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The Air-Launched Balloon System (ALBS) Development Program, Phase II

ANDREW S. CARTEN, Jr.

15 December 1981

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HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

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Chief Scientist

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The circumstances leading to the second phase of the Air-Launched Balloon System Development Program are described, along with the governing design constraints. Individual component development efforts and system design modifications are described in turn: the procurement and testing of the new dewar, the qualification of the updated cryogenic unit, the redesign of the balloon/parachute interface, the solution of the extraction line recoil problem, and the development of a reliable cryogenic unit recovery system. The complicated command, control, and telemetry subsystem is also described in detail. The

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20. Abstract (Continued)

results of component tests and a system dress rehearsal system test are summarized. Preparations for two full-scale system tests conducted in 1981 are covered in considerable detail. The results of those tests are presented and the test data are analyzed. It is concluded that the system's air-launch and mid-air inflation techniques are acceptable. The balloon requires structural reinforcements, however, before the system can be said to be fully developed.

Preface

As in the first phase of the Air-Launched Balloon System Development Program, the author is indebted to a large number of people for the extensive support he received during the period covered by this report. That support made possible the many successes achieved and is deeply appreciated by him. Thanks are due, therefore, to his parent organization, the Air Force Geophysics Laboratory; to the two principal supporting organizations, the Air Force Flight Test Center (AFFTC) and the Thermophysical Properties Division of the National Bureau of Standards (NBS); and to the other organizations that provided important support: The U.S. Army's White Sands Missile Range; the Military Airlift Command (and the 62nd Military Airlift Wing), and the Aeronautical Systems Division (AFSC).

At AFGL the author was assisted and encouraged on a day-to-day basis by his many co-workers and by the in-house support groups (Mechanical Engineering, Fabrication Services, Technical Photography, etc.), for which he is truly grateful. Particular thanks are owed to Mr. Ralph Cowie, Chief, Balloon Instrumentation Branch, for his dedicated and vital technical contributions and to TSgt. James Fiebrink for his special electronics support effort. The full-scale flight tests carried out in 1981 required extensive assistance from the personnel at AFGL's Detachment No. 1 at Holloman AFB. That assistance was generously and effectively provided and is acknowledged with thanks.

The contributions of Mr. Michael Wuest of the 6520 Test Group, AFFTC, in the areas of test management, parachute system design, and aircraft test support were immeasurably valuable to the program. Also acknowledged are the dedicated endeavors of Capt. Matthew Raimo, now of the 6594th Test Group, Hickam AFB,

Hawaii during his role as AFFTC ALBS Test Manager. Mr. Wuest and Capt. Raimo were assisted, in turn, by numerous co-workers and support personnel at Edwards AFB whose cheerful cooperation eased the program through a number of difficult situations and ensured the ultimate success of the flight tests.

Mr. Charles Sindt of the Thermophysical Properties Division, NBS, Boulder, Colorado was a major contributor to the ALBS development effort throughout both of its phases. The outstanding performance of the NBS-designed cryogenic unit during ALBS full-scale tests is a tribute to Mr. Sindt's competence and dedication in a difficult technical area. It also constitutes a significant breakthrough. Mr. Sindt's outstanding support to the program is acknowledged with sincere gratitude.

A final note of thanks is due to Miss Beth Hennessy of the Aerospace Instrumentation Division, AFGL, whose enthusiastic and persevering assistance in the preparation of this report turned a laborious effort into a pleasant task.

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The Air-Launched Balloon System (ALBS) Development Program, Phase II

1. INTRODUCTION

This is the first and final technical report on the work performed under AFGL In-House Work Unit (IHWU) 76591101, "Air Launched Balloon Techniques." It covers the second phase of the Air-Launched Balloon System (ALBS) development program. The first phase was accomplished principally under IHWU 66651101, which was terminated on 30 September 1977.

The term "air-launched" implies launching from an aircraft in flight. However, for the reasons given in paragraph 2.2, the prototype ALBS test model actually developed during the first phase could not be so launched. As a result, flight tests involving that model were to have been made with another balloon as the launch (drop) vehicle. Unfortunately, the first attempted balloon drop of the complete system, in January 1978, ended disastrously. The carrier balloon, which was to have taken the prototype to 25,000 ft (7.62 km) for the drop, was accidentally destroyed at launch and, in the process, the ALBS model was damaged beyond repair.[1]

After a lengthy reappraisal of the program at AFGL, a decision was reached in March 1978 to proceed with the planned second development phase, using a new "hardened" ALBS model, specifically configured for aircraft extraction. This

(Received for publication 4 December 1981)

1. Carten, A.S., Jr. (1978) Flight Tests of the Air-Launched Balloon System (ALBS) Prototype Model, AFGL-TR-78-0074, AD A057 610.

report will cover the design, assembly, and laboratory testing of the new model, the flight tests required to verify changes made in the parachute subsystem, and the live flight tests of the overall system carried out in March and September 1981.

2. BACKGROUND

2.1 Basic Requirement

The Air-Launched Balloon System development program seeks to satisfy the requirement for a quick-reaction capability to put a lighter-than-air tactical communications relay platform into position at high altitudes. Such a requirement is called out in TAC ROC 305-75 entitled, "A Satellite Airborne Communications Relay System for Tactical Air Forces." (Discussions by the author in 1980 and 1981 with a representative of Headquarters TAC confirmed the continuing validity of this requirement.)

The ALBS development concept calls for the packaged system to be extracted from a C-130 aircraft at 25,000 ft (7.62 km). When the system is properly deployed in midair by a tandem parachute array, the stored ALBS balloon will be extended vertically and filled from a cryogenic helium (He) storage unit. The inflated balloon will then carry the attached communications relay, which weighs approximately 200 lb (890 N), to its assigned altitude of 70,000 ft (21.34 km). The inflation hardware, meanwhile, floats to the ground (see Figure 1).

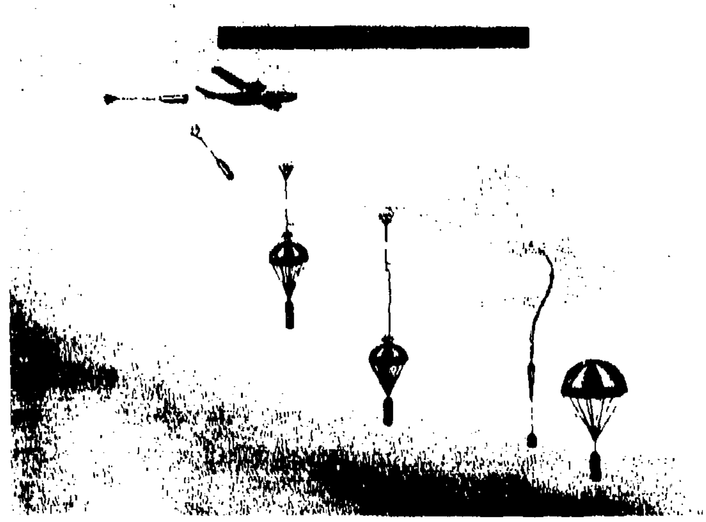

Figure 1. ALBS System Concept

2.2 Previous Development History

The report entitled "Flight Tests of the Air-Launched Balloon System Prototype Model," AFGL-TR-78-0074, summarizes the early development history of the program. It discusses the reasons for storing He cryogenically and describes the successful development, by the National Bureau of Standards, of the hardware needed for this type of storage. The report also describes the special ALBS balloon and provides details of the parachute subsystem qualification tests successfully carried out in 1977 by the Air Force Flight Test Center (AFFTC) at the National Parachute Test Range, El Centro, California. It concludes with a description of the preparations for and the results of the abortive balloon drop test of the prototype ALBS model at the White Sands Missile Range (WSMR) in January 1978.

As stated above, the early ALBS prototype was not designed for aircraft extraction. This circumstance arose from schedule and budget restraints on the inhouse project. For example, in December 1975, after the initial heavy, ground-based cryogenic unit successfully inflated a 145,000 ft^3 (4106 m^3) balloon, which carried a 300-lb (1334.4 N) payload to 75,000 ft (22.86 km), a decision was made to build a lighter-weight version of the unit for flight tests. Annual fund allocations ruled out the timely procurement of a lightweight dewar sized specifically for the ALBS. An oversized "make-do" configuration was established, therefore, using two smaller titanium (Ti) dewars left over from the NASA Apollo program (see Figure 2). It was reasoned that an ALBS model so configured would be suitable for a "proof of concept" balloon drop and, with the exception of the aircraft extraction step, would adequately demonstrate all other planned air-launch functions. The development of a more sophisticated model incorporating a single, full-size hardened dewar could then follow in Phase II. As it turned out, this plan of action had to be compressed, thanks to the unscheduled loss of the make-do model.

The March 1978 decision to proceed directly into Phase II, with the hardened cryogenic unit, placed the first full-scale flight test two years or longer into the future because of the time required to prepare the procurement specifications, solicit bids, award a contract, take delivery, and qualify the new unit. However, the delay had the advantage of permitting additional testing of the parachute subsystem to correct deficiencies pointed up in the 1977 AFFTC tests. It also allowed the redesign or refinement of a number of system components (inflation tubing, interface hardware, release devices, etc.) and the complete revamping of the timing and control circuits. All of these points will be discussed in further detail in the sections which follow.*

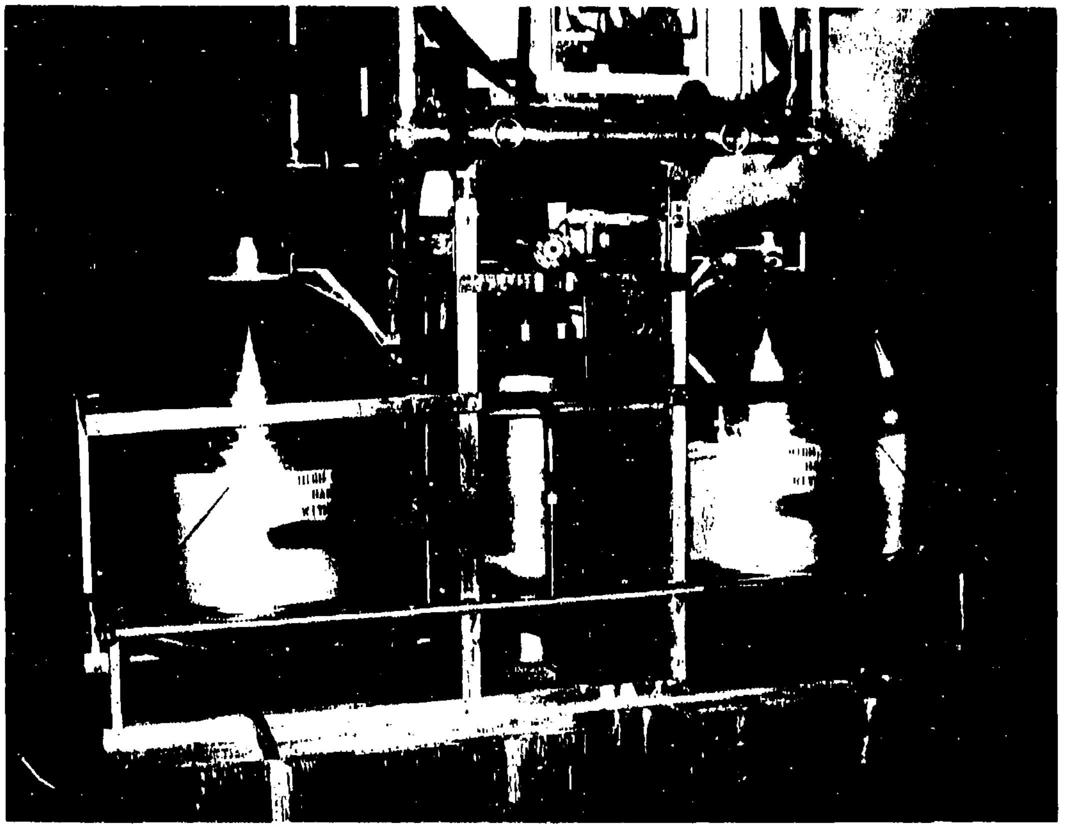

Figure 2. Phase I Cryogenic Unit

*The Thermophysical Properties Division of the National Bureau of Standards, Boulder, Colorado, agreed to support the new effort, thus continuing the previous close NBS involvement in the ALBS development program. The detailed dewar procurement specifications were to be prepared by the NBS and the contract would be administered by that agency, in close coordination with the Air Force work unit monitor. The AFGL-AFFTC ALBS support agreement was also renewed to permit AFFTC engineering inputs and tests connected with the parachute subsystem refinement effort.[2] The "decisions" mentioned in the sections that follow typically represent the consensus reached after discussions among all interested parties: AFGL, AFFTC, and NBS. No attempt will be made to identify individual decision makers.

2. Wuest, M.R. (1981) The Air-Launched Balloon System, Phase II, AFFTC-TR-81-33.

3. ESTABLISHMENT OF THE NEW PHASE II SYSTEM CONFIGURATION

3.1 General Considerations

In arriving at a new ALBS system configuration for Phase II, an attempt was made to preserve those features whose suitability had been established by test in the earlier phase. However, because a new set of requirements was being addressed, a new system geometry was called for. A design and acquisition plan took shape in which the new hardened cryogenic unit was to play a key role: The structure developed to house that unit would be extended to house all other system components. Once the design parameters were worked out, a contract would be let for fabricating the cryogenic unit and the extended structure. New in-house items and items saved from the previous program would be assembled to the delivered structure by the participating government activities. The system would then be ready for flight tests. As in January 1978, these tests were to be conducted over the WSMR, at a date yet to be established, with aircraft takeoff from Holloman AFB.

3.2 The "Hardened" Cryogenic Helium Storage System

3.2.1 DESIGN CRITERIA

The new hardened cryogenic unit was to be functionally identical with the one destroyed in the January 1978 test (Figure 2), that is, it was to deliver a minimum of 102 lb (453.7 N) of helium (He) to the deployed ALBS balloon in 5 min. The primary difference was to be mechanical: The configuration, including the extended structure mentioned above, was to be as compact as possible and carefully stressed to withstand the anticipated greater extraction and deployment forces. Overall weight was to be kept at a minimum. Also, safety requirements for the aerial transportation of liquefied helium (LHe) were to be satisfied.

It should be pointed out here that the term "cryogenic unit" refers to the entire subsystem devoted to pre-flight storage and in-flight transfer of He to the ALBS balloon. Thus, it consists of a dewar or dewars to store LHe, a pressurization system designed to force the LHe out of the dewar at the time of balloon inflation, and a heat exchanger to warm the now gaseous He to a temperature that the balloon film will tolerate (see Figure 3). The three major components (dewar, hot-bed heat exchanger, and pressure tank) are joined to one another by fluid transfer lines in which flow is controlled by regulators and timer-activated solenoid valves. The system terminates in a filler pipe, 5.5 in. (13.97 cm) in diameter, to which the balloon's inflation tubing is secured.

Although the dual Ti dewars of the earlier make-do system were clearly destroyed in the January 1978 accident, the associated 4500 psia (3.1×10^4 kPa)

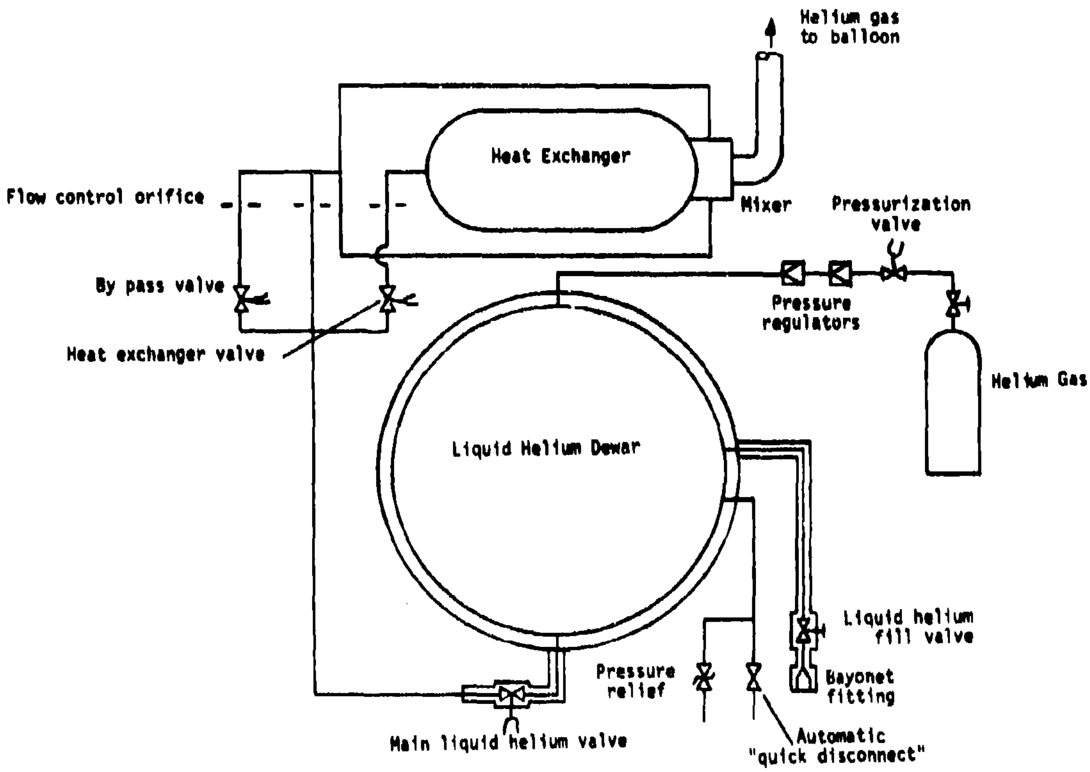

Figure 3. Cryogenic Unit Schematic Diagram

pressurization tank and the heat exchanger appeared to have survived with only minor damage.* They were judged to be reusable without major repair – a mistaken judgement as later events proved (see paragraph 3.5.4.2). Thus, top priority was given to the design and procurement of a single-vessel LHe storage dewar (and associated structure) with the understanding that it would be mated to the original heat exchanger and pressurization tank at the NBS after delivery.

The new full-size dewar became the pacing item in Phase II. Its diameter determined the cross-section of the new system test model. Its ability to meet specified requirements was vital to program success. Its availability date established the schedule for the all-out, complete system test. Also, too great a differential between procurement cost and fund availability would have ensured a stretched-out procurement or no procurement at all. Fortunately, a reasonable cost/budget balance was attained.

*Figure 2 shows the rugged, all-welded construction of the heat exchanger (located between the two dewars). Only a limited internal inspection was possible without costly and time-consuming disassembly.

3.2.2 CHOICE OF MATERIAL

The two half-size Ti dewars employed in the earlier test model were exceptionally light in weight [approximately 80 lb (355.84 N) apiece]. They were also very expensive and were available to the program only as NASA surplus items. The use of Ti in the new hardened dewar was out of the question, fundwise. The primary metal was to be an aluminum alloy, with some use of stainless steel. Because the dewar was to be a low-pressure vessel [75 psia (517 kPa) maximum operating pressure] the use of aluminum (Al) did not impose severe weight penalties. As it turned out, the new single full-size Al dewar weighed in at 218 lb (969.66 N), empty, versus 160 lb (711.68 N) total for the two half-size Ti dewars, also empty.

3.2.3 DEWAR SIZE AND ITS EFFECT ON THE ALBS TEST CONFIGURATION

It was decided that the new dewar would hold 377 l (103.79 lb) of LHe when full, and would have 10 percent ullage, that is, space above the liquid. It was also decided that the dewar would be spherical in shape, rather than a domed cylinder, to minimize surface area and boil-off losses. To accommodate the volume requirement, the sphere's inside diameter would have to be slightly over 3 ft (36.42 in., 92.5 cm). On this basis, the sphere's outside diameter was taken as 40 in. (101.6 cm), to allow for double-wall construction, with a layer of insulation between walls. This dimension became the starting point for determining the size of the new overall ALBS test system.

3.3 Overall System Configuration

3.3.1 BASIC GEOMETRY

A long rectangular configuration had earlier been chosen as the most desirable system shape for ease of fabrication, handling, extraction, deployment, and recovery. Thus, the 40-in. (101.6 cm) outside diameter of the new sphere dictated at least a 40 in. × 40 in. (101.6 cm × 101.6 cm) cross-section (inside dimensions) for the overall system package or module. However, when allowance was made for securing the sphere, the module's minimum inside cross-section increased to 43 in. × 43 in. (109.2 cm × 109.2 cm). The next step was to see if the packed ALBS parachutes, balloon, payload, and other deployment hardware could fit inside a volume with this cross-section. If so, this interior cross-sectional area could be maintained throughout the module's length – a very desirable situation. Assuming that this condition could be met, the length and the exterior wall thicknesses (framework plus plywood) would be the final items required to establish the complete dimensions of the new module.

3.3.2 PAST EXPERIENCE VS PRESENT NEEDS

The design of the destroyed ALBS Phase I test model was very helpful here. Shaped like an inverted T, that model consisted of two separate sections or submodules that were joined together just before the flight (see Figure 4). The upper section was a large box, open at the top, in which were stored the main parachute, the balloon, the payload, and the recovery parachutes. The lower section was the cryogenic unit, with its two dewars, pressurization system, and heat exchanger mounted in a special frame. The most direct approach to the preferred new Phase II configuration, that is, a long box of constant cross-section, was simply to rotate the vertical member (upper box) of the original T clockwise 90° and to line it up with the cross member (cryogenic unit). The resulting long rectangular module would then be made up of two framed sections of approximately equal length, corresponding to the two sections of the earlier model, and mounted one above the other, when viewed in the vertical, balloon-fill system orientation (see Figure 5). The upper box section would be sheathed in plywood and the lower cryogenic section would be an open frame. Actually, the upper box section employed in Phase I was too big, with interior dimensions of 54 in. × 38 in. × 78 in. (137.16 cm × 96.52 cm × 198.12 cm). Measurements made on the stored components to be used in Phase II suggested a new box with interior dimensions of 43 in. × 43 in. × 67 in. (109.2 cm × 109.2 cm × 170.45 cm). Thus, the cross-section required for the new dewar could be maintained throughout the entire length of the module, as had been desired.

3.3.3 OVERALL DIMENSIONS

The length of the new upper box section was established, therefore, as approximately 5.5 ft (1.68 m). It was also determined that the heat exchanger could be mounted above and transversely to the new dewar, thus allowing the cryogenic unit components to fit into a 43 in. × 43 in. × 68 in. volume (109.2 cm × 109.2 cm × 172.72 cm). With this, the lower section's length was also established as approximately 5.5 ft (1.68 m). When fully developed, the overall module length (combined sections) turned out to be just under 12 ft (143 in., 363.22 cm), including junctions and suspension line attachment hardware (see Figure 5). The overall cross-section was 47 in. × 47.25 in. (119.38 cm × 120.02 cm), thanks to the use of 1.5-in. (3.81-cm) tubular steel framing along with 0.5-in. (1.27-cm) and 0.75-in. (1.91-cm) plywood sheathing.

3.3.4 OPERATIONAL PLAN

The operational plan for the new module was that the two sections would be prepared for flight separately and brought together at Holloman AFB just before the test. They would be securely joined, end to end, while in a horizontal orientation, and loaded aboard the aircraft. At launch over the WSMR, the assembled

Figure 4. Phase I T-Shaped System Configuration

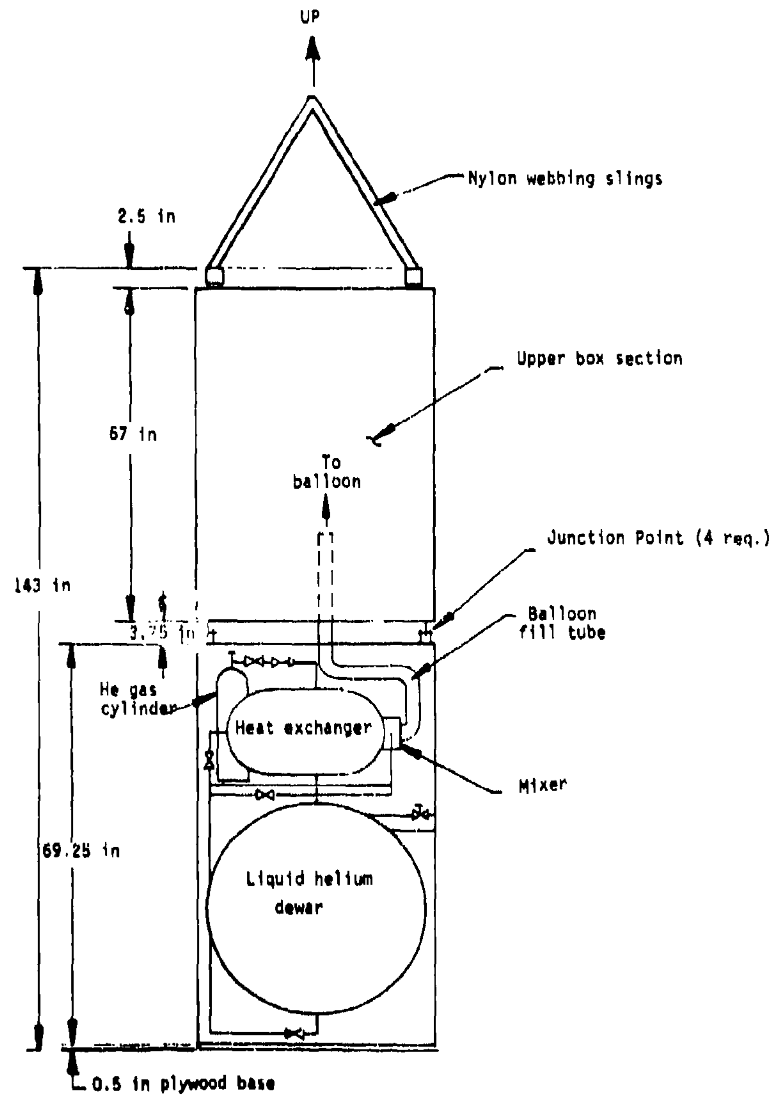

Figure 5. ALBS Full-Scale Module

module would be extracted horizontally from the aircraft, through the action of the drogue parachute, and would quickly reposition itself vertically with the box section uppermost (see Figure 5). The balloon and main parachute would then be withdrawn from the box section for mid-air deployment. The horizontal attitude assumed by the module while aboard the launch aircraft and during extraction would have no harmful effect on system performance, as had been proved in many flight tests at El Centro in 1977. After inflation and release of the balloon with its payload (see paragraph 3.8.1), the empty box and cryogenic unit would float to the ground as a unit on its own recovery parachute. There the two sections could be separated, if necessary for ease of recovery, by the removal of four bolts.

3.4 Safety Considerations

3.4.1 CRYOGENIC SYSTEM SAFETY

In the process of arriving at a new ALBS system configuration, consideration was given to the details of transporting it to launch altitude on a standard Military Airlift Command (MAC) aircraft and of positioning it within that aircraft for a safe extraction. In this connection, two trips were made to Wright-Patterson AFB, Ohio, in April and July 1978, to discuss Air Force standards for military air drops and for the transport of hazardous cargo. Meetings were held with personnel of the Aeronautical Systems Division (Parachute and Aerial Delivery Branch) and the Air Force Logistics Command (Hazardous Materials Branch). One of the concerns leading to the trips was the design of the LHe dewar and its pressurization system. Were there any AF regulations that would prohibit the intended use or require unanticipated engineering changes in the system? Working pressures and pressure relief systems of the cryogenic system were discussed with AFLC and were judged to be in compliance with DOT and AF standards. No objection was raised to transporting the system in a MAC aircraft, provided that boil-off gas from the dewar was discharged overboard through the aircraft vent system. A quick-release coupling would be used to facilitate disconnecting the vent just before launch. Any subsequent pressure buildup within the system was judged to be of no importance. If the launch were aborted the vent connection would be remade; otherwise, the system would soon be clear of the aircraft. In this regard, it was also agreed that the switch for turning on the cryogenic unit would be lanyard-operated, that is, it could not be activated except by the actual extraction step.

3.4.2 EXTRACTION SAFETY

The new system configuration introduced another safety concern: Were the aircraft extraction techniques developed at El Centro in 1977 still valid?

In the El Centro tests a simulated ALBS test system was employed. It will be called the "parachute test vehicle" here. A comparatively short cube-shaped box, 48 in. (121.92 cm) to a side, it was designed to hold the ALBS deployment parachute and balloon only. The weights of the missing system components (payload, recovery parachutes, and cryogenic unit) were accounted for by the use of heavy structural members in the box and by the addition of lead ballast. Thus, although the 1977 test vehicle did not truly simulate the overall volume and weight distribution of the final system, its faithful representation of system gross weights allowed an accurate determination of parachute performance. This was true both in the system extraction and deployment functions and in the mid-air extension of the balloon.

