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GEMINI SPACECRAFT PARACHUTE LANDING SYSTEM

by John Vincze

Manned Spacecraft Center
Houston, Texas

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ABSTRACT

A 2 1/2-year development and qualification test program resulted in the Gemini landing system. This consists of an 8.3-foot-diameter conical ribbon drogue, an 18.2-foot-diameter ringsail pilot, and an 84.2-foot-diameter ringsail main landing parachute. The significant new concepts proven in the Gemini Program for operational landing of a spacecraft include: (1) the tandem pilot/drogue parachute method of deploying a main landing parachute, and (2) attenuation of the landing shock by positioning the spacecraft so that it enters the water on the corner of the heat shield, thus eliminating the need for built-in shock absorption equipment.

CONTENTS

Section Page

TABLES

FIGURES

Figure		Page

GEMINI SPACECRAFT PARACHUTE LANDING SYSTEM

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SUMMARY

The Gemini landing system uses an 84.2-foot-D_o (nominal canopy diameter) ringsail parachute for terminal descent, and the landing shock is attenuated by entry into water on the corner of the heat shield. A 2 1/2-year development and qualification test program resulted in an operational landing system consisting of a high-altitude, conical-ribbon drogue parachute, a ringsail pilot parachute, and the ringsail main landing parachute. The drogue parachute is deployed nominally at 50 000 feet and will stabilize the spacecraft down to 10 600 feet where its next function is to extract the pilot parachute from its mortar can. The two parachutes which are in a tandem arrangement separate the rendezvous and recovery section from the cabin section of the reentry module, thus deploying the main landing parachute. The Gemini landing system has used the design concepts and experience gained from other programs, notably, Project Mercury. The significant new concepts that were proven in the Gemini Program for operational landing of a spacecraft include: (1) the tandem pilot/drogue parachute method of deploying a main landing parachute, and (2) attenuation of the landing shock by positioning the spacecraft, thus eliminating the need for built-in shock absorption equipment.

INTRODUCTION

Two different types of spacecraft landing systems were considered in the early phases of the Gemini Program. One was a parachute system designed to land the reentry module in water, similar in concept to the system used in Project Mercury. The other consisted of a paraglider wing and landing gear to allow the reentry module to be landed at a preselected airfield. Both designs underwent parallel development. Hardware was procured, and development testing was begun on both systems with the intent that the paraglider landing system would be used on Gemini missions as soon as possible. However, as testing progressed, it became apparent that the problems encountered during the development of the paraglider could not be solved in time to meet the Gemini flight schedules. Consequently, the parachute system became the prime landing system planned for use on all Gemini flights.

A drop test program spanning 2 1/2 years culminated in the qualification of two separate Gemini parachute landing system configurations. The first configuration that was developed and qualified consisted of a pilot parachute to separate the rendezvous and recovery (R and R) section from the reentry module and to deploy the main canopy. The use of this configuration depended upon the reentry control system (RCS) to maintain subsonic stability down to an altitude of 10 600 feet. This landing system configuration performed successfully on the unmanned Gemini II mission. The second configuration that was qualified is used for all manned flights and is different from the first only by the addition of a third parachute and its associated hardware. A study of the spacecraft stabilization control system revealed the desirability of additional redundancy to assure spacecraft stability at subsonic velocities. The method selected to accomplish this was the addition of a drogue parachute. The drogue parachute will stabilize the reentry module at subsonic velocities without aid from the RCS. The pilot parachute was retained with the final configuration to provide a sufficiently low rate of descent to the R and R section to prevent its recontact with the main canopy. The pilot parachute will also separate the R and R section in case of drogue failure, and the alternate method of main parachute deployment is used. The primary objectives of the drop test program were to develop parachute sizes, reefing ratios, reefing times, and the associated hardware necessary to safely land the reentry module. Subsequent to the drop test program, the complete landing system was qualified under simulated spacecraft operating conditions. The test program is discussed in the section on tests and results.

A basic difference between the Gemini and Mercury landing systems is that the Gemini system has no provision for automatic control; therefore, a flight crew member must manually initiate all functions. Otherwise, the proven design concepts of the Mercury parachute landing system were employed in the Gemini system wherever possible. The same type of ringsail main parachute canopy was selected; however, it was enlarged to provide the desired rate of descent to the heavier Gemini reentry module. Other Gemini landing system component designs such as bridle disconnects, pyrotechnic devices, and baroswitches also are based on Mercury designs. In the design of the Gemini landing system, the philosophy of redundancy was carried out. All functions are backed up by duplicate hardware except that of the main parachute. In the event of main parachute failure, the ejection seats serve as a backup for safe recovery of the flight crew.

SYSTEM DESCRIPTION

The components which comprise the final parachute landing system configuration used on the manned Gemini flights consist of a high-altitude drogue parachute (fig. 1), a ringsail pilot parachute (fig. 2), a ringsail main landing parachute (fig. 3), and the associated stowage, deployment, and control equipment.

Drogue Parachute Assembly

The drogue parachute configuration that was selected is an 8.3-foot-diameter*, 20° conical ribbon-type parachute which provides a stability level within ± 24° of vertical during descent from an altitude of approximately 50 000 to 10 600 feet. The canopy contains 12 gores and is constructed primarily of 200-pound, 2-inch-wide nylon tape. Twelve suspension lines, each having a tensile strength of 750 pounds, attach the canopy to the riser assembly. Three layers of 3500-pound nylon webbing are used for each of the three legs of the riser assembly. The riser legs are attached to the face of the R and R section by means of steel cables.

The drogue parachute has two reefing lines installed. One is a 1000-pound synthetic fiber line sewn to the skirt of the canopy to prevent over-inflation of the canopy, and consequent rapid pulsations. The other is a conventional reefing line of 1000-pound nylon cord with sufficient length to provide a reefing ratio of 43 percent of the parachute's apparent canopy diameter (D_o)*. The design reentry dynamic pressure is 120 pounds per square foot (psf) at an altitude of 50 000 feet, and in the case of a launch abort, 143 psf at an altitude of 40 000 feet.

Pilot Parachute Assembly

The 18.2-foot-diameter* ringsail pilot parachute performs two functions. First, it provides sufficient drag, in tandem with or without the drogue parachute, to separate the R and R section from the reentry module, and to deploy the main parachute canopy. The second function is to provide a rate of

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*Diameter = D_o

*D_o = nominal canopy diameter, that is, $\sqrt{\frac{4S_o}{\pi}}$ feet, where S_o = total cloth area of the canopy or design surface area including slots and vent.

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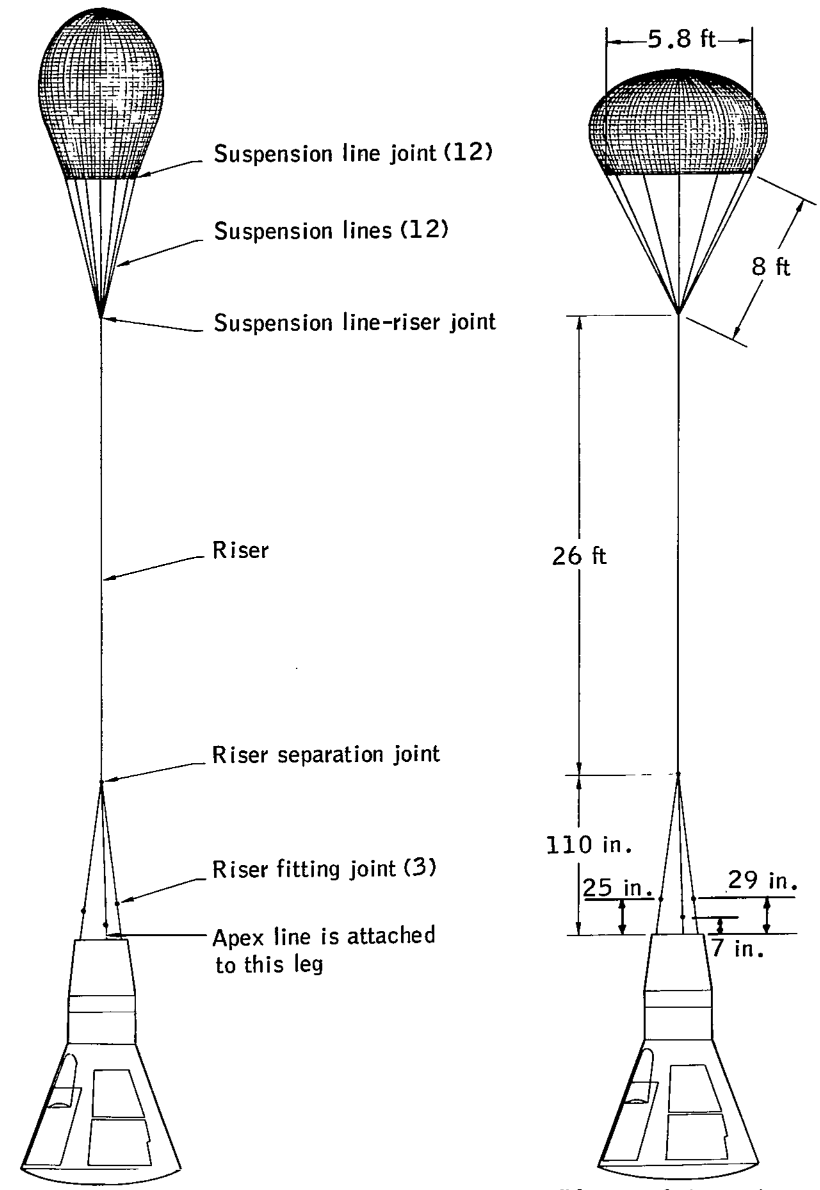

(a) Reefed parachute

(b) Disreefed parachute

Figure 1.- Drogue parachute assembly.

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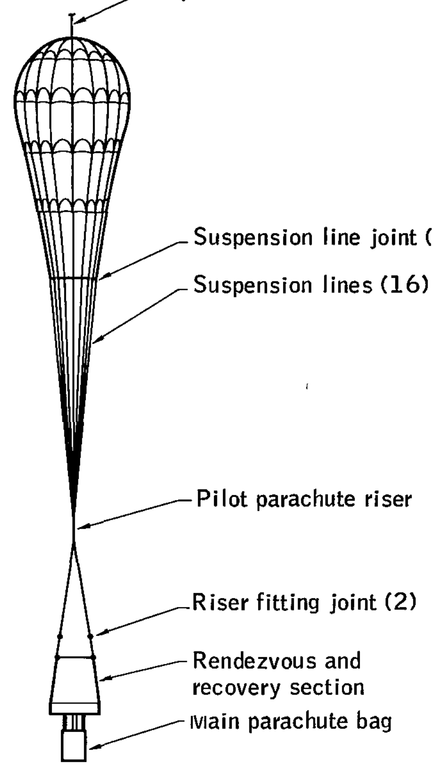
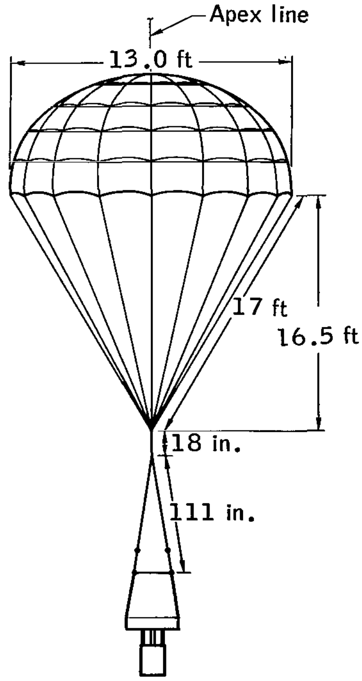


(a) Reefed parachute



(b) Disreefed parachute

Figure 2.- Pilot parachute assembly.

