment with minimum of danger to personnel or objects on the ground.

Packing

There are various methods by which a spin-recovery parachute can be packed in a deployment bag. These methods are listed so that the designer can make a preliminary decision as to which method would be the most appropriate one.

The various methods by which a spin-recovery parachute can be packed in a deployment bag are as follows:

(1) Hand pack.- The canopy can be hand-packed when space is not a major factor. Pack density is about 320 kg/m^3 (20 lb/ft^3).

(2) Vacuum.- The vacuum packing method is useful when packing irregular shapes and when greater packing densities are needed. Pack density is about 480 kg/m^3 (30 lb/ft^3).

(3) Lace.- The lace method is limited to cylindrical shapes, but considerable reduction in volume can be obtained by using a mechanical advantage lever known as a "grasshopper." Pack density is about 560 kg/m^3 (35 lb/ft^3).

(4) Mechanical.- The use of a mechanical press can give higher pack densities than other methods but is limited by the difficulty in lacing the pack when it is under pressure. Pack density is about 640 kg/m^3 (40 lb/ft^3).

If reefing rings and line cutters are packed in the bag along with the parachute canopy, care must be taken that the packing pressure is not so great as to damage the rings and cutters. Of course, if the hardware is damaged, the parachute fabric probably will be also. X-ray pictures should be taken of the packed deployment bag, if possible, to determine the condition of the hardware parts. For example, pyrotechnic line cutters have been observed by X-ray pictures in a fired condition due to high-density packing. Bent hardware also can be observed. Although this X-ray technique is not completely effective, its use will decrease the danger of having damaged hardware in the deployment bag with a possible malfunction of the system should it be needed.

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TABLE I.- DIMENSIONS OF SPIN-RECOVERY AND PILOT PARACHUTES AND LINE LENGTHS USED ON FULL-SCALE AIRPLANES DURING DEVELOPED SPINS

Aircraft	Parachute compartment		Spin-recovery parachute						Pilot parachute						$\frac{S_p}{S_s} \times 100$, percent
	Attached	Detached	Diameter		S_s		l_R		Diameter		S_p		l_B		
			m	ft	m^2	ft^2	m	ft	m	ft	m^2	ft^2	m	ft	
1		✓	8.7	28.5	59.1	635.0	17.0	55.6	1.0	3.3	0.8	8.5	1.9	6.3	1.3
2		✓	7.6	25.0	45.6	490.0	15.9	52.0	1.0	3.3	.8	8.5	1.9	6.3	1.7
3	✓		10.2	33.5	90.2	970.0	30.5	100.0	1.8	6.0	2.7	28.5	3.7	12.0	3.0
4	✓		7.3	24.0	41.9	450.0	27.1	89.0	1.3	4.2	1.3	13.9	6.3	20.8	3.1
5		✓	7.6	25.0	45.6	490.0	26.2	86.0	1.5	5.0	1.8	19.6	2.7	9.0	3.9
6	✓		9.0	29.6	64.0	688.0	24.4	80.0	1.78	5.83	2.5	26.8	4.2	13.8	3.9
7	✓		7.3	24.0	41.9	450.0	21.1	69.0	1.5	5.0	1.9	20.0	9.2	30.0	4.0
8		✓	13.4	44.0	139.5	1500.0	30.5	100.0	*4.2	13.7	12.4	133.0	17.2	56.5	8.9

*Permanently reefed to 3.7 meters (12.0 ft) diameter.

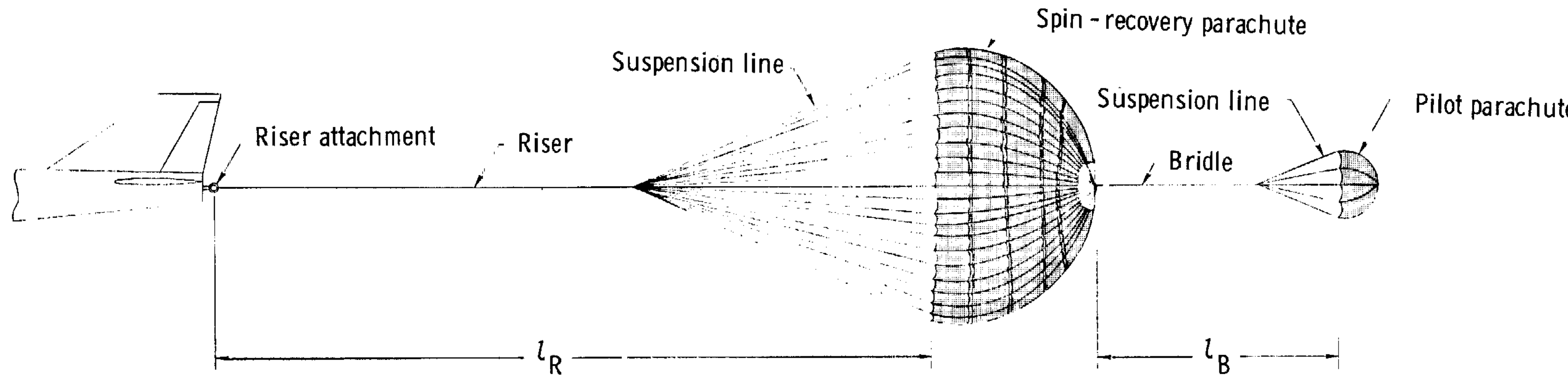

Figure 1.- Sketch of spin-recovery parachute system and its nomenclature.