Because of its short length, the original parachute test vehicle could be secured, before takeoff, to the moveable ramp of the C-130 (see Figure 6). The ramp

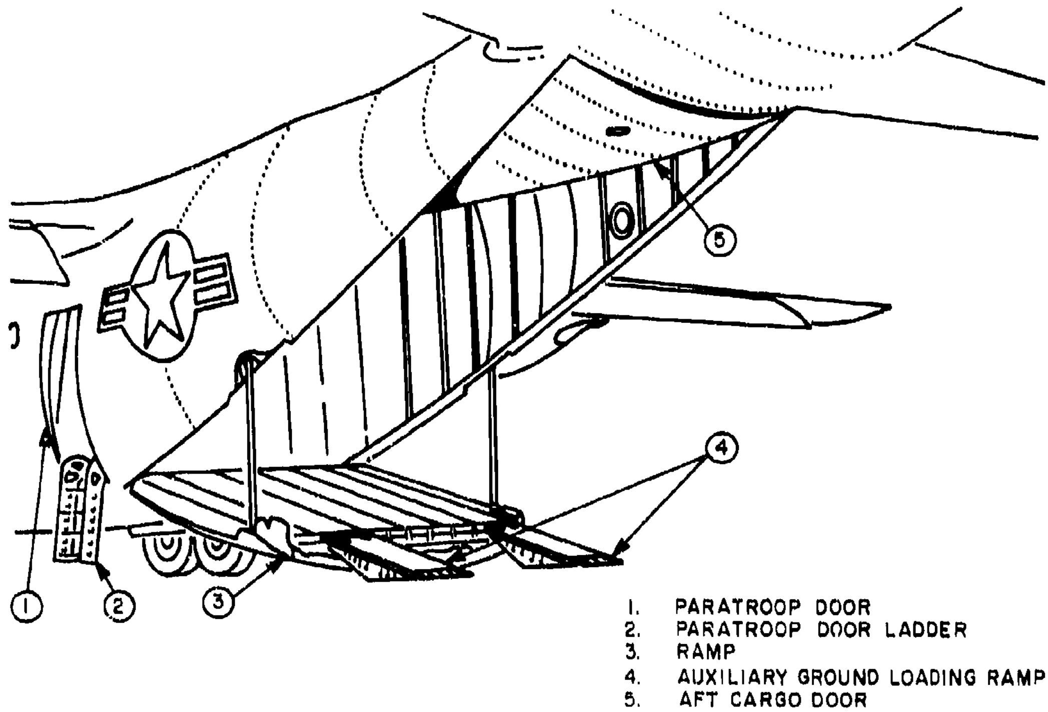

Figure 6. C-130 Ramp and Aft Cargo Door

would then be closed for the flight to launch altitude. Prior to launch, the ramp would be lowered, automatically putting the test vehicle in the ideal position (flush with the ramp edge) for extraction, without the need for in-flight repositioning. The new 12-ft long ALBS system module would not permit this procedure, however. It would have to be secured forward of the ramp hinge line during flight. If it were to be extracted from the ramp's edge, as was the case with the parachute test vehicle, it would have to be moved rearward in flight, a hazardous and unacceptable procedure, particularly if it meant loosening tie-down restraints. (The fear here is that unanticipated aircraft motion could cause lurching of the unrestrained load, with unpredictable consequences.)

The discussions at ASD were focused on this issue. One suggestion was to mount the ALBS module on a wide pallet that would engage the side rail system of the C-130 and would allow better control of module movements. The disadvantage to this suggestion was that the pallet, which would be extracted with the module, would be so lightly loaded that the system would probably "fly" when extracted, possibly striking the empennage of the aircraft. It would also make for a very ungainly system configuration. Another suggestion was to use the gravity-drop technique, that is, to put the aircraft in a nose-high attitude so that the released module would simply roll off the end of the ramp – with no assist from the extraction parachute. This idea was not adopted because of the poor nose-high flying characteristics of the C-130 at high altitude. Fear of tumbling of the module and of tangled lines was also a strong deterrent.

The discussions ended with an agreement that the module would be extracted, without a pallet, from a point forward of the hinge line, that is, it would not be moved out to the edge of the ramp. It would also be positioned on the aircraft's center line, to provide maximum clearance on both sides. The module would be mounted securely on a 0.75-in. (1.91-cm) thick plywood sheet, 4 ft long × 12 ft wide (1.22 m × 3.66 m), to ensure smooth passage over the aircraft roller system.

Although the extraction procedure actually used varied somewhat from the above agreement (see paragraph 4.3.2.1), the reaching of an agreement was a significant milestone. It meant that procurement of the new dewar and extended frame could proceed with confidence. Likewise, the necessary parachute-balloon interface design effort could be initiated and refinements could be made to the parachute subsystem and to the recovery subsystem.

3.5 Dewar Procurement and Cryogenic Unit Assembly

3.5.1 EQUIPMENT SPECIFICATION

A detailed procurement specification for the new dewar and its accompanying framework (see paragraph 3.3.2) was prepared in the summer of 1978 at the Thermophysical Properties Division of the NBS for fixed-price competitive bidding. The salient features of the specification are summarized in the design data sheets contained in Appendix A of this report. Note that the various acceleration forces that the unit must withstand are spelled out on the sheets, with a maximum of 9 g in the aft direction. One of the key features of the specification was its emphasis on allowable overall weight limits. Prospective bidders were warned that bids would be penalized, in the evaluation process, for any excess poundage. For example, for each kilogram (2.2 lb) that a prospective bidder's system weight exceeded the 790-lb (3513.9 N) target weight, his bid price was artifically raised by $100.00.

3.5.2 CONTRACT AWARD AND PERFORMANCE

A contract award was made by the NBS to Cryolab, Inc., of Los Osos, California in November 1978 (Contract CST-8469). Delivery was to be made 160 days after contract award. For a number of reasons this goal was not met, however. Some of the delay was attributable to late deliveries by vendors on component items. The major cause of delay was a test failure which occurred when the inner sphere of the dewar failed a 100 psia (609 kPa) maximum pressure proof test and had to be reconstructed. In any event, the original 160 days stretched out to slightly over a year. The saving features were that the quality of the items delivered was high and that, after some initial corrective actions (see paragraph 3.5.4.1), the Cryolab dewar met all performance requirements. The associated framework was of all-welded, cross-braced construction, employing hollow members made of type 4130 alloy steel [tensile strength: 110 000 psi (7.58×10^5 kPa)]. The members had a square cross-section, 1.5 in. (3.81 cm) to a side, with wall thickness varying from 0.049 in. (0.124 cm) to 0.125 in. (0.32 cm). This method of fabrication, which was based on a thorough pre-construction stress analysis, provided a very strong frame at minimum weight. [The empty upper and lower frames weighed 200 lb (889.6 N) and 182 lb (809.54 N), respectively.]

Another novel and effective weight-saving feature of the Cryolab design was the method of securing the dewar. Instead of the usual trunnion mount, the contractor chose an array of low-stretch polyester straps that cradled the dewar like a large ball in its center (see Figure 7). The net result of the various weight reduction techniques was that the contractor delivered a unit that weighed about 190 lb (845.12 N) less than the target minimum weight – a very commendable achievement.

Figure 7. Dewar and Straps

Before the items under contract could be accepted they had to undergo rigorous tests. This testing was divided into two phases: pre-acceptance tests at the contractor's plant and final tests at NBS, Boulder, Colorado.

3.5.3 PRE-ACCEPTANCE TESTS

3.5.3.1 Upper Framework Tests

On 11 December 1979 stress tests were conducted on the various structural members of the ALBS module's upper framework. All attachment points, welds, and tubular members were subjected to appropriate tension, compression, and bending loads imposed through a hydraulic device. In every case, the static loading equalled or exceeded the specified 9-g dynamic force. There were no failures. Similar tests were carried out successfully on the upper section of the lower framework, which supports the cryogenic unit and the heat exchanger. After these tests the upper frame, which holds the balloon, parachutes, and payload, was trucked to AFFTC, Edwards AFB, where the plywood sides would be attached and the unit would be readied (see paragraph 4.3.2.1) for the full-scale test over the WSMR, now planned for March 1980.*

3.5.3.2 Lower Framework Tests

Tests of the lower half of the lower frame, on 12 December, imposed a 7.3-g load on the liquid nitrogen (LN_2)-filled dewar and on the straps holding it in place. There was no damage to the dewar under this loading. Since the maximum expected load on the dewar is 5.5 g, the test demonstrated a safety factor of at least 1.3 in the dewar design. (Testing of the dewar to the specified 9-g load was not done, because of an unjustifiable risk of damage to the dewar at that loading. See paragraph 4.2.4.)

3.5.3.3 THERMAL TESTING

On 13 December the dewar was filled with about 50 lb (224.4 N) of LN_2 for boil-off tests to determine preliminary heat-leak characteristics. The dewar passed these tests. The valve assemblies on the cryogenic unit were also subjected to functional tests. The lower frame assembly, including the dewar, was then cleared for shipment to NBS where the heat exchanger unit and the pressurization system were to be added and the complete unit would be tested with LHe. Final acceptance was contingent on satisfactory performance at LHe temperatures. Although the test just conducted with LN_2 hinted at no problems in this regard, some did show up, as will be described.

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*While the dewar and frame were being built, several other ALBS problems were being resolved (see paragraphs 3.6 through 3.9). The balloon/parachute interface was redesigned, extraction line recoil was eliminated, and the subsystems for controlling and dropping away the cryogenic unit were perfected. All of these items were flight qualified in November 1979 (see paragraph 4.2.3). The scheduling for the live WSMR test was thus keyed at this time to the availability of the cryogenic unit. The selected March 1980 date assumed quick, trouble-free testing of that unit, an assumption that proved to be unrealistic.

3.5.4 FINAL ACCEPTANCE TESTS

The dewar and the lower frame arrived at NBS Boulder early in January 1980. The first test there was to determine the boil-off rate with LHe: 4 percent per day. This was slightly above the specified 3 percent rate, but, being well within the requirements of the planned test flight, it was considered acceptable.

3.5.4.1 Flow Rate Problems

By the first week in February 1980, the cryogenic unit had been completely assembled (dewar, heat exchanger, pressurization system) and was ready for performance tests simulating the mid-air balloon inflation process. Several short runs of about 1 min. in duration had been made by mid-month, each using 75-100 l (21.6-27.5 lb) of LHe. The gas temperature at the outlet was slightly lower than desired (250°K vs 260°K expected as a minimum). (See paragraph 4.5.6). More importantly, however, the gas flow rate was much too low. It had been specified at 0.353 lb/s (1.57 N/s) but was actually averaging about 65 percent of that rate, that is, 0.229 lb/s (1.02 N/s). With this low flow rate the cryogenic unit could not inflate the ALBS balloon in 300 s as required. Clearly, remedial action was necessary. At first, the problem was thought to be ice trapped in the lines. To check this out the system was warmed to room temperature and the lines purged. Another short run was made, with no change in the flow rate. The next suspected blocking agent was an inert "yarn" which had been placed in some of the lines by the contractor to eliminate thermal oscillation. About two weeks were devoted by NBS and contractor personnel to removing this material from the LHe lines. Then another run was made, with no improvement in flow rate. Attention was now shifted to the LHe valve assembly. It was found to have an excessive pressure drop due to an undersized inlet port. It was shipped to Cryolab for modification on 5 March 1980 and was received back a month later. New short tests at NBS then showed that the revised flow rate, 0.42 lb/s (1.87 N/s), actually exceeded the specified rate, although this was not a problem.* Gas temperatures on the abbreviated tests were still somewhat low (255°K) at the outlet port of the heat exchanger, however. This was seen as a function of the heat exchanger and the plumbing associated with it, rather than a fault of the dewar. Thus, final acceptance approval was granted on the dewar.

*The higher gas flow rate means that more He could enter the balloon in the 300-s inflation period. The additional inflatant mass, which would come from the pressurization system, or from He deliberately added to the ullage space, would augment system free lift and provide a measure of insurance against underinflation.

3.5.4.2 Gas Temperature Problems

The above problems with the cryogenic unit had adversely affected the scheduling of the live ALBS test over the WSMR. The March 1980 date (see paragraph 3.5.3.1) had slipped to April, and then to May, with no firm date capable of being established until at least one full run of the cryogenic unit [300 s, 102 lb (453.7 N) of LHe] had been successfully made at Boulder with outlet gas temperatures averaging not less than 260°K. Now, with the flow rate problem out of the way, the time had come for such a full run (on 25 April 1980). It was hoped that the observed, lower-than-expected temperatures of the short runs would be counter-balanced by warmer temperatures farther along in the full run. Once again disappointment was in order, as the hoped-for warming trend failed to materialize. Even worse, the temperature plummeted to much lower values, bottoming out at 62°K at the end of 300 s. Suddenly, it was clear that the heat exchanger had indeed suffered damage in January 1978 and that "channeling" was now occurring. In other words, the gas was streaming through open channels in the bed of Al_2O_3 pellets (heated to 1005°K), instead of diffusing through the interstices normally found in association with tightly-packed beads. Because channeling destroys the conditions necessary for good heat transfer, the gas was extracting only a small portion of the intended heat and was exiting the exchanger only a little warmer than at the entrance.

Although the extent of the damage inside the heat exchanger was unknown, the situation had been aggravated by the decision to mount the heat exchanger transversely in the frame (see paragraph 3.3.3). Referring back to Figure 2, we note that the Phase I arrangement had the cold gas enter the heat exchanger (located between the two dewars) from the top and pass down through the bed to the mixing chamber at the base. With this arrangement gravity alone ensured tight packing of the beads. With the transverse layout, on the other hand (see Figure 5), gravity tends to create channels at the top of the bed as the gas flows from left to right.

Because of administrative pressures arising from slipped schedules, there was an urgency to reestablish effective heat transfer in the cryogenic unit quickly. To avoid the three-month delay and the heavy costs associated with rebuilding the heat exchanger, serious consideration was given to repositioning the exchanger vertically, to duplicate the Phase I orientation. Another run was made on 8 May 1980, with the heat exchanger temporarily so oriented.* The poor results established conclusively that the real problem was the internal damage and that rebuilding was unavoidable. Reluctantly, the flight test was rescheduled for the beginning of Fiscal Year 1981. Residual FY80 funds were consolidated to cover the cost of the heat exchanger rehabilitation work, which was to be carried out at the NBS.

*Permanently reorienting the heat exchanger would have required structural changes to the ALBS frame, but these would have been less costly in money and time than rebuilding the heat exchanger.

3.5.4.3 Rehabilitation of the Heat Exchanger

When the heat exchanger was disassembled at the NBS in May 1980 it was discovered that some of the internal bead separators had been crushed and, in addition, some of the tie-rod attachment bolts had broken off – all as a result of the January 1978 accident. Because the thermal exchange value of the separators was questionable, NBS decided to omit them this time, filling the voids so created with more Al_2O_3 beads. (Although this would add somewhat to the weight of the heat exchanger, it would also increase its heat capacity.) All of the beads would be shaken in place, to ensure maximum packing density. New, stronger tie-rods would be used, to guarantee greater resistance to g-loads. A new design feature would also be incorporated: A series of crescent-shaped barrier plates would be placed at the top of the bed, as oriented in Figure 5. These barriers would be at right angles to the direction of flow and would penetrate slightly into the bed. Any gas that tried to flow in the channel created at the top by the settling of the beads would, thus, be forced back down into the hot bed.

By August 1980, the above changes had been accomplished. The heat exchanger's inner shell was then wrapped in its thermal blanket, as before, and assembled to the outer shell, with a layer of Min-K insulation between the shells. The insulated volume was sealed and a prolonged evacuation cycle was begun. By the end of September, the refurbished heat exchanger was reassembled to the dewar and the cryogenic unit was ready for additional temperature runs. In the meantime a new WSMR test date had been established, 18 November 1980.

3.5.4.4 Tests of the Refurbished Heat Exchanger

The first test of the cryogenic unit with the refurbished heat exchanger took place on 30 September 1980. A short run [50 s, 100 l (27.5 lb)], with a normal flow rate, it ended with the gas temperature at 258°K and rising, a very encouraging sign. The by-pass valve (see Figure 3) failed to work during this test, and was afterwards torn down and refurbished. The very similar heat exchanger valve was likewise cleaned and adjusted. Then, on 10 October, a full-scale run [300 s, 102 lb (453.70 N)], was conducted. The flow of gas ceased early, at 270 s, when system pressure dropped below 40 psi (276 kPa). (For the next test, a check valve was installed to prevent this from happening again.) Approximately 96 lb (427 N) of LHe was transferred out of the dewar during the truncated run. The most significant data, however, were the temperature readings, which showed not only that the previous problem of channeling had been solved, but that the exiting gas was now actually too warm. From an initial reading of 300°K, the gas temperatures rose to a maximum of 352°K and then tailed off, at the end of the run, to 220°K. Because the allowable gas temperature range is from 218° to 323°K, the observed temperatures called for adjustments in the flow control system. Minor adjustments were made, but they were not enough, as verified in short runs on 16 and 20 October.*

The NBS now moved the main flow control orifice (see Figure 3) to the heat exchanger line, to direct more of the flow around the heat exchanger. (The internal flow resistance of that unit had apparently been reduced during refurbishing.) A short run on 23 October showed this move to be very effective. The temperature at the 60-s mark was now 45° lower than on the 20 October test, and indicated that temperatures later in the run would stay within the specified range. This was welcome news, as preparations for the 18 November 1980 test at the WSMR were well underway. It was decided that no further adjustments were necessary and that the cryogenic unit could now be interfaced with the AFGL timing and control circuits for one final full-scale laboratory test prior to the actual air launch. (See paragraph 4.3.2.2.)

3.5.5 A SUMMING UP

The preceding paragraphs on the dewar procurement action and on the assembly and testing of the cryogenic unit covered a time span of two and one quarter years (summer of 1978 to fall of 1980). Most of this time was not dead time with respect to other aspects of ALBS system development, however. The decision to proceed with the dewar procurement had triggered a number of about-to-be described corollary actions that were completed successfully and flight-qualified during the same period.

3.6 Parachute-Balloon Interface Redesign

3.6.1 BACKGROUND

3.6.1.1 The Nature of the Interface

The ALBS mid-air deployment scheme (Figure 1) puts the balloon above the main parachute, to minimize stress on the balloon film (1.5 mil polyethylene). To connect the balloon to its gas supply (the cryogenic unit) beneath the main parachute, a long inflation tube (referred to henceforth as the external inflation tube or

*The unsuccessful attempts, on 16 and 20 October, to lower the He gas temperature by fine tuning the flow controls were strongly influenced by the results of the first short run with the refurbished system on 30 September. An anomalous temperature dip noted at the time was assumed, on the basis of previous experience, to be the result of an incorrectly-sized flow restriction orifice. However, when the subsequent runs indicated that changes to the orifice size actually had little effect, it was concluded that the 30 September temperature dip must have been caused by a temporary and undetected malfunction of the heat exchanger valve. (That valve, as previously noted, was adjusted after the 30 September run, strictly as a precautionary measure.) The temperature dip did not reappear but the bias it had created persisted through two frustrating, deadline-oriented weeks of orifice size adjustments.

tubing) is required. It must be lightweight, flexible enough to be packed with the main parachute and able to withstand deployment and parachute opening forces. It must also accommodate peak gas pressures generated during inflation, while offering minimum resistance to gas flow. A key consideration is the manner in which the tubing is positioned up through the lines of the main [42-ft (12.8-m) diameter] ring-sail parachute. Also important is the method of connecting it to the base of the balloon. Unlike ordinary balloons, which are filled through external inflation ducts attached to the gores, the ALBS balloon is filled through its base. Thus, the bottom end fitting of the balloon must serve both as an attachment point for the load which the balloon takes to altitude* and as a gas inlet port, to which the external inflation tube is secured. (An internal inflation tube carries the incoming gas to the balloon's apex.) This leads to a complicated interface between the base of the balloon and the apex of the main parachute. The interface includes not only the external and internal inflation tubes, but also many of the hardware and fabric items attached to or surrounding the main parachute and the balloon. Any major change in the method of connecting the inflation tubes to the end fitting automatically calls for a redesign of the interface.

3.6.1.2 1977 Test Experience; the "Elbow" Design

In the early 1977 parachute system tests at El Centro,[1] a dummy balloon was used. It was made up of 102 ft of double-thickness, nine-ply type XXVI nylon riser material, to simulate the size and weight distribution of the real balloon, less end fittings. A 6-in. (15.24-cm) diameter external inflation tube was also used at that time, constructed of 3-mil (0.0076-cm) lay-flat balloon-grade polyethylene tubing. It was attached to the main parachute's heavy centerline, as shown in Figure 8, and was terminated just below the apex of the parachute, that is, was not connected to the balloon, because no inflation was involved. Under this arrangement, the tubing [about 60 ft (18.29 m) long] withstood deployment forces well. Later, when a real balloon was employed, the same type of tubing was rerouted up a suspension line and over the parachute canopy to the base of the balloon [total length about 100 ft (30.48 m)]. This path was selected to bypass the unexpectedly severe deployment shocks that had been measured at the parachute's apex (see paragraph 3.6.2.2). Unfortunately, the new path necessitated the welding of a large elbow to the balloon's bottom end fitting, that added weight and complicated the balloon-parachute interface (see Figure 9). Partial mid-air inflation of the balloon was attempted twice with this configuration. On the first attempt the external tubing burst as the result of inadvertent over-pressure. The second attempt was doomed by an unrelated event: System recoil damage incurred during extraction from the aircraft (see paragraph 3.7.1). Thus the 1977 flight series ended without ever qualifying the selected

*The balloon's load includes the collapsed main parachute and the real or simulated communications payload.

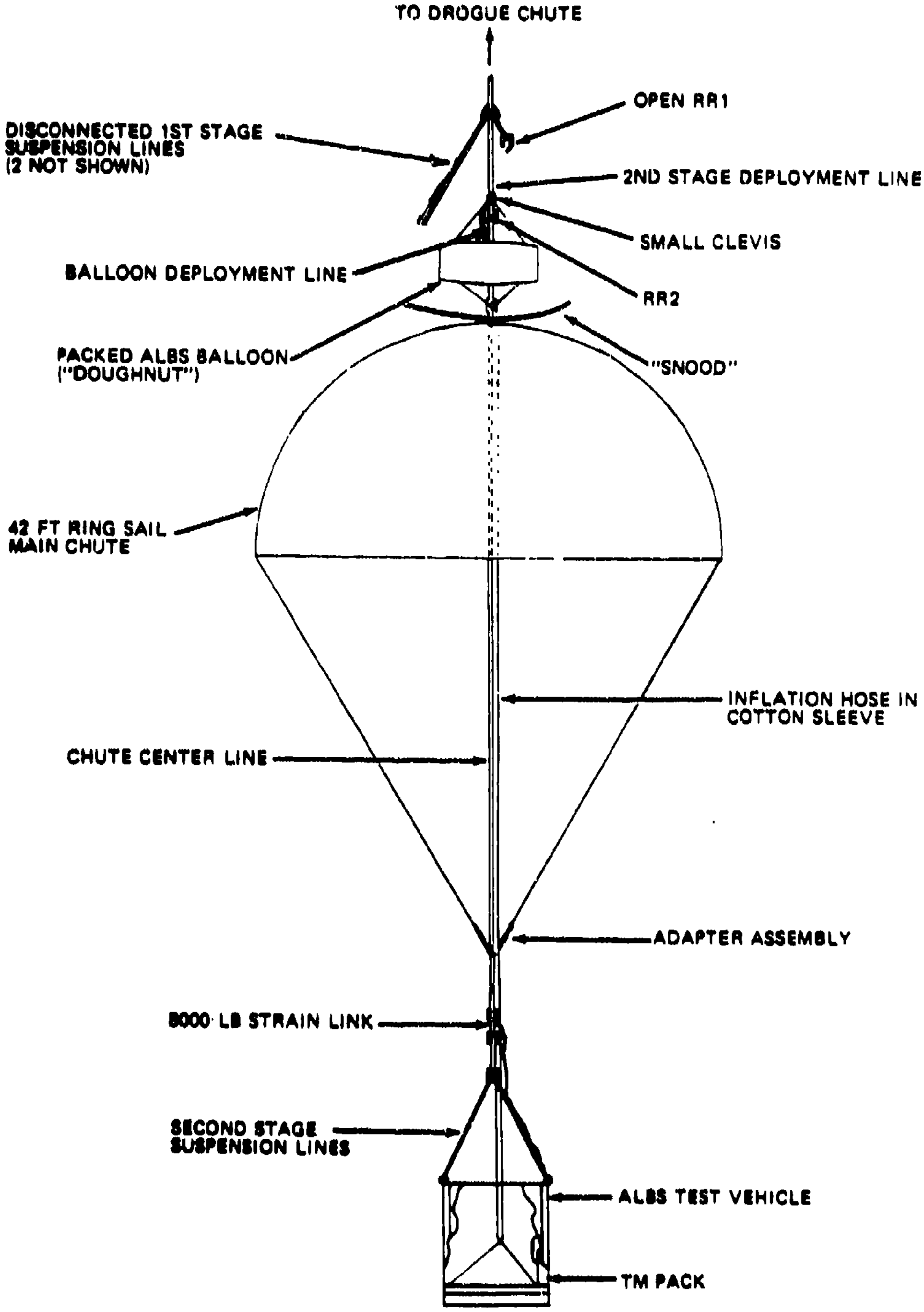

Figure 8. Parachute System Test Vehicle, Second Stage Configuration

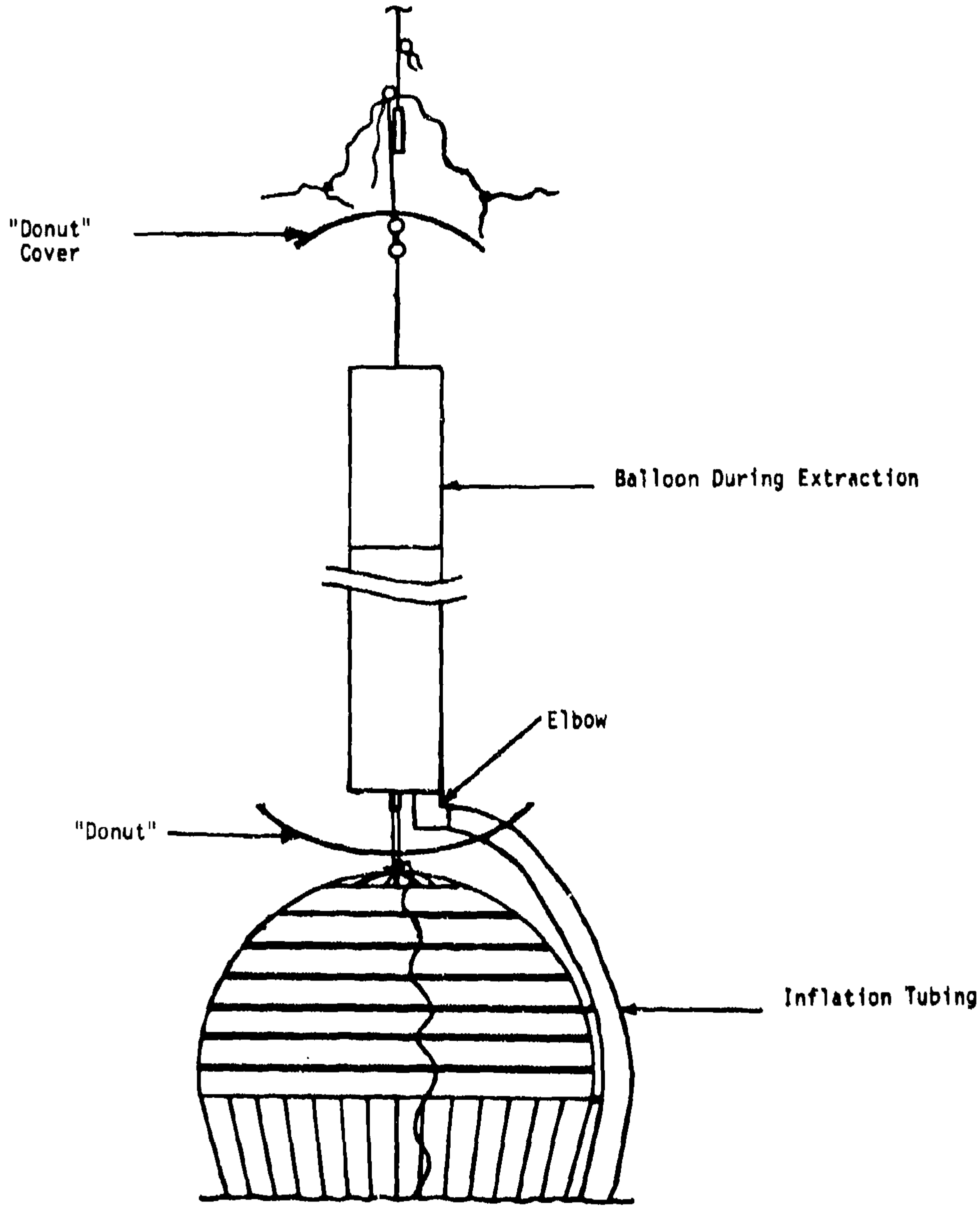

Figure 9. Early ALBS Test Configuration

tubing, even though it had demonstrated adequate strength during several bench tests and in-flight (no inflation) deployments. The indefinite status of the tubing (material, routing, attachment method, etc.) had to be resolved, therefore, as part of the Phase II development effort initiated in 1978.

3.6.2 THE MAIN PARACHUTE/INFLATION TUBING REDESIGN EFFORT

3.6.2.1 A Key Decision

The key Phase II decision in this area was to put the inflation tubing back at the center of the main parachute, per the arrangement of Figure 8. This reduced the length of tubing required to 69 ft (21.03 m) and eliminated the elbow. It also introduced a number of major changes to balloon-parachute interface system components.

3.6.2.2 Changes to the Centerline; Choice of New Tubing Material

With the earlier elbow design, only high-strength fabric and hardware items had to be located in the zone of violence at the main parachute's apex.* Now the fragile tubing would have to pass directly through it, enroute to the base of the balloon. To isolate the tubing from the shock forces, a special dual ring fitting (Figure 10) had to be designed and integrated into the apex area of the main parachute assembly, along with a companion single ring (Figure 11) for the base of the parachute. These new fittings would safely carry the deployment force loads while the inflation tubing floated inside of them. They would also provide attachment points for the main parachute's suspension lines, for centerline extensions to the drogue parachute, for connecting lines to the balloon and its pack above the apex, and for lines to the hardware suspended below the main parachute.