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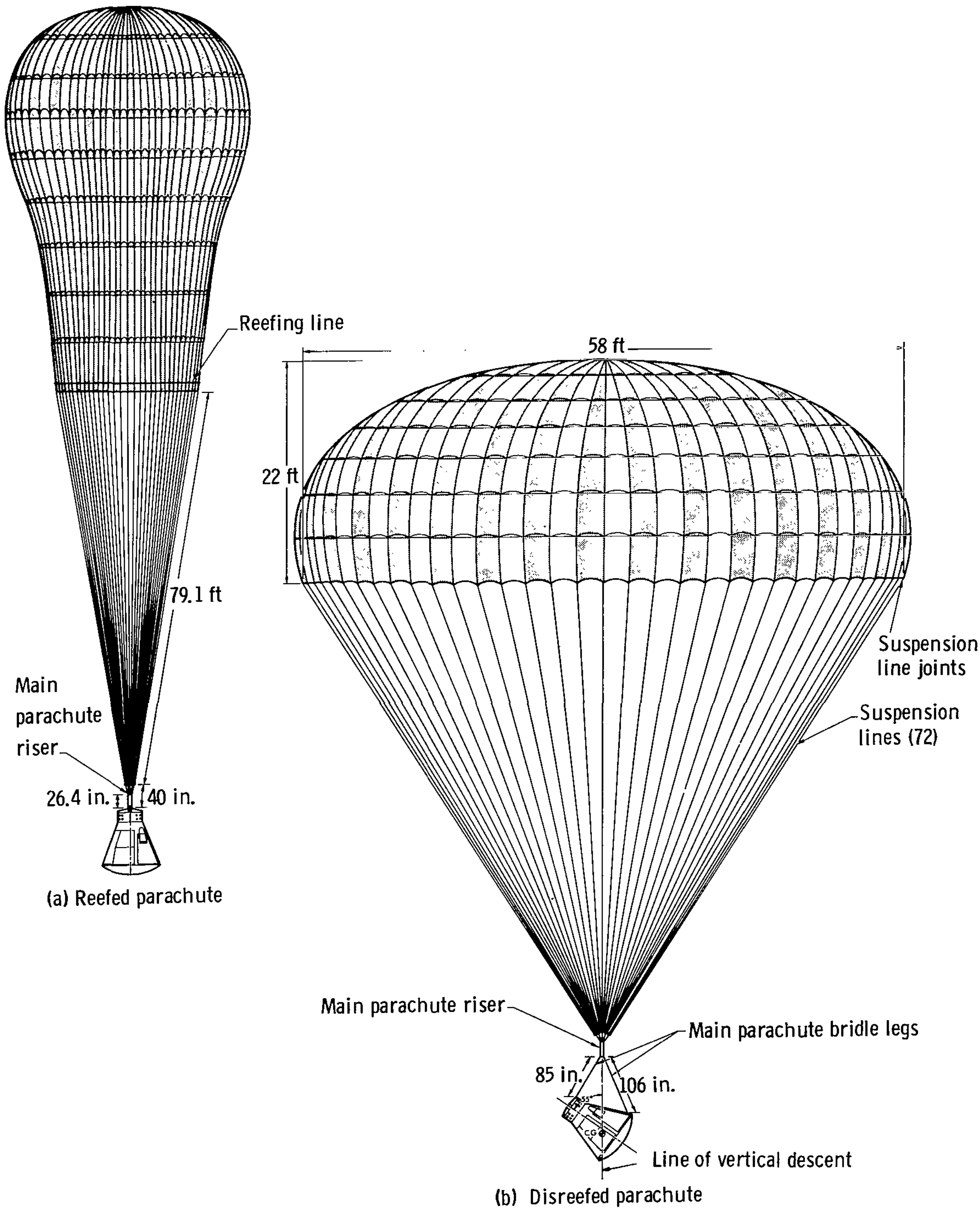

(a) Reefed parachute

(b) Disreefed parachute

Figure 3. - Main parachute assembly.

descent that prevents recontact of the R and R section with the main parachute canopy (less than 48 feet per second at an altitude of 10 000 feet, with a weight of 330 pounds).

The pilot parachute canopy has 16 gores and 5 rows of sails and is fabricated from 1.1- and 2.25-ounce-per-square-yard nylon cloth. Sixteen suspension lines of 550-pound nylon cord attach the canopy to a split riser constructed of four layers of 2600-pound nylon webbing. The two riser ends are attached to steel cables fastened to the face of the R and R section. A reefing line of 750-pound nylon cord controls the reefing ratio to 11.5 percent of D_o. (A reefing ratio of 13 percent of D_o was used for the unmanned Gemini II flight.) The reefed parachute is designed to withstand a deployment dynamic pressure of 120 pounds per square foot at an altitude of 10 000 feet.

A 6000-pound nylon pilot parachute apex line is fastened to one of the drogue parachute riser legs. The function of the apex line is to pull the pilot parachute from its mortar upon release of the drogue parachute. A leather grommet was used to guide the apex line during the development of the pilot parachute; however, the grommet was later deleted. The apex line is free to float between the crossed-over suspension lines at the vent of the pilot parachute.

Main Parachute Assembly

The main parachute is an 84.2-foot-diameter* ringsail parachute designed to land the reentry module at a descent rate of 29.8 ± 1.8 feet per second at 1000 feet above sea level. The canopy has 72 gores and 13 rows of sails and is fabricated from 1.1- and 2.2-ounce-per-square-yard nylon cloth. Seventy-two suspension lines of 550-pound nylon cord attach the canopy to eight legs of a main riser comprised of eight layers of 5500-pound nylon webbing. The main riser is connected to a two-legged bridle assembly which allows repositioning of the reentry module from a single-point, nose-up suspension to a two-point suspension with the nose 35° above the horizontal.

The reefing line is made of 2000-pound nylon cord, and its length controls the main parachute reefing ratio to 10.5 percent of D_o. The reefed canopy is designed to withstand a nominal deployment dynamic pressure of 120 psf, and an ultimate dynamic pressure of 180 psf. The maximum allowable load imposed to the spacecraft structure is 16 000 pounds.

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*Diameter = D_o

Attendant Landing System Equipment

The following paragraphs contain descriptions of the landing system equipment provided in addition to the major components previously described. This equipment, except crew-station controls and displays, is shown in figures 4 and 5.

Main parachute bridle assembly. - The forward leg of the bridle assembly is constructed of three layers of 9000-pound nylon webbing, and the aft leg consists of four layers of 6000-pound webbing made of special heat-resistant HT-1 nylon. The bridle design loads are 9400 pounds for the forward leg and 7650 pounds for the aft leg.

Bridle disconnect assemblies. - The aft leg of the bridle assembly is stored in a trough located between the hatches and extends the length of the reentry module. The pyrotechnic-operated main bridle disconnect assembly, equipped with two separate cartridges, bears the shock of opening loads. Upon release of the main disconnect (crew function), the aft leg of the bridle assembly is drawn out of the trough, and the reentry module is suspended from two disconnect assemblies at each end of the reentry module. All three disconnect assemblies are similar in construction and operation.

Mortar assemblies. - The pilot and drogue parachutes are packed in deployment bags and stored in identical mortar tubes. A breech assembly containing two electrically-activated pyrotechnic cartridges is located at the base of each mortar tube to eject the parachutes. In the case of the pilot parachute, however, the mortar is fired only in the event of a drogue parachute malfunction. The drogue parachute mortar breech assembly is constructed of aluminum, whereas the pilot parachute mortar breech assembly is steel. The stronger material is necessary in the second case because different types of cartridges, which detonate sympathetically, resulting in higher breech pressures, are used in the pilot breech. A higher ejection velocity for the pilot parachute pack is desired to insure proper deployment in the event a failure necessitates selection of this sequence.

Guillotines. - Four guillotines associated with the parachute landing system are located near the face of the R and R section. An apex line guillotine severs the pilot parachute apex line in case of a drogue parachute malfunction. The remaining three are drogue parachute riser guillotines provided to sever the three riser cables near their attachment points. Each guillotine has two cartridges, and each cartridge has a separate electrical circuit to provide redundancy.

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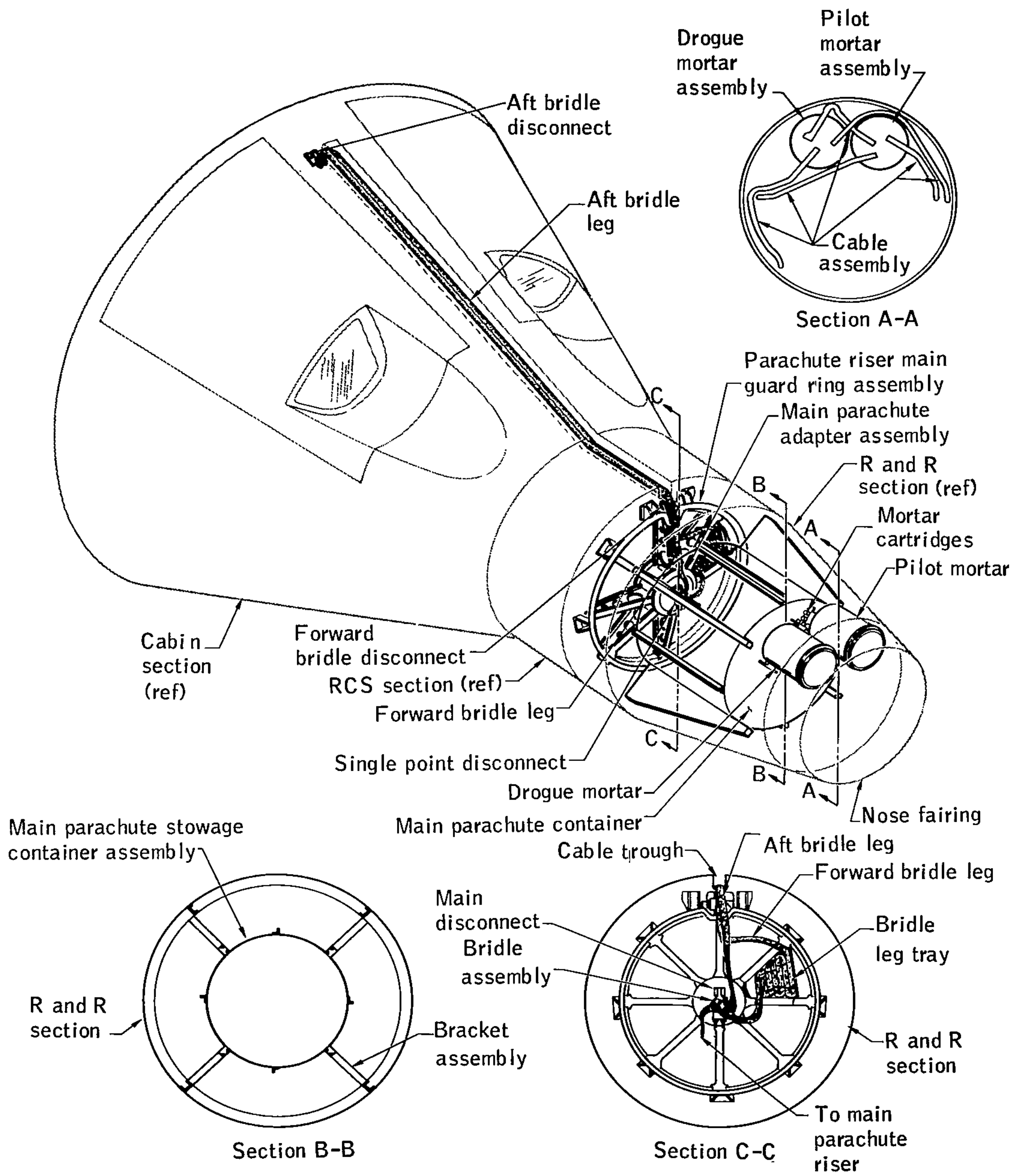

Figure 4.- Parachute landing system components.

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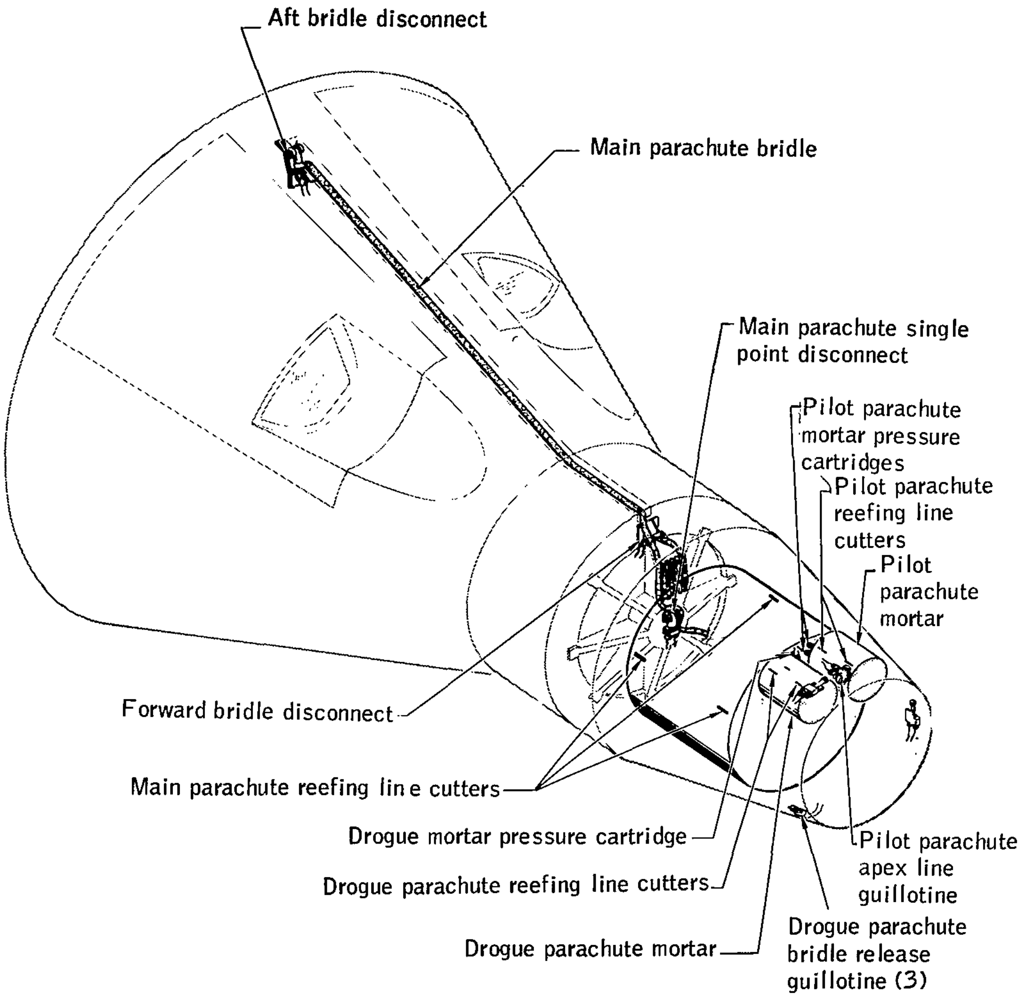

Figure 5.- Parachute landing system pyrotechnics.