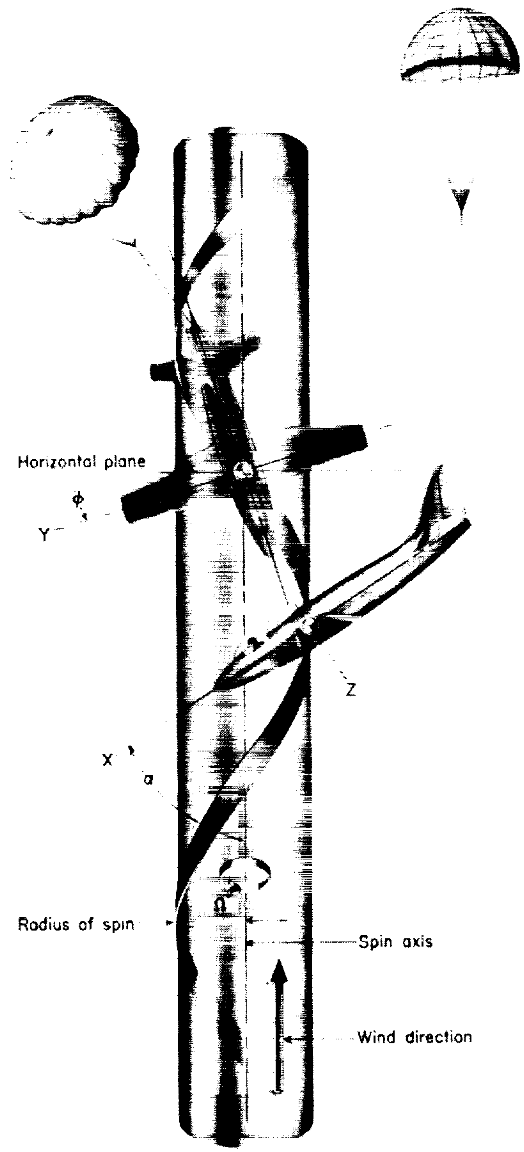

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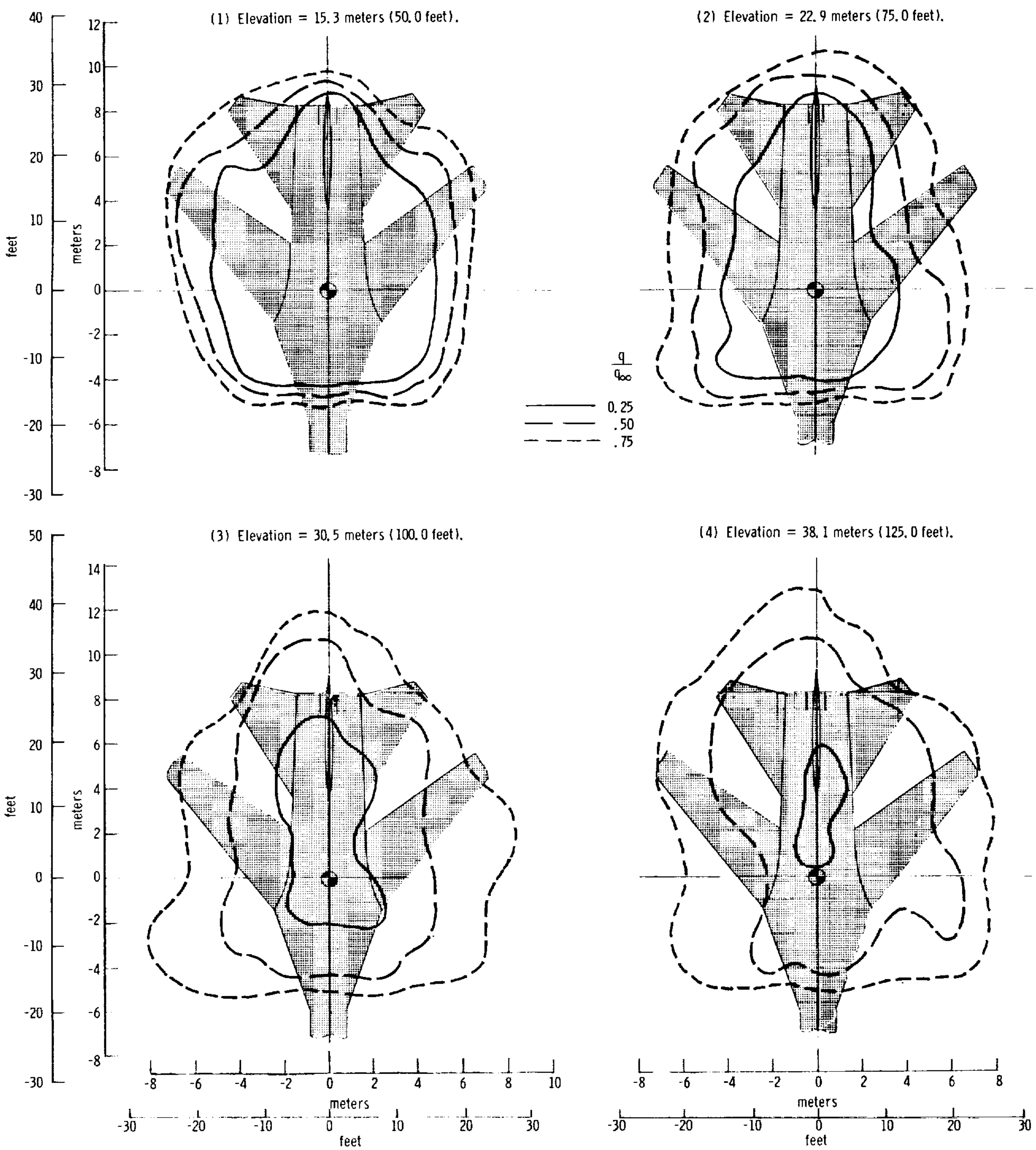
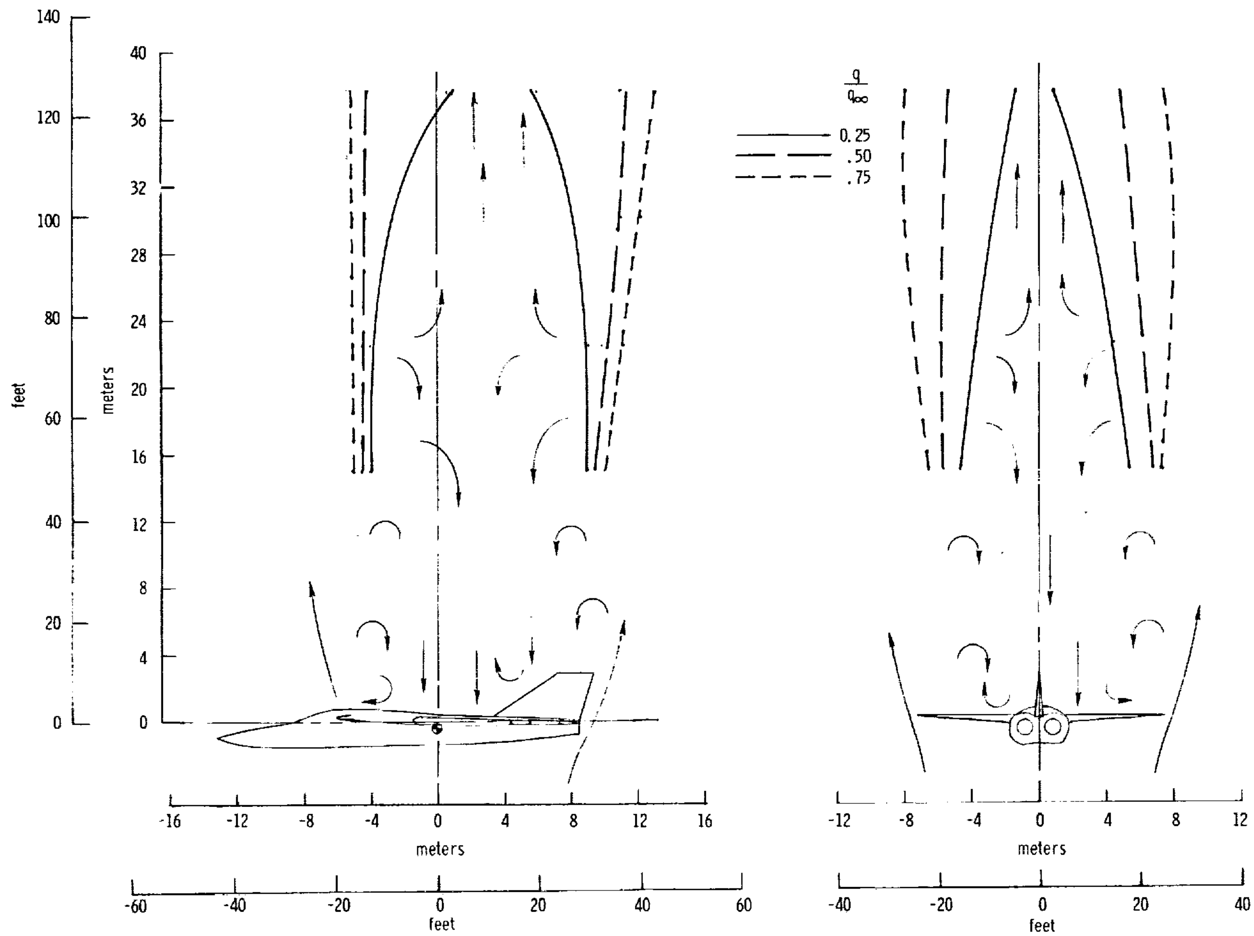
Figure 2.- Illustration of an airplane in a right spin with deployed parachute. Arrows indicate positive direction of angles.



(a) Contours of dynamic-pressure ratio.

Figure 3.- Contours and profiles of dynamic-pressure ratio q/q_∞ at various elevations above model. Dimensions are full scale. Angle of attack, 90^o; angle of wing tilt, 0^o; wing sweep, 50^o; $\Omega = 0$.



(b) Profiles of dynamic-pressure ratio.

Figure 3.- Concluded.

