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HIGH ALTITUDE SMOKE PROGRAM (HASP)

L. James Larson

HYCOR, INC.
10 Gill Street
Woburn, MA 01801

31 May 1978

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Final Report
4 February 1977 through 31 May 1978

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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

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Two (2) dispensers for high altitude (>85,000ft.) release of smoke puffs were designed, developed and flight tested in support of Air Force Geophysics Lab stratospheric turbulence studies. Each self-contained dispenser provided environmental protection and sequentially ejected six (6) smoke puff canisters containing equal weights of $TiCl_4$ and a 50/50 Water-Methanol mixture. Canisters were functioned 100 feet below the

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balloon platform via a tethered lanyard.

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1. INTRODUCTION

The objective of the High Altitude Smoke Program (HASP) was to provide two (2) dispensers for high altitude ($>$85,000 ft) balloon release of smoke puffs in support of Air Force Geophysics Lab stratospheric turbulence studies. Each self-contained dispenser provided environmental protection and sequentially ejected six (6) smoke puff canisters containing equal weights of $TiCL_4$ and a water/methanol mixture. Each canister functioned at 100 feet below the balloon platform via a tethered lanyard. Barometric switches safed the system below 14,000 foot altitudes and automatically ejected any unexpended payloads upon descent below 30,000 feet. A cable cutter severed all lanyards after payload ejection to preclude potential interference during the airborne recovery operation.

2. TECHNICAL APPROACH

2.1 Canister Design

The HYCOR technical approach to the smoke-puff canister design takes advantage of an innovative canister design entailing using a chemically strengthened glass as the primary canister material. In addition to providing an excellent container for fluid payloads, this glass is extremely durable due to chemically produced compressive stresses in all external surfaces. Since glass only fails under tensile loading, these surface compressive stresses must be exceeded before fragmentation can occur. When pierced with a sharp, hard point, however, this glass exhibits a secondary unique characteristic in that the entire canister disintegrates instantaneously as equilibrium between the outer compressive stresses and internal tensile load is destroyed. Because of this latter characteristic, this pre-stressed glass is often referred to as frangible glass and the resulting canisters as frangible glass canisters. An additional feature which makes these frangible glass canisters attractive for this smoke puff application is the ability to contain two separated, reactive fluids within one canister via a sealed bulkhead. Upon total canister disintegration, fluid mixing occurs giving off smoke at the point of release below the balloon.

The HYCOR smoke puff canister design is shown in Figure 1. Note that a single 1.25" diameter x 6" long frangible glass canister has been divided into two sections containing equal weights of $TiCL_4$ and a 50-50 H_2O/methanol mixture. The payload separator contains a hole for filling the upper section with $TiCL_4$ prior to sealing with a pipe plug. The lower section also has an end-cap with pipe plug hole for filling the lower section with methanol and water. The canister upper end-cap contains a spring loaded pinger assembly for initiating canister fragmentation. The pinger is prevented from moving by a restraint pin. This pin is attached to a 100 ft. braided tether line which is nylon wrapped on a spool contained in the dispenser. After canister ejection from the dispenser, the tether line unravels from the spool over 100 ft. of descent and the pin is pulled. Total canister disintegration occurs instantaneously as the hard, sharp tipped pinger point penetrates the glass. This allows immediate interaction between the $TiCl_4$ and the methanol/water which results in the generation of the desired smoke puff. This sequence of events is depicted in Figure 2.

2.2 Dispenser System

The HASP dispenser is a self-contained system that can be raised to a high altitude by a balloon and will individually eject, upon command, six payload canisters containing smoke generating chemicals. The system is safed by a barometric switch during ascent until an altitude of 14 to 17 thousand is reached at which time the system is able to operate. After ejection, the payload canisters function at a point 100 feet below the dispenser via a lanyard. The system is designed to operate at altitudes in the area of 100,000 feet and contains sufficient power to have a mission time of 12 hours with temperatures as low as $-65^{\circ}F$. The payload chemicals are maintained at temperatures no lower than $0^{\circ}F$ at the time of ejection.

