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LONG-LINE-LOITER SUPPORT EQUIPMENT

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AEROSPACE MEDICAL RESEARCH LABORATORY

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LEAR SIEGLER, INCORPORATED

MARCH 1971

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13. ABSTRACT

Several applications of the Long-Line-Loiter concept were tested during the period June 1968 to December 1970. The test program used fixed-wing, tow aircraft to place and retrieve remote masses from ground and air positions. Supplies and equipment required to support the research activities and provide for a safe and successful research program included "off the shelf" commercial items and unique hardware designed and fabricated for a specific test. Described and discussed are the various types of equipment used, ranging from airplanes to lines, the methods used to achieve successful test results, and precautions taken against safety hazards. The advantages and disadvantages of the different types of equipment and supplies are presented to aid in the selection of these items for future research.

Key Words: Rescue
Supply missions

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FOREWORD

This research was initiated by the Flight Environment Branch, Human Engineering Division, Aerospace Medical Research Laboratory, under Project No. 7184, "Human Performance in Advanced Systems," Task No. 718405, "Design Criteria for Unusual Flight Environments." The research was performed in part by Lear Siegler, Incorporated, under Contract F33615-69-C-1687. B. C. Dixon was the principal investigator for Lear Siegler, Incorporated.

The authors acknowledge the contributions of George Zelinskas, Chief of the Experimental Parachute Branch, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, for his assistance in designing and modifying parachutes and the Bag Deployment System; and Lieutenant Colonel John Simons, Chief of the Flight Environment Branch and principal investigator on the Long Line Loiter project, for his assistance in the preparation of this report.

The authors also acknowledge the contributions of the following Aeronautical Systems Division Zone Shops personnel who fabricated various hardware used in the Long Line Loiter program: Wilson E. Hyer, Ralph Riepenhoff, David Swars, Fred Fritsch, Orville Fisher, Frank Hogue, Donald Tillman, and William Rentas.

This research was performed during the period June 1968 to December 1970.

This technical report has been reviewed and is approved.

CLINTON L. HOLT, *Colonel, USAF, MC*
Commander
Aerospace Medical Research Laboratory

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SECTION I

INTRODUCTION

Several applications of the Long Line Loiter (LLL) concept were tested during the period of June 1968 to December 1970. The objective was to use fixed-wing, tow aircraft to place and retrieve remote masses from ground and air positions. During this time, it was necessary to test all types of hardware applicable to the research and testing phases of this program. The equipment included airplanes, lines and ropes, line-storage containers, line-handling and line-measuring devices, bombsights, safety items, automatic controls, and communications components.

The various applications studied thus far have been covered in previous reports (see Bibliography) and will not be discussed except where significantly related to equipment.

SECTION II

AIRPLANES

To date, six different type airplanes have been used on the LLL program. The first was a Cessna 175, a four-place high-wing airplane with a 175-hp engine, a fixed-pitch propeller, and fixed landing gear. This airplane, used for the initial three flights was capable of performing a circling maneuver to stall the line and indicate feasibility of the program. However, the low power and lack of a constant-speed propeller made the Cessna 175 inadequate for towing and launching heavy loads.

The second airplane used was a Cessna 182 which is similar to the 175, except that it has a 230-hp engine and a constant-speed propeller. This airplane was suitable for towing and launching masses weighing up to 100 pounds, but its performance becomes marginal for towing objects above that weight. Sizes of masses were limited by the size of the baggage door opening used for line exit from the airplane.

The Cessna U-206 was the workhorse for the program. It is a high-wing, six-place airplane with a 285-hp engine, constant-speed propeller and fixed landing gear. The airplane, designed to haul cargo, has removable double-doors opening on the right side. This larger opening facilitated the ease of handling the line as it exited the airplane and allowed larger size masses to be deployed from the air. The increased horsepower allowed pickups of masses up to 150 pounds before the airplane performance became marginal. A disadvantage of the Cessna U-206 was that the line exited on the right side, making it necessary to fly orbits in a right bank. In order to see the ground while orbiting, the pilot flew from the right seat which made it difficult to see the flight instruments on the left side of the panel. With minimum practice, all pilots who flew the program were able to easily overcome this initial disadvantage.

The Army U-6A, a DeHaviland "Beaver" designed for bush flying, has a high-wing, 450-hp engine, constant speed propeller and a fixed landing gear. The U-6A was very stable at slow airspeeds (70 to 100 mph) making it ideal for LLL flying. It was used to launch dummies weighing up to 231 pounds while launch accelerations of the dummies were measured. This airplane was chosen because of the increased horsepower required to lift heavier dummies which the Cessna U-206 could not safely launch. The authors were convinced that an airplane of the C-7, C-119, C-123, OV-10A or C-130 would be much more suitable for LLL flying due to the inherent safety and greater launch capabilities of the additional power provided by multiple engines. Additionally, the rear-opening fuselage would facilitate handling of line and deployment of larger and heavier masses.

An Air Force Convair C-131 was flown on two flights to prove feasibility of a larger aircraft for the program. During the flight, a 65-pound dummy was launched, air-loitered, and ground-delivered to demonstrate the capabilities of a larger airplane to fly delivery, loiter, and launch maneuvers.

An Air Force OV-10A was flown to prove feasibility and to acquaint the pilot with the LLL program. The orbits were flown at 85- to 90-knot airspeed and 30-degree bank. The installation included a faking barrel and 3500 feet of ⅜-inch nylon line with a tensile strength of 2000 pounds. The double deployment and delivery technique was used to deliver the line to the ground. This technique is detailed in the next section.

SECTION III

METHODS

Several methods were employed to deploy, deliver, and retrieve lines to and from the airplane and the ground. The most widely used was a technique called double-line deployment[1] and skip-bomb delivery. The line was deployed in a large trailing loop, with one end attached securely to the airplane and the other end attached to a weight in a bomb shackle at the airplane (see figure 1). A drag cone was attached at one end of the loop and allowed to slide freely to the trailing end of the line to keep the two lines separated and under tension. The airplane was then flown over the ground target at 500 to 1000 feet above ground, and the weighted end of the line was bombed to the ground. To avoid raising the weighted end of the line off the ground until retrieved by the ground crew, the orbit was started immediately after bomb release. The low altitude use of this method proved to be an accurate technique for delivery to a ground target.

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[1] Patented by J. C. Simons