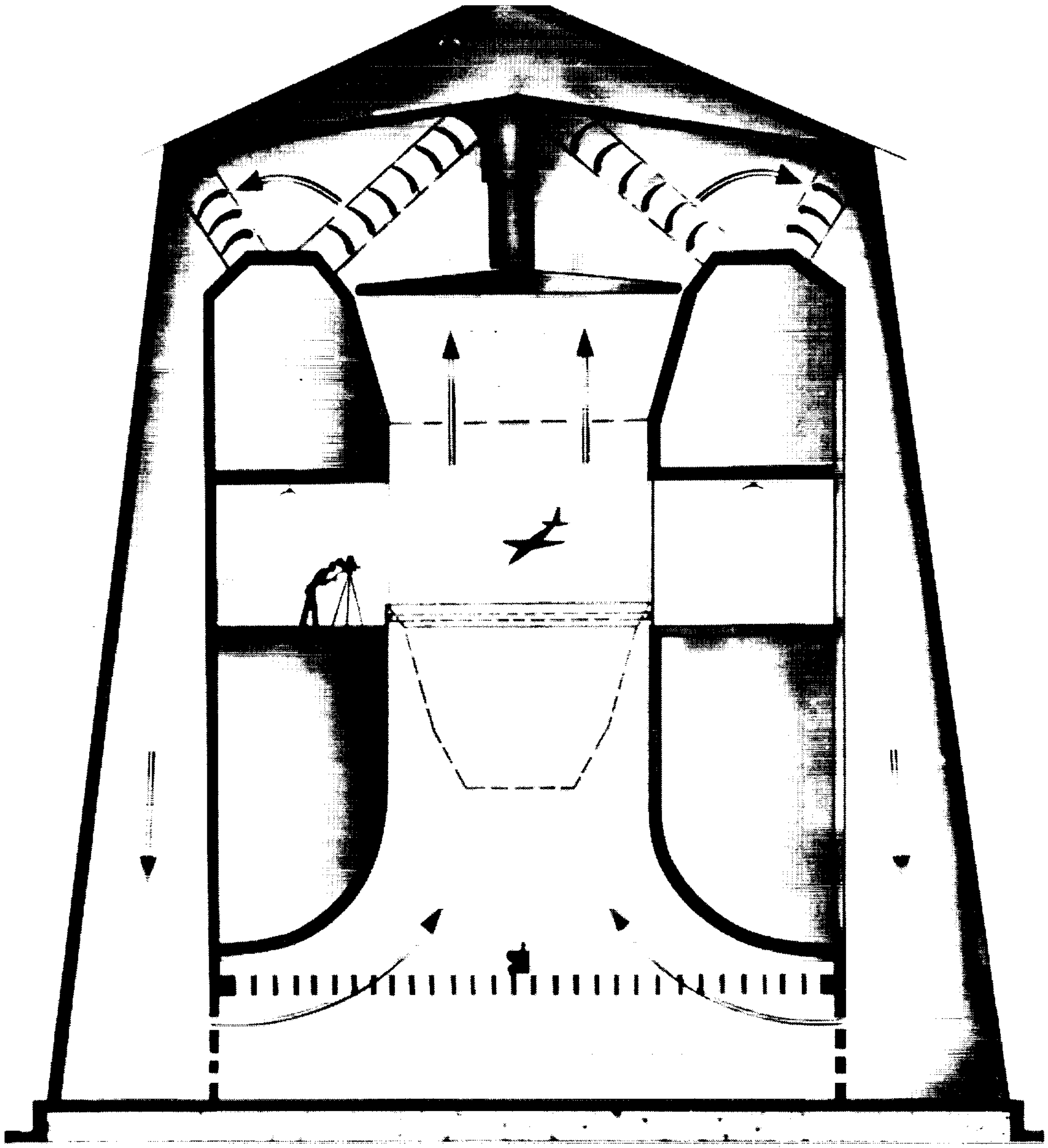


Figure 4.- Cross-sectional view of Langley spin tunnel.

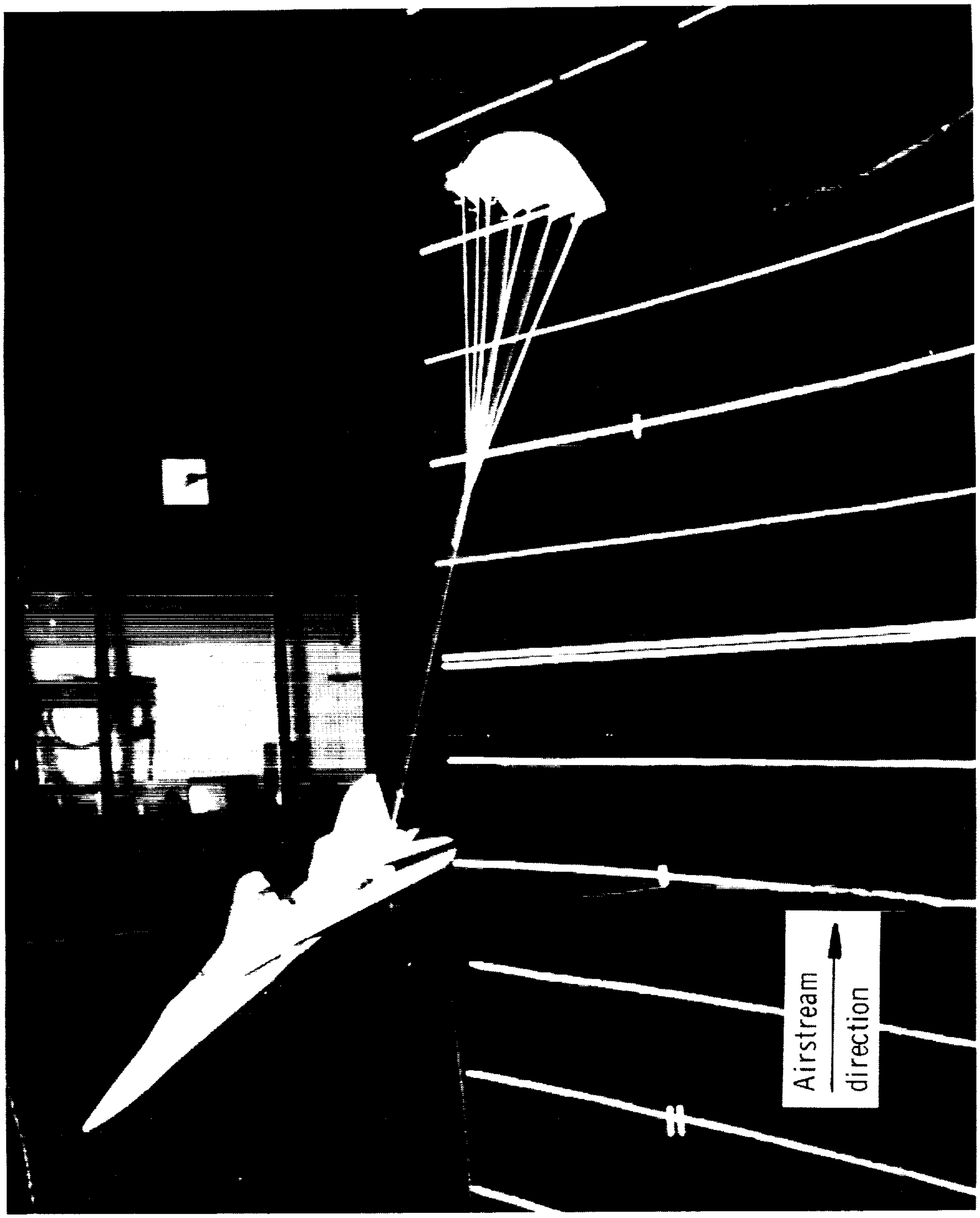


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Figure 5.- Dynamic model with deployed parachute recovering from spin in Langley spin tunnel.

