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# THE DEPLOYMENT OF PARAWINGS FOR USE AS RECOVERY SYSTEMS

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## Introduction

Recently the NASA Langley Research Center has conducted a series of investigations to study some of the problems of deploying parawings for the recovery of boosters and nonlifting spacecraft. These investigations were conducted by means of radio-controlled drop tests of free-flying dynamic models. All of the deployment tests were conducted at low subsonic speeds. The prime considerations of the investigations were the mechanics and sequencing of events for deployment, and the dynamic stability and control characteristics of the configurations during the deployment. A limited amount of information was also obtained on the model accelerations and suspension line loads for one of the configurations during the deployment. Three different types of parawings and four different deployment techniques have been studied. This paper presents a summary of the information obtained during the investigations. Some of the problem areas encountered and the particular solutions employed to alleviate the problems will be discussed.

## Model Flight-Test Technique and Equipment

The model flight-test technique consisted of launching unpowered radio-controlled models from a helicopter and controlling the deployment sequences from the ground. Three electrically driven 16-millimeter movie cameras with telephoto lenses were used to photograph the models during their flights. Two of the cameras were ground based and mounted on motorized tracking units which were also equipped with binoculars to assist the pilot of the model and trackers in viewing the flight of the model and with communications equipment and a radio-control unit. The third camera was in the launch helicopter which was also equipped with a special launching rig for the model. The helicopter was used to carry the model to an altitude of approximately 3500 feet and then release it at near zero airspeed. Magnetic tape recorders were used to record the control signals and all voice communications between the helicopter, a coordinator, and the pilot of the model in order to assist in the analysis of test results. Evaluation of the flight behavior was based on the pilot's observations and the qualitative information obtained from the motion-picture records. One of the spacecraft models was instrumented to obtain accelerations and suspension line loads during the deployment. These data were telemetered to the ground and were also recorded on magnetic tape.

Free-flight stability and control tests were performed before the deployment tests in order to determine the proper trimmed-flight condition of the model, so that when subsequent deployment tests were made, any unusual motion occurring during the deployment and accompanying transition from vertical descent to normal trimmed gliding flight could be attributed directly to the deployment process and not to any untrimmed condition of the model.

## Models

Four different configurations were investigated and are illustrated in figures 1 through 4. None of the models were exact scale reproductions of any particular vehicle-parawing combination.

The first configuration (fig. 1) consisted of a model of a rocket booster with a foldable rigid parawing. The structural members, that is, the leading edges, the keel, and the spreader bars were fabricated from aluminum-alloy tubing and were so constructed that the leading edges could be retracted back until they were parallel to the keel, and then the leading edges and the keel could be folded back on themselves so as to make the overall packaged length approximately one-half of the keel length. This was done in order to facilitate the packing of the parawing on the side of the booster without overhanging either end. Eight suspension lines were used which positioned the booster approximately 16° nose down with respect to the parawing keel.

The second configuration (fig. 2) consisted of a model of a blunted-cone nonlifting spacecraft with a telescoping rigid parawing. Again the structural members were fabricated from aluminum-alloy tubing. The leading edges on this wing could also be retracted until they were parallel to the keel and then they could be telescoped three times so that the overall packaged length was approximately one-third of the keel length. This was done so that the packaged parawing would be no longer than the straight portion on the side of the spacecraft. A system of four suspension lines was used which positioned the capsule in a heat-shield-down attitude beneath the parawing for gliding flight.

The third configuration (fig. 3) was similar to the second except that the structural members of the parawing were inflatable fabric tubes. These tubes were pressurized with the air from 3 high pressure air bottles carried one within each of the leading edges and the keel. The suspension line geometry and the essentials of the deployment sequence were the same as for the telescoping parawing.

The fourth configuration (fig. 4) consisted of a Gemini-type spacecraft with an inflatable parawing. The pressurization system for this wing consisted of a single air bottle stowed within the spacecraft model. The deployment sequence and the suspension line geometry were similar to that proposed for the Gemini vehicle. Three linear accelerometers in the model (located at the center of gravity) and tensiometers in each of the suspension lines measured the accelerations and line loads encountered during deployment.