To assure symmetrical shock load distribution, the old single centerline of the main parachute was replaced by a set of four Nylon lines, (type 10, breaking strength = 9000 lb (40 032 N) running between the new top and bottom rings and spaced 90° apart. Loops on the inflation tubing's protective cotton sleeve secured the plastic tubing inside the lines, leaving it free to adjust to dimensional changes in the Nylon (see Figure 12a). In addition, the inflation tubing was fabricated this time from a much stronger but equally light and flexible material, Raven Industries' "RUFCO," a 4-mil (0.01-cm) high-density, oriented and cross-laminated polyethylene film, formed into a 5.4-in. (13.72-cm) diameter tube via a resin-bead overlap seam.

3.6.3 CHANGES TO THE BALLOON CONTAINMENT BAG ("DONUT")

3.6.3.1 Reason for Change

The old off-center (elbow) inflation tube arrangement (Figure 9) isolated more than just the inflation tubing from shock forces. It also protected the material of

*When the main parachute is deployed, and its centerline becomes taut, an exchange of momentum occurs which subjects the heavy load beneath the parachute to 5.4 g and the lighter components at the apex to more than 25 g (see Appendix C of AFGL-TR-78-0074).[1]

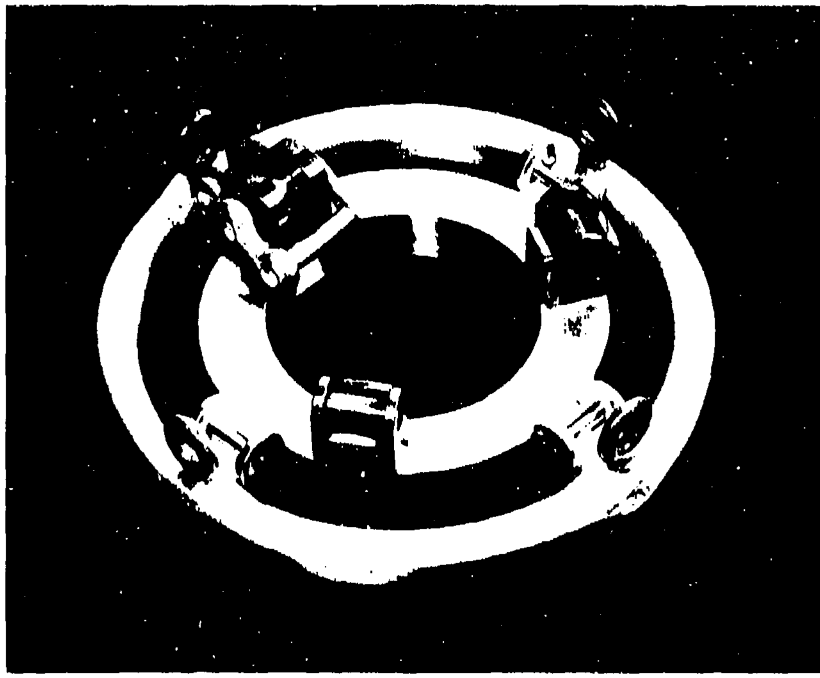

Figure 10. Dual Ring Assembly for Apex of Main Parachute

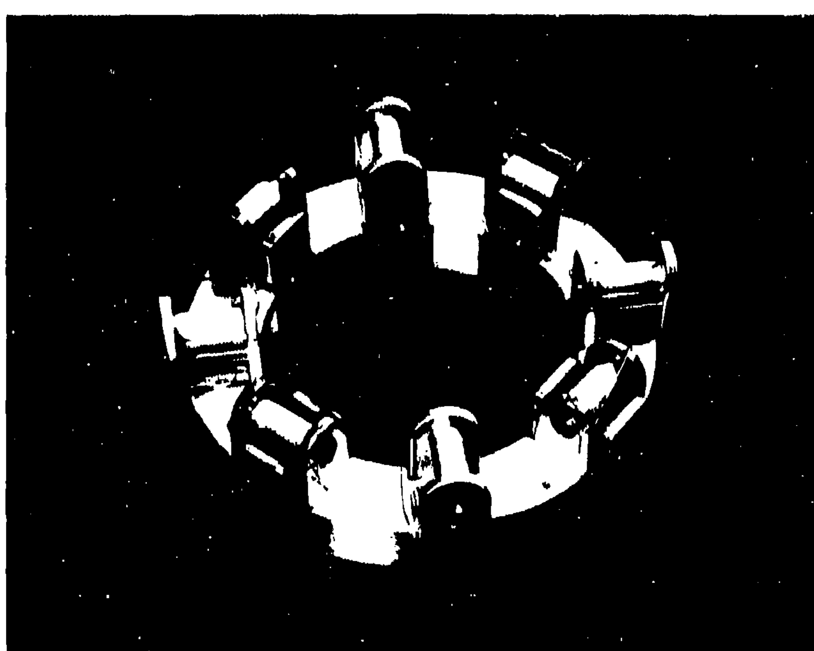

Figure 11. Single Ring Assembly for Base of Main Parachute

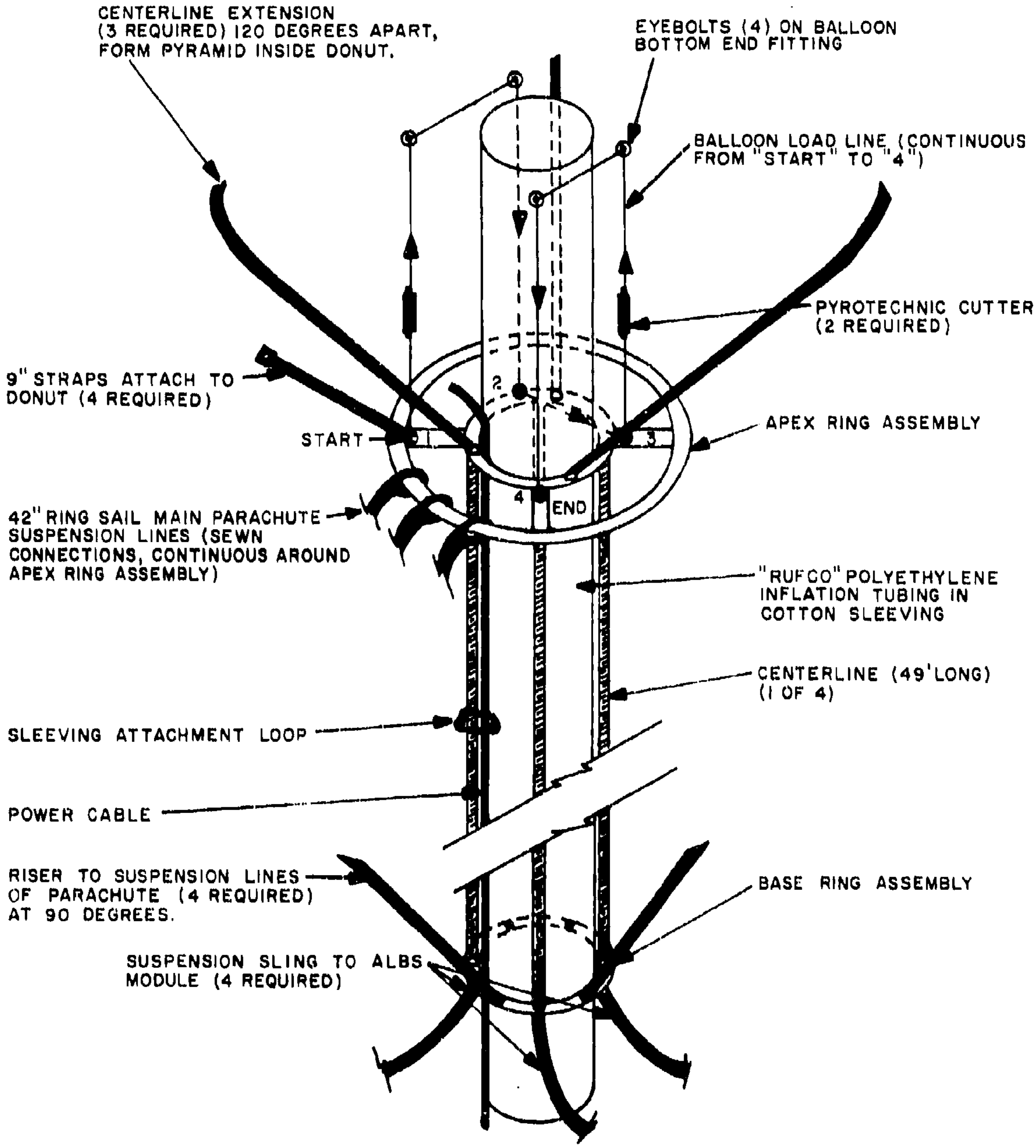

Figure 12a. Four-Piece Center Line Arrangement Inside Main Parachute

the folded balloon. Now, with the elbow gone and the inflation tubing relocated to the center, a new way had to be devised to protect the balloon. This required a modification of the balloon containment bag. It also affected the redesign of the balloon's bottom end fitting. To explain the complexity of the changes it is necessary first to consider the physical dimensions of the balloon and the manner in which it is stored for deployment.

3.6.3.2 The Packed Balloon

The ALBS balloon comes from the manufacturer evacuated and folded into a long flat pack, 1 to 2 in. (2.54 to 5.08 cm) thick, about 15 in. (38.1 cm) wide and 102 ft (31.09 m) long. Except for the 15 ft (4.57 m) nearest the apex, the entire length is enclosed in a 3-mil (0.0076-cm) reefing sleeve, with a 1-mil (0.0025-cm) tear panel. The reefed assembly, in turn, is sealed in a protective red polyethylene sleeve and is S-folded into its shipping box. Two cast aluminum ring-shaped fittings,* approximately 18 in. (45.72 cm) in diameter (drawing B10104), have been attached at the factory, one at the apex and one at the base of the balloon. [The apex fitting accommodates the required EV-13 He valve and strobe light assembly and the lines (with cutters) to the drogue parachute (see Figure 12b); the base fitting accommodates the ALBS bottom end fitting assembly (see paragraph 3.6.3.4), the internal and external inflation tubing, and the lines to the apex of the main parachute].

When the balloon is being readied for an air-launch mission, it is removed from its shipping container and stretched out on a long parachute table. The apex and base hardware items are added to the ring fittings and the protective red wrapping sleeve is removed. The balloon is then S-folded once more, this time into its special canvas in-flight containment bag, nicknamed the "doughnut" or "donut"[3] because of its original toroidal shape (see paragraph 3.6.3.3). As a final step, the donut cover is laced in place. The packed balloon assembly is now ready to be joined to the packed main parachute and placed in the ALBS module's upper box section. Later on, after mid-air deployment of the main parachute, the balloon pack is supported temporarily at that parachute's apex (see Figure 13). Then the donut cover is removed and the balloon is pulled out vertically by the action of the drogue parachute (see Figure 9). The manner in which the balloon has been folded is critical to the success of this step: The S-folds have to be removed without snags or twists.

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*Figure 20, which appears later in the report, depicts one of these castings.

3. Massey, W.N., and Wuest, M.R. (1978) Air Launched Balloon System, AFFTC-TR-42.

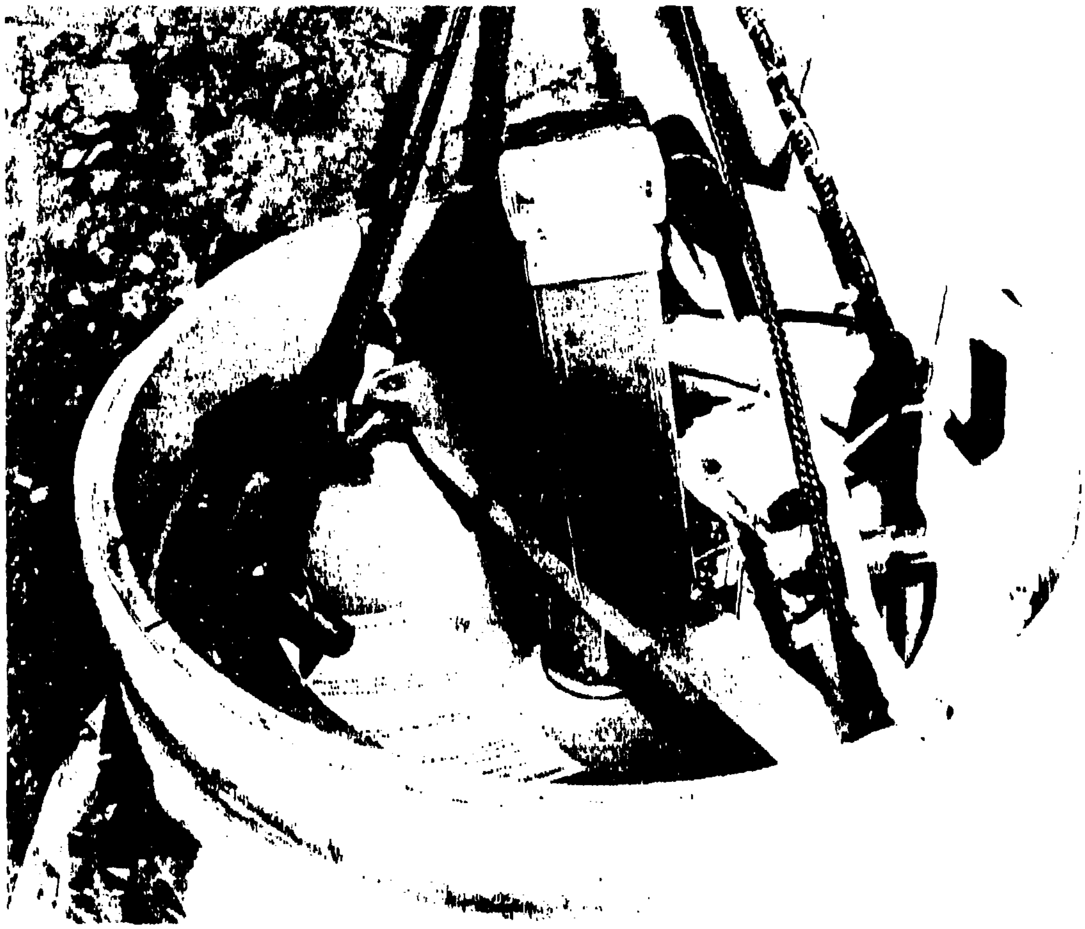

Figure 12b. Balloon Apex Components (EV-13 Valve Housing Displaced by Landing Impact)

3.6.3.3 Evolution of the Toroidal Shape

From the requirement for precise folding of the balloon there evolved the idea of a toroid, that is, a large pumpkin-shaped canvas container with a hollow fabric centerpost (see Figure 14). The centerpost would allow the load-carrying centerline extension to go from the apex of the main parachute to a point above the donut, thus isolating the carefully folded balloon, which would occupy the volume surrounding the centerpost, from the powerful main parachute deployment forces. The original donut was designed to this concept by the AFFTC and was used very successfully in the early dummy balloon tests at El Centro, in 1977. In the later tests, with a real balloon, the donut was modified slightly to accommodate the bulky end fittings. The principal change was to reduce the diameter of (but not eliminate) the centerpost and to increase the interior volume. It was at this time, incidentally, that the inflation tubing routing was also changed (to over the canopy) and

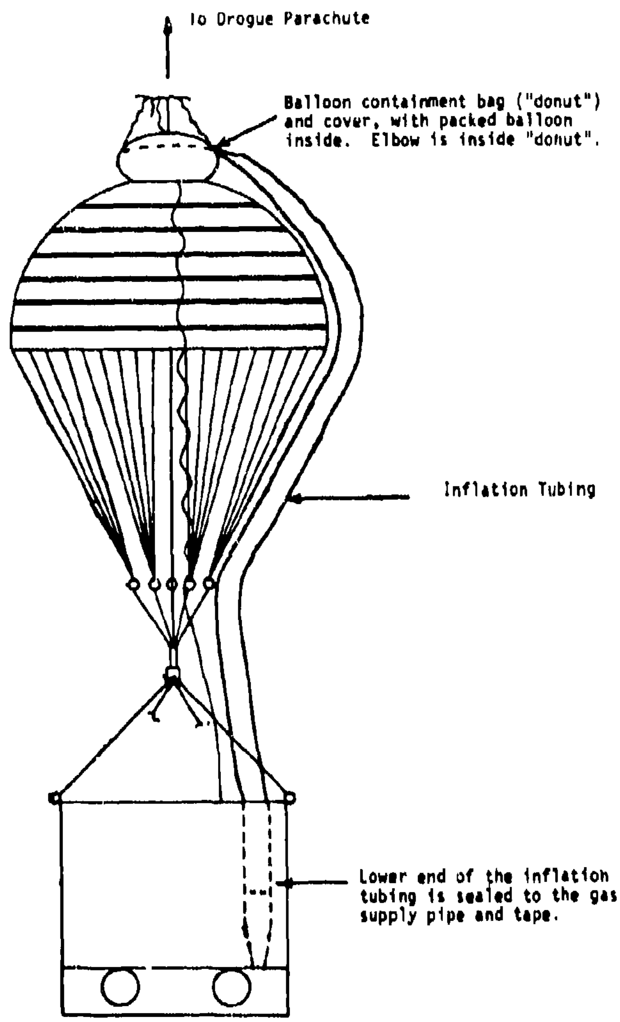

Figure 13. Positioning of "Donut" at Apex of Main Parachute

the elbow was added to the balloon's bottom end fitting (see paragraph 3.6.1.2). The inflation tube could now be brought into the donut from the side, through the laced seam where the donut and its cover are joined (see Figures 13 and 15). This off-center arrangement was vulnerable to twisting, however, and that led to the addition of a steel "No-Twist-Link" (NTL) to connect the balloon to the main parachute (see Figures 15 and 16). Because the suitability of the elbow arrangement was unproven and very questionable, it was abandoned when plans were made for Phase II. This, plus the decision to put the inflation tubing back at center, meant that radical changes were in store for the donut.

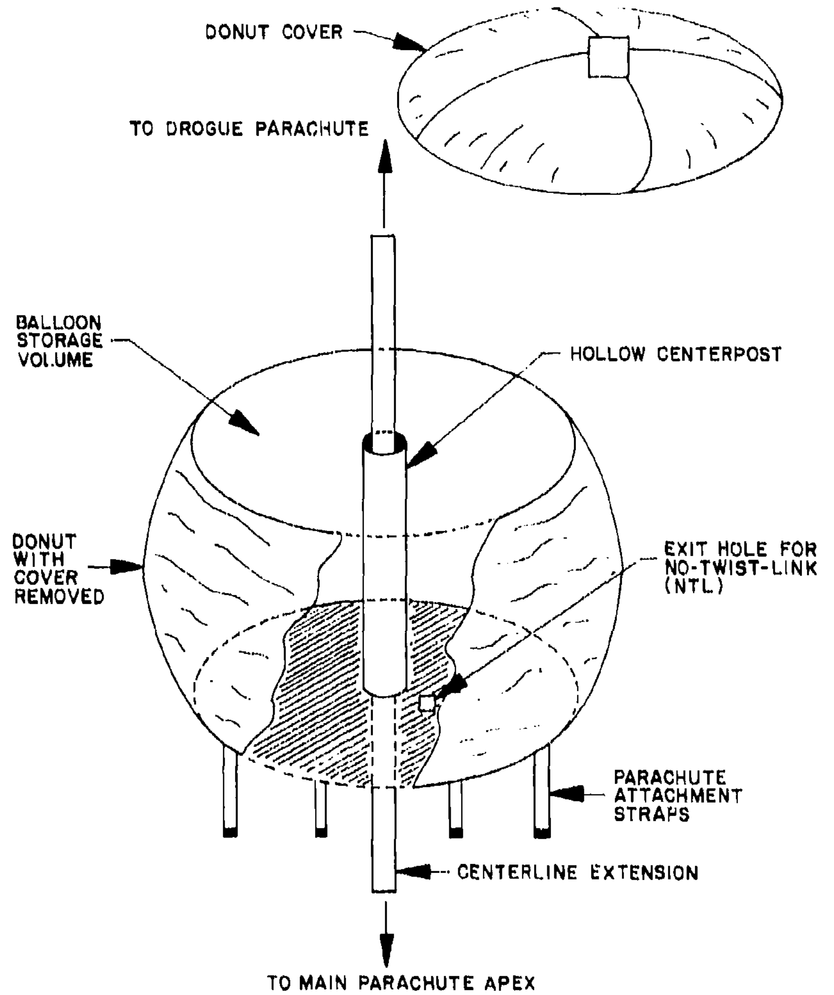

Figure 14. Outline of Original ALBS Balloon Containment Bag ("Donut")

3.6.3.4 Relocation of the Gas Port; A Pyramid to Replace the Centerpost

Figure 15 shows the off-center, angular positioning of the original bottom end fitting, with added elbow, in the Phase I donut. Note that there was no interference with the centerpost and that the NTL passed through the base of the donut in its own reinforced exit hole. (The bottom ends of the NTL and the center line

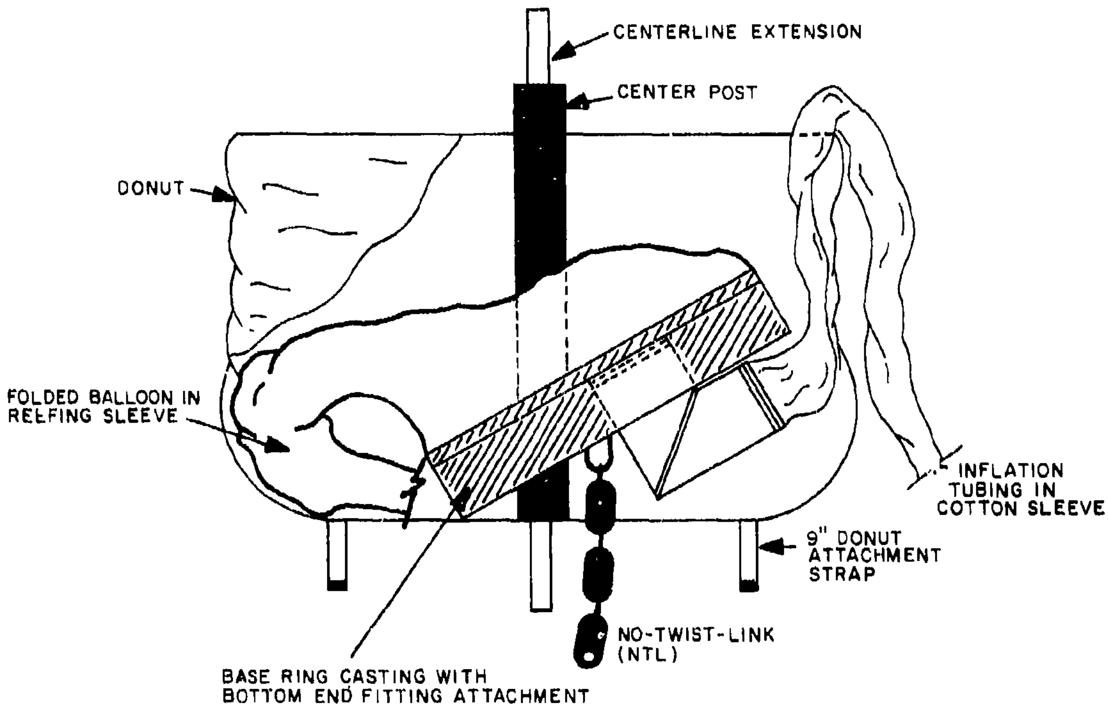

Figure 15. Orientation of Phase I Bottom End Fitting (With Elbow) Inside Original "Donut"

Figure 16. No-Twist-Link (NTL)

extension were attached to the clevis at the apex of the main parachute.)* Portraying still another detail of the Phase I interface, Figure 17 shows the locations of the elbow-shaped gas inlet port (off center) and the load bolt (dead center) in the bottom end fitting.

Figure 17. Phase I Balloon Bottom End Fitting, With Elbow

The above arrangements were unsuitable for Phase II. The new inflation tube would have to convey the gas through the center of the bottom end fitting, which, in turn, would be positioned flat over a new hole in the center of the donut. Two decisions followed. First, the balloon load would be carried by four smaller eyebolts, 90^{o} apart (see Figure 18); second, the hollow centerpost in the donut would be eliminated. How was the balloon material to be isolated from shock forces

*In the original design the center line extension carries the shock load experienced during the deployment and opening of the main parachute, which occurs 10 s after the ALBS module leaves the aircraft. Ten seconds later that line's connection to the drogue parachute is severed and it becomes slack. The balloon deployment line (see Figure 9) then removes the donut cover and starts to pull the balloon out. When the balloon is fully extended the donut collapses. The NTL, also shown on Figure 9, is now the sole load-bearing link between the balloon and the main parachute and payload, until the balloon flight is terminated. Thus, both the center line extension and the NTL were vital parts of the original system and had to be accounted for in any redesign.

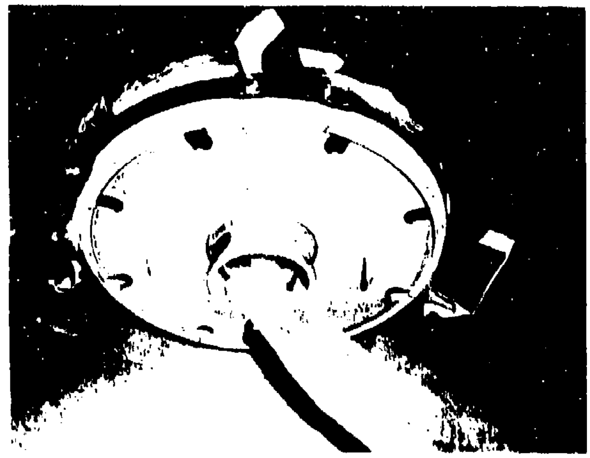

Figure 18. Phase II Balloon Base Assembly, Bottom View

then? The answer lay in the dual ring assembly discussed in paragraph 3.6.2 and illustrated in Figure 10. The shock forces would travel up the four-piece centerline assembly (Figure 12a) to the dual ring. From there they would go around the base of the balloon on three extension lines, spaced 120^{o} apart and fed through holes in the base of the donut. These lines, coming together above the donut at a breakaway link connection to the drogue parachute, would constitute a pyramid (see Figure 19). This would be the functional equivalent of the old centerline extension inside the hollow centerpost. Thus, the shock loads would be carried up through the center of the donut as before, with the balloon (folded in the space surrounding the pyramid) isolated from the shock. A wrap-around layer of muslin (nicknamed the "teepee" and not shown in Figure 19) would cover the pyramid, to keep the actual load-carrying lines out of contact with the surrounding balloon material. At the same time, its flap would give the reefed balloon an exit into the interior volume of the donut.*

3.6.4 REINFORCEMENT OF THE BASE CASTING

The new pyramid assembly was described above as the functional equivalent of the earlier centerline extension. Actually there was one major difference: The centerpost design isolated both the balloon material and the hardware at the balloon

*By examining the background of Figure 19 the reader can see the reefed balloon extending away from the base and up into the shipping box. This is indicative of the path the balloon would follow inside the donut, that is, it would go out of the interior space of the pyramid (through the teepee's flap) and then double back into the donut's storage volume. A series of S-folds would stack the balloon layers up evenly around the compressed pyramid. The balloon's apex fitting would be at the top of the stacked folds, ready for connection to the balloon deployment line.

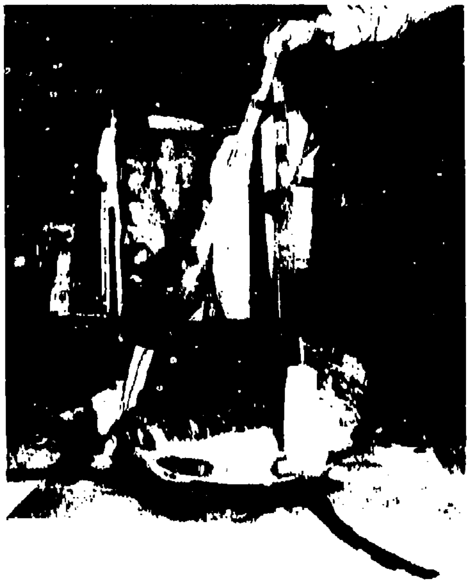

Figure 19. Phase II Balloon Base Assembly, Top View, Showing Pyramid Straps

base from the deployment shock; the pyramid design isolates only the balloon material. The base hardware is subjected, therefore, to the 5.4-g deployment shock (see paragraph 3.6.2.2). This equates to a force of 10,000 lb (44,480 N) to 11,000 lb (48,928 N), transmitted via the four-piece centerline and its 3-legged extension, the pyramid. If each extension leg carries one-third of the load, say 3500 lb (15,5[illegible]8 N), at an angle of 45° from vertical, there is a horizontal component of 0.707 × 3500 or 2474 lb (11 004.35 N) directed against the base hardware in each of three places.

Figure 20 shows the empty ring casting, with the base of the severed balloon still attached. Figure 21 shows the Phase II bottom end fitting which is to be secured, with the gas inlet port pointing down, to the internal flange of that casting. This arrangement leaves the lower part of the casting without any reinforcement against hoop stresses. Thus, when stress analyses* showed that the casting might crack, under the three-point distribution of deployment forces introduced by the pyramid design, a notched aluminum disc was added for reinforcement. This, in turn, required the extension of the gas inlet port to permit installation of the

*A certain amount of damage to the base of the donut was noted at El Centro in 1977.[1] This lead to reinforcement of the base. It is certain that some of the deployment shock force is transferred to the packed donut by the four short 9-in. (22.86-cm) straps that connect the donut base to the parachute apex(see Figure 14). The percentage has not been determined, however, and hoop stresses were calculated on the basis of 100 percent loading of the pyramid straps.