Reefing cutters. - The reefing cutters are pyrotechnic devices sewn to the skirts of the drogue, pilot, and main parachute canopies. When initiated, these devices disreef the parachutes after specified time delays, as indicated below:

Parachute	Number installed	Circumferential separation, degrees	Time delay, seconds
Drogue	2	180	16
Pilot	2	180	6
Main	3	120	10

All seven reefing cutters are similar in design and operation. A cutter consists of a tubular body containing a blade, firing mechanism, and a percussion-fired, time-delay cartridge. A hole in each side of the body permits reefing-line installation. A cutter is initiated by means of a lanyard upon deployment of the associated parachute and, after the specified time delay has elapsed, severs the reefing line. Proper functioning of only one cutter is sufficient to perform disreefing.

Controls and displays. - In the normal sequence of operation of the landing system, four switches must be manually operated by the crew. These switches are located in the crew station on the pedestal instrument panel and are labeled, from left to right: "DROGUE, PARA, LDG ATT, and PARA JETT" (See fig. 6 for details). If a drogue parachute malfunction necessitates initiation of an alternate landing sequence of operation, the "PRE-MAIN 10.6K" switch, located in the upper left corner of the command pilot's instrument panel, is operated. Two amber warning lights are installed adjacent to the "PRE-MAIN 10.6K" switch. The light labeled "40K" illuminates at an altitude of 40 000 feet, reminding the crew to confirm deployment of the drogue parachute. The light labeled "10.6K" illuminates at 10 600 feet, reminding the crew to deploy the main parachute.

SYSTEM OPERATION

Near the conclusion of the reentry phase of a flight, after the reentry module has passed through an altitude of 80 000 feet, the command pilot

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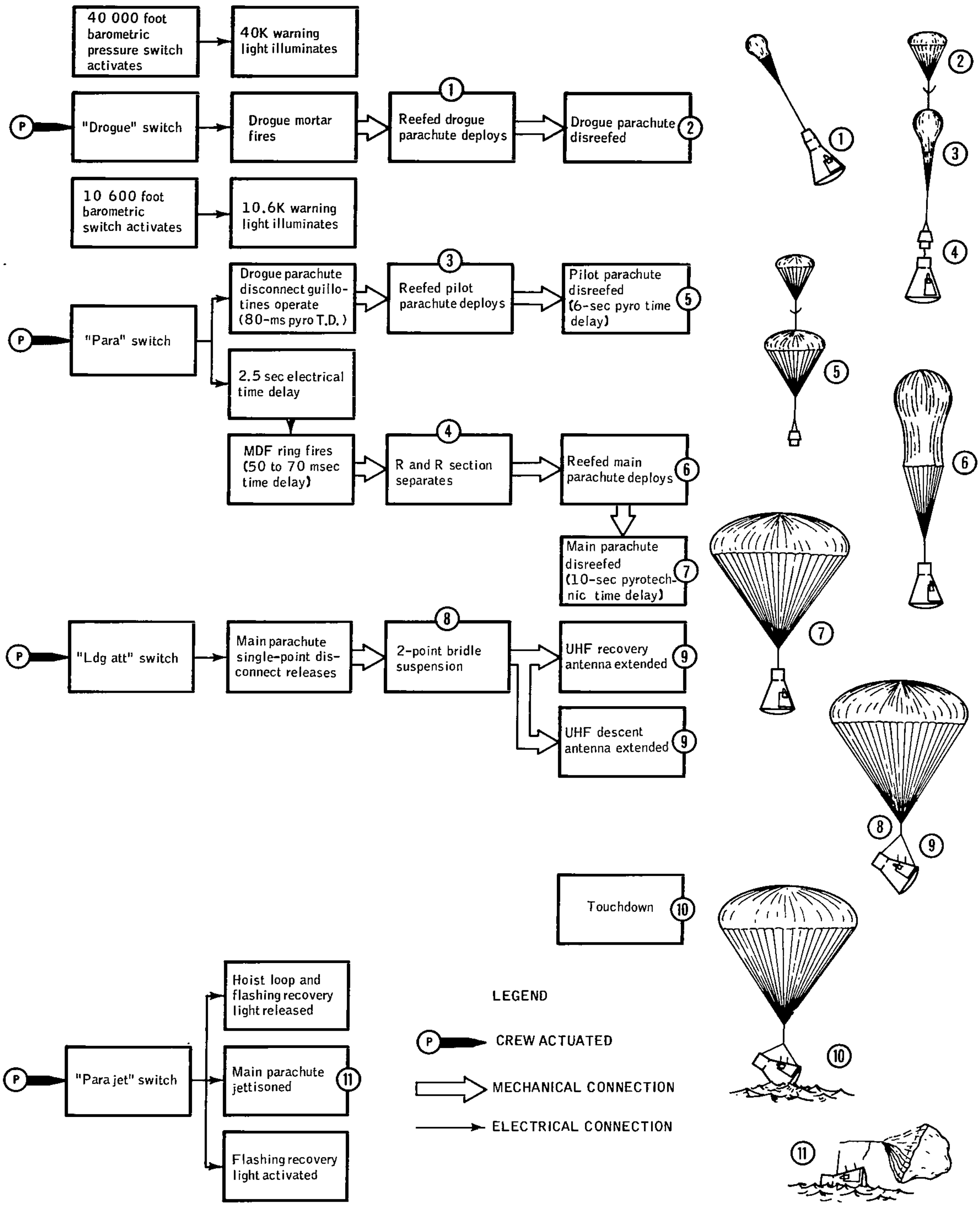

Figure 6.- Normal sequence block diagram.

places the "LANDING" switch, located on the left switch/circuit breaker panel, in the "ARM" position. This connects electrical power to the landing common control bus from which the "40K" and "10.6K" baroswitches are armed. The "LANDING" switch also energizes the landing squib buses that furnish power to the "DROGUE, PRE-MAIN 10.6K, PARA, LDG ATT, and PARA JETT" switches, to the relays they control, and to the associated pyrotechnics. The command pilot initiates the landing sequence by pressing the "DROGUE" switch after passing through an altitude of 50 000 feet, as indicated by the altimeter. The resulting sequential functions following this action are illustrated by the block diagram in figure 6. Operation of the "DROGUE" switch initiates the two pyrotechnic cartridges in the drogue mortar. The gas pressure from the detonation of the cartridges ejects the drogue parachute pack from the mortar, and the drogue inflates in the reefed condition. Sixteen seconds after drogue ejection, two reefing-line cutters sever the reefing line; the disreefed drogue then stabilizes the reentry module until the main parachute is deployed. At an altitude of 40 000 feet, the "40K" baroswitch contacts close, illuminating the "40K" warning light on the command pilot's instrument panel.

Normal Main Parachute Deployment Sequence

As the reentry module passes through an altitude of 10 600 feet, as indicated by the altimeter, the command pilot presses the "PARA" switch to initiate the main parachute deployment sequence. The "10.6K" baroswitch-controlled warning light also illuminates at 10 600 feet, indicating to the flight crew that the main landing parachute should be deployed. The first event to occur after depression of the "PARA" switch is the activation of the drogue riser guillotines. These guillotines sever the three steel cables that attach the drogue parachute to the R and R section. The drogue then extracts the pilot parachute pack from its mortar by means of the pilot parachute apex line, as shown in figure 7(a), and the pilot parachute deploys in the reefed condition.

Approximately 2.5 seconds after deployment of the reefed pilot parachute, four wire bundle guillotines are initiated (two on each side of the separation plane). These guillotines cut two wire bundles, and the R and R section is separated from the reentry module by a mild detonating fuse (MDF) ring which fractures 24 attachment bolts. As the R and R section is pulled away by the pilot parachute, the main landing parachute is deployed in an orderly manner with straight-lined payout of suspension lines and canopy. Six seconds after deployment of the pilot parachute, two reefing-line cutters disreef the canopy.

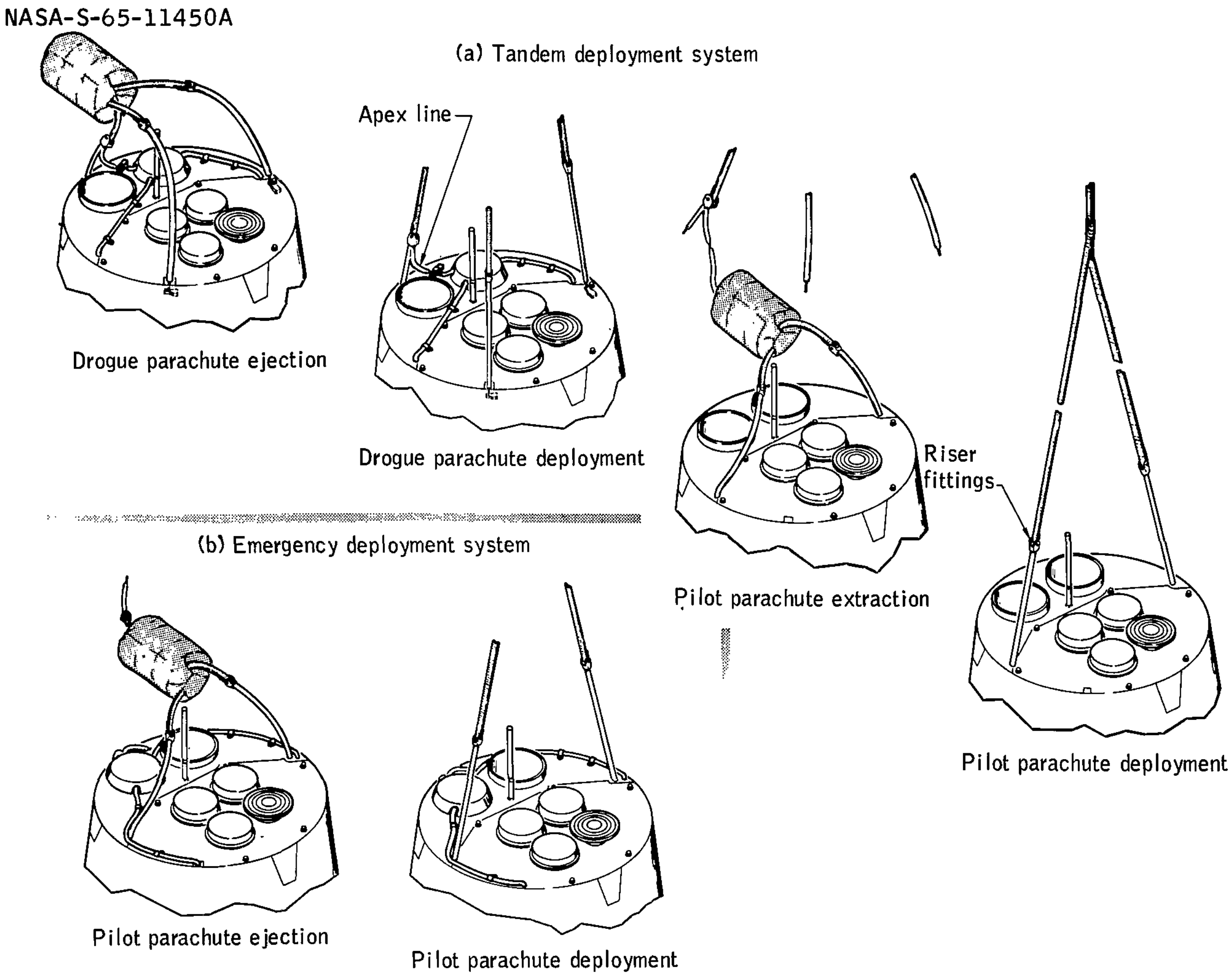

Figure 7.- Drogue and pilot parachute operation.