## Results and Discussion

Separate investigations were conducted with each of the four different parawing-vehicle combinations, and the detailed results of three of these investigations are given in references 1 to 3. These investigations were conducted somewhat in the manner of development projects - that is, they were intended to devise a successful method of deployment for each particular case and not to provide an exhaustive study of all possible deployment processes. Successful methods for deploying the parawings were developed in each case, but the development process involved trying a number of deployment steps, or features, that were not always successful - and, from these successes and failures, some general understanding of the problems and the importance of various features of the deployment process has been obtained. All of the deployment systems developed follow the same general program. The wing was deployed in the zero-lift condition with the apex attached to the spacecraft, or booster, then the transition was made to a lifting condition and gliding flight. The successful deployment systems developed are not necessarily the only nor the best techniques that can be devised. However, many aspects of the deployment process were found to be common to all four of the parawing-vehicle combinations tested, and will probably constitute valuable guidance in the development of deployment techniques for future cases. These common aspects are discussed in the following sections of the paper in terms of the various phases of the deployment.

## Stabilization of Vehicle Before Deployment

One feature that seems to be absolutely necessary is that the vehicle from which the parawing is to be deployed must be at some predictable attitude when the deployment is initiated as well as during the deployment itself. If the booster or spacecraft alone is unstable, it will be impossible to predict what the attitude might be at any particular instant during a free fall, and therefore equally impossible to devise a deployment technique which would be successful at all times. Since the boosters and spacecraft tested were not dynamically stable some auxiliary device had to be employed to make them stable. In each case a drogue parachute was used as being the smallest, lightest, and most reliable system which would stabilize the vehicle and consequently predetermine its attitude along the flight path, so that the deployment could be started from a known and consistent set of conditions.

## Spreading the Wing

It was found to be very desirable to spread the leading edges of the wing to the desired flight sweep angle before the wing starts to develop lift. The reason for this is simply that it requires less work to spread the leading edges while the wing is in a zero lift condition. Before the wing starts to develop lift, the fabric between the leading edges and the keel is slack and therefore does not apply a force to the leading edges which would have to be overcome in order to spread them to the desired flight sweep angle. Graphic examples of this were obtained in tests of two of the vehicles. In each case spring-loaded spreader bars which were perfectly capable of spreading the leading edges while the parawing was at zero angle of attack and not producing any lift, were unable to spread the leading edges once the wing had started to develop lift. Even when the leading edges were spread while the wing was at zero lift, however, there was still considerable drag on the leading edges that the spreader bars had to overcome. This drag force is present whether the wing is lifting or not so there cannot be a trade-off of one force for another. Therefore, the minimum work required to spread the leading edges to the desired sweep angle will occur while the wing is at zero lift.

## Separation of Wing from Vehicle

Another important factor common to each deployment technique that was found to be absolutely essential was that some positive means must be provided for separating the parawing from the vehicle, getting it into a lifting attitude, and holding it in the desired position relative to the vehicle until any oscillations set up by the deployment have damped out. In all of the investigations a drogue parachute attached to the apex of the wing was used to accomplish these functions. In two cases a second drogue was used while in the other two cases the stabilizing drogue was made to perform this function when the wing was released from the vehicle. Other aerodynamic devices might be devised to perform this function (for example, a turned-up nose on the parawing), but no such devices have been tried in the Langley deployment work.

One example of the necessity of using some device to assure positive separation of the wing from the vehicle and get it into a lifting attitude was brought out by the booster-parawing tests. In this case the parawing would usually separate from the booster of its own accord, but it would not necessarily stay separated and on numerous occasions, before a second drogue parachute was added to the parawing, the parawing would fall back against the booster with disastrous results. Sometimes this would cause one or more of the suspension lines to foul, thus preventing the booster-parawing combination from ever becoming properly oriented with respect to each other. This in turn precluded the possibility of the configuration ever attaining the desired trimmed gliding flight condition. Sometimes, when the parawing fell back against the booster, it would cause the booster-parawing configuration to be at an unsatisfactory attitude when the drogue parachute from the booster was jettisoned, which would prevent the model from achieving a trimmed gliding flight attitude. In order to cure this situation, a second drogue parachute was attached to the parawing in such a manner as to cause a positive pitching moment.

Another example of this same phenomena was obtained in the case of a parawing and blunted cone spacecraft. On some occasions when a drogue parachute was not used to effect a positive means of separating the parawings from the spacecraft, the parawings would not rotate up to a lifting condition. In these instances, the spacecraft and parawing would fall vertically with the parawing at a zero lift and zero angle-of-attack condition, sometimes trailing and sometimes leading the spacecraft, with no indication that the parawing would ever attain a lifting condition which would allow the vehicle to start gliding.

In conjunction with using a drogue parachute to force the parawing to a lifting condition, care must be taken that the drogue be attached in such a way that it cannot make the parawing yaw.