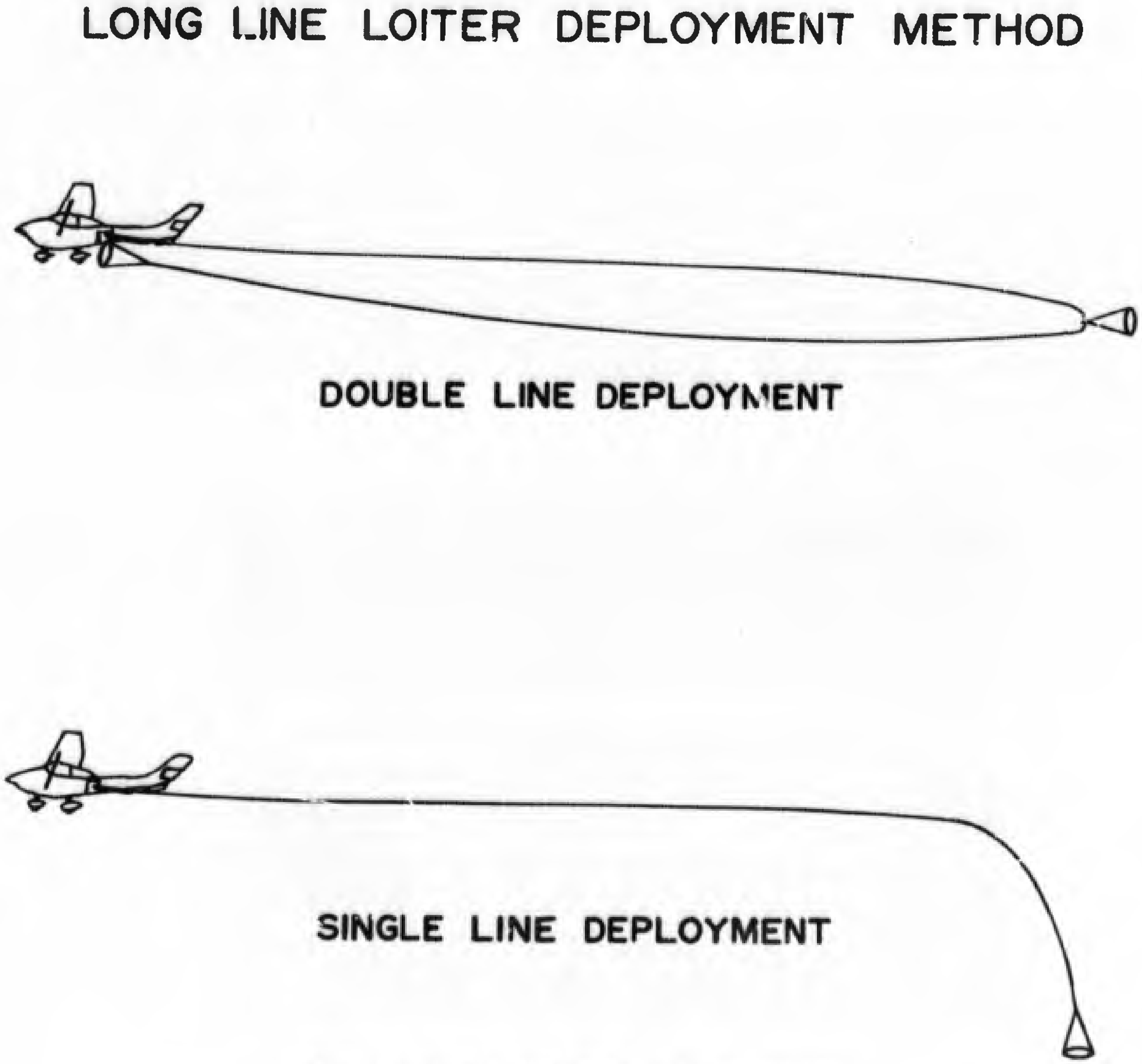

Figure 1. Double- and Single-Line Deployment

Another older technique utilized was that of single-line deployment and delivery. The line was deployed from the airplane in single-line configuration, with a mass on the end of the line (see figure 1). Orbits were started over the ground target to stall the line and drop the weighted end to the ground for retrieval. The disadvantage of this technique was the difficulty in accurately delivering the end of the line. Often it was necessary to retrail and stall the line several times before it was dropped close enough to the ground crew for them to retrieve it conveniently. However, this system can be used where there is a possibility of knotting the double-line during deployment.

A desirable long-line system would be self-contained and require little or no aircraft modifications. In July 1969, the parachute branch of the Aeronautical Systems Division was given the problem of designing and fabricating a bag-type container[2] for deployment of the line and mass. Items specified as contents to be included in the deployment were 2500 feet of 1000-pound-test Dacron® line, a high mass weighing 7 pounds, an additional 600 feet of 1000-pound-test Dacron line, and a low mass weighing 10 pounds.

The first package involved winding the line on a spool, then removing the spool and packaging the roll of line in a manner to allow the line to pay out from the center of the roll. The objective was to place the 10-pound low mass on the ground while the 7-pound high mass remain suspended 600 feet up on the line. This system failed during flight evaluation because the line tended to knot as it payed out at high speeds. The package was redesigned into two interlocked bag compartments. The 2500 feet of line was packaged in one bag compartment with the line wound in skeins (figure 2), and the high and low mass plus the additional 600 feet of line were packaged in the second bag compartment.

During deployment the 2500 feet of line payed out properly. When all 2500 feet of line was out, it activated a circular knife which allowed the low mass, the 600 feet of additional line, and the high mass to deploy from the second bag compartment. During flight test, the system deployed properly, but lack of stretch in the line caused the low mass to separate from the high line and high mass. For the final package configuration, a loop was formed in the high line toward the end by attaching four 10-foot lengths of bungee cord to the line. Deployment shock was absorbed by the bungee cords until the loops in the high line were straight.

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[2] Suggested by J. C. Simons

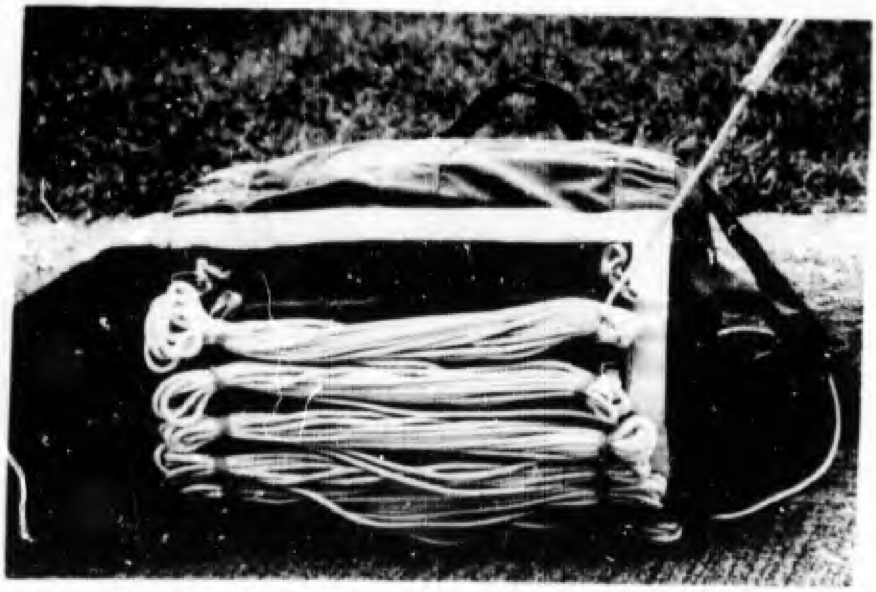

Figure 2. Bag Deployment

SECTION IV

LINES

The sizes and types of line used for the LLL program ranged from ⅛-inch nylon parachute shroud line with 375-pounds-test tensile strength to ½-inch Polypropylene rope with 4200-pounds-test tensile strength. Nylon, polyethelene, polypropelene, and Dacron lines were used (see figure 3). Hollow-woven lines, solid-woven lines, and twisted three-strand rope were tested. Hardwire lines with wire conductors woven within the line were used to conduct signals for several purposes.

Nylon parachute shroud line (⅛-inch) with a tensile strength of 375 pounds was used during early flights but was soon replaced with ⅛-inch nylon parachute shroud line with a tensile strength of 550 pounds. The latter hollow line is woven with seven internal smaller strings of nylon which add strength and body to the line. This line, commercially delivered in rolls of 2100 feet, was spliced by overlapping and sewing two ends. It was used extensively in lengths up to 5500 feet. New line of this type will stretch approximately 15 percent with a 100-pound load applied.

After the line was deployed and reeled in approximately 10 times, it became stretched and twisted. This made it unusable for double-line deployment because of its tendency to form knots in the loop. An emergency line-cutter mounted in the airplane was not considered to be necessary, because the line would break before damage could be done to the aircraft when it inadvertently entangled with a ground object.

