

Final Project Report
for
AEROBEE 350 RECOVERY SYSTEM

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Contracting Officer: A. H. Wessels
Technical Monitor: Francis M. Collins, Jr.

Prepared by:

Cook Electric Company
Tech-Center Division
Morton Grove, Illinois

for

Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

Three recovery systems for retrieving scientific payloads from Aerobee 350 Sounding Rocket Vehicles were designed and fabricated, development tested, qualification tested, and field tested in aircraft drops. The units utilize a two-stage aerodynamic decelerator system with associated timing, programming and control circuitry. The equipment is described in detail, and the preliminary aerodynamic, thermal and structural analyses are discussed. The development tests are covered, including structural integrity tests, separation system tests, first and second stage decelerator deployment tests and air drop tests, pyrotechnic initiation tests, electrical system performance and shock survival tests, and high temperature pulse test. The Qualification and Acceptance Test Program and the field drop tests are also discussed. For the latter, Field Checkout Units were designed and built, and their operation is described.

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FINAL PROJECT REPORT
FOR
AEROBEE 350 RECOVERY SYSTEM

1.0 RECOVERY SYSTEM DESCRIPTION

1.1 System Description

The Aerobee 350 Sounding Rocket Payload Recovery System, see figure 1 and 2, is a sophisticated, two stage deceleration device incorporating a redundant electrical control subsystem, a redundant pyrotechnic subsystem, a pneumatic inflation subsystem, and a passive thermal control subsystem. It is designed to recover a 300 to 700 pound net weight payload from a hostile re-entry environment and with a terminal velocity of 30 feet per second. Physically, the unit consists of a cylindrical package 22 inches in diameter, 13.75 inches in overall length, and approximately 110 pounds gross weight. When mounted to the flight vehicle the recovery system has a skin length of 12.62 inches, see drawing 206600 in Appendix A. The center of gravity of the recovery system is located approximately 6.75 inches from the face of the forward mounting ring.

1.2 Deceleration Devices

Two deceleration devices are utilized on the recovery system: the first stage decelerator is a paraloon, and the second and final stage is an extended skirt parachute.

1.2.1 Paraloon

The paraloon is a uniquely designed decelerator which is part parachute and part balloon, hence the name paraloon. The balloon part of the paraloon is a bladder which when inflated takes on roughly the shape of an ice cream cone. More specifically, it has the shape of a frustum of an inverted cone having a hemispherical top and a flat base. The overall height is 56 inches, with the maximum diameter of 21 inches and a base diameter of 15.12 inches.

The parachute part is a flat canopy in the shape of an annular disk which is fastened to the paraloon at the maximum diameter of the latter. The suspension lines are attached to the outer perimeter of the 7.5 foot diameter skirt and to the circumferential bridle near the base of the paraloon. This skirt is initially reefed to the side of the balloon. A buffer is also attached near the base of the paraloon in order to inhibit any abrasion of the bladder material.

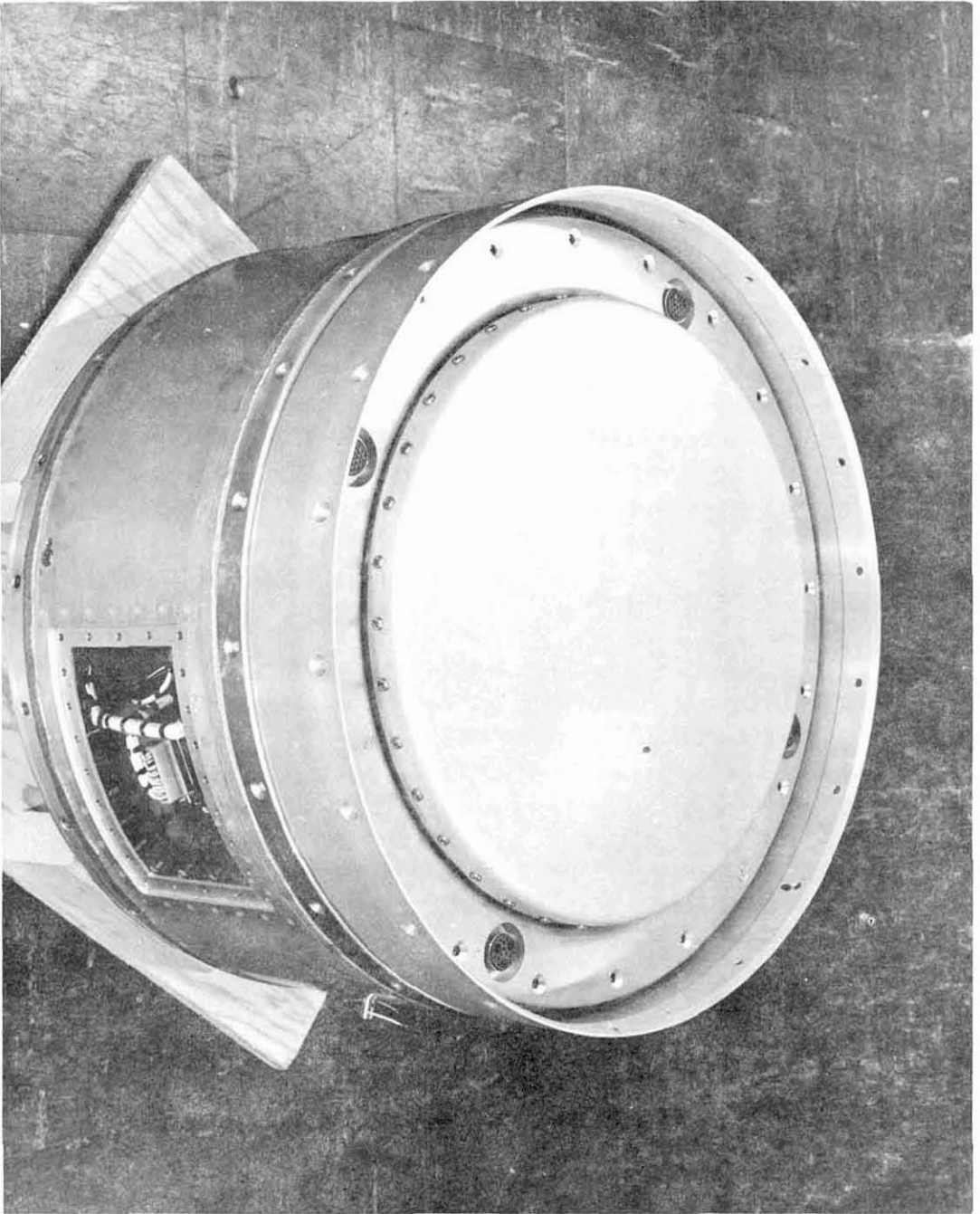


Figure 1. Aerobee 350 Recovery System, Hatch Removed

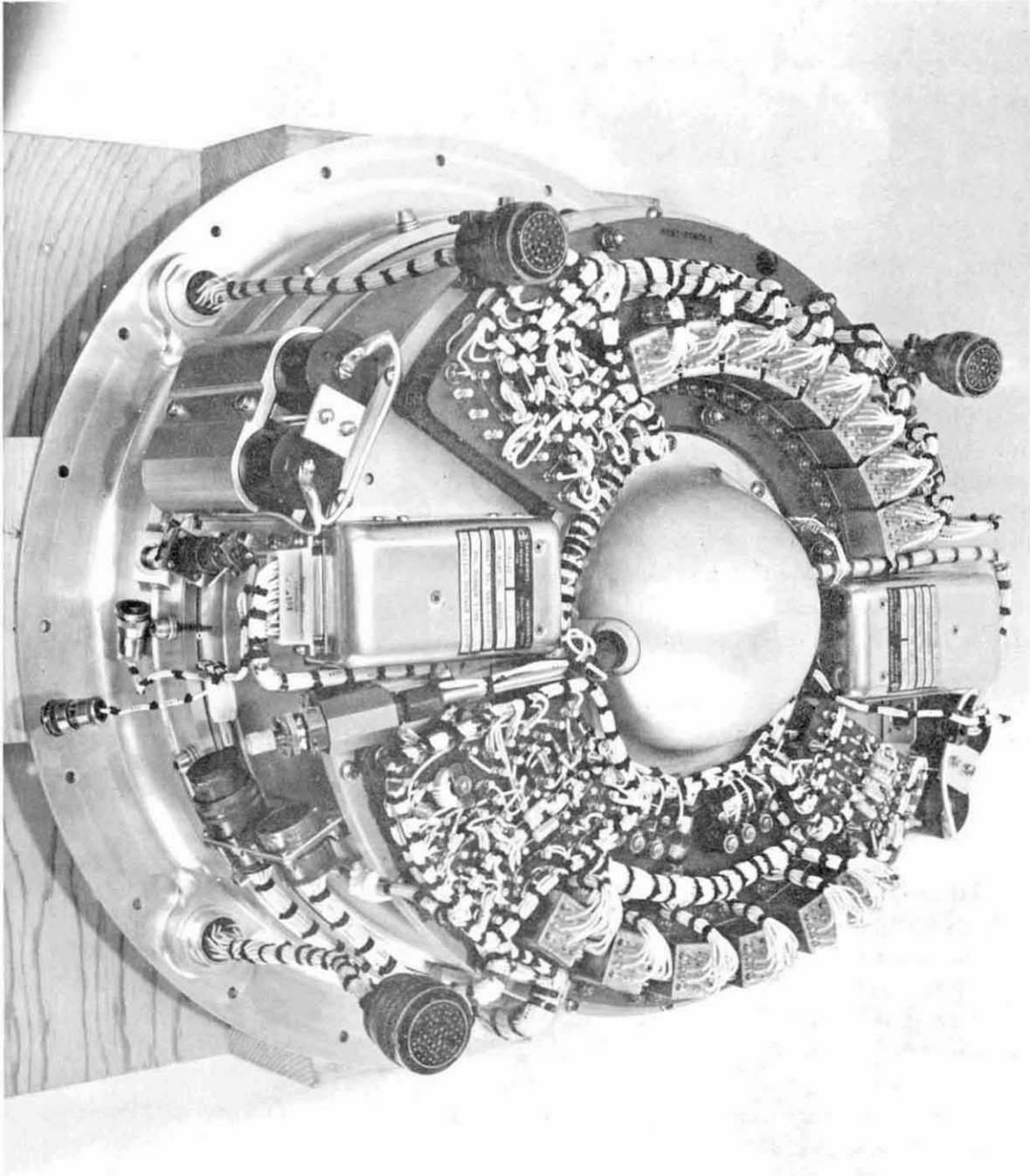


Figure 2. Aerobee 350 Recovery System Inner Assembly

The bladder is constructed of nomex (high temperature nylon) cloth, which is coated on both sides with polyurethane to form an air tight fabric. The remainder of the paraloon is fabricated from basic nomex material.

The paraloon is deployed with the firing of the explosive valve of the reservoir system. The stored gas is directed into the packed paraloon, forcing it to push against the domed paraloon cover. When the pressure is sufficiently high, the screws fastening the cover extension ring to the paraloon separation ring are sheared and the paraloon is deployed.

Four seconds after deployment, two pyrotechnic reefing line cutters function, disreefing the skirt so that it may inflate to its full diameter. Operation of either reefing line cutter will deploy the drag skirt. The paraloon has a calculated drag area of 4.25 sq ft in the reefed state and 25.0 sq ft disreefed.

1.2.2 Parachute

The parachute utilized for the recovery system is a nominal 35 foot diameter, 10 percent flat extended skirt parachute. The canopy of the parachute consists of 1.1 and 0.7 ounce per square yard material fabricated into a total of 36 gores. A total of 18 continuous suspension lines are used, each of which are secured to one leg of the bridle, pass up over the vent of the parachute and terminate at a second leg of the two legged bridle. The suspension lines are fabricated from nylon cord with a rated tensile strength of 200 pounds.

The "X" shaped bridle is fabricated from 6000 pounds, 1 inch wide webbing which is secured to the recovery system structure.

The parachute is packed in a toroidal shaped bag which is secured to the parachute cover.

Deployment of the parachute is initiated by detonating the 7 gr/ft FLSC charge which severs the paraloon separation ring. The paraloon then becomes a drogue which extracts the parachute. The parachute is deployed reefed at the edge of the skirt. Four seconds after deployment, the fourteen foot long reefing line is severed by either of the two pyrotechnic reefing line cutters, allowing the parachute to fill completely.

The parachute has a calculated drag area during filling in the reefed state of 50 sq ft, increasing to a final drag area of 81 sq ft before disreef. The fully disreefed parachute has a calculated drag area of 775 sq ft under a steady state condition. This is designed to provide a terminal velocity of approximately 30 feet per second.

1.3 Electrical Control Systems

Two identical electrical control systems are incorporated in the recovery system. These are designated as Control System "A" and Control System "B". Either of these systems can perform all the required functions. In addition, the timers and relays in each system provide a back up function in event of failure of the corresponding component in the other system. The Schematic and Reference Designation Diagram are presented in Appendix I as drawings 206590 and 206592, respectively.

Both control systems are capable of operating in either a programmed mode or a command mode or a combination of the two modes. The programmed mode is a completely automatic sequencing of the functions of the recovery system and will result in a normal recovery with the recovery events occurring at a preset time or altitude. The command mode allows for deviation from a normal programmed recovery sequence to the extent that a particular event may be commanded to take place from the ground, but only if the necessary command is received prior to the time the programmed mode automatically executes the particular event. The command mode also allows for a mission abort. In this case the only command necessary would be Separation, which would then allow the payload to be recovered in a normal fashion.

1.3.1 Programmed Mode, Normal Recovery

The following is a description of the control system operating during a typical flight in the automatic or programmed mode. The referenced designations given correspond to those presented on the Schematic Drawing 206590 (see Appendix I).

Upon first movement of the Aerobee 350 vehicle after motor ignition, the recovery system lanyard pins are pulled allowing the switch plungers to retract into the recovery system. The eight lanyard operated switches, S1 through S4 of 1A2A2 and 1A2A3 switch assemblies, then change state, thus applying "A" system battery power to the "A" system timer motor and "B" system battery power to the "B" system timer motor. Both timers begin operation at this time and continue to operate until power is removed from the motors by cam activation of switches S4 in timer 1A1M1 and S4 in timer 1A1M2. The timer "turn-off" position is chosen after the timers have activated the separation detonators in the normal recovery mode.

After the timers have functioned for a preset time switch S2 of each timer is actuated. These switch closures arm the normal recovery mode and the command mode of the "A" and "B" systems. The preset time for the S2 switch may be as early as five seconds

after launch (after separation from the vehicle) to as late as any time prior to separation by either programmed or command mode. Arming of the normal recovery mode consists of switch S2 of the "A" system timer completing the "A" circuit to S5 of the "A" timer and S6 of the "B" timer, and switch S2 of the "B" system timer completing the "B" circuit to S5 of the "B" timer and S6 of the "A" timer.

Switches S5 and S6 on each timer are activated at the preselected time for separation. Control system "A" power passes through S5 of 1A1M1, the lanyard operated switches, the closed contacts between pins 3 and 9 of relays K6 and K8, through the Flight/Arm connector plug, to the separation "A" detonator. In a similar fashion control system "B" power passes through S5 of 1A1M2, the lanyard switches, the closed contacts between pins 3 and 9 of K5 and K7 relays, through the Flight/Arm connector plug, to the separation "B" detonator. Switch S6 of both timers forms a segment of the cross redundancy of the recovery system and will be discussed later in this report.

At the same time that the "A" and "B" system detonators are initiated, "A" system power is applied to the "A" circuit portion of the aneroid switch assembly and the time delay circuit S1 and "B" system power is applied to the "B" circuit portion of the aneroid switch assembly and the time delay circuit S2. After a 10 second interval S1 actuates applying "A" system power to the coil of relay K3 closing the contact 1 and 10 in the "A" circuit and 4 and 9 in the "B" circuit. Similarly S2 applies "B" system power to the coil of relay K4 closing contact 1 and 10 in the "A" circuit and 4 and 9 in the "B" circuit. Functioning of either of these time delay circuits arms the aneroid circuit in both the "A" and "B" system. In a normal flight the altitude switches are open at this time.

When the preset altitude is reached (descending), the altitude switches in both circuits close. Power from the "A" system battery is applied to the coils of the K10 and K12 relays. These relays change state. Relay K12 completes the "A" circuit to the "A" paraloon squib and its protective delay pyrotechnic switch. Relay K10 completes the "B" circuit to the "B" paraloon squib and its protective pyrotechnic delay switch. Power from the "B" system battery is applied to the coils of the K9 and K11 relays. These relays change state. Relay K11 completes the "B" circuit to the "B" paraloon squib and its protective pyrotechnic delay switch. Relay K9 completes the "A" circuit to the "A" paraloon squib and its protective pyrotechnic delay switch. The function of the pyrotechnic delay switches is to remove power from the paraloon squibs four seconds after they have been fired.

In addition to initiating paraloon deployment relays K9 and/or K12 apply "A" system battery power to time delay switch S3 and relays K10 and/or K11 apply "B" system power to time delay switch S4. After

15 seconds time delay S3 closes and applies "A" system battery power to relay K14. This relay changes state initiating the "A" system parachute deployment squib. Similarly S4 closes and applies "B" system battery power to relay K13. This relay changes state initiating the "B" system parachute deployment squib. This completes the normal sequence of events of the programmed mode of flight.

1.3.2 Command Mode, Normal Recovery

The operation of the normal recovery system command mode is identical with the operation of the programmed mode up through the operation of the S2 switches of the timers. Arming of the command mode by the closure of S2 of the "A" system timer consists of applying "A" system power to the open contacts between pins 1 and 10 of relays K6 and K8 and to pin G of the interface connector 1P1. Similarly, S2 of the "B" system timer applies "B" system power to the open contacts between pins 1 and 10 of relays K5 and K7 and pin F of the interface connector 1P1.

The command link to operate the command mode must be provided as part of the payload and range support. Pins F and G in the interface connector apply "A" and "B" system power to the proper sets of open contacts on the command receiver located in the payload. At the desired time in the Aerobee 350 flight profile for command operation a command receiver contact closure must be initiated by the range command transmitter. Transmission of the command signal may be based on time after launch or real time range tracking information. Initiation of the "A" system separation command provides a path for "A" system power from pin G to pin E on 1P1, actuating relays K6 and K5. These relays change state removing the programmed timer from the circuit and completing the path for "A" system power through contacts 1 and 10 of K6 to the separation "A" squib and for "B" system power through contacts 1 and 10 of K5 to the separation "B" squib. Similarly, initiation of the "B" system separation command provides a path for "B" system power from pin F to pin D on 1P1 actuating relays K7 and K8. These relays perform the same function as relays K6 and K5.

The redundancy and cross connection feature of the separation relays will be discussed in another section of this report. Following separation command it is possible to allow the programmed mode to complete the sequence of operations of the recovery system in the same manner as it would have been accomplished if the program timers had initiated separation. The system, however, does provide the capability of commanding paraloon deployment. Paraloon command may be employed where good real time range tracking data is available. Initiation of the "A" system paraloon command provides a path for "A" system power from pin G to pin B on 1P1, actuating relay K1. This relay changes state providing a path for "A" system

power through contacts 1 and 10 of K1 and for "B" system power through 4 and 9 of K1. The effect of this is to apply power to the K10, K12, K9 and K11 relays through a path which bypasses the S1 and S2 time delay circuits, the aneroid switches and the contacts of relays K3 and K4. When power is applied to the K10, K12, K9 and K11 relays the paraloon squib pyrotechnic switch grounds are removed and power is applied to the squibs in the same manner as in the programmed mode.

Parachute deployment will occur 15 seconds later in the same manner as in the programmed mode of operation. The capability for command parachute deployment has been provided in the recovery system by providing a path for "A" and "B" system power to reach the coils of K14 and K13 relays from the 1P1 interface connector. It is thus possible with the command system to bypass the programmed mode of operation through the S3 and S4 time delays and fire the parachute deployment squibs.

It should be emphasized that the programmed mode is always present and functioning and that the command mode is merely a means of overriding or backing up the former by commanding an event (Separation, Paraloon Deployment, Parachute Deployment) to take place at a time different than programmed. If such an event command is not received by the time the event takes place via the programmed mode, then the later mode prevails and executes the event. Thus a command system failure, human error, or any other operational anomaly resulting in failure of the recovery system to receive most commands will not result in failure of the recovery mission.

1.3.3 Command Abort Mode

It has been previously stated that the command mode can be armed by the S2 switches of the timer at a preset time which can be as early as 5 seconds. This feature allows the user to exercise the option of having a command abort mode for the recovery system. If the S2 switch is set for 5 seconds, which is after burnout of the first stage Nike booster, it is possible to command separation at a very early time in the flight. This capability may be a desirable feature if it is desired to maximize the probability of a successful recovery in the event of an early cut down of the vehicle by range safety. It should be noted that a separation command below 20,000 feet altitude will not result in a paraloon deployment if the payload coasts to a higher altitude in less than 10 seconds. In the event that it does, paraloon deployment would take place when the vehicle reaches 20,000 feet on the way down. Of course, it is always possible to command paraloon immediately following separation in the event trajectory information indicates the payload is falling rather than rising and is at an altitude of 5,000 feet above the terrain.

1.3.4 Failure Modes and Effects

A discussion of individual major component failure and also of several simultaneous major component failures and the resulting effect upon the recovery system will be discussed in this section. Due to the symmetry of the "A" and "B" electrical circuits, a failure of a component or components in one circuit only will introduce effects into the system which are identical to the effects introduced by the same component or components failing in the other circuit only. Sample failure modes will be assumed in this discussion in the "A" circuit only, and due to the above symmetry considerations the reader may see that failures of like components in the "B" circuit would introduce like effects.

Since full redundancy is provided in the system, a loss of all of circuit "A", by whatever means, will not deter the recovery system from properly fulfilling its recovery task, as circuit "B" will continue to perform all necessary functions.

The loss of the "A" battery will result in the loss of all "A" circuit functions, since the "A" circuit relays will not receive power.

The failure of the "A" timer to start will result in the loss of all "A" circuit functions. The failure of the "A" timer (1A1M1) by a stoppage after actuation of the S2 switch will not result in the loss of all "A" circuit functions. It may be seen that power will be routed to meet the "A" power requirements by the "B" timer (1A1M2). At the activation of S6 on 1A1M2, "A" power will be fed to S5 on 1A1M1. Since that pole has not been activated, "A" power will be fed through it and the lanyard switches and relays K6-K8 to the "A" power buss. All remaining "A" circuit functions may then be fulfilled using "A" power.

The failure of either complete lanyard switch assembly, or the failure of any one lanyard switch without the failure of the corresponding switch in the other lanyard switch assembly will not inhibit complete system function. This may be seen by examination of the schematic.

Should time delay S1 fail in the open mode, its associated relay K3 will not actuate. Assuming such a failure, S2 will still cause K4 actuation after 10 seconds and the contacts of relay K4 which are redundant to K3 will insure circuit "A" path integrity and thus both circuits will function normally. The failure of the delay circuit by shorting will cause activation of the associated relay at the instant of separation. The function affected by this action is that the required compulsory 10 second delay between separation and

paraloon deployment in the command mode only is negated. However, to fail by shorting would be extremely unlikely, because the switch is normally open and its single closing during a particular mission completes its function. The failure of K3 to function will result in identical consequences to that caused by time delay failure in the open mode.