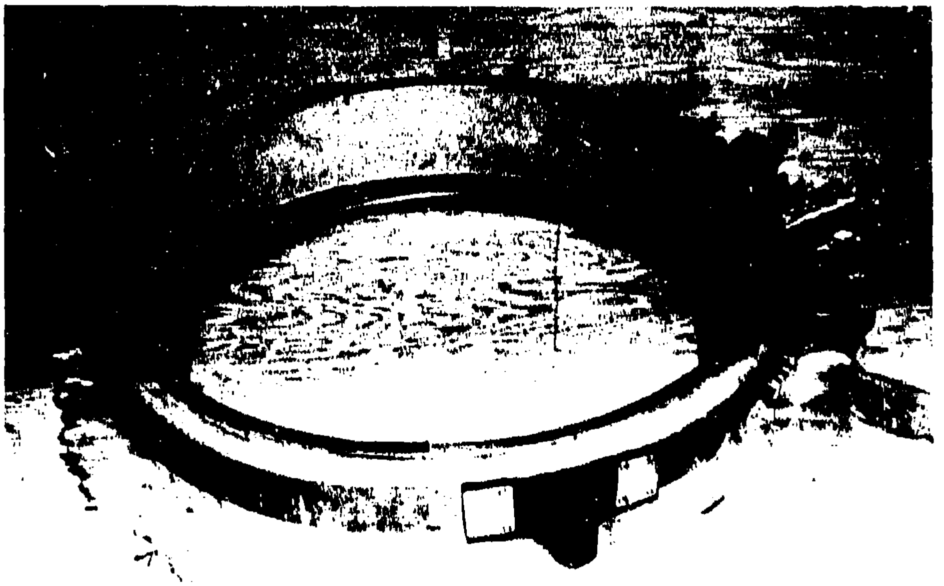

Figure 20. Ring Casting Used at Base of Balloon (Identical to One Used at Balloon Apex)

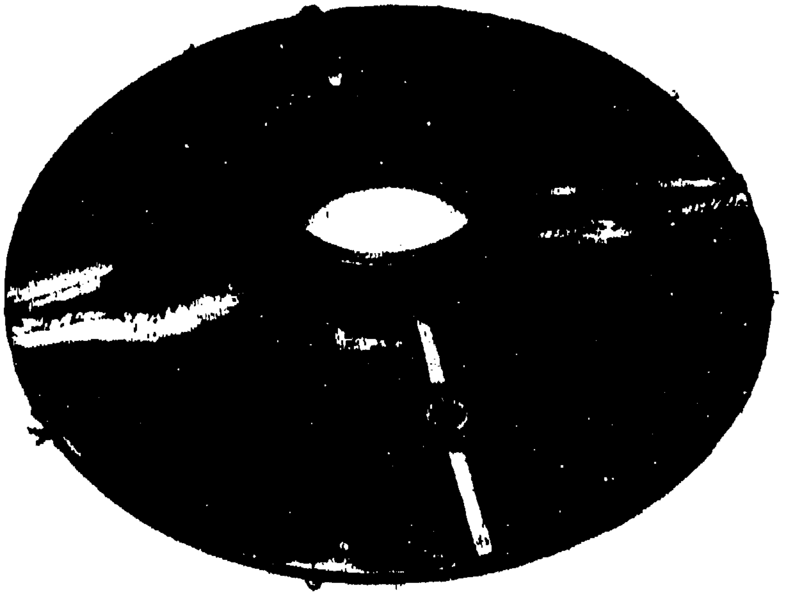

Figure 21. Phase II Balloon Bottom End Fitting, With Center Port

inflation hose (see Figure 18). The notches, incidentally, were made in the disc to allow the bottom end fitting and the disc to be preassembled and then installed as a unit in the base casting.

A circumferential band assembly with three reinforced loops at 120° intervals was also added to the base casting, over the balloon material, to keep the pyramid straps properly separated. The band, made of 1.5 in. × 0.032 in. (3.81 cm × 0.08 cm) stainless steel, was secured to the base by a turnbuckle (see Figure 20). The attached 0.5-in. (1.27-cm) felt padding and muslin sleeves, which keep the pyramid straps out of contact with the material at the base of the balloon, appear in Figure 19.

3.6.5 REVISIONS TO THE BALLOON LOAD LINE

The last item in the Parachute/Balloon Interface Redesign effort was the balloon load line. This line must be strong enough to support the collapsed main parachute and the communications payload during the actual balloon flight. It must also be capable of being cut on command at the termination of that flight. (At termination, the collapsed parachute would partially or fully reopen and would serve as the recovery parachute for the payload.)* The NTL used earlier as the balloon load line (see paragraph 3.6.3.3) was not appropriate for Phase II, because of the four-point load-carrying arrangement on the new balloon bottom end fitting, and was replaced by a looped cord.

Figure 22 depicts the overall interface configuration which resulted from the changes discussed in the preceding paragraphs. The new balloon load line [2400 lb (10675.2 N) nylon braid] is identified on the figure as the Payload Support Line. It is a continuous line, going from an eyebolt on the parachute apex ring to a corresponding eyebolt on the balloon's bottom end fitting, thence between the donut base and the end fitting to a second eyebolt on the end fitting, thence down to a second eyebolt on the apex ring, etc., until all eight eyebolts (four on the apex ring, four on the bottom end fitting) are connected. The vertical section of the payload line is shown folded and tied with a light break line, to match the length of the 9-in. (22.86-cm) donut attachment straps. This is the preflight picture. When the balloon is deployed in mid-air, the 9-in. (22.86-cm) straps serve only to retain the empty donut. Each leg of the payload support line then unfolds to a 24-in. (60.96-cm) height. Two of the legs have pyrotechnic line cutters attached, to provide a redundant balloon/parachute separation system controlled by UHF/HF

*There was some discussion about whether the centerlines should be cut to ensure that the main parachute would reopen fully after balloon flight termination. It was calculated, however, that even if only one half of the drag area of the 42-ft (12.8-cm) ring sail parachute were available, it would still provide enough deceleration for safe recovery of the 200-lb (889.6-N) communications package. The centerline cutting suggestion was not pursued further, to avoid unnecessary additional complexity.

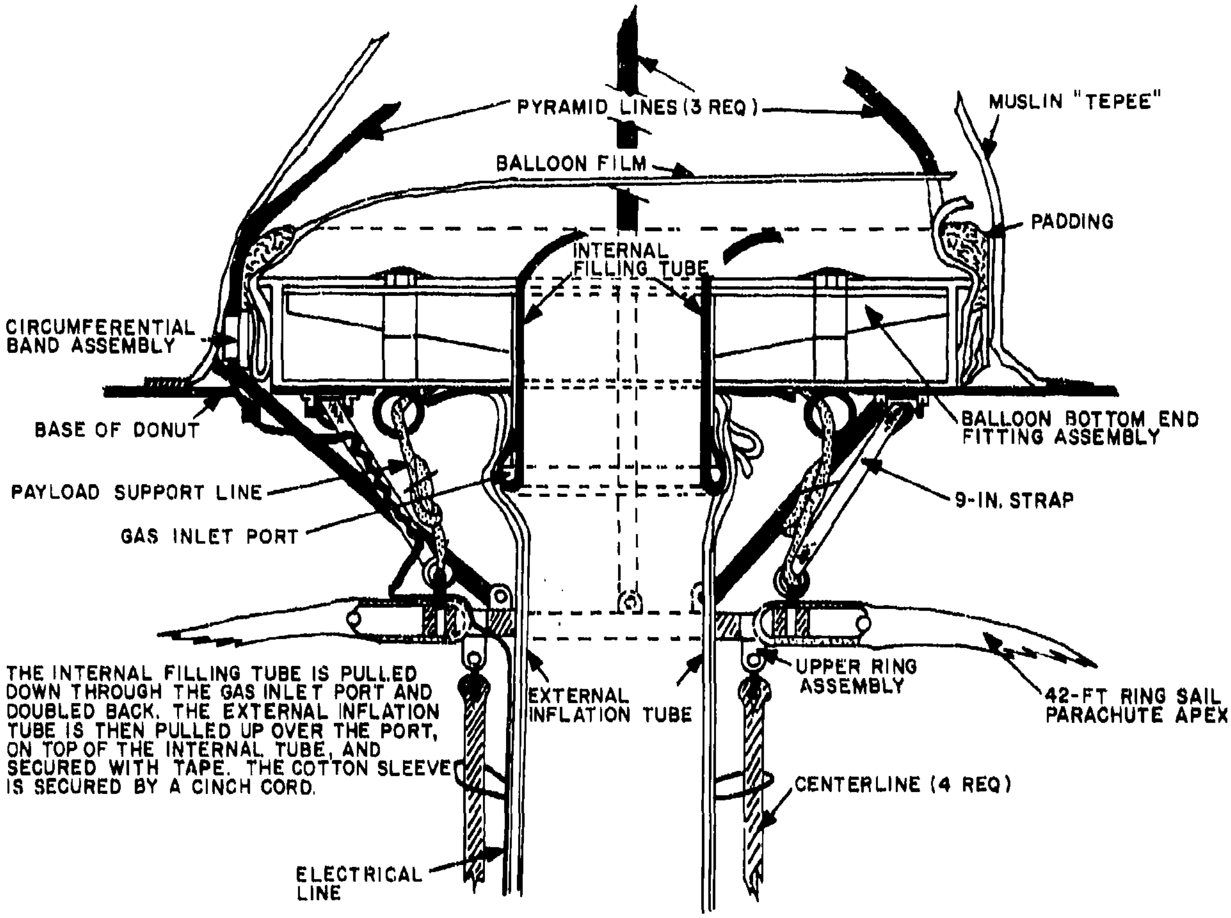

Figure 22. ALBS Balloon-Parachute Interface

commands (see also Figure 12a). The balloon rip panel cord, not shown in Figure 22, is also part of the interface and is attached to an eyebolt on the apex ring of the parachute. It is severed by a lanyard-operated, delayed-action cutter after it has ripped out a designated balloon panel at flight termination.

3.6.6 AN OVERVIEW OF REDESIGN

The preceding lengthy discussion of the parachute/balloon interface redesign effort indicates that it was a complicated process requiring many hours of engineering discussions and planning and necessitating the fabrication of a number of new components. The functional success of the endeavor is described in Section 4, where the Phase II full-scale flight tests are covered. One disappointing aspect of the effort was the weight penalty associated with the new hardware. Although the balloon assembly weight stayed about the same, the parachute assembly gained 24 lb (106.75 N), which effectively reduced the useful payload of the balloon system by that amount. This area is a prime candidate for weight-reduction engineering in any follow-on system.

3.7 Parachute Subsystem Refinements

3.7.1 BACKGROUND

On the last flight of the 1977 ALBS test series at El Centro the main parachute was prematurely deployed as the system was leaving the aircraft. Severe damage was experienced by that parachute and by the balloon, and the test was a failure. Although the same extraction technique had been used successfully in prior tests, this failure showed that the technique's reliability was only marginal. If the program were to be continued, reliability had to be improved. The built-in time delay caused by the procurement of the new hardened dewar offered an opportunity to conduct diagnostic flight tests at the AFFTC directed towards solution of the extraction problem. The opportunity was seized, with gratifying results, as will be described.

3.7.2 NATURE OF THE PROBLEM

At the start of the extraction sequence, under the 1977 test configuration, a pendulum release mechanism casts the 28-ft (8.53-m) ring slot parachute pack into the airstream behind the C-130. One end of the 200-ft (60.69-m) extraction line remains attached to the ALBS module; the remainder of the line is deployed as the pack drifts aft. When the line is fully extended the parachute is pulled from the pack, lines first. At line stretch, a 2000-lb (8896-N) force spike occurs. As this force develops, the tie cords on the first stage suspension lines are broken. The first stage suspension line pyramids are then formed, with the 10-s time delay, pyrotechnically-operated radioplane release No. 1 (RR1) at the lower apex. (Figure 23, which shows the system oriented vertically, can be used to identify the components mentioned. It is to be remembered, however, that the system is oriented horizontally during the extraction mode.) Finally, the lines restraining the ALBS module in the aircraft are broken. As the module starts to move out* the force in the extraction line momentarily drops almost to zero (see Figure 24). Line recoil now causes the pyramids to retract, drawing the radioplane release back into the front end of the module. Then, as the parachute begins to open, the extraction line becomes taut again and the pyramids are reformed with the release at the lower apex once more. However, because the parachute has descended below the height of the aircraft, the developing force has a downward component. In October 1977 this component apparently caused the release to strike the bottom of the module on its way out again, thereby initiating premature staging.

*This is time zero, t_0, in the ALBS deployment process.

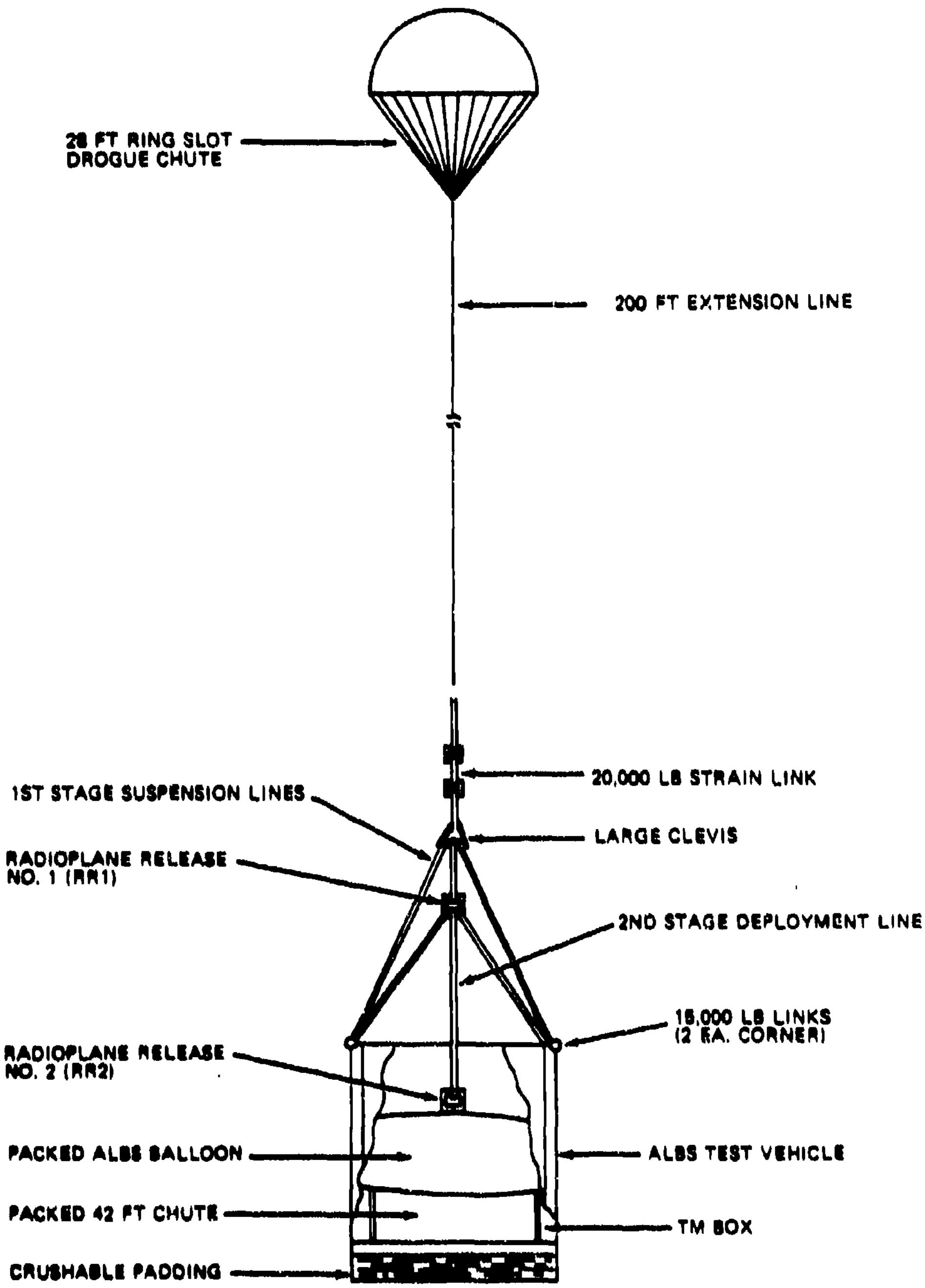

Figure 23. Parachute System Test Vehicle, First Stage Pyramids

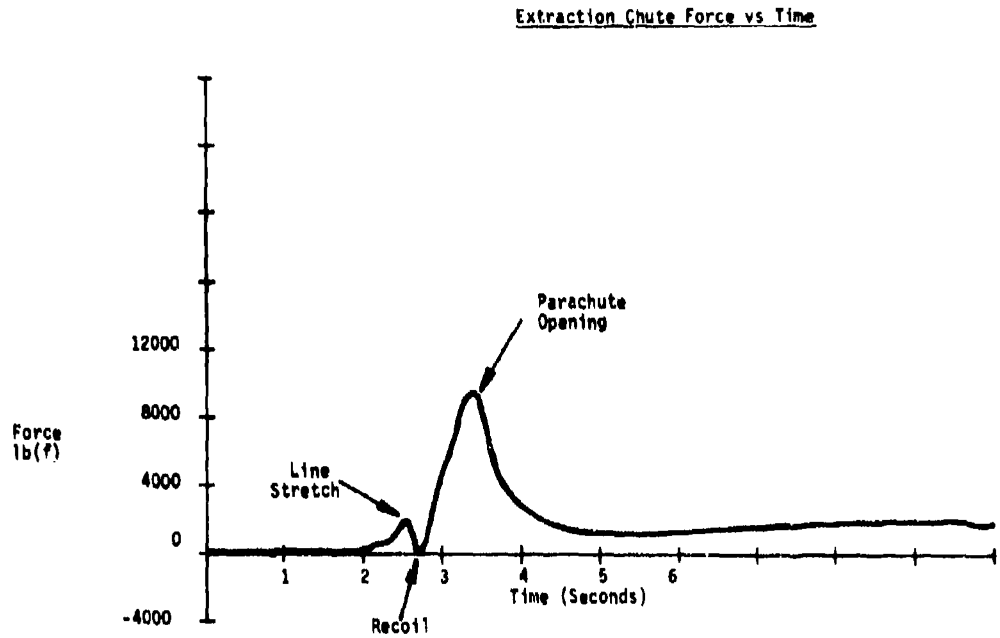

Figure 24. Extraction Chute Force vs Time Graph

3.7.3 THE ATTACK ON THE PROBLEM

Two radically different remedial approaches were considered. One was to remove the radioplane release from the apex of the first-stage pyramid and to use an array of four releases instead, with one release secured to each corner of the module. Under this method no release could be slammed against the module at line recoil. Detailed analysis and limited testing (in early 1979) showed this approach to be too costly and cumbersome, however. Thus, efforts were concentrated on the second approach, recoil elimination.

3.7.3.1 Changes in Tie Strength

It was reasoned that recoil could be reduced significantly if the velocity difference between the aircraft and the decelerating parachute pack could be decreased at line stretch. To achieve this, a change was necessary in the strength of the numerous individual ties used on the 200-ft (60.96-m) line. In the 1977 configuration, this line is folded into six tiers when stowed in the parachute pack. Each tier has 30 ties, each consisting of a single turn of "3" cord [effective breaking strength: 20 lb (88.96 N)]. Three different tie strengths were now chosen to test the decreased-velocity approach:

a. Two turns of "3" cord; effective breaking strength: 40 lbs (177.92 N)

b. One turn of 80-lb cord; effective breaking strength: 80-120 lbs (355.84-533.76 N)

c. Two turns of 80-lb cord; effective breaking strength: 160-240 lbs (711.68-1067.52 N).

C-130 parachute tow tests were conducted by the AFFTC at 10,000 ft (3.05 km) at Edwards AFB on 10 April 1979 to measure the forces developed with the tie options described above. As it turned out, option "a" was clearly ineffective in reducing the snatch force. In the case of option "c", the ties were so strong that the parachute covers were not opened. Option "b" (tested twice) appeared at first to have reduced recoil action. Additional analysis of the test data showed that the change to 80-lb cord had not made any significant difference, however.

3.7.3.2 Addition of a 5-ft RGS Parachute

A new approach was then pursued wherein the ties were specified as single turns of 80-lb cord throughout. The extraction line's strength was increased from 12,000 lb (53376 N) to 15,000 lb (66720 N) and its length was decreased from 200 ft (60.96 m) to 180 ft (54.86 m). Two components were attached in a "V" configuration at a clevis secured to the end of the extraction line:

a. A 20-ft (6.1-m) extension line, connected to the parachute pack

b. A small [5-ft (1.52-m) diameter] ribless-guide-surface (RGS) parachute. In theory, this parachute would open at the time of line stretch and would produce steady drag on the main line, thus inhibiting recoil. It would not interfere with the opening of the 28-ft (8.53-m) extraction parachute.

On 28 June 1979 two weight bomb tests were conducted successfully from a C-130 flying at 10,000 ft (3.05 km) over Edwards AFB. The force trace showed the the previous sharp spike had been eliminated. The peak force at line stretch had increased from 2000 lb (8896 N) to about 2600 lb (11564.8 N) but this was offset by the fact that the force, as it decreased, leveled off gradually to 1520 lb (6760.96 N), thus assuring continuous tension on the extraction line. This appeared to solve the problem, a conclusion substantiated by later full-scale flight tests (see Section 4).

3.8 Development of a Four-Point Release System

3.8.1 NATURE OF THE PROBLEM

When the mid-air inflation of the ALBS balloon is completed, 340 s after the system leaves the aircraft, the 12 ft (3.66 m) long module must be dropped away. This separation is necessary to release the balloon for ascent to float altitude with its payload. (The drogue parachute will already have been cut loose, at t_0 + 180 s.) The residual items — the empty upper module section and the still joined lower cryogenic unit section — must now be recovered on the lightweight 100-ft (30.48-m) diameter triconical parachute stored in the upper section. This separation/recovery function was not qualified during Phase I because: 1) It was not included in the 1977 El Centro test configuration (no full-scale inflations were scheduled at El Centro); and 2) The launch mishap in January 1978 (see paragraph 1) ruled out any trial of the release arrangement planned for the balloon drop. Moreover, during Phase II planing, it was not possible to build on the untried January 1978 single-point separation scheme, because of the changes made in the main parachute's centerline (see paragraph 3.6.2.2). Innovation was necessary, therefore, to arrive at a workable separation arrangement.

3.8.2 DESIGN CONSIDERATIONS

Figure 23 shows that, under the Phase I configuration, the ALBS module is initially secured to the drogue parachute extension line by a four-sling pyramid arrangement (first-stage suspension lines), with each sling starting at the large clevis, passing downward through a 15,000-lb (66720-N) link and then upward to a single attachment point, RR1. When lanyard-initiated RR1 fires, the slings are released and the main parachute is deployed, as shown in Figure 8. The four top corners of the module are now attached, via a new pyramid of slings (second stage suspension lines) to the adapter assembly shown at the base of the main parachute. However, the new four-piece centerline chosen for Phase II (Figure 12) made the adapter assembly obsolete and it had to be replaced by a ring assembly. [The 8000-lb (35584-N) strain link of Figure 8 was also eliminated.] The new parachute base ring assembly is shown in Figure 11. Its top side has attachment points for four parachute risers and for the four center lines stretching above it to the apex of the parachute. The bottom side's four attachment points are for the slings to the module, an arrangement which complicates the separation process. To overcome the difficulties presented by the new suspension configuration, the Phase II design team selected an electrically-fired array of releases capable of separating all four slings simultaneously from their respective module corners.

3.8.3 THE SOLUTION

The system that materialized was the result of joint planning, with much of the component engineering accomplished at AFGL. The standard Tenney release mechanism, commonly used on balloon flights, was redesigned to suit this application and to accept dual-bridge power cartridges instead of the usual explosive squibs. In addition, a timer-controlled firing circuit was made up to apply power simultaneously to the four cartridges at the proper time. The new releases and firing circuits were assembled to the ALBS test vehicle at Edwards AFB (Figure 25) and tested successfully twice on the ground in October 1979. A month later they were used in the AFFTC "dress rehearsal" flight test of the full-scale ALBS system model (see paragraph 4.2.2). They withstood all deployment shocks and they effected a clean dropping away of the module at the appropriate moment. The

Figure 25. Tenney Release on ALBS Test Vehicle Frame

four-point release system was thus considered qualified for the planned full-scale ALBS test involving the cryogenic inflation system.

3.9 Command, Control, and Telemetry (CCT) Subsystem

3.9.1 INTRODUCTION

In the preceding discussion there were several references to ALBS event times: t_o + 340 s, t_o + 10 s, etc. There was almost no mention, however, of the methods used to start the events at the designated times. The complicated command and control subsystem, which had to be developed at AFGL to initiate and terminate ALBS functions precisely and positively, will now be described in some detail.* As will be noted, this subsystem was given an additional telemetry capability, to furnish project personnel with real time information on cryogenic unit performance and on system flight parameter status, hence the designation "Command, Control, and Telemetry (CCT) Subsystem."

3.9.2 DESIGN OBJECTIVES

Besides its primary task of controlling and monitoring the performance of the cryogenic unit during balloon inflation, the CCT subsystem was assigned the equally important function of controlling the subsequent balloon flight. The equipment to perform both of these tasks was to be incorporated into a single package

*See paragraph 4.5 for a discussion of actual performance of the CCT subsystem.

that would be attached to the base of the main parachute and which would constitute the simulated ALBS payload on the full-scale WSMR test.*

The resultant CCT subsystem pack (Figure 26) was made up of removable rack-mounted components. The racks were housed inside a rugged, styrofoam-insulated Aluminum frame which protected them against both ALBS deployment shock loads and cold-soak conditions at 70,000 ft (21.34 km). Overall dimensions were approximately 25 in. × 24 in. × 28 in. (63.5 cm × 60.96 cm × 71.12 cm). Four (4) shoulder eyebolts [1/2-in. (1.27-cm) shank diameter] were added to facilitate removal of the pack from the box above the cryogenic unit at the

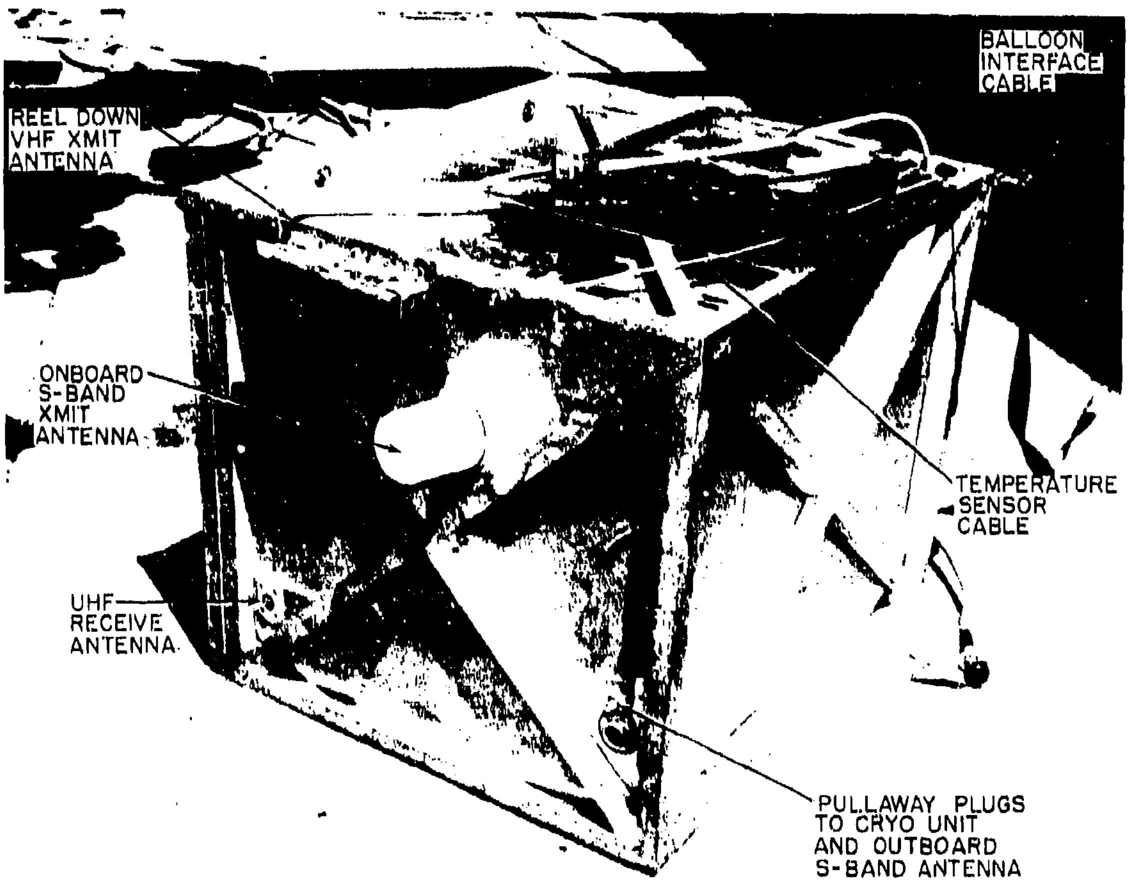

Figure 26. Command, Control, and Telemetry (CCT) Subsystem Package (eyebolts are hidden from view)

*The "single package" configuration was modeled after the CCT pack used in the January 1978 test.[1] Its use in Phase II was dictated by test convenience. Actually, many of the components of the CCT package can remain with the cryogenic unit. Presumably, the flight-control hardware remaining with the balloon in any real application of the ALBS would be kept at a minimum.

completion of the balloon inflation process.* The basic pack weight was approximately 180 lb (800.64 N). With ballast it could be increased to 200 lb (889.6 N), to simulate the communications payload more fully.