Upon deployment, the main parachute inflates to a reefed condition. After a 10-second time delay, the main parachute is disreefed. The loads resulting from the opening of the main parachute to the reefed condition and to the fully inflated condition are imposed on the single-point (main) disconnect assembly on the face of the RCS section. After disreefing of the main canopy and its stabilization in the fully inflated condition, manual operation of the "LDG ATT" switch results in initiation of the pyrotechnic-operated, single-point disconnect assembly. Operation of the single-point disconnect allows the reentry module to rotate to the two-point bridle suspension. The bridle positions the reentry module to a 35° nose-high attitude. This is the optimum position for entry into the water on the corner of the heat shield. After landing, the "PARA JETT" switch is activated. This initiates the two redundant pyrotechnic-operated bridle disconnect assemblies and releases the main parachute to prevent it from dragging the reentry module through the water.

Alternate Main Parachute Deployment Sequence

If the drogue parachute system fails, an alternate deployment sequence is manually activated at an altitude of 10 600 feet by depressing the "PRE-MAIN 10.6K" switch. This initiates four guillotines. One severs the apex lanyard, and three cut the steel attach cables, freeing the drogue parachute from the reentry module, figure 7(b). After a 0.5-second delay from switch operation, the pilot parachute pack is ejected from its mortar and deployed, as shown by the sequential block diagram in figure 8. From this point on, the landing sequence of operation is the same as the normal mode.

Launch Abort

The parachute landing system would also be used in the event of a launch abort above 15 000 feet. Special procedures have been formulated for the crew to follow to utilize the landing system for safe recovery.

TESTS AND RESULTS

Development Test Program

Drogue parachute.- The objectives of the drogue parachute test series were to establish reefing ratio, reefing time, and qualification of the drogue canopy. The development and qualification of the riser assembly were accomplished during the complete systems tests and will be discussed in the section on system qualification. The tests were conducted at the Department

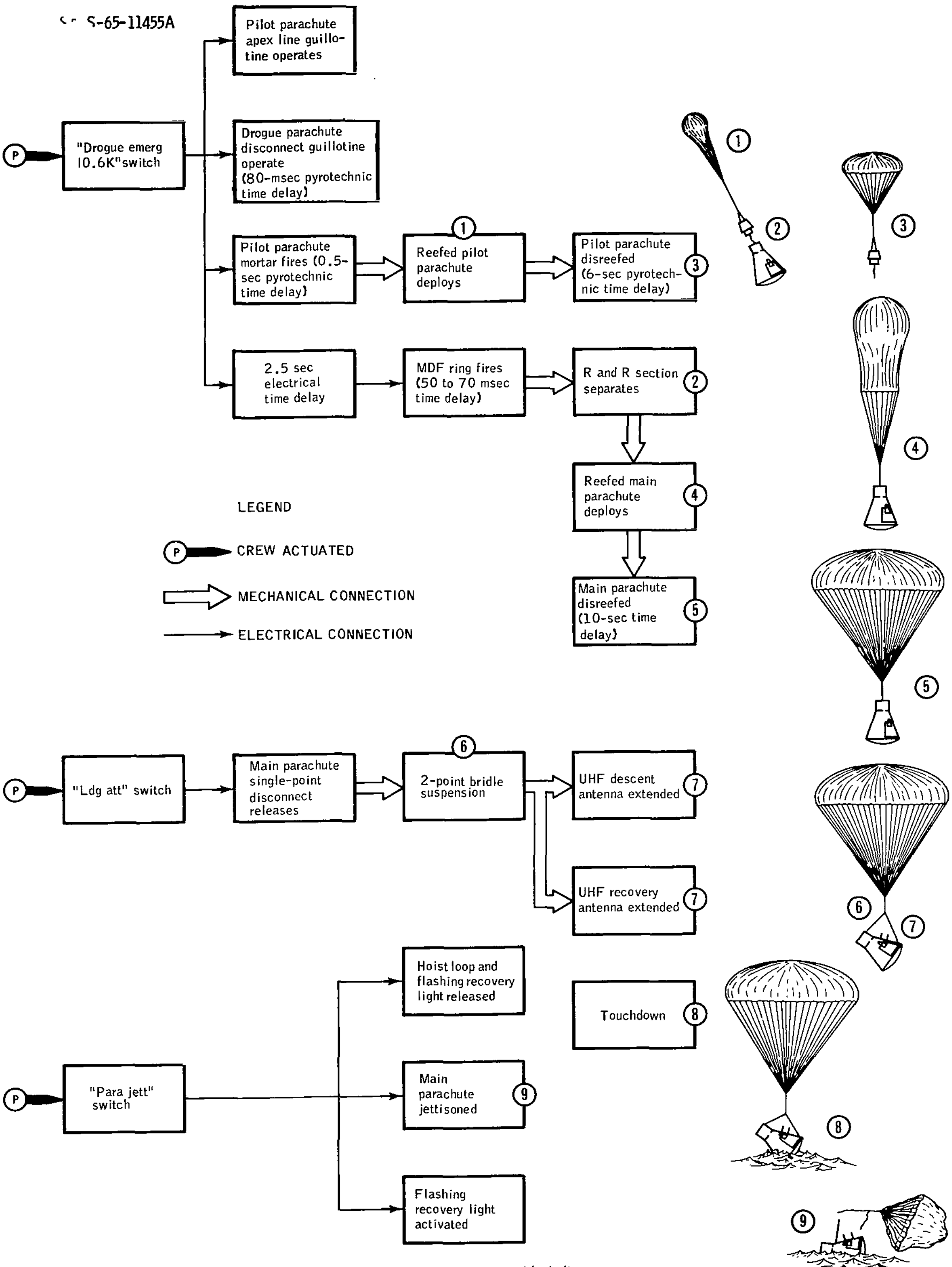

Figure 8.- Auxiliary landing sequence block diagram.

of Defense Joint Parachute Test Facility, El Centro, California. A summary of the tests is presented in table I.

Test configuration: The test vehicle was a simple cylindrical bomb equipped with telemetry and onboard cameras. It had the same design weight as the Gemini reentry module, but it did not match the drag area. Three parachute mortars were installed in the aft end. One mortar deployed a drag parachute to provide a simulation of the Gemini drag area, and a second deployed the test canopy. The third mortar contained a high-strength drag parachute that was deployed to slow the vehicle in case of a test failure, enabling the main recovery parachute to be deployed safely.

A study conducted by the contractor (Aerodynamics Information Note No. 51, McDonnell Aircraft Corporation, 1964) established the size of the drogue parachute and the number of riser-leg attachments to provide the necessary stability level of $\pm 24^\circ$.

Parameter selection: For a nominal Gemini spacecraft reentry, the trajectory parameters for drogue parachute deployment are indicated as follows:

Parameter (a)	Deployment of reefed drogue at 50 000-ft altitude	Drogue disreef at 40 000-ft altitude (b)
Mach number, M	0.84	0.57
Dynamic pressure, q	120 psf	98 psf
Flight-path angle	-65°	-89°

[a]Determined by analytical studies.

[b]Approximate altitude 16 seconds after drogue deployment in the reefed condition.

Because of performance limitations of the test aircraft, it was not possible to match the flight parameters of the nominal Gemini spacecraft trajectory. The dynamic pressure, q, could not be matched with the proper Mach number, M, and the flight-path angle was too shallow. These conditions resulted in an excessively rapid dynamic pressure decay, and the preselected 16-second reefing time could not be duplicated. To balance out the reefed

TABLE I. - HIGH-ALTITUDE DROGUE PARACHUTE DEVELOPMENT DROP TESTS

Test number		Launch altitude, ft	Drag parachute deployment altitude, ft	Test parachute										Main parachute					Remarks
				Deployment altitude, ft	Reefing conditions		Deployment	Reefed opening		X factor	Disreef			Reefing conditions		Deployment	Reefed opening force, lb	Disreef force, lb	
MAC[a]	El Centro, California				Percent D_o	Time, sec	q, psf	Mach number	Force, lb	(b)	q, psf	Mach number	Force, lb	Percent D_o	Time, sec	q, psf			
39 D1	0382F64	45 000	N/A[c]	N/A	35	16	N/A	N/A	N/R[d]	N/A	N/A	N/A	N/R	10.5	10	N/A	N/A	N/R	Parachute disconnect malfunction, vehicle destroyed
43 D2	0589F64	45 500	43 975	N/A	35	16	N/A	N/A	N/R	N/A	N/A	N/A	N/R	10.5	10	N/A	N/A	N/R	Sequence malfunction, no data
44 D3	0756F64	44 500	43 450	37 000	35	16	106	0.56	2250	1.51	84	0.43	2900	10.5	10	71	10 800	12 300	Good data
46 D4	0870F64	45 000	44 450	40 900	35	16	104	.63	2200	1.41	80	.46	2850	10.5	10	133	13 300	16 000	Good data
48 D5	0932F64	45 000	34 250	44 300	35	6	122	.74	2300	1.24	N/A	N/A	N/R	10.5	10	128	N/R	N/R	Drogue parachute did not disreef
49 D6	1004F64	45 000	41 100	44 400	49.5	12	123	.74	3750	1.23	102	.63	3700	10.5	10	83	11 500	12 250	Reef ratio increased to 49.5 percent, rapid pulsation
50 D7	1085F64	42 000	38 075	42 000	49.5	12	117	.68	3450	1.28	108	.61	3300	10.5	10	83	10 700	13 800	Inflation control line installed, good data
51 D8	1154F64	44 000	42 900	39 800	48	16	148	.73	4300	1.29	78	.44	2500	10.5	10	84	10 500	14 800	140 q test, good data
52 D9	1188F64	45 200	42 000	42 500	48	12	159	.82	4980	1.33	94	.56	3150	10.5	10	159	11 200	13 200	160 q test, good data
53 D10	1189F64	45 000	41 350	41 400	48	12	188	.85	5600	1.27	156	.66	5400	10.5	10	156	17 000	14 000	180 q test, good data
54 D11	1509F64	44 000	42 600	39 400	48	10	146	.71	4700	1.37	76	.46	2500	10.5	10	152	12 400	10 500	Reef ratio reduced to 43 percent
55 D12	1600F64	43 200	41 600	39 000	43	6	144	.70	4100	1.30	93	.53	3100	10.5	10	145	10 700	13 900	Abort mode test
56 D13	1601F64	43 000	39 000	42 700	43	6	118	.69	2900	1.27	103	.64	3400	10.5	10	113	12 700	14 600	Design q test
57 D14	1709F64	43 800	42 100	39 500	43	6	153	.73	4650	1.41	101	.55	3200	10.5	10	153	11 200	15 000	Abort mode test
58 D15	1912F64	43 600	41 450	40 000	43	6	143	.76	3750	1.33	161	.71	5350	10.5	10	132	13 250	14 700	Abort mode test

[a]McDonnell Aircraft Corporation.

[b]Opening shock factor: the relationship of peak opening shock force divided by the constant forces at equivalent velocity.

[c]Not applicable.

[d]Not recorded.

opening and the disreef shock loads, it was necessary to compromise in the selection of test parameters. It was decided that the dynamic pressures under reefed-opening and disreef conditions would be matched. The opening and disreef shock loads were limited to less than 3500 pounds, all-angle-design pull-off load, and 4300 pounds for the launch abort case.

Although a reefing cutter having a time delay of less than 16 seconds was eventually required to approximate the disreef parameters, testing was started with a 16-second reefing time and a reef ratio of 35 percent to determine opening shock factors for extrapolation of data.

Test procedure: A typical test sequence began with release of the test vehicle from 45 000 feet. The drag parachute was deployed, and the vehicle free-fell to the selected Mach number and dynamic pressure. The test parachute was then mortared out, and the canopy was disreefed at the selected time. At 10 600 feet, a baroswitch actuated two explosive bolts which freed the aft section and deployed the main recovery parachute. The test canopy and drag parachute provided a sufficiently low rate of descent for the aft section so that it could be recovered and reused.

Results: The first test resulted in catastrophic failure of the test vehicle. During the second test, a premature deployment of the parachute invalidated the data. The third and fourth tests were completely successful. Data revealed that the dynamic pressure was too low at both parachute opening and disreef. On the fifth drop, the opening shock test parameters were approximated, but a failure of the reefing cutters occurred, and no disreef data were obtained. Examination of the data showed that the opening shock loads and drag area were low; consequently, an adjustment in reefing ratio was made. The reefing time was also reduced because the dynamic pressure was too low at disreef. The reefing ratio was changed to 49.5 percent of D_o, and the time delay reduced to 12 seconds. The sixth test resulted in severe pulsations after disreef, a condition caused by overinflation during disreef. An overinflation control-line made of synthetic fiber was installed to control the fully inflated diameter. The reefing ratio was adjusted to 48 percent of D_o, and the 8th through 11th tests were completed successfully.