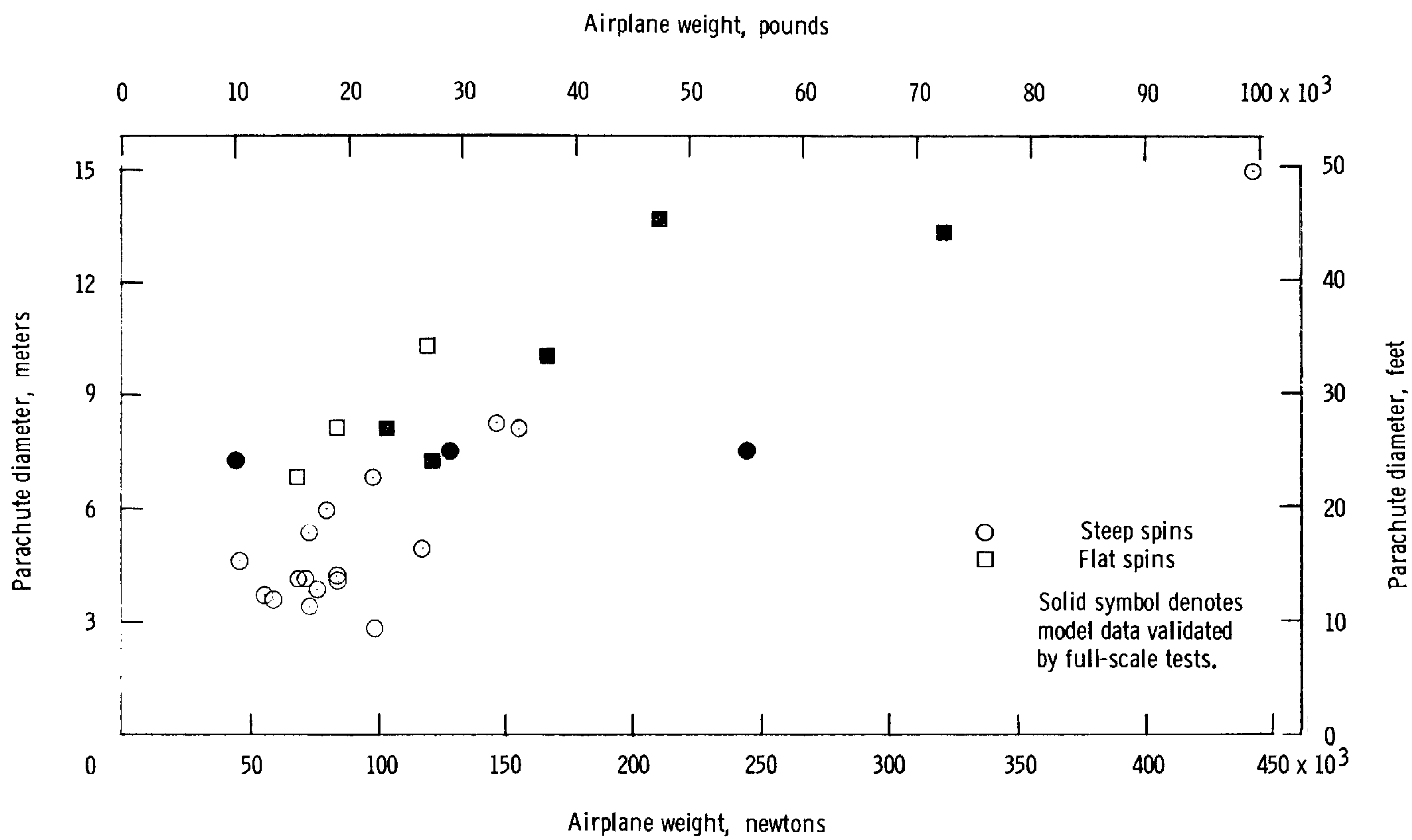


Figure 6.- Parachute diameter. Model data scaled up to full-scale values.

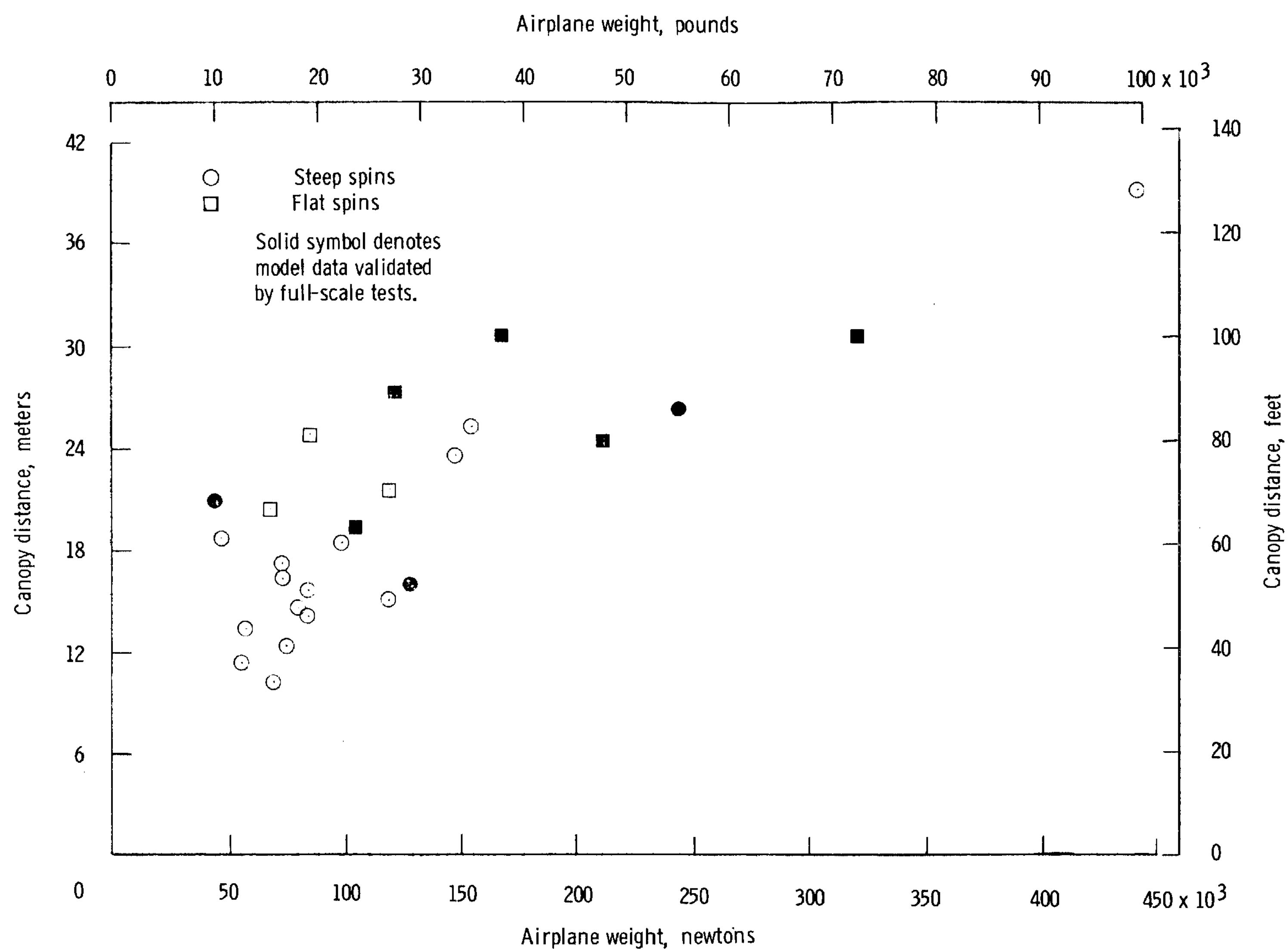
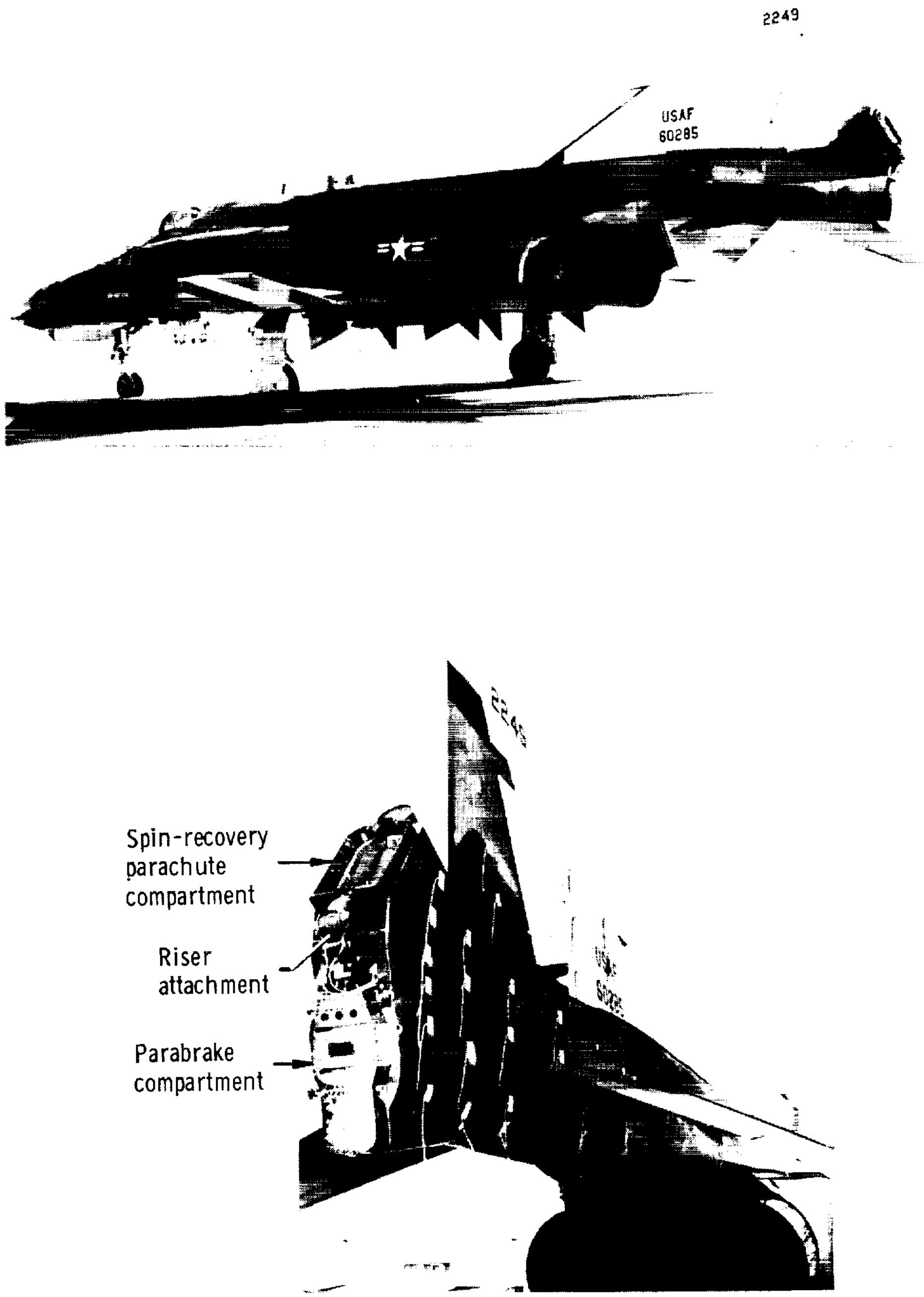