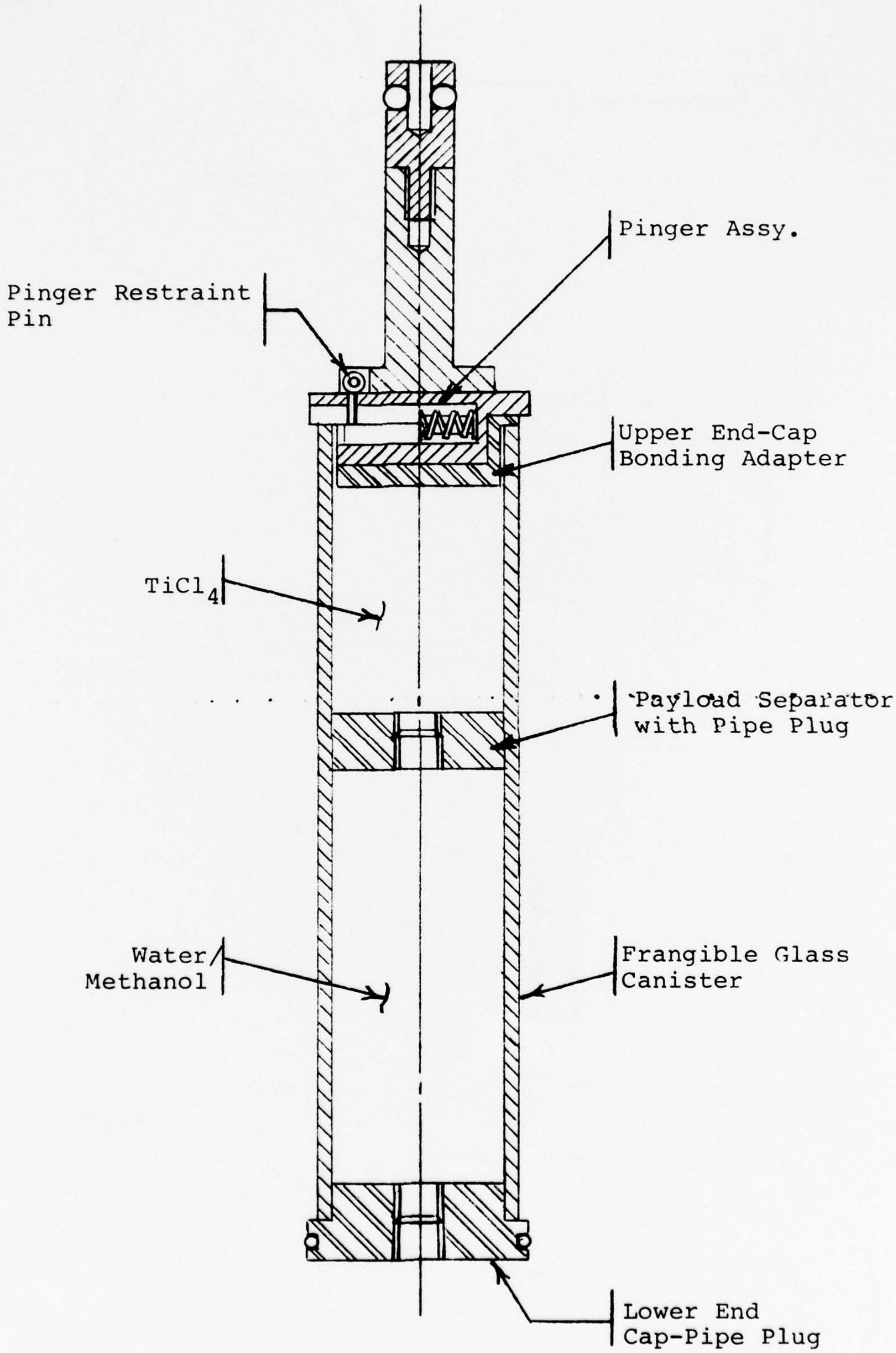

Figure 1. HYCOR SMOKE PUFF CANISTER-REFERENCE DESIGN

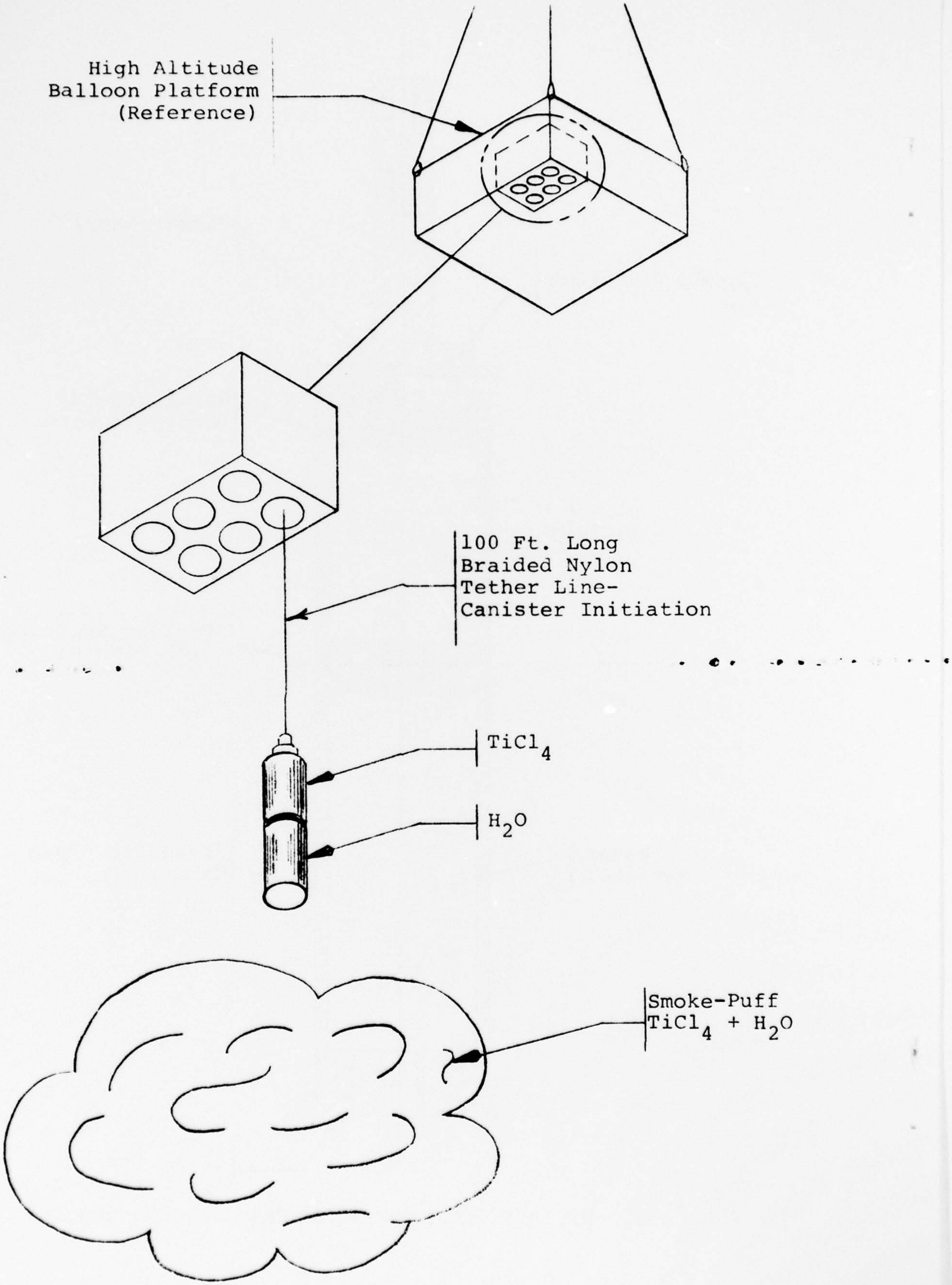

Figure 2. CONCEPTUAL SCHEMATIC-SMOKE-PUFF DISPENSER SYSTEM

If the dispenser/balloon system should descend prior to dispensing all payloads, unexpended payloads are automatically dispensed at an altitude of 28-32 thousand feet during descent up to 12 hours after launch. An additional feature provides for cutting all payload function lanyards after the last ejection so that they will not interfere with recovery operations.

2.2.1 Mechanical Design

The mechanical design of the HASP dispenser assembly is shown on HYCOR Drawing 101400-Figure 3 and pictorially in Figure 4. All components, both mechanical and electrical, are housed in an aluminum case that is 12 inches long by 8.5 inches wide and 18 inches deep. External features are mounting flanges, a guarded on-off toggle switch, and an interface connector. The upper cover of the case is removable without disturbing the internal wiring. This allows access to the batteries and electrical system for servicing and pre-test operations in the field.

Internally, the aluminum case has 1 inch of foam insulation on all sides to retard heat loss during ascent and while at high altitude. In addition, the complete space between the payload tubes is filled with insulation. This was done to minimize heat loss through empty tubes after a payload had been ejected. Heat is supplied internally to the dispenser via (8) 5 watt resistors mounted on the central and lower mounting plates. Heat transmission is through these plates and the ejector tubes surrounding the payloads. The mounting plates are thermally insulated from the outer case by fiberglass strips to minimize heat loss via conduction flow to the outer case. A thermal sensor to control the heaters is mounted in the center of the upper mounting plate. This is almost the center of the overall package and is very close to the payload compartments in the lower half of the dispenser.