The drag area versus reefing ratio relationships obtained from the tests are shown in figure 9(a). Figure 9(b) shows drag area versus time from drogue mortar firing. A reefing ratio of 69 percent of D_o reflects the fully inflated configuration. The structural integrity of the canopy was demonstrated by deploying the parachute at 188 psf, which is greater than the required 1.5 times the design q. Tests conducted at the abort condition showed that the loads were slightly larger than the design loads. An analysis of the

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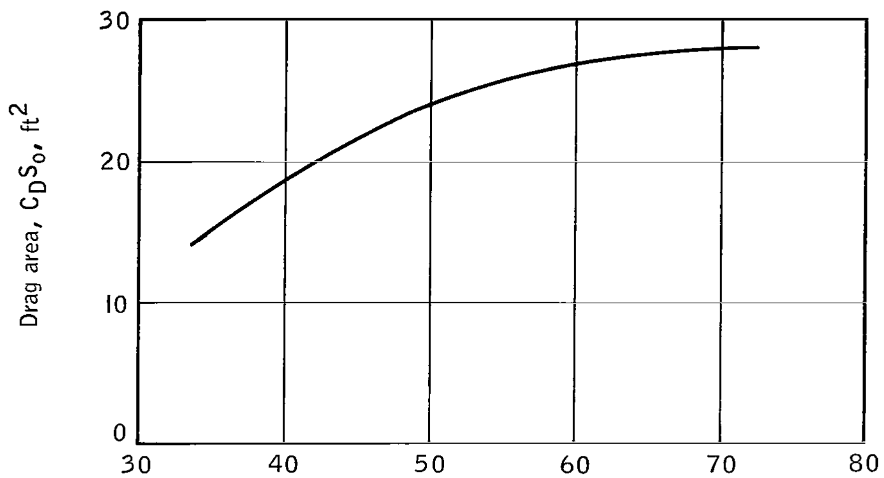
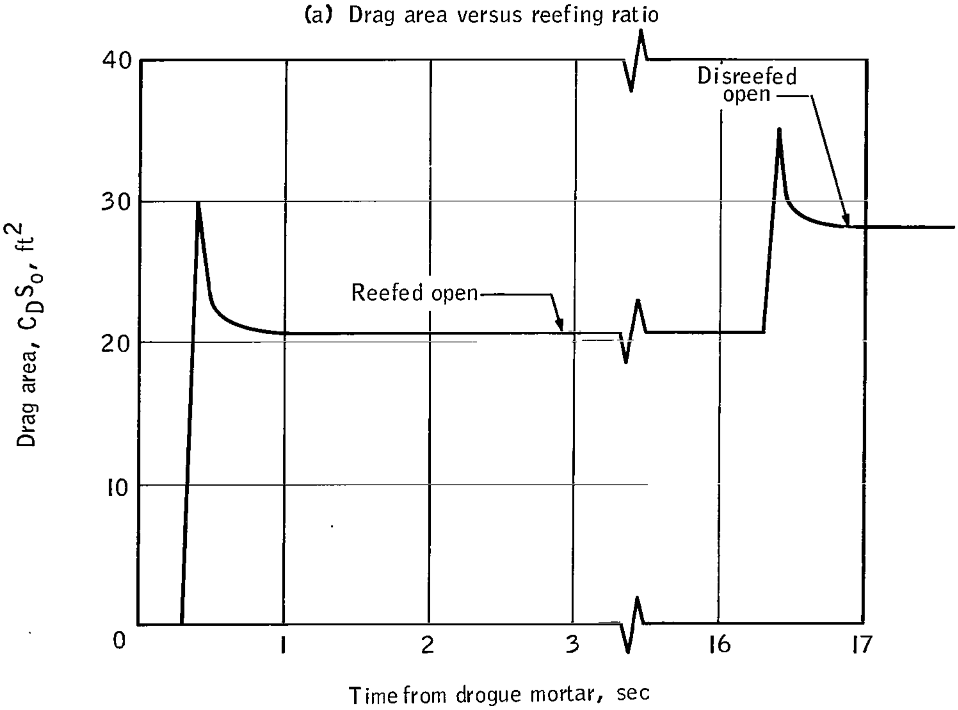


(a) Drag area versus reefing ratio



(b) Drag area versus time from drogue mortar firing

Figure 9.- Drogue parachute data.

structure showed that it could withstand the loads and still have a margin of safety for the abort case. Drops 12 through 15 were conducted with 43-percent reefing ratio and 6-second reefing cutters. Figures 10(a) and 10(b) show the opening and disreef loads data obtained from all the tests.

Qualification of the canopy was completed at the worst abort condition of 146 psf at 40 000 feet during drops 12, 14, and 15. The qualification of the riser assembly was completed during the complete landing system tests (see the section on system qualification) where the use of the static article test vehicles provided for proper rigging of the riser and attach cables.

Pilot parachute. - The objectives of the pilot parachute development test program were to verify the specified rate of descent and reefing ratio which would not exceed the structural design limit of the R and R section.

Test configuration and procedure: For this series of tests, the reefing time was set at 6 seconds. In tests 1 through 4 (table II), the R and R section was simulated by a simple bomb weighing 330 pounds. In the first test, the parachute was reefed to 8 percent of D_o, which resulted in loads well below the design limit. After the fourth test, the pilot parachute and riser were tested in conjunction with the main canopy. The reefing ratio was increased during subsequent testing. This was done to increase the separation velocity between the R and R section and the reentry module so that the main canopy would be deployed in a straight line and would not invert the R and R section (this inversion is caused by the main canopy stripping out and forming a long sail, deploying faster than the R and R section separates). Figure 11(a) shows a plot of reefing ratio versus drag area. For the pilot parachute, 13.5-percent reefing was used, and 11.5-percent reefing was used for the pilot/drogue tandem system. Originally, reefing was used to limit the loads to less than 3000 pounds. For the pilot and drogue parachutes in tandem, this limit was increased to 3500 pounds.

The testing of the mortar to eject the pilot parachute pack was accomplished during the later boilerplate drops. An extensive ground test program was also completed to insure proper deployment of the bag and attach cables.

The qualification of the canopy and the development and qualification of the riser assembly were completed during the complete landing systems testing with the boilerplate and static article test vehicles. (See the section on system qualification.)

Results: Detailed results of the pilot parachute development tests are given in tables II(a) and II(b). Testing has shown that the 6-second reefing time satisfies the requirement to prevent recontact with the main canopy. The

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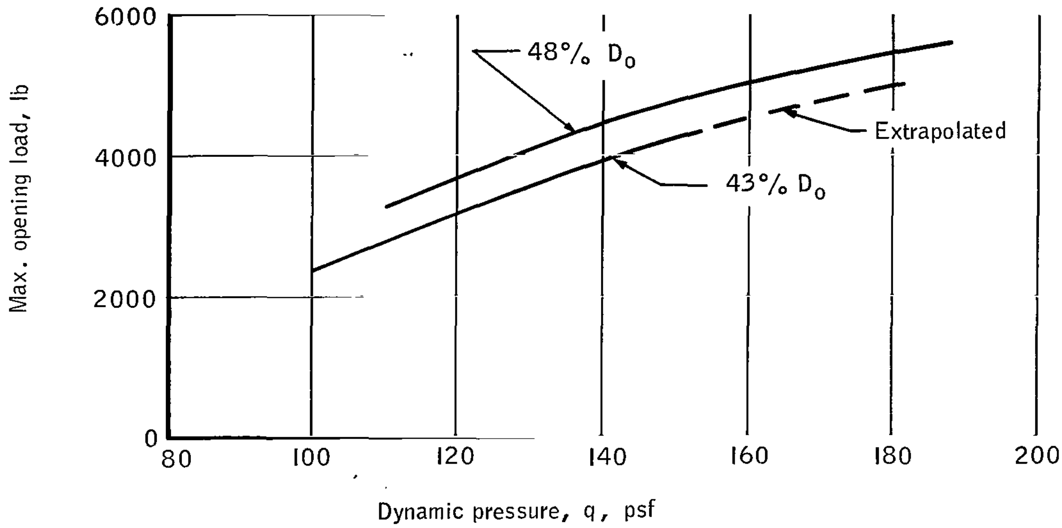
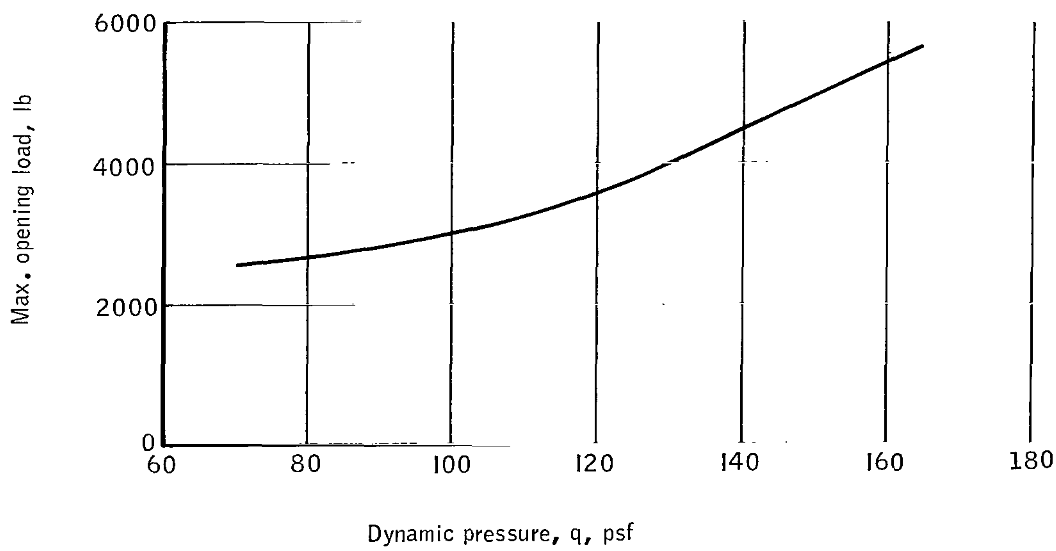


(a) Reefed open



(b) Disreefed open

Figure 10.- Drogue parachute loads data.

TABLE II. - DEVELOPMENT DROP TESTS

(a) Pilot and main parachute

Test number		Launch altitude, ft	Free-fall weight, lb	Pilot parachute				Main parachute								Remarks
				Reefing		Deployment q, psf	Maximum reefed, open load, lb	Reefing		Deployment q, psf	Maximum reefed, open load, lb	Maximum disreefed, open load, lb	Rate of descent MSL[b], ft/sec	Maximum bridle loads, lb		
MAC[a]	El Centro, California			Percent D_o	Time, sec			Percent D_o	Time, sec					Fwd[d]	Aft	
1	1480F62	3 096	330	11	6	52	1150	N/A[d]	N/A	N/A	N/A	N/A	44.9	N/A	N/A	Drop altitude low
2	1492F62	10 770	330	8	6	38	650	N/A	N/A	N/A	N/A	N/A	46.1	N/A	N/A	Rate of descent satisfactory
3	1481F62	10 740	330	8	6	48	1000	N/A	N/A	N/A	N/A	N/A	131.0	N/A	N/A	Did not disreef
4	1523F62	10 600	330	8	6	60	850	N/A	N/A	N/A	N/A	N/A	43.9	N/A	N/A	Rate of descent satisfactory
5	1733F62	10 300	4730	N/A	N/A	N/A	N/A	9.5	8	83	N/A	N/A	29.5	N/A	N/A	3 to 5 gore infold
6	1734F62	10 250	4400	N/A	N/A	N/A	N/A	9.5	8	79	10 475	12 350	29.6	N/A	N/A	3 to 5 gore infold
7	1778F62	10 800	4850	8	6	N/A	1200	9.5	8	N/A	N/A	N/A	27.2	N/A	N/A	3 to 5 gore infold
8	1779F62	11 100	4850	8	6	90	1100	9.5	8	130	8 600	N/A	N/A	N/A	N/A	21-foot conical cap failed and parachute streamed
9	1887F62	9 560	4730	8	6	93	1100	9.5	8	130	9 500	15 000	30.6	N/A	N/A	Conical cap removed, infold present
10	1795F62	10 800	4730	10	6	92	1520	9.5	8	128	10 400	15 400	30.0	N/A	N/A	Main parachute reinforced, pilot parachute reef ratio increased
11	1964F62	10 800	4730	11	6	89	1550	10.5	8	105	12 000	14 200	30.0	N/A	N/A	Infold present, pilot and main parachute reef ratio increased
12	1984F62	10 800	4730	11	6	94	1900	10.5	8	121	12 800	13 200	30.0	N/A	N/A	Infold present
13	1993F62	10 800	4730	11	6	94	1600	10.5	8	120	12 200	13 300	28.7	N/A	N/A	Main parachute reinforced, infold present
14	2045F62	10 800	4730	11	6	96	1750	10.5	8	119	13 000	13 700	29.2	N/A	N/A	Fullness removed from upper sails
15	2048F62	11 460	4780	11.5	6	121	1600	10.5	8	141	14 700	13 700	28.6	N/A	N/A	115 percent design q, pilot parachute reef ratio increased
16	2049F63	11 750	4730	11.5	6	134	1850	10.5	8	150.7	16 300	13 700	26.7	N/A	N/A	125 percent design q
17	2063F63	12 325	4780	11.5	6	155	1850	10.5	8	168.2	15 100	14 000	30.0	N/A	N/A	140 percent design q
18	0001F63	14 550	4770	11.5	6	181	2800	10.5	8	176.3	14 100	15 800	30.0	N/A	N/A	150 percent design q, sail damage
19	0002F63	15 000	4730	11.5	6	178.5	2600	10.5	8	177	17 700	14 700	30.0	N/A	N/A	150 percent design q, sail damage
20	0086F63	15 000	4770	11.5	6	171	2600	10.5	8	180.5	17 000	14 700	30.0	N/A	N/A	150 percent design q, sail damage
21	0760F63	20 000	4730	11.5	6	113	2380	10.5	8	112	13 800	12 300	30.0	3700	3600	Unilon shock absorber
22	0802F63	20 000	4730	11.5	6	121	2000	10.5	8	123	15 600	11 700	27.0	N/A	3800	Shock absorber deleted
23	0865F63	20 000	4730	11.5	6	112	N/A	10.5	8	111	11 800	12 700	30.5	N/A	5800	Good test
24	0883F63	20 000	4730	11.5	6	96	2070	10.5	8	100	11 200	13 000	30.0	7200	5800	Infold present
25	0922F63	20 000	4730	11.5	6	96	N/A	10.5	8	105	13 900	12 500	29.0	N/A	5850	Infold present
31	1219F63	20 000	4730	11.5	6	111	N/A	10.5	8	72	14 650	11 500	N/A	6000	N/A	Water landing
33	1312F63	20 000	4730	11.5	6	118	N/A	10.5	8	115	12 700	11 300	N/A	6575	5200	Water landing