3.9.3 EXCLUDED FUNCTIONS

Certain events, associated principally with the extraction of the ALBS module from the launch aircraft, with the deployment of the main parachute and with the extraction of the balloon from the donut, are not controlled by the CCT subsystem. Rather, they are initiated sequentially and automatically through the action of an array of AFFTC-supplied lanyards and delayed-action explosive releases and cutting devices. For example, when the ALBS module leaves the C-130, a lanyard is pulled which activates the 10-s delay cartridges in RR1 (see Figure 23). When RR1 fires, and the main parachute is deployed, more lanyards are pulled to cut various lines and to initiate balloon extraction, all after specified time delays of 4 to 10 s. These systems are described in AFFTC-TR-77-42.[2]

3.9.4 THE TIMER

The heart of the CCT subsystem is a solid-state timer that controls the operation of the cryogenic unit by sequentially applying electrical power to and removing it from the solenoids of the unit's gas-actuated valves, per Table 1.†

The timer also controls the release of the drogue parachute,‡ the firing of the four Tenney releases at the end of inflation, and the release of the 40.350-MHz VHF antenna required later for transmission of balloon flight data (see Figure 27). Although the timer is the primary control for the functions listed on Table 1, it is

*When the four Tenney releases fire at t_o + 340 s, per Table 1, the pack is pulled upward out of the box and is taken to balloon float altitude at the base of the 42-ft (12.8-m) main parachute. At the end of the flight the balloon is cut away and the CCT pack descends on the main parachute.

†The reader should refer back to Figure 3 to identify the valves listed on Table 1. In general: 1) The <u>pressurization valve</u>, in conjunction with the pressure regulators, controls the <u>high-pressure</u> He gas that forces the LHe out of the dewar. (The high-pressure He also activates the gas piston-operated valves.) 2) The "<u>hot gas</u>" or <u>heat exchanger valve</u> controls gas flow through the heat exchanger. 3) The <u>by-pass valve</u> increases the flow of cold gas around the heat exchanger, and 4) The <u>LHe valve</u> controls the flow of very cold He fluid out of the dewar. The times on Table 1 were determined during tests at the NBS (see paragraph 3.5) to be those required to provide inflation gas to the ALBS balloon at average temperatures of 272°K or higher.

‡The release of the drogue parachute, at t_o + 180 s, cannot be accomplished by the action of the timer alone. By design, it requires a complementary radio command to remove an "inhibit" placed in the circuit which fires the drogue line cutting devices. This allows the project officer to keep the drogue parachute in place if the balloon inflation does not go to completion during an air-launch test. Under this arrangement the deceleration capability of the drogue is conserved, if required, to support the under-inflated balloon during descent, thereby minimizing the risk to the payload and assuring meaningful post-flight damage assessment.

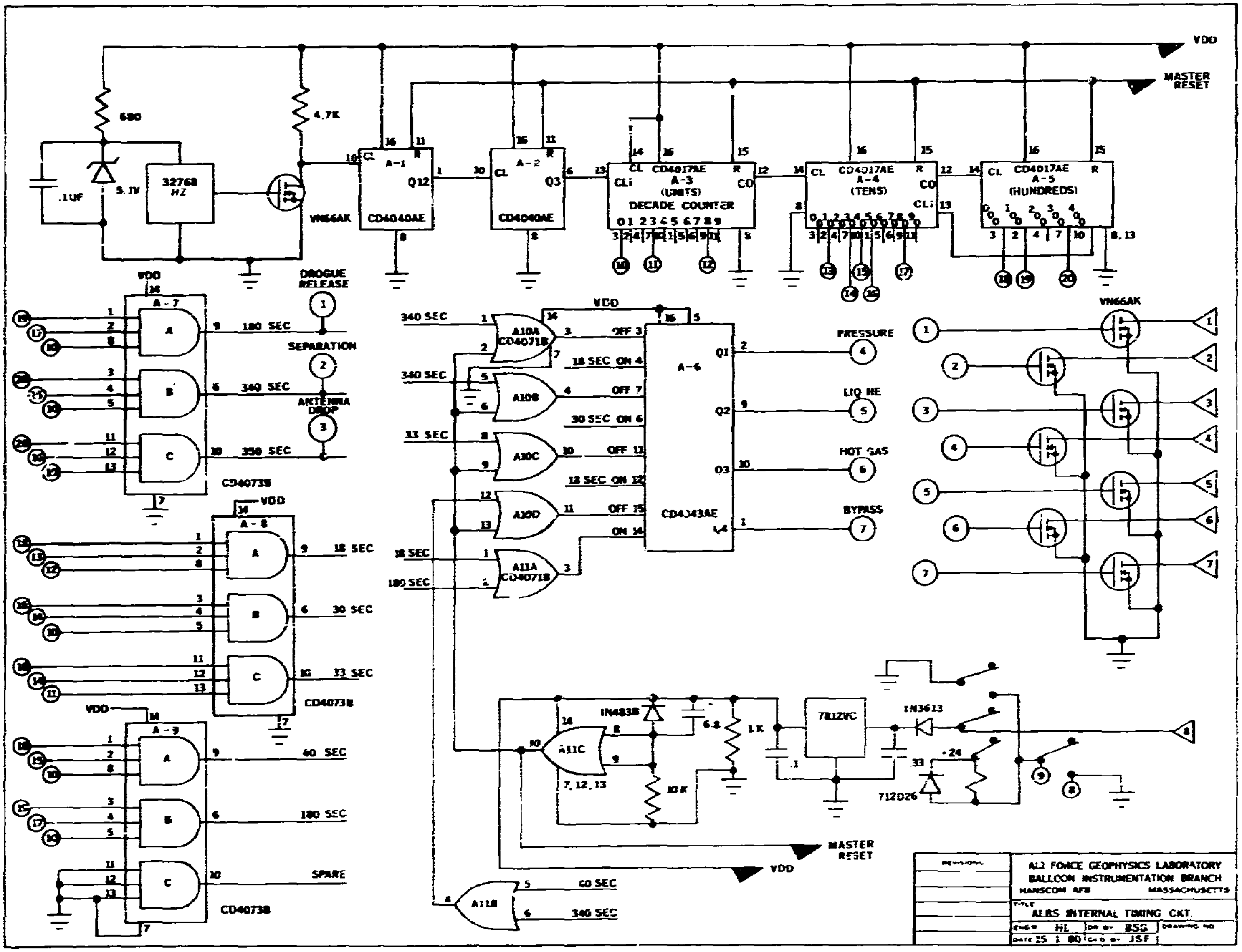

Figure 27. ALBS Internal Timing Circuit

Table 1. Events Controlled by ALBS Timer

Time in Seconds after t_o	Event	Remarks
0	Lanyard switch closes	This is t_o (Manual "start" switch is closed prior to t_o)
+ 18	Pressurization valve on*	Normally closed valve opens
+ 18	Hot gas (heat exchanger) valve on	Normally open valve closes
+ 18	By-pass valve on	Normally open valve closes
+ 30	LHe valve on	Normally closed valve opens
+ 33	Hot gas valve off*	Normally open valve opens
+ 40	By-pass valve off	Normally open valve opens
+180	Drogue release on	Power is applied to two explosive line cutters
+180	By-pass valve on	Normally open valve closes
+340	Fire four Tenneys (Cryo Drop)	Power is applied to four explosive cartridges
+340	Pressure valve off	Normally closed valve closes
+340	By-pass valve off	Normally open valve opens
+340	LHe valve off	Normally closed valve closes
+350	Antenna drop	

*"on" means power applied
"off" means power removed

augmented and backed up by a dual-frequency (HF and UHF) radio command system that can provide substitute control functions if required (see paragraph 3.9.5).

Power is applied to the CCT subsystem by a manual switch closure just before the air launch. Flight system timing does not begin, however, until the ALBS module actually starts to move out of the aircraft. It is at this point, t_o, that a second, lanyard-operated switch is closed, activating the timer. The events of Table 1 then follow. The first of those events, incidentally, the opening of the pressurization valve at t_o + 18 s, occurs after the separately-controlled (see paragraph 3.9.3) deployment of the main parachute, at t_o + 10 s, and just prior to the extraction of the balloon from its donut, at t_0 + 20 s. Figure 28a depicts the physical layout of the fully deployed ALBS, just prior to inflation. Figure 28b, drawn to the same approximate scale, shows the layout of the major ALBS electrical control circuits powered by the CCT subsystem.

3.9.5 HF/VHF/UHF COMPONENTS

3.9.5.1 Command and Data Channels

Table 2 shows the commands that can be transmitted to the ALBS via HF and UHF channels. Note that there is considerable redundancy between the timer and the radio system commands, to guarantee execution of essential steps. (This redundancy permits a second chance at controlling the functions of the cryogenic unit, in case the timer should fail to operate properly.)

Table 3 shows the data telemetered to the ground at VHF and S-band frequencies.

Table 2. HF/UHF ALBS Command List

Command Channel		
HF*	UHF†	Function
1	1	Override drogue chute release inhibit
2	2	40.350 MHz Antenna deploy and add flight termination time and continuous key
3	-	Encoder Fast/Slow Data speed control
4	3	2233.5 MHz Transmitter Select "on" or "off"
6	-	Latch gas valve open
7	4	Open gas valve, failsafe close and latch valve closed
9	5	Flight Termination
10	6	Fire – Drogue Chute Release
11	7	Start inflation (operates both pressure and LHe valves)
13	8	Drop Cryogenic Inflation Unit

*Command frequencies utilized: 6771.5 or 11177.5 kHz

†Command frequencies utilized: 437.5 MHz

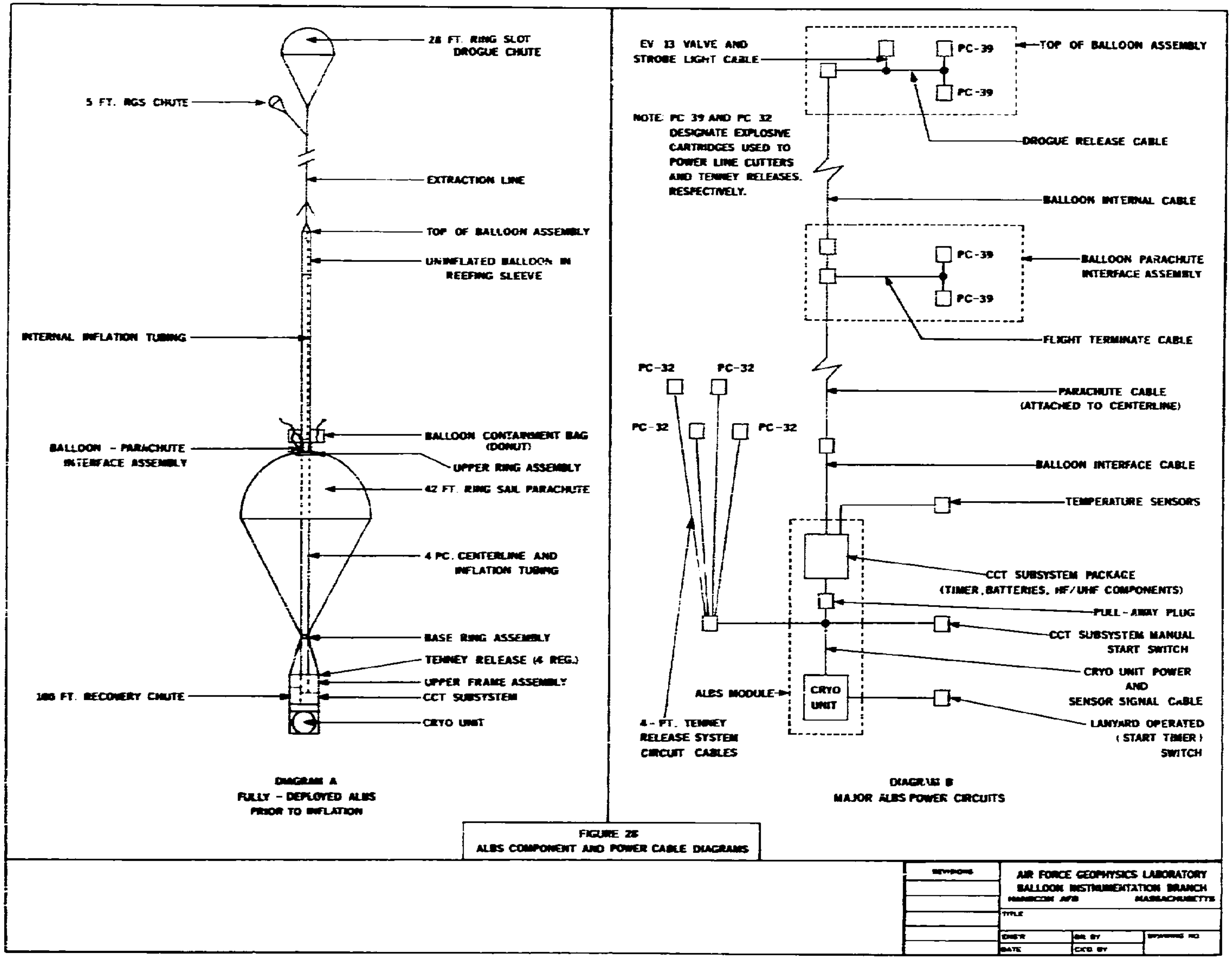

Figure 28. ALBS Component and Power Cable Diagrams

Table 3. ALBS Data Encoder Channels for Telemetry Down Link on 40.350 MHz and 2233.5 MHz

Data Channel VHF and S-Band	Information
1	Low altitude sensor (0-15 psia)
2	Medium altitude sensor (0-2 psia)
3	UHF Command Rcvr Signal Strength
4	Summing Module: EV-13 Gas valve full open, 1.29 V Flight termination, 2.57 V, 3.86 V after valve full open
5	Sub-Commutated Monitor Channel: a. Timer Status – 2.57 V b. 5 V standard – 5.00 V c. 12-V battery d. 30-V battery
6	NBS Cryo unit pressure No. 1 (100 psia)
7	NBS Cryo unit pressure No. 2 (100 psia)
8	Command channel verification read out
9	VT-30 Cryogenic Gas Temperature Monitor
10	VT-30 Excitation 3.01 V
11	VT-20 Cryogenic Gas Temperature Monitor
12	VT-20 Excitation 3.01 V

3.9.5.2 Receivers and Transmitters

There are two command receivers and two data transmitters in the CCT subsystem pack:

a. Receivers (To receive commands transmitted from the ground, per Table 2):

1. A dual frequency (6771.5 kHz; 11177.5 kHz) HF receiver [Zenith Model BCR4 (modified)]. The antenna for this receiver is incorporated in the parachute power cable, permitting good reception during the balloon filling operation.

2. A UHF receiver (Conic Model CCR210-3), set to 437.5 MHz. The UHF Antenna is attached to the base on the CCT subsystem pack. Because this location blocks off most of the incoming UHF signals during the balloon filling operation, the HF receiver is the primary receiver at that time.

b. Transmitters (To verify HF command channel selection and to telemeter encoded housekeeping and system performance data, per Table 3):

1. A VHF transmitter (LCC Model FMT40A), operating at 40.350 MHz. This transmitter employs a reeled down antenna.

2. An S-band transmitter (Conic Model CTS 705) operating at 2233.5 MHz. It has two antennas, an outboard antenna mounted on the cryogenic unit framework, and an onboard antenna at the base of the CCT pack. (The former is used before cryogenic unit separation; the latter afterwards.)*

Both transmitters are frequency modulated by a 3 kHz audio signal keyed on and off by the system's PCM encoder (see paragraph 3.9.6.2). The Conic transmitter is IRIG-qualified and is designed for very much higher data rates than those used in the ALBS. (Its full capabilities are routinely used at the AFGL Balloon Telemetry Facility[4] at Holloman AFB where voluminous PCM data from scientific balloon flights are computer processed and displayed in real time.) Even though its high data rate transmission capabilities are underutilized in the ALBS application, the S-band transmitter plays a vital role, serving as the primary balloon-borne transmission medium during the balloon filling process (see paragraph 3.9.5.3). After cryogenic unit separation, the VHF and S-band transmitters provide a desirable telemetering redundancy.

3.9.5.3 Telemetry Reception

Although the VHF and S-band transmitters provide identical data, the reception of signals transmitted at the two different frequencies can vary markedly, depending on circumstances. The goal, in the ALBS full scale test, was to have a real time printout of the Table 3 data from the moment that the airborne transmitters were energized inside the aircraft. Prior to the actual test date, the drop zone and the heading of the aircraft could not be known precisely, however. Thus, contingency arrangements had to be made to ensure that data goals were met.

It was known that the VHF transmitting antenna would not be unreeled until about 350 s into the test and that the VHF receiving antenna at AFGL ground control

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*The S-band transmitter output is switched between the two antennas by a transfer relay, with the signal going to the outboard antenna only when the relay is energized. Because that antenna is required from launch until t_o + 340 s, the relay must be energized before the ALBS module leaves the aircraft. Under the original system design, this was accomplished by installing a special plug which permitted power to flow from the batteries to the relay. (This plug is pulled away at "Cryo Disconnect," see Figure 26.) In order to avoid power drain, however, the installation of the plug had to be delayed until the last minute. This means that the loadmaster was charged with this task during the busy pre-launch period. Later on, the system was changed so that the plug could be installed early without causing power drain. The loadmaster could now energize the relay at the same time he activated the CCT pack by simply pressing the system start switch.

4. Giannetti, A., and Erickson, J.C. (1980) AFGL Balloon Telemetry Facility, AFGL-TR-80-0029, AD A084 811.

(Bldg. 850, Holloman AFB) is not of the high gain type. In addition, the S-band receiving dish there is not equipped with an auto-track capability. Therefore, the possibility of marginal signal reception during the first part of the test was anticipated.

It was also known that there was a WSMR mountain top relay station located favorably with respect to the probable aircraft flight path. This station has a high gain autotrack S-band antenna. It was judged capable of receiving and recording the ALBS S-band transmissions emanating from the open end of the C-130 aircraft, within the anticipated range of aircraft headings. It could also demodulate and retransmit the ALBS signals directly to the AFGL ground station, employing a second S-band frequency. Thus, a decision was made to rely on the relayed S-band signals to provide test data in real time.

3.9.6 COMMAND DECODERS, PULSE CODE MODULATION (PCM) ENCODERS

3.9.6.1 HF Command Decoder-Selector

A vital component of the CCT subsystem pack is the BCS-18A Command Decoder-Selector.[5] Its function is to decode the radio command signals transmitted from the ground control station on the HF carrier frequencies when a particular Table 2 command is to be executed.

3.9.6.2 Encoder-Timer

A second, equally important component of the CCT pack is the LENC-16 Encoder-Timer.[6] This multi-channel data encoder converts analog transducer signals (pressure, temperature, etc.) into a serial digital code (PCM) suitable for transmission. Its ALBS functions are listed in Table 3.

3.9.6.3 UHF Decoder

The BCS-18A Command Decoder Selector is not used with the UHF (437.5 MHz) command system because the IRIG-qualified Conic Corp. UHF receiver, model CCR210-3, has its own decoder/command execution subsystem. The UHF system serves as backup during the balloon fill operation, however, because of the poor location of its receiving antenna. The HF system, while not instantaneous, provides direct access to the ALBS, regardless of line of sight considerations. An HF channel can be preselected and held, ready to activate at any desired time after verification of system control. The ALBS physical configuration does not permit the same confidence in UHF commands transmitted prior to t_0 + 345 s.

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5. Laping, H. (1980) <u>BCS-18A Command Decoder Selector</u>, AFGL-TR-80-0249, AD A099 384.

6. Laping, H. (1980) <u>A Poor Man's Balloon Control and Data System</u>, a paper presented at the International Telemetering Conference, San Diego, California, 14-16 October 1980.

4. FULL-SCALE SYSTEM TESTS

4.1 General Considerations

Numerous limited-scale component or subsystem tests were described in Section 3, preceding. The discussion will now center on full-scale system tests in which all of the steps required to launch and inflate a balloon in mid-air are carried out and an actual balloon flight is undertaken. Figure 1, at the beginning of the report, depicts such a test.

The ALBS components that ascend to float altitude are the balloon, the 200-lb (889.6-N) payload, and the collapsed main parachute. The total nominal weight of these components is 575 lb (2557.6 N).* If we allow for 10 percent excess or "free" lift to guarantee ascent, the total nominal lift requirement becomes 633 lb (2815.58 N). The cryogenic unit was sized, therefore, to deliver this much lift (plus a small reserve). The inherent efficiency of cryogenic storage dictated a low-pressure dewar, with an outside diameter of only 40 in. (101.6 cm). (As noted in paragraph 3.2.1, this diameter helped to establish the overall cross-sectional area of the ALBS module.) The net result was a lightweight inflatant storage medium of uniquely small size. While this was ideal, from a system configuration point of view, it did introduce certain problems in the testing area in that no realistic in-flight simulation of or substitution for the performance of the cryogenic unit was possible. Potential alternative systems, using compressed gaseous He, were either too large and too heavy or, if kept within ALBS dimensions, were far too limited in lift capacity. The significance of this limitation was that, unlike the performance of the cryogenic unit, which could be predicted accurately from bench tests, the true performance of the special ALBS balloon design could not be determined before flight tests in which the full capacity of the cryogenic unit was actually utilized. (This fact was amply demonstrated during the full-scale tests of 17 March and 1 September 1981. See paragraphs 4.3.3 and 4.4.3.)

4.2 "Dress Rehearsal" Test

4.2.1 RATIONALE

In the summer of 1979, after the new balloon-parachute interface design had been established (see paragraph 3.6), and the details of the 4-point release system had been developed (see paragraph 3.8), there was compelling logic for the scheduling of a quasi full-scale test, to qualify these system modifications, prior to a real full-scale test. [The cryogenic unit had not even been delivered yet (see

*See also paragraph 4.5.6.

paragraph 3.5.3) and its availability date was still several months away.] The proposed test would be a dress rehearsal of the first true full-scale test and would enhance the prospects for the success of that test by identifying for correction any observed design deficiencies. It would also reduce the amount of risk to which the expensive cryogenic unit would be subjected on its first flight.*

4.2.2 TEST PREPARATIONS

The actual dress rehearsal test, which would employ a real ALBS balloon, was scheduled for November 1979 at the AFFTC. The much-used AFFTC parachute test vehicle would be flown in this test also, first undergoing a 20-in. (50.8-cm) elongation from 48 in. to 68 in. (121.92 cm to 172.72 cm) to accommodate the 100-ft (30.48-m) recovery parachute and the simulated communications payload. Borrowing again from the El Centro tests, a mini-inflation system was selected which would utilize two "K" bottles of gaseous He, each holding about 220 standard cubic feet (SCF) or 6.23 standard cubic meters (SCM). [The ALBS dewar, by contrast, yields approximately 10,000 SCF (283.2 SCM) of He.] Preparation of the mini-system was to be accomplished by the National Bureau of Standards, with gas pressures and flow rates set at the values established for the cryogenic unit. Mini-system functions would be controlled by a preliminary version of the AFGL CCT Subsystem which was described in paragraph 3.9, employing an NBS-furnished rotary cam-operated timer. The CCT subsystem would also control the simulated cutting away of the drogue parachute and the actual dropping away of the test vehicle to demonstrate the cryogenic unit separation function.

Only a small gas bubble would be created at the top of the balloon during the dress rehearsal test and no ascent to altitude was possible. This was not critical, however, with respect to planned subsystem qualification testing. There had been some concern, incidentally, that the reefing sleeve might keep the folds of the balloon so tightly packed, particularly when the balloon was fully extended vertically, that the internal inflation tubing would be squeezed shut, thus inhibiting gas bubble development. To allay this concern a bench test was conducted at Edwards AFB on 2 November 1979, using the mini-inflation system. The balloon was extended full length horizontally in its reefing sleeve and placed under about 300 lb (1334.4 N) of tension to simulate the pull of the drogue parachute. When the mini-inflation system was turned on the gas rapidly traversed the length of the balloon to form the expected bubble. The balloon was not damaged.

*On 31 July 1979, a flight test was conducted at the AFFTC, Edwards AFB, to try out the new rings and center lines of the 42-ft main parachute and the deployment of the new RUFCO inflation tubing (paragraph 3.6.2.2). The AFFTC-designed dummy balloon and parachute test vehicle, which had been used extensively during the El Centro tests (paragraph 3.6.1.2), were called back into service for this test. Flight altitude was 25,000 ft (7.62 cm) and aircraft speed was 130 kt. While the test results showed that the new components met all objectives, the scope of the test was too limited to qualify as a quasi full-scale (dress rehearsal) test.

Figures 29 and 30 show the elongated parachute test vehicle being prepared for the dress rehearsal test. The plywood sides have not yet been attached. The topmost large item in the vehicle is the donut with the packed balloon inside. The packed 42-ft (12.8-m) main parachute is just below. In Figure 29 the CCT subsystem is seen below the main parachute pack, at left. The crushable padding stacked endwise at right serves to fill packing voids. Figure 30 shows the test vehicle rotated 90^{o} clockwise. The lightweight 100-ft (30.48-m) triconical recovery parachute and the mini-inflation system's diffuser (gas outlet pipe) are clearly visible, as is the sleeve-protected inflation tubing. The latter is attached to the diffuser and extends up into the packed main parachute. Two of the four Tenney releases, for the simulated cryogenic unit separation function, are visible at the top of the test vehicle framework. Figure 31 shows the fully-assembled test vehicle lying on its side, ready for loading on board the launch aircraft. The rectangular package secured to the center of the plywood panel contains the AFFTC Telemetry System. The two K bottles of the mini-inflation system are visible at right, surrounded by crushable padding.

4.2.3 DRESS REHEARSAL TEST RESULTS

The dress rehearsal test was carried out successfully on the afternoon of 8 November 1979 at 25,000 ft (7.62 km) over Edwards AFB, California (EAS was 130 kt). The drop aircraft was a C-130 from the 6514th Test Squadron at Hill AFB. All test objectives were met: bubble formation at the top of the balloon (see Figure 32), simulated drogue release, dropping away and recovery of the test vehicle, and recovery of the CCT pack. In this test the pyramid, the redesigned balloon bottom end fitting, and the circumferential band assembly (see Figure 22) were tried for the first time. Although these components did what was expected of them some minor damage was noted, for example, torn loops on the circumferential band. This led to a strengthening of the affected components prior to the full-scale test.

It was concluded from the successful dress rehearsal test that the new interface arrangement fully protected the balloon and inflation hose without interferring with the deployment, staging, and inflation functions. Also, the development of the expected He bubble in the deployed balloon served to qualify the inflation system for the full-scale test involving the larger cryogenic He storage system.