The failure of a single aneroid switch to open during vehicle ascent or close during vehicle descent will not result in a failure of either the "A" or the "B" system to function properly. The four aneroid switch assemblies are wired into the "A" and "B" circuits respectively in a series/parallel arrangement. It may be seen from an examination of the schematic how this switch arrangement provides the necessary protection.

The relay configuration of K10-K12-K9-K11 assures a high degree of reliability in the paraloon deployment function of the recovery system. The redundant-cross-redundant contact configuration of the relays has been designed such that any one of the four relays can fail to operate with no loss of complete system function by both "A" and "B" circuits. Further, any three of the four relays may fail to operate and one complete circuit will still function. These combinations may be verified by examination of the schematic.

A failure of time delay S3 to close will result in failure to energize K14. The "B" circuit, however, will initiate deployment. A failure of K14 itself will similarly have no effect.

The failure of either delay circuit (S3 or S4) by shorting will result in the activation of the parachute deployment relay and result in parachute deployment at the time of paraloon deployment. This would cause failure to recover the payload, but as was discussed earlier for S1 and S2, this mode of failure of the time delays, as employed in this system, is extremely unlikely.

The combination of failures of squibs and/or detonators is obvious and will not be discussed further in this report.

A failure within the system of either circuit battery or a failure of either timer to start inhibits the application of the circuit power to the interface connector 1P1 and the programmed mode timer switch. Thus all functions controlled by that circuit's power will be lost. The other system function would be unimpaired. However, as previously noted a timer stoppage after arming of the programmed and command modes by the timer will not result in the loss of that system.

The contact configuration of the command separation relays K5, K6, K7 and K8 is arranged such that a failure of any single relay to operate on command will not deter the proper function of both circuits.

A simultaneous failure of both K6 and K8 or K5 and K7 will result in only one circuit being able to ignite its separation detonator. However, any other combination of two simultaneous relay failures will not deter the capability of both circuits to function normally. Further, any three of the four relays may fail to actuate and one of the two circuits will remain capable of firing its associated detonators.

A failure of either command paraloon relay K1 or K2 to actuate will not reduce complete system function due to the cross connection of their contacts.

It should be noted that throughout this discussion of failure mode and effect investigation the primary failure mode assumed for the latching relays used in the recovery system has been failure to actuate. Although Minuteman Electronic Parts Failure Percentages, No. D2-16358-1, lists failure to transfer as 43 percent of failure modes, it is believed that the failure to transfer percentage is very much higher in this system. The rationale for this assumption follows. Open or shorted relay coils exhibit themselves in this system in an identical way to relay failure to transfer. Also, no relay contact in the system is required to open under electrical load and therefore the probability of contact degradation leading to contact welding is reduced. Further, the preflight checkout of the electrical system will verify contact integrity.

In the previous discussions, it was assumed for purpose of presentation that the timers operating normally would provide contact closure at the same time, or if one failed, then its contacts would not subsequently actuate during the course of the flight. A more realistic operating condition for a flight where no timer failures are evidenced is one where one of the timer's contacts are activated just before the other timer's contacts. This is brought about, of course, by a lack of completely perfect synchronization of the two timers.

It may be seen by examination of the schematic that for this brief period of time, the timer that is running the slowest will appear to the circuitry in an identical way as if it had failed. That is to say that if circuit "A" timer reaches its separation time prior to the circuit "B" timer, circuit "A" power will be delivered to the "A" separation detonator through switch S5 of timer 1A1M1 and separation will occur. The timers are configured in such a manner that the first of the four switches, S5 and S6 of both timers, to change state will result in separation. In reality, simultaneous detonation of both detonators will be purely coincidental and would require exact synchronization of the switches.

However, in the event that timer "A" failed with the "A" circuit battery functioning at some point after arming of the programmed

and command modes, either switch S5 or S6 of 1A1M2, whichever reaches switch closure first, will apply power to the "B" or "A" separation detonator, respectively, but not to both. If switch S5 closes first, "B" power is transferred directly to the "B" separation detonator. If switch S6 closes first, "A" power is transferred through S6 of timer 1A1M2 and S5 of timer 1A1M1 and then on to the "A" separation detonator through the normal circuitry. Again, only one detonator would be ignited. The remaining detonator would be destroyed by the violence of the pyrotechnic event. When power would be applied to that detonator, an open circuit would exist.

A similar situation is evident if the circuit terminology is reversed due to the symmetry of the control system. The timers are redundant in the sense that if one timer would fail after system arming, the other timer still has the capability of initiating either detonator.

The above is true for all three pairs of squibs incorporated in the system in that a truly simultaneous initiation for the same event is purely coincidental.

1.3.5 Circuit Features

1.3.5.1 Event Marker

Provision is made within the recovery system to provide as a telemetry input an indication of squib ignition. This is accomplished by an event marker circuit. The circuit consists of a torroidal transformer whose primary is in series with the power buss. Current surges on the buss are transformer coupled to a pulse shaper circuit from the secondary of the transformer. The pulse shaper limits and stretches the transformer pulse to one suitable for telemetry use. Separation event marker circuits are used for channel "A" and channel "B" monitoring.

1.3.5.2 Relay Reset

All relays used in this system are magnetic latching, double coil, with four form "C" contacts, not necessarily all used. Complete operation in either preflight checkout or in actual flight requires no more than one actuation per relay. To enable expedient resetting of relays to proper preflight position, a relay reset provision is made at the checkout connector 1A1J1. All relay reset coils are connected in parallel and brought to this connector through leads electrically isolated from the balance of the recovery system circuitry.

1.3.5.3 Relay and Timer Status

Each relay used in the system has one set of contacts used only to indicate status. These contacts are wired such that if all of them are in a proper preflight condition, a circuit path is maintained to the

umbilical and checkout connectors which may be used as an indication of a "safe" status. If any one relay is not returned to its preflight condition, this path is broken, resulting in an indication of an unsafe condition. The relays are grouped such that those used for command recovery may be monitored separately from those for programmed recovery. Switch S3 on both timers are similarly interconnected such that if either is not in its preflight condition an "unsafe" indication will be given. These status condition leads are brought to both umbilical and checkout connectors.

1.3.5.4 Timer Reset

After each flight and after each preflight operation of the timers, it is necessary to reset them to their preflight condition by external application of power through the checkout connector 1A1J1. Both S1 switches are connected such that this applied power will be fed to the timer motors until they reach the proper preflight position, at which time the S1 switch position will change, disconnecting external power and reconnecting the motor to the internal power buss.

1.3.5.5 Function Status

Provision is made within the recovery system to monitor and provide to the telemetry interface connector, 1P1, the paraloon deployment gas bottle pressure analog and to provide an indication of separation of the vehicle motor section from the recovery section. Internal resistor bias networks provide appropriate output signals for monitoring. Power for status monitoring must be provided from a regulated 5 volt supply through the 1P1 interface connector.

1.3.6 Components and Subassemblies

The following sections will discuss the components and sub-assemblies of the control systems. It must be noted that the recovery system is designated as Unit 1 electrically, and therefore all component identifications have the prefix 1.

1.3.6.1 Batteries

Power is supplied independently to each control system from a pair of Gulton Nickel Cadmium 10V0.500 SSCP batteries, providing both 12 and 24 volt sources. The 12 volt power is for the timer only, while the 24 volt source is for the remainder of the control system. The removable battery assemblies are designated at 1A1A2 and 1A1A3 for the "A" and "B" control systems, respectively.

The battery assemblies are delivered uncharged. The correct charging rate for the batteries is 25 to 40 ma. A full charge requires 20 hours at a 40 ma rate. The batteries may be trickle charged indefinitely at a 7 to 12 ma rate.

1.3.6.2 Lanyard Assemblies

None of the events of the recovery system, either in the programmed or command modes, can take place if the lanyard pins have not been pulled.

The lanyard assemblies are cross coupled so that in the event one lanyard is not pulled, both "A" and "B" control systems will still function properly.

Each of the lanyard assemblies, designated 1A2A2 and 1A2A3, is composed of four switches designated S1 through S4. Each of the switches is essentially a double pole double throw configuration. S1 is a part of the "A" circuit and is in series with timer "A" for the functions of Command Arming and "A" Separation. S2 provides the same functions for the "B" circuit. Switch S3 starts both of the "A" and "B" timers, while S4 is for lanyard status only, to indicate a Safe or Unsafe condition on the Checkout Unit.

1.3.6.3 Program Timers

Two removable program timers are incorporated in the control system, and are designated 1A1M1 and 1A1M2 for the "A" and "B" control systems, respectively. The timers, manufactured by Datametrics, Inc. are of a 720 second maximum duration. The timers will draw 325 ma a piece at 12 ± 2 volts dc. Six individually adjustable cams are provided, with each cam operating a SPDT micro-switch. Cams 1, 3, and 4 are of the single detent design while cams 2, 5, and 6 are of the split type with adjustable dwell. The timers are normally delivered with the cams set at nominal values and should be properly set prior to a flight.

Number 1 cam is for timer control, i.e. starting the timer and providing for timer reset and runout functions. Cam No. 2 is for command and programmed mode arming. The third cam is for Timer Status, either Safe or Unsafe as indicated on the Checkout Unit. Number 4 cam is for timer control and turns off the timer. The number 5 cam establishes "A" separation for the "A" timer and "B" separation for the "B" timer, while the number 6 cam controls the "B" separation for the "A" timer and "A" separation for the "B" timer.

For cams 5 and 6, if one timer should fail, after performing its arming function, the other timer will apply power to the "A" and "B" separation circuits. However, due to the nature of the event of separation, either cam of either timer, whichever reaches switch closure first will detonate only one detonator, the other being destroyed by the violence of the explosion.

1.3.6.4 Aneroid System

The aneroid system consists of a sealed chamber housing four aneroid switch assemblies, three pressure sensing ports mounted on 120 degree centers on the skin of the recovery system, and equal lengths of tubing leading from the ports to the aneroid chamber. The aneroid system is a segment of the programmed mode control system providing for paraloon deploy.

The heart of the aneroid system is the four pressure sensing aneroid switches contained in the aneroid chamber. Each aneroid switch consists of a bellows, two microswitches and a cantilever arm which actuates the microswitches. These switches are set to close at a pressure altitude of 22,500 feet when descending. During ascent, the switches open at approximately 23,000 feet pressure altitude. The four switches are wired into the "A" and "B" systems in a series/parallel arrangement.

A removable plug is provided in the aneroid chamber at the Fin III position to allow flight simulation of the aneroid system operations with the use of a calibrated vacuum pump in system. Of course, the three pressure ports must be sealed with tape for this simulation.

A pressure transducer is mounted on the aneroid chamber and is wired to the interface connector, 1P1. The manifold pressure may be monitored by telemetry with this transducer.

1.3.6.5 Ground Safe and Flight Arm Connector

Two independent connect plugs are provided for connector 1A1J7, the Ground Safe/Flight Arm connector. The Ground Safe (green) connector plug is normally installed for safety purposes for shipping and handling. It provides a shorted condition across all of the pyrotechnic circuits.

The Flight Arm (red connector) plug is used for flight only and, as the name implies, arms the pyrotechnic circuits so the detonators may be ignited at the proper timer by the control systems. The Flight Arm connector plug is normally installed during the Final Arming Procedure.

It should be noted that the extracted lanyard system provides an additional safety device prior to launch.

1.3.6.6 Protective Fuses

A protective series fuse is provided in each of the pyrotechnic circuits. The function of these fuses is to protect the power supply if an extended short should appear after a pyrotechnic device has functioned.

In addition a pyrotechnic switch has been incorporated in the paraloon squib circuits to remove these squibs from the line four seconds after firing of the paraloon squibs.

1.3.6.7 Checkout and Status Monitoring

The recovery system control systems are designed with the capability of being monitored through three connectors.

Connector 1A1J1, designated the checkout connector, is provided for use with the Checkout Unit. This feature allows the control systems to be exercised and monitored for proper operation.

Section 5.1 Recovery System Checkout Unit, discusses the various capabilities provided.

Connector 1J9, which mounts to the aft face of the recovery system, is provided for blockhouse monitoring of the recovery system. The status of the lanyards, timers and relays can be monitored.

The final connector is connector 1J1, which is the interface between the recovery system and the telemetry system of the payload. This connector is utilized for commanding the recovery system control circuits and monitoring the pressure reservoir, event marker circuits, and the aneroid chamber pressure.

1.3.6.8 Through Circuitry

Three separate cables are provided which pass through the recovery system proper and are independent of the control system itself. They appear on the Reference Designation Diagram, Drawing No. 206592 as P/N's 206608, 206609, and 206610. The first two have 20 and 23 conductors respectively, while the third consists of two coax cables.

1.4 Pyrotechnic Systems

There are four pyrotechnic systems utilized in the operation of the recovery system which provide the following functions.

- A. Separation
- B. Paraloon Deployment
- C. Parachute Deployment
- D. Paraloon and Parachute Disreef

1.4.1 Separation

Separation of the recoverable payload is provided by a flexible linear shaped charge (FLSC). It is a 15 gr/ft RDX explosive with a Configuration IV Lead Sheath, manufactured by the Ensign Bickford Company of

Simsbury, Connecticut. The FLSC is installed in the recovery system structure and will sever the skin circumferentially at a point just aft of the circular steel band.

In order to initiate the FLSC, a pair of detonators is utilized, one for each control system. These are manufactured by Halex, Inc. of Hollister, California, and are designated as Cook P/N 600190-001. The explosive charge contained within each detonator consists of 100 mg of Lead Azide and 200 mg of RDX. It requires an electrical impulse for detonation and has the approved 1 amp or 1 watt for five minutes no-fire capability.

1.4.2 Paraloon Deployment

The paraloon is deployed by initiating one of the squibs within the explosive valve. The squib generates a high pressure within the valve, forcing a piston to shear a diaphragm thus releasing the high pressure gas stored in the reservoir. A slip joint connection directs the gas into the packed paraloon. When the proper amount of pressure has been generated within the paraloon, the screws fastening the extension ring to the paraloon separation ring shear. The paraloon cover is then ejected and the paraloon deployed. The explosive valve mounts to the air reservoir, and contains two independent and redundant squibs, one for each of the control circuits. Each of these have the approved 1 amp or 1 watt for five minutes no-fire rating. The valve is manufactured by Cartridge Activated Devices, Inc., of Fairfield, New Jersey.

The recovery system is delivered with the explosive valve installed, and with a shorting connector mated to connector 1A1A4P1 for safety purposes.

1.4.3 Parachute Deployment

The parachute is deployed with the assistance of a 7 gr/ft RDX Configuration IV FLSC explosive charge which severs the structural ring restraining the paraloon. When the charge is initiated, the ring is severed which releases the paraloon, and this in turn extracts the parachute. The 7 gr/ft FLSC is similar in design and function to the 15 gr/ft FLSC used for separation. Again, two redundant detonators are provided, each a component of one of the control circuits.

These detonators are also manufactured by Halex, Inc., and have similar electrical and pyrotechnic characteristics to the separation detonators previously described, with the exception of having only 150 mg of RDX as the main charge. The connector and mounting threads are different, however, to preclude the possibility of transposition between the two in installation and connection. The Cook P/N is 600190-003.

1.4.4 Paraloon and Parachute Disreef

Both the paraloon and the parachute are provided with a reefing line in order to reduce the opening shock loads. At a nominal four seconds from their respective deployments, the reefing lines are severed by the reefing line cutters. Two cutters are installed on both the paraloon and parachute.

The reefing line cutter is a lanyard operated pyrotechnic device manufactured by Atlas Chemical Industries, Inc., of Valley Forge, Pennsylvania. Although the cutters are pyrotechnic in nature, they do not pose a safety hazard such as do the FLSC and detonators.

1.5 Reservoir System

The reservoir system is a basic high pressure gas storage system incorporating a spherical steel reservoir, a remote fill/vent pressurization coupling, a pressure transducer to monitor the pressure, an explosive valve to release the gas when required and the necessary interconnecting tubing.

The reservoir, fabricated from 4130 alloy steel, is centrally located within the recovery system. Either high pressure dry air or nitrogen may be used as the gaseous medium.

A remote fill breakaway-type male coupling is provided on the exterior near Fin 1 of the recovery system pointing aft at an angle of 45 degrees. Its purpose is to allow remote pressurization of the reservoir prior to flight or to vent the pressurized reservoir in the event of an extended hold.

In a normal launch, the pressurization hose with a mating female coupling is automatically released by a special device which is a part of the launch tower. Both segments of the coupling seal automatically when disconnected.

The reservoir is normally pressurized some time in advance of a flight to allow for temperature stabilization. A period of 24 hours is recommended, to allow the reservoir to cool to room temperature. An acceptable pressure for flight is between 3050 and 3500 psig.

The pressure transducer is utilized to monitor the reservoir system pressure. The explosive valve, previously discussed, is also a part of the system. When desired, the explosive valve releases the gas which in turn deploys the paraloon.

1.6 Thermal Protection System

In the early part of the preliminary design phase of the program, several trajectory analyses were conducted varying the configuration,

weight, center of gravity, spin rate and orientation of the payload prior to re-entry. Due to the high re-entry velocities, several thermal analyses were conducted in order to specify the necessary thickness of ablation material required in order to limit the maximum temperature of the recovery system to 400 degrees Fahrenheit. Appreciably higher temperatures could have, for instance, damaged the paraloon fabric.

The ablation material selected is Thermolag T-395 manufactured by Thermal Systems, Inc. of St. Louis, Missouri. This material begins ablating at about 395°F. The thicknesses established are sufficient to maintain the temperature of the recovery system structure at a maximum of 400°F.

It must be noted that the Thermolag T-395 material is somewhat fragile and should not be subjected to rough handling.

1.7 System Reliability

A reliability analysis of the Aerobee 350 Recovery System has been performed and previously submitted as a separate report entitled "Reliability Prediction, Aerobee 350 Recovery System." Due in part to the relatively short flight time (approximately 700 seconds) the probability of a successful mission is computed as 99.989 percent. This is predicated on constant chance failure rates of all components which in turn connotes a lack of any part wear out phenomenon during the course of a flight.

Failure rates for the system components were taken from MIL-HANDBOOK-217A where possible, and others were taken from "Reliability Growth Prediction During the Initial Design Analysis," a paper by D. R. Earles which was published in the Proceedings of the Seventh National Symposium on Reliability and Quality Control. Application k-factors were applied on the rates obtained in each source. As an example, a basic failure rate for batteries was taken from the latter source and this number is 1.4 failures/10⁶ hours. This number was then multiplied by the missile application k-factor of 400 (from the same source) for an adjusted battery failure rate, in a missile, of 560 failures/10⁶ hours.

A system mean-time-between-failure (MTBF) was calculated from a summation of the basic failure rates, taken parallel redundancies into account in accordance with the formula:

$$\frac{1}{\lambda_p} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} - \frac{1}{\lambda_1 + \lambda_2}$$

where

λ_1 = failure rate of one of the parallel branches in failures/ 10^6 hours

λ_2 = failure rate of the other parallel branch, also in failures/ 10^6 hours,

and

λ_p = failure rate of the parallel combination, in failures/ 10^6 hours.

The recovery system MTBF was computed to be 169.9 hours, with a total adjusted failure rate of 5884.89 failures per 10^6 hours of operation.

2.0 DESIGN AND DEVELOPMENT PROGRAM

2.1 General

An extensive design and development program was undertaken and accomplished during the course of this project. Studies were conducted concerning vehicle aerodynamics, dispersion and thermal protection during re-entry. The mechanical structure was designed, analyzed and tested to withstand the various loads encountered. The various pyrotechnic and electromechanical components were selected and tested, based on the environmental conditions prevailing. The electrical control systems were designed, developed and tested in order to establish the maximum reliability of vehicle recovery attainable.

A previously submitted document entitled "Preliminary Design and Analysis Report, Aerobee 350 Recovery System," dated September 1967, contains a thorough discussion of aerodynamic analysis, dispersion analysis, weight analysis and loads analysis; the reader is referred to that document for consideration of these areas.

2.2 Thermal Analysis

Due to the high re-entry velocities which were disclosed during the aerodynamic analysis, it became evident that thermal protection of the recovery system will be necessary. To further define the requirements, a computer study was performed by the Emerson Electric Company of St. Louis, Missouri, utilizing the maximum heating trajectories for the points under consideration.

2.2.1 Heating Considerations

The study was performed based on the following criteria:

- a. A maximum allowable structure temperature of 400°F.
- b. An initial structure temperature of 200°F.

A total of four positions on the recovery system structure were selected as follows:

- Position 1 - The center of the paraloon cover
- Position 2 - The edge of the paraloon cover
- Position 3 - The edge or shoulder of the interface ring
- Position 4 - The cylindrical side wall of the recovery system.

The initial study was performed utilizing Thermo-Lag, T-500 ablating material. However, during the course of this program, it was discovered that the T-500 material requires a relatively high curing temperature. Since the recovery system explosive components are installed at the time of application, this presented a safety hazard and was unacceptable. Thermo-Lag, T-395 was then selected since it may be applied and cured at room temperature.

Trajectory Case 32, a 736 pound OG1-3, aft center of gravity, six caliber configuration was selected for computing the required Thermo-Lag thicknesses at positions 1, 2, and 3. The angle of attack at peak heating during re-entry is approximately 170° with this trajectory, presenting the maximum total heat pulse due to the essentially tail first condition.

Trajectory Case 21 was used to establish the ablative material thickness required at position 4. This also represents a 736 pound vehicle. However, the configuration is designated as C03-2 having a forward center of gravity, six caliber vehicle length. The angle of attack at peak heating is 70° presenting a slightly nose first side re-entry.

2.3.2 Ablation Requirements

Since the initial study was performed based on utilizing the Thermo-Lag, T-500 ablative material, the thicknesses computed were revised and updated to that for the Thermo-Lag, T-395 material. The required thicknesses of the T-395 ablation material are presented below.

<u>Position</u>	<u>T-395 Thickness</u>
1	0.085 inch
2	0.085 inch
3	0.065 inch
4	0.058 inch

Using the above values, and a T-395 density of 88 lb/cu ft, the total weight of ablation material required is computed to be 4.0 pounds. See drawing 206600 in the Appendix for further details of the coating and masking. For the complete thermal analysis report, see Section 6.0 of "Preliminary Design and Analysis Report."

It should be noted that these thicknesses were based on the most severe re-entry trajectories and could probably be reduced for less severe flights.

2.3 Decelerator System Analysis

2.3.1 Design Deployment Conditions

Although paraloons have been successfully deployed and have functioned supersonically, they are essentially subsonic devices. The paraloon designed for use as a first stage decelerator is a refinement of a successful design incorporated in another recovery system. That system was successfully tested at dynamic pressures of 500 psf at Mach 1.0. The design q for the Aerobee 350 Parloon is 440 psf, allowing sufficient latitude for error in sensing of deployment conditions without exceeding 500 psf.