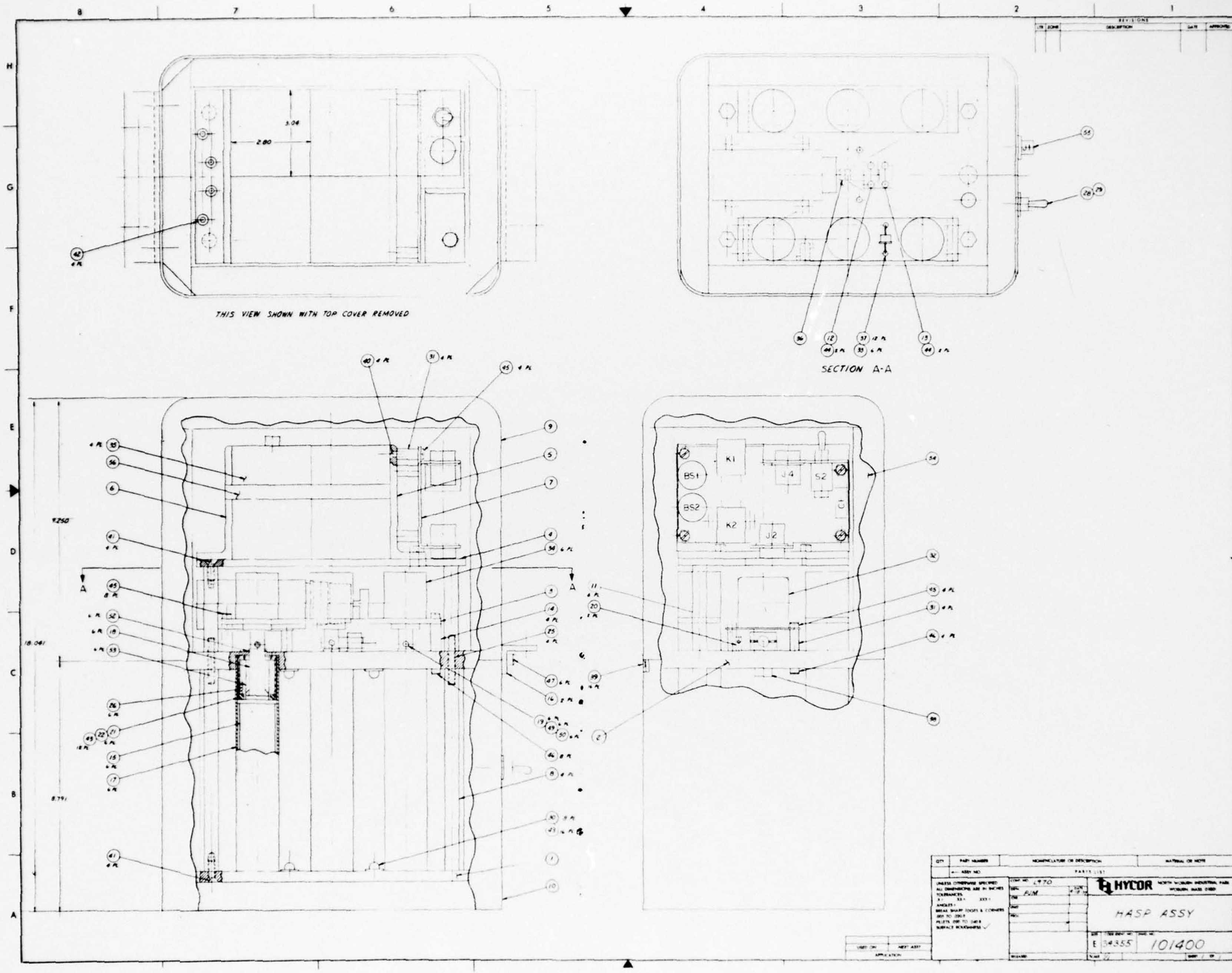

Figure 3 HASP ASSEMBLY DRAWING

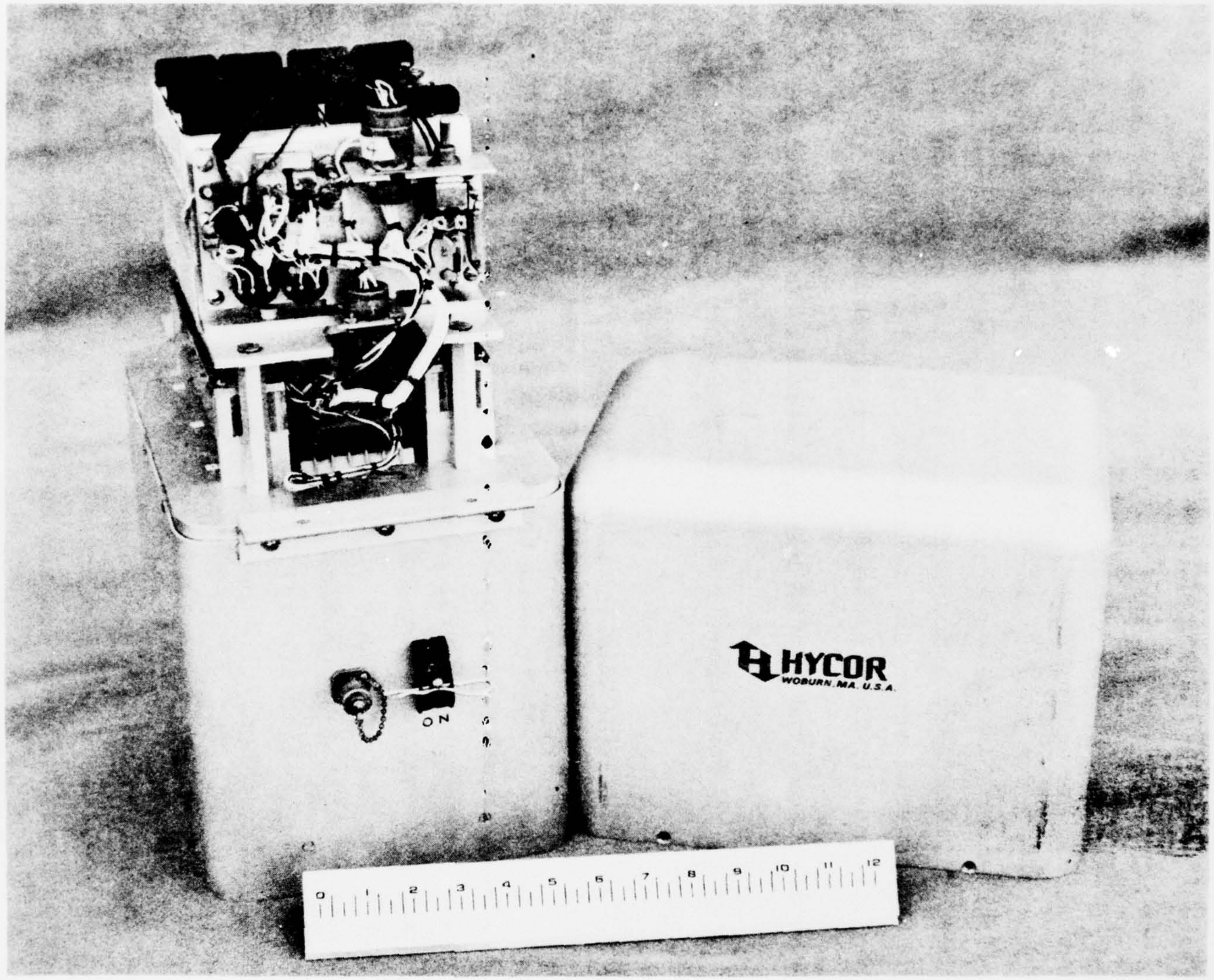

Figure 4 HASP DISPENSER SYSTEM

Six ejector tubes are mounted between the two mounting plates. Two aluminum plates are mounted on stand-offs above the upper mounting plate. Each of these plates was used to mount three release solinoids or, in the case of the third flight, three explosive bolts. Between these plates, the stepper switch and cable cutter are mounted to the upper mounting plate. Stand-offs support a mounting plate for the batteries which positions them above the release solinoids. In this position, they are easily removeable for field servicing.