[a]McDonnell Aircraft Corporation.
[b]Mean sea level.
[c]Forward.
[d]Not applicable.

TABLE II. - DEVELOPMENT DROP TESTS

(b) Infold fix tests on main parachute

Test number		Launch altitude, ft	Free-fall weight, lb	Main parachute			Remarks
				Reefing		Deployment q, psf	
MAC[a]	El Centro, California			Percent D_0	Time, sec		
26	1074F63	6 000	4400	10.5	8	85	Sail no. 8 reduced 2.3 percent by tape, infold partially eliminated
27	1120F63	10 200	4400	10.5	8	58	Sail nos. 8 and 10 reduced 2.3 percent by tapes, infold partially eliminated
28	1196F63	10 000	4400	10.5	8	72	Sail nos. 7 to 13 reduced 2 percent by tapes, no infold
29	1199F63	6 000	4400	10.5	8	72	Same configuration as test 28, no infold
30	1209F63	10 000	4400	10.5	8	72	No infold
32	1231F63	10 000	4400	10.5	8	120	No infold

[a]McDonnell Aircraft Corporation.

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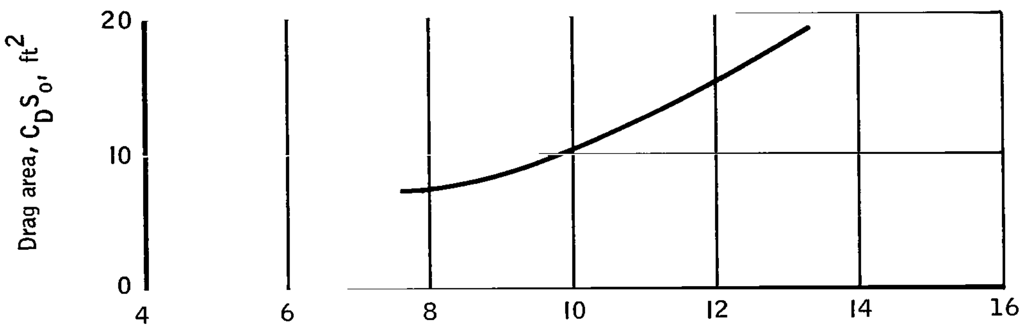
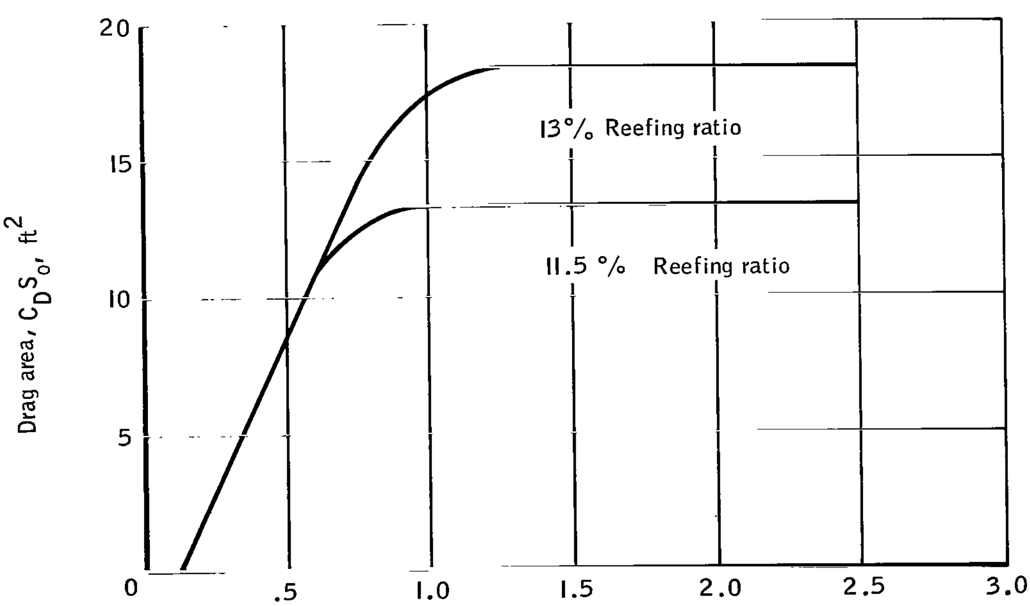


(a) Drag area versus reefing ratio



(b) Drag area versus time from pilot mortar firing

Figure 11.- Pilot parachute data.

pilot parachute does not have a well-defined opening shock load as shown by figure 11(b). The requirement for a rate of descent less than 48 feet per second at 10 000 feet with a fully opened canopy was demonstrated during the complete landing systems tests. The loads imposed on the structure were less than the specified 3500 pounds.

Main parachute. - The objectives of this test program were to demonstrate rate of descent, reefing parameters, structural integrity of the canopy and bridle assembly, deployment with the pilot parachute, and complete landing sequential system operation.

Test configuration and procedure:

(1) Tests 6 through 20 - The first series of main parachute drop tests was conducted with a parachute-test-vehicle bomb as noted in table II(a). These tests determined the reefing ratio, the reefing time necessary to keep the loads to an acceptable limit, and they demonstrated the structural integrity of the canopy at 1.5 times design dynamic pressure. The reefing ratio was set at 10.5 percent for 8 seconds, resulting in satisfactory reefed-opening and disreef loads.

(2) Tests 21 through 25 - Tests 21 through 25 were conducted with a boilerplate spacecraft. This vehicle simulated the weight, center of gravity, and aerodynamic shape of the reentry module. Use of the boilerplate vehicle allowed for the phasing-in of other components so that complete system testing could be accomplished. These additions were the pilot parachute and riser, repositioning bridle, and the deployment of the main parachute from a simulated R and R section. Instrumentation was added to the two bridle legs so that loads could be measured. A summary of bridle loads is presented in tables II(a) and III. After drop 21, a shock absorber was deleted from the forward bridle leg, because the loads were not of sufficient magnitude to require special attenuation.

(3) Tests 26 through 30, and 32 - During the initial series of tests, it was noted that infolding of several gores of the main canopy occurred after disreef and during steady-state descent. The infolding resulted from an excessive amount of material in the gore design. The circumferential fullness was greater than that required to provide a free-equilibrium shape when fully inflated. To solve the problem, the following approaches were considered.

a. Remove material from the width of each gore.

b. Restrict the gore width with control tapes.

c. Lengthen the suspension lines.

TABLE III. - TANDEM PILOT/DROGUE PARACHUTE DEVELOPMENT DROP TESTS

Test number: MAC[a]	Test number: El Centro, California	Launch altitude, ft	Free-fall weight, lb	Tandem pilot/drogue parachutes: Reefing (pilot), Percent D_o	Tandem pilot/drogue parachutes: Reefing (pilot), Time, sec	Tandem pilot/drogue parachutes: Deployment q, psf	Tandem pilot/drogue parachutes: Maximum reefed, open load, lb	Main parachute: Reefing, Percent D_o	Main parachute: Reefing, Time, sec	Main parachute: Deployment q, psf	Main parachute: Maximum reefed, open load, lb	Main parachute: Maximum disreefed, open load, lb	Main parachute: Maximum bridle loads, lb, Fwd[b]	Main parachute: Maximum bridle loads, lb, Aft	Remarks
36T1	0034F64	20 000	4730	11.5	6	69	N/A[c]	10.5	8	72	10 600	11 400	7600	5700	Good test, no load data
37T2	0099F64	20 000	4730	11.5	6	N/A	4250	10.5	8	N/A	9 800	12 200	7600	5000	Loads exceeded 3500-pound limit
38T3	0114F64	20 000	4730	11.5	6	N/A	N/A	10.5	10	N/A	10 200	11 200	6400	5300	Pilot attach cables broken
40T4	0333F64	20 000	4730	11.5	6	N/A	2900	10.5	10	N/A	9 100	11 600	7200	4900	Good test
41T5	0523F64	20 000	4730	11.5	6	N/A	4450	10.5	10	N/A	9 600	11 000	7400	5300	Pilot parachute bag handles broken

[a]McDonnell Aircraft Corporation.

[b]Forward.

[c]Not applicable.

The method considered most desirable at the time was to restrict the gore width with control tapes. Rings 8 through 13 were reduced in circumference by 2 percent. Six tests (drops 26 through 30, and 32) were conducted; the last four of these showed no evidence of infolding. A detailed analysis of the infolding phenomenon by the manufacturer is presented in Report No. 3663, Northrop-Ventura, 1964. In later qualification testing of the parachute landing system, the infolding reoccurred on a random basis. However, due to the impact which a design change would have had on schedules, the present design was used. The infold does not result in any degradation in reliability or rate-of-descent characteristics.

(4) Tests 31 and 33 - Tests 31 and 33 were conducted over water to demonstrate the landing attitude and the acceptable decelerations upon entry into the water. The maximum accelerations recorded in the y direction (along the yaw axis) were 2.1 and 2.4g* and in the z direction (along the roll axis) 3.8 and 2.4g.

At this point in the program, the reefing time was increased to 10 seconds. The tolerance of the 8-second time delay was on the low side and could result in too short a reefing time. Therefore, the time delay was increased to obtain a better balance between the reefed-opening and disreef loads.

Results: A detailed summary of the test results is presented in table II(a) and II(b). A plot of drag area versus deployment time, obtained from test data, for the main canopy is given in figure 12. The average rate of descent, based on drop test data, versus the density parameter is plotted in figure 13(a). The maximum reefed open load versus the dynamic pressure is plotted in figure 13(b).

Tandem pilot/drogue parachutes. - With the addition of the high-altitude drogue parachute to the landing system, it was necessary to integrate the drogue into the landing system sequence. Five drop tests (nos. 36T1, 37T2, 38T3, 40T4, and 41T5) were conducted with the boilerplate to develop the deployment characteristics, and to obtain load and rate-of-descent data.

Test configuration and procedure: The pilot parachute reefing was set at 11.5 percent for 6 seconds. An off-the-shelf 8.3-foot-D_o parachute was used to simulate the drogue parachute because its development had not been completed. The average drag area of both parachutes was 37 square feet, before R and R section release and pilot parachute disreef.

*g = acceleration of gravity, approximately 32.2 feet per second per second at sea level.