One interesting sidelight of the test was the manner in which the RUFCO tubing connection was broken at the end of inflation. Referring back to Figure 28a, we note the routing of the external inflation hose from deep within the test vehicle (see also Figure 30) up through the parachute to the base of the balloon. The top and bottom ends of this tubing are secured by one turn of 3-in. (7.62-cm) wide tape to the balloon's bottom end fitting and to the diffuser in the box, respectively. When

Figure 29. Assembled Dress Rehearsal System (vehicle sides removed). Balloon pack is on top, with main parachute and CCT pack below

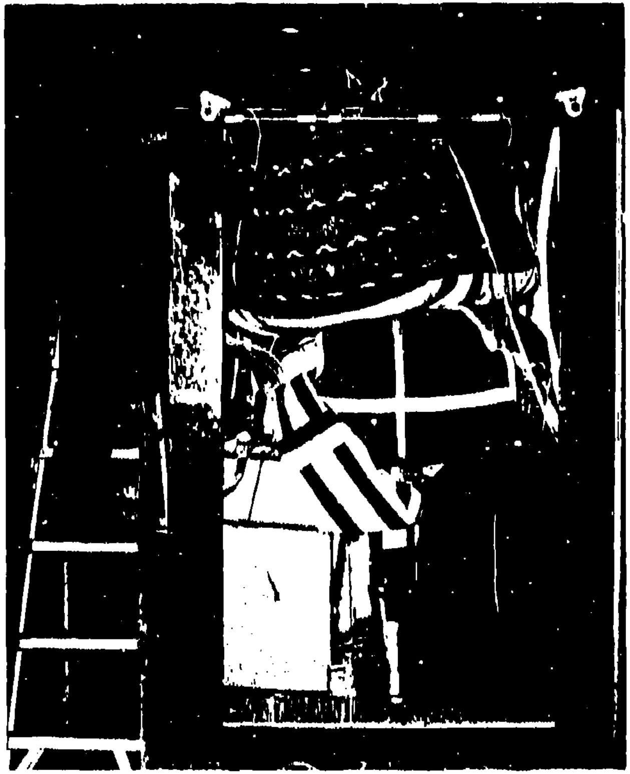


Figure 30. Another View of Assembled Dress Rehearsal System Showing Packed Balloon, Main Parachute, Inflation Hose, Diffuser, 100-ft Parachute, and Tenney Releases (at top)

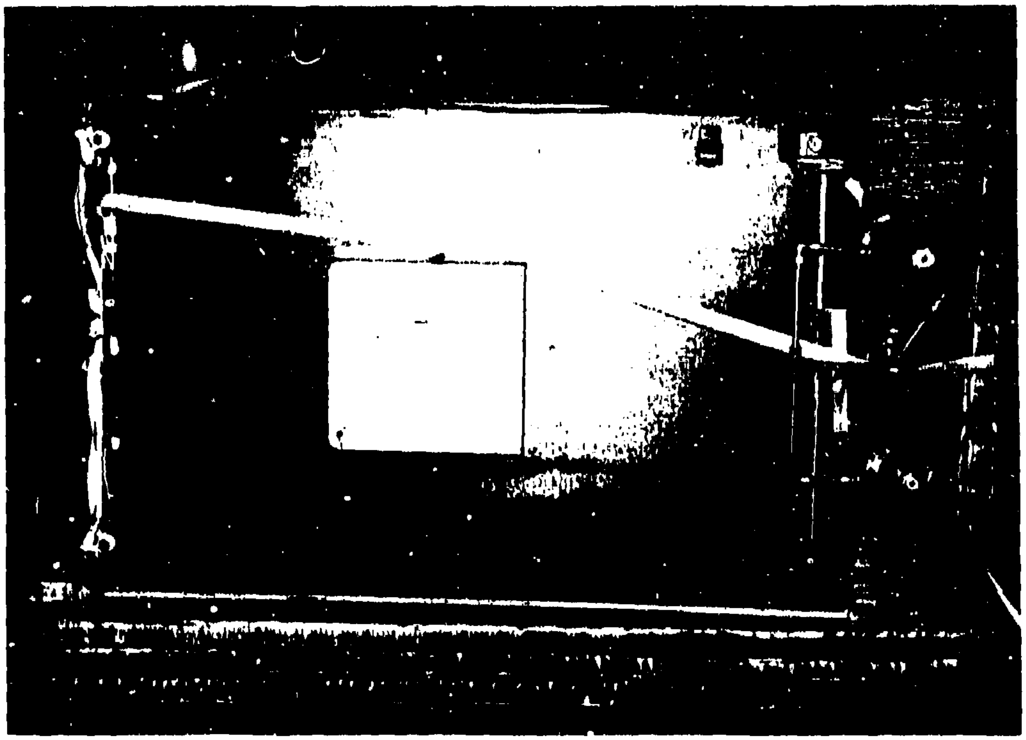


Figure 31. Fully Assembled and Rigged Dress Rehearsal System Showing Mini-Inflation System Secured to Base and AFFTC TM Pack Attached to Side Panel

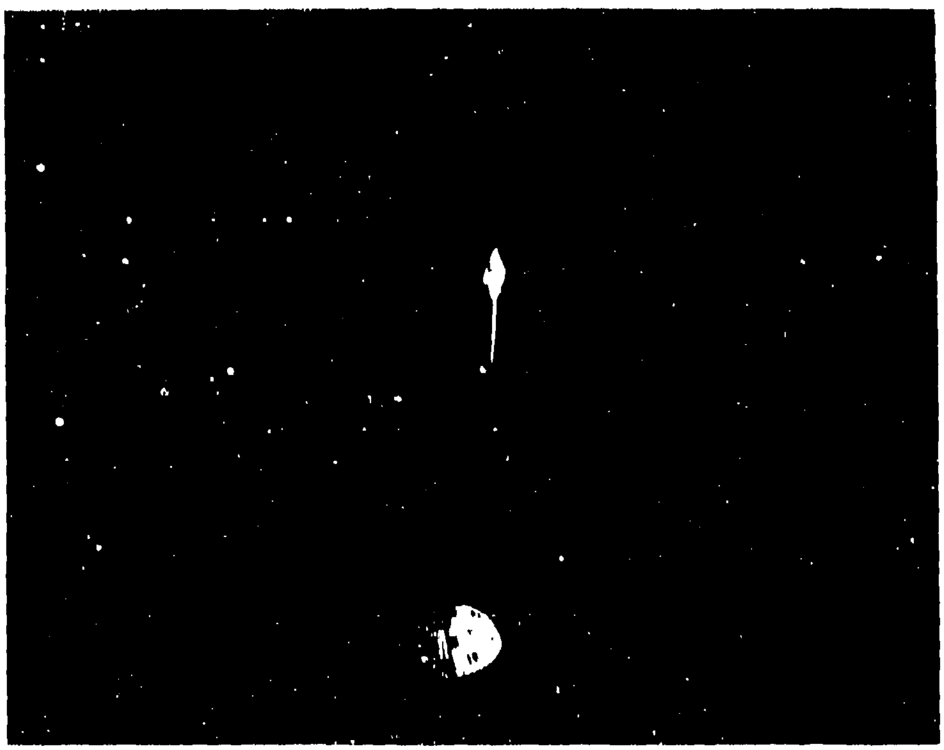


Figure 32. Dress Rehearsal Test -- Small Bubble in Balloon

the 1400 lb (6227.2 N) test vehicle drops away, at the firing of the four Tenney releases, the tubing is subjected to severe tensile forces. It had been believed that one of the tubing ends would slip off the pipe to which it had been taped. [Laboratory tests had established that a force of 350 lb (1556.8 N) was required to pull an end free.] What happened, instead, was a "necking" of the stretched tubing, leading to delamination (ply separation) and rupture of the tubing about halfway up its length. In any event, the desired result, disconnection of the tubing, was achieved. This same mode of separation was observed later on the full-scale tests.

4.2.4 SHOCK FORCES ("g" LOADINGS)

Another important aspect of the dress rehearsal test was that it verified, by actual measurement, the "g" loadings that could be anticipated in the full-scale test. The test vehicle illustrated in Figures 29 through 31 was a fairly accurate replica, volumewise, of the upper section of the new ALBS module described in paragraphs 3.3.3 and 3.5.2. However, because of its massive structural members, its empty weight was much greater than that of the new upper section. By design, the 68-in. (172.72-cm) long test vehicle, fully assembled as shown in Figure 31, with the mini-inflation system attached and with about 270 lb (1200.96 N) of lead ballast inside, had the same overall weight, 2272 lb (10105.86 N), as the loaded new 143-in. (363.22-cm) long ALBS module illustrated in Figure 5. The shock forces measured during parachute deployments and openings in the dress rehearsal test (Table 4) would be applicable, therefore, to the full-scale tests. It was on the basis of the Table 4 test results, incidentally, that the decision was made to stress the dewar to only 7.3 g during acceptance testing, instead of to the specified 9 g (see paragraph 3.5.3.2). Table 5, which was based on the results of the dress rehearsal test, shows the planned sequence of events for the full-scale tests.

Table 4. Force Data from Telemetry Records, Dress Rehearsal Test, 8 November 1979

a.	28-ft (8.53-m) parachute line stretch force	3 263 lb (14513.82 N)	1.4 g	
b.	28-ft (8.53-m) parachute opening force	11 148 lb (49586.30 N)	5.3 g	(opening time: 0.84 s)
c.	42-ft (12.8-m) parachute deployment force	(10 228 lb est) (45494.14 N)	5.4 g	
d.	42-ft (12.8-m) parachute opening force	M	4.0 g	(opening time: 0.84 s)
e.	100-ft (30.48-m) parachute opening force	M	2.2 g	

Note: System weight, Figure 31 configuration plus extraction parachute and extraction line: 2372 lb (10550.66 N)

Table 5. Sequence of Events, ALBS Mid-Air Deployment

Total System Weight: 2375 lb				
Event Number and Description	Event Time (s)	Cumulative Time (s)	Event Completion Altitude (ft)	Event Completion Velocity (FPS)
1. Extraction Stage (First Stage)				
a. Aircraft pilot gives release command.	0	-2.6	25,000	327.8 (130 kt)
Pendulum expels packed drogue chute from aircraft.	1.3	-1.3		
b. 180-ft drogue extension line pays out, becomes taut; RGS chute opens.	0.7	-0.6		
c. Drogue chute is pulled out of pack, becomes taut. ALBS module is pulled off ramp.	0.6	0	24,994 (drogue)	267.0 (drogue, V_H)
(Lanyard activates 10-s delay pyro device here – to deploy 42-ft chute at event 2a.)				
d. Drogue chute inflates (Opening shock: 11 148 lb, 5.3 g)	0.85	0.85		
e. System transitions to vertical attitude.				
f. Drogue chute reaches equilibrium velocity (approximately).	9.15	10.0	≅24,300 (system)	-109.0 ($-V_y$)
2. Main Chute Deployment Stage (Second Stage)				
a. Main chute is deployed (Shock = 5.4 g)	1.4	11.4	24,218	-31.62
Lanyard activates second 10-s delay here for extraction of balloon (event 3b).				
b. Main chute is opened. (Shock = 4.0 g)	1.3	12.7	24,162	-52.43

Table 5. Sequence of Events, ALBS Mid-Air Deployment (Cont.)

Total System Weight: 2375 lb				
Event Number and Description	Event Time (s)	Cumulative Time (s)	Event Completion Altitude (ft)	Event Completion Velocity (FPS)
2. Main Chute Deployment Stage (Second Stage) (Cont.)				
c. Both chutes at equilibrium velocity. (Loads: drogue 567 lb, main 1808 lb)	7.3	20.0	23,760	-54.84
3. Balloon Extraction Stage (Third Stage)				
a. RR2 releases 2nd set of suspension lines, 70 percent of drogue load is transferred to main chute.				
b. Drogue pulls ALBS balloon out of container on top of main chute.	4.6	24.6	23,491 (main chute)	-58.58 (main chute)
c. System achieves a new equilibrium velocity.	5.4	30.0	≃23,200 (system)	-54.30 (system)
4. Balloon Inflation (Fourth Stage)				
a. Inflation of balloon begins.		30.0	≃23,200 (system)	-54.30 (system)
b. Drogue chute is cut away via two explosive line cutters at EV-13.		180.0	≃16,000	-44.7 (system)
c. Balloon inflation ends.	310	340	9,800	-36.02 (system)
d. Fire four Tenneys Cryo unit falls away.		340	≅9,800	-36.02 (system)
e. Cryo unit descends on 100-ft parachute.	6.05 min	11.72 min	4,000	-15.46
5. Balloon Ascends to Float Altitudes	≃60 min	≃66 min	70,000	

Table 5. Sequence of Events, ALBS Mid-Air Deployment (Cont.)

Total System Weight: 2375 lb				
Event Number and Description	Event Time (s)	Cumulative Time (s)	Event Completion Altitude (ft)	Event Completion Velocity (FPS)
6. Flight Termination				
a. Separate balloon from chute apex. (Two explosive line cutters.)	≅120 min	≅186 min	70,000	
b. Payload descends on main parachute.	≅35 min	≅221 min	4,000	-18.4

4.3 The First Full-Scale Test

4.3.1 INTRODUCTION

Although the successful dress rehearsal test of November 1979 opened the way for a true full-scale test, such a test was not actually conducted until 17 March 1981. One reason for the delay was the string of problems experienced with the cryogenic unit (see paragraphs 3.5.4 through 3.5.5). As these problems neared resolution the full-scale test was scheduled for the October-November 1980 time period and extensive test preparations were initiated. Unfortunately, the 6514th Test Squadron was unable to furnish the customary C-130 aircraft support and an alternate source had to be developed. The California Air National Guard (ANG) promised to support a drop over the WSMR during the week of 16 November 1980, and, on the strength of that commitment, final test preparations (see paragraph 4.3.2) were carried through almost to completion. Then on 14 November 1980 the California ANG regretfully announced that its support to the ALBS test had to be cancelled because of an unexpected higher-priority mission. The Military Airlift Command (MAC) was subsequently approached and a Special Assignment Airlift Mission (SAAM) was arranged. The MAC airlift agreement, which included transportation of AFFTC equipment and personnel to and from Holloman AFB, required prior Aeronautical Systems Division (ASD) approval of the ALBS air drop technique. The AFFTC successfully obtained the ASD approval and the test was rescheduled for the week of 15 March 1981.

4.3.2 FULL-SCALE TEST PREPARATIONS

Preparations for the full-scale test required a large number of discrete tasks to be accomplished more or less simultaneously at AFGL, AFFTC, and NBS, with the AFGL Project Officer coordinating the overall effort. The products of these separate endeavors would be brought together just before the test at Holloman AFB. There, representatives of the three organizations would jointly assemble and check the test system and conduct the actual test.

4.3.2.1 AFFTC Tasks

The AFFTC role was to prepare, pack, and rig the upper box section of the new ALBS module, to formalize the procedures for extracting the complete 12-ft (3.66-m) module from the C-130, and to coordinate aircraft support.

The test vehicle used in the dress rehearsal tests (Figure 30) had essentially the same volume and attachment points as the new upper box section. Thus, the balloon and parachute packing and loading experience gained in prior tests could be used again, without major changes. The same was true of the procedures used to rig the system for extraction and deployment. However, the new upper box section had been received from Cryolab, Inc. as an empty frame (paragraph 3.5.3.1) and needed work done on it before it could accept the components it was to house. This work included a modification to one section of the framework, the installation of four removable exterior plywood sides and the addition of a plywood base and a new gas fill pipe. Also, sheets of 1.5-in. (3.81-cm) styrofoam had to be tailored to fit the voids in the framework and then cemented to the exterior panels. This latter construction feature assured smooth passage of the donut, the parachute packs, and the CCT subsystem pack out of the box during the ALBS test.

By mid-summer, 1980, the AFFTC had completed the required modifications and additions to the upper box section. It had also done some preliminary ALBS parachute packing. Final assembly and rigging of the upper box section would be accomplished in November, when AFGL personnel would be present at Edwards AFB to assist. Figure 33, which is a post-recovery view of the interior of the box, illustrates some of the above-mentioned construction details. The different framing techniques employed in the new box are apparent: lightweight welded tubular members versus the massive L-beams of the original test vehicle. The new method of framing was mandated by the need to keep the overall system weight constant, despite the increase in length to 12 ft (3.66 m) (see also paragraph 3.5.2).

The overall length of the ALBS module was causing renewed concern in another area: aircraft extraction procedures. The decision reached at ASD in 1978 (see paragraph 3.4.2) to launch the module from a point forward of the ramp hinge line, without a rail-engaged pallet, was considered in need of revision in the interest of launch effectiveness, crew safety, and eventual MAC acceptability. A new technique was now chosen at AFFTC: The ALBS module would be secured to and launched from a special, roller-equipped aluminum pallet, about 20 ft (6.1 m) long, and

Figure 33. Interior View of New Upper Frame, Showing Styrofoam Panels, Gas Filler Tube and Suspension Slings Employed in Recovery

wide enough to engage the C-130 rails.* This pallet would remain in the aircraft at all times during the test flight. It would be locked forward of the ramp until the aircraft reached launch altitude. Then it would be winched aft, to position the ALBS module at the ramp edge. After ALBS launch, the pallet would be winched forward again and the aircraft ramp closed. The advantage of this new technique is that it permits the desired rearward movement of the ALBS module in flight without having to disengage its restraints.†

*A special-purpose ground support vehicle known as a K-loader (size: 25 K or 40 K) is required for placing the pallet and ALBS module on board the drop aircraft.

†The new technique was approved in March 1981 by MAC for tests over the WSMR. This does not mean that MAC has accepted the technique operationally, however, a situation that must be considered in any future ALBS development work.

4.3.2.2 AFGL/NBS Tasks

The major task of NBS, Boulder, Colorado, was to complete the testing and adjustment of the cryogenic unit to ensure that it would deliver He of the proper quantity and at the right temperature during the mid-air inflation. The cryogenic unit was then to be interfaced and tested with the AFGL CCT subsystem at Boulder, Colorado. Once that had been accomplished, the unit would be trucked to Holloman AFB, where it would be cooled down, filled with LHe and integrated with the upper box section being airlifted from Edwards AFB.

Early in November 1980, the AFGL representatives interfaced the CCT subsystem with the cryogenic unit at NBS and participated in a successful full-scale laboratory test of the combined subsystems. This cleared the cryogenic unit for shipment to Holloman AFB. The CCT subsystem was then taken to Edwards AFB for integration into the upper section of the ALBS module. It was during the packing and rigging of the upper section that word of the sudden withdrawal of the promised C-130 aircraft support (see paragraph 4.3.1) was received, forcing test cancellation. Fortunately, the revised test date, 17 March 1981, was close enough that most of the preparations accomplished in November did not have to be done over.

4.3.3 FULL-SCALE TEST NO. 1 RESULTS

On 15 March 1981, a C-130 from the 62 Military Airlift Wing (MAW), McChord AFB, Washington, transported the Edwards AFB support personnel and the fully-rigged upper box section to Holloman AFB, where the box section was joined to the waiting cryogenic unit. (Table 6 shows the weight values used for this test.) Then, on the morning of 17 March the C-130 dropped the completely assembled module from 25,000 ft (7.62 km) over the 50-mile area of the WSMR. All components functioned very well and balloon inflation was initiated. However, early in the filling process, the balloon's internal inflation tubing ruptured near the base, causing a double bubble. This led to a bunching of the reefing sleeve (see Figure 34) and the balloon was eventually torn open by excessive pressure at the base. It then separated from the apex of the main parachute and drifted off, still supported by the drogue parachute. The test was quickly terminated by radio command and all components were recovered safely (see Figure 35).

4.4 Full-Scale Test No. 2

4.4.1 TEST PREPARATIONS

Because the reason for failure in the above test was both clear and correctable and because the ALBS module had been recovered in undamaged condition, a repeat full-scale test was authorized, provided that it could be accomplished before the

Table 6. Reference ALBS Weights for 17 March 1981 Full-Scale Test

	(lb)	(N)
Upper Frame, empty, modified struts	206	916.3
Plywood for upper frame (includes fasteners)	140	622.7
Crushable padding used in upper frame (spacers)	15	66.7
Two-ft flanged pipe for gas fill tube	5	22.2
Styrofoam panels for upper frame	15	66.7
Sub-total A	381	1694.7*
Plywood for lower frame (includes fasteners)	65	289.1
Reinforced lower frame, empty dewar, straps, dewar plumbing	450	2001.6
Heat exchanger	350	1556.8
Pressure bottle and miscellaneous controls	35	155.7
LHe	104	462.6
Sub-total B	1004	4465.8*
15 K links, Tenney's, power cartridges, wiring, etc.	15	66.7
Ties, tape, extra lines	20	89.0
Contingency	100	444.8
Radio plane releases (two)	10	44.5
First stage suspension lines, black clevis, etc.	20	89.0
Crushable padding, glue, lanyard switch	20	89.0
Sub-total C	185	822.9*
LCC box (including batteries)	180	800.6
100-ft recovery parachute	110†	489.3
Balloon, as packed in "donut" less EV-13/strobe	225	1000.8
EV-13/, strobe, cutters	17	75.6
42-ft ring sail parachute, fully packed	168	747.3
Sub-total D	700	3113.6
All items in ALBS module (sum of subtotals A, B, C, D)	2270	10097.0
Extraction chutes and extraction line	100	444.8
Grand Total	2370	10541.8

*Sub-totals in Newtons reflect rounding-off imprecision.

†This includes the weight (5 lb) of the parachute bag. In the September 1981 test this bag remained attached to the balloon payload.

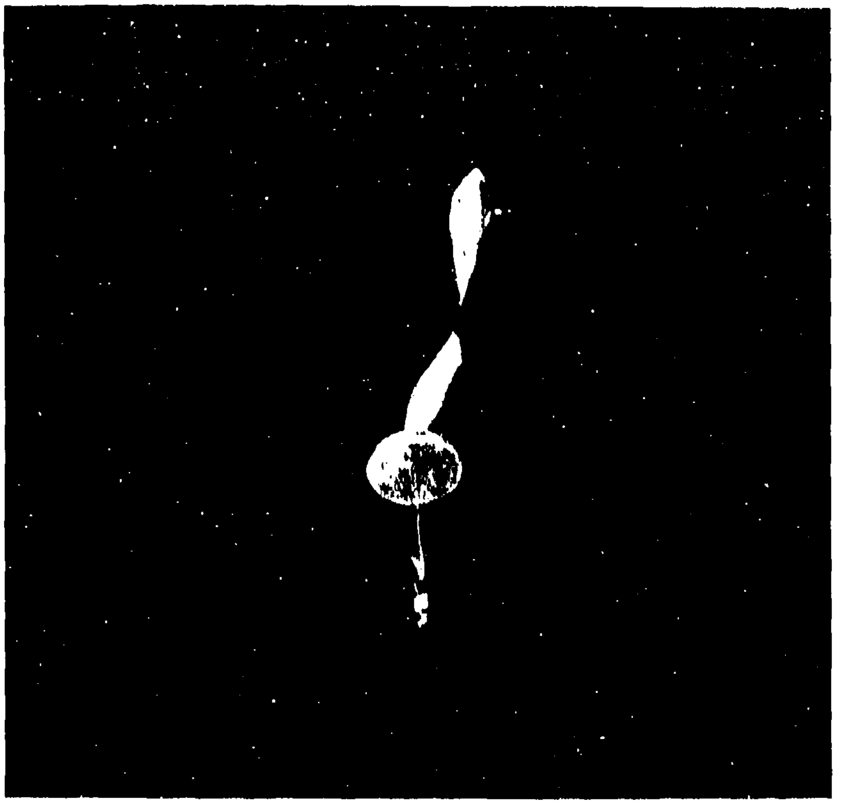


Figure 34. First Full-Scale Test—Double Bubble Formation

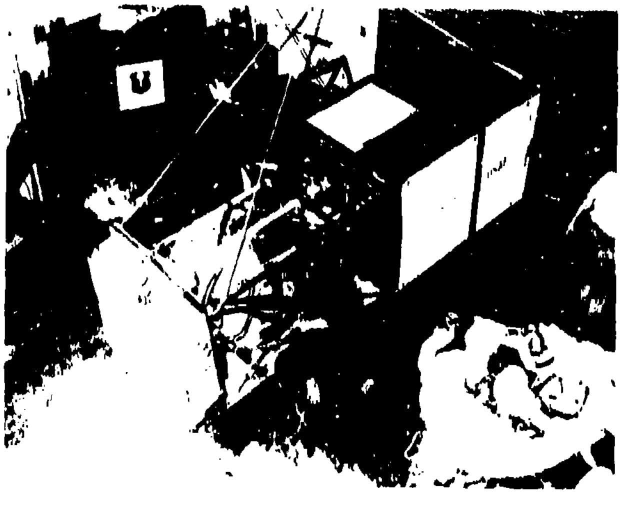


Figure 35. Recovered Module After First Full-Scale Test

close of FY81. In May, the one remaining balloon (of the four procured for the program) was shipped to Edwards AFB where a new internal inflation tube was installed. The new tube was made of the same cross-laminated, 4-mil (0.01-cm) RUFCO material (see paragraph 3.6.2.2) that had carried the inflation gas up through the main parachute during the 17 March test and had performed very well. For the repeat test, the RUFCO tubing was pulled through and secured to the original manufacturer-installed internal inflation tube that had been made from 3-mil (0.008-cm) regular polyethylene film. The plan was to have the inflation pressures applied to the RUFCO tubing rather than to the original tubing that was less than half as strong. Except for some minor changes in the CCT subsystem [for example, the transfer relay power modification (see footnote to paragraph 3.9.5.2 b2) and the addition of special cables to permit charging of batteries* in place], this was the only system modification made for the repeat test and it proved to be a good solution to the problem addressed.

Another MAC special assignment Airlift Mission was arranged to accommodate a planned 1 September 1981 repeat test over the WSMR. As was done in preparation for the first full-scale test, the AFGL team visited NBS, Boulder, Colorado, and Edwards AFB, California, in late August to assist in checking and preparing the system components for the upcoming test. Previous experience made these preparations go very smoothly and most tasks were accomplished ahead of schedule.

On Sunday, 30 August 1981, a C-130 from the 62 MAW once again transported the rigged ALBS upper box section and the support team from Edwards AFB to Holloman AFB. There the box section was joined to the waiting cryogenic unit and final preparations and checks were accomplished by AFGL, AFFTC, and NBS personnel.

4.4.2 TEST RESULTS

The air drop was conducted over the WSMR 50-mile area on 1 September as planned, despite broken layers of cloud which degraded optical coverage. Release from 25,000 ft (7.62 km) was made at 0840 MDT. All steps occured as scheduled. The RUFCO inflation tubing inside the balloon easily handled peak gas pressures and a large bubble developed at the top of the balloon. This bubble expanded downward, forcing open the reefing sleeve as it grew in size (Figure 36). The test appeared to be going very well when, suddenly, about halfway through the inflation cycle, the balloon tore away from its base (Figure 37). At this point, there were two separate descending systems: 1) the drogue parachute and the damaged balloon and 2) the main parachute with the ALBS module suspended below.

*The CCT pack employs 7 ea 12-V and 2 ea 6-V Gel Cell batteries, to provide 30-V and 12-V power. The four cartridges fired at "Cryo Drop" draw 6 A.

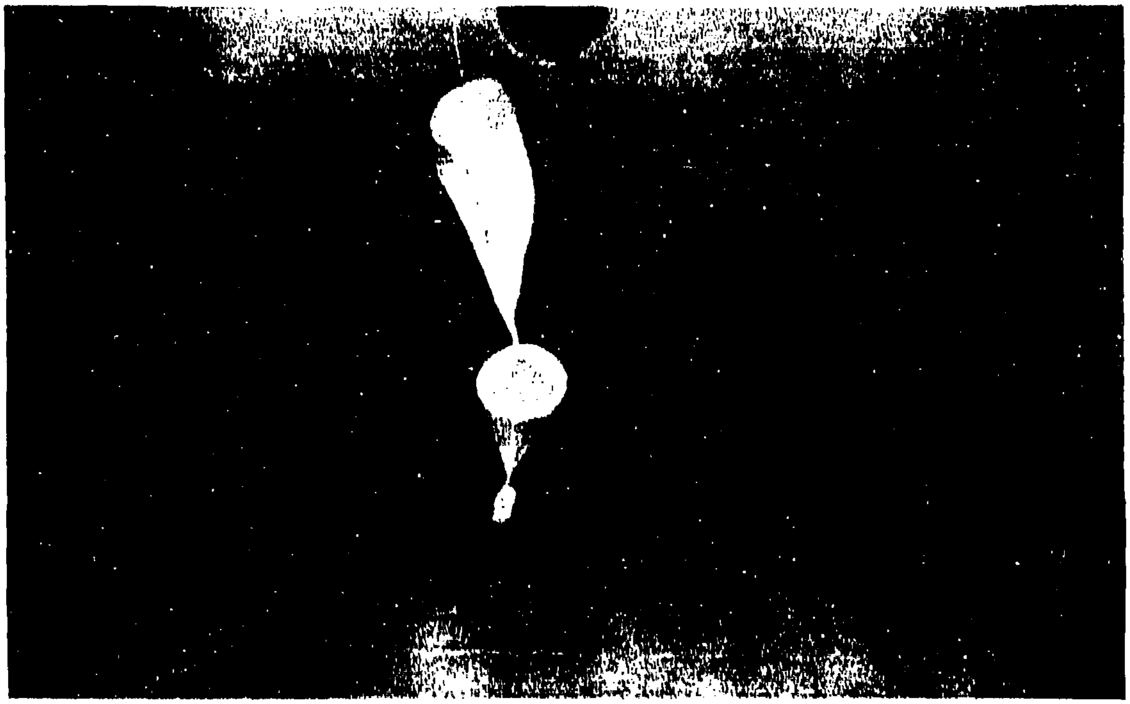


Figure 36. Second Full-Scale Test – Balloon Inflation

Figure 37. Second Full-Scale Test – Balloon Tearing Away from Base

Because of the balloon malfunction, the drogue parachute was not cut away, as would have been the case with a normal inflation. At 5 min. and 40 s into the test, the CCT timer activated the cryogenic unit release system, to create a third descending system, namely the ALBS module on the 100-ft (30.48-m) triconical parachute. (The main parachute was now supporting only the CCT subsystem.)

All systems descended safely. Strong surface winds kept the 100-ft parachute inflated, however, and it dragged the inverted module about 600 ft (182.88 m) across the recovery area (Figure 38). (The system design did not call for an impact switch-operated parachute dump.) This caused moderate damage to the dome of the cryogenic unit's heat exchanger. Except for this, and some cosmetic damage (scraped paint, etc.) the system components were recovered in good condition (Figure 39).

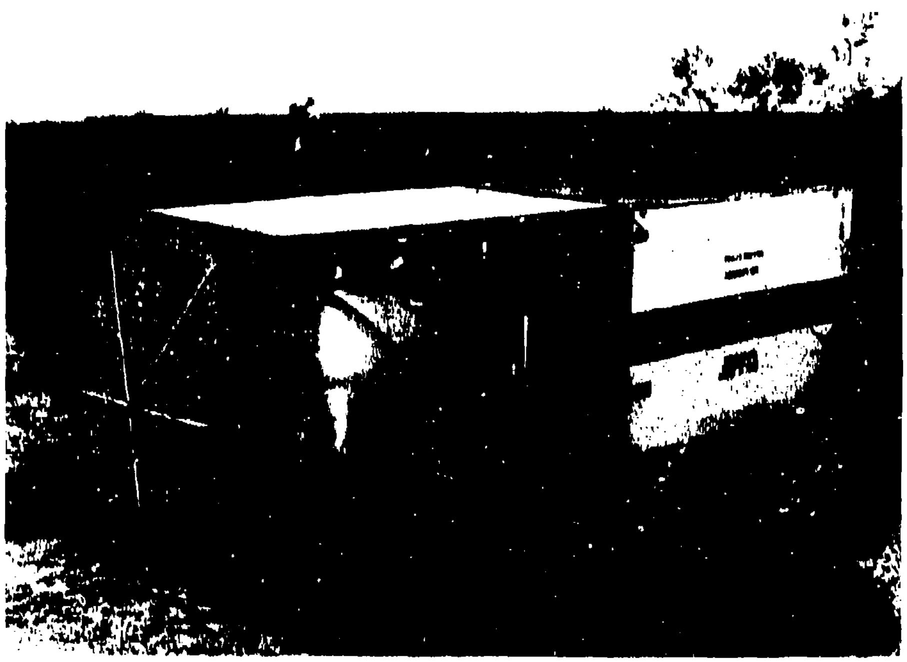


Figure 38. Second Full-Scale Test – Inverted Recovered Module

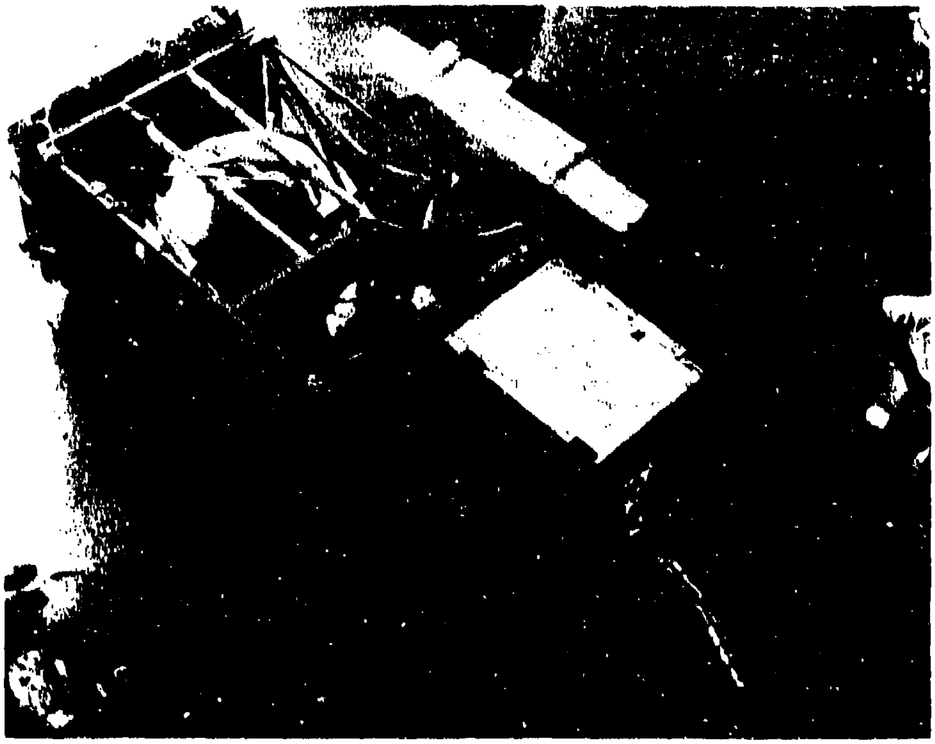


Figure 39. Second Full-Scale Test – Uprighted Recovered Module (note damage to heat exchanger dome)

4.4.3 POST-FLIGHT ANALYSIS

Films of the test, taken with high-speed telescopic cameras, showed that the inflating balloon was subjected to considerable buffeting (Figure 40) as the system descended. The tearing away at the base occured very abruptly. It is possible that the balloon film was simply overstressed by peak transient loads (see below) and that the failure was the natural consequence. A more likely cause of failure, however, was the series of sharp or rough edges found along the periphery of the balloon's base casting (Figures 41 and 42), instead of the specified smooth radius. (Unfortunately, this condition was not discovered until after the test.) The buffeting caused the stressed film to move back and forth across the roughness points on the casting, weakening the film and thus removing any chance that the balloon might have had for survival. Whatever the true cause of failure, the adequacy of the balloon design, with respect to the current ALBS operating environment, is open to question.