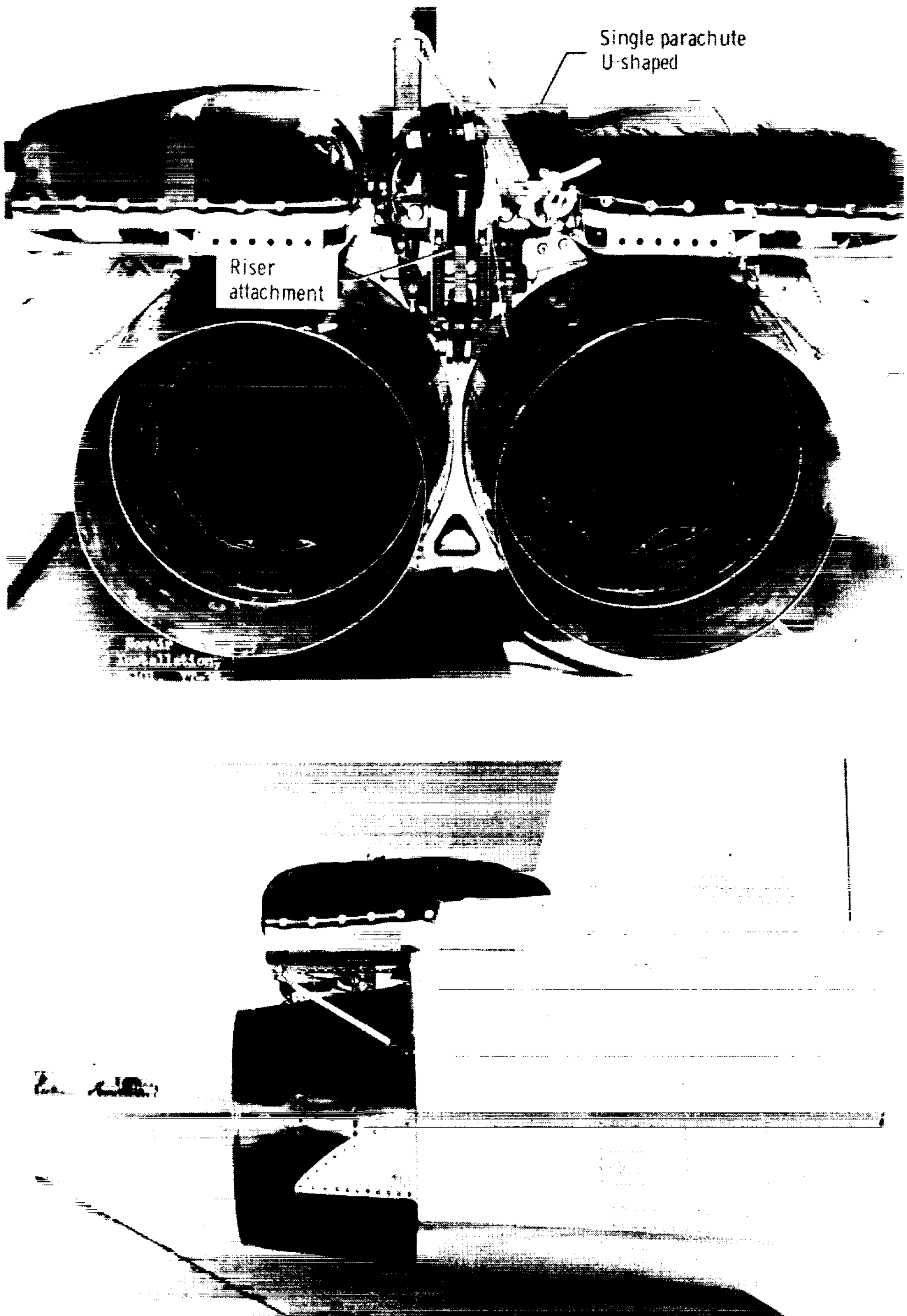
Figure 7.- Canopy distance above attachment point. Model data scaled up to full-scale values.



L-72-2456

(a) Permanently attached compartment. Mortar-ejected pilot parachute. Canopy-first deployment of main parachute.

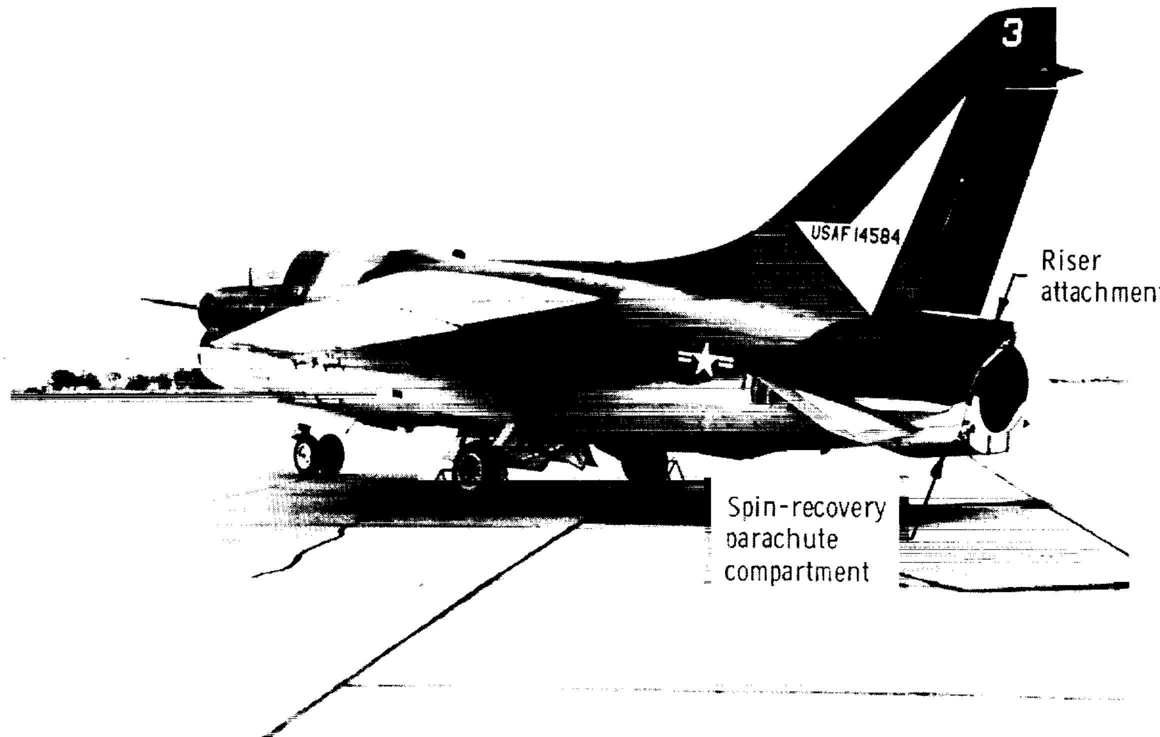
Figure 8.- Full-scale spin-recovery parachute installations.