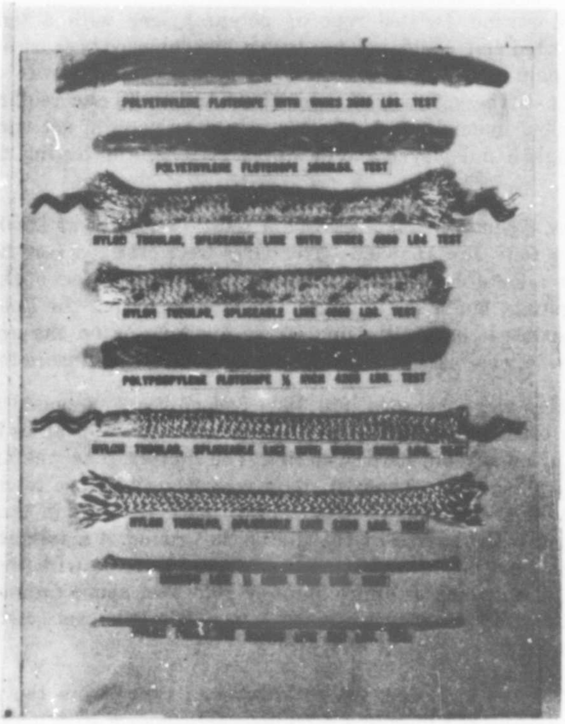

Figure 3. Lines

Solid-woven, 1/4-inch Dacron line with a tensile strength of 1000 pounds was used on tests requiring more than a 550-pound line, but less than a 2000-pound line. It was chosen for the smaller storage space requirement for relatively long line lengths. The line is solid-woven, does not stretch, and cannot be spliced. This line also tended to form knots while being double-line deployed after several uses. The friction of the lines rubbing together in a knot caused them to burn and weaken making this line inferior to the 550 pound-test nylon line for the LLL program.

A 3/8-inch, hollow-woven, polyethylene line with 2000 pounds of tensile strength was used for projects launching masses from 40 to 150 pounds. This line does not stretch, has a very slick finish and never knotted during double-line deployment. This line is very light for its size and tends to ride at a higher altitude during trail which makes is necessary to add more weight to the end of the line for a single-line delivery. The line is yellow which makes it more visible than the white line both from the airplane and the ground. The line is available in 600- or 1200-foot rolls, and it is very easy to splice ends together or splice loops on the ends to hold hooks. A special splicing tool provided splices that were as strong as the line. The line was used in lengths up to 3600 feet.

A hollow-woven, 1/2-inch nylon line with 4000 pounds of tensile strength was used for launching anthropometric dummies. The line stretching tended to reduce launch accelerations of the dummy over non-stretching lines. This line was ideal for deploying double-lines without knotting. This hollow line has a flat cross-section which appeared to provide added lift for launching and towing objects over 200 pounds. Available in 2500 feet lengths, the line was easily spliced with a special splicing tool. The line was more flexible and required less storage space than the polyethylene or twisted strands.

A 1/2-inch, three-strand, twisted rope of polypropylene with a tensile strength of 4200 pounds was tested but could not be double-line deployed because of extensive twisting and knotting. Compared to the hollow-woven types, this line was very difficult to splice. Because of its stiffness, it was more difficult to handle and required more storage space than the flexible nylon line. Also, it was heavier and did not trail as high as the woven line when single-line deployed and delivered. After initial testing, the rope-type line was not used again.

A hollow-woven, 3/8-inch nylon line with a tensile strength of 2000 pounds was internally woven with four No. 16 wires. The wires were crimped (see figure 3) approximately every inch to allow for line stretch. Twenty five hundred feet of the line was single-line deployed for testing, but a static charge was generated on the line to a magnitude which made it impossible to handle the line at the airplane or on the ground, even with heavy gloves. This line was tested on one flight and considered unsafe for use.

Four No. 20 wires were threaded into 3600 feet of the 2000-pound polyethylene line and tested for static electricity. The charge generated did not appear to be of the magnitude as that of the nylon-shroud, hard-wire line. The current flow was measured between the wires and the airplane to determine if there was enough charge to cause a spark discharge. Current readings were taken in the aircraft with the line in trail, with the line stalled in mid-air and with the end of the line on the ground. A maximum current flow of 9 microamperes was read between the wires and the airframe with the end of the line on the ground and the airplane at approximately 2000 feet above ground level. The very low current flow indicated the induced current was tolerable, and tests requiring this type line were continued.

Of all the lines tested and used, the hollow-woven types were the easier to handle, splice and store, and appeared to enhance flying performance with added lift while towing or launching. The more desirable materials were nylon and polyethylene, the choice depending upon whether or not a stretching line is desirable. Due to an undesirable static charge being generated, it was not safe to use a woven nylon line with wires inside the line. Wires woven into a polyethylene line, however, appeared to be safe to handle and use for LLL testing.

SECTION V

LINE-STORAGE EQUIPMENT

Winches with spools and faking barrels[3] were used for line storage in the airplane. Four winches[4] were developed. The first design was a simple hand-cranked spool capable of holding 2000 feet of 1/8-inch line. This winch was used only during the Cessna 175 trials and proved to be an effective tool for use in line storage, line deployment, and retrieval.

The second winch (figure 4) was fabricated for the Cessna 182 airplane and later adapted for the Cessna U-206. The spool could store 5500 feet of 1/8-inch line or over 3000 feet of 1/4-inch line. It was power driven with belts by a 12-vdc reversible landing-gear motor which turned the spool approximately 300 rpm. The winch could reel-in loads of up to approximately 30 pounds.

As the program progressed into heavier line loads, it became necessary to use larger lines with more strength. Because the second winch could not store enough 3/8-inch or 1/2-inch line, another winch was fabricated. The third winch (figure 5) was a larger more rugged unit designed to hold 2500 feet of 1/2-inch line or up to 10,000 feet of 1/4-inch line. The structure was stressed for loads up to 2000 pounds and the spool driven by a 28-vdc,