For example, in the case of the spacecraft configurations if a single load line from the drogue parachute were attached to the apex of the parawing, and if the parawing should become yawed slightly while still at or near zero degree angle of attack, then the drogue parachute would cause the parawing to yaw even more until a condition was reached where the wing could not possibly pitch up to a lifting condition. To cure this situation the drogue parachute was attached to the parawing with a three-point bridle. One point was located at the apex of the wing and the other two points were located one on each leading edge at the same positions that the two roll lines were attached. The lengths of the bridle lines were such that the wing was free to yaw only a few degrees before the drogue parachute would apply a restoring moment. Once the three-point bridle was incorporated, the wings always pitched up to a lifting condition after they had been released from the spacecraft. A three-point bridle was not necessary with the booster-parawing configuration, however, because the geometry of the suspension lines from the parawing to the booster prevented the parawing from yawing. This was not the case with the suspension line geometry used with the spacecraft and parawing combinations because the suspension lines came in to a more-or-less common point on the spacecraft and did not restrain the yawing.

Transition to Gliding Flight

The next important factor common to each deployment technique was that the parawing must not be allowed to make a transition from zero lift to its trim gliding condition too rapidly. Not only does this impose excessive loads on the structure, but it may also cause the vehicle to become violently unstable and begin an end-over-end tumbling motion and be completely out of control. For example, in the case of the blunted-cone spacecraft-parawing combinations, the suspension lines were relatively long and were all attached to a small area of the spacecraft. Therefore, when the apex of the parawing was released from the spacecraft the drogue parachute caused the parawing to rotate very quickly to $90^{\circ}$ angle of attack before the suspension lines became taut. However, once the suspension lines did become taut the configuration had a center of gravity about which it was stable and had a very large nose down pitching moment with the wing at $90^{\circ}$ angle of attack. This diving moment caused the parawing to pitch down toward its trim angle of attack of about $30^{\circ}$, but the parawing did not have sufficient damping in pitch to prevent it from overshooting its trim condition and begin to tumble uncontrollably. Therefore, in order to limit the rate of rotation of the parawing, a fifth line (called a snubber line) was attached near the nose of the parawings and to a motor-operated winch inside the spacecraft. This line limited to approximately $20^{\circ}$ the initial travel of the wings in pitch when they were separated from the spacecraft; and from this position the snubber line was slowly extended by the motor-operated winch until it finally became slack and all the load was being carried by the four suspension lines. A similar arrangement was used during the Gemini-type deployment test, except that since the Gemini-type configuration already had five suspension lines, no extra line was added for a snubber. Instead, while the parawing was in its packaged condition, the free length of the forward pitch line was wound on the drum of a winch and was used as a snubber line as well as a suspension line.

The booster-parawing combination was different, however, because the inertia of the model booster prevented the parawing from rotating too quickly to a lifting condition. Initially the booster and parawing were descending in a near vertical attitude. When the parawing deployed, it was allowed to rotate only about $16^{\circ}$ before all suspension lines became taut. In order for the parawing to continue rotating up to its trimmed glide attitude, it had to rotate the booster as well and the inertia of the booster was sufficient to prevent an excessive rate of pitch.

Jettisoning the Drogues

The timing of the jettisoning of the drogue parachutes was found to be very important. The drogues should not be jettisoned before the oscillations resulting from the wing deployment have damped out - for two reasons. First, because the drogue provides a powerful damping of the pitching oscillation; and second, because of the possibility of jettisoning the drogue during a phase of the oscillation when the abrupt change in pitching moment would reinforce the oscillation and cause the model to tumble.

Another important aspect of jettisoning the drogue parachutes is to jettison them in the proper sequence when more than one drogue is used. For example, in the case of the booster-parawing combination it was found that the small drogue attached to the wing must be jettisoned before the larger drogue attached to the booster. If the booster drogue was jettisoned first, the drogue attached to the parawing caused the configuration to enter a series of violent stalls which were likely to cause the model to start an end-over-end tumbling motion. On one occasion when such a motion was encountered, the first time the configuration became inverted, the booster fell down on top of the parawing partially collapsing it. The configuration was stable this way, but it was falling vertically at $90^{\circ}$ angle of attack and was uncontrollable.

Load Considerations

From the one spacecraft which was instrumented, it was found that the deployment loads may be many times greater than the steady-state flight loads. Therefore, the problem of deployment loads should be studied further with a view toward optimizing the deployment techniques, thereby reducing the structural requirements of the parawing which in turn will keep the weight and volume of the system at a minimum.