The most severe recovery condition results from use of the short (six caliber), heavy (736 pound) cone-cylinder or ogive-cylinder re-entry body trimmed for an angle of attack of 180 degrees (most aft CG location). While these configurations were investigated in the Six Degree of Freedom (SDF) program as cases 24 and 32, respectively (see "Preliminary Design and Analysis Report"), these cases assumed a nose first re-entry attitude, requiring vehicle turn-around to the trimmed condition. As indicated, the vehicle turn-around and oscillation about the trim point yields a higher average re-entry drag than the same body re-entering tail first, which should be essentially the same as the point mass case with identical 180 degree drag. A comparison of data shows that case 24, the most severe SDF trajectory, decelerates to: $q = 440$ psf, $t = 59.62$ sec, Mach 0.80, at 19,857 ft altitude. The point mass trajectory for the short, 736 pound re-entry body, trimmed at 180 degrees, launched at 90 degrees decelerates to: $q = 442$ psf, $t = 58.3$ sec, Mach 0.78, $h = 18,400$ ft, $V = 814$ fps. These point mass data were therefore taken as the nominal deployment design conditions for the paraloon.

2.3.1.1 Altitude Sensing

Preliminary results of the wind tunnel testing to determine the pressure coefficients on the aneroid port indicate that C_p values of -0.4 to -0.5 can occur which will result in a total pressure reading of:

$$\begin{aligned}P_T &= P_{amb} + C_p q \\&= 1035 + (-0.5) 440 \\&= 815 \text{ psf}\end{aligned}$$

This corresponds to a standard pressure altitude of about 24,000 feet, for an error of 5,600 feet for the design condition. This spread in altitude error narrows as the vehicle decelerates. Trajectory analysis indicates that for such a condition, the vehicle will descend to 14,000 feet before the aneroids "see" a total pressure equal to P_{amb} at 18,400 feet (1035 psf). The vehicle decelerates little, so a $C_p = -0.5$ still applies. Therefore, at 14,000 feet:

$$\begin{aligned}P_T &= 1242 - 0.5(417) \\&= 1035 \text{ psf}\end{aligned}$$

As later calculations will show, for the stated design conditions, the paraloon/parachute system requires about 6,700 feet to decelerate to the nominal terminal velocity of 33.8 fps at 11,700 feet altitude. Initiating deployment at 14,000 feet would delay this recovery terminal velocity condition until the vehicle reached about 7,500 feet, which is about 1,500 feet lower than the tallest peak in the area. This, then, is a marginal condition which can be prevented by:

1. Adjusting the aneroids to trip at a higher altitude pressure; say equivalent to 22,00 feet.
2. Command deployment.

2.3.2 Deployment Dynamics

2.3.2.1 Paraloon Deployment

The following design values are based upon the nominal deployment conditions of $q = 440$ psf at 18,400 feet, for 736 pound, six caliber body trimmed at 180 degrees.

In order to reduce the opening shock, a 4 second reefing of the paraloon skirt was incorporated. This is a unique, mid-skirt reefing which reduces the full drag area of 25.0 ft^2 to a value of 4.25 ft^2 .

These values have been verified by drop test on previous programs. Initiation of paraloon inflation is caused by firing the explosive value on the air bottle. Within one second, the cover is ejected and the balloon extends to full length. Firm inflation results at 2.0 - 2.5 seconds. Thus, the pins are pulled on the reefing cutters about one second after initiation and disreef occurs 4 seconds later. The following calculations take time zero to be the point of paraloon inflation valve ignition. Thus, the initiation signal occurs at $t = 0$ seconds.

The reefed opening force is calculated as follows at $t = 1.0$ second:

$$F_{O_r} = (C_d S)_r q XK$$

$$(C_d S)_r = 4.25 \text{ ft}^2, \text{ equivalent drag area, reefed,}$$

$$q = 440 \text{ lb/ft}^2$$

$$XK = 1.50 \text{ opening shock factor, reefed,}$$

$$F_{O_r} = (4.25)(440)(1.50) = 2,800 \text{ pounds}$$

Total drag (paraloon plus vehicle) during the 4 second reefed deceleration period depends on how much of the paraloon is blanked by the vehicle body. Effective drag of the 180 degree trimmed recovery body with reefed paraloon laid back along the side is estimated to be 6.9 ft^2 . The offset drag of the paraloon will rotate the vehicle to a new trim position near 110 degrees (calculated in the following pages) resulting in a higher total drag. However, for conservatism, reefed deceleration is calculated using the 6.9 ft^2 drag area.

Disreef shock is calculated to be

$$F_{O_r} = (C_d S)_o q XK$$

$$XK = 1.0 \text{ at disreef}$$

$$q = 240 \text{ lb/ft}^2 \text{ at } 15,700 \text{ ft}$$

$$(C_d S)_o = 25.0 \text{ ft}^2$$

$$= (1.0)(240)(25)$$

$$= 6000 \text{ pounds at } t = 5.0 \text{ seconds}$$

The vehicle then decelerates for an additional 10 seconds, slowing to a velocity of 199 feet per second at an altitude of 12,850 feet at which time the parachute is deployed.

2.3.2.2 Parachute Deployment

The paraloon is released at this point by firing the inner (7 gr/ft) FLSC charge. The paraloon then deploys the 35 foot extended skirt recovery parachute to full line stretch. Assuming negligible vehicle velocity change in this interval, time to deploy the parachute to full line stretch is 1.6 seconds.

The differential velocity generated between paraloon and vehicle in this time is approximately 75.0 fps. Assuming the full mass of the paraloon and parachute to be accelerated once again to vehicle speed, the snatch force generated in the suspension lines to absorb this differential kinetic energy is conservatively calculated as 1010 pounds.

This assumes the paraloon remains attached to the chute. In the actual system, the parachute vent lines are tied to the deployment bag and paraloon with a 200 pound line which is broken at snatch, so this snatch force is never fully realized.

The following is a table of the parachute inflation dynamics calculated in accordance with the procedures in the USAF Parachute Handbook. An iterative computer program was employed to select the reefing ratio which yields the favorable reefed opening shock and full open shock given below. Time at beginning of parachute inflation is taken as $t = 16.6$ seconds.

Time	Event	Force (lb)	q (psf)	Altitude (ft)	Velocity (fps)
16.6	Full line stretch	-	31.8	12,530	199
16.8	Reefed inflation	1582	31.0		
20.6	Disreef	939	11.5		
21.4	Max. opening force	1968	7.72		
23.2	Chute full open	990	1.28	11,740	38.5
24.6	Terminal velocity	746	0.96	11,690	33.4

The calculations employed a total parachute drag area of 775 ft² which assumes a drag coefficient of 0.8 for the 35 foot diameter 10 percent flat extended skirt chute. Initial reefed drag area was taken as 50 ft² with a final area of 81 ft² before disreef. Based upon the design parameters and geometry of the parachute, the correct reefing line length is selected from Fig. 4-86 in the USAF Parachute Handbook, December '63 and is established as 14.03 feet.

In general, it was felt that the 0.8 drag coefficient assumed would be easily achieved with the lighter weights yielding terminal velocities below 25 fps. At the heavier weights this value may decrease to 0.75

thus yielding slightly higher than spec terminal velocities in the 736 pound range. Rather than arbitrarily build a bigger parachute in a worst case assumption, the 35 foot size will establish its own particular characteristics.

2.3.3 Decelerator System Performance Summary

Table 1 is a summary of the performance of the paraloon and parachute systems. In addition to the recovery phase for the limit load case (736 pound re-entry body, 90 degree launch, 180 degree trim), data for recovery of the lightest R/B is also tabulated (336 pound, 90 degree launch, 180 degree trim).

2.4 Stress Analysis

Using the loads indicated in the "Preliminary Design and Analysis Report," a stress analysis of the recovery system structure was performed. The philosophy of the analysis was to obtain the maximum strength from the material involved utilizing the minimum material thickness necessary, thus producing an adequate, yet efficient structure.

The recovery system structure consists mainly of rings, interconnected cylinders, and circular plates fastened together by conventional hardware, welding or by interlocked bearing surfaces. Due to the highly redundant nature of the major structural components, conservative assumptions were made in an effort to minimize analysis time and insure structural integrity. Where practical, exact solutions were obtained. The stress analysis contained in the "Preliminary Design and Analysis Report" will not be repeated in this report.

The analysis was conducted with the assumption that the entire recovery system structure is at a temperature of 400°F when the re-entry loads are applied. Appropriate material strength reduction factors were taken from MIL-HDBK-5 and applied. In all cases the factors utilized assumed the material was at a temperature of 400°F for one-half hour.

A factor of safety of 1.5 was applied to the design loads in order to determine the ultimate design loads or stresses. Correspondingly, a factor of safety of 1.0 was applied for the design loads or yield stresses. However, in all cases the margin of safety was shown to be positive for the load or stress involved.

$$\text{Margin of Safety} = \frac{\text{Allowable Load or Stress}}{\text{Applied Load or Stress}} - 1$$

TABLE 1 - DECELERATOR SYSTEM PERFORMANCE

Time	Event	Re-entry Condition (1) (Case 24)			Re-entry Condition (2) (Case 20)		
		Altitude (ft)	Velocity (fps)	q (psf)	Drag Force (lb)	Altitude	Velocity (psf)
0	Initiate Paraloon	19,200	832	450	1156	18,974	
1	Paraloon Reefed Inflation	18,400	814	440	2800	18,460	176
5	Paraloon Disreef	15,700	575	240	6000	16,809	83.3
15	Paraloon Cutoff	12,850	199	31.6	790	15,059	137
16.6	Parachute Line Stretch	12,530	199	31.7	200*	14,841	138
16.8	Reefed Inflation Force			31.0	1582		
20.6	Disreef	11,910	116	11.5	939	14,410	77
21.4	Max. Opening Force Condition (1)			7.72	1968		4.5
24.6	Terminal Velocity Condition (1)	11,690	33.4	0.96	746		
26.3	Terminal Velocity Condition (2)					14,120	23.9
	Altitude Loss from t = 1.0	6,710				4,340	

Re-entry Condition (1) 736 lb, 6 caliber vehicle, 180° trim, 90° launch, point mass trajectory, C03-3

Re-entry Condition (2) 236 lb, 6 caliber vehicle, 180° trim, 90° launch, point mass trajectory, C03-3

*Break tie strength between paraloon and parachute apex.

2.5 Electrical System

The electrical system as initially proposed was a relatively simple system utilizing pyrotechnic switches and other highly reliable devices. During the course of the program, requirements were instituted which evolved into the somewhat complex, relatively sophisticated redundant system presently utilized.

As an example, initially only one lanyard switch was to be utilized, the timers were "g" switch actuated and the time delay and relay functions were performed by a variety of pyrotechnic switches and a limited amount of status checks could be performed.

The present design is completely redundant, including dual lanyard switch assemblies. The pyrotechnic switches have been replaced by a series of relays and time delays allowing the unit to be completely checked and exercised prior to a flight.

A complete description of the present control system was presented in Section 1.4.

3.0 DEVELOPMENT TESTING

Many tests have been conducted during the program in an attempt to verify the design integrity of the recovery system. Using the design criteria initially given and that generated during the design and development phase of this project, a variety of tests were conceived and performed.

The tests performed ranged from component selection and evaluation through prototype system tests with a complete recovery system. This section describes the tests performed, the manner in which they were conducted, the results and conclusions.

3.1 Structural Integrity Tests

Several tests were conducted on the recovery system structure simulating the maximum design loads expected from the deployment of the paraloon and of the parachute. The structure was firmly mounted to a test fixture and all loads were applied hydraulically.

The maximum design load due to the paraloon is 6000 pounds, which occurs when the skirt of the paraloon is disreefed. Correspondingly, a maximum load of 2000 pounds is applied to the structure during disreefing of the parachute. For the paraloon, the maximum design loads were applied along the axial and transverse axes and at an oblique angle, thus simulating the various attitudes at which the loads may be applied. Parachute loads were applied in the axial direction only.

In the initial phase of the program, a prototype structure was fabricated and subjected to a series of structural tests in order to substantiate the preliminary stress analysis calculations. After these initial tests, the structure was modified and again subjected to a series of structural tests. For the final tests, dial indicators were utilized to measure the deflection at various points of the structure.

The initial tests consisted of axial and transverse pull test for the paraloon fittings and axial tests for the parachute fittings. The second set of tests were conducted in the axial, transverse and oblique directions, respectively, for the modified paraloon fitting only. Between tests, the paraloon fitting was modified by reducing the cross section of, and segmenting the prototype split ring into twelve separate tiedowns.

The initial test conducted on the parachute fitting was successful. The fitting was later modified significantly, reducing internal structural stresses to a minimum value. Pull testing of the modified fitting was considered unnecessary in view of the results of the initial tests and of the lower stresses anticipated.

3.1.1 Paraloon Structural Tests

The recovery system was mounted to the test fixture. Axial loads of 6000 and 9000 pounds were applied using a simulated paraloon bridle with twelve tie-down points. Each tie-down point was considered evenly loaded due to the symmetry.

The recovery system structure was then removed and remounted in order to apply the load along the transverse axis.

Again, the 6000 pound load was applied twice, but with only three of the 12 tie-down points in tension. This could be expected if actual disreefing would occur while the vehicle was at an angle of attack of 90 degrees.

Observation of the structure during the test, and post-test inspection did not disclose any indication of a permanent set or excessive strain.

This concluded the prototype testing of the paraloon fitting. The structure was then modified as previously described and retested using dial indicators to measure deflections. See figures 3, 4, and 5.

3.1.2 Parachute Structure Tests

The paraloon structure was removed from the prototype recovery system, exposing the parachute fittings. Simulated parachute risers were fabricated for the test and installed to simulate parachute operation during descent.

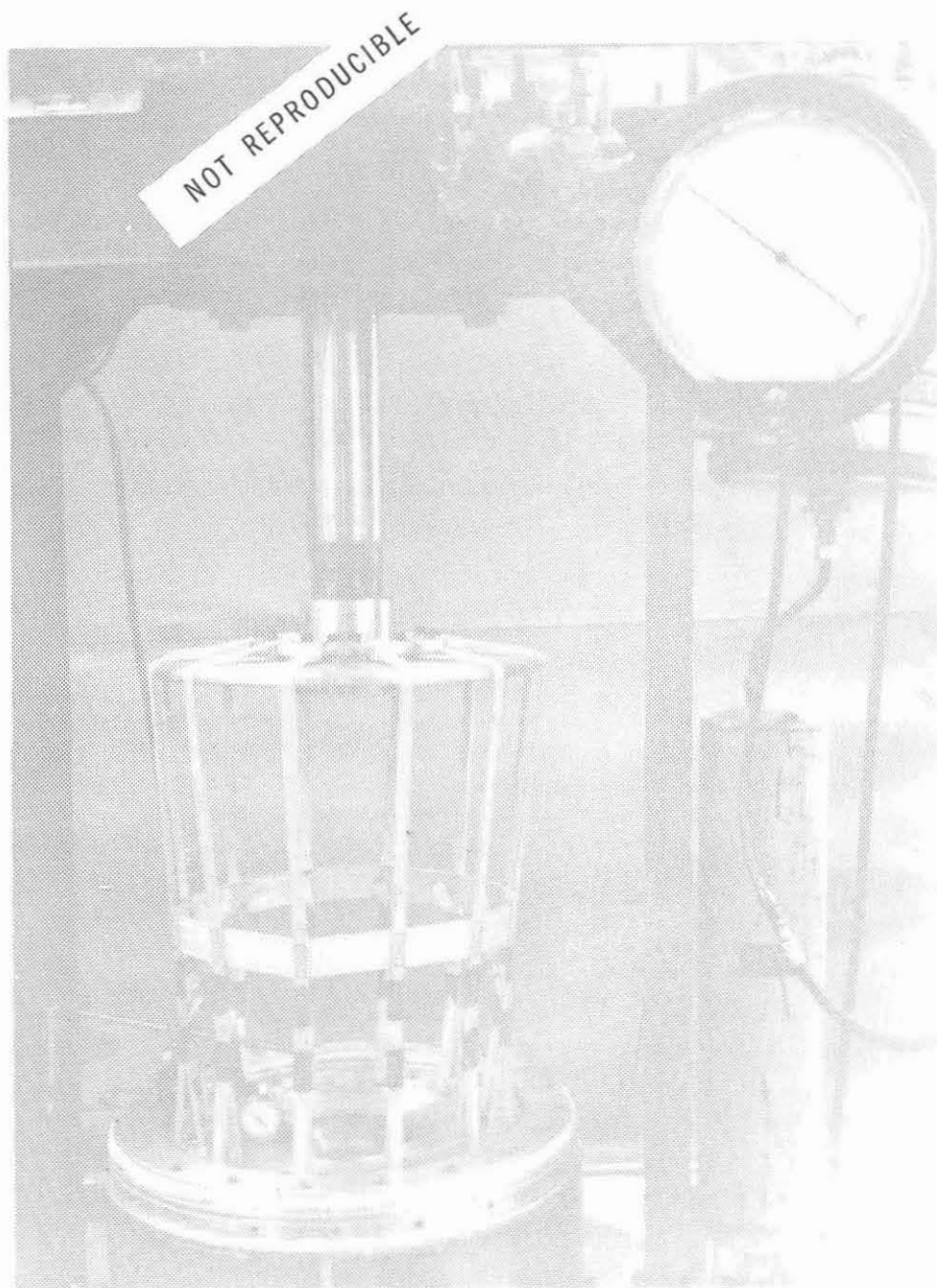


Figure 3. Paraloon Axial Pull Test

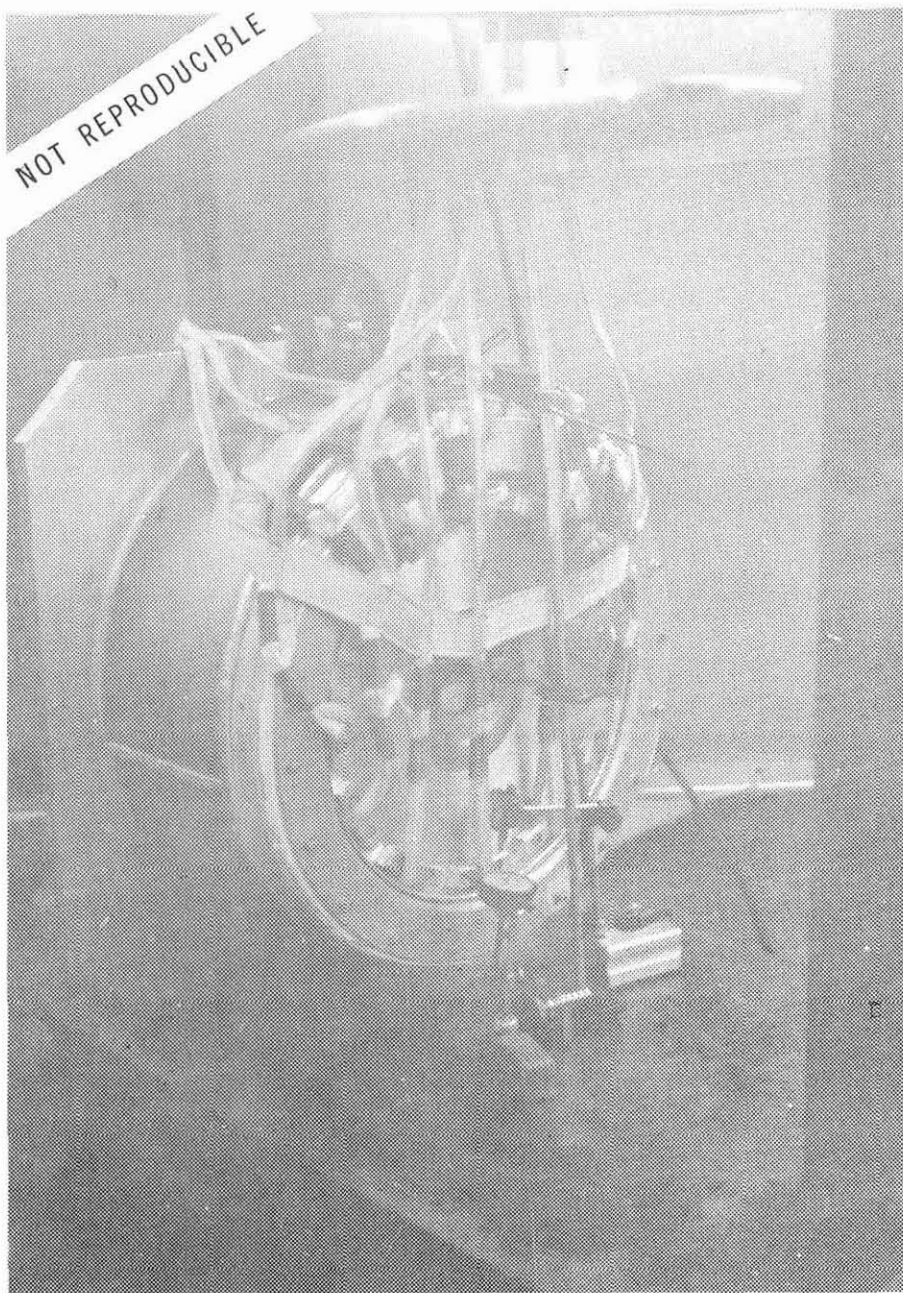


Figure 4. Paraloon Transverse Pull Test

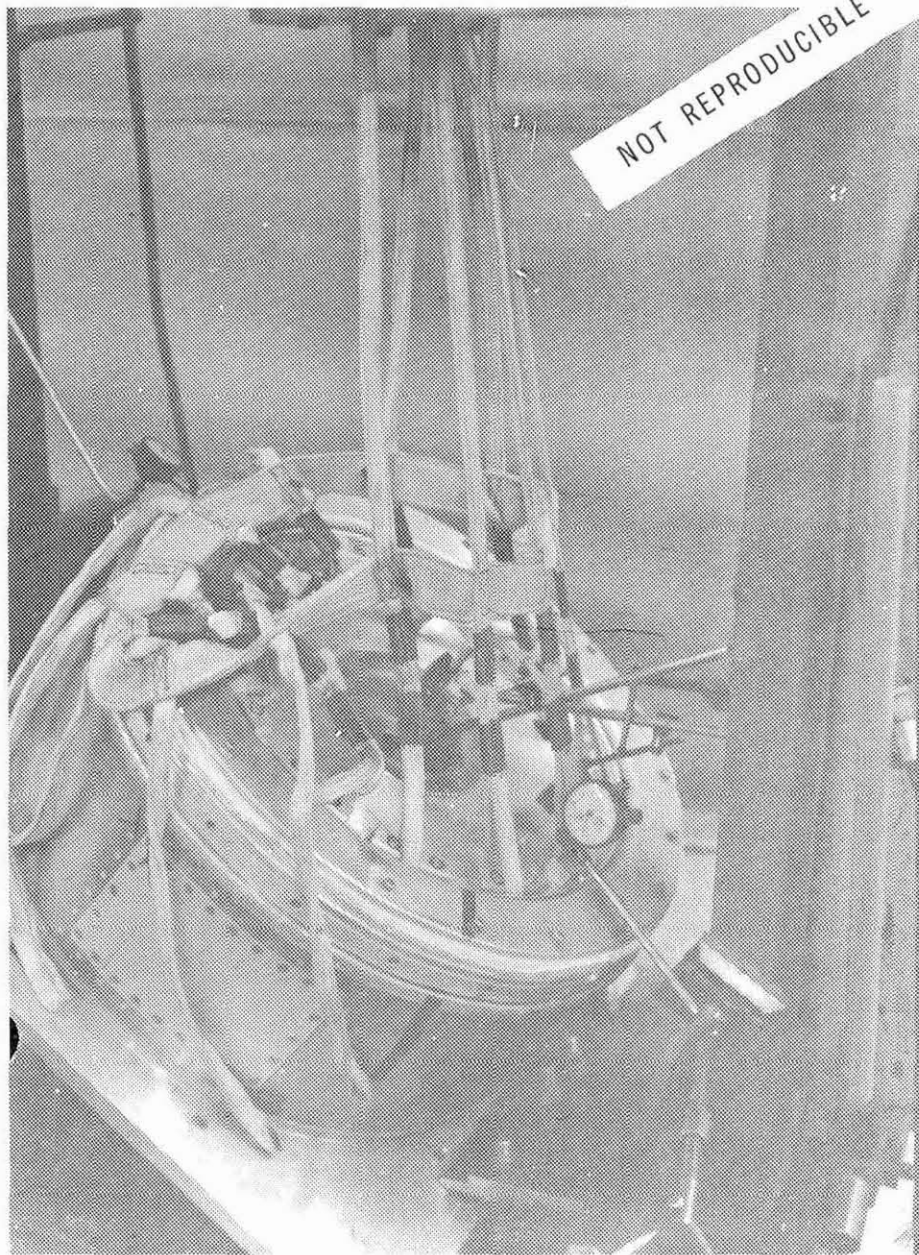


Figure 5. Paraloon Oblique Pull Test

For the first test, both parachute fittings were utilized, with an axial load of 2000 pounds. After that test, one of the parachute riser lines was disconnected and the load was again applied to just one fitting. See figure 6.

