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VOLUME I

LONG-LINE LOITER: IMPROVEMENT OF SOME FREE-FALL AND CIRCLING-LINE TECHNIQUES

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TECHNICAL REPORT ASD-TR-69-95, VOLUME I

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AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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Volume I

FOREWORD

This report was prepared by the Flight Environments Branch, Human Engineering Division, 6570th Aerospace Medical Research Laboratory, under Project No. 7184, "Human Performance in Advanced Systems" in support of Project No. 1559 "Limited/Special Air Warfare Test and Evaluation" under the auspices of the Deputy for Limited War of the Aeronautical Systems Division with Major Robert Hammond acting as ASD sponsor. The authors wish to express their appreciation to Lt. William Klepser of the 6570th AMRL who helped with many of the analytical and inflight phases and acknowledgement is also made to the following personnel:

Personnel	Unit	Effort
T/Sgt E. Bunch	AMRL	Test Equipment
Mr. M. Val Dahlem	AFFDL	Lifting Surfaces
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Mr. J. Ross	AFML	Flying Lines
T/Sgt R. Fancher	AMRL	Field Tests
Mr. C. W. Sears	AMRL	Contracts, Test equipment
M/Sgt Millard	AMRL	Field Tests
Mr. W. Kama	AMRL	Remote Handling
Mr. Nils Aume	AMRL	LLL Simulator

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

for John C. Simons
JULIEN M. CHRISTENSEN, PhD
Director, Human Engineering
Division

ASD-TR-69-95
Volume I

ABSTRACT

Maneuvering techniques for fixed-wing aircraft positioning a towed mass near the center of an on-pylon turn are discussed. Free-fall and circling-line techniques were improved and several applications demonstrated. Successful ground launching of 100-pound masses with the system prompted a decision to man-rate it for air-to-ground pickup of personnel. New delivery and retrieval methods are discussed.

Future efforts involving longer lines and heavier masses are discussed in terms of flying lines, lifting surfaces, a long-line loiter (LLL) simulator, and a large cabin aircraft.

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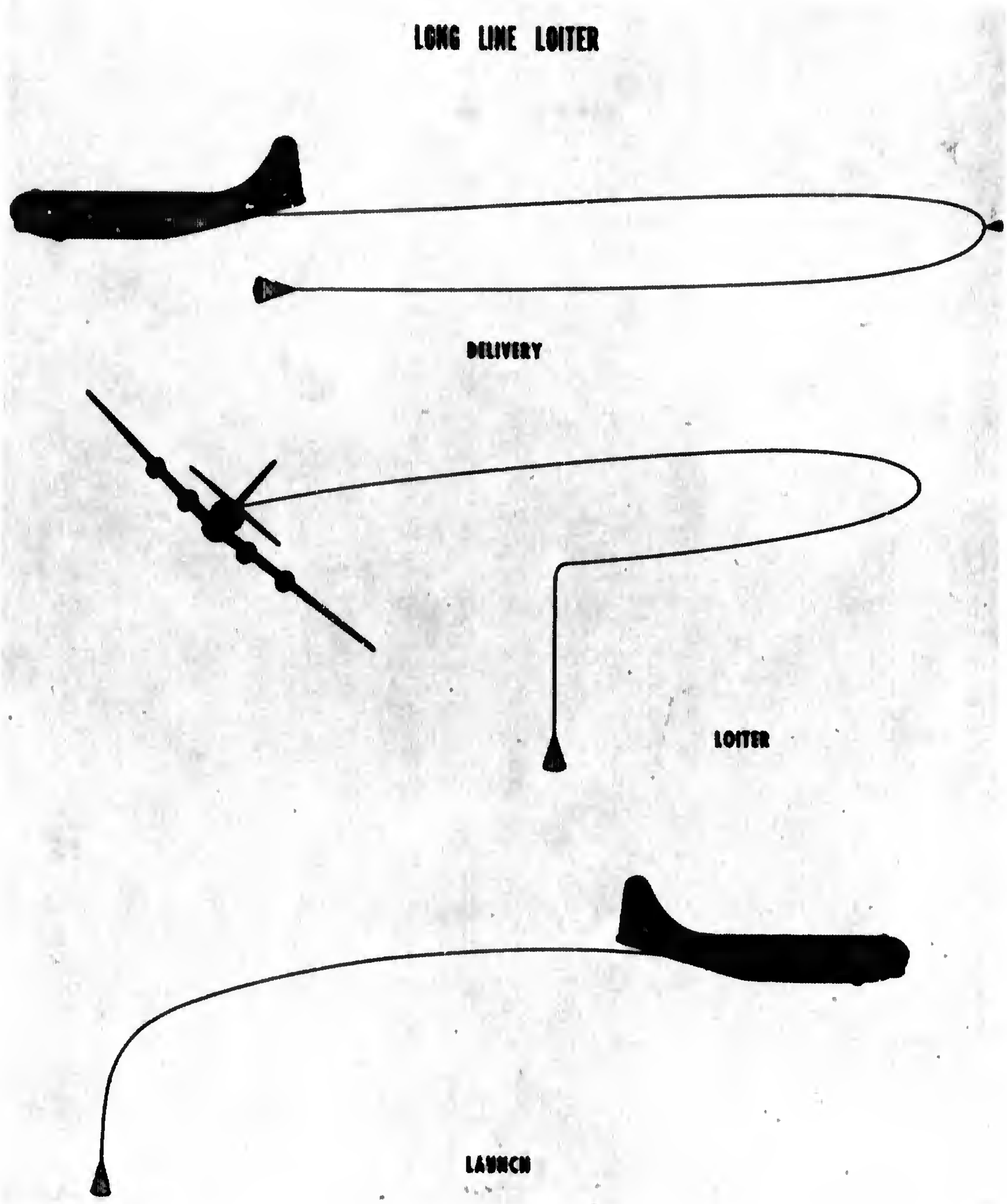
LONG LINE LOITER
DELIVERY
LOITER
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SECTION I