Three linear accelerometers were mounted inside the Gemini-type spacecraft model at the center of gravity and tension strain gages were inserted into each of the five suspension lines. The data from these instruments were telemetered to the ground and recorded on magnetic tape. Figure 5 is a time history of the spacecraft linear accelerations and the suspension line loads obtained during a successful deployment test. The loads and the time presented are model values for a total model weight of 119 pounds (spacecraft $109\frac{3}{4}$ lb and parawing $9\frac{1}{4}$ lb). As can be seen from the time history, high loads occurred twice during the deployment process. The first time was when the aft ends of the leading edges and the keel were released, and in this case both the two roll lines and the rear pitch line experienced sudden increases in their loading. The second time was when the apex was released, and at this time all of the suspension lines were loaded very heavily and the accelerations along all axes were at a maximum. During this time the greatest line load occurred in the forward pitch line and reached a value of approximately twice the weight of the model. A maximum resultant acceleration of 5.1g was encountered at the same time. The high peak line loads and accelerations encountered were probably caused by the fact that the electric motor-powered winch, on which the forward pitch line was wound, was not capable of sufficiently restraining the rate at which the line was played out. It was the same winch which had been used successfully in the two previous investigations with the nonlifting capsule, but the loads encountered during this series of tests were greater than for either of the two previous studies, and were greater than had been anticipated for the present investigation. For this reason it is believed that all of the line loads and accelerations encountered during the half second or so following the release of the apex could have been decreased somewhat by the optimization of the rate at which the forward pitch line was played out. Even with a more optimum winch, however, there will probably still be high peak accelerations and loads at the time the apex is released for this particular configuration due to an initial displacement of the apex of the parawing from the spacecraft. This is caused by the fact that it is impossible, because of the geometry of the system, to snub the forward pitch line to a length short enough to prevent this sizeable initial displacement.

The deployment procedure for parawings has certain random elements which will give some scatter to the data because the attitude of the model is not always exactly the same when a given deployment step is initiated, and these differences in attitude will affect the loads. Therefore, in order to obtain a reliable indication of the maximum and average loads, it would be necessary to conduct numerous deployment tests in order to obtain enough statistical data to indicate the scatter and enable accurate prediction of the loads.

## Concluding Remarks

In general, the investigations showed that parawings can be successfully deployed at subsonic conditions from boosters and various spacecraft configurations. The deployment techniques developed all followed the same general program - the wing was deployed in the zero-lift condition with the apex attached to the spacecraft, or booster, then the transition was made to a lifting condition and gliding flight. The deployment techniques which were developed are satisfactory, but are not necessarily the only nor the best techniques which may be devised.

It is apparent that there are several important factors which were common to each of the deployment systems investigated.

1. The vehicle from which the parawing is to be deployed must be stabilized at some predictable attitude before and during the deployment.

2. It is advisable to spread the leading edges to the desired sweep angle before the wing begins to produce lift.

3. Some positive means of separating the parawing from the recovery vehicle and getting it into a lifting attitude and holding it there is absolutely essential.

4. The parawing must not be allowed to make a transition from zero lift to its fully deployed lifting condition too rapidly.

5. The timing and sequencing of jettisoning the drogue parachutes are important to the stability of the configurations after the deployment.

The deployment loads may be many times greater than the steady-state flight loads. Therefore, the problem of deployment loads should be studied further with a view toward optimizing the deployment techniques, thereby reducing the structural requirements of the parawing which in turn will keep the weight and volume of the system at a minimum.