A post-test inspection revealed that the structure capability was much greater than the applied load. No indication of yielding was evident and all components were within tolerance.

Later, the parachute fitting was redesigned and moved aft in the structure. A retest was considered unnecessary due to the results of the initial test and the obvious improvement made by the modification.

3.1.3 Structural Pressurization Tests

Internal pressurization tests were conducted to establish the adequacy of the sealing techniques on the forward bulkhead and cylindrical sidewalls. A design requirement was established that the recovery system must be sealed so that during flight no gases will escape. Initially, the two hatches of the recovery system were provided with a 70 Shore A Durometer gasket. A fillet of Dow Corning Silastic 732 RTV was applied around the doubler on the inside of the skin of the test vehicle. Each rivet of the doubler was also coated with the RTV to provide sealing.

A test fixture consisting of a concave aft bulkhead of 0.090 inch thick 6061-T6 aluminum welded to a mating ring was fabricated to simulate the forward bulkhead. A liberal amount of silicone grease was applied to the O-ring of the fixture mating ring and the ring was installed as the separation ring of the recovery system. Pressurization of the unit was provided through a valve welded to the fixture bulkhead.

For each test, the system was pressurized to the desired pressure and immersed in a tank of water to inspect for leakage. A total of four tests were conducted.

During the fourth test, the unit was pressurized to 15 psig for 15 minutes. The unit was completely airtight except for a slight leakage at two rivets of a hatch doubler.

As a result of the tests, the hatch gaskets of 0.090 inch thick by 0.375 inch wide 50 Shore A Durometer silicone rubber were incorporated into the final design. The O-ring seal on the test fixture was considered adequate. Positive sealing of each unit was exhibited during the Acceptance Tests prior to delivery.

It should be noted that the 0.090 inch thick concave bulkhead did not invert under pressure. A similar bulkhead of 0.090 inch

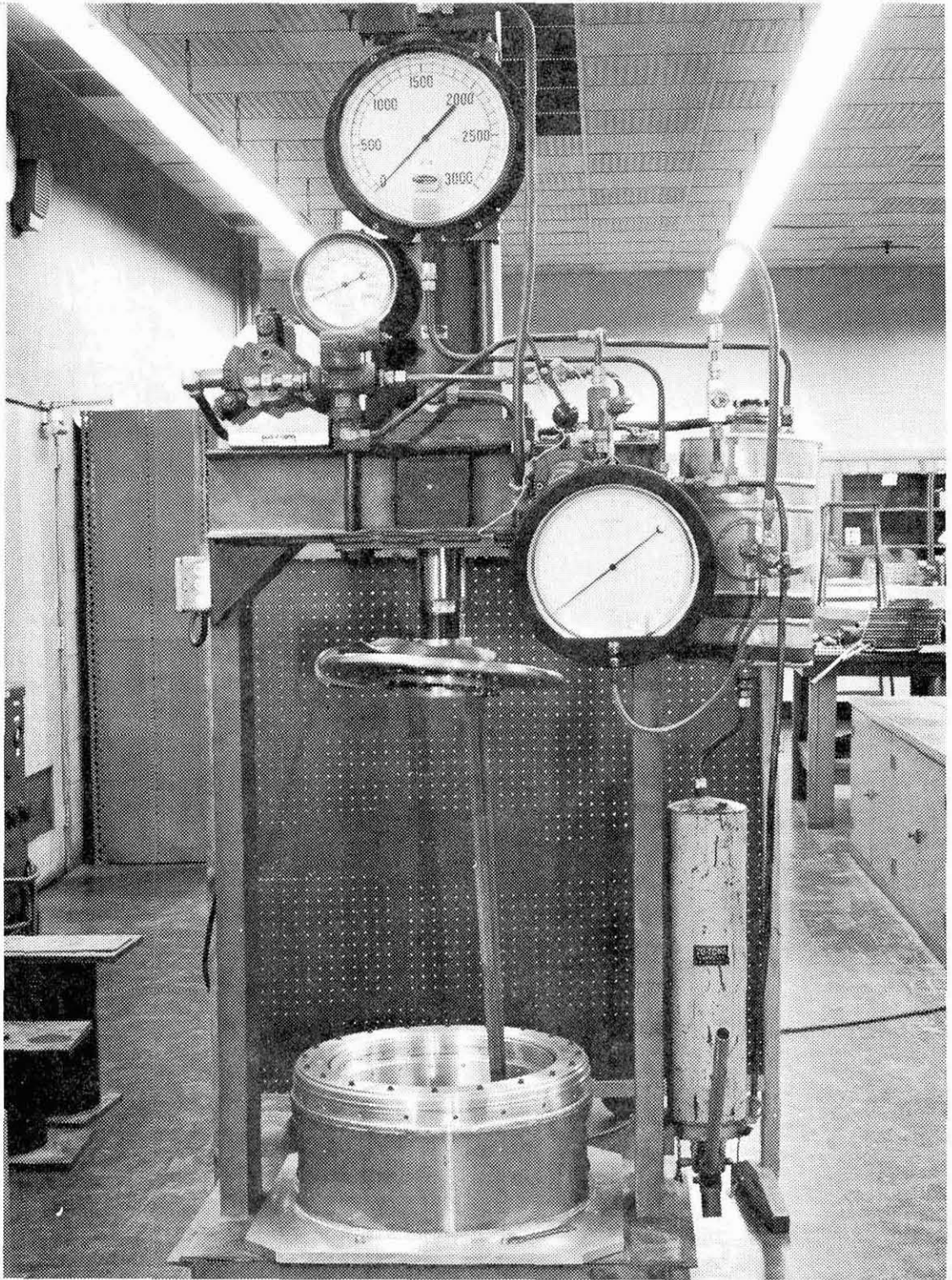


Figure 6. Parachute Axial Pull Test

thick 6061-T6 aluminum is incorporated into the design of the recovery system as the forward bulkhead, to conform to the design criteria of a 15 psig pressure differential from either side.

The stress analysis indicated a positive margin of safety for the forward bulkhead with an external pressure tending to invert it. This was substantiated during the pressurization tests.

3.2 Flexible Linear Shaped Charge (FLSC) Separation Systems

Preliminary testing was initiated utilizing past experience gained from similar separation systems incorporated on previous programs.

In the initial design phase of the separation systems, it was decided to update the FLSC to be used with the latest, most efficient FLSC available, Ensign-Bickford Company's Configuration IV shape with RDX explosive. After the new FLSC was purchased and testing commenced, considerable difficulty was experienced in initiating the new FLSC. Many back-initiation methods were attempted with varying degrees of success at a sacrifice of ease of installation and reliability. A reliable technique for back initiation was derived, which, however, required local flattening of the basic FLSC shape. This procedure was deemed unsatisfactory from the standpoint of production reliability, and testing was continued. After considerable investigation, tests, and discussions with vendors, a satisfactory initiation system was developed which utilizes a detonator with a single ruggedized bridgewire, Cook P/N 600190. A basic feature of the separation system is that the detonator is positioned normal to one side of the V of the FLSC, hence the term "side initiation." This technique presents a larger target area of the FLSC for the detonator blast, and couples the energy much more efficiently than attempting to back initiate on the symmetrical axis of the FLSC cross section (i. e., on the point of the V).

The design of the recovery system incorporates two independent separation systems, each consisting of a circumferential length of flexible linear shaped charge (FLSC) and two independent detonators. Two detonators are provided as good design practice in order to insure a high level of reliability through redundancy, with each detonator in a separate control system.

The following sections describe the two separation systems.

3.2.1 Separation System FLSC

Separation occurs at a specified time during flight, controlled by the programmer timers or by a T/M command. Power is normally applied via a timer in the recovery system which activates the detonators which, in turn, initiate the FLSC, separating the payload from the rocket.

The FLSC selected is manufactured by the Ensign Bickford Company of Simsbury, Connecticut. It has a 15 gr/ft RDX explosive core encased in a Configuration IV chevron shaped lead sheath. The FLSC itself is contained in a chevron shaped Teflon jacket which is designed to provide the optimum stand-off distance for best cutting capability. Also, the insulating qualities of the Teflon allow a higher temperature pulse environment than unprotected FLSC could tolerate. The FLSC assembly, Ensign Bickford Company P/N 205026 consists of the Teflon backup strip, P/N 204004 and the FLSC, P/N 206033. The FLSC itself is designated as a thin-wall FLSC having the performance characteristics of a 15 gr/ft core loading with the dimensions of a 10 gr/ft FLSC.

The separation ring has a total thickness of 0.100 inch of aluminum alloy 6061-T6 at the separation plane. Utilizing the Ensign Bickford Company data sheets, the FLSC has a 0.99999 reliability at a 90 percent confidence level for severing a 0.125 inch thick specimen when a standoff of 0.032 inch is utilized. The FLSC selected is more than adequate to assure the required separation function.

3.2.2 Parachute Deployment System FLSC

The FLSC utilized for parachute deployment is also manufactured by the Ensign Bickford Company, and is their P/N 206003. It consists of a 7 gr/ft RDX explosive core loading, also encased in a Configuration IV chevron shaped lead sheath. The FLSC is used to sever a 0.050 inch thick ring of aluminum alloy 2024-T351.

Statistical data is scarce pertaining to the reliability of a 7 gr/ft RDX FLSC severing this alloy with the specified thickness. However, one manufacturer claims that a maximum cut of 0.090 inch is possible. Statistical data does exist, however, for aluminum alloy 6061-T6.

In referring to the Ensign Bickford data, the FLSC has a reliability of 0.99999 at a confidence level of 90 percent with a standoff of 0.026 inch to sever a 0.064 inch thickness of aluminum alloy 6061-T6. Assuming that a "scaling" based on the shear strength of the materials can be utilized, the FLSC will sever and have the same reliability for a 0.048 inch thickness of aluminum alloy 2024-T351 at room temperature. Since the actual thickness is 0.050 inch and the ring will be at an elevated temperature during separation, a high reliability exists for complete severance.

3.2.3 Detonators

A total of four detonators are used in each recovery system. Each of the two separation systems utilizes two detonators spaced 180 degrees apart, with the butted ends of the FLSC located 90 degrees from the detonators.

The detonators are similar in explosive charge and internal geometry to the ruggedized detonator presently used in the Capache separation system. Both types of detonators contain a single bridge wire, with 100 mg of lead azide as the primer. 200 mg of RDX explosive is used for the main charge of the separation detonators, and 150 mg for the parachute deploy detonators. They are designated as Cook P/N 600190-001 and -003, respectively. The mounting threads and connector of the two are different to prevent inadvertent cross installation or cross connection.

During installation, the Teflon jacket is removed from the 15 gr/ft FLSC in the area under the detonator to assure initiation of the FLSC. Both strands of FLSC are cemented in place to prevent shifting in the groove.

In the later stages of the program, a detonator bridge wire sensitivity problem developed where if both detonators were wired in parallel to fire simultaneously, one of the detonators would malfunction leaving the skin material opposite the detonator intact. Also, a detonator in close proximity (such as the parachute deployment detonator) would lose continuity due to the shock of the nearby separation detonation. This problem was resolved by contacting the vendor and specifying a detonator with a more ruggedized bridge wire.

Subsequent tests to date have revealed that the latest detonators, Cook P/N 600190-001 and -003, are adequately ruggedized to survive the shock spectrum encountered.

3.2.4 Separation System Tests

During the early part of the program, extensive FLSC initiation and separation tests have been conducted. These tests were reported in detail in the "Final Design and Analysis Report," and will not be reported here. The following discussion pertains exclusively to tests conducted subsequent to that report.

The tests conducted include a series of initiation tests where a detonator test block is utilized in order to verify the initiation technique. The other tests conducted utilized the prototype structure in order to test the complete separation system, including the detonator initiation reliability.

In each of the tests, the same FLSC was utilized. However, several detonators were initially selected for evaluation before finalizing on the presently used detonator. These are listed below.

1. Hercules Powder Company P/N D119F0, 100 mg Lead Azide and 100 mg RDX

2. Halex P/N 7305, Cook P/N 600140-003, 100 mg Lead Azide, 200 mg RDX
3. Hole P/N 7899, Cook P/N 600190-001, 100 mg Lead Azide, 200 mg RDX.

The results of these tests are summarized in table 2.

3.2.5 Parachute Deployment System Tests

In a similar fashion, many FLSC separation tests for parachute deployment have been conducted. This report will consider only those tests conducted subsequent to those reported in detail in the "Preliminary Design and Analysis Report." In that document, these tests were called "Paraloon Separation FLSC Tests," and were presented in Table III.

For each of the subsequent tests, the same (prototype) FLSC was used, 7 gr/ft RDX Configuration IV FLSC, Ensign Bickford P/N 206003. This separation system is similar in design to that used for separation, two detonators are used, spaced 180 degrees apart on the circumferential charge, with one detonator electrically driven by the "A" control system and the other by the "B" system.

The detonator finally selected presently utilized for this function is designated as Cook P/N 600190-003. The "side initiation" technique discussed in Section 3.2 is used again here.

Table 3 summarizes both systems tests and initiation tests using small detonator blocks machined to duplicate the designed FLSC-detonator interface.

The detonators tested are listed below.

1. Hercules Powder Co., P/N D119F0, mg Lead Azide and 100 mg RDX
2. Halex P/N 7899, Cook P/N 600190-003, 100 mg Lead Azide with 150 mg RDX.

3.3 Paraloon Tests

Several tests were conducted in order to prove the adequacy of the paraloon design. The tests were designed to simulate the actual flight environment as nearly as practical. The tests included the sequence of events of paraloon deployment given below:

A. Cover ejection and inflation

TABLE 2 - SEPARATION SYSTEM TESTS

Test No.	Date	FLSC	Detonator	Comments	Results
23	1-2-68	15 gr/ft E. B. P/N	Hercules D119F0 (two)	Preliminary systems test using backside initiation.	FLSC initiated, cut was excellent. The steel band restricted the flaring of the aluminum ring.
24	10-14-68 at NASA	Same	Holes P/N 7305, Cook P/N 600140-003 S/N 101 and 102	First separation test conducted at NASA/GSFC. Two detonators, S/N 103 and 104 mounted to slate for shock survivability check. Both detonators fired simultaneously.	FLSC initiated, but skin not severed at one detonator, S/N 103 bridgewire broken by shock. No flaring of aluminum ring due to steel band. FLSC groove area distorted at detonators.
25	10-15-68 at NASA	Same	Same S/N 105 and 106	Second separation test conducted at NASA/GSFC. Both detonators fired simultaneously.	FLSC initiated with good cut of skin. No problem even though structure damaged in previous test. No flaring of aluminum ring.
26	10-24-68	Same	Same S/N 203 and 204	First ballast separation test for Drop Test Program. Two chute deploy detonators, P/N 600140-001 installed for shock check.	Misfire. Detonators self ejected from welding mounting "boss" due to annealing of material. No initiation. -001 dets OK.
27	11-1-68	Same	Same S/N 205 and 206	Second ballast separation test. Two -001 dets also installed for survivability shock. Both dets fired simultaneously.	FLSC initiated and cut skin except at one detonator. Both -001 dets survived. No flaring of skin.

TABLE 2 - SEPARATION SYSTEM TESTS (Contd)

Test No.	Date	FLSC	Detonator	Comments	Results
28 thru 32	4-2-69	Same	Holox P/N 7899 Cook P/N 600190-001	Individual initiation tests using detonator blocks. Detonators used were S/N 001, 002, 004, 005, and 008.	FLSC initiated and cut was excellent all five times.
33	4-3-69	15 gr/ft E.B. P/N 205026	Holox P/N 7899 Cook P/N 600190-001 S/N 009 & 010	First Prototype System Test using complete R/S S/N 003.	FLSC initiated and cut was excellent.
34	4-10-69	Same	Same S/N 011 & 013	Second Prototype System Test using complete R/S S/N 003.	Same.
35	5-9-69	Same	Same S/N 003 & 006	Second Drop Test at El Centro using R/S S/N 001.	Same.
36 thru 43	7-23-69	Same	Same	Continuation of series of initiation tests using individual detonator test blocks.	Same.
44 thru 55	7-25-69	Same	Same	Same. Completion of 25 individual detonator block tests.	Same.

TABLE 3 - PARACHUTE DEPLOYMENT SYSTEM TESTS

Test No.	Date	FLSC	Detonator	Comments	Results
28	1-2-68	7 gr/ft RDX Conf. IV E.B. P/N 206003	Hercules D119F0 (two)	Preliminary systems test using prototype structure. Backside initiation.	FLSC initiated and cut was excellent.
29 thru 31	4-2-69	Same	Holox P/N 7899, S/N 002, 003, and 004	Initiation tests using detonator blocks.	Same.
32	4-3-69	Same	Same. S/N 007 and 009	First prototype systems test using R/S S/N 003.	Same.
33	4-10-69	Same	Same. S/N 015 and 016	Second prototype systems test using R/S S/N 003.	Same.
34	5-1-69	Same	Same. S/N 006 and 018	First Drop Test at El Centro using R/S S/N 001.	Same.
35	5-9-69	Same	Same. S/N 001 and 010	Second Drop Test at El Centro using R/S S/N 001.	Same.
36 thru 43	7-23-69	Same	Same	Continuation of initiation tests using detonator blocks.	Same.
44 thru 57	7-25-69	Same	Same	Same. Completion of initi- ation tests for a total of 25 detonator block tests.	Same.

- B. Operation under flight conditions
- C. Pressurization

A brief description of each test is given in the following sections.

3.3.1 Cover Ejection and Inflation Tests

Cover ejection tests were performed to demonstrate the capability of the inflating paraloon to forcibly remove the paraloon cover for deployment and inflate. This technique has been successfully utilized many times on previous programs to remove the paraloon cover and deploy the paraloon.

The operation is essentially that of inflating a paraloon restricted in a compartment. When enough force is generated, 20 No. 6 screws are sheared, thus releasing the cover and allowing the paraloon to continue to inflate.

A paraloon minus the drag skirt was fabricated for the tests. For each test, the recovery system was assembled and the paraloon packed into the compartment provided.

The design of the recovery system has the paraloon cover attached to the extension ring which is in turn fastened to the paraloon separation ring with shear screws. The revised stress analysis shows that the 36 No. 8 screws at the interface connection of the paraloon cover to the extension ring yield a margin of safety in shear of 1.24 against re-entry design pressure loads. Primarily, past experience dictated the use of 20 No. 6 shear screws for the fastening of the packing ring to the recovery system structure. The utilization of 20 shear screws allow the paraloon to build up pressure, remove the cover and to rapidly inflate during deployment. The screws used have an ultimate strength in single shear of 382 pounds at 400°F and 510 pounds at room temperature. This requires a total force of 7640 pounds at 400°F to shear 20 screws and eject the cover, but 10,200 pounds at 50°F at which temperature the ground tests were conducted. The area of the paraloon cover is approximately 200 square inches, so the gas pressure required to shear the screws is a nominal 50 psi at the test temperature.

A 225 cubic inch reservoir and manifold was assembled to the recovery system for test purposes. Since this is approximately 3.2 times the prototype bottle volume, the reservoir was pressurized with nitrogen to 1100 psig and mated to the test fixture. The nitrogen was to be released into the paraloon by activating a solenoid valve.

The first test occurred on 6 July 1967 (see figures 7 and 8) approximately one second after release of the nitrogen, the paraloon cover was ejected approximately 50 feet into the air. The paraloon inflated to about 1 psig in about 5-6 seconds.

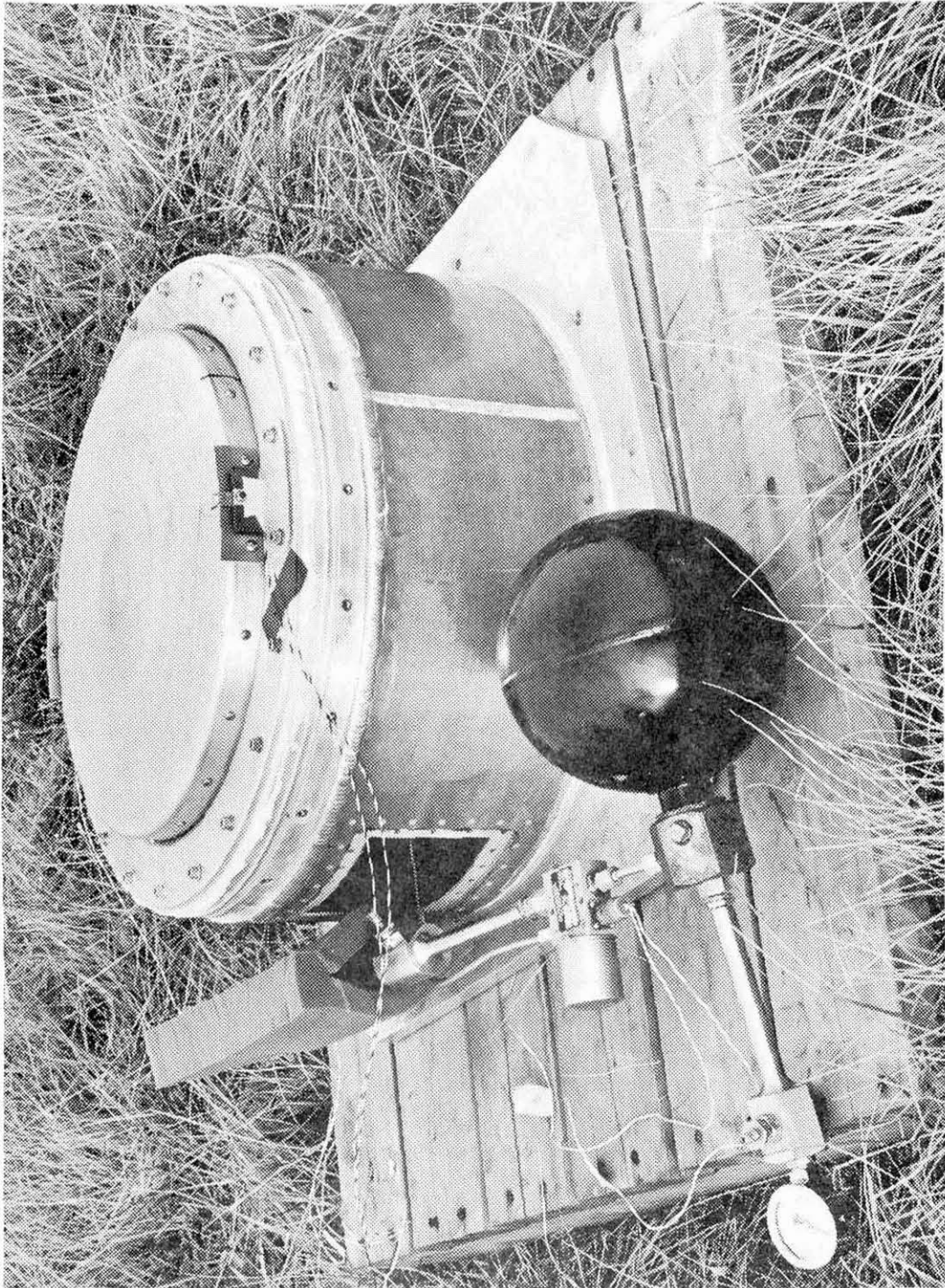


Figure 7. Paraloon Cover Ejection Test Setup



Figure 8. Paraloona Inflated After Test

The 20 shear screws sheared as expected but the total elapsed time to fill the paraloon was more than expected. The long fill time was attributed to the relatively low pressure differential of the initial impulse and the length and small ID of the tube connecting the reservoir to the paraloon.