Figure 4. Second Winch Mounted in Airplane

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[3] Suggested by M. Moran

[4] Designed by B. C. Dixon

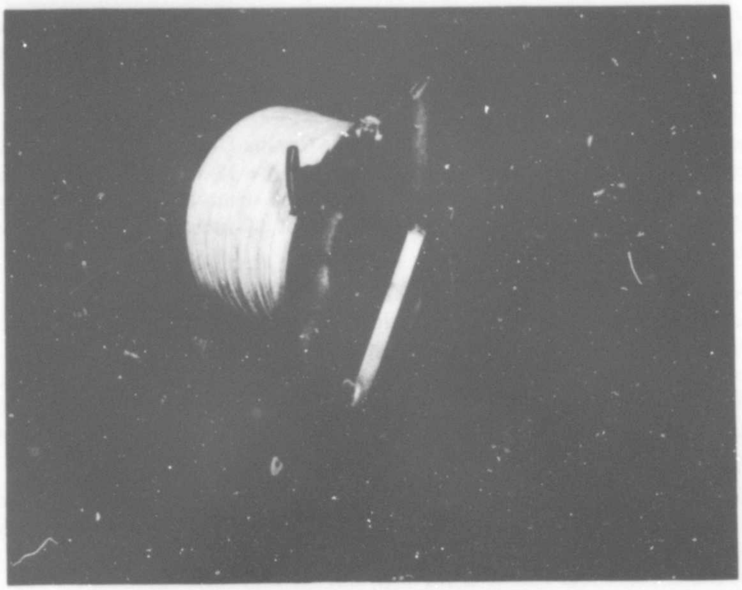

Figure 5. Third Winch, for 2000-Pound Stress

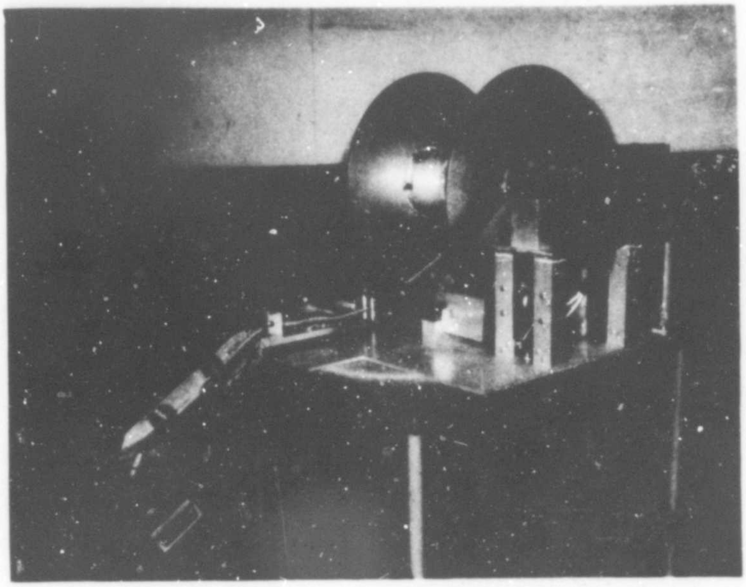

Figure 6. Fourth Winch, for Cessna U-206

4.9-hp motor. The drive mechanism incorporated a four-speed transmission to change the speed of the spool depending on requirements. The winch was designed to be used on larger airplanes with 28-vdc electrical systems. Because of low priorities, the heavy military airplane was never made available; however, plans for a C-130 installation were approved.

A winch was designed and constructed for the Cessna U-206 (figure 6) airplane using the same size spool as the above winch. It is powered by a 12-vdc reversible motor through a 30:1 reduction gear. The spool can store 25,000 feet of nylon parachute-shroud line; 3500 feet of ⅜-inch polyethylene line; or 2500 feet of ½-inch nylon line. The winch has been shop tested but has not been flown.

In order to use heavier lines in the Cessna U-206 airplane, faking barrels (figure 7) have been used for line storage. The barrels were welded on a plate and mounted on the airplane floor. The line was hand-deployed by wrapping it around a barrel for breaking friction. Two thousand feet of ½-inch nylon line can be deployed in 5 to 8 minutes using this method. When the test ended, the airplane was flown over the ground crew and the line released from the airplane to be retrieved by the ground crew. The faking barrel proved to be an inexpensive and effective tool for line storage and deployment.

A hand-cranked winch (figure 8)[5] was designed to wind the line on the ground. It had the capability of storing large quantities of line on spools 36 inches in diameter and 15 inches wide. The spools were easily and quickly replaced, enabling the line to be reeled onto a spool, the entire spool removed for line storage and then immediately replaced with a different spool. This winch proved very effective in the retrieval of line by the ground crew.

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[5] Designed by TSgt. R. Blue

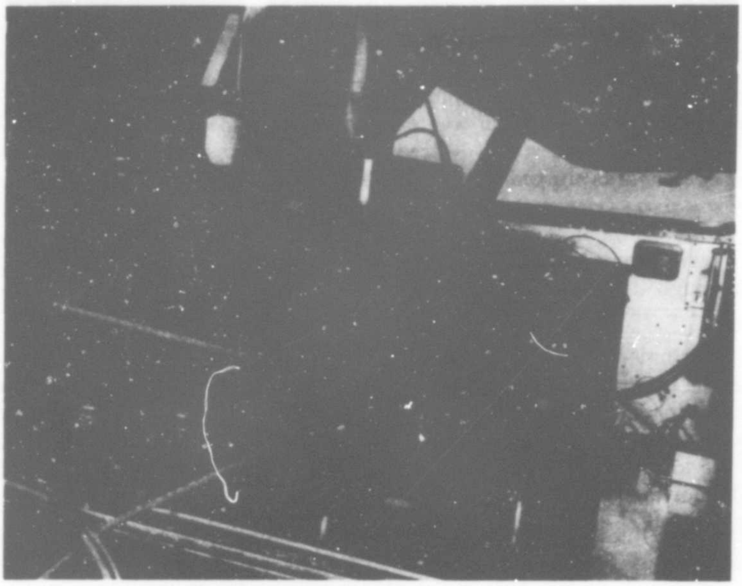

Figure 7. Faking Barrels in Airplane

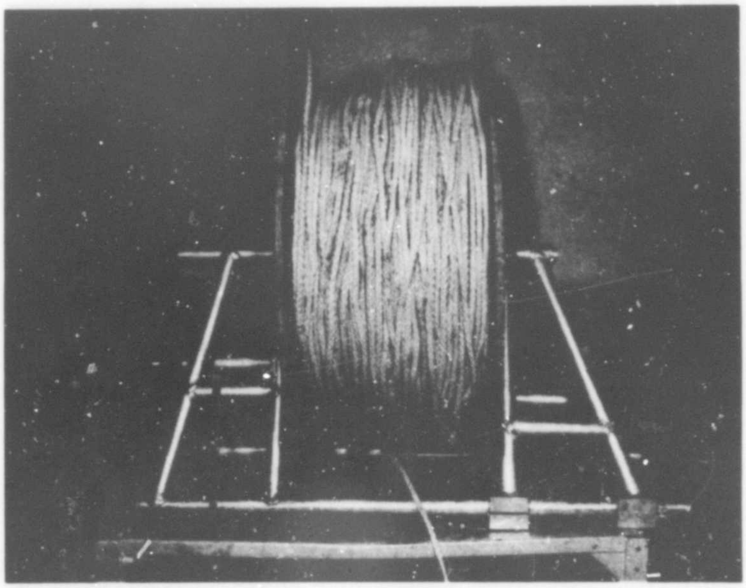

Figure 8. Ground Retrieval Winch

SECTION VI

LINE-HANDLING EQUIPMENT

Several different pieces of equipment have been used for line-handling for various types of projects. Initially, a boom was developed to guide the line from the airplane (figure 4) over pulleys along the desired path. Rings provided another method of guiding the line. The line was slipped through a metal ring at the points where a turn was necessary. There was more friction on the line with the rings than with the pulleys; but in the hand-deployment method, the added friction was desirable. During initial deployment, a 16-inch 30-degree fiberglass cone was usually attached to the line. The cone included 1-inch holes through its surface to provide more drag on the line and to stabilize the cone in flight.

When the single-line deployment was used, the cone was attached to the end of the line and the line deployed. During loiter the cone provides the necessary drag and weight to cause the line to stall faster. During double-line deployment, the cone was attached to the line with a hook and, under airstream pressure, slid along the line, keeping the cone at the end of the loop[6]. This retained tension on the lines and aided line separation which discouraged knotting.

When heavier lines were used, a weight of 5, 10, or 20 pounds was placed in the cone to provide more drag. During earlier stages of testing, smaller plastic cones were used for this purpose, but did not provide enough line tension to inhibit knotting. Cones of various sizes and shapes, weighing up to 40 pounds, were employed (figure 9).

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[6] Suggested by B. C. Dixon

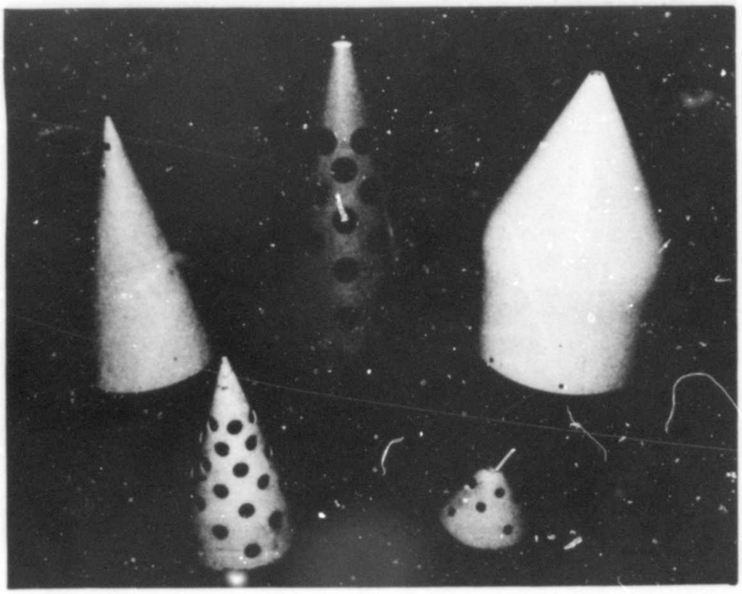

Figure 9. Cones

Several different weights were used for the program (figure 10). Usually, the weights were made of heavy canvas bags containing lead shot. Solid lead weights such as those used by scuba divers on their belts were tried, but were not successful, because they were difficult to see during a drop and tended to bury themselves in the ground on impact making them difficult to find.