INTRODUCTION

The significant combat success of the Aerospace Medical Research Laboratory side-firing concept has established the on-pylon type turn as a maneuver for Air Force strike tactics. During the initial tests of that concept, the author was impressed with the ease with which he could track a point using a simple single mark on the windshield (Reference 1). The first on-pylon tracking attempt was flown continuously for ten minutes with varying airspeed, pitch angle, lateral distance, and altitude. The on-pylon tracking low speed pilot was not plagued with the problems of yaw rigidity and changing control forces which often degrade the high speed dive-bomber pilot's performance. This report discusses our attempts to place and hold a tethered mass at the center of an on-pylon tracking maneuver; and make several improvements in the execution of these; and also a method of retrieving the mass from the ground.

In July 1966, the following concept was proposed to the Aeronautical Systems Division (Reference 1):

"Long-Line Loiter (LLL) Craft - With the use of a remotely controlled vehicle on the end of a long line (2 to 3000 feet), the pilot might be able to position a package over or upon a ground target for short periods of time. By proper usage of parent vehicle control surfaces and remote vehicle thrusters, control surfaces and rapid-line deployment and retrieval reels, the pilot may be capable of remotely performing "a variety of missions." The maneuver would permit precise delivery and pickup of packages including personnel delivery and rescue.

In 1966, the authors were unaware of the extensive circling-line studies and concepts already in the literature (References 3-9). Reference 8 describes the circling maneuver - "the aircraft plays out the line and circles the pickup site until the line moves into an equilibrium state whereby the lower end describes a circle at the same angular velocity as the aircraft, but of much smaller diameter." The references discuss four significant problems which curtailed previous efforts: vertical bounce (yo-yo) of the mass, elliptical motion of the mass, difficulty in maintaining a constant radius turn, and the effects of wind and turbulence on the mass. Table I lists several major factors and their influences on control problems as discussed in the literature.