Past experience has shown that a properly sized reservoir pressurized to about 3000 psig and located close to the paraloon will give "working form" to a paraloon in about 1.0 to 1.5 seconds. Normally, a 16 to 17 psia paraloon pressure presents excellent deployment characteristics at deployment altitude.

The second test was a repeat of the first, and occurred on the same day with similar results. The capability of the inflating paraloon to eject the paraloon cover and deploy itself was satisfactorily demonstrated.

A third cover deployment test was conducted on 14 December 1967 to simulate the actual paraloon deployment conditions during re-entry except for the heating environment. Provision for measuring the deflection of the center structure during paraloon pressure buildup prior to shearing of the cover screws and the total time from the releasing of the nitrogen in the reservoir until the cover is ejected, was included.

Three cover shear screws were added at a 120 degree spacing to simulate a "q" load of 1530 pounds on the paraloon cover during deployment at an angle of attack of 180 degrees, which is twice the 750 pound load actually anticipated at deployment. A rigid member was attached to the center of the underside of the paraloon attachment plate, with the forward end just contacting a pad of beeswax mounted to the forward bulkhead to measure the total deflection of the parachute cover and inner structure during deployment. In addition to the above, a pair of small Winchester connectors, acting as switches, were positioned 180 degrees apart on the paraloon cover with the circuit connected to a two-channel brush recorder.

The same 225 cubic inch reservoir with a solenoid operated valve was used but the fill line length was reduced to about 24 inches. The reservoir was pressurized to 1100 psig.

When the nitrogen in the reservoir was released, the cover was ejected approximately 50 feet into the air. The total elapsed time of 0.5 second from application of power until cover removal was indicated by both channels of the Brush recorder. Time to full shape was approximately 2.0 seconds. A total deflection of 0.1 inch was indicated by the impression left in the beeswax pad. No permanent deflection of any structure was detected after the test. The paraloon was pressurized to 21 psia after stabilization.

The main purpose of the test was to measure the deflections of the parachute cover and the forward deck which act together. Since this was demonstrated to be only 0.1 inch, the stresses involved are not critical. The parachute cover in the final design has a minimum thickness of 0.090 inch while the forward deck has a 0.093 inch thickness.

The reactive force which generated this deflection is calculated to be 11,730 pounds, which is the ultimate single shear force for the 39 shear screws employed in this test. This force far exceeds any of the other axial force on the inner structure during launch, re-entry or recovery. Thus the adequacy of the central structure design has been conclusively demonstrated.

3.3.2 Bong Drop Tests

Two drop tests of the paraloon were performed at Bong AFB on 13 September. The drop vehicle was a boiler plate version of a 6 caliber cone cylinder (03-2) weighing 375 pounds with a CG 3.72 diameters from the nose. In the first test, the paraloon was pre-inflated to 2.0 psig with the skirt reefed. The vehicle was suspended beneath a helicopter by a nose lug with the paraloon down (see figure 9). The drop was made at an altitude of 1100 feet, with the vehicle reoriented nose up. Disreef occurred at 4 seconds. The terminal velocity was about 110 fps, and oscillations were in the range of ± 10 -20 degrees.

Test No. 2 was intended to confirm stability and terminal conditions; the paraloon skirt was not reefed. The vehicle was dropped in the horizontal attitude from 1200 feet above ground. Terminal conditions were identical to Test No. 1.

3.3.3 Pressurization Test

A prototype paraloon was designed and fabricated for the test, which was conducted on 8 September 1967. In order to assure a proper design, the paraloon was given a proof pressure test which consisted of pressurizing the paraloon to 10 psig, and holding for a period of 10 minutes. During this time there was a pressure drop to 9.75 psig, which is considered not significant. An actual leak would have resulted in a greater pressure drop. This proof pressure is 1.75 times the maximum design overpressure of 5.74 psig. During recovery, the paraloon is utilized for only 15 seconds, and therefore the 10 minute test period was considered more than adequate.

3.4 Parachute Tests

Two parachute drop tests were conducted utilizing the boiler-plate test vehicle and a packed parachute installed on the prototype

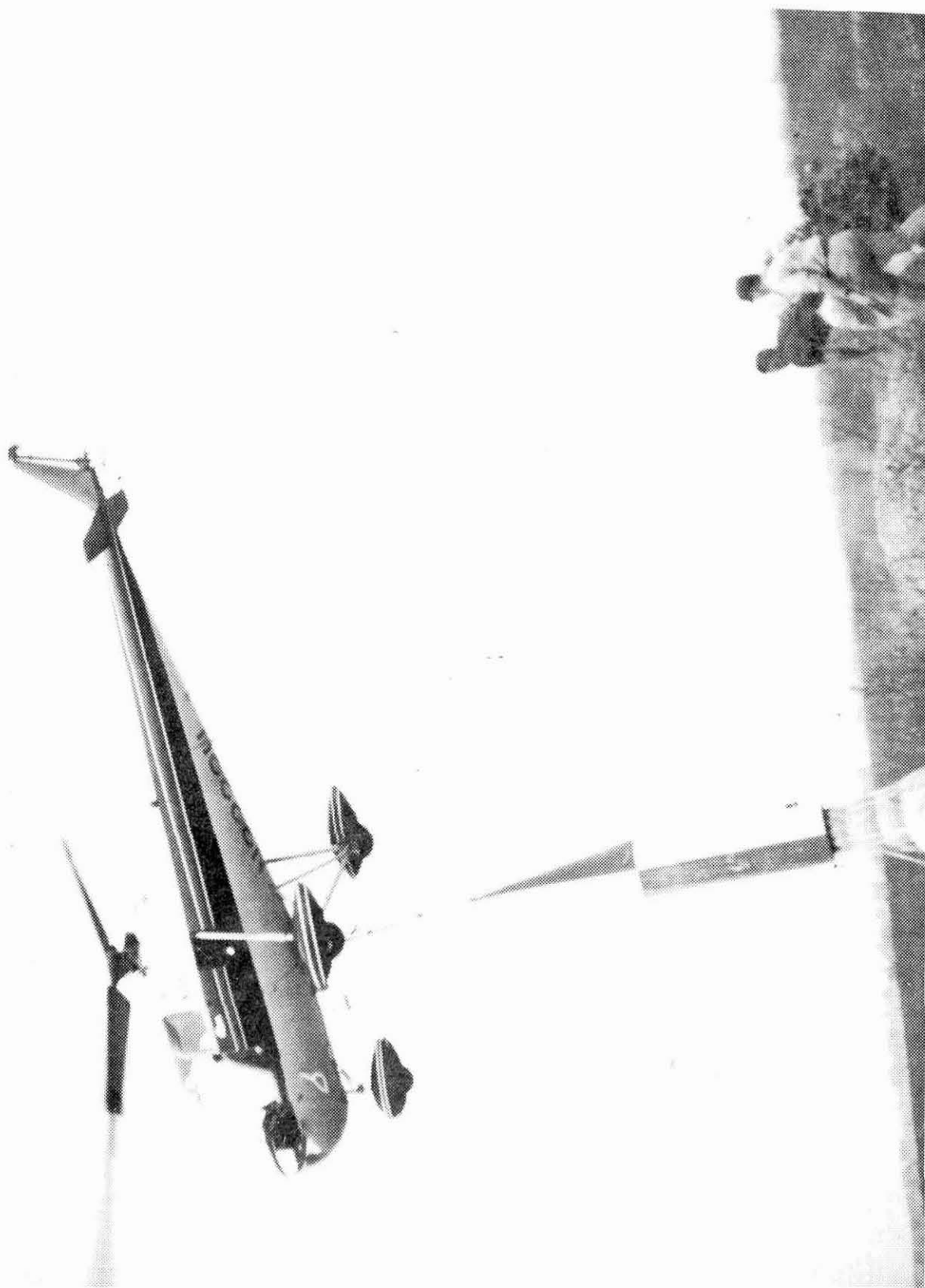


Figure 9. Helicopter Lifting Test Vehicle for Paraloon Drop Test

recovery system. The tests were conducted at the Richard Bong Recreation Area located in Kenosha County, Wisconsin. A Brantly helicopter was chartered to conduct the tests.

The boilerplate test vehicle was fabricated from commercial grade steel into a 3:1 cone plus a 3:1 cylinder configuration. Ballast was added for a total weight of 362 pounds with the prototype recovery system installed. The center of gravity was located at a point 52 inches from the aft end for the drop presenting an extreme forward c.g. condition.

The first test was conducted with the vehicle being launched from a horizontal stationary position at an altitude of 2500 feet above ground level. The vehicle had a 4.7 second free fall from the helicopter at 2500 feet altitude to achieve a velocity of about 150 fps ($q = 26.8$ psf). At the end of 4.7 seconds (controlled by pyro-delay cutters), the parachute was deployed by a 3 foot diameter pilot parachute. The 35 foot extended skirt canopy was reefed for 4 seconds, and then successfully disreefed. Due to high wind drift, and distance from the observers to the ground impact point, only approximate measurements of terminal velocity were achieved. An estimated terminal velocity of approximately 30 feet per second was attained by measuring the time interval of the final 150 feet of descent with a drop line attached to the vehicle. The chute functioned perfectly in every respect and incurred no damage whatsoever. Oscillation was about ± 10 degrees. The deployment bag and pilot chute separated from the main canopy apex and were not recovered.

The test deployment dynamic pressure of 26+ psf compares to a maximum expected operational q of 31.7 psf, and is considered good preliminary verification of design.

The second parachute drop test was conducted in an attempt to obtain a more accurate terminal velocity measurement. Again, the vehicle was dropped from an altitude of 2500 feet. The chute was rigged for static line deployment rather than using a pilot chute as employed previously. Due to a tight line stow loop in the deployment bag, the static line break tie snapped before all the lines were deployed. The drop vehicle was destroyed and most of the prototype R/S structure was distorted so as to be useless for further testing.

Despite the tight line stow loops, the parachute would have deployed properly had a pilot chute been used as in the first test, rather than a static/break line. A subsequent pull test on the tight loop indicated an approximate force of 40-50 pounds to pull the line bundle free. A 3.0 foot pilot chute such as used previously would generate an extraction force in excess of 50 pounds with a q of 10 psf (91 fps) which would be surpassed in about 2.5 seconds of free fall.

The deployment bag was redesigned so that the stow loops are more carefully controlled dimensionally. The loops and panel locks have also been increased in size to accommodate the larger 200 pound suspension lines now being used.

3.5 Control System Tests

During the course of the development program, the control system evolved into the present reliable form through a series of tests evaluating components and eventually exercising the completed prototype control system. The following sections discuss the finalized components of the control system, the simulator and Checkout Unit developed for factory testing the control systems, and the testing of the finalized prototype control system.

3.5.1 Component Evaluation and Tests

This section summarizes the more significant results of the development testing performed on components and subassemblies of the electrical control system.

3.5.1.1 Program Timer

The original program timer selected for use in the Aerobee 350 Recovery System was a 5 cam mechanical timer manufactured by Acton Laboratories, Acton, Massachusetts, Model No. 4-23-5-640. It was determined early in the program that Acton could not deliver within cost or schedule, so their purchase order was canceled and an order was placed with Datametrix, Inc., Waltham, Massachusetts for a slightly modified version of their Model 657 timer. The Datametrix unit (see figure 10) is slightly larger than the Acton, has six adjustable cams (three solid, three split), and operates on 12 Vdc. Complete specifications for the timer are contained on Drawing 600100, some of which are:

- a. Total timed duration up to 720 seconds (dial indication).

Total timed duration up to 760 seconds (actual 360° cam rotation).

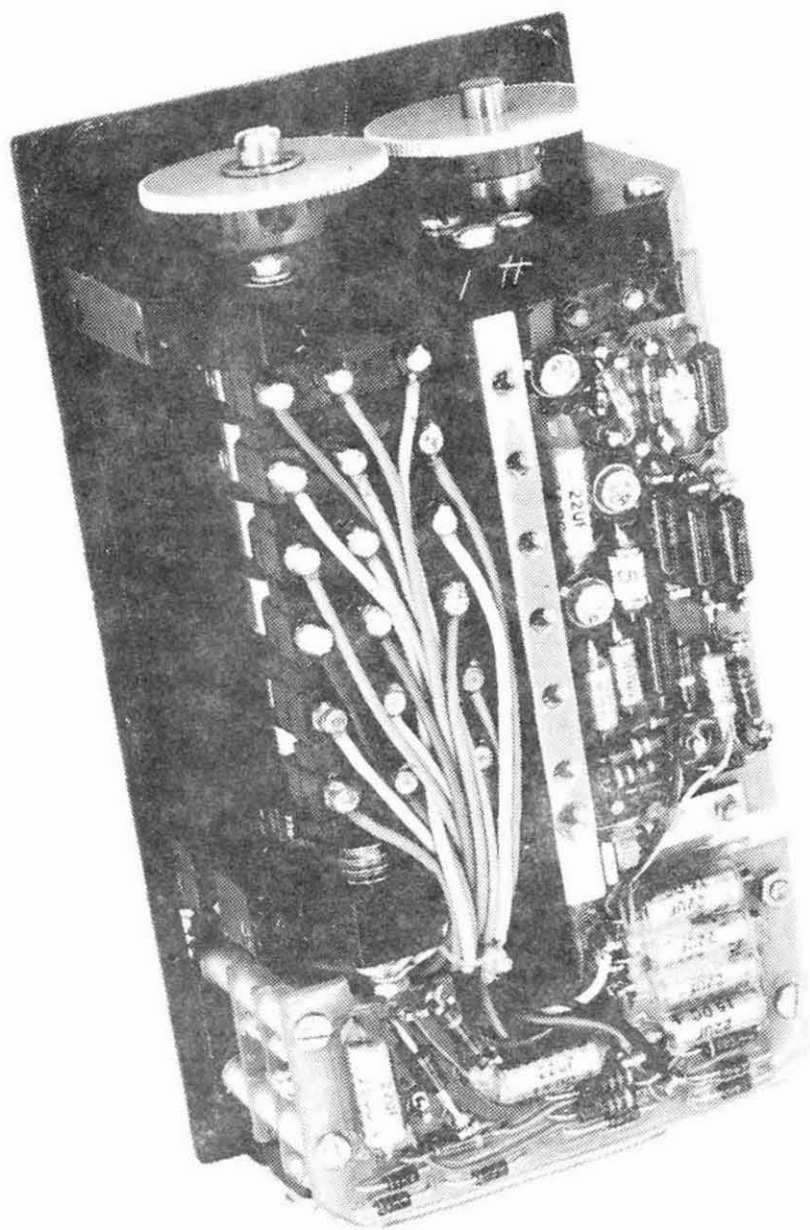
- b. Accuracy:

At room temperature, from reset position, 12 Vdc
±1.8 sec, 10-720 sec range.

At -15°F to +140°F, from reset, 12 Vdc ±2 V,
±7.2 sec ±1% of setting.

- c. Life - 1000 hours under stated environmental conditions.

Figure 10. Program Timer



- d. Switching capability: 28 Vdc, 7 amps resistive, 40 amp surge current.

The Datametrics timers were received and timing accuracies were checked out to be well within spec. Test results yield a timer accuracy of ± 0.5 percent of full scale (720 seconds) plus ± 0.5 percent of setting over the temperature range of -15°F to $+140^{\circ}\text{F}$ and input voltages from 10 to 14 Vdc. Thus, for a 400 second mission within these environmental ranges, accuracy will be ± 3.5 sec plus ± 2.0 sec for a total expected variation of ± 5.5 seconds. However, time variation with temperature is a regular, not random, function, i.e., at 140°F , the timer repeatability error is actually ± 0.20 percent or less, as it is at room temperature. Thus, if timer temperature during flight is known, temperature effects compensation can be applied to practically eliminate timing errors.

From this it can be seen that the timing accuracy is about a factor of 2 to 1 better than specified. The following table lists timing accuracies achieved on S/N 4 timer at various temperature-voltage conditions. The timer was initially set to the full 760 second position. Subsequent tests were from the reset position.

Input Voltage	Time (sec) at Specified Temperature					
	Room	140°F	180°F	Room	-30°F	-15°F
10 Vdc	760	766		759	751	754
14 Vdc	758	766	767	759	751	

In the 2-10 second range the above test was repeated. The timer is initially set to 2.4 seconds and subsequent tests are run from the electrical reset position.

Input Voltage	Time (sec) at Temperature					
	Room	140°F	180°F	Room	-30°F	-15°F
10 Vdc	2.40	2.50		2.50	2.60	2.65
14 Vdc	2.40	2.25	2.00	2.20	2.65	

The basic version of this timer, the Datametrics Model 657, has been qualified to environments well in excess of those of the Aerobee 350 R/S.

As stated in another section, the program timer was mounted to the test structure during the FLSC testing and has survived without damage, except for a uniform shift of one second in the actuation time of all switches due to takeup of mechanical slack in a common mounting screw.

Figure 11 is a photograph of the prototype/breadboard electrical control system with the two timers. Referring once more to Fig. 10,

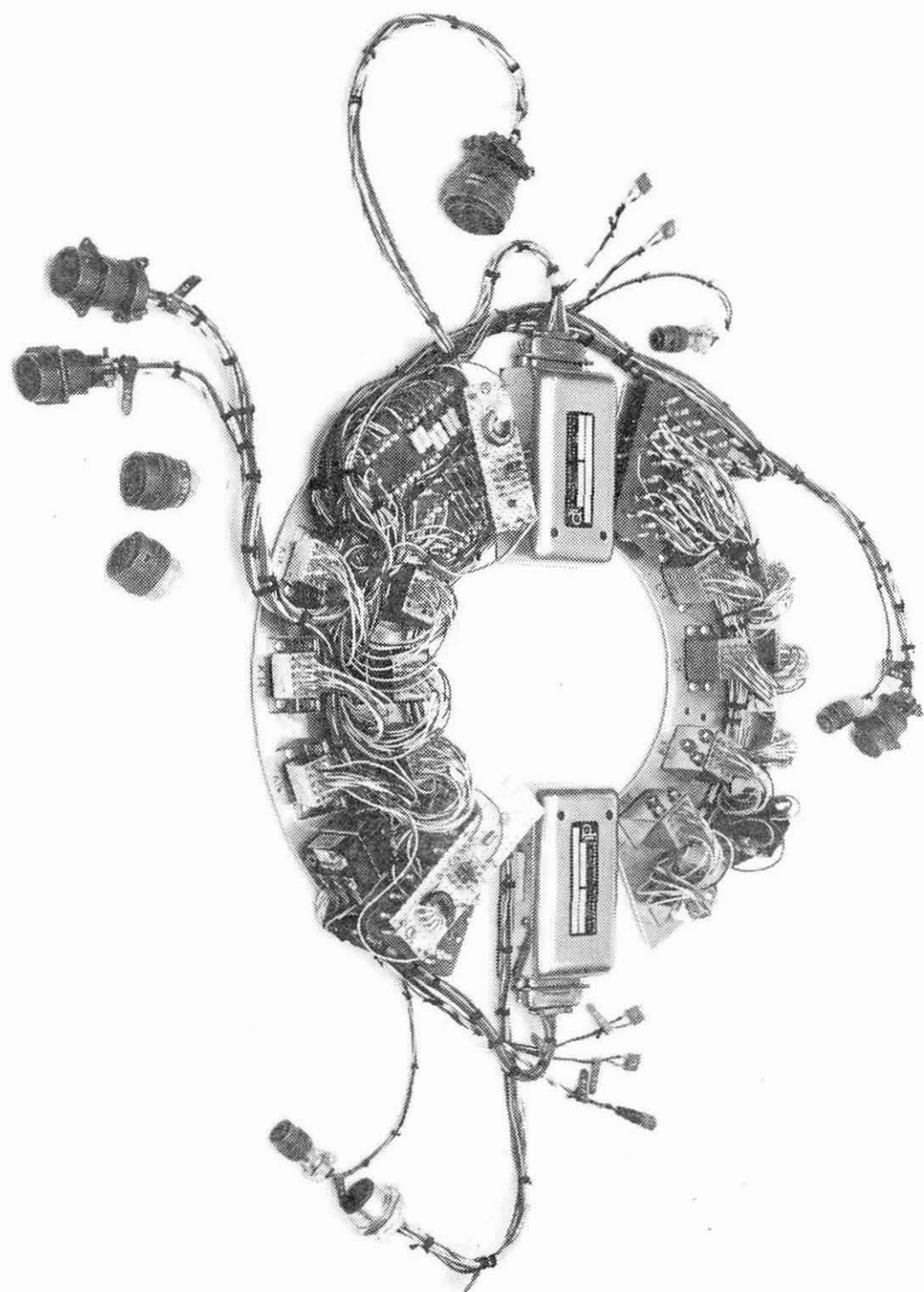


Figure 11. Breadboard Electrical Control System

counting from the left side, cams 1, 3, and 4 are solid with a single detent point and thus create only momentary closures in switches 1, 3, and 4. Switches 1 and 4 provide motor control; timer shutoff of 4, runout and reset on 1. Switch 2 provides power to the payload command and programmed mode circuits as early as 5 seconds after first movement. Switch 3 is timer status. The width of the detent slot in the cam provides about 5-6 seconds of dwell for the switch buttons. The split cams 5 and 6 provide the desired time delay for the separation switch signals in the "A" and "B" circuits.