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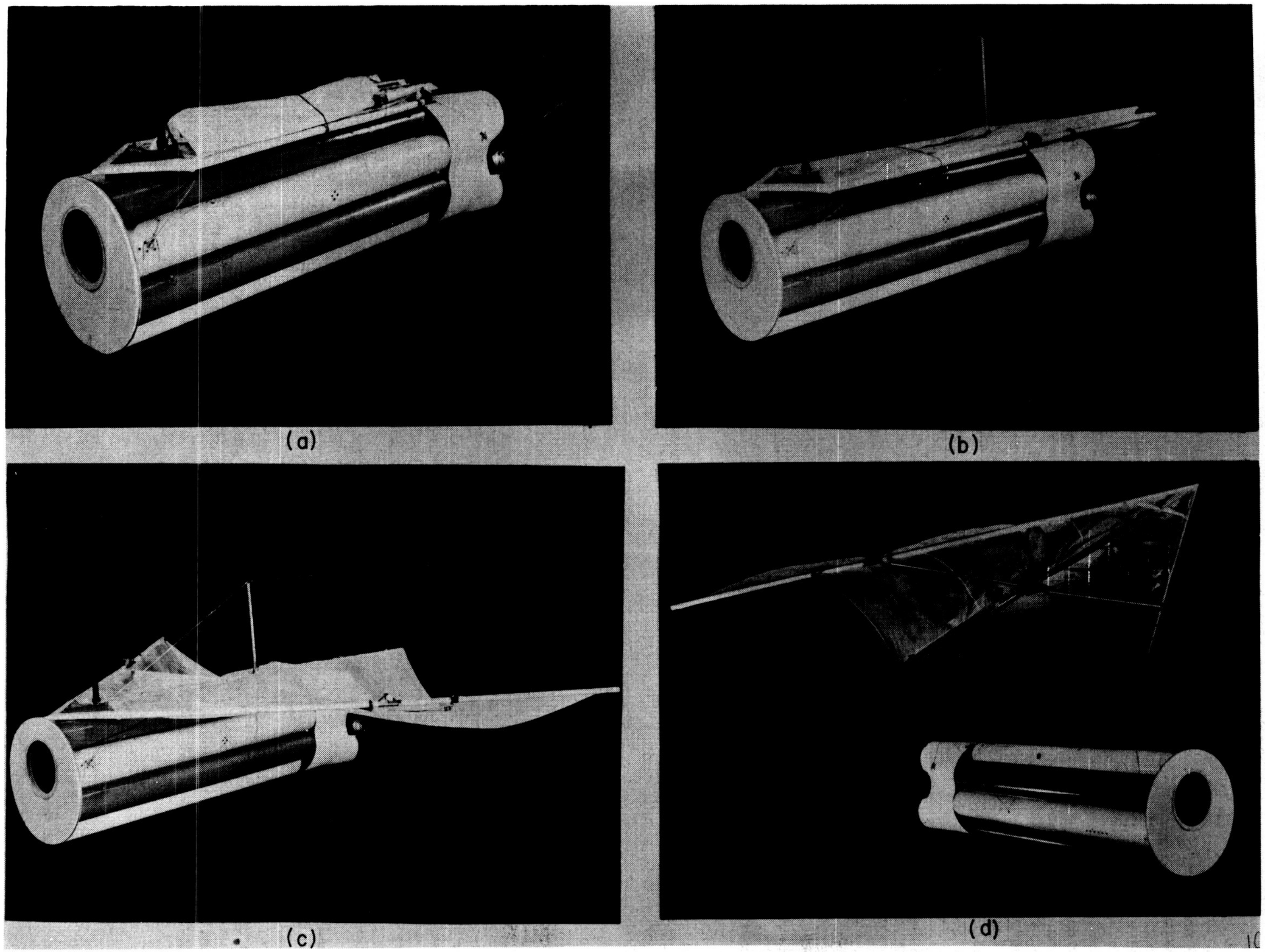


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Figure 1.- Model booster and foldable rigid parawing configuration.