TABLE I

MAJOR FACTORS AND THEIR INFLUENCES

VARIABLES	TO DECREASE MASS ORBIT*	TO DECREASE LINE OSCILLATION	TO INCREASE VERTICAL SEPARATION	
			Normal	Yo-Yo
Aircraft				
Velocity	Inc	Dec	Dec	
Radius	Dec		Dec	Vary
Line				
Length	Inc		Inc	Vary
Diameter	Inc		Dec	
Density	Dec		Neg	
Line Taper (mass end)	Inc			
Number of Turns			Inc	
Mass Density	Neg		Neg	
Mass				
Weight	Dec	Inc	Inc	
Drag	Inc		Neg	
Shape		Stable		

* For Example, to decrease the size of the orbit of the mass, one can increase aircraft velocity or decrease the radius of the aircraft orbit.

SECTION II

EXPLORATORY FLIGHTS

1. CESSNA 175*

The Cessna 175 is a four-place high-wing aircraft equipped with a 175 hp engine, a fixed pitch propeller, and a fixed landing gear. The equipment installed in the aircraft was a simple hand crank reel with the line guided out the rear of the aircraft. A two and a half-pound high drag cone was deployed at the end of 2000 feet of 550-pound test nylon parachute shroud line cord. A fish scale was used to provide an approximate measurement of line tension at the aircraft.

In mid-June 1968, three flights were flown to acquaint the authors with the circling-line techniques and problems. Figure 1 shows a photographic sequence of a drop to the ground during the third flight.

The orbits were flown at approximately 1000 feet altitude, at a speed of 60 to 70 mph, while maintaining a bank angle of 40 to 50 degrees. This low speed and steep bank were necessary to stall the line. High cruise power and 20-degree flaps were used to maintain a safe flight configuration. These flights established the following factors:

1. Airborne detection of a 11 x 16-inch(30 degrees) international orange cone on a 2000-foot line is easy.

2. Lowering the cone by increasing bank is preferred. Losing altitude resulted in increased airspeed which trailed the cone.

3. First detection of the cone occurred frequently when it appeared low, forward, and often directly beneath the aircraft flight path.