To adjust the cams, the cover must be removed from the timer, and the cam gear must be released from the cam shaft by loosening its clamp hub. The end of the cam shaft is then rotated with a screwdriver and the individual cams locked into the desired positions by set screws in the cam faces.

3.5.1.2 Event Marker Circuit

The event marker circuit originally designed and breadboarded was based upon a successful unit Cook has used previously. However, the total usable pulse length of the event marker was determined to be effectively less than the 200 milliseconds necessary for reliable time sharing on a commutated TM channel. The circuit was redesigned to increase the time constant so that a usable pulse width of 2 seconds is achieved.

3.5.1.3 FLSC Shock Environment Tests

In conjunction with the FLSC cutting tests, all the electrical components intended for use in the control system were hard mounted to the test structure to determine their ability to withstand the explosive shock. During the four initial 15 grain FLSC tests, the components tested were:

Aneroid - Aeromechanisms	Model No. 910
Relay - Potter-Brumfield	Model No. TL17DB
Relay - Babcock	Model No. BR18AX-D4-V3
Relay - Potter-Brumfield	Model No. SC11DB
Time Delay Switch - Jay El Co.	Model No. 10166
Timer - Acton Industries	Model No. 4-23-10
Fuses - Picofuse (Littelfuse Inc.)	Model No. 275001
Resistor	MIL RN 60
Switch (snap action)	MS 25348-1

The Potter-Brumfield TL17DB failed just from the shock of the detonator alone, i.e., an open contact that would not close. A later test of the same model wherein the FLSC functioned normally,

D

severely damaged the interior structure of the TL17DB. The Babcock relay was undamaged and did not actuate due to shock.

An unpotted Jay El time delay switch broke a capacitor lead internally on one test. The potted units to be used in the flight hardware survived without any change.

The aneroid changed setting by 4000 feet in one test due to loose housing screws.

On 1 January 1968, the preliminary system test was performed wherein the 15 grain FLSC, explosive air valve, and 7 grain FLSC were detonated in sequence. In conjunction with the above, the following electrical components were mounted to the structure as indicated:

- 1 Aneroid - Aero Mechanisms, Model 9010 -
mounted to the inside of an installed access hatch.
- 2 Time Delay Switches - Jay El, Model 10166 -
mounted to a simulated control deck shock mounted on
the front of the chute compartment.
- 2 Relays - Babcock, BR191AX-D3-V3 -
mounted to same deck as the time delay switches.
- 1 Timer - Datametrics, Cook P/N 600100, S/N 002 -
mounted to parachute compartments.

The timer and relays were exercised after each of the three explosive events.

The time delay switches and the relays were unaffected by all explosive shock tests and operated normally before and after each test.

The aneroid shifted its opening and closing settings during the test by about 3500 feet. Inspection revealed that the three case assembly screws were slightly loosened, allowing switch movement relative to the aneroid bellows.

The screws were tightened and the aneroid was rechecked in the vacuum chamber. This recalibration yielded switch opening at 24,800 feet and closure at 19,100 feet which is identical to its original setting before the FLSC tests. All aneroid screws in the flight hardware will be checked and secured with Locktite.

The Datametrics timer was unaffected except for a uniform one second shift in all six switch trip times. This shift was due to the

clearance takeup between the switches and a common mounting screw which passes through a hole in each of the switches.

3.5.1.4 Protective Fuses

It sometimes happens that bridgewire leads in electric detonators will short to case ground or contact each other after successfully igniting the explosive mixture. To prevent damage to the batteries from such an occurrence, protective fuses have been incorporated in each of the six detonator power lines. These fuses must provide the desired degree of protection and yet not be so delicate or marginal in their time-current blow characteristics that they might be blown prematurely. Therefore care was exercised in the selection of the proper fuse size. Also, the fuses are installed between the checkout connector and the detonators so that the checkout current does not pass through the fuses.

In the initial FLSC firing tests a Picofuse 275002 was used in series with the detonator bridgewire. Fusing time of the detonators ranges from 2.5 ms at 3.5 amperes for the CAD valve to 2.7 ms at 4.5 amperes for the Halex detonators, Cook P/N 600190. The 275002 fuse has a blow time of 50 ms at 4.5 amperes. With the detonator bridgewire shorted, the 24 volt 10V0500SP battery can deliver a minimum short circuit current of about 9.6 amperes, which indicates 1.0 ohm of internal battery resistance at that current. Blow time of the 275002 fuse at 9.6 amperes is about 5 ms.

The foregoing numbers indicate a sufficient time spread between the 50 ms for the fuse and the 2.7 ms for the detonators. However, since the batteries can certainly stand the short current of 9.6 amps for more than the 5 ms blow time of the 275002 fuse, even longer fusing times were investigated.

The fuse selected for use in the flight hardware is the high reliability Picofuse 265004 which has a 25 millisecond blow time at the 9.6 amperes minimum short current. At the 4.5 amp firing current level, the blow time of the 265004 is over 100 seconds.

3.5.1.5 Detonator Simulation

In order to permit rapid, safe, and inexpensive functional testing of the control system, it was decided to simulate the bridgewire action of the detonators using fuses with the same current blow time characteristic.

The following table lists the blow times of the basic electric detonators used in the 350 Recovery System.

Holox (Cook P/N 600190)	2.7 ms at 4.5 amp, 1.0 $\pm$ 0.1 ohm
Flare Northern NNS 105A	2.5 ms at 3.5 amp, 1.15 $\pm$ 0.15 ohms

A simple test setup quickly determined that a 3AG 1/2 fuse, Littelfuse No. 312.500, has the required characteristics:

Resistance	1.25 ohms
Blow Time	4.5 ms at 5.6 amps 3.1 ms at 6.5 amps

The Simulator/Checkout box detailed in Section 3.5.2 of this report utilizes 3AG 1/2 fuses to simulate the detonator bridgewire action of all six circuits.

The use of these fuses permitted the repeated testing of the event marker circuits to establish optimum biasing and pulse output. It was also possible to repeatedly function the entire control system in Automatic and Command Mode to show reliable performance, to demonstrate that sympathetic relay actuation does not occur, and to prove that the Jay El time delays will not short out or change timing accuracy due to surges from the heavy firing current.

3.5.1.6 Time Delay Switches

Four R-C solid state time delay switches are used in the electrical control system; S1 and S2 are 10 second lockouts to prevent premature paraloon deployment by the aneroids after command separation, and S3 and S4 are 15 second delay switches which automatically cause parachute deployment 15 seconds after paraloon deployment.

The switches used are Jay El Products, Inc., Model No. 10166-20, Cook P/N 700574. The unit is foam potted and has passed all required functional and shock tests. The time delay is a linear function of the external resistance placed across contacts 1 and 2 of the switch. Delays up to 36 seconds can be attained with a resistance of one megohm. Each switch varies slightly so that in order to achieve the most accurate 10 and 15 second delay values, the resistors are hand selected for each switch.

Functional testing of the full system has revealed no timing variation in the time delay switches due to transients on the lines when the detonators are fired.

3.5.2 Factory Simulator and Checkout Unit

For development and production testing, a combined control system simulator and checkout unit was constructed to:

- a. Provide input stimuli to the control system to simulate lanyard, timer, and aneroid switch closures.
- b. Simulate command signal inputs from a simulated TM payload.
- c. Provide fusible loads for the detonator circuits to simulate their bridgewire action.
- d. Monitor system status and performance. Provide quick system cycling and reset capability.
- e. Provide a proven piece of equipment for factory test of the three deliverable systems.

Figure 12 shows the control panel of the Simulator/Checkout box. The cables coming from the top of the unit terminate in connectors matching those of the prototype control system, so that the box can be mated anywhere in the system to simulate in input signal or monitor response.

Referring again to figure 12, the functions of the various controls can be described more or less in the order of a simulated mission.

Prior to launch, the status of the timers, lanyard switches, and the normal command recovery relays can be monitored either through the Pad Checkout indicator lights (upper left) or the Blockhouse Status indicator lights (lower left).

The relay reset control (center panel) operates through the pad checkout connector.

Aneroid status is indicated by the position of the switch handles (lower right).

The status of the air bottle pressure or the separation indicator jumper is presented on the microammeter (right center). The switch to the left of the meter selects either the joined/separation switch (bottom center) or the potentiometer simulating the pressure transducer (top center) to be displayed on the meter.

At the left center are located the six receptacles for the 3AG 1/2 fuses used to simulate the detonator bridgewires. Each of these is wired in parallel with the indicator light above it, which turn on to give a visual indication that the firing current has been applied.

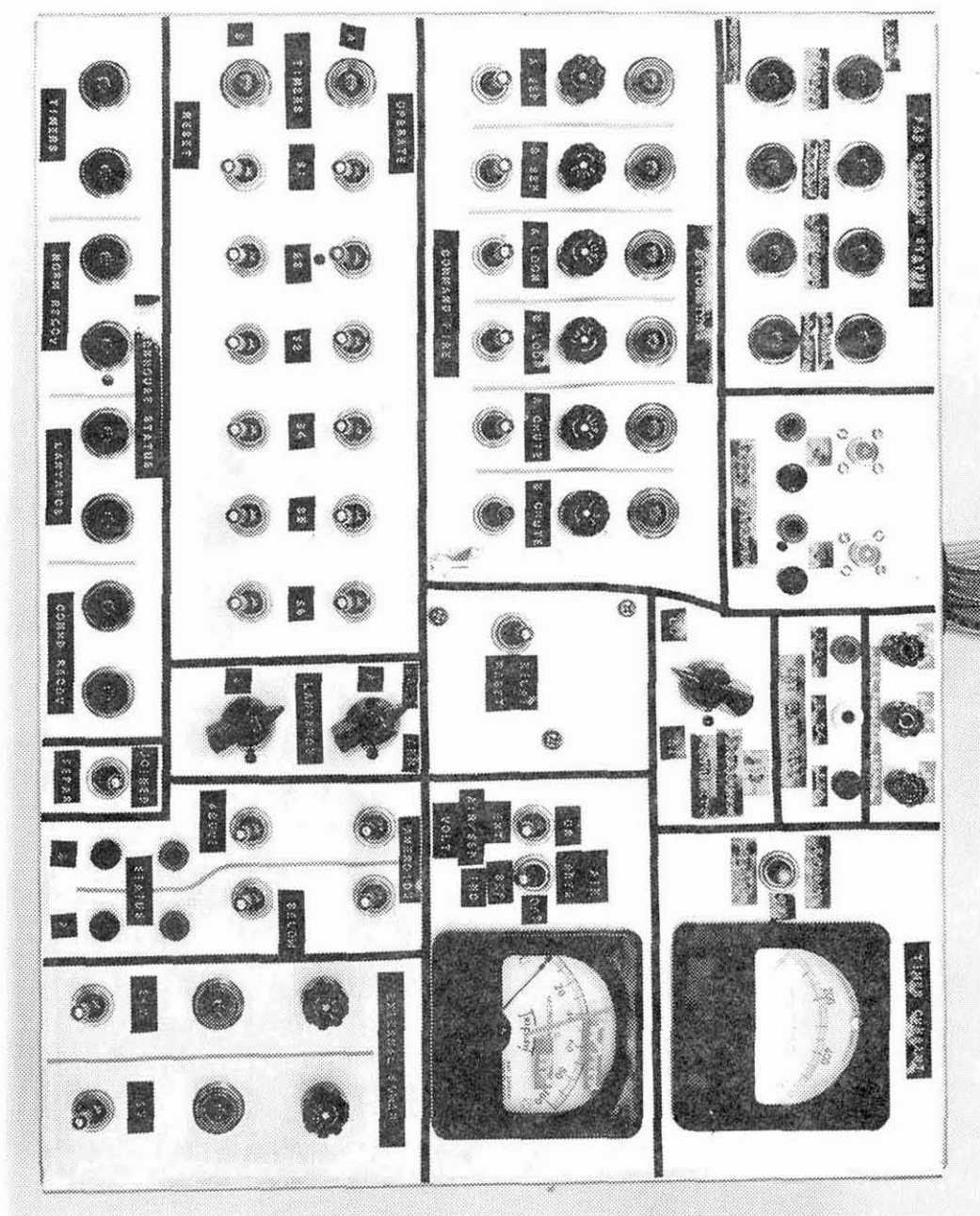


Figure 12. Simulator Checkout Box

These stay lighted until the firing relay or switch has been reset. Below these fuses are the TM command switches. These toggles are spring loaded and are normally off.

If the program timers are not used, their switch action can be simulated by the 12 switch array at the lower left center of the panel. The lights, A and B, indicate when power is being applied to the timer motors (i. e., through switches S1 and/or S4).

At liftoff, the lanyard switches are moved to the "Arm" position, applying power to the timers (status lights go to red).

Approximately 3 seconds later, timer switches S2 and S3 close, supplying power to the command circuits, and changing the timer status lights to red (operating indication).

The aneroid toggle switches are flipped to simulate ascent through the 19,000 foot altitude level.

At the preset time, timer switches S5 and S6 close, fire the "A" and "B" system separation detonators (fuses blow, indicator lights on). The event marker output is most easily monitored on an oscilloscope with a recording camera. If proper matching of the one megohm impedance of the ECM can be achieved, a pen-recorder or oscillograph can be used to provide a time-based record of the events.

Ten seconds after separation, time delay switches 1A1A1S1 and 1A1A1S2 close and actuate relays 1A1A1K3 and 1A1A1K4. The normal recovery status lights switch to red.

The aneroid simulator switches are flipped to the "Below" position to indicate passage through 19,000 feet altitude. The "A" and "B" paraloons detonators (fuses) blow (indicator lights on).

Fifteen seconds after paraloons deployment, time delay switches 1A1A1S3 and S4 close, actuating relays K13 and K14. These supply firing current to the parachute deployment detonators (indicator lights on, fuses blow).

Timers shut off; timer current (upper right meter) goes to zero.

Timers run out and reset (switch, upper right corner).

Command mode can be interjected into this procedure to command separation, paraloons deploy, and/or parachute deploy. The 10 second interlock (delay) provided by time delay switches S1 and S2 and be demonstrated by flipping the aneroid switches to "Below" prior to 10 seconds after command separation; the paraloons detonators will not

fire until after the 10 second delay actuates relays K3 and K4. However, the command paraloon deployment switch closure will fire the paraloon detonators any time after command separation.

3.5.3 Simulated System Tests

After the electrical system simulator/checkout box was completed, complete control system tests were performed as follows. Figure 13 is a photograph of the test setup.

1. Prelaunch status checks and reset of all relays were performed through side checkout connector and blockhouse umbilical connector.
2. With the simulator box switches performing the timer cam functions, the following sequence was repeatedly demonstrated:
 - a. Lanyard switch connection of power to the timer motor circuit at first motion.
 - b. Arming of control system after 6 second lockout.
 - c. Separation signal to outer skin detonators. Power from on-board batteries routed through firing relays, protective fuses and arming plug to initiate (simulated) detonator bridge wires. Bridge wires were simulated with 3AG 1/2 fuses with similar blow time/current characteristics.
 - d. 10 second time delays (S1 and S2) functioned on time, actuating K3, K4.
 - e. Either and/or both aneroid switches were functioned (simulator switch action) and in all cases both "A" and "B" system paraloon valve detonators fire successfully. As in (c), detonator bridge wires were simulated by 3AG fuses.
 - f. 15 seconds after aneroid switch closure, S3 and S4 functioned, actuating K13, K14. These, in turn, successfully fired the parachute deployment "A" and "B" detonators (simulated).
 - g. Event marker outputs were scope-monitored and photographed, yielding 2 second usable pulses.
 - h. Command override signals for separation and paraloon deployment were fed in through the

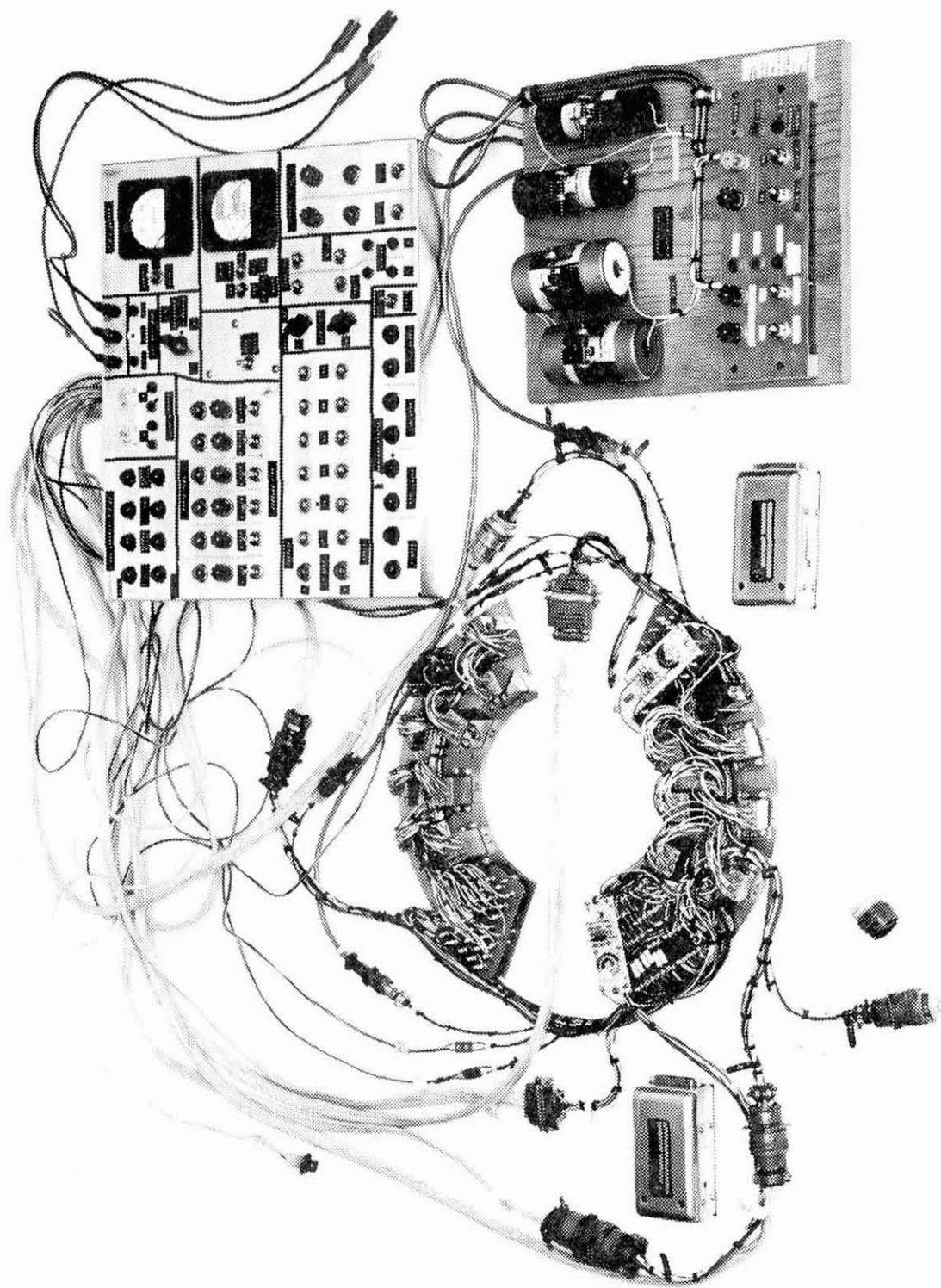


Figure 13. Simulated System Test

forward payload connector (1P1) and all subsequent functions were performed satisfactorily. The S1 and S2 time delay switches prevented automatic paraloon deployment by aneroid for 10 seconds after command separation.

The above tests were then repeated using the Datametrics program timers. The simulator was used to provide lanyard switch arming and aneroid switch closure. The timers performed satisfactorily and were run out and reset repeatedly during the exercise.

3.6 Recovery System Tests

Several systems tests were conducted. The first test was performed in order to evaluate the recovery sequence and its effect on selected prototype electromechanical components mounted to the recovery system structure.

The second and third tests conducted were full systems tests utilizing the completed recovery system, S/N 003. All of the components with the exception of the paraloon and parachute were installed. The mass of the parachute was simulated, however, by packing fabric in the parachute compartment to an equal density. The test was conducted by pulling the lanyards, allowing both control systems to function in the programmed mode. Appropriate safety considerations were incorporated allowing manual control of the aneroid switches for activation of the time delays. The explosive valve for paraloon deployment was bypassed for these two tests.

3.6.1 Preliminary System Tests

A, preliminary system test was conducted incorporating the major prototype components of the recovery system. See figure 14. The test simulated the following functions in the specified sequence.

- a. Separation
- b. Paraloon Cover Ejection and Deployment
- c. Paraloon Separation

In conjunction with the above, several electromechanical components were mounted to the structure in order to test their response to the various functions. Similar components were initially screened during the separation ring tests discussed earlier.

These electromechanical components included:

- a. Aero-Mechanisms, Inc., Model 9010 Aneroid mounted to the inside of an installed access hatch.

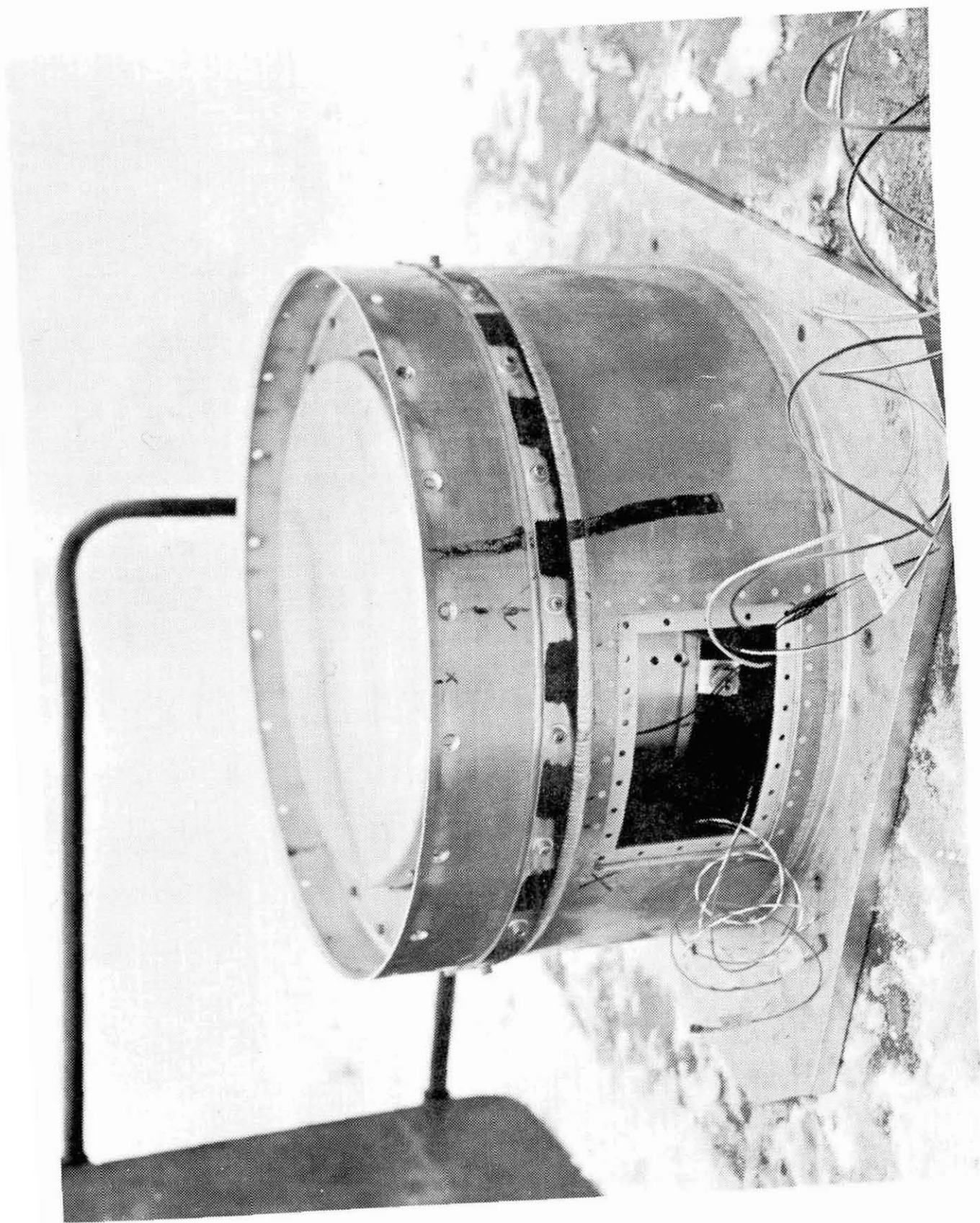


Figure 14. System Test Unit Prior to Test

- b. Two Jay El time delays, Model 10166, were mounted to a special plate fastened to the forward deck with small rubber shock mounts.
- c. Two relays, Babcock Model No. BR191AX-D3-V3 mounted to the same plate as item 2.
- d. One Datametrics timer, Cook P/N 600100, S/N 002 was hard mounted to the forward deck.