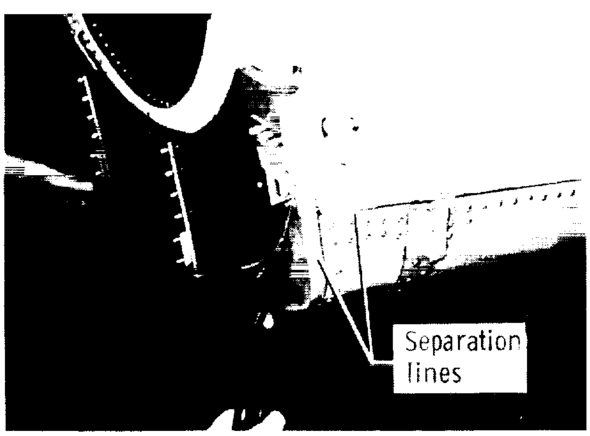


L-72-2457

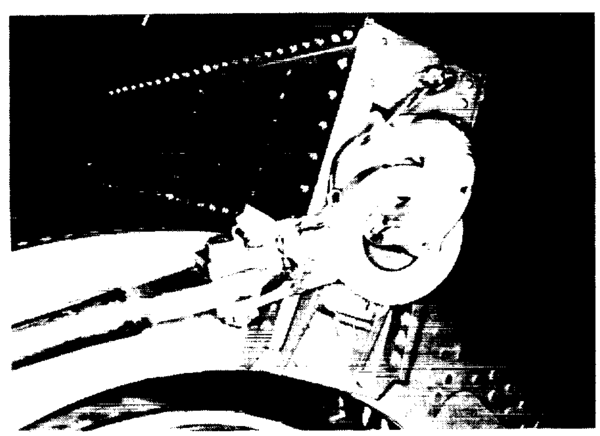
(b) Permanently attached platform. Spring-ejected pilot parachute.
Line-first deployment of main parachute.

Figure 8.- Continued.





Spin-recovery parachute compartment

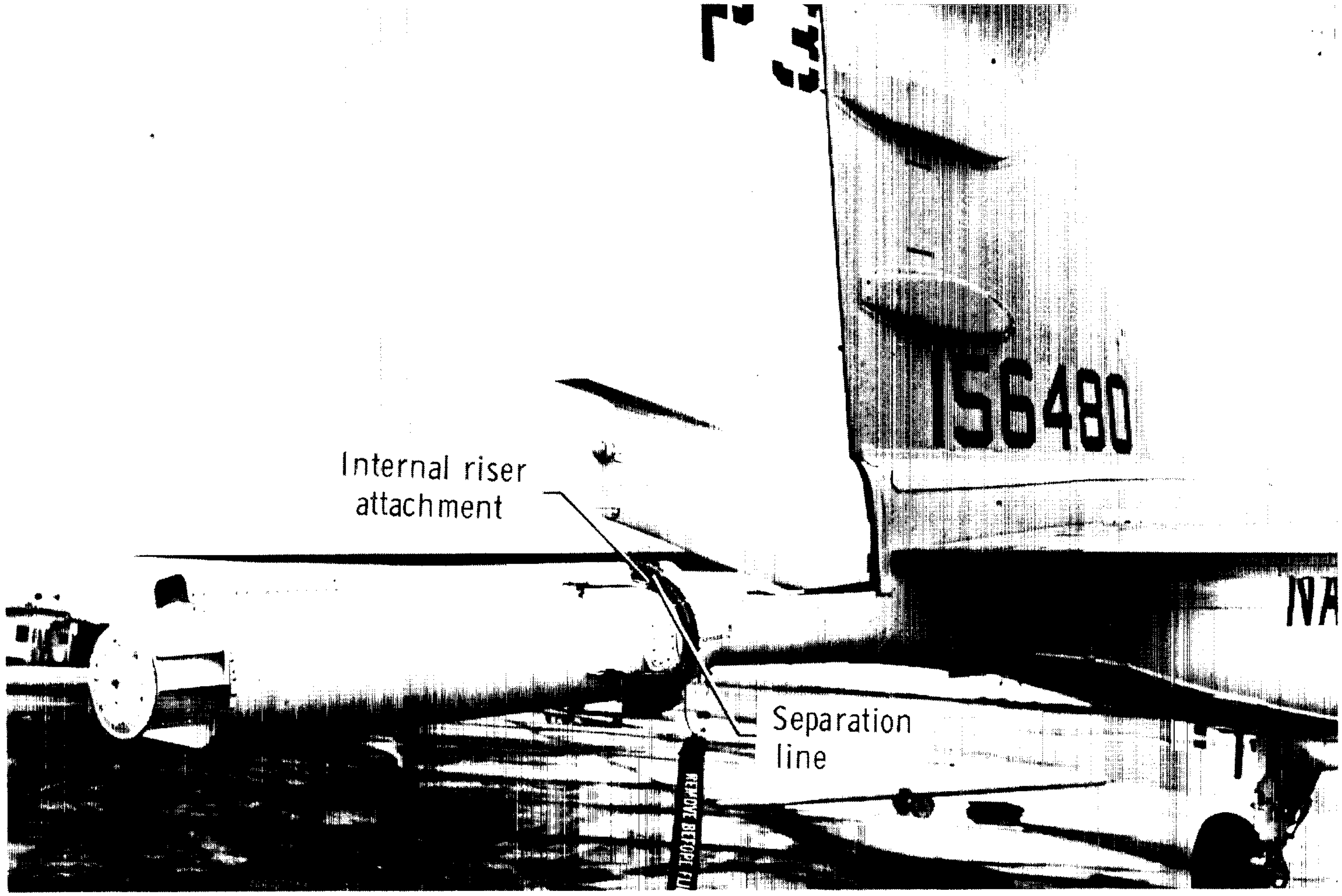


Riser attachment

L-72-2458

(c) Detachable compartment. (Back cover plate jettisoned and bottom cover plate released but remains tied to bridle line upon initiation of deployment.) Spring-ejected pilot parachute. Line-first deployment of main parachute.

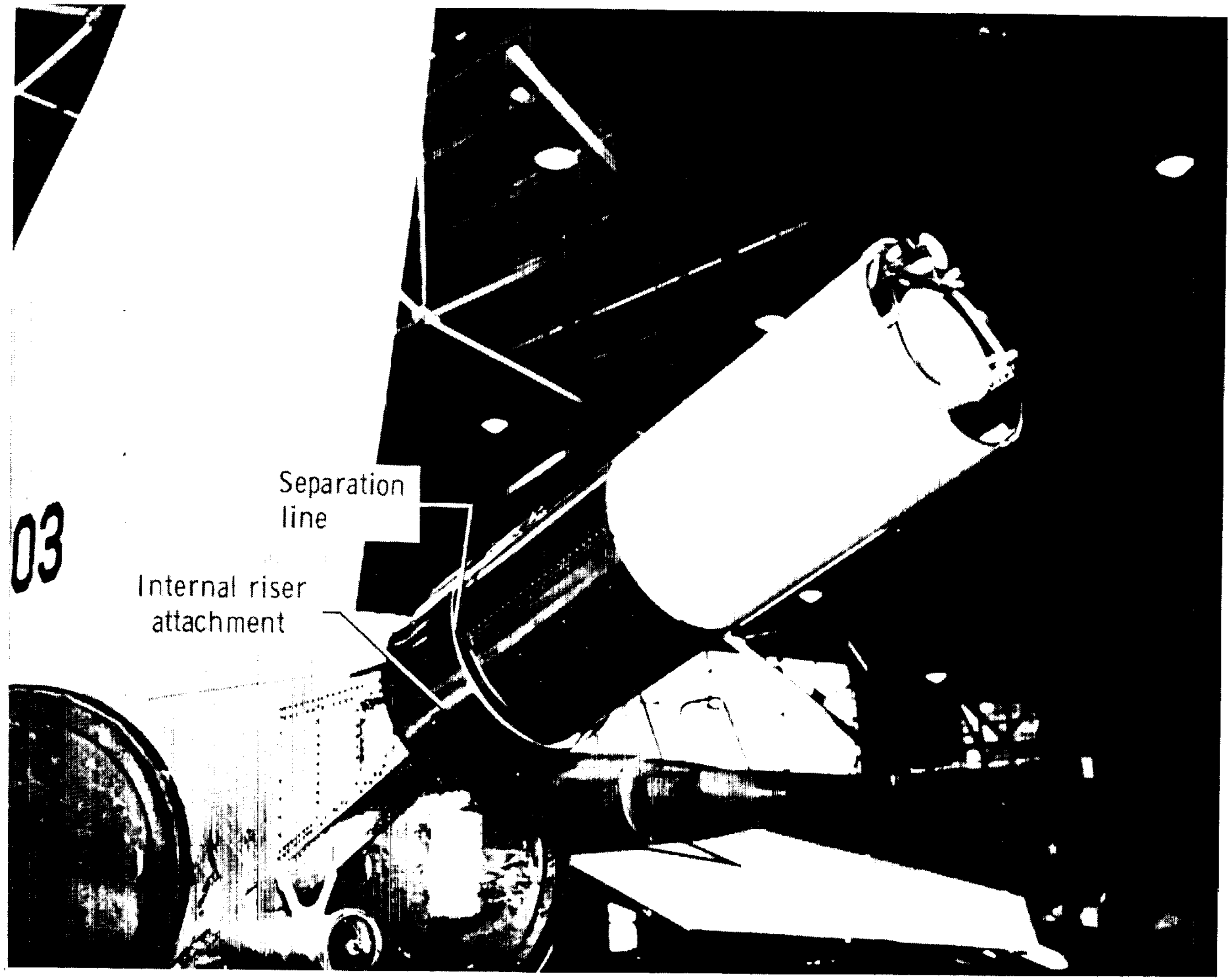
Figure 8.- Continued.