Initially, standard 10-pound-shot bags used for aircraft ballast were used, but the canvas on them was not strong enough to withstand ground impact without breaking. Special round, pancake-shaped bags were designed and fabricated of heavier canvas with reinforcement at the necessary points to reduce the breakage problem. The bags were weighted with 5, 10 and 20 pounds of lead shot. These weights were used to bomb the end of the line into the ground when the double-line delivery system was used. They were also used to weight cones and to slide down the line to provide weight at the end when that was desirable during loiter.

Figure 10. Weights

There have been two basic types of hooks used to attach hardware to the end of the line and for sliding objects down the line (see figure 11(A)). One type of latch opened into the eye of the hook and others opened out from the eye. Tests revealed that with the latch opening inward, the hook would catch on the line during slides and hang up. When using hooks with a latch opening outward, the latches had a tendency to open and the hardware would be lost, especially during line slides. However, the larger eye openings in this type hook and the smooth finish plus ease of operation made them more desirable. The problem of the latch opening was solved by wrapping a piece of tape around the latch and hook which was easily torn away for removal. This type hook was used almost exclusively during the past year of experimentation.

A special latch assembly (figure 11(B))[7] was designed for releasing a dummy from the line in mid-air during the dummy-rescue testing. The latch was used with loads of more than 700 pounds of line tension to launch a 230-pound dummy. It was designed to withstand large stresses and to be easily released when a lever on the side was actuated

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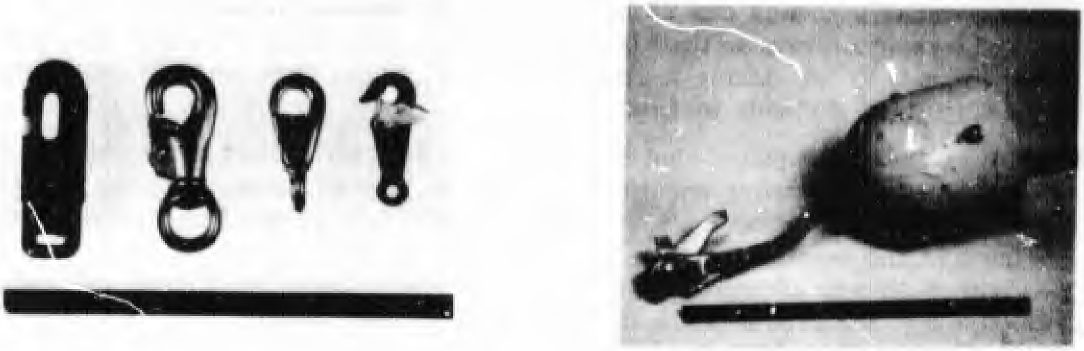
[7] Designed by Moran



A. Various Hooks B. Special Latch Assembly

Figure 11. Hooks and Special Latch Assembly

by being struck by a hardwood block slid down the line. Initially, there was a problem with the releasing lever spring breaking. This was resolved by designing and installing a heavier spring.

Flights were made using parachutes in the line for lifting weights as well as acting as a soft-landing device in case of line separation. (figure 12)[8] Parachutes with 3-foot to 28-foot canopies were used for these purposes, with the line attached to the apex of the parachute canopy and the hardware to be launched in the harness. As the launch is made and the line in tow, the parachute trailed in a streamer condition which provided some additional lift for the load but also increased drag.

During tow with the open chute, care was exercised not to bank the aircraft more than 15 degrees to avoid excessive oscillations of the mass upon resumption of level

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[8] Suggested by J. C. Simons

Figure 12. Dummy Being Launched With Open Chute

flight. During loiter, the parachute canopy opens and the mass can be soft-landed while attached to the airplane with the line. This type system has proven very useful where more lift is needed or where it is absolutely necessary to soft-land the hardware on the end of the line. The greatest problems experienced with this type of launching, tow and delivery system is the oscillations when in tow if the airplane is banked too steep. Also the launching of a mass is much more difficult for the ground crew when working with an open chute canopy, especially in moderately strong winds. The larger the chute canopy, the more difficult became the launching job.

A flying wing (figure 13)[9] was designed and fabricated to place in the towline and provide additional lift when launching, towing, or loitering heavy masses. Test flights indicate that lift may be added to the system with a minimum of drag by placing such a lifting device in the tow line. The lift could be added near the mass or at a point several hundred feet from the line end as required for a specific task.

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[9] Designed by B. C. Dixon

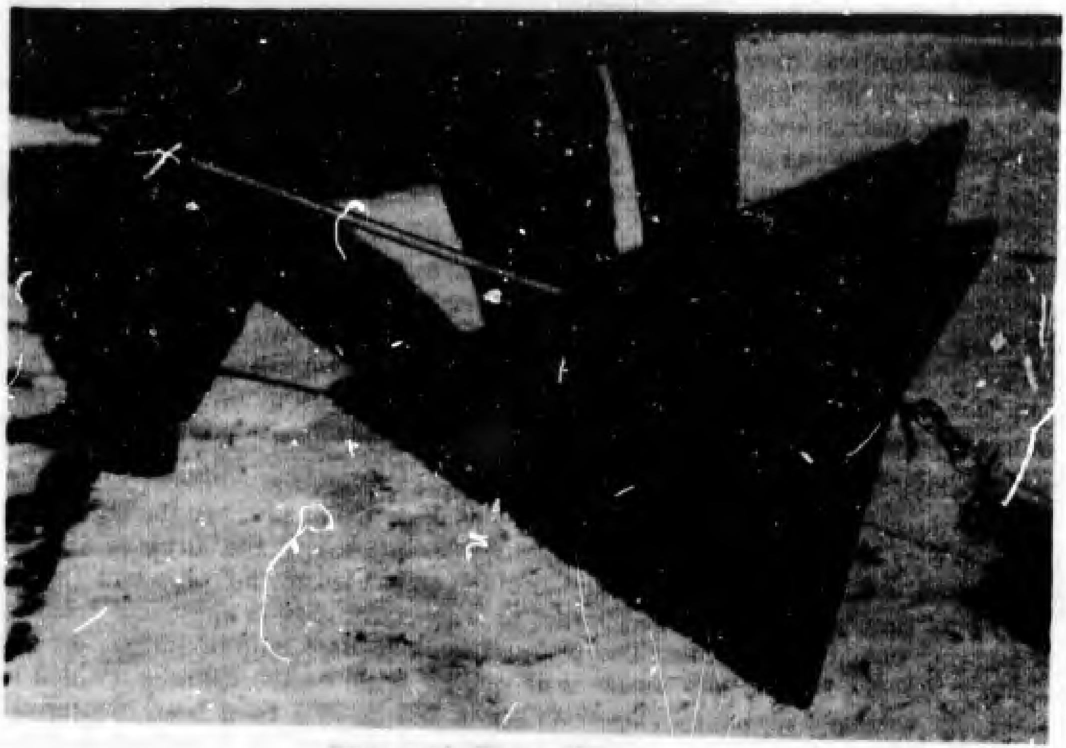

Figure 13. Flying Wing

SECTION VII

LINE-MEASURING EQUIPMENT

In order to dynamically describe the systems response history, the line length and tension were recorded. Several methods were used to measure both parameters and to provide a continuous readout.