At the time that the balloon failure occurred, the ALBS array was at about 15,400 ft (4.694 km), descending at 43 to 44 fps (13.11 to 13.41 mps). Table 7, which lists the outputs of representative pre-flight system descent data calculations, calls for a dynamic pressure of 1.39 psf (0.066 kPa) at this point and a gas

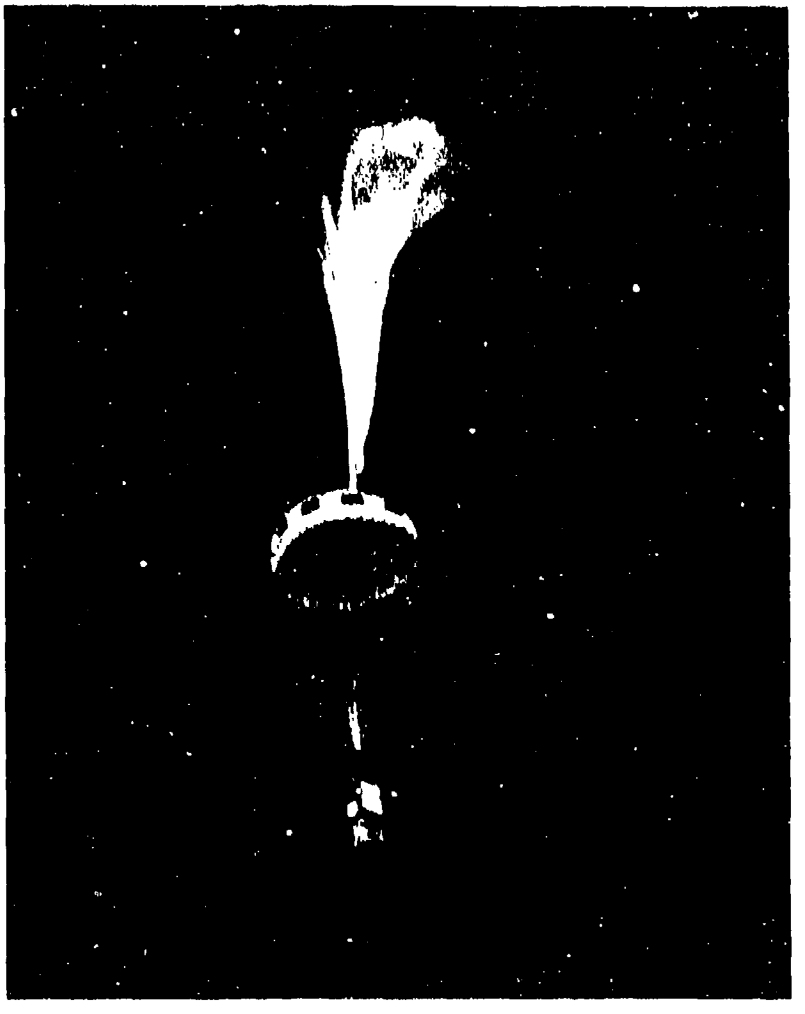


Figure 40. Second Full-Scale Test – Buffeting of Balloon

bubble diameter of approximately 26 ft (7.92 m). Assuming a spherical bubble with a coefficient of drag (C_D) of 0.5, the Table 7 calculations give a steady-state drag force on the balloon of 376.8 lb (1676.0 N). However, even with a more conservative C_D of 1.0, the calculated drag force would have been only 753 lb (3351.2 N), whereas the maximum recommended payload for the ALBS balloon is 850 lb (3780.8 N).

The balloon is not actually supporting a payload during the inflation process and the only load on the balloon is the drag force. Clearly, the higher steady-state drag force value calculated above, 753 lb for a C_D of 1, is less than the allowable maximum payload. This steady-state value may not be appropriate, however, in view of the observed buffeting. What seems more likely is that distortions in the balloon shape (also observed on the film record) created drag force

H (ft)	σ	P (Atm)	Air Temp. °K	L/M Ratio	Δt (sec)	ΣΔt (sec)	V_e (fps)	q (psf)	ΣΔMHe (lb)
23200.	.47779	.4017					-54.21		
23000.	.48108	.4051	259.0	6.217	3.714	3.714	-53.50	1.6375	1.346
22800.	.48446	.4085	259.4	6.217	3.757	7.471	-52.96	1.6153	2.661
22600.	.48784	.4121	259.8	6.217	3.795	11.265	-52.46	1.5961	3.992
22400.	.49122	.4157	260.2	6.217	3.830	15.095	-51.99	1.5786	5.336
22200.	.49460	.4192	260.6	6.217	3.864	18.959	-51.54	1.5622	6.693
22000.	.49798	.4227	261.0	6.217	3.897	22.855	-51.11	1.5468	8.061
21800.	.50145	.4264	261.4	6.217	3.929	26.785	-50.69	1.5320	9.441
21600.	.50492	.4300	261.8	6.217	3.961	30.746	-50.28	1.5179	10.833
21400.	.50840	.4337	262.2	6.217	3.993	34.740	-49.88	1.5042	12.236
21200.	.51187	.4373	262.6	6.216	4.025	38.765	-49.49	1.4909	13.651
21000.	.51534	.4410	263.0	6.216	4.056	42.821	-49.11	1.4780	15.076
20800.	.51890	.4448	263.4	6.216	4.088	46.909	-48.74	1.4654	16.513
20600.	.52247	.4486	263.8	6.215	4.119	51.028	-48.37	1.4531	17.961
20400.	.52603	.4523	264.2	6.215	4.151	55.179	-48.00	1.4411	19.420
20200.	.52960	.4561	264.6	6.215	4.182	59.361	-47.64	1.4293	20.890
20000.	.53316	.4599	265.0	6.214	4.213	63.575	-47.29	1.4177	22.372
19800.	.53682	.4638	265.4	6.214	4.245	67.820	-46.94	1.4063	23.864
19600.	.54047	.4677	265.8	6.213	4.277	72.096	-46.59	1.3951	25.368
19400.	.54413	.4717	266.2	6.213	4.308	76.405	-46.25	1.3841	26.882
19200.	.54778	.4756	266.6	6.213	4.340	80.744	-45.92	1.3732	28.408
19000.	.55144	.4795	267.0	6.212	4.372	85.116	-45.58	1.3624	29.946
18800.	.55519	.4835	267.4	6.211	4.403	89.519	-45.25	1.3518	31.494
18600.	.55895	.4876	267.8	6.211	4.436	93.955	-44.93	1.3413	33.054
18400.	.56270	.4916	268.2	6.210	4.468	98.423	-44.60	1.3309	34.625
18200.	.56646	.4957	268.6	6.210	4.500	102.923	-44.28	1.3206	36.207
18000.	.57021	.4997	269.0	6.209	4.533	107.456	-43.96	1.3105	37.801
17800.	.57406	.5039	269.4	6.208	4.566	112.022	-43.65	1.3004	39.407
17600.	.57791	.5081	269.8	6.208	4.599	116.620	-43.34	1.2904	41.024
17400.	.58176	.5122	270.2	6.207	4.632	121.255	-43.03	1.2805	42.653
17200.	.58561	.5164	270.6	6.206	4.665	125.917	-42.72	1.2706	44.293
17000.	.58946	.5206	271.0	6.206	4.505	130.422	-46.07	1.4876	45.946
16800.	.59341	.5249	271.4	6.205	4.357	134.780	-45.73	1.4752	47.541
16600.	.59736	.5292	271.8	6.205	4.390	139.170	-45.39	1.4634	49.086
16400.	.60131	.5336	272.2	6.205	4.422	143.592	-45.06	1.4517	50.640
16200.	.60526	.5379	272.6	6.205	4.455	148.047	-44.73	1.4400	52.206
16000.	.60921	.5422	273.0	6.205	4.487	152.534	-44.41	1.4285	53.784
15800.	.61326	.5467	273.4	6.205	4.520	157.054	-44.08	1.4170	55.373
15600.	.61731	.5512	273.8	6.205	4.554	161.608	-43.76	1.4056	56.974
15400.	.62136	.5556	274.2	6.204	4.587	166.195	-43.44	1.3943	58.587
15200.	.62541	.5601	274.6	6.204	4.621	170.815	-43.13	1.3830	60.212
15000.	.62946	.5646	275.0	6.204	4.655	175.470	-42.81	1.3717	61.849
14800.	.63361	.5692	275.4	6.203	4.689	180.159	-42.50	1.3606	63.497
14600.	.63776	.5738	275.8	6.203	4.724	184.882	-42.18	1.3494	65.158
14400.	.64192	.5784	276.2	6.202	4.759	189.641	-41.88	1.3384	66.831
14200.	.64607	.5830	276.6	6.201	4.794	194.434	-41.57	1.3273	68.517
14000.	.65022	.5876	277.0	6.201	4.829	199.264	-41.26	1.3163	70.215
13800.	.65448	.5924	277.4	6.200	4.865	204.129	-40.96	1.3054	71.925
13600.	.65874	.5972	277.8	6.199	4.901	209.030	-40.65	1.2945	73.648
13400.	.66299	.6019	278.2	6.198	4.938	213.968	-40.35	1.2836	75.384
13200.	.66725	.6067	278.6	6.197	4.975	218.943	-40.05	1.2728	77.133
13000.	.67151	.6115	279.0	6.197	5.012	223.954	-39.76	1.2619	78.895
12800.	.67587	.6164	279.4	6.196	5.050	229.004	-39.46	1.2512	80.671
12600.	.68024	.6213	279.8	6.195	5.088	234.092	-39.16	1.2404	82.459
12400.	.68460	.6263	280.2	6.194	5.126	239.210	-38.87	1.2297	84.261
12200.	.68897	.6312	280.6	6.193	5.166	244.383	-38.58	1.2190	86.077
12000.	.69333	.6361	281.0	6.192	5.204	249.588	-38.28	1.2083	87.906
11800.	.69780	.6412	281.4	6.190	5.244	254.832	-37.99	1.1976	89.750
11600.	.70227	.6463	281.8	6.189	5.284	260.116	-37.70	1.1870	91.607
11400.	.70674	.6514	282.2	6.188	5.325	265.441	-37.41	1.1763	93.479
11200.	.71121	.6565	282.6	6.187	5.366	270.807	-37.13	1.1657	95.365
11000.	.71568	.6616	283.0	6.186	5.408	276.215	-36.84	1.1550	97.266
10800.	.72026	.6668	283.4	6.184	5.450	281.664	-36.56	1.1444	99.181
10600.	.72484	.6721	283.8	6.183	5.493	287.157	-36.27	1.1338	101.111
10400.	.72943	.6773	284.2	6.182	5.536	292.693	-35.99	1.1232	103.057
10202.	.73397	.6825	284.6	6.180	5.529	298.222	-35.71	1.1127	105.000

Table 7. ALBS Balloon Inflation Calculations

)	q (psf)	ΣΔMHe (lb)	He Temp. °K	ΣΔL (lb)	W_S (lb)	V_B (ft^3)	d_B (ft)	$(C_DS_0)_S$ (ft^2)	$(C_DS_0)_B$ (ft^2)	D_B (lb)	D_D (lb)	D_M (lb
21					2375.00			1419.31				
50	1.6375	1.346	258.0	8.37	2366.63	281.858	8.13	1445.30	25.99	42.55	554.55	1769.
96	1.6153	2.661	258.4	16.55	2358.45	553.368	10.19	1460.05	40.74	65.82	547.05	1745.
46	1.5961	3.992	258.8	24.82	2350.18	824.271	11.63	1472.45	53.14	84.82	540.54	1724.
99	1.5786	5.336	259.2	33.18	2341.82	1094.126	12.78	1483.49	64.19	101.32	534.61	1705.
64	1.5622	6.693	259.6	41.61	2333.39	1362.812	13.76	1493.61	74.30	116.08	529.08	1688.
11	1.5468	8.061	260.0	50.12	2324.88	1630.273	14.60	1503.04	83.73	129.52	523.84	1671.
69	1.5320	9.441	260.4	58.70	2316.30	1895.865	15.36	1511.91	92.60	141.86	518.85	1655.
28	1.5179	10.833	260.8	67.35	2307.65	2160.055	16.04	1520.32	101.01	153.32	514.05	1640.
88	1.5042	12.236	261.2	76.07	2298.93	2422.866	16.66	1528.36	109.05	164.03	509.41	1625.
49	1.4909	13.651	261.6	84.86	2290.14	2684.315	17.24	1536.07	116.76	174.07	504.92	1611.
01	1.4780	15.076	261.9	93.72	2281.28	2944.425	17.78	1543.49	124.18	183.54	500.55	1597.
74	1.4654	16.513	262.3	102.64	2272.36	3202.357	18.29	1550.64	131.33	192.46	496.29	1583.
87	1.4531	17.961	262.7	111.64	2263.36	3458.891	18.76	1557.57	138.26	200.91	492.13	1570
00	1.4411	19.420	263.1	120.70	2254.30	3714.071	19.21	1564.28	144.98	208.93	488.05	1557.
64	1.4293	20.890	263.5	129.83	2245.17	3967.933	19.64	1570.82	151.51	216.55	484.05	1544
29	1.4177	22.372	263.9	139.03	2235.97	4220.511	20.05	1577.18	157.87	223.82	480.13	1532
24	1.4063	23.864	264.3	148.29	2226.71	4470.489	20.44	1583.35	164.05	230.70	476.27	1519
69	1.3951	25.368	264.6	157.62	2217.38	4719.138	20.81	1589.38	170.07	237.27	472.48	1507
25	1.3841	26.882	265.0	167.02	2207.98	4966.506	21.17	1595.27	175.97	243.55	468.74	1495
92	1.3732	28.408	265.4	176.49	2198.51	5212.633	21.51	1601.04	181.73	249.55	465.05	1483
58	1.3624	29.946	265.8	186.02	2188.98	5457.556	21.84	1606.69	187.38	255.29	461.40	1472
25	1.3518	31.494	266.2	195.62	2179.38	5699.900	22.16	1612.20	192.89	260.75	457.81	1460
93	1.3413	33.054	266.5	205.29	2169.71	5941.032	22.47	1617.60	198.29	265.97	454.25	1449
60	1.3309	34.625	266.9	215.03	2159.97	6181.003	22.77	1622.90	203.59	270.97	450.74	1438
28	1.3206	36.207	267.3	224.84	2150.16	6419.352	23.06	1628.12	208.81	275.76	447.25	1427
96	1.3105	37.801	267.7	234.71	2140.29	6657.618	23.34	1633.24	213.93	280.35	443.80	1416
55	1.3004	39.407	268.0	244.66	2130.34	6892.424	23.61	1638.24	218.93	284.70	440.39	1405
24	1.2904	41.024	268.4	254.67	2120.33	7126.135	23.88	1643.16	223.85	288.86	437.01	1394
03	1.2805	42.653	268.8	264.75	2110.25	7358.799	24.13	1648.01	228.70	292.85	433.65	1383
72	1.2706	44.293	269.1	274.90	2100.10	7590.456	24.38	1652.78	233.47	296.66	430.32	1373
07	1.4876	45.946	269.5	285.12	1961.88	7821.145	24.63	1318.83	238.18	354.32	0.00*	1607
73	1.4752	47.541	269.9	295.01	1951.99	8037.681	24.85	1323.20	242.56	357.82	0.00	1594
99	1.4634	49.085	270.3	304.59	1942.41	8243.098	25.06	1327.32	246.67	360.98	0.00	1581
06	1.4517	50.640	270.7	314.24	1932.76	8447.778	25.27	1331.38	250.74	364.00	0.00	1568
73	1.4400	52.206	271.1	323.96	1923.04	8651.733	25.47	1335.40	254.76	366.86	0.00	1556
31	1.4285	53.784	271.5	333.74	1913.26	8854.996	25.67	1339.38	258.73	369.59	0.00	1543
88	1.4170	55.373	271.9	343.59	1903.41	9054.947	25.86	1343.26	262.61	372.13	0.00	1531
76	1.4056	56.974	272.3	353.51	1893.49	9254.202	26.05	1347.10	266.45	374.53	0.00	1518
14	1.3943	58.587	272.7	363.50	1883.50	9452.801	26.23	1350.90	270.25	376.80	0.00	1506
13	1.3830	60.212	273.0	373.55	1873.45	9650.777	26.42	1354.66	274.01	378.95	0.00	1494
31	1.3717	61.849	273.4	383.68	1863.32	9848.161	26.59	1358.38	277.74	380.98	0.00	1482
10	1.3606	63.497	273.8	393.88	1853.12	10042.867	26.77	1362.03	281.38	382.84	0.00	1470
68	1.3494	65.158	274.2	404.14	1842.86	10237.003	26.94	1365.54	285.00	384.59	0.00	1458
08	1.3384	66.831	274.5	414.48	1832.52	10430.608	27.11	1369.23	288.58	386.23	0.00	1446
7	1.3273	68.517	274.9	424.89	1822.11	10623.713	27.27	1372.78	292.13	387.75	0.00	1434
6	1.3163	70.215	275.3	435.37	1811.63	10816.348	27.44	1376.30	295.65	389.17	0.00	1422
6	1.3054	71.925	275.7	445.93	1801.07	11005.199	27.60	1379.73	299.08	390.42	0.00	1410
5	1.2945	73.648	276.0	456.55	1790.45	11193.584	27.75	1383.13	302.49	391.57	0.00	1398
5	1.2836	75.384	276.4	467.25	1779.75	11381.542	27.91	1386.51	305.86	392.61	0.00	1387
5	1.2728	77.133	276.8	478.03	1768.97	11569.102	28.06	1389.86	309.21	393.56	0.00	137
6	1.2619	78.895	277.1	488.88	1758.12	11756.295	28.21	1393.19	312.54	394.41	0.00	136
6	1.2512	80.671	277.5	499.80	1747.20	11940.437	28.36	1396.44	315.80	395.12	0.00	135
5	1.2404	82.459	277.8	510.81	1736.19	12124.236	28.50	1399.67	319.03	395.73	0.00	134
7	1.2297	84.261	278.2	521.89	1725.11	12307.728	28.65	1402.88	322.24	396.26	0.00	132
[illegible]	1.2190	86.077	278.6	533.04	1713.96	12490.944	28.79	1406.07	325.43	396.69	0.00	131
[illegible]	1.2083	87.906	278.9	544.28	1702.72	12673.912	28.93	1409.25	328.60	397.03	0.00	130
[illegible]	1.1976	89.750	279.3	555.59	1691.41	12853.050	29.06	1412.33	331.69	397.23	0.00	129
0	1.1870	91.607	279.6	566.98	1680.02	13031.960	29.20	1415.41	334.76	397.34	0.00	128
[illegible]	1.1763	93.479	280.0	578.46	1668.54	13210.675	29.33	1418.46	337.81	397.37	0.00	127
9	1.1657	95.365	280.3	590.01	1656.99	13389.226	29.46	1421.50	340.85	397.32	0.00	125
[illegible]	1.1550	97.266	280.7	601.65	1645.35	13567.639	29.59	1424.52	343.87	397.18	0.00	124
[illegible]	1.1444	99.181	281.0	613.37	1633.63	13743.058	29.72	1427.47	346.83	396.92	0.00	123
7	1.1338	101.111	281.4	625.18	1621.82	13918.375	29.84	1430.42	349.77	396.58	0.00	122
[illegible]	1.1232	103.057	281.7	637.07	1609.93	14093.626	29.97	1433.35	352.70	396.15	0.00	121
1	1.1127	105.000	282.1	648.95	1598.05	14267.419	30.09	1436.24	355.60	395.66	0.00	120

d_B (ft)	$(C_DS_0)_S$ (ft^2)	$(C_DS_0)_B$ (ft^2)	D_B (lb)	D_D (lb)	D_M (lb)
	1419.31				
8.13	1445.30	25.99	42.55	554.55	1769.53
10.19	1460.05	40.74	65.82	547.05	1745.59
11.63	1472.45	53.14	84.82	540.54	1724.82
12.78	1483.49	64.19	101.32	534.61	1705.89
13.76	1493.61	74.30	116.08	529.08	1688.23
14.60	1503.04	83.73	129.52	523.84	1671.52
15.36	1511.91	92.60	141.86	518.85	1655.59
16.04	1520.32	101.01	153.32	514.05	1640.28
16.66	1528.36	109.05	164.03	509.41	1625.49
17.24	1536.07	116.76	174.07	504.92	1611.15
17.78	1543.49	124.18	183.54	500.55	1597.20
18.29	1550.64	131.33	192.46	496.29	1583.61
18.76	1557.57	138.26	200.91	492.13	1570.33
19.21	1564.28	144.98	208.93	488.05	1557.33
19.64	1570.82	151.51	216.55	484.05	1544.57
20.05	1577.18	157.87	223.82	480.13	1532.03
20.44	1583.35	164.05	230.70	476.27	1519.74
20.81	1589.38	170.07	237.27	472.48	1507.63
21.17	1595.27	175.97	243.55	468.74	1495.69
21.51	1601.04	181.73	249.55	465.05	1483.92
21.84	1606.69	187.38	255.29	461.40	1472.29
22.16	1612.20	192.89	260.75	457.81	1460.82
22.47	1617.60	198.29	265.97	454.25	1449.48
22.77	1622.90	203.59	270.97	450.74	1438.26
23.06	1628.12	208.81	275.76	447.25	1427.15
23.34	1633.24	213.93	280.35	443.80	1416.14
23.61	1638.24	218.93	284.70	440.39	1405.25
23.88	1643.16	223.85	288.86	437.01	1394.46
24.13	1648.01	228.70	292.85	433.65	1383.75
24.38	1652.78	233.47	296.66	430.32	1373.11
24.63	1318.93	238.18	354.32	0.00*	1607.56
24.85	1323.20	242.56	357.82	0.00	1594.17
25.06	1327.32	246.67	360.98	0.00	1581.43
25.27	1331.38	250.74	364.00	0.00	1568.76
25.47	1335.40	254.76	366.86	0.00	1556.18
25.67	1339.38	258.73	369.59	0.00	1543.67
25.86	1343.26	262.61	372.13	0.00	1531.28
26.05	1347.10	266.45	374.53	0.00	1518.96
26.23	1350.90	270.25	376.80	0.00	1506.70
26.42	1354.66	274.01	378.95	0.00	1494.50
26.59	1358.38	277.74	380.98	0.00	1482.34
26.77	1362.03	281.38	382.84	0.00	1470.28
26.94	1365.64	285.00	384.59	0.00	1458.27
27.11	1369.23	288.58	386.23	0.00	1446.29
27.27	1372.78	292.13	387.75	0.00	1434.36
27.44	1376.30	295.65	389.17	0.00	1422.46
27.60	1379.73	299.08	390.42	0.00	1410.66
27.75	1383.13	302.49	391.57	0.00	1398.88
27.91	1386.51	305.86	392.61	0.00	1387.13
28.06	1389.86	309.21	393.56	0.00	1375.41
28.21	1393.19	312.54	394.41	0.00	1363.71
28.36	1396.44	315.80	395.12	0.00	1352.08
28.50	1399.67	319.03	395.73	0.00	1340.46
28.65	1402.88	322.24	396.26	0.00	1328.86
28.79	1406.07	325.43	396.69	0.00	1317.27
28.93	1409.25	328.60	397.03	0.00	1305.69
29.06	1412.33	331.69	397.23	0.00	1294.18
29.20	1415.41	334.76	397.34	0.00	1282.67
29.33	1418.46	337.81	397.37	0.00	1271.17
29.46	1421.50	340.85	397.32	0.00	1259.67
29.59	1424.52	343.87	397.18	0.00	1248.17
29.72	1427.47	346.83	396.92	0.00	1236.71
29.84	1430.42	349.77	396.58	0.00	1225.25
29.97	1433.35	352.70	396.15	0.00	1213.78
30.09	1436.24	355.60	395.66	0.00	1202.40

LEGEND

H	Altitude
σ	Atmospheric density ratio (ρ/ρ_0)
P	Atmospheric pressure
L/M ratio	Lift/Mass ratio lb lift/lb gas
Δt	Time differential
$\Sigma\Delta t$	Cumulative differential
V_e	System equilibrium descent velocity
q	Dynamic pressure
$\Sigma\Delta$MHe	Cumulative quantity of Helium transferred
$\Sigma\Delta$L	Cumulative buoyancy added to system
W_S	Overall system loading on parachutes
V_B	Volume of gas bubble
d_B	Diameter of gas bubble
$(C_DS_0)_S$	Total effective drag area
$(C_DS_0)_B$	Effective drag area of gas bubble (balloon)
D_B	Drag of Balloon
D_D	Drag of Drogue
D_M	Drag of Main Chute

Note 1. $D_B + D_D + D_M = D_S = W_S$ at Equilibrium Velocity

Initial Conditions:

H_e Temp. = 258.0°K

Transfer Rate = 0.3642 lbs/s

Air Temp = 258.6°K

Initial Δt = 3.80 s

Drag Area Main Chute = 1080.65 ft^2

Wt Drogue and Howre = 128.00 lb

Drag Area Drogue = 338.66 ft^2

Lift at Drogue Rel = 275.00 lb

*Drogue Cut-away Point

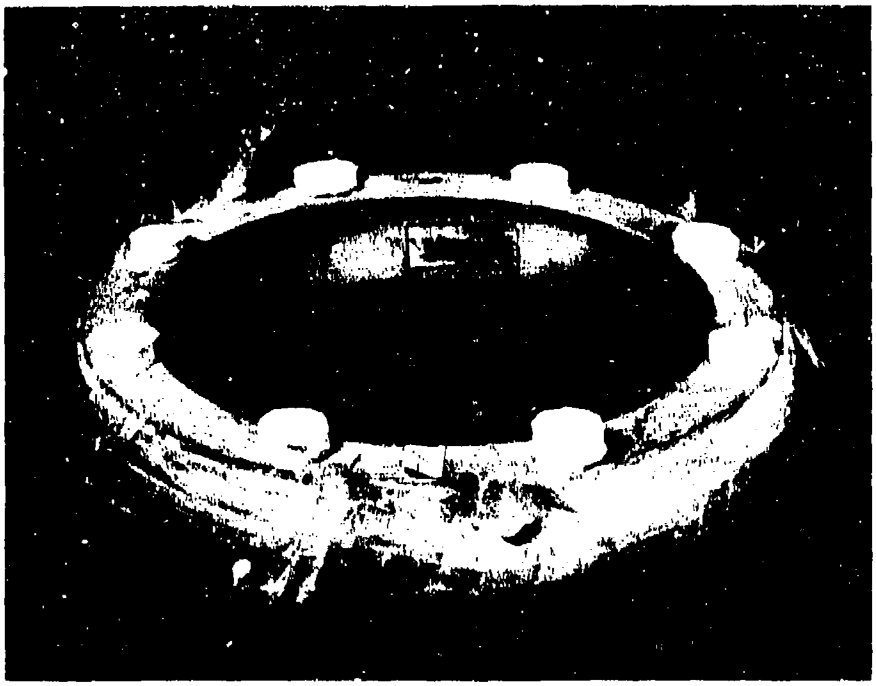


Figure 41. Second Full-Scale Test – Recovered Base Casting and Balloon Remnants

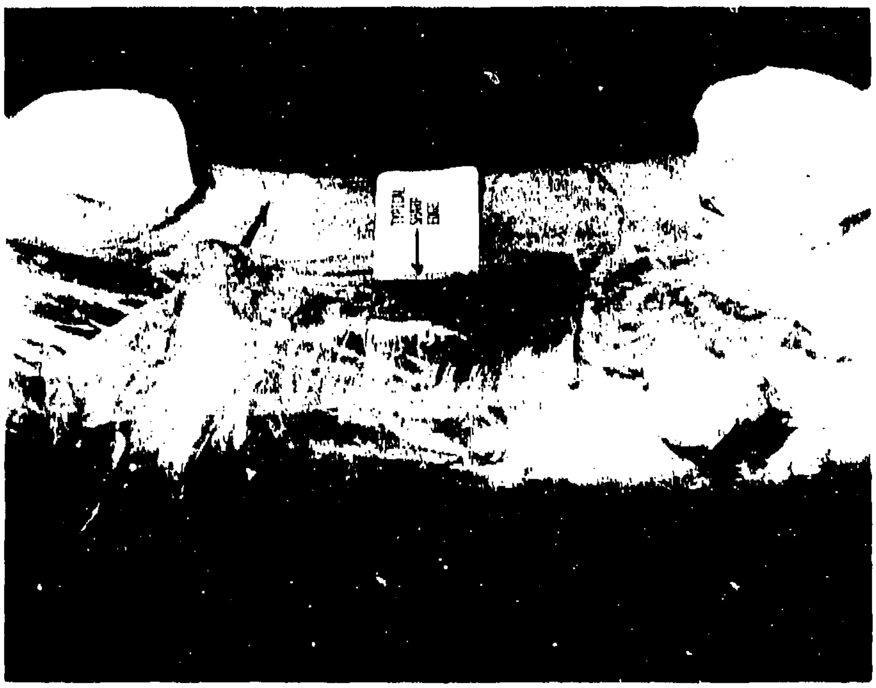


Figure 42. Second Full-Scale Test – Recovered Base Casting, Closeup of Sharp and Rough Edges

situations which temporarily exceeded the recommended balloon load or introduced excessive localized forces. The resultant peak loads, in conjunction with the rough edges on the base casting, were too much for the balloon to handle. The distortions in the balloon's shape, incidentally, were caused at least partially by the fact that the reefing sleeve was less effective than planned in containing slack balloon material.