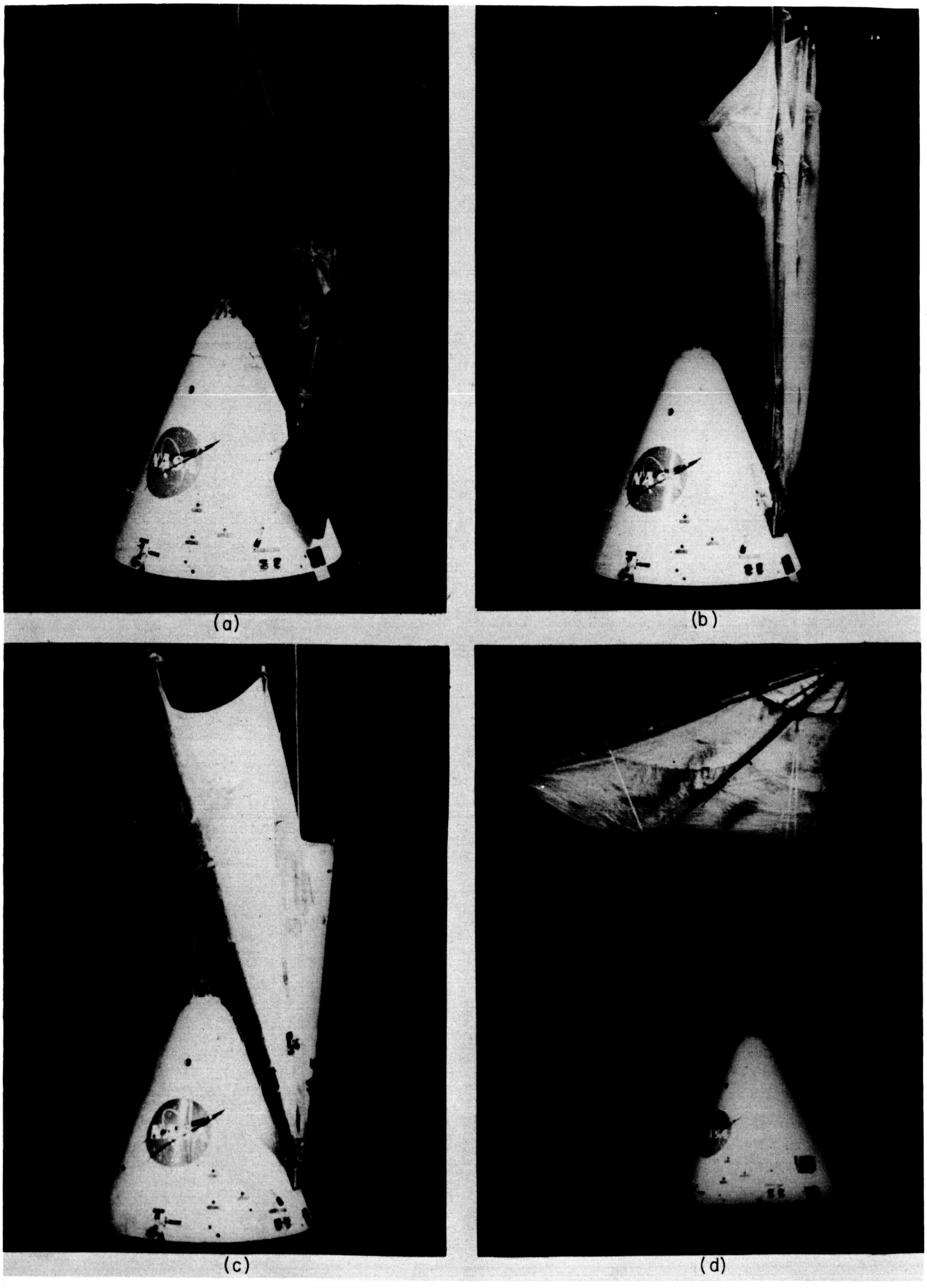


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Figure 2.- Model of blunted cone spacecraft and telescoping rigid parawing configuration.