During the Cessna 175 and initial Cessna 182 flights, only 2000 feet of line was wound on the spool for a flight and it was all deployed. Later, the line was painted with red spots about 6 inches long at 50-foot increments. To provide line-length information, the winch operator counted the spots as the line was deployed. This method was accurate to within a few feet, but it was a time-consuming job to paint the spots on the line. The winch operator had to devote full time to counting spots; consequently he could not keep check on other equipment or deployed line during the deployment operation. Finally, a two-way digital counter operated by microswitches on a pulley in the line-deployment system was added to provide a digital readout of line length.

Line tension was measured initially by a fish scale attached to the line inside the airplane. Later, a system was designed to measure line tension with a readout provided for the pilot.[10] A bar instrumented with strain gages in a bridge circuit was mounted in the system with a pulley at the end over which the line was guided (figure 16). The strain gages were attached to measure bending stresses on the bar and were wired to provide temperature compensation.

The circuit was excited by dry-cell batteries and was provided with adjustments to make daily calibrations and, thus, compensate for normal battery deterioration. The calibrations were made prior to each flight by attaching a fish scale to the end of the line and pulling to several different tensions. While holding a known amount of tension on the scale, the indicator was adjusted to read that amount. The indicator was provided for the pilot so he could monitor line tension at all times. Two scales were provided: from 0 to 150 pounds and from 0 to 300 pounds.

When larger lines were used, a system was designed to measure the higher line tensions. A hydraulic cylinder and piston assembly[11] was connected to the airplane (usually landing gear or boom assembly) on one end and the line connected to the other end (see figure 15). A hose was connected from the cylinder to a pressure gage to provide a reading when the cylinder was pulled by the line. The piston face was 0.98 square inches, so the pressure reading on the gage was also a measure of pulling force on the cylinder (which represented line tension with a 2% error). Tensions up to 750 pounds have been measured using this system. A pressure transducer could be mounted in the system to provide a remote tension readout gage or to record.

When it was desirable to measure line tension on the ground, a fish scale[12] was attached between ground and the end of the line. A scale of 0 to 100 pounds was sufficient for most cases.

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[10] Designed by B. C. Dixon

[11] Suggested by B. C. Dixon

[12] Suggested by B. C. Dixon

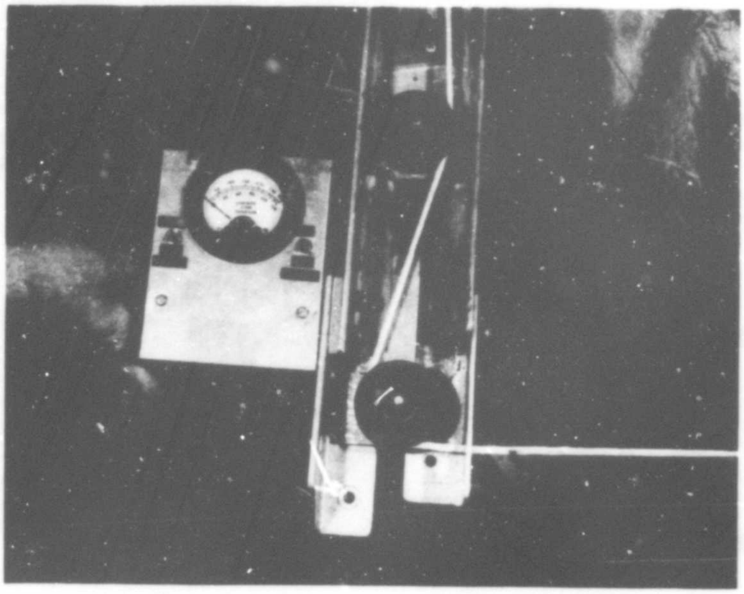

Figure 14. Tension Readout System

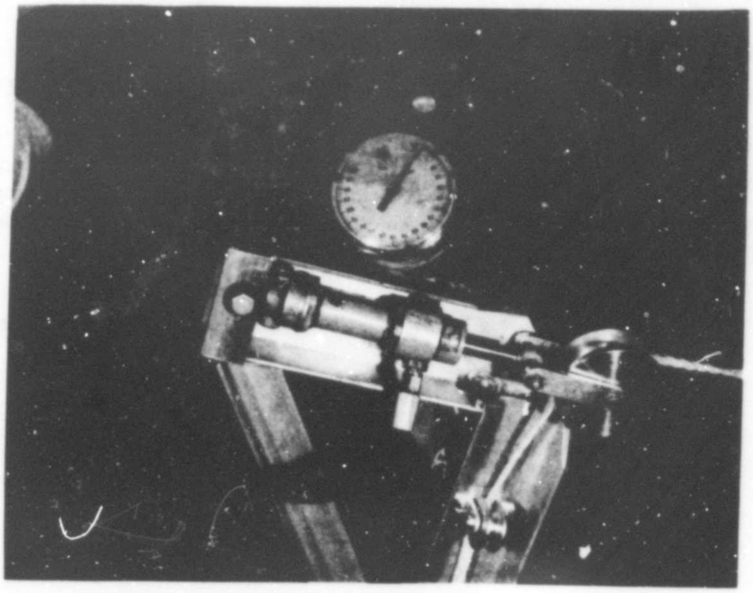

Figure 15. Hydraulic Tension Readout System

SECTION VIII

BOMBSIGHTS

One problem associated with the double-line delivery method is that of accurately bombing the end of the line to the ground from an unmodified aircraft that occludes a view of the target well before delivery. This task can be performed using a bombsight. Two different sights were designed and fabricated to enable the observer to place the end of the line within 25 feet of the ground target.

A. Reffner **B. Sears**

Figure 16. Bombsights

The Reffner bomsight (figure 16(A))[13] was a simple cross hair within a tube which was rotated in pitch as the target approached. The Sears bombsight (figure 16(B))[14] was a periscope arrangement with scales on the mirror to help with the sighting. Much better accuracy was obtained using these sights and the 25-foot accuracy was realized when bombing from up to 1000 feet above the ground.

The sights had to be mounted on rented airplanes which had to be returned to the owners unmodified (no holes may be drilled). For this reason, the sights were mounted with a C-clamp to the edge of the fuselage at the door opening; thus were not optimally placed for viewing. The winch operator sighted and directed the pilot to fly—which introduced communication problems. In the ideal test situation, a full time LLL airplane would be assigned, with all equipment permanently mounted. A special sight could then be properly aligned and mounted securely at the pilots position.

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[13] Designed by SSgt. W. W. Reffner

[14] Designed by C. W. Sears

SECTION IX

SAFETY ITEMS

AIR SAFETY

A test program involving moving lines and falling weights introduces hazards to the airplane, aircrew and ground team. Safety of the personnel and equipment was always considered during the test operations. Safety equipment was provided, and safety procedures were incorporated into all field testing.

Initially, a line-cutter was included as a precaution against the line becoming caught on a ground object or person and causing an accident. The only type line-cutters used were those with an electrically fired explosive which actuated a knife.

Figure 17. First Line-Cutter

The first cutter (figure 17) was locally designed and fabricated for the smaller lines (1/8-inch to 1/4-inch) and featured an automatic tension sensor to fire the cutter when the line tension reached a preset level. The automatic feature proved to be both unnecessary and undesirable during testing, as it caused inadvertent line cutting when the tension would peak to the preset level during a normal test operation. There was enough line slack and stretch during the circling-line maneuver to allow ample time for an aircrew member to manually actuate the cutter. Two pushbuttons were provided so any of the crew members could cut the line in an emergency. Later testing experiences proved that there was no need for a line-cutter in the system when using lines with tensile strengths below 1000 pounds. The light lines broke, without endangering either the airplane or crew, before it was necessary to use a cutter.