Mounted on one end of the battery pack is an electrical component board which contains the barometric switches, relays, test connector, reset switch and related electrical components.

The payload ejectors are mechanical springs which are located within the ejector tubes and are restrained to the system so that they do not exit with the payloads. When compressed the payloads are preloaded by the springs to about 50 lbs. When released the springs will stroke the payloads for 3.8 inches causing an exit velocity of about 16 ft/sec. The payloads will fall under the influence of gravity to a point 100 feet below the dispenser at which time the velocity will be approximately 80 ft/sec. During the fall a braided nylon line unreels from an open faced spool in the same manner as a spin fishing reel. At 100 ft. below the dispenser, a pull-pin in the upper end cap of the payload canister is removed, allowing a spring loaded plunger to drive a hardened pin into the surface of the frangible glass causing it to dice instantly. Thereby, the chemical payloads are released to mix and react in the airstream.

Two methods of releasing the spring mechanisms were used in the program. For flight 1 and 2, ball locks controlled by electrical solinoids were used. For flight 3, the solinoids and ball locks were replaced by self-contained electrically initiated explosive bolts. This method was considered more reliable under the extreme temperature environment and resulted in easier assembly procedures. The dispenser system fully configured for flight test weighed 45 pounds.

2.2.2 Dispenser Control System

The dispenser control system for the HASP Dispenser is shown schematically in Figure 5. The main purpose of the system was to provide the release signal for each smoke puff canister upon receiving a command signal from the balloon telemetry system. A secondary function was to provide temperature control within the dispenser unit. The performance features of the system are as follows:

a. Safing of the dispensing functions such that no ejection could be made below 14,000 ft.
b. A jetison feature that would eject all remaining canisters if the system went above 30,000 ft. and then returned below that level.
c. A heating system to maintain the temperature within the package above 0°F.
d. Provisions to cut all canister lanyards after all units were ejected.

The principle components of the HASP control system and their functions are described as follows:

a. A battery pack consisting of four (4) nominal 6 volt silver-zinc batteries connected in series to provide power for control functions and for heating the interior of the package.
b. A thermostat and eight (8) five watt resistors to provide heat for the interior package.
c. A barometric switch set at 14,000 ft. altitude to safe all functions except heating.
d. A barometric switch set at 30,000 ft. altitude which coupled with a latching