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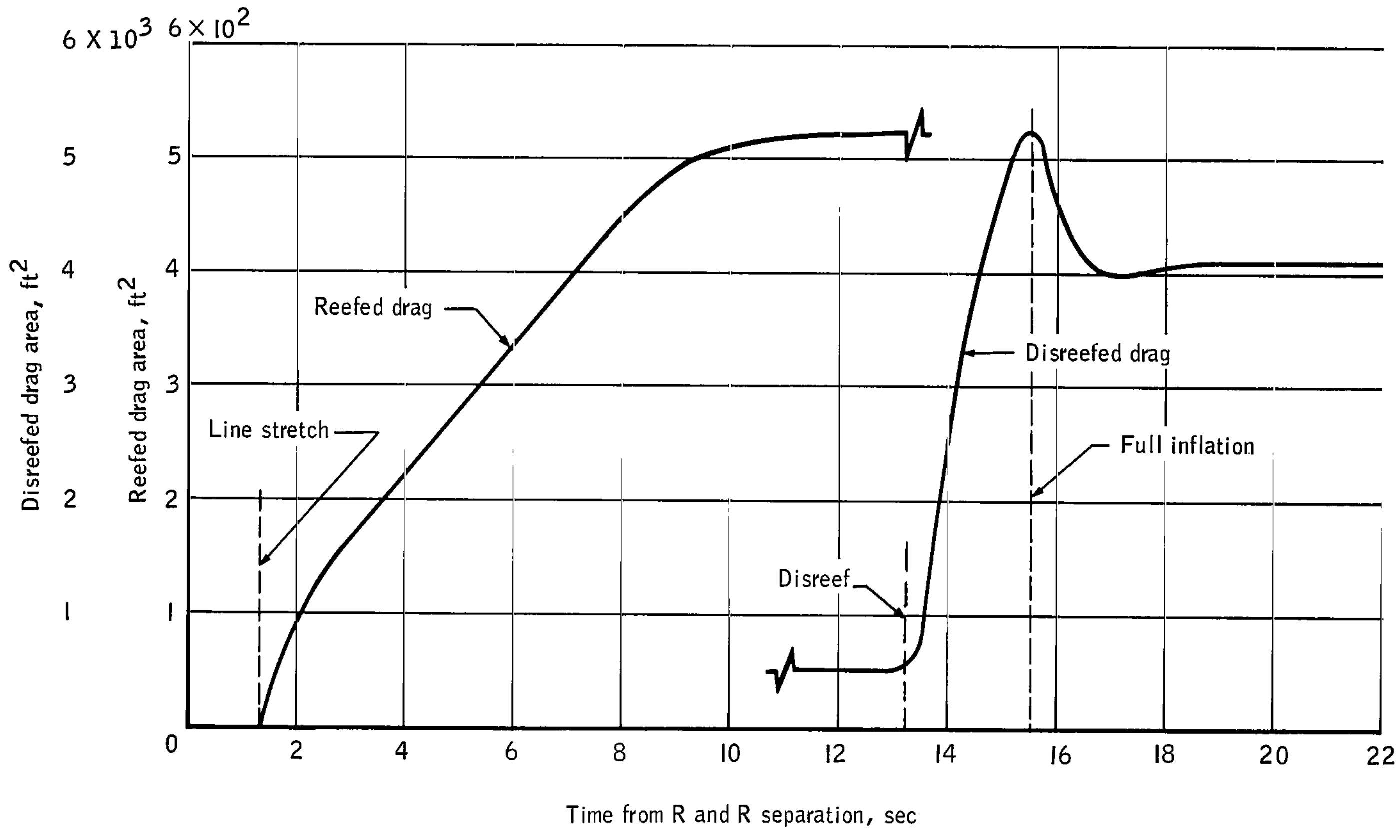

Figure 12.- Main parachute drag history.

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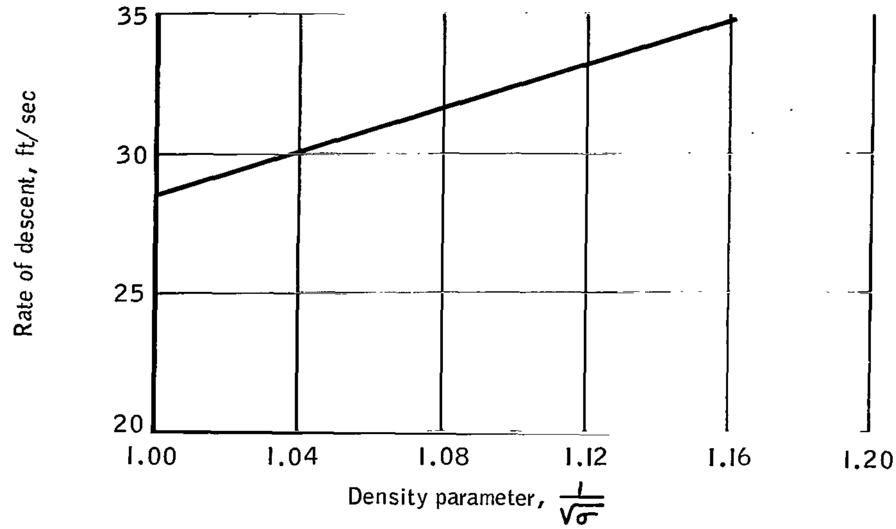
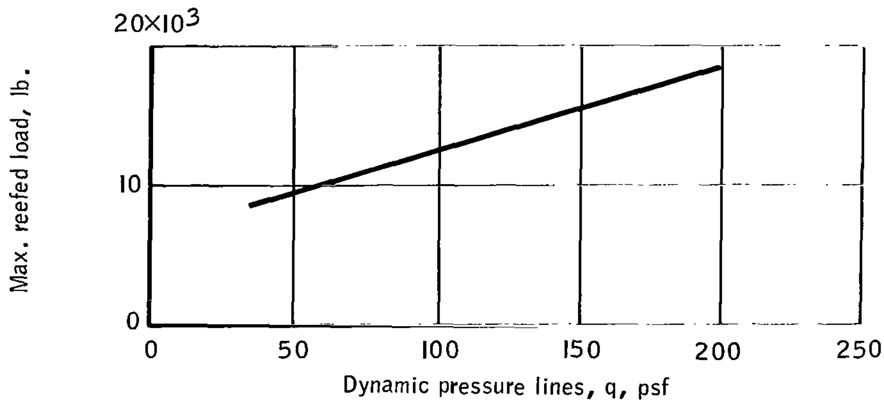


(a) Average rate of descent versus density parameter



(b) Maximum reefed open load versus dynamic pressure

Figure 13.- Main parachute drop test data.

Results: A summary of the test results is given in table III. These tests proved the feasibility of a tandem-type deployment, and that the loads would not be excessively high. Further development and the final qualification of the drogue and parachute risers were accomplished during the complete landing systems testing. (See the section on system qualification.)

System Qualification

Unmanned spacecraft landing system. - The first production Gemini spacecraft to be recovered was an unmanned vehicle equipped with a parachute landing system design which was qualified prior to the completion of high-altitude drogue parachute development testing in order to meet the launch schedules.

Test configuration and procedure: This landing system configuration consisted of a pilot parachute and riser assembly, pilot parachute mortar assembly, main parachute and riser assembly, repositioning bridle, disconnect assemblies, and all necessary spacecraft sequential hardware and pyrotechnics that make up a production spacecraft landing system. The vehicle used for qualification tests (Static Article 7) had a production R and R section and RCS section. These sections were attached to a boilerplate conical section containing the landing sequential system, wiring, and instrumentation. The assembled vehicle had the same aerodynamic shape and weight as a production spacecraft. Drops were made from an aircraft flying at an altitude of 20 000 feet.

Although the pilot and main parachutes had been developed individually over a long test program, the purpose of these tests was to qualify all the hardware while functioning together as a complete landing system. One change was made to the pilot parachute, however. The reefing ratio was raised to 13 percent in order to increase the separation velocity between the R and R section and the reentry module. This resulted in a better deployment of the main canopy. The test conditions for main landing system deployment were at an altitude of 10 600 feet and a dynamic pressure of 120 psf.

Results: On the first test (42S1) the R and R separation sensor switches failed, and the fiber-glass container that holds the main parachute in the R and R section came out with the bag, having failed its attach points during MDF firing. The second test (45S2) revealed that the reinforcing of the main parachute, container-support structure was not sufficient. Although the structure did not fail the second time, it was deformed. The separation switches were removed prior to the next test and the sensing function was picked up from the signal that detonated the MDF. For test 47S3, the instrumentation was removed from the parachute bridles, and production hardware and fabric components were used throughout the system. The test was completely successful and all objectives were satisfied. A summary of the tests and the data acquired is shown in table IV(a).

Manned spacecraft landing system. - Ten tests were conducted in this series. These drop tests qualified the three complete parachute assemblies, the attaching spacecraft hardware, structure, and sequential system.

Test configuration and procedure: Two vehicles were used in the qualification test series. One was Static Article 7 that was used on the previous tests, and another identical vehicle was constructed and designated Static Article 4A. The major change in the configuration from that previously described was the addition of a modified R and R section containing the high-altitude drogue mortar.

The test vehicles were dropped from an aircraft flying at an altitude of 33 000 feet. The vehicles fell unstabilized until the terminal dynamic pressure of 120 psf was achieved at an altitude of approximately 27 000 feet, at which time the drogue was deployed. This stabilized the simulated reentry module down to an altitude of 10 600 feet, where a baroswitch (taking the place of the manual crew function) deployed the main landing parachute. The repositioning maneuver to the landing attitude was accomplished after a 22-second time delay from MDF initiation had elapsed.

Results: The first four tests showed a weakness in the drogue riser design. The problem was that when all three drogue legs were guillotined free, the leg to which the apex line is attached was restrained by the pilot parachute pack while the other two were unrestrained; it thus recoiled upward, fracturing the stitching at the confluence point. A redesigned confluence point solved this problem, and the next four tests were completely successful.

The final two tests simulated a failure in the drogue parachute system. The first of these simulated failure of the drogue mortar. At 10 600 feet, the drogue attach cables and the apex line were guillotined free and the pilot parachute was deployed by its mortar. The normal landing system sequence then followed. The second of these tests simulated a drogue canopy failure after being deployed by its mortar. At 10 600 feet, the streaming drogue and the apex line were guillotined free, and the pilot parachute was mortared out. The remaining events were the same as in the previous test. A summary of the test data is given in table IV(b).

The complete parachute landing system sequence (drag area versus time history) is shown in figures 12 and 14. These plots give the average nominal time delays for the events to occur. The nominal values for time versus

TABLE IV. - SYSTEMS QUALIFICATION DROP TESTS

(a) Unmanned

Test number		Launch altitude, ft	Free-fall weight, lb	Pilot parachute				Main parachute								Remarks
				Reefing		Deployment q, psf	Maximum reefed, open load, lb	Reefing		Deployment q, psf	Maximum reefed, open load, lb	Maximum disreefed, open load, lb	Rate of descent, MSL[b], ft/sec	Maximum bridle loads, lb		
MAC[a]	El Centro, California			Percent D_o	Time, sec			Percent D_o	Time, sec					Fwd[c]	Aft	
42S1	0573F64	20 000	4730	13	6	129	N/A[d]	10.5	10	125	N/A	N/A	30.5	N/A	N/A	No repositioning, parachute container failed
45S2	0874F64	20 000	4730	13	6	135	2550	10.5	10	125	5800	5000	30.2	5800	4700	Parachute container fittings deformed
47S3	0965F64	20 000	4730	13	6	N/A	N/A	10.5	10	125	N/A	N/A	30.0	N/A	N/A	No instrumentation, good test

[a]McDonnell Aircraft Corporation.
[b]Mean sea level.
[c]Forward.
[d]Not applicable.

TABLE IV. - SYSTEMS QUALIFICATION DROP TESTS

(b) Manned

Test number		Launch altitude, ft	Free-fall weight, lb	Drogue parachute				Pilot parachute				Drogue and pilot parachute combined load, lb	Main parachute				Remarks
				Deployment altitude, ft	Reefing		Deploy-ment q, psf	Deployment altitude, ft	Reefing		Deploy-ment q, psf		Reefing		Deploy-ment q, psf	Rate of descent, MSL[b], ft/sec	
MAC[a]	El Centro, California				Percent D_o	Time, sec			Percent D_o	Time, sec			Percent D_o	Time, sec			
59 C-1	2421F64	33 000	4730	24 250	43	16	130	10 350	11.5	6	70	4500	10.5	10	85	32.1	Drogue riser separation at confluence
60 C-2	2492F65	33 000	4730	24 800	43	16	127	9 750	11.5	6	67	3850	10.5	10	66	32.7	Drogue riser separation at confluence
61 C-3	2508F65	33 000	4730	24 500	43	16	119	10 350	11.5	6	71	3950	10.5	10	70	33.7	Drogue riser separation at confluence; infold present
62 C-4	0011F65	28 000	4730	19 650	43	16	130	10 100	11.5	6	73	3800	10.5	10	70	31.5	Drogue riser separation at confluence; infold present
63 C-5	0065F65	33 000	4730	25 750	43	16	111	10 150	11.5	6	72	3850	10.5	10	75	33.8	New riser design satisfactory; infold present
64 C-6	0095F65	33 000	4730	25 100	43	16	N/A[c]	9 950	11.5	6	70	4250	10.5	10	74	33.7	Infold present
65 C-7	0095F65	33 000	4730	25 550	43	16	125	10 250	11.5	6	67	4250	10.5	10	70	31.7	0.099 hole diameter MDF bolts; infold present
66 C-8	0142F65	33 000	4730	25 200	43	16	112	9 750	11.5	6	68	N/R[d]	10.5	10	67	31.5	Infold present
67 C-9	0266F65	17 000	4730	N/A	43	16	-	10 100	11.5	6	138	N/R	10.5	10	125	29.9	Infold present; emergency mode, no drogue
68 C-10	0267F65	17 000	4730	15 200	43	16	77	9 050	11.5	6	121	N/R	10.5	10	117	29.7	Emergency mode, streaming drogue

[a]McDonnell Aircraft Corporation.
[b]Mean sea level.
[c]Not applicable.
[d]Not recorded.