The second line-cutter, used for lines over 1/4-inch diameter, was capable of cutting a 1/2-inch steel cable (figure 18) and was actuated in the same manner as the previous cutter. The line was cut periodically as a preflight testing procedure.

In addition to the explosive cutters, the winch operator had a hook knife available which was capable of cutting the 1/2-inch nylon line with one stroke. The hook knife, used in routine cutting and splicing operations, proved to be very effective in line cutting.

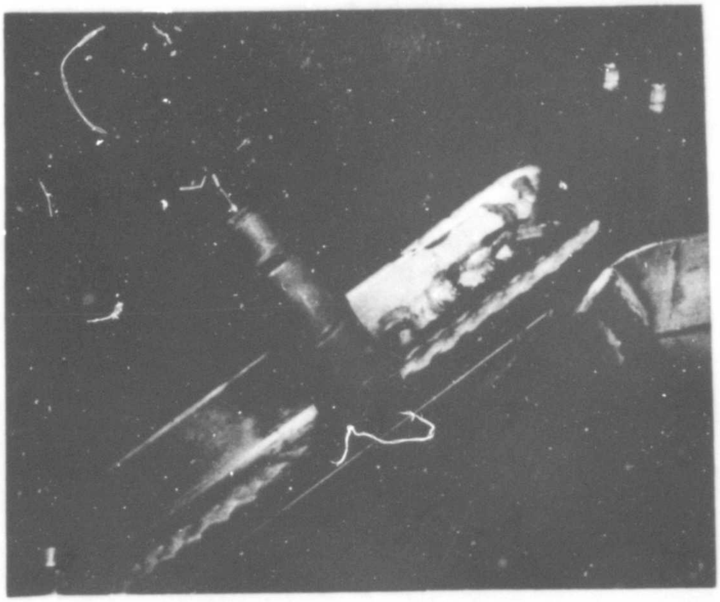

Figure 18. Commercial Line-Cutter

During initial testing, control problems were experienced when the towline flew over the top of the horizontal stabilizer and elevator of several craft. To eliminate this, a fending line was tied from the tip of the stabilizer to the wing strut preventing the towline from rising over the stabilizer. Due to the design of the U-6A empennage, it was necessary to design a special guard and fending line (figure 19) to eliminate the problem of the line getting into a forward-notched elevator control.

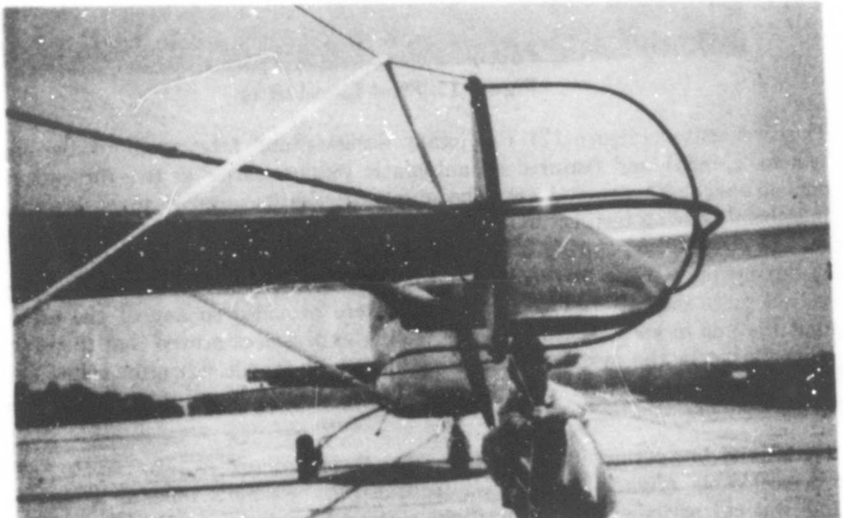

Figure 19. Guard and Fending on U-6A

Normally, three aircrew members flew during the tests. The pilot and co-pilot were in the front seats, and the winch operator was located in the rear compartment. The winch operator was in a hazardous area because he was constantly moving and working around an opening large enough to fall through. He, therefore, wore a parachute and was tethered to a seatbelt tiedown with a nylon strap buckled to the parachute harness. The tether was not long enough to allow him to fall out the open doorway. Heavy gloves were worn to protect his hands against line burns, cuts, etc., and a helmet and goggles were worn to allow him to work in a high wind area with the least amount of discomfort.

GROUND SAFETY

Precautions were also taken to provide a safe working environment for the ground team.

All members of the ground team, as well as visiting observers, were required to wear helmets for head protection against falling objects. In addition, all ground team members working in the line target area wore boots and gloves for foot and hand protection, and each carried a hook knife to cut the line in an emergency. No testing was started until firm communications were established between air and ground crews. A safety officer, appointed for each field test, monitored all safety procedures. No tests were conducted during high surface winds, and no testing with an open parachute was conducted when surface winds were more than 15 knots. There were always two experienced people working with the line on the ground. The ground crew remained on the upwind side to avoid ground lays of the line. This was especially important when working with an open parachute in the system, to avoid being entangled in the canopy or shroud lines.

SECTION X

COMMUNICATIONS

Careful attention was given in selecting communications equipment for the program. The equipment was required to operate, both, in an airplane with a 12-vdc electrical system and on the ground using available power supplies or portable radios with a low current drain. Two Bendix Model RT-221 A/AE trancievers with 360 channels were selected. These all-transistor units operated on a 12-vdc supply using less than 1 ampere for receiving and less than 5 amperes for transmitting. The radios were mounted in aluminum cases about the size of a briefcase with a built-in speaker and plugs for external speakers, headsets and a microphone. The airplane radio was connected to the airplane electrical system for power and the ground radio connected to one of the ground vehicle batteries. Initially, both radios were used with the built-in speakers, but later were modified to provide better communications.

Because of the wind and engine noise from the open door, it was difficult to place the aircraft radio in a position where all three people could hear. Normally, only one air crew member could talk to the ground team. Consequently, the airborn radio was connected to four headsets with boom mikes. A "hot" intercom (no switches) modification was installed so the aircrew could converse among themselves without shouting. When one aircrew member transmitted to the ground team, all aircrew members could hear the transmission and the reply clearly through the headsets. Thus, everyone was kept informed at all times. Usually, the copilot conducted communications with the ground team. The pilots headset was split, with one earphone connected to the aircraft radio which was always tuned to the control tower frequency and the other earphone connected to the LLL communications. The pilot normally communicated with the control tower.

The ground radio was equipped with an external 15-watt public address speaker and a 50-foot extension connected to the microphone cable which allowed the ground radio controller to move around and maintain communications. The speaker could be heard by all of the ground team members most of the time.

In addition to the air-to-ground radios, walkie-talkie units were used by the ground team. The air-to-ground controller and safety officer each had a walkie-talkie and the line handlers had one at their station. A test frequency of 27.575 kilohertz was assigned by FCC for the walkie-talkie units (E.F. Johnston Company, Model 242-109).

SECTION XI

GROUND VEHICLES

Most of the LLL testing was done with the ground team in the center of an open field which made it necessary to have a means to transport personnel and equipment to the ground testing site. Usually, two vehicles were used for this purpose. A 2½-ton truck with a van-type, closed-in-bed was equipped with shelves to store equipment and supplies. The truck was always taken into the field when a test flight was made, so that all needed supplies and equipment were available at all times.

A station wagon was used for transporting personnel. Occasionally, the station wagon was used to retrieve lines or equipment on the line, but usually these events were close enough to accomplish on foot.