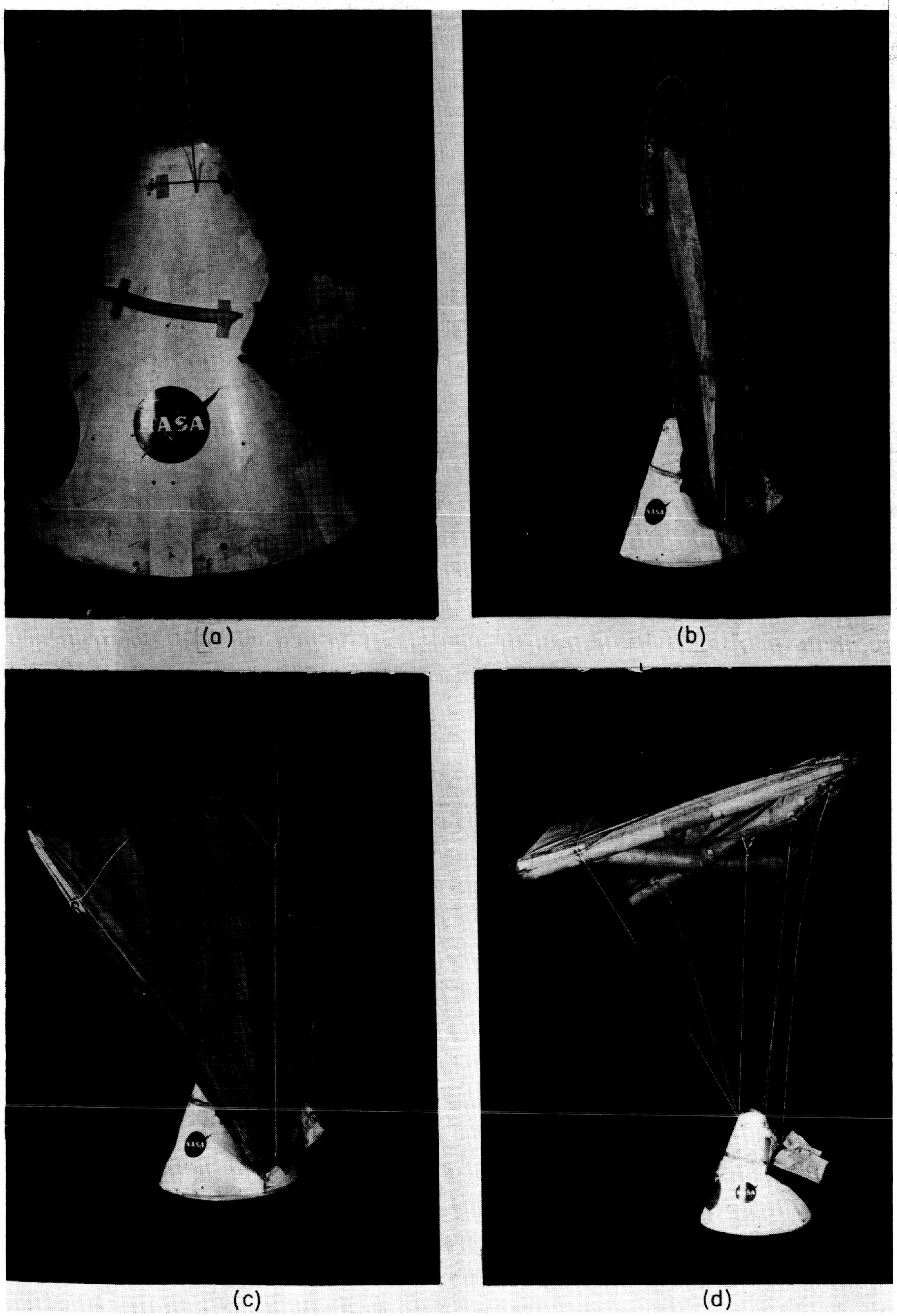


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Figure 3.- Model of blunted cone spacecraft and inflatable parawing configuration.

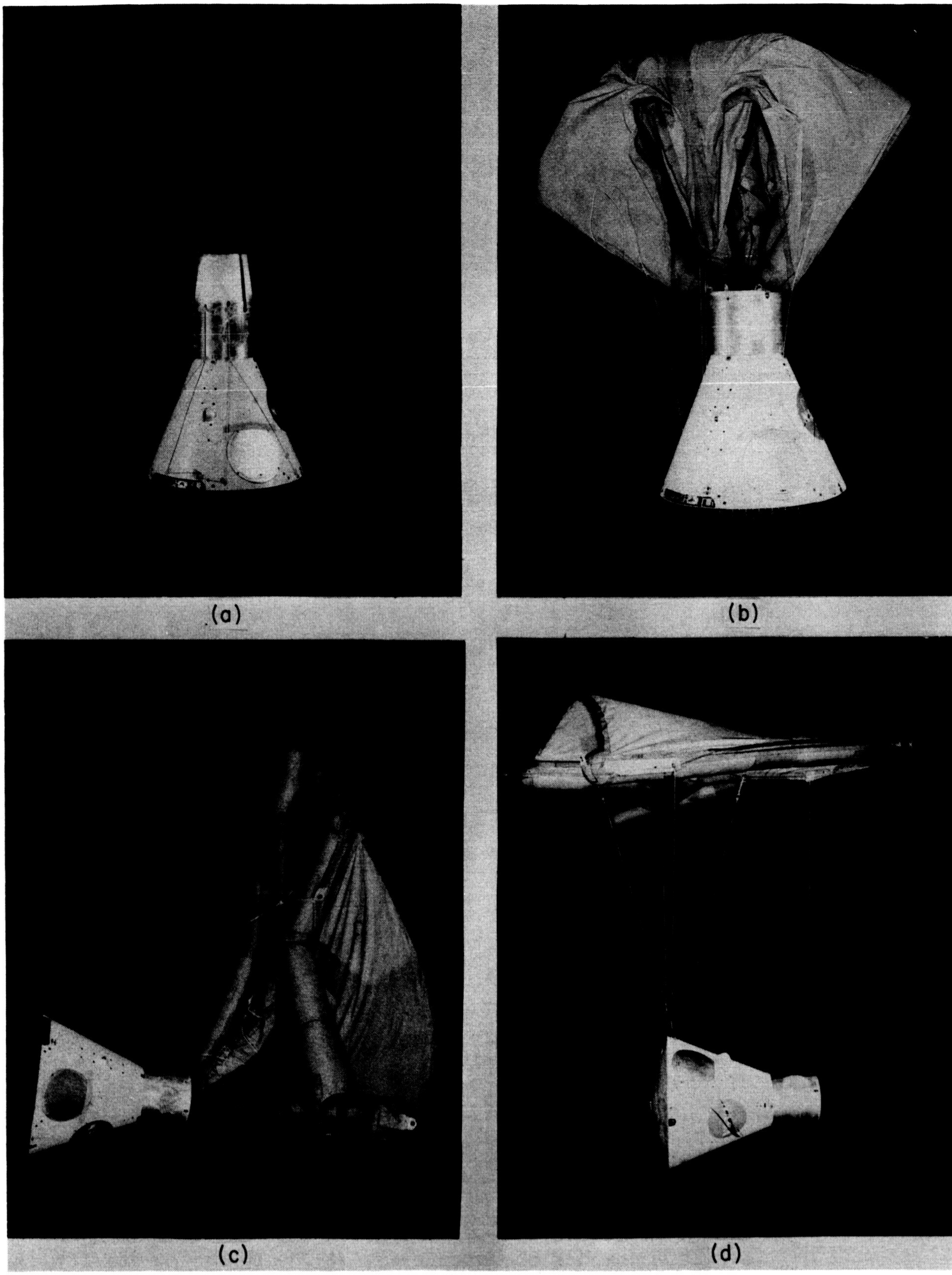

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Figure 4.- Model of Gemini type spacecraft and inflatable parawing configuration.