Each test involved the use of pyrotechnics and/or a pyrotechnic device.

The paraloon was fastened at the neck closure and the 12 tiedowns. A small slit in the hemisphere of the paraloon was necessary to release entrapped air during packing. A "vent" bleed was later provided in the production units for this purpose. After the paraloon was packed, the cover was installed, and the prototype reservoir was pressurized to 3025 psig.

After all necessary electrical and visual checks, the test commenced. The timer was actuated prior to the separation test and terminated after the test. On subsequent tests, the timer had pre- and post-test checks. The No. 2 and No. 3 relays were given pre- and post-test checks for each event.

The separation FLSC was initiated utilizing Hercules D119F0 detonators with backside initiation. The cut was virtually perfect. The steel restraining strap functioned properly and prevent the flaring out of the aluminum structure (see figure 15).

For paraloon inflation and cover deployment, power was applied to the prototype explosive valve, releasing the stored nitrogen. The cover was deployed and the paraloon inflated.

It appeared that the paraloon was underpressurized, and inspection revealed that leakage had occurred during inflation at the slip fitting on the output of the explosive valve. This was found to be due to distortions in the breadboard structure which were not fully removed after the heavy ground impact damage experienced in the drop tests at Bong AFB in September 1967. These distortions permitted a relatively minor deflection of the parachute cover to vent nitrogen past the "O" ring seals of the slip fitting. To minimize back-pressure during inflation, the check valve in the fill neck was removed and replaced with a coated fabric "flapper valve" over the diffuser ports inside the paraloon. The slip joint engagement was also lengthened to minimize chances of premature separation.



Figure 15. System Test Unit After Separation

For paraloon separation, the 7 gr/ft FLSC cut was a full 360 degrees and the parachute cover was ejected from its position (see figure 16).

The cut edge remained recessed as initially designed to prevent abrasion of the parachute riser lines. No cut edges were observed above the recess, and no evidence of blow-by into the parachute compartment was found.

All electromechanical components survived the test and were still operable. However, the aneroid and the timer had changed settings. Refer to Section 3.5.1.3 for a discussion of these effects.

In conclusion, the test was extremely successful. All electro-mechanical components including the relays remained operable during and after the test. A method to correct the aneroid was found, and the shift in the timer was not critical since its function is to regulate the time for separation only.

The steel band on the outside of the separation ring prevented the aluminum structure from flaring out, thus minimizing the possibility of damaging the paraloon during deployment.

The prototype pneumatic system for paraloon deployment and cover ejection was tested. Design improvements resulting from the test include removing the check valve, lengthening and revising the mating assembly, installing a flap valve inside the paraloon on the diffuser and a vent valve on the top of the paraloon for pump down.

The paraloon separation functioned perfectly and no redesign was necessary in this area.

3.6.2 Prototype System Tests

Two prototype system tests were conducted utilizing the production unit, Recovery System S/N 003. The purpose of the tests was to verify that the detonator bridgewire problem has been resolved utilizing the latest in detonator design. A secondary purpose was to check all of the electrical and electromechanical components of the recovery system under the shock environment produced at separation and parachute deployment. The tests were conducted identically, using the final configuration components and hardware. The paraloon deploy event was not demonstrated since the shock spectrum involved in minimal by comparison.

The unit was modified slightly by eliminating the aneroid switches from the circuit and substituting a hand held switch for safety purposes. In the normal circuitry, programmed mode, the paraloon deploy event would occur simultaneously with separation, with the vehicle below

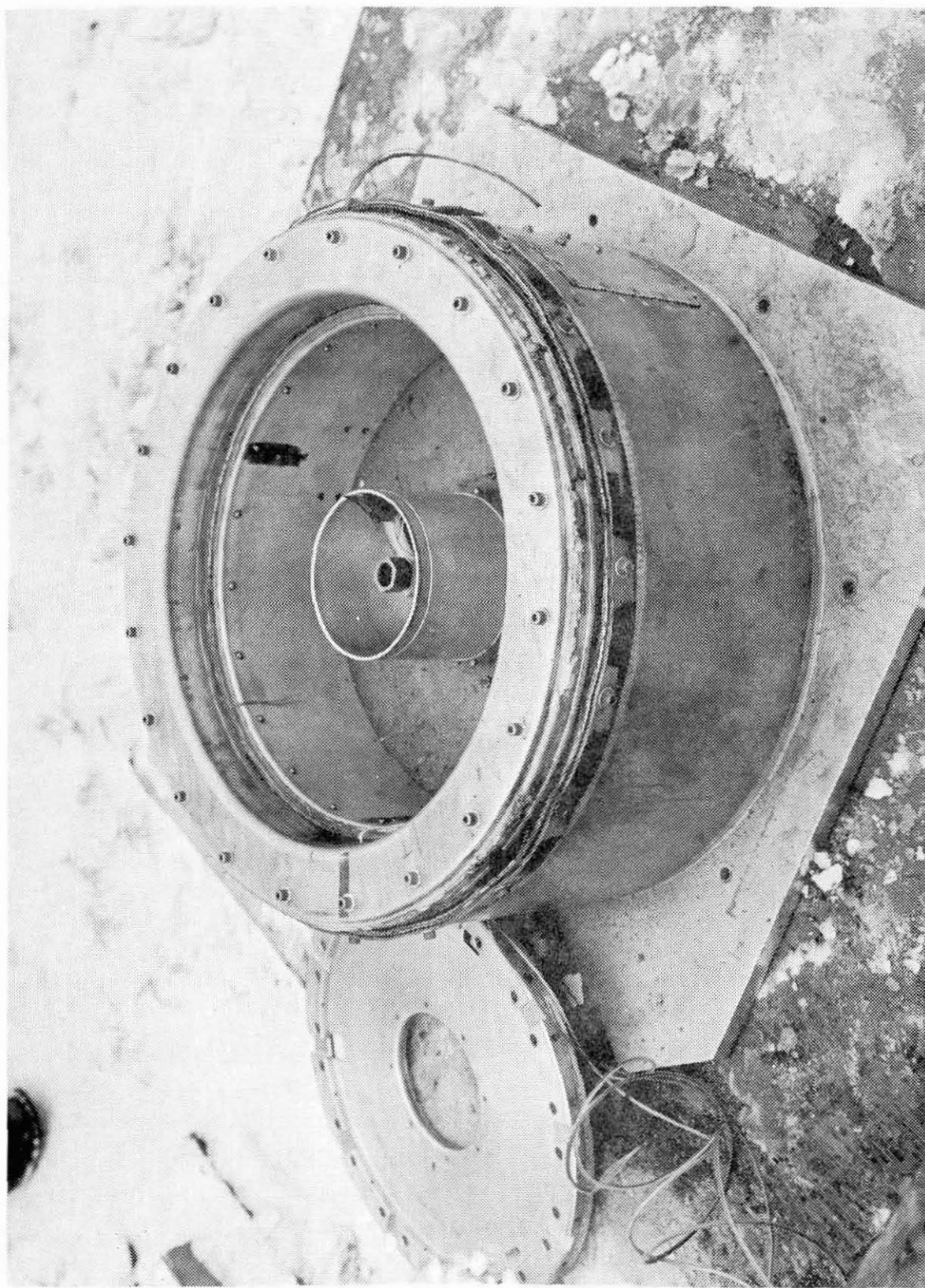


Figure 16. System Test Unit After Paraloon Separation

altitude. Also, 15 seconds later, the parachute deploy event would occur. Interrupting the programmed mode permitted visual inspection of the unit between events and allowed the tests to be conducted with the required safety.

Both tests conducted in the following fashion.

- A. Both control systems fully exercised prior to the test as a preset calibration.
- B. Test commenced by pulling lanyards, utilizing internal battery power to run timers, with the timers switching power to the detonators for separation.
- C. Visual inspection of unit.
- D. Close simulated aneroid switch to activate the fifteen second time delays. When the time delay expires, the parachute deploy event occurs.
- E. Visually inspect unit.
- F. Exercise both control systems as a post-test calibration.

Both tests were conducted successfully with no discrepancies noted. For each test, the modified Horex detonators were used. The separation detonators utilized were Cook P/N 600190-001 (Horex P/N 7899) while the parachute deploy detonators used were Cook P/N 600190-103 (Horex P/N 7898). For each event, two detonators of each of the above types were utilized, for a total of four per test.

3.7 High Temperature Tests

Several high temperature tests were conducted in an attempt to verify the ability of the selected components to survive and operate in the expected environment, and also to evaluate the response of the structure to the thermal input expected during reentry. The following sections describe the tests conducted and their results.

3.7.1 Detonator Selection Tests

Initial work began early in the program to select a detonator which would function properly in the environment considered. A one dimensional heat transfer study was made of the interface ring area. This was accomplished by assuming the existence of a three inch thick insulated aluminum plate, initially at a temperature of 200°F, but subjected to a ramp input surface temperature rising to 400°F in 25 seconds, and this held constant at 400°F for an additional period.

This would simulate the 736 lb, 180 degree trim, point mass re-entry heating condition. The indications were that the detonator utilized for parachute deployment would have a temperature of 325°F at paraloon separation for a worst case trajectory (Curve T₃, figure 17). The following describes the verification tests conducted.

3.7.1.1 FLSC Initiation Tests

Two small test fixtures were made simulating the recovery system structure. A flexible linear shaped charge of 7 grains/foot Configuration I lead sheath RDX explosive. Ensign Bickford Company P/N B-7, and a detonator, Hercules Powder Company P/N D119B2, were installed using backside initiation with zero gap. A thermocouple was placed near the detonator and both units were placed in an electric oven. The temperature was monitored continually during the test.

The temperature was raised from ambient to 200°F and soaked at that temperature for ten minutes in order to simulate the trajectory to be flown. The temperature was then rapidly raised to 355°F where power was applied to each detonator.

Both units functioned normally. The detonators ignited and in turn initiated the FLSC. A 0.063 inch thick 2024-T4 aluminum plate was shattered by the detonation.

It was concluded that the above mentioned detonators and RDX FLSC were capable of withstanding the temperature environment expected at the time of paraloon separation.

3.7.1.2 Autoignition Tests

Three autoignition tests were conducted using the same detonators as above for each test. A thermocouple was fastened to one of the detonators by positioning the thermocouple on the cylindrical surface of the detonator, wrapping aluminum foil around the pair, and crimping the foil in place. Equal amounts of foil were used on each detonator to assure a similar thermal mass.

The detonators were placed in an electric oven with the temperature monitored at suitable time intervals by a Leeds and Northrop potentiometer.

A temperature profile was used which simulated the flight environment including reentry. The detonators were placed in the oven at ambient temperature. The temperature was raised until a temperature of 200°F was observed on the detonator. The detonator was soaked at 200°F for ten minutes and then rapidly increased until autoignition occurred.

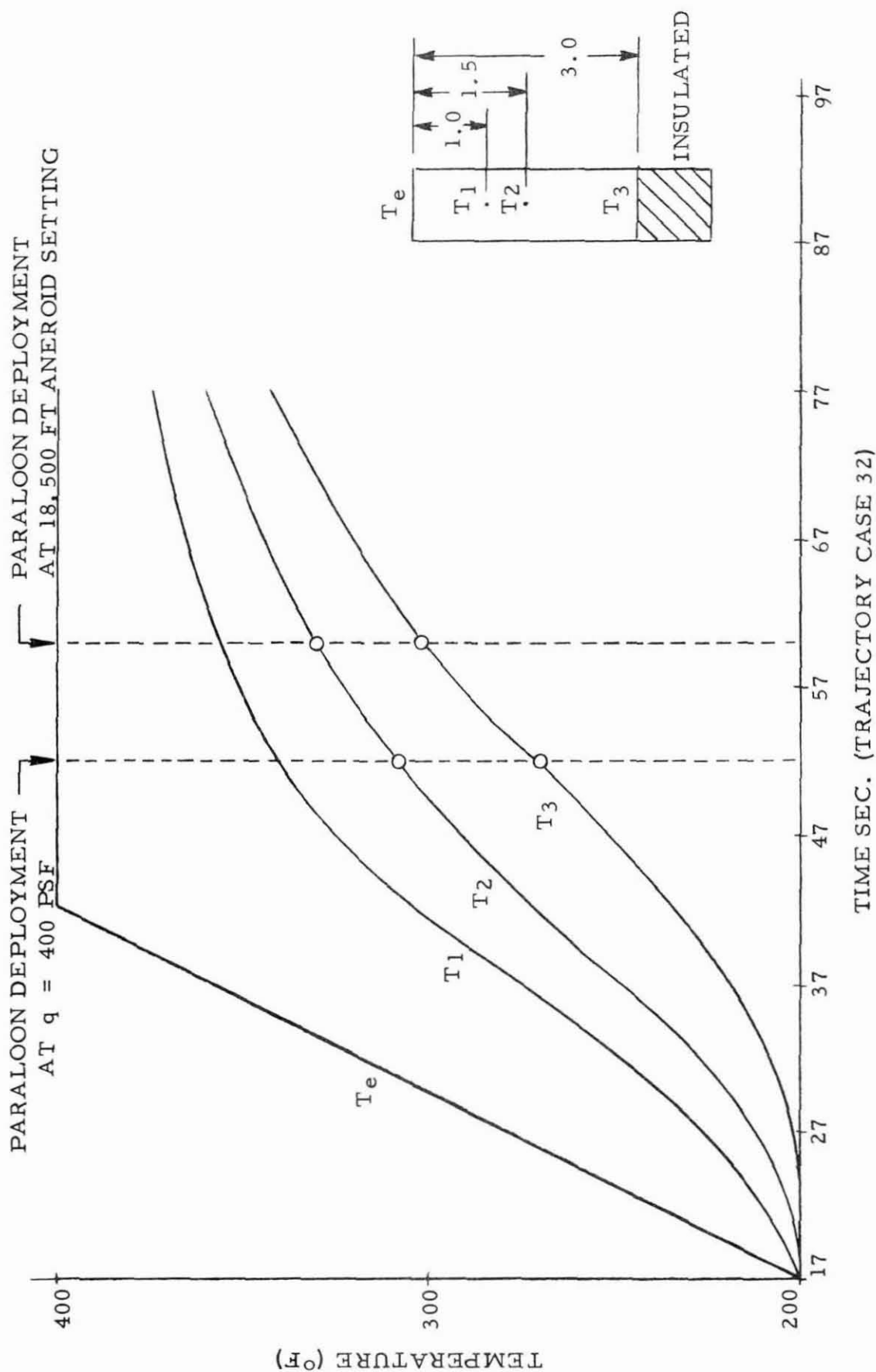


Figure 17. Calculated Plate Temperature Response of a Three-inch Thick Aluminum Plate Subjected to a Surface Temperature T_e and Initially at 200°F .

Pre-test visual inspection and resistance checks during heating were made to assure a valid test.

The following table gives the results of the autoignition test.

	Test No. 1		Test No. 2		Test No. 3	
Detonator	A	B	C	D	E	F
Autoignition Temp. °F	410	410	415	415	410	420

The minimum autoignition temperature was 410°F. Although only one detonator was monitored for each test, it can be safely assumed that the other was at close to the same temperature. Information received from the manufacturer states that an autoignition temperature of above 400°F would be expected.

Although the above tests were with a detonator other than that utilized in the final design, the final design detonator also contains lead azide and RDX explosive in approximately the same amount. The determining factor is the autoignition temperature of the lead azide.

3.7.2 Structure Thermal Response Test

Since the inner FLSC does not fire until after reentry, it and its detonators must withstand whatever heat is conducted to the groove area from the 400°F outer skin, without autoignition. In order to determine the peak temperature at the inner FLSC ring in the most severe re-entry heating trajectory (case 32), it was decided to perform a test simulating the 350 R/S structure response to the heat pulse input.

For this test, the recovery system rear face was exposed to a specified temperature profile. A heat source, consisting of a high wattage infrared lamp array, was targeted on the rear face of the recovery system, and was programmed to produce the following time-temperature response in the R/S structure. The temperature at the inner FLSC groove was raised to 200°F and maintained for 300 seconds, after which the outer temperature of the interface ring was increased to 454°F in 30 seconds and then abruptly terminated by removing the lamps. Structure temperature was monitored by thermocouples. Two thermocouples were located on the outside of the interface ring and two more at the inner FLSC groove.

The results of this test are plotted in figure 18. As can be seen, the temperature of the inner groove after the 30 second heat pulse has risen from 201°F to only 223°F while the outer surface of the

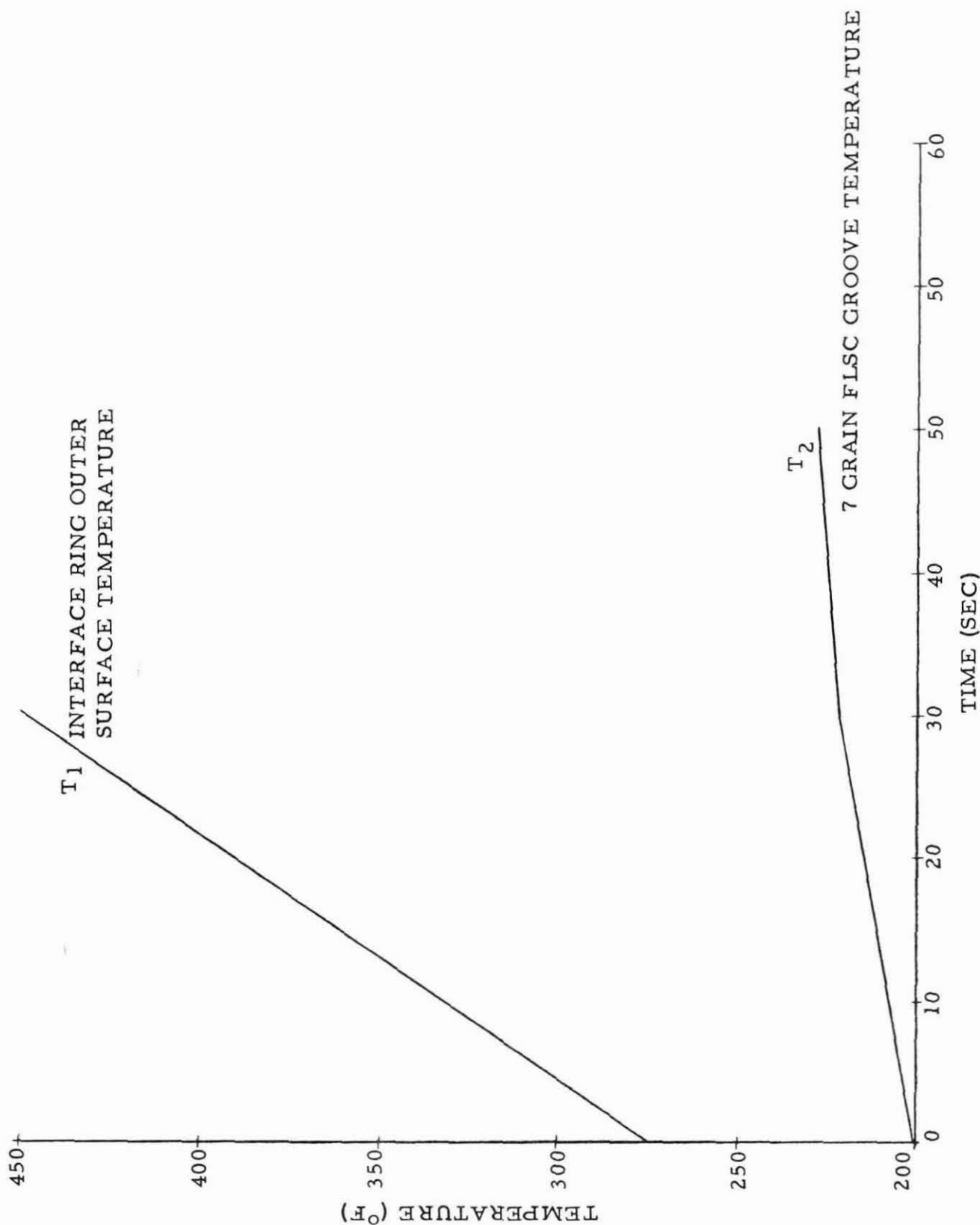


Figure 18. Interface Ring Temperature Profile. Rear Surface of R/S Expose to a 30 Second Ramp Heat Input to 400°F.

interface ring has risen from 275°F to 454°F. Therefore, it is apparent that the temperature of the FLSC and detonators for parachute deployment will be well within acceptable limits. This was later verified during the High Temperature Qualification Test, see Section 4.1.6 where the temperature at the FLSC groove did not rise appreciably.

3.7.3 Paraloon Fabric Tests

The purpose of these tests was to check the response of the paraloon fabric (polyurethane coated HT-3 nomex, manufactured by Stern and Stern of Hornell, New York), to a high temperature environmental such as heating of the paraloon cover during reentry.

Four fabric samples were used measuring 6 x 7 inches, with a typical seam in the center parallel to the short side. An aluminum plate was heated in an oven to 400°F. The plate temperature was monitored by a thermocouple on the surface of the plate. When the plate reached 400°F the fabric sample was placed on it with a block of wood and a 10 pound weight on top of it.

The block of wood simulated the insulating qualities of the packed paraloon and the 10 pound weight simulated the packing density. The time for each sample was varied.

The first fabric sample with the wood block and weight were placed on the test plate for a period of thirty seconds. The only change noted was an elongation when first removed from the oven. When allowed to cool to room temperature, the fabric sample regained its original shape with no permanent deformation.