SECTION XII

DUMMY ACCELERATION DATA

In the process of man-rating the rescue system, it was necessary to record the triaxial acceleration forces exerted on a man during the actual launch. A triaxial acceleration package was fabricated to fit into the dummy chest cavity with a four-wire shielded cable (see figure 20). The cable was routed to the right foot of the dummy where it was secured leaving a pigtail about 18 inches long, with a breakaway plug on the end. A 600-foot cable of the same type was fitted with a mating breakaway plug and laid on the ground in the direction of launch in a zig-zag fashion to the instrumentation vehicle.

During launch, data was recorded until the dummy reached the end of the 600-foot cable and the breakaway plug disconnected. This varied from 5 to 13 seconds, the shorter time due to a premature breakaway.

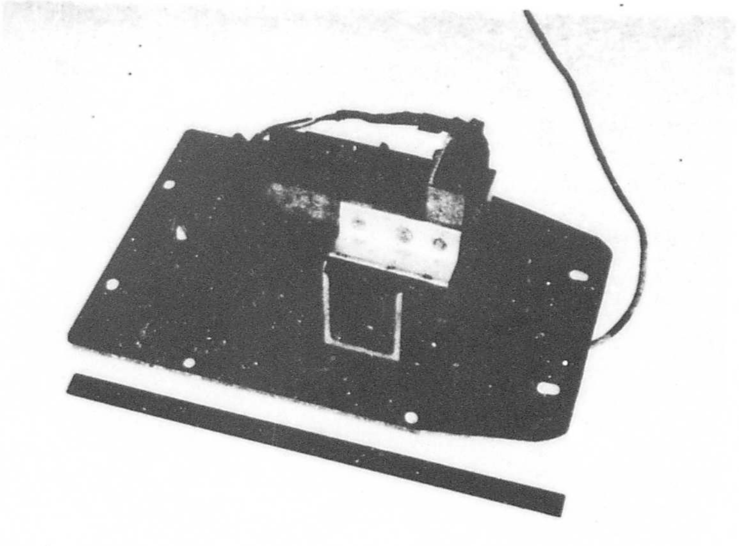

Figure 20. Triaxial Acceleration Package

The accelerometers used in the "X" and "Z" axis were linear force balance servo type manufactured by Columbia Research Laboratories, Inc.; Model SA-102-B, with a range of ±10 G. The accelerometer used in the "Y" axis was a linear force balance servo type manufactured by Donner; Model 4310 with a range of ±1 G. The 600-foot cable contained four No. 20 wires in a single shield with a plastic coating over the shield. The 28-vdc power for the accelerometers was provided by a Hewlett Packard Model 6205B regulated power supply. The signals were recorded on a Consolidated Electrodynamics Corporation (CEC) Model 5-124 18-channel recorder. CEC type 7-315 galvanometers were used and the signals scaled to deflect the trace approximately 1 inch per G. A 1-second timing sequence was recorded plus an event trace to mark launch time. See figure 21. This test was conducted in the center of a parachute drop zone where no commercial power was available, so a portable gasoline-driven alternator with a 115-volt, 60-cycle, 1100-watt output was used to supply power for the instrumentation.

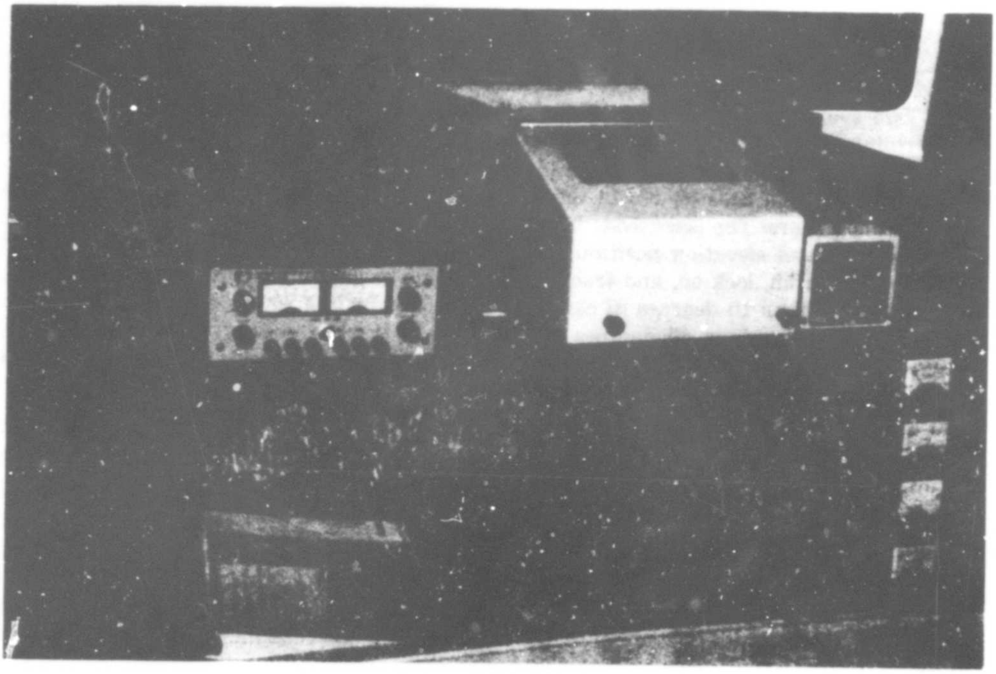

Figure 21. Recording System

SECTION XIII

PILOT DISPLAY AND AUTO CONTROL

Two systems were considered for aiding the pilot to manually or automatically fly the orbital maneuver. One of these units was flown in a LLL airplane. The Rendezvous and Station Keeping Optical Radar (RASKOR) designed by IBM, Owego, New York was developed as a possible aid in rendezvous and maintaining position for air-to-air refueling maneuvers. The laser system provided range data up to 6000 feet, and range rate plus azimuth and elevation position indicators for the servoed transciever unit. It was designed to search, lock on, and track a cooperative target automatically. In search mode, the lightbeam fans 10 degrees in elevation and 1 degree in azimuth while the transciever unit mechanically scans 40 degrees in azimuth. In track, the beam is narrowed to a 1 degree fan in elevation and azimuth and the transciever will track ±5 degrees in elevation and ±20 degrees azimuth with a tracking rate of 5 degrees per second.

The RASKOR was modified for testing in the Cessna U-206 at IBM, Owego, New York and two test flights were flown. Results of the test flights indicate several changes should be made in the RASKOR prior to additional testing.

Tracking should be increased beyond the ±5 degrees in elevation limit. During the LLL orbits, it was necessary for the bank angle to vary more than ±5 degrees even on a relative calm day. Tracking rate should be increased beyond the 5 degrees per second limit. Abrupt movements of the airplane, caused by fast control movements by the pilot or by slight turbulence, would cause the system to break track and return to the search mode.

The C-130 gunship II computer and radar system was studied as a possible aid in flying LLL orbits. The University of Dayton Research Institute investigated the possibility of using the gunship computer for flying LLL orbits in June 1970. (ref 3) A theoretical system was programmed into a computer and trial orbits flown. The results of the trials show that an unmodified gunship II computer system would not be suitable for flying LLL orbits, because it would not provide stable orbits if wind compensation was required. However, with a modified gunship II computer, stable orbits were flown with winds up to 27.3 mph.

In July 1970, test flights were conducted in a AC-119K gunship equipped with an AWG-13 computer. These flights indicated that a maximum of 300 meters offset may be used to compensate for wind conditions and the wind setting should be set at "0" regardless of actual conditions. Most C-119 navigators who used the system in combat agreed that a 0 wind setting is the best operating setting. All navigators agreed that wind setting was little help, if any, in controlling the orbit. These flights supported the conclusion of the University of Dayton Research Institute that it was necessary to modify the gunship II computer system prior to attempting to use it as a controlling element for flying stable orbits as required in the LLL system.

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