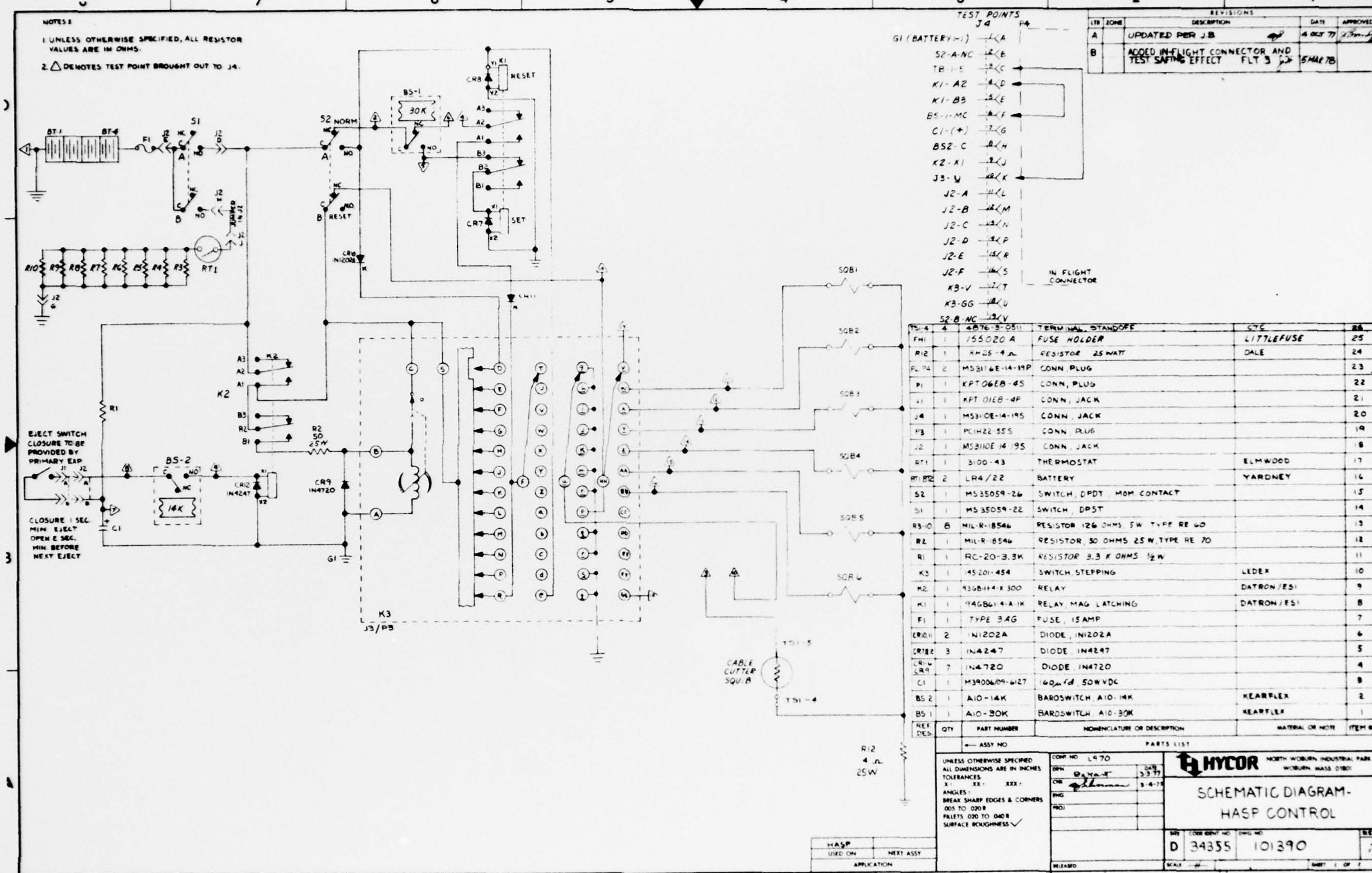
NOTES:
1. UNLESS OTHERWISE SPECIFIED, ALL RESISTOR VALUES ARE IN OHMS.
2. △ DENOTES TEST POINT BROUGHT OUT TO J4.
EJECT SWITCH CLOSURE TO BE PROVIDED BY PRIMARY EXP.
CLOSURE 1 SEC. MIN. EJECT OPEN 2 SEC. MIN. BEFORE NEXT EJECT
TEST POINTS J4 P4
IN FLIGHT CONNECTOR
CABLE CUTTER SQUIB
REVISIONS
A UPDATED PER J.B. 4 OCT 77
B ADDED IN-FLIGHT CONNECTOR AND TEST SAFING EFFECT FLT 3 5 MAR 78
TS1-4 4 4876-3-0511 TERMINAL, STANDOFF CTC 26
FH1 1 155020 A FUSE HOLDER LITTLEFUSE 25
R12 1 RH25-4 Ω RESISTOR 25 WATT DALE 24
P2, P4 2 MS3116E-14-19P CONN, PLUG 23
P1 1 KPT06EB-4S CONN, PLUG 22
J1 1 KPT 01EB-4P CONN, JACK 21
J4 1 MS3110E-14-19S CONN, JACK 20
P3 1 PC1H22-55S CONN, PLUG 19
J2 1 MS3110E 14 19S CONN, JACK 18
RT1 1 3100-43 THERMOSTAT ELMWOOD 17
BT1-BT2 2 LR4/22 BATTERY YARDNEY 16
S2 1 MS35059-26 SWITCH, DPDT, MOM CONTACT 15
S1 1 MS35059-22 SWITCH, DPST 14
R3-10 8 MIL-R-18546 RESISTOR 126 OHMS 5W TYPE RE 60 13
R2 1 MIL-R-18546 RESISTOR, 50 OHMS 25 W, TYPE RE 70 12
R1 1 RC-20-3.3K RESISTOR 3.3 K OHMS ½ W 11
K3 1 145201-454 SWITCH, STEPPING LEDEX 10
K2 1 93GB114-X 300 RELAY DATRON/ESI 9
K1 1 94GB614-A-1K RELAY, MAG LATCHING DATRON/ESI 8
F1 1 TYPE 3AG FUSE, 15 AMP 7
CR10, 11 2 1N1202A DIODE, 1N1202A 6
CR7 & 2 3 1N4247 DIODE, 1N4247 5
CR1-6 CR9 7 1N4720 DIODE, 1N4720 4
C1 1 M39006/09-6127 160 μfd, 50 WVDC 3
BS 2 1 A10-14K BAROSWITCH, A10-14K KEARFLEX 2
BS 1 1 A10-30K BAROSWITCH, A10-30K KEARFLEX 1
REF DES. QTY PART NUMBER NOMENCLATURE OR DESCRIPTION MATERIAL OR NOTE ITEM NO.
PARTS LIST
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES
HYCOR NORTH WOBURN INDUSTRIAL PARK WOBURN MASS 01801
SCHEMATIC DIAGRAM-HASP CONTROL
D 34355 101390
HASP

Figure 5

relay to provide a jetison capability.

e. A stepping switch which coupled with a non-latching relay is used to transmit the command signal to the canister release system.

f. A squib activated cable cutter to cut the lanyards to the smoke puff canisters after all have been ejected.

Referring to Figure 5, function of the system is described in the following paragraphs.

Upon closure of S_1, the system is activated. Power is supplied through thermostat R_1, as required, to the heater resistors (R_3-R_{10}). Power is also supplied, through R_1 to C_1, to supply the power to activate the non-latching relay K_2 which, when enabled by the 14K baro, will step the stepping switch when a command signal is received. Power is also at A_2 of K_2 and will eventually provide the output power to the HH point of the stepping switch. Power is also on the C terminal of the 30K baro, which will eventually be used to set K_1 and enable the automatic jetison system.