L-72-2459

(d) Detachable compartment. Spring-ejected pilot parachute. Line-first deployment of main parachute.

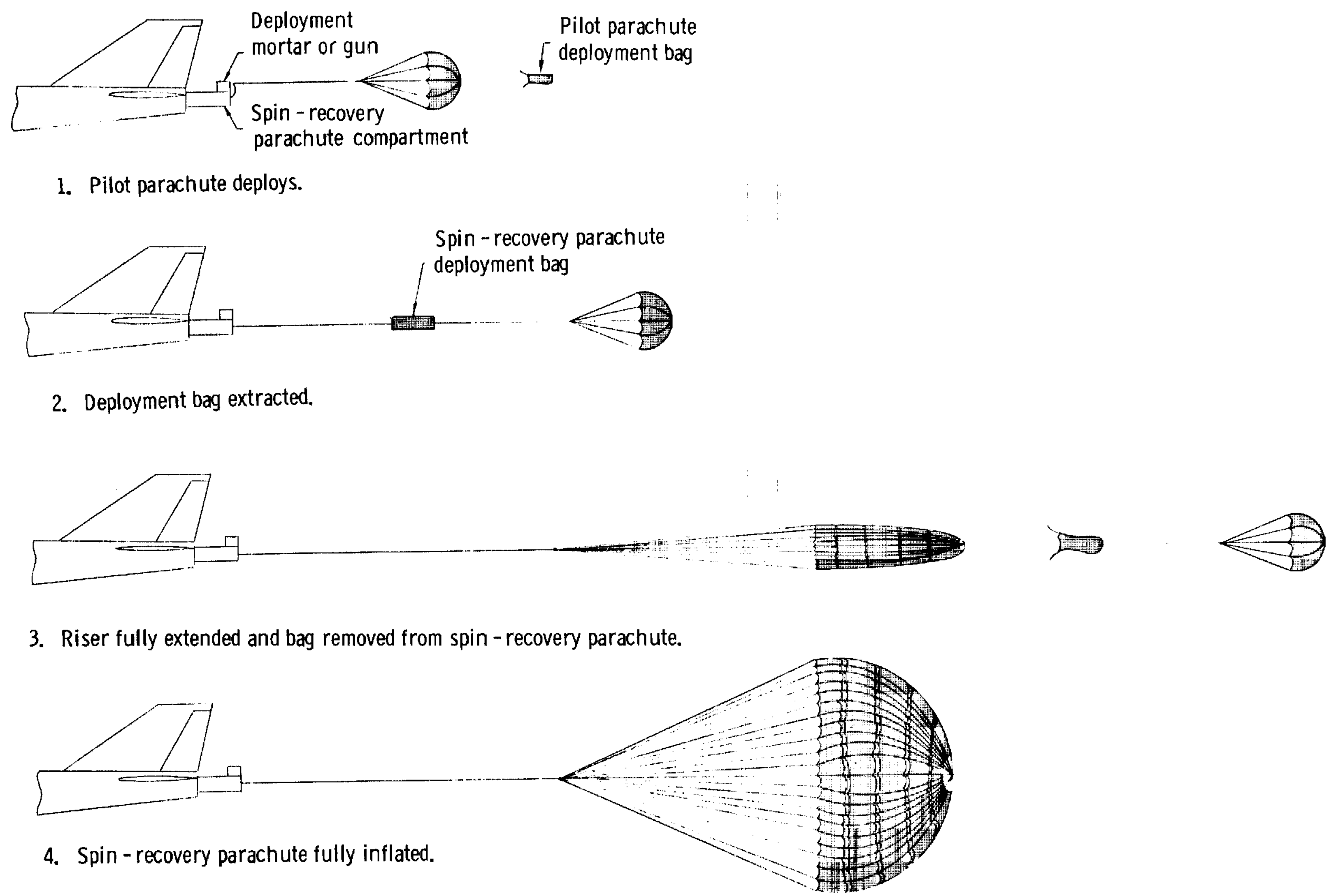
Figure 8.- Continued.



L-72-2460

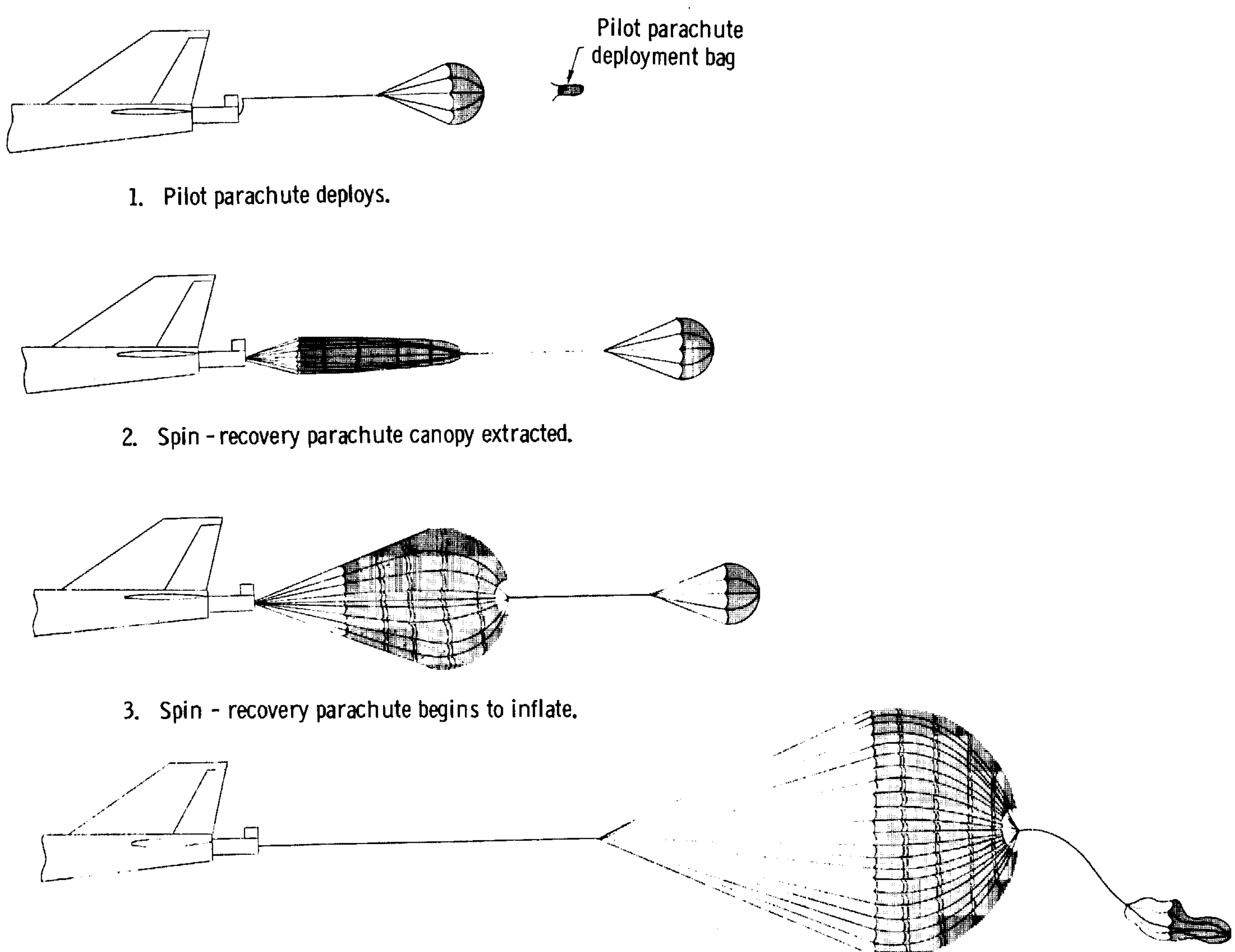
(e) Detachable compartment. Mortar-ejected pilot parachute. Line-first deployment of main parachute.