4.5 Test Flight Data

4.5.1 INTRODUCTION

The CCT Subsystem has already been described at length (section 3.9). The performance of that subsystem during the two full-scale tests will now be examined in some detail.

4.5.2 TIMED CONTROL FUNCTIONS

The timer is the primary control for the cryogenic unit functions. Before each flight, its performance was thoroughly checked at NBS, Boulder, in full-length live runs with the cryogenic unit.* It was also rechecked on the ground (dry runs) at Holloman AFB, the day before each full-scale flight test. These checks showed the timer to be precise, fully repeatable, and very reliable — an evaluation which was verified in flight.

In the first full-scale test (17 March 1981), the failure occurred at t_o + 140 s. The test was terminated at approximately t_o + 250 s. The telemetry records (see paragraph 4.5.4) and the behavior of the balloon indicate that the events through t_o + 40 s on Table 1 took place as scheduled. The two events at t_o + 180 s also occurred on schedule in all likelihood (no recorded event markers), but were irrelevant to the test because: 1) The "Drogue Release Inhibit Override" radio command was purposely not sent (see paragraph 3.9.4), and 2) the gas from the cryogenic unit was, by that time, venting to the atmosphere.

Once the balloon and the drogue parachute had separated from the main parachute (see paragraph 4.3.3), the ALBS module was being supported by the main parachute only and it began to accelerate downwards. To prevent excessive altitude loss, the "Cryo Drop" event, which the timer was to initiate at t_o + 340 s, was commanded prematurely by energizing HF Channel 13 at t_o + 250 s.

At "Cryo Drop," the CCT pack is permanently separated from the cryogenic unit and the pull-away plug connection to that unit [see Figure 28b] is broken. This means that the timer is no longer controlling the cryogenic unit and, thus, any cryogenic events that have not taken place before pull away will not be initiated at

*Actually, a "mini" version of the CCT subsystem (timer circuits only) was used at Boulder in August 1981, to simplify the problem of quickly transporting equipment between test preparation sites.

the scheduled times. In the test under discussion, the impact of the early disconnect action was negligible. The cryogenic unit simply shut down early. (At recovery, it still had some LHe on board.) The VHF antenna was dropped on schedule, t_o + 350 s, however, because it is independent of the cryogenic unit.

In the second full-scale test (1 September 1981) the failure occurred at t_o + 165 s (see paragraph 4.4.2). Unlike the first test, however, HF Channel 13 was not energized to effect "Cryo Drop" prematurely. The drop was initiated at t_o + 340 s by the timer. This meant that all of the events of Table 1 were carried out on schedule.* It also signified that the cryogenic unit made a complete mid-air run, even though the He was simply being vented to the atmosphere after t_o + 165 s. This circumstance provided valuable performance data on the cryogenic unit and pointed up the partial return of the channeling problem. (See also paragraphs 3.5 and 4.5.6.)

4.5.3 HF/UHF COMMANDS

The Table 2 commands were functionally tested and verified on the ground (through live transmissions) at Holloman AFB before each full-scale test. During the actual flight tests, however, only one radio command was actually used, the "Drop Cryogenic Inflation Unit" command (HF Channel 13), which was employed successfully in the first test. In the second there was an intent to employ this channel, but the timer initiated the event before the command could be transmitted. HF Channel 1, the "Drogue Chute Release Inhibit Override" channel, was "selected," that is, made ready for activation in the second test, but was not actually energized.

It should be noted here that the decision to initiate a radio command is dependent on real-time knowledge of the events taking place. In the balloon inflation sequence, where many events occur in rapid succession, the project officer must rely on verbal reports, transmitted from the chase aircraft, or on relayed television camera coverage of the events. Ideally, he has both sources of information at his disposal. This was the case in the first full-scale test. In the second test, there was no TV signal at the control center until t_o + 250 s. By that time, the failure had already occurred. The exact nature of the failure had not been made clear by the verbal reports and, when TV coverage finally appeared on the control room monitor, there was a time delay while the true situation was ascertained. Then, when the decision was made to terminate the test via HF Channel 13, the timer was already in the process of initiating the event.

Many of the Table 2 commands pertain to events connected with the balloon flight which was to follow the inflation sequence. Because of the test failures, no such flight took place and, thus, there was no occasion to employ the flight-oriented

*The drogue parachute separation did not actually take place, however, because, as in the first test, the "Drogue Release Inhibit Override" radio command was not transmitted.

commands. Even so, the instantaneous execution of the Cryo Drop command in the first test was an excellent indication of the command system's efficiency.

4.5.4 TELEMETRY SYSTEM PERFORMANCE

During both full-scale tests, the encoded data outputs listed on Table 3 were transmitted flawlessly from the CCT package, from the opening of the C-130's cargo door until flight termination. On the first test, there was no real time data reception at Balloon Flight Control, however, due to noise in the S-band link between the WSMR mountain top relay station and the Control Center (see paragraph 3.9.5.3). The data had been recorded at the relay station, however, and were retransmitted and analyzed later. During the second full-scale test the telemetry relayed from the mountain top was received in real-time and the data were printed out as the test progressed.

4.5.5 PRESSURE DATA

Encoded pressure transducer voltages were telemetered back from two locations on the ALBS cryogenic unit. The first set of readings, P1, was from the transducer that measured pressure inside the dewar. The second, P2, was from a transducer placed between the dewar and the heat exchanger.

The normal range of pressure values for P1 (as determined from the voltage readings) is from 15 to 85 psi (103.4 to 586.1 kPa). For P2 the range is from 6 to 40 psi (41.37 to 275.8 kPa). However, during the March 1981 test, P1 out-of-range pressure values of 100 psi (689.5 kPa) were obtained. (The P2 values were within range.) The P1 values were highly questionable in view of the fact that the pressure regulator for the dewar was set at 70 psi (482.6 kPa) and the pressure relief valve was set at 75 psi (517.1 kPa). It was later discovered that the pressure sensor (Celesco model P2805) was abnormally sensitive to extraneous electrical noise and physical jarring. To get around this problem, the sensor output signal ground was changed, before the September test, by adding a low pass filter to eliminate the undesirable noise. This change proved to be very effictive. The P1 trace from the September 1981 test was particularly valuable in that it showed that the pressurization system functioned as planned during the entire mid-air inflation cycle, despite the tearing away of the balloon.

4.5.6 TEMPERATURE DATA

The temperature of the He gas, as it leaves the mixer aft of the heat exchanger and heads for the balloon, is critically important. As mentioned in paragraph 3.5.4.4, an allowable range (218° to 323°K) had been established, to stay within the gas temperature limits which the polyethylene film could tolerate without degradation. Within that range, the gas temperature value is primarily an indicator of gas buoyancy. If the gas is too cold, relative to ambient air temperatures, lift is seriously reduced and the inflated balloon might not rise when released. A key parameter here is the Lift to Mass (L/M) ratio, which determines how many pounds of lift a given quantity (lb) of He will produce. A nomogram, Table 8, was developed to predict the approximate lift (including free lift) that could be expected, under particular free air and gas temperature conditions, for a given quantity of He transferred from the dewar to the balloon. (Gas and air pressures are assumed to be equal. Appendix B gives the rationale behind the nomogram.)*

For example, referring to Table 8(a), if the average air temperature during inflation is 270°K and the average gas temperature is the same, the L/M value is the nominal 6.245. If 103 lb (458 N) of LHe are transferred to the balloon, the resultant lift is 643 lb (2860 N), found by reading down vertically from the intersection of the horizontal 103 lb quantity line and the diagonal 6.245 L/M line on Table 8. If the balloon system weighs 600 lb (2669 N), this corresponds to a free lift of 7.2 percent, per Table 8(b). If, on the other hand, the average gas temperature is only 250°, with the average free air temperature remaining at 270°, the L/M value decreases to 5.71. In this case the lift is less than 600 lb, which means that a 600 lb system would have no buoyancy and would descend.

During the two full-scale ALBS flight tests in 1981, two thermistors [Gulton Models VT-20 (range: 228-293°K) and VT-30 (range: 253-328°K)] were mounted inside the gas filler pipe, to measure the temperature of the He as it left the mixer. Encoded temperature sensor voltages were telemetered back to Balloon Flight Control on data channels 9 and 11 (see Table 3). In the 17 March test, the recorded gas temperatures were higher than anticipated, peaking at 327.7°K, 4.7°K higher than allowed. This in-flight maximum temperature was also 12° higher than that recorded at NBS, Boulder, Colorado, in November of 1980 (paragraph 4.3.2.2). In addition, the 17 March test temperatures stayed at 300° or above almost to test termination at t_o + 250 s (see paragraph 4.5.2), whereas, at Boulder, the temperatures had begun to tail off after 150 s, decreasing to about 220°K at t_o + 250 s.

There was some reluctance at first to believe the recorded temperatures from the March test, but this was dispelled when a post flight recalibration of the sensors proved their accuracy. It was concluded that the gas was indeed quite warm although there was no evidence of any degradation in the balloon or inflation tubing material as a result. Because the ambient air temperature was relatively cold on the day of the test, about 244°K at the start of inflation, the system would have been unusually buoyant, had the inflation process gone through to completion.

One minor change was made to the cryogenic unit's fluid transfer lines in preparation for the September 1981 full-scale test: The flow restriction orifice

*The program by which Table 7 was generated computes lift more exactly and is a more thorough diagnostic approach. The reader is referred to Appendix E of AFGL-TR-78-0074[1] for an explanation of that program.

Table 8. ALBS Balloon Lift Nomogram

Procedure

1. Find L/M Ratio on Table 8a from knowledge of T_{He}, T_{air}.
2. Find intersection of diagonal L/M Line and horizontal LHe (lb) line. Read down to find Available Lift (lb).
3. From Table 8b find % Free Lift from knowledge of available lift and balloon load.

Lift (lb) = L/M × LHe

$$L/M = 7.245 \cdot \frac{T_{He}}{T_{air}} - 1 = 6.245 \text{ when } T_{He} = T_{air}$$

Table 8a. Lift to Mass (L/M) Ratios, per T_{He} and T_{air}

T_{He} ↓	Ambient Air Temperatures (T_{air}) in °K								
°K	245	250	255	260	265	270	275	280	285
245	6.245	6.10	5.96	5.83	5.70	5.57	5.45	5.34	5.23
250	6.39	6.245	6.10	5.97	5.83	5.71	5.59	5.47	5.36
255	6.54	6.39	6.245	6.11	5.97	5.84	5.72	5.60	5.48
260	6.69	6.53	6.39	6.245	6.11	5.98	5.85	5.73	5.61
265	6.84	6.68	6.53	6.38	6.245	6.11	5.98	5.86	5.74
270	6.96	6.82	6.67	6.52	6.38	6.245	6.11	5.99	5.86
275	7.13	6.97	6.81	6.66	6.52	6.38	6.245	6.12	5.99
280	7.28	7.11	6.96	6.80	6.66	6.51	6.38	6.245	6.12
285	7.43	7.26	7.00	6.94	6.79	6.65	6.51	6.37	6.245

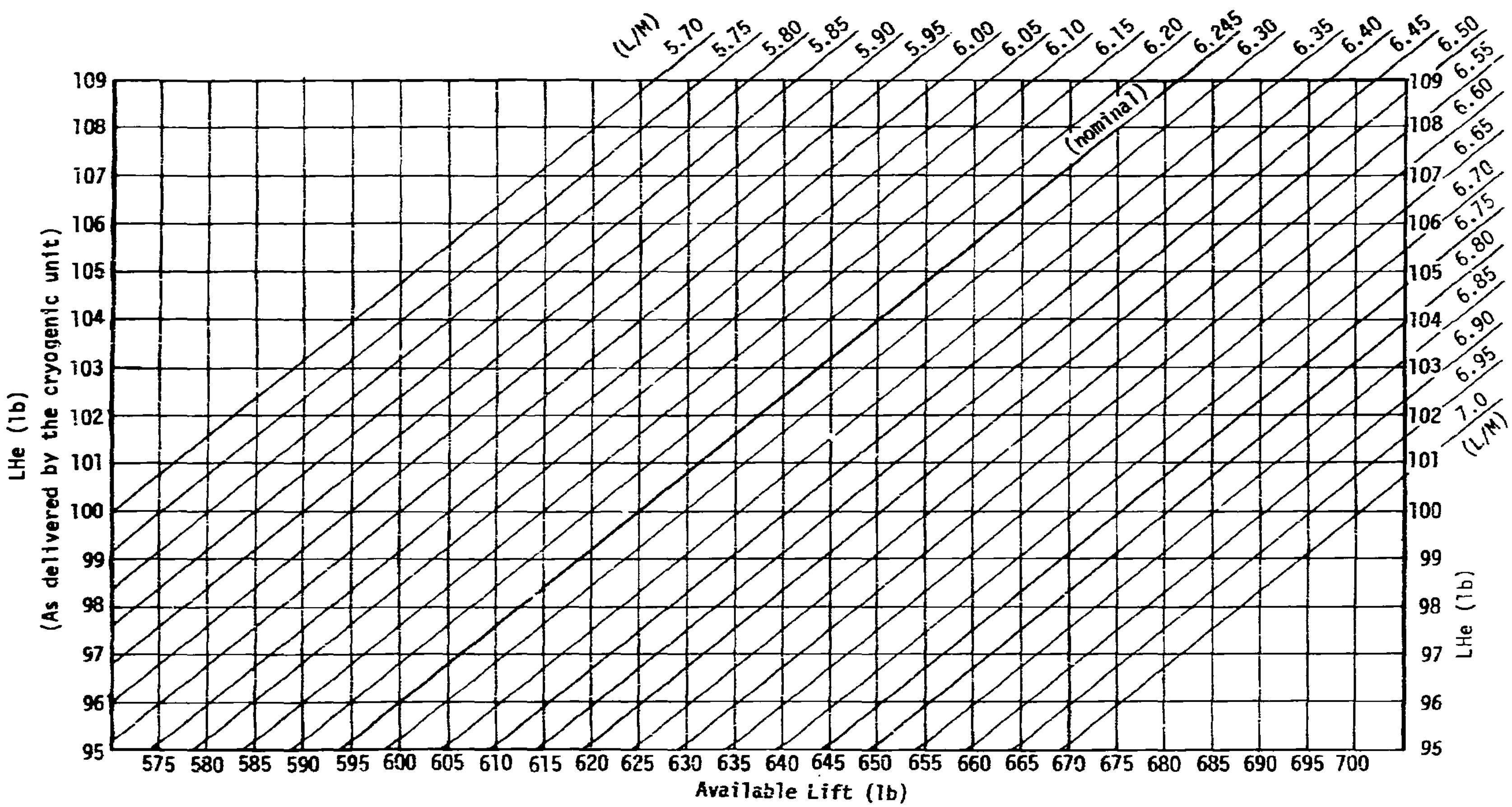
Table 8b. Percent Free Lift, Per Gross Weight of System and Available Lift

		Available Balloon Lift (lb)	→	590	595	600	605	610	615	620	625	630	635
Balloon System	575 lb;	Free Lift %	→	2.61	3.48	4.35	5.22	6.09	6.96	7.83	8.70	9.57	10.35
Gross Weight:	590 lb;	Free Lift %	→	0	0.85	1.69	2.54	3.39	4.24	5.08	5.93	6.78	7.63
(Balloon plus payload):	600 lb;	Free Lift %	→	-	-	0	0.83	1.67	2.5	3.33	4.17	5.0	5.83
	615 lb;	Free Lift %	→	-	-	-	-	-	0	0.81	1.63	2.44	3.25

		Available Balloon Lift (lb)	→	640	645	650	660	670	680	690	700
Balloon System	575 lb;	Free Lift %	→	11.30	12.17	13.04	14.78	16.52	18.26	20.00	21.74
Gross Weight:	590 lb;	Free Lift %	→	8.47	9.32	10.17	11.86	13.56	15.25	16.95	18.64
(Balloon plus payload):	600 lb;	Free Lift %	→	6.67	7.50	8.33	10.00	11.67	13.33	15.00	16.67
	615 lb;	Free Lift %	→	4.07	4.88	5.69	7.32	8.94	10.57	12.20	13.82

Table 8. ALBS Balloon Lift Nonogram (Cont.)

Table 8c. Chart



in the heat exchanger line was reduced by 5 to 7 percent. It was hoped that this would keep the gas temperatures within the allowable range while not lowering them substantially. The values actually recorded on 1 September were sharply lower than anticipated, however, and exhibited a reduction which could not have been caused by the orifice change alone. On that date, the maximum recorded gas temperature was 274°K, at t_o + 120 s. The temperature value declined sharply thereafter, to 236°K at t_o + 150 s and to off-scale minimal values for the remainder of the test (see Figure 43). Thus, had the inflation process gone to completion, there would have been some question about the amount of free lift available, particularly in view of the relatively warm ambient temperatures that day (approximately 259°K at the start of inflation). Possible compensating factors would have been adiabatic, conductive, and solar warming of the He gas and the availability of as much as 110 lb of LHe from the dewar.

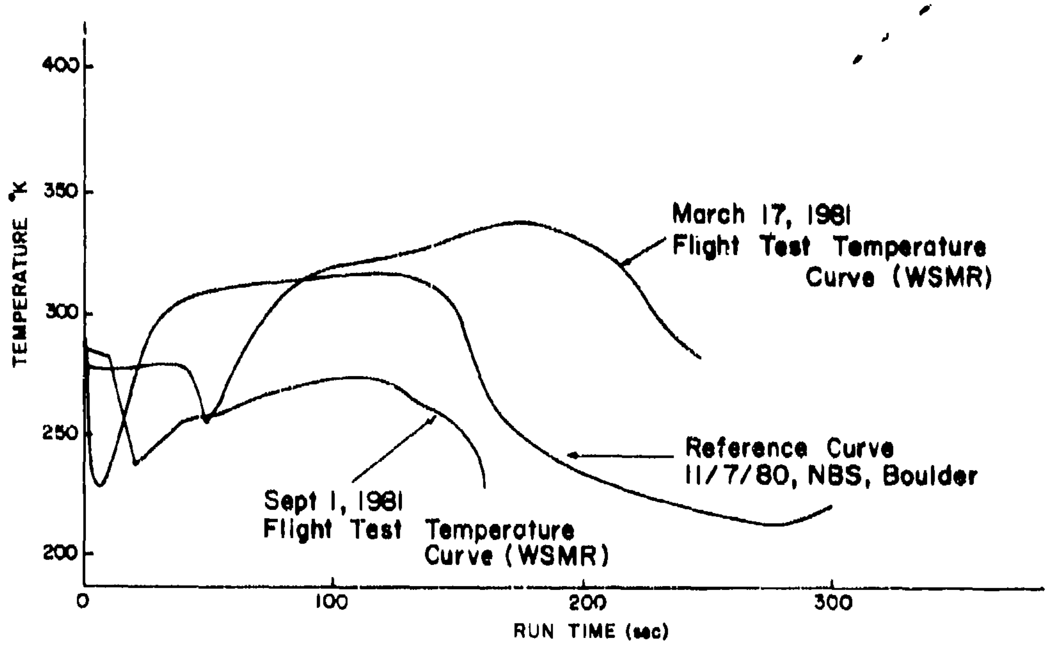


Figure 43. ALBS Cryogenic Unit Temperature Curves

It is impossible to say whether or not the system would have been buoyant on 1 September. It is clear, however, that channeling (see paragraph 3.5.4.3) was recurring, indicating that the arrangement of the packed bed of Al_2O_3 pellets in the heat exchanger had been disturbed between the two tests. It is believed that the bed was jarred into an exceptionally dense configuration by deployment shocks during the March test. In the September test the tight packing was apparently missing, indicating that it is not a permanent design feature and is affected by deployment and handling. This is clearly an area of further investigation in any continuation of the ALBS development program. Also, the diagnostic value of the telemetered temperature recordings is readily apparent here.

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Phase II of the ALBS Development Program has been described in its entirety, from the establishment of the new system configuration in 1978 to the full-scale tests of 1981. By the end of the program, it had been shown that the large-scale air-launched concept was feasible and could be executed routinely from standard Air Force cargo aircraft. Mid-air inflation of the balloon from a cryogenic source and recovery of the inflation hardware had also been demonstrated successfully. However, a structural weakness in the balloon prevented realization of the program's final objective, that is, a successful balloon flight following the mid-air inflation. Erratic behavior on the part of the hot-bed heat exchanger was also observed.

The balloon's weakness is believed to be correctable through selective reinforcement of areas subjected to severe dynamic stresses. The channeling which degraded the performance of the heat exchanger is also seen as correctable, through a design modification. If these two faults are corrected, there appears to be no reason why all of the original ALBS objectives could not be achieved. A relatively short third phase of the program should suffice to qualify the modified balloon and heat exchanger.

If a Phase III is authorized, the balloon design modification should be preceded by an analysis of the aerodynamic interaction between the descending main parachute and the inflating balloon. This analysis would, presumably, both identify the true causes of the balloon stresses observed in the full-scale tests and point up appropriate stress alleviation methods, including the aforementioned structural reinforcement.

6. ADDENDUM

Parts of this report were presented in a paper given at the AIAA 7th Aerodynamic Decelerator and Balloon Technology Conference, San Diego, California, 21-23 October 1981.[7]

7. Carten, A.S., Jr., and Wuest, M.R. (1981) The Air-Launched Balloon System (ALBS) Phase II Design Improvement and Test Program, AIAA Paper 81-1930, AFGL-TR-81-0310, AD A107 214.

References

1. Carten, A.S., Jr. (1978) Flight Test of the Air Launched Balloon System (ALBS) Model, AFGL-TR-78-0074, AD A057 610.
2. Wuest, M.R. (1981) The Air Launched Balloon System, Phase II, AFFTC-TR-81-33.
3. Massey, W.N., and Wuest, M.R. (1978) Air Launched Balloon System, AFFTC-TR-42.
4. Gianetti, A., and Erickson, J.C. (1980) AFGL Balloon Telemetry Facility, AFGL-TR-80-0029, AD A084 811.
5. Laping, H. (1980) BCS-18A Command Decoder Selector, AFGL-TR-80-0249, AD A099 384.
6. Laping, H. (1980) A Poor Man's Balloon Control and Data System, a paper presented at the International Telemetering Conference, San Diego, California, 14-16 October 1980.
7. Carten, A.S., Jr., and Wuest, M.R. (1981) The Air-Launched Balloon System (ALBS) Phase II Design Improvement and Test Program, AIAA Paper 81-1930, AFGL-TR-81-0310, AD A107 214.

Appendix A

Specification Design Data Sheets

1. LHe Dewar	
1.1. Capacity	377 l (103.8 lb), plus 10 percent ullage at 4.22 K, 14.7 psia (101 kPa)
1.2. Maximum test pressure	100 psia (689 kPa)
1.3. Design operating pressure	75 psia (517 kPa)
1.4. LHe boiloff rate	3 percent per 24 h
2. LHe Dewar Piping	
2.1. Design flow rate	0.353 lb/s (0.16 kg/s) at 4.2 K, 14.7 psia (101 kPa)
2.2. Discharge tube I.D.	0.4 in. (1.1 cm) diameter
2.3. Pressurization tube I.D.	0.4 in. (1.1 cm) diameter
2.4. Pressure drop in liquid discharge valve	5 psi (34.5 kPa) at design flow rate
3. Acceleration Forces*	
3.1. In the aircraft	
3.1.1. Force	3 g
3.1.2. Aft	9 g
3.1.3. Up	4.5 g
3.1.4. Down	2 g
3.1.5. Lateral	1.5 g

*These forces are relative to the ALBS; therefore, 9 g aft causes a force equivalent to nine times the weight to be applied to the ALBS load supports in the forward direction and 4.5 g up causes a force 4.5 times the weight to be applied to the ALBS supports in the downward direction.

3.2. In the balloon fill position.*

3.2.1. Up — 9 g

3.3. ALBS recovery

3.3.1. Up — 5 g

4. Leakage Rates in Aircraft Loaded Position†

4.1. Main LHe valve

4.1.1. Leakage at 16 psia (110.3 kPa) with dewar full of LHe — 3 standard cm^3/s He gas

4.2. Automatic quick disconnect valve

4.2.1. Leakage at 16 psia (110.3 kPa) – 10 s after disconnecting from the dewar full of liquid and venting at boiloff rate – — 20 standard cm^3/s He gas at 80 K

4.3. Pressure relief valve

4.3.1. Leakage at 0 to 16 psia (110.3 kPa) — 3 standard cm^3/s He gas

5. Leakage Rates in Balloon Fill Position†

5.1. Main LHe valve

5.1.1. Leakage at design dewar pressure with dewar full of LHe — 2000 standard cm^3 of He gas

5.1.2. Leakage after liquid flow — no visible liquid discharge

5.2. Automatic quick disconnect valve

5.2.1. Leakage at design dewar pressure 30 s after disconnecting from the dewar full of liquid and venting at boiloff rate. — 2000 standard cm^3/s of He gas

5.3. Pressure relief valve

5.3.1. Leakage at 60 psia (465 kPa) — 30 standard cm^3/s of He gas

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*This 9 g force is identical to the 9 g aft aircraft load.

†Standard cm^3 He in this specification means He gas at 15°C and 14.7 psia (101 kPa).

Appendix B

Helium Lift Considerations

Table 8 in the main text uses the Lift to Mass (L/M) Ratio for helium in determining the amount of lift obtainable under certain conditions (helium quantity, air temperature, gas temperature).

The L/M ratio is defined as the ratio of the specific lift of He to the density of He, where the specific lift of He equals the density of air minus the density of He, or:

$$\text{L/M ratio} = \left(\frac{\rho_{air} - \rho_{He}}{\rho_{He}}\right) = \left(\frac{\rho_{air}}{\rho_{He}} - 1\right) . \tag{1}$$

Let $\rho_{2,air}$ and $\rho_{2,He}$ represent air and helium densities at a particular altitude. Also, let $\rho_{1,air}$ and $\rho_{1,He}$ represent standard MSL densities of air and helium at a pressure (P_1) of one atmosphere and a temperature (T_1) of 288°K, whence:

$$\rho_{1,air} = \rho_{MSL,air} = 0.07651 \text{ lb/ft}^3 \ (12.02 \text{ N/m}^3) \tag{2}$$

and

$$\rho_{1,He} = \rho_{MSL,He} = 0.01056 \text{ lb/ft}^3 \ (1.66 \text{ N/m}^3) . \tag{3}$$

The density of a gas at a new set of conditions (temperature, pressure) can be obtained from a reference density by the general relationship:

$$\rho_2 = \rho_1 \cdot \frac{T_1}{T_2} \cdot \frac{P_2}{P_1} \tag{4}$$

This allows the following three equations to be written:

$$\rho_{2,air} = \rho_{1,air} \cdot \frac{T_1}{T_2} \cdot \frac{P_2}{P_1} = 0.07651 \cdot \frac{288}{T_2} \cdot \frac{P_2}{1} = 22.035 \frac{P_2}{T_2} \tag{5}$$

and

$$\rho_{2,He} = \rho_{1,He} \cdot \frac{T_1}{T_2} \cdot \frac{P_2}{P_1} = 0.01056 \cdot \frac{288}{T_2} \cdot \frac{P_2}{1} = 3.0413 \frac{P_2}{T_2} \tag{6}$$

whence:

$$\text{L/M ratio} = \left(\frac{22.035}{3.0413} \cdot \frac{P_{2,air}}{P_{2,He}} \cdot \frac{T_{2,He}}{T_{2,air}} - 1\right) \quad . \tag{7}$$

If it is assumed that the gas pressure in a zero-pressure balloon, $P_{2,He}$, is equal to the external ambient air pressure, $P_{2,air}$, equation (7) becomes

$$\text{L/M ratio} = \left(7.245 \cdot \frac{T_{2,He}}{T_{2,air}} - 1\right) \tag{8}$$

and

$$\text{L/M ratio} = 6.245, \text{ when } T_{2,He} = T_{2,air}$$

From the above, it can be seen that the temperature of the gas in the balloon and the temperature of the ambient air are important to the lift calculations. Gas and air pressures are not significant as long as they are equal.

It should be noted here that the program that generated Table 7 prints out values of pressure but does not use them in L/M calculations.