For the second fabric samples, the procedure was similar except one side of the fabric was folded on itself and the time period was again thirty (30) seconds on the 400°F plate.

Upon removal, the folded edge seemed tacky and stuck together slightly. Also, the sample was more resilient but returned to normal after cooling.

The procedure for the third fabric sample was similar except both edges were folded and the time increment was one (1) minute.

After removal, both folds were tacky and stuck together slightly. No unbonding of the polyurethane was observed as the sample was unfolded. Again the sample was more resilient heated than at room temperature. Some permanent set of the fabric did occur.

The final sample was folded on both edges and left in contact with the plate for five (5) minutes.

Upon removal, the fabric initially adhered to the aluminum plate and the wood block. A slight trace of the polyurethane was left on the wood block. The folder portion adhered to itself and was difficult to pull apart. Approximately five (5) positions were observed where the polyurethane coating had been transferred, exposing the weave of the base HT-3 nomex material. Permanent deformation was also evident in that the folds were retained on the sample and rippling of the edges was evident.

For each test, the plate temperature was observed to drop to approximately 380°F.

In conclusion, it appears that the fabric can withstand a temperature of 400°F for a brief period of thirty seconds without a significant change. The increase in elongation or resiliency at elevated temperature is expected. However, exposure to a high temperature over increasingly longer periods of time such as greater than five (5) minutes could result in a complete unbonding of the polyurethane coating.

For a conservative design approach and inexpensive insurance, a liner of several plies of nomex material was incorporated in the design between the paraloon cover and the packed paraloon.

4.0 UNIT QUALIFICATION AND ACCEPTANCE TESTS

Two separate series of tests were performed on completed recovery systems. The first series of tests were Qualification Tests, and were performed on S/N 1 to verify the capability of the design to survive the expected environmental conditions and to successfully perform the intended functions.

A second series of tests were performed on all three units prior to delivery in order to verify that each was assembled properly and was an accurate duplicate of the Qualification Test Unit. This series of tests was termed the Acceptance Tests.

Both series of tests were conducted in accordance with Cook Electric Company Specification 4890-206600-01, "Qualification and Acceptance Test Plan," and Procedure 4890-206600-02, "Control System Function Test Procedure."

The results of the tests were covered in detail in "Qualification and Acceptance Test Report for Aerobee 350 Recovery System," and the reader is directed to that document for further information on these tests.

5.0 FIELD TESTING

After the initial three recovery systems were completed and delivered, a field test program was initiated and executed in order to realistically evaluate the performance of a recovery system under actual flight conditions. This consisted of aircraft drop tests, and was conducted at the Joint Parachute Test Facility, El Centro, California during May 1969.

In conjunction with the test program, two identical Recovery System Checkout Units and three vehicle payload configurations were designed and delivered. The tests were performed with Recovery System S/N 001, which was modified slightly for this purpose.

This section discusses the equipment and instrumentation fabricated and prepared for the field test program. The contractor's responsibilities with respect to the aircraft drop tests proper were limited to providing personnel support, and therefore these tests and test results are not here covered in detail. For more detail information on the tests and test results, the reader is directed to the Contract Technical Monitor at Goddard Space Flight Center.

5.1 Recovery System Checkout Unit

The Aerobee 350 Recovery System Checkout Unit, see figure 19, is a self-contained device complete with power and interconnecting cables whose sole purpose is to dynamically test and monitor the operation of the Aerobee 350 Recovery System. This unit, which is similar to the Factory Simulator and Checkout Unit, is designed for field usage with a complete recovery system that is fully assembled and ready for flight.

Two Checkout Units were designed, fabricated, and delivered during the program. They are identified as Cook P/N 206800, S/N 001 and 002. A more complete description of the Checkout Unit is given in Section 3.0 of the "Aerobee 350 Recovery System Field Test Procedure."

5.2 Test Vehicles

Three different test vehicle configurations were designed and delivered, one for each of the three planned drop tests. In each case, the design was compatible with the recovery system as well as the necessary instrumentation and T/M gear.

The T/M rack with the required instrumentation and telemetry gear was mounted to the forward face of the forward ring of the recovery system. The telemetry system was designed to monitor and broadcast

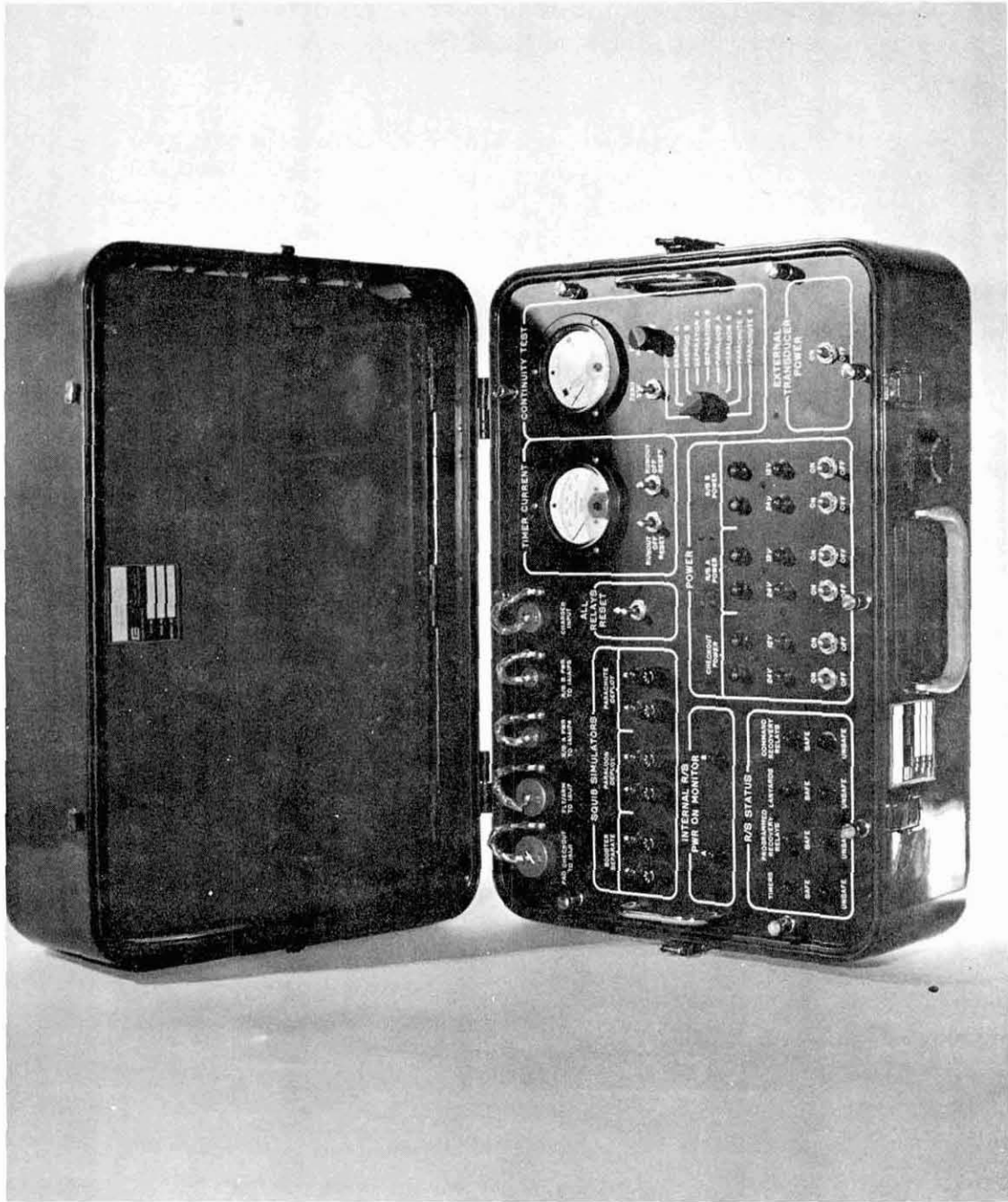


Figure 19. Aerobee 350 Recovery System Checkout Unit

the shock and vibration loads imposed on the vehicle during the drop test recovery sequence and to process the command signals broadcast to it.

5.2.1 First Drop Vehicle Configuration

The vehicle configuration for the first planned drop test was a cone-cylinder having an overall length, including the recovery system, of 132 inches, or six vehicle diameters. The nose cone had an overall length of three diameters. The unit was ballasted to 736 pounds and a forward center of gravity located approximately 52 inches from the paraloon cover.

5.2.2 Second Drop Vehicle Configuration

The vehicle configuration for the second planned drop test was designed to simulate the proposed NASA/GSFC 17.04 Rocket Flight Payload. It consisted of essentially a long, blunt-nosed cylinder having a total length of 112.25 inches. The vehicle was ballasted to a total weight of 640 pounds with the center of gravity located approximately 40 inches from the paraloon cover.

5.2.3 Third Drop Vehicle Configuration

The final drop vehicle configuration was again a cone-cylinder dimensionally identical to that planned for the first drop. The vehicle was ballasted for a payload weight of 736 pounds and an aft center of gravity located approximately 25.5 inches forward of the paraloon cover.

In addition to the basic payload, an external jettisonable ballast of 364 pounds was mounted to the aft end of the recovery system. The purpose of the external ballast was to allow the vehicle to accelerate more rapidly in order to reach the design paraloon deployment velocity while falling from the aircraft. At the proper time the external ballast would be released by a simulated "Separation" event. Two seconds later the paraloon would be deployed. This drop was scheduled to be a full systems test, with the recovery system performing the three events of separation, paraloon deployment and parachute deployment.

5.3 Instrumentation

As a requirement for the test program, both the recovery system and the payload were instrumented in order to provide a comparison of actual flight data and that predicted. A variety of instrumentation was provided and data was to be transmitted via a telemetry unit within the payload. In addition to broadcasting the measured values, the T/M system was capable of receiving and processing the "Command Mode" signals to the recovery system.

5.3.1 Recovery System Instrumentation

A vibration pickup transducer, Endevco Model 2221E, was mounted to a fiberglass electronics mounting board on the forward deck. The purpose of the pickup was to measure the response of the board during the three pyrotechnic initiated recovery events. The unit has a range of +50 g.

In addition to the vibration pickup, several pressure transducers were installed. A Servonics Instruments, Inc., pressure transducer, Model 2091, with a range of 0-400 psig was mounted to the reservoir, thus allowing the reservoir pressure to be monitored at all times during flight via the telemetry link.

Four 0-15 psia pressure transducers, Servonics Model No. 3031, were also installed. Three were installed at positions on the skin adjacent to the present manifold pressure port points. The fourth was mounted to sense the actual aneroid chamber pressure in an attempt to correlate the time lag between the actual pressure sensed at the three individual ports and that within the aneroid chamber itself. Post test data analysis would provide an accurate pressure port coefficient allowing the altitude sensing aneroid switches to be set more precisely in the future for the desired deployment altitude.

5.3.2 Payload Instrumentation

In addition to the telemetry gear of the payload, accelerometers were placed to monitor the "g" loads in all three axes. Magnetometers were used to measure the vehicle roll rates in the yaw, pitch and roll modes. Three pair of solar eyes were mounted to the payload skin as an aid in measuring vehicle attitude.

The information gathered by all of the sensors plus that produced at other strategic monitor points was telemetered and recorded for post test evaluation.

5.4 Drop Tests

Two drop tests were conducted. The initially scheduled first drop vehicle configuration was used for the first drop. Due to range scheduling problems, the second drop configuration was deleted and the planned third drop vehicle configuration with the external ballast was actually utilized for the second drop test.

5.4.1 First Drop Test

The first drop test was conducted on 1 May 1969. The recovery system operating sequence was altered slightly by deleting the "Separation" event. The first event which was scheduled to occur

after the vehicle was launched from the tailgate of the C-130 aircraft was "Paraloon Delay." This was to be followed by "Parachute Deploy" 15 seconds later.

The vehicle was dropped from the C-130 at a pressure altitude of 25,000 feet. This corresponded to an actual altitude of approximately 25,990 feet MSL. The vehicle fell for approximately 29 seconds to an altitude of 19,300 feet MSL where "Paraloon Deployment" occurred at a "q" of 91 psf and a velocity of 377 feet per second.

Approximately 15 seconds later, the parachute was deployed as programmed. At that time, the "q" was 41 psf and the vehicle velocity was 238 feet per second. Ground impact occurred at a total elapsed time of 368 seconds, and at a rate of descent of 36 feet per second.

5.4.2 Second Drop Test

The second drop test was performed with the test vehicle configuration initially intended for the third drop test, including the external jettisonable ballast. The test plan called for recovery to be initiated by commanding the "Separation" event. To accomplish this, the recovery system circuitry was altered slightly in the following fashion.

The connector to the aneroid switches was disconnected and the circuit left open. Suitable wiring changes were made which utilized the S1 and S2 time delays to deploy the paraloon two seconds after the "Separation" event. The remainder of the circuitry was left intact, with "Chute Deploy" scheduled to occur 15 seconds after "Paraloon Deploy."

The drop test occurred on 9 May 1969. Again, the vehicle was dropped from the C-130 at a pressure altitude of 25,000 feet (MLS altitude of 26,780 feet). The command "Separation" was scheduled to be commanded from the ground at approximately 32 seconds from the initial drop time. However, due to launching problems aboard the aircraft, the scheduled drop time was missed and actually occurred some 12 seconds late. Since the precise zero time was missed by the aircraft, and the vehicle was dropped late, ground personnel did not have the proper zero time to initiate the "Command" recover sequence. Recovery was initiated however by the programmer in the Automatic Mode.

The "Separation" event occurred at 34 seconds as programmed. The 15 gr/ft RDX FLSC was initiated, thus severing the ring and releasing the external ballast. Two seconds later, the paraloon was deployed as programmed, and at a "q" of 114 psf. However, approximately 9 seconds later, the parachute was deployed. This was some 6 seconds too early for the programmed mode. This apparent anomaly was investigated and explained during a post drop evaluation, and a minor circuit modification will preclude its reoccurrence in the future. The remainder of the drop was normal and the vehicle was recovered.

BIBLIOGRAPHY

1. "Preliminary Design and Analysis Report, Aerobee 350 Recovery System," P4890, Tech-Center Division, 21 September 1967
2. "Final Design and Analysis Report, Aerobee 350 Recovery System," P4890, Tech-Center Division, 15 April 1968
3. "Qualification and Acceptance Test Plan for Aerobee 350 Recovery System," 4890-2006600-01 Rev. C), Tech-Center Division, 19 June 1968
4. "Control System Functional Test Procedure for Aerobee 350 Recovery System," 4890-206600-02 (Rev. 1), Tech-Center Division, 8 May 1968
5. "Qualification and Acceptance Test Report for Aerobee 350 Recovery System," P4890, Tech-Center Division, June 1968
6. "Aerobee 350 SRV Recovery System Field Test Procedure," Tech-Center Division, 1 October 1969
7. "Reliability Prediction, Aerobee 350 Recovery System," Tech-Center Division, 25 August 1968
8. "Aerobee 350 Payload Recovery System Specification," 4890-206600-03, Tech-Center Division, 29 October 1968

APPENDIX I

DRAWINGS

FIRING DATA:

BRIDGEWIRE RESISTANCE - 1.0 ± 0.1 OHMS
DIELECTRIC STRENGTH - 1000 VOLTS AC
RMS MAX.
PIN-TO-CASE RESISTANCE - 3 MEGOHMS MIN
AT 500 VDC.

MATERIAL AND FINISH DATA:

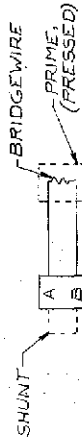
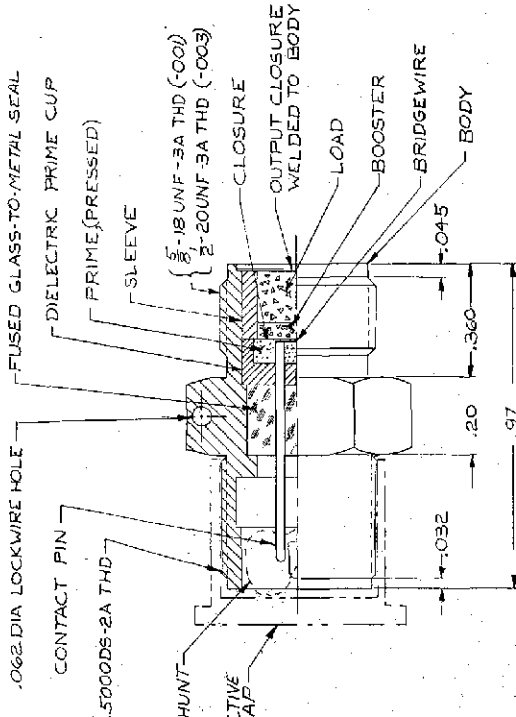
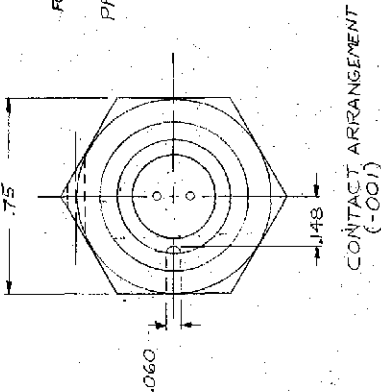
BODY - - - - B1113/C1010 STEEL
CONTACT PINS - - C1010 STEEL
OUTPUT CLOSURE - C1010 STEEL

THE ABOVE TIN PLATED PER MIL-T-10727,
TYPE I

THE HOLEX PART NUMBER, SERIAL NUMBER,
PER MANUFACTURING ORDER AND LOT NUMBER
IS RUBBER STAMPED ON THE HEX FLATS.

APPROVED SOURCE OF SUPPLY

OLEX INC.
N JUAN RD
DOLLISTER, CALIF.
BENDER PART NO. -001, P/N 7898-1
-003, P/N 7898-1
CODE IDENT. 10640



FOLDOUT FRAME

ENCLOSURE FRAME

HOLEX P/N	DASH NO.	BOOSTER LOAD	MAIN LOAD	FUNCTION	WATES WITH BENDIX CONN	MTG THREAD
7898-1	-001	100 MG LEAD AZIDE	200 MG RDX	SEPARATION (5000 PSI) RDX	PCOE-8-25	5/16 UNF-3A
7898-1	-003	100 MG LEAD AZIDE	150 MG RDX	DEPLOY (7000 PSI) RDX	PCOE-8-25W	1/2-20UNF-3A

[illegible][illegible]

FOLDOUT FRAME

2

FOLDOUT FRAME

LIST OF MATERIAL	

TECH-CENTER DIVISION
COOK ELECTRIC CO., MORTON GROVE, ILLINOIS

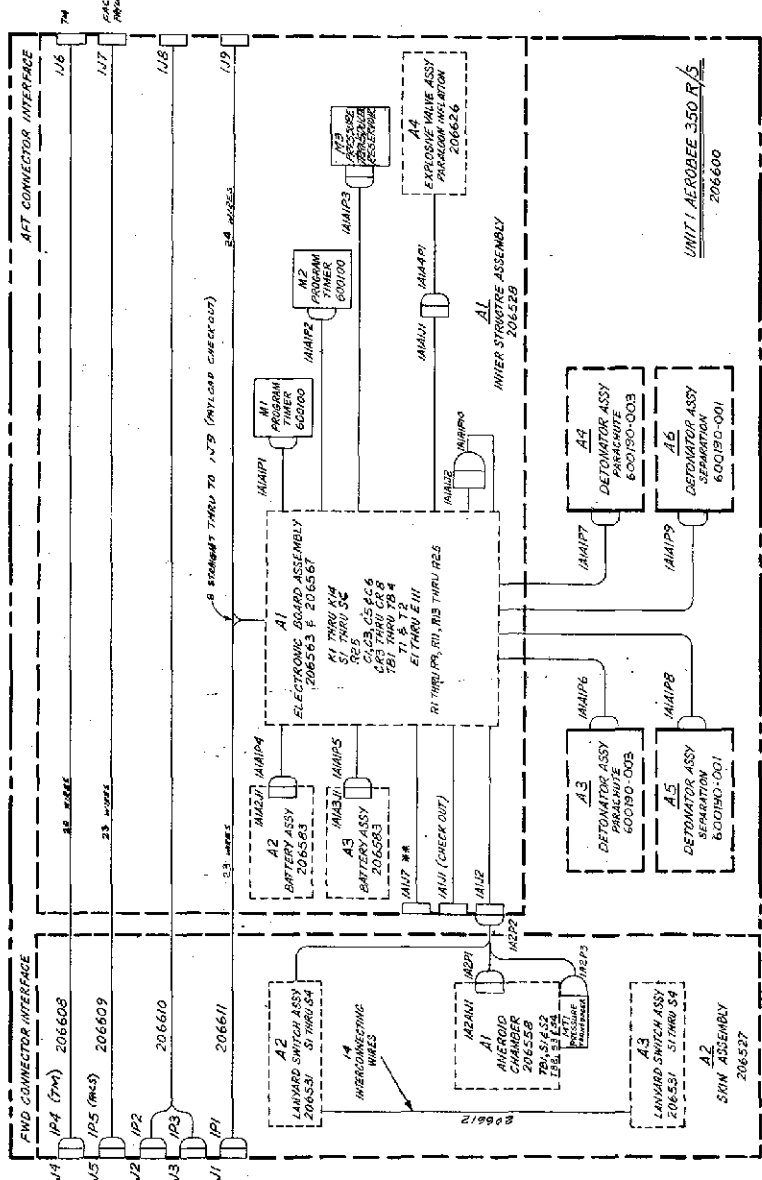
AEROBEE 350
REFERENCE DESIGNATION
DIAGRAM

CODE	INSTR NO.	SITE	REV	REV
71888	D	206592	D	D
SCALE	NO	NO	NO	NO
	ACT	CALC	CALC	CALC
				SHEET 2 OF 12

NOTES:

[illegible]

NOTES:



* * * IAU17 WILL RECEIVE EITHER FLIGHT ARMING PLUS OR GROUND SAFE ARMING PLUS.

FOLDOUT FRAME

REVISION SHEET 1 OF 2 SHEET 1 OF 2

REV	DATE	DESCRIPTION	BY	CHKD
1	10-1-64	INITIAL		
2	10-1-64	REDESIGN WITH CHANGES		
3	10-1-64	REDESIGN WITH CHANGES		
4	10-1-64	REDESIGN WITH CHANGES		
5	10-1-64	REDESIGN WITH CHANGES		
6	10-1-64	REDESIGN WITH CHANGES		
7	10-1-64	REDESIGN WITH CHANGES		
8	10-1-64	REDESIGN WITH CHANGES		
9	10-1-64	REDESIGN WITH CHANGES		
10	10-1-64	REDESIGN WITH CHANGES		

REV	DATE	DESCRIPTION	BY	CHKD
1	10-1-64	INITIAL		
2	10-1-64	REDESIGN WITH CHANGES		
3	10-1-64	REDESIGN WITH CHANGES		
4	10-1-64	REDESIGN WITH CHANGES		
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7	10-1-64	REDESIGN WITH CHANGES		
8	10-1-64	REDESIGN WITH CHANGES		
9	10-1-64	REDESIGN WITH CHANGES		
10	10-1-64	REDESIGN WITH CHANGES		

FOLDOUT FRAME