Figure 8.- Concluded.



(a) Line-first method.

Figure 9.- Basic spin-recovery parachute deployment technique.



1. Pilot parachute deploys.

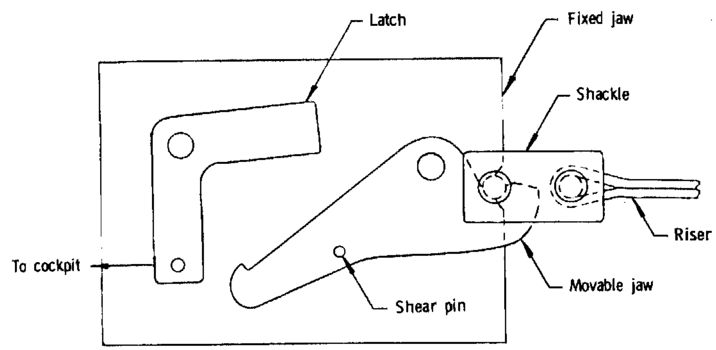
2. Spin - recovery parachute canopy extracted.

3. Spin - recovery parachute begins to inflate.

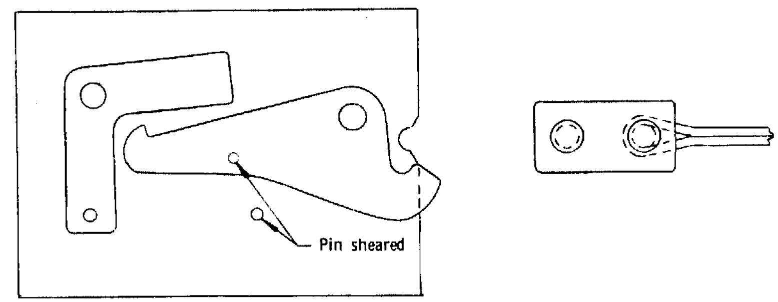
4. Riser fully extended and spin - recovery parachute fully inflated.

(b) Canopy-first method.

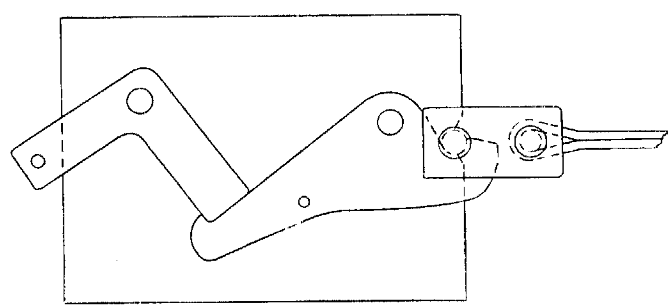
Figure 9.- Concluded.



(1) Latch is open and jaws are closed for takeoff, landing, and normal flight operation to allow for premature jettisoning of parachute.



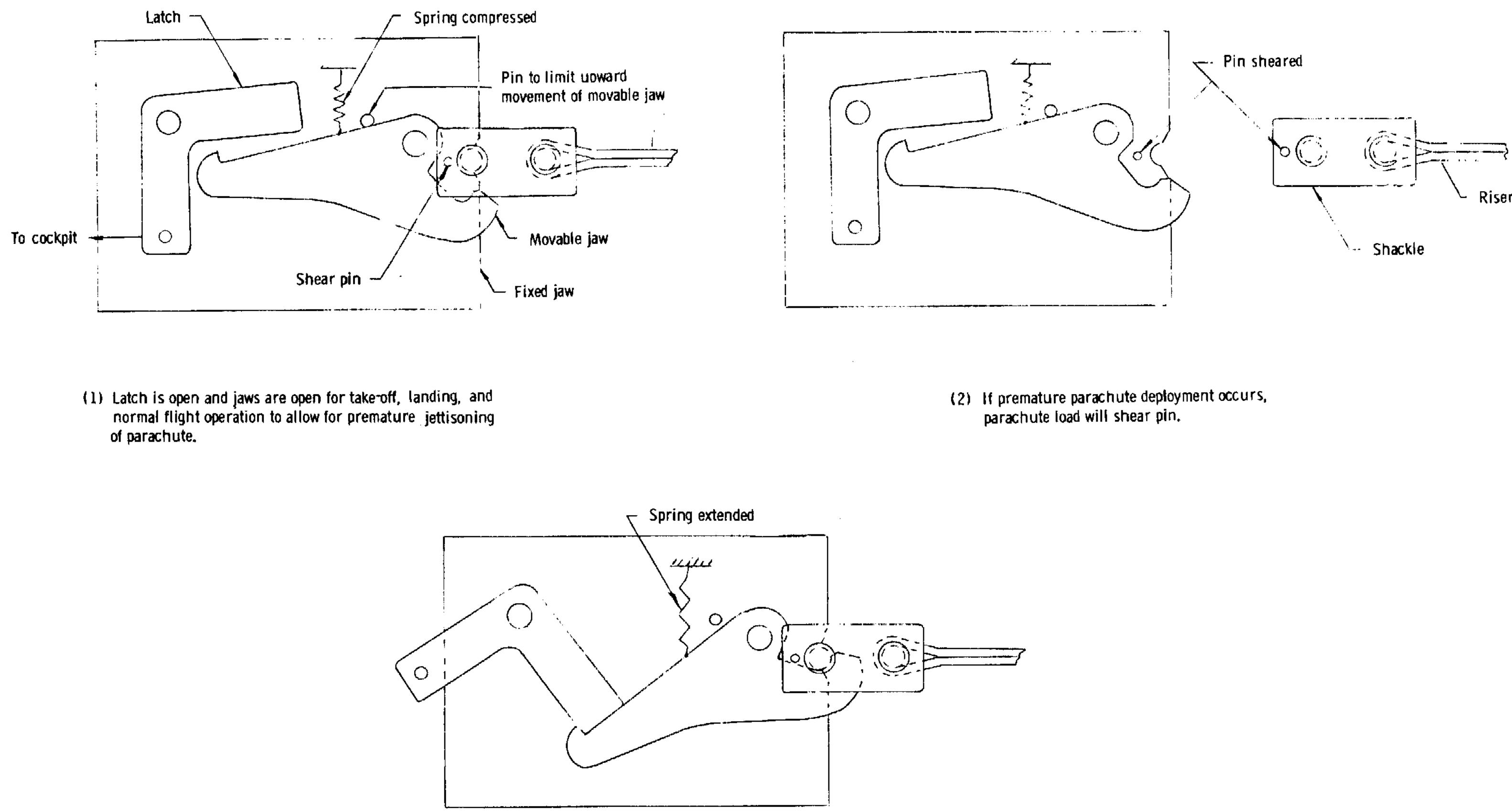
(2) If premature parachute deployment occurs, parachute load will shear pin.



(3) For normal deployment of parachute, latch is closed prior to spin entry to retain parachute riser in jaws.

(a) Closed-jaw concept.

Figure 10.- Parachute attachment and release mechanisms.



(1) Latch is open and jaws are open for take-off, landing, and normal flight operation to allow for premature jettisoning of parachute.

(2) If premature parachute deployment occurs, parachute load will shear pin.

(3) For normal deployment of parachute, latch is closed and jaws are closed prior to spin entry to retain parachute riser in jaws.

(b) Open-jaw concept.

Figure 10.- Concluded.