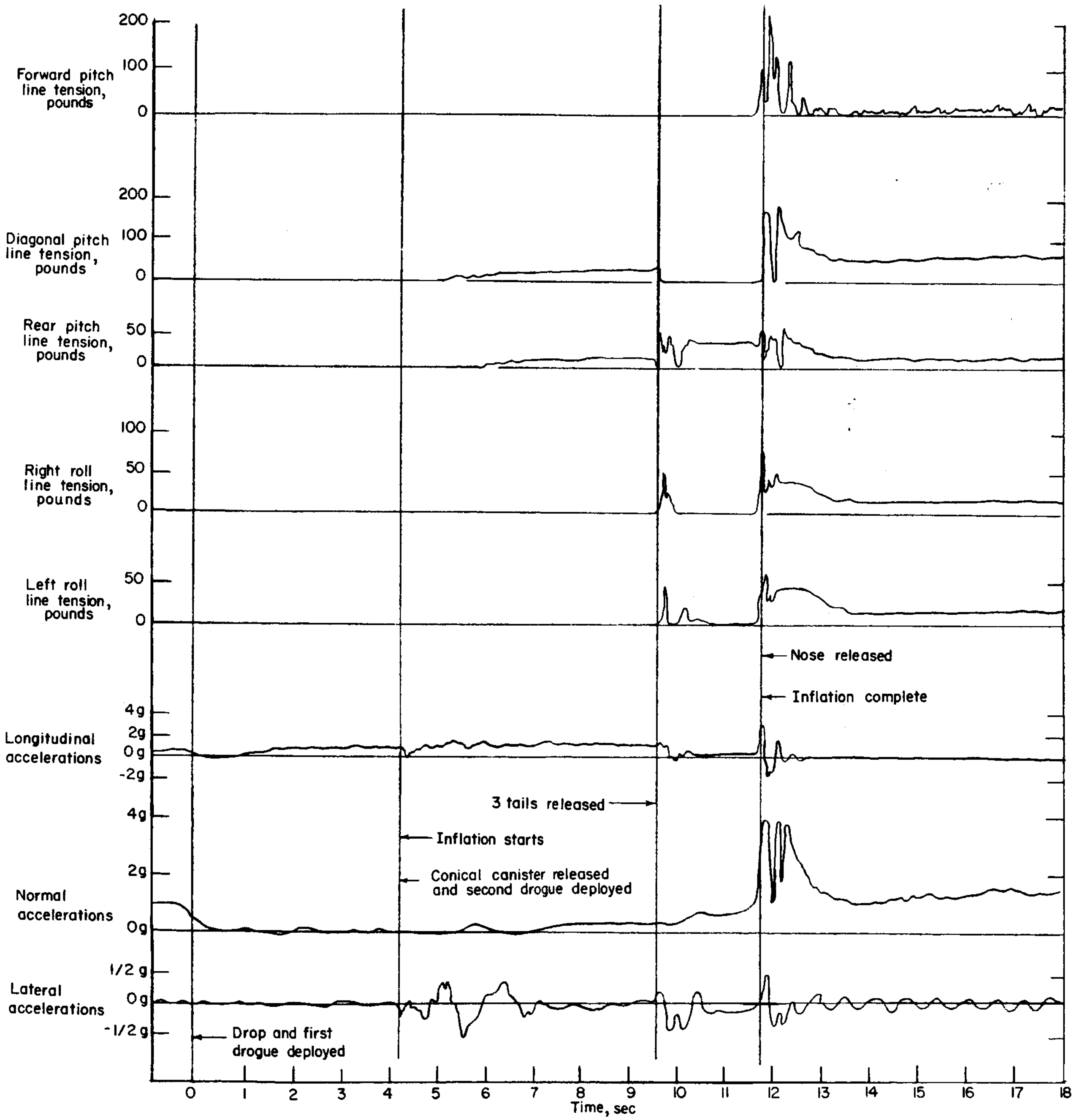


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Figure 5.- Time history of suspension line loads and linear accelerations of the spacecraft at the center of gravity.

NASA-Langley, 1964