The next function occurs when the 14K baro functions which will enable delivery of the voltage on C_1 to the coil of K_2 when an external command signal is received.

Upon flight above 30,000 ft. altitude, the 30K baro will function applying power to the set coil of K_1 causing it to latch in the set position. Notice that if the 30K baro should reclose at this time, power will be supplied through the 30K baro NC contact and the K1 relay A1 and A2 contacts fo contact and S contact of the stepping switch which will step the stepper through all positions by applying power to point C. This will eject all canisters and function the cable cutter.

However, under normal conditions, single canister ejections will be made when a command signal is received. Upon closure of the command switch, power stored on C, is applied to the coil of the non-latching relay K2 causing it to function. As can be seen, the action between R_1 and C_1 will only allow this relay to be closed for a short period of time and then it will re-open as R_1 dominates the coil resistance. R_1 and C_1 have been chosen for this application to allow a relay closing of about 100 ms which is sufficient to provide output signals and then remove power from the output lines. When K2 operates, the power which has been present on A2 of K2, is connected to A1 of K2 causing the following simultaneous steps:

a. Power is supplied to HH of the stepping switch to provide output power.

b. Power is supplied to C of the stepper switch which initiates stepping.

c. Power is supplied through B2 and B1 of K2 to supply holding power through R2 to the stepping coil.

As the stepper switch moves to position 2, power is supplied via HH and w of the stepper to provide an output signal and a canister ejection. In about 100 ms, as previously described, K2 will fall out leaving the stepper in position 2 with all power removed ready for another command signal when C1 has re-charged-approximately 1 second.

The next 5 command signals will, in the same manner, eject pay-load canisters 2 through 6. The seventh signal received will function the cable cutter removing the canister lanyards from their tie point causing them to fall away from the dispensers.

An additional ground function is provided by the momentary switch S2. Whenever this switch is operated and the stepping switch is out of the Zero position, it will reset the system to Zero. Power is supplied through the NO contacts of S2 to the reset coil of K1 and through f and S of the stepping switch causing it to step automatically to the Zero position.

An additional connector J4 allows trouble-shooting of various system components by allowing voltage and continuity checks of certain items. It also provides a means on the ground of bypassing the baro switches for system checkout.

2.3 Ground Development Tests

Ground Development Tests were conducted in two phases. The first phase consisted of Breadboard Tests which were used to evaluate and debug the key subsystems and components of the dispenser system. The second phase consisted of System Functional Tests which evaluated the complete system under as near operational systems as could be simulated. THis testing is described in detail in the following paragraphs.

2.4.1 Breadboard Tests - Breadboard testing was conducted on three specific parts of the system. These were the Payload Ejector System, the Control System and Chemical Payload Tests.

a. Payload Ejector Tests - A single tube breadboard of the payload ejector was fabricated and evaluated. Initially these tests were conducted using a ball lock release mechanism. The mechanism was functional at both ambient and $0^{o}F$ conditions and the release force of the ball lock was measured. Changes in material hardness, finish and lubrication was made until a reliable release force less than 3 lbs. was attained. The release solinoid was tested and had a minimum pull force of 5 lbs.

After conducting initial tests a solinoid was mounted to the breadboard and operated at minimum anticipated battery voltage. A 30 ft. lanyard was used on the model and six successful ejections were made, four with dummy payloads and two with actual chemical payloads.

Later in the program the breadboard was revised and the unit operated with a self contained explosive bolt in place of the ball lock-solinoid combination. Tests were conducted on two units at $0^{o}F$ with dummy payloads. In addition to finding an inherent improvement in reliability due to less dependence on friction variability for functioning, the assembly procedure for inserting the payload was found to be much easier and less time consuming.

b. Control System Tests - A prototype of the control system was fabricated for evaluation purposes. The components used were the same as for the first system test dispenser. After initial checkout and resistor and capacitor optimization in the command input circuit the system was evaluated for the following parameters:

1) Command input on and off requirements. Determined that 1 second on and 2 seconds off would allow sufficient safety factors.
2) Output signal duration - 100 ms minimum.
3) Output signal voltage - 20 volts at battery minimum voltage.
4) Output circuit isolation - Essentially no voltage on output cicuits not being energized.

At the conclusion of electrical checkout tests the breadboard was mated with the single tube ejector breadboard and several ejections of dummy payloads was conducted.

In conjunction with the electrical component breadboard tests, battery load tests were conducted on the silver-zinc battery pack. The battery pack was discharged into a 15 ohm load, the heater net impedance load, and was found to have a capacity of 22 ampere hours at 70°F and 18 ampere hours at 0°F. Battery minimum voltage prior to cut off was 22 volts.

c. Chemical Payload Tests - Initially it was planned to conduct these tests in a temperature - altitude chamber at full scale. However, it was not possible to find a convenient facility to conduct these tests, due to vendor reluctance to test a corrosive material in their tanks. It was therefore decided, with the concurrence of the technical monitor, to conduct the tests at 1/4 scale in a bell jar. Three units were evaluated. They were preconditioned to 0°F and within five minutes transferred to a bell jar which was evacuation to a pressure altitude of 100,000 feet and actuated. In all cases a heavy white smoke instantly filled the bell jar.