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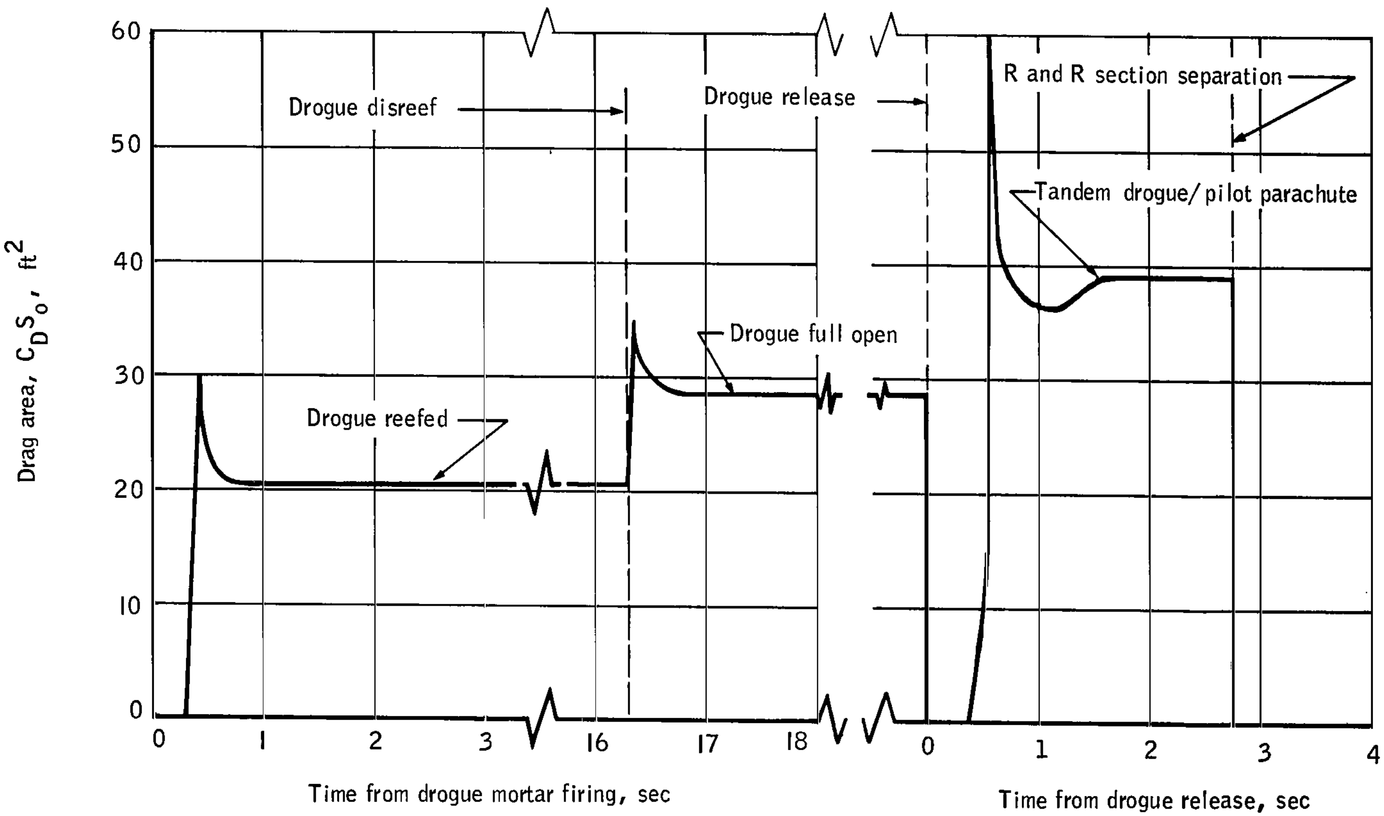

Figure 14.- Drogue and pilot parachute drag history.

altitude at which the landing system sequences occur are shown in figure 15. Figure 16 gives the nominal Mach number, dynamic pressure, and velocity as functions of the altitude that the landing system experiences during its operation from an altitude of 50 000 feet to touchdown.

CONCLUSIONS

The objectives of the development and qualification test program were successfully attained. The final configuration of the Gemini parachute landing system is the result of design concepts and experience gained in the use of hardware and parachutes developed for previous programs, notably, Project Mercury. The new concepts successfully proven in the Gemini Program for operational landing of spacecraft were:

1. Use of a high-altitude drogue parachute to deploy the pilot parachute pack.

2. The tandem pilot/drogue parachute method of deploying a main landing parachute.

3. Use of the pilot and drogue parachutes to prevent recontact of the R and R section with the main parachute canopy.

4. The concept of landing shock attenuation by water entry of the cabin section at the corner of the heat shield, thus eliminating the additional weight and complexity of shock absorption equipment.

In conclusion, the performance of a large ringsail-type parachute was demonstrated by the use of the 84.2-foot-D_o main landing parachute.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, March 29, 1966

NASA-S-65-11453A

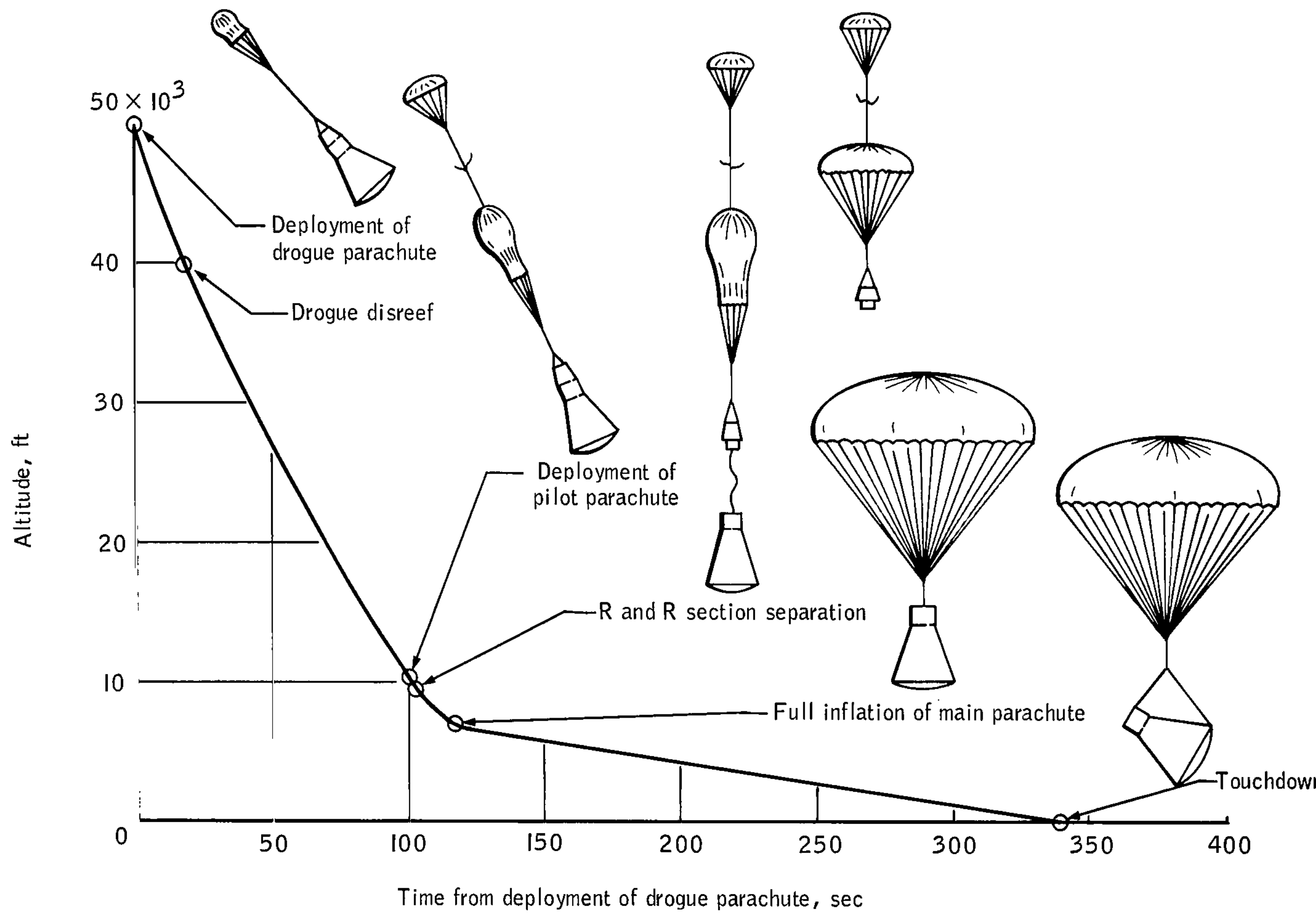

Figure 15.- Nominal landing system events.

NASA-S-65-11443A

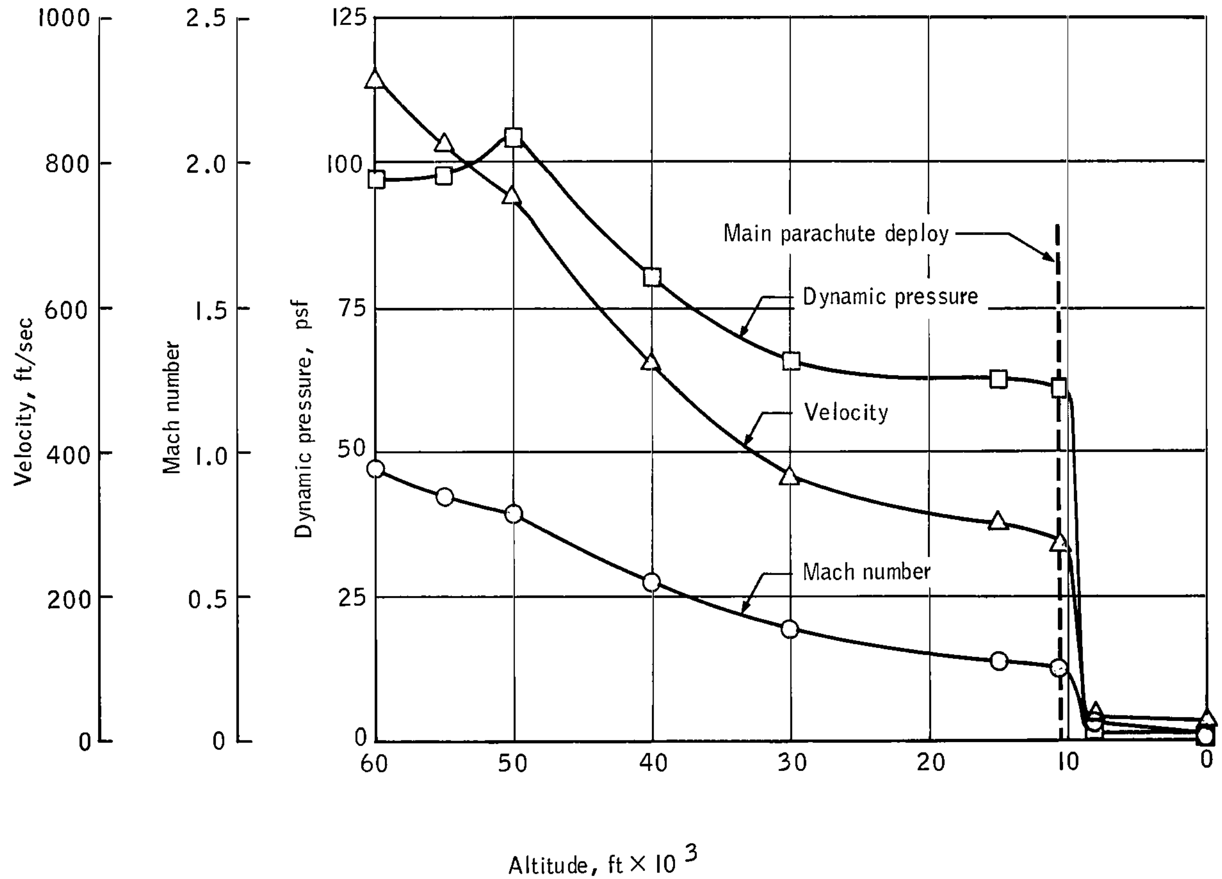

Figure 16.- Nominal landing system aerodynamic parameters.

NASA-Langley, 1966 S-106

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