2.4.2 System Functional Tests - System tests were conducted on a single complete dispenser system. Tests were conducted at ambient conditions and at the anticipated "in-flight" condition.

a. Ambient Tests - Full scale ambient functional tests were conducted at AFGL from a 90 foot high tower on 3 June and 16 June 1977. The test configuration was identical to the flight configuration except 80 ft. lanyards and inert liquids were used. The initial attempt on June 3rd was unsuccessful due to an electrical wiring error. However, several canisters were mechanically ejected and functioned properly. The inability to eject electrically was traced to a wiring error in the control system which halved the voltage to the release solinoids. The error was corrected and the test successfully reconducted on 16 June 77 at AFGL. Units were electrically ejected and functional 80 ft. below the dispenser.

b. Low Temperature Tests - Low temperature tests were conducted at HYCOR during early August, 1977. In the first test the dispenser was soaked at -65°F for six hours and then 1 payload was ejected each hour for six hours. All ejections were successful.

For the second test, the dispenser was soaked for 12 hours at -65°F and all six units were salvoed via the jetison feature.

For each of the above tests the dispenser was instrumented with five thermacouples and the battery voltage was monitored. In each test the internal temperature of the dispenser dropped to about 40°F and remained stable at that level. Battery voltage at the conclusion of each test was a little over 23 volts.

3. FLIGHT TEST SUPPORT AND RESULTS

Upon notification of a firm test schedule for the initial test, HYCOR packaged and shipped a complete High Altitude Smoke Payload (HASP) Dispenser System to Chico, California on 3 October 1977. HYCOR engineers provided all required field support service and hardware refurbishment tasks from 5 October through 24 October 1977.

The initial balloon launch occurred on 13 October 1977. The mission was terminated prematurely after balloon ascent to approximately 30,000 ft. altitude. The HASP barometer safety switches functioned as planned causing payload ejection and tether line separation. Subsequently, the complete system was successfully recovered during parachute descent by a helicopter.

The HASP system was returned to HYCOR, refurbished and re-delivered to Chico, California in time to support a second scheduled launch attempt on 20 October 1977. This launch was also aborted prematurely after reaching approximately 14,000 ft. The complete HASP system was recovered intact. Attempts to schedule a third launch were unsuccessful. HYCOR field support was completed on 24 October 1977.

A second test was scheduled for 14 March 1978 at Holloman AFB, New Mexico. A refurbished dispenser with explosive bolts replacing the solonoid actuators was delivered to Holloman AFB to support this test. HYCOR engineers provided field support services from 13 March to 25 March.

The second balloon launch took place on 24 March. Camera and video data indicated that all (6) units were successfully ejected, however, only (2) units produced a discernable smoke cloud. Examination of the dispenser after recovery indicated that (1) unit had broken in the dispenser prior to launch but all other launch tubes were clear with lanyards properly cut. It was evident by the corrosion present which launch tube had contained a broken unit. This also precluded deployment of the upper end-cap of the canister which was lodged in the bottom of the tube. Apparently, the unit broke either during pre-launch handling or shortly after launch but the O-ring seal on the lower end-cap precluded all the fluid from leaking out. Upon ejection, the spring drove the upper end-cap down such that the hydraulic pressure of the remaining fluid pushed the lower end-cap free thereby releasing the remaining fluid. The impact with the remaining fluid and lower end cap stopped the motion of the upper end-cap and the corrosion present caused it to hang-up in the tube. The lanyard was still in tact and the pull-pin in place.

A detailed review of the film and video data does not explain the reason for the failure of the remaining units to function properly. Potential reasons postulated include a thermal problem which allowed the $TiCl_4$ to freeze and hence not react properly upon canister release. Examination of the battery after the test, however, indicates proper power drainage for the mission time period. Also, the units that did function properly were obviously not frozen and had no preferred location relative to the other units. Another suspect area involves the apparent tumbling of several of the canisters as seen on the film data. This could allow the lanyard to wrap around the canister such that the pull-pin would not be actuated upon reaching the end of the 100 ft. lanyard length. No evidence of this occurrence was seen in any of the development tests, however. Further studies and tests are in process in an attempt to understand the above results and insure proper operation in the future.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the two missions flown, it is concluded that the High Altitude Payload System offers a simple and low-cost technique for obtaining high altitude data in support of stratospheric turbulence studies. System performance and reliability improvements are clearly required, however. The following recommendations address these areas.

It is recommended that prior to future flights of the HASP system, the system be put through a complete 12 hour low temperature-altitude cycle with sufficient thermocouples operating to monitor proper temperatures in all launch tubes. The $TiCl_4$ portions of the payload canisters will have to be simulated for this test since available environmental test facilities will not accept the $TiCl_4$ due to potential corrosive damage. It is further recommended that the lanyard technique be eliminated and replaced by small pyrotechnic delay mechanisms (PDM's) having an explosive output to initiate fragmentation of the canisters. HYCOR has developed a family of these devices with .3 to 1.75 second delays and delivered over 10,000 countermeasure canisters containing them to the U.S. Navy. Operationally qualified military aircraft squibs would be used to eject the smoke canisters and initiate the pyrotechnic delay mechanisms. The current HASP dispenser configuration can be used with minimum modification to be adapted to this technique.