4. The cone can be found by looking along the line.

5. The line is quickly stalled by rapidly rolling to 50 degrees bank.

6. It is difficult for the aerial observer to judge the height of the cone above the ground.

7. Line tension in the aircraft never exceeded 12 pounds.

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* Owned by B. Dixon

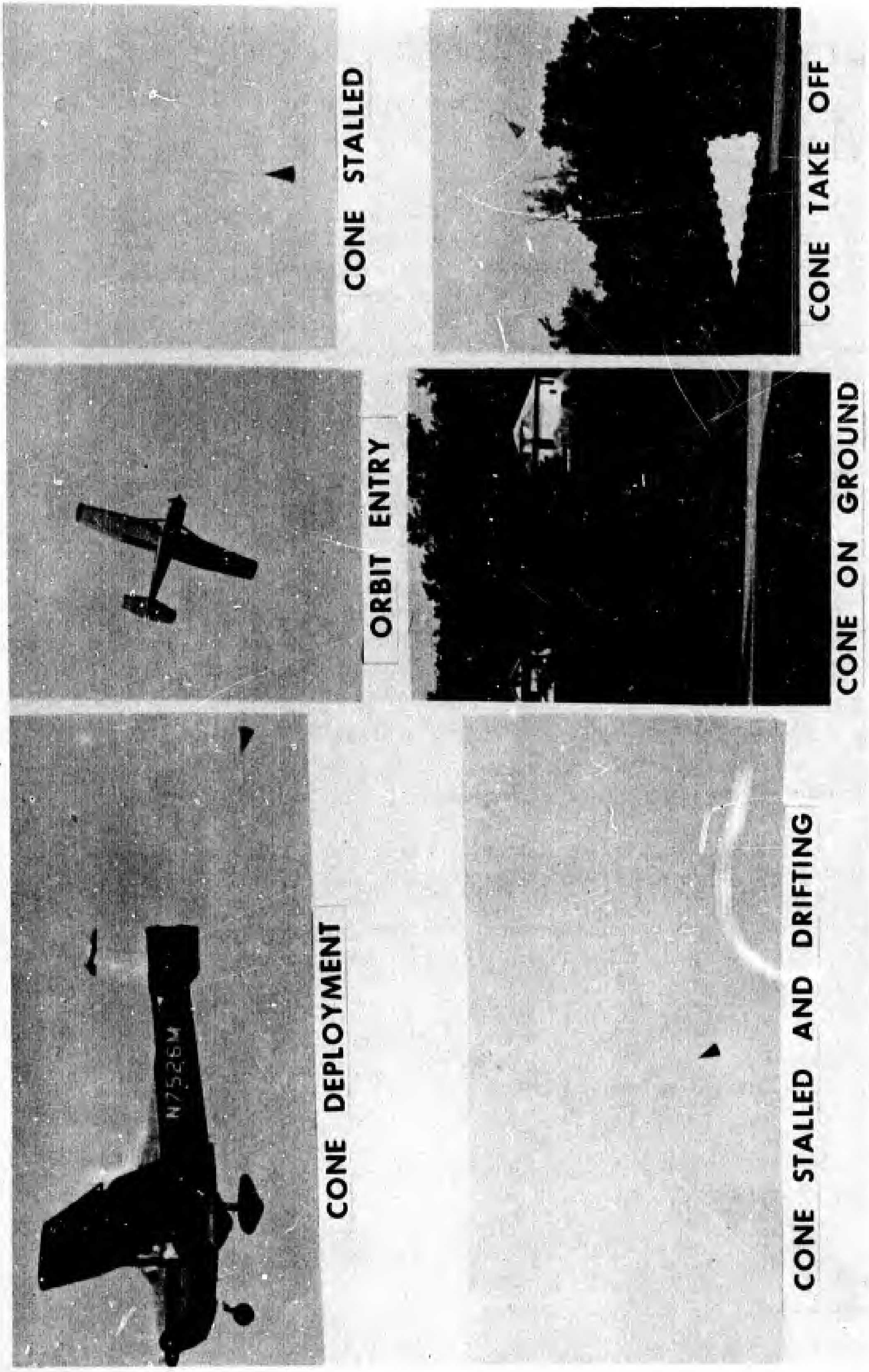


Figure 1. Cessna 175 Trials

8. Under wind conditions, orbits could be started upwind of the desired touch-down point and the entire system drifted toward the target.

2. CESSNA 182

The Cessna 182 is a high-wing four-place airplane, equipped with a 230 hp engine, constant speed propeller, and a fixed landing gear. The equipment (Figure 2) included a motor-driven reel with boom, an automatic line cutter, and a smaller cone that was used to maintain line tension during double-line deployment. All equipment was mounted in the baggage compartment with the line routed out the baggage door. A fending line was tied between the tip of the horizontal stabilizer and the cabin port to discourage tow lines from riding on top of the horizontal stabilizer. Initially, the orbits were flown in the Cessna 182 airplane using approximately the same pilot techniques as were used with the Cessna 175.

Flights flown by the authors in this aircraft during October through December 1968 established the following factors:

a. Mass Slides

One-pound lead weights were grouped to provide masses from one to three pounds to slide down the line. These light masses tended to hang up temporarily on horizontal portions of the line and accelerated to very high speeds along the vertical line, which resulted in extremely high terminal speeds. A one-pound mass arrived at the cone 37 seconds after deployment along an 1800-foot line. As expected, mass slides performed with the cone above the ground resulted in a vertical fall of the stalled line. A whip action occurred at the end of the vertical fall as the weights plunged below the cone due to higher descent rates of the masses (Figure 3).

A long-line loiter simulator will be used to quantify methods for reducing the sink rate of sliding masses by deploying more line, higher aircraft speeds, shallower bank angles, or perhaps combinations of these factors. Experiments with higher drag masses will determine if the increased drag will provide more speed along the horizontal line and less terminal velocity when reaching the end of the vertical line.

b. Fending Line

When the cone was held by ground observers or when towing heavy masses, the tow line moved forward toward the low wing. The line was often picked up by the horizontal stabilizer when the bank angle was decreased. The previously described fending line was used to try to eliminate this problem and was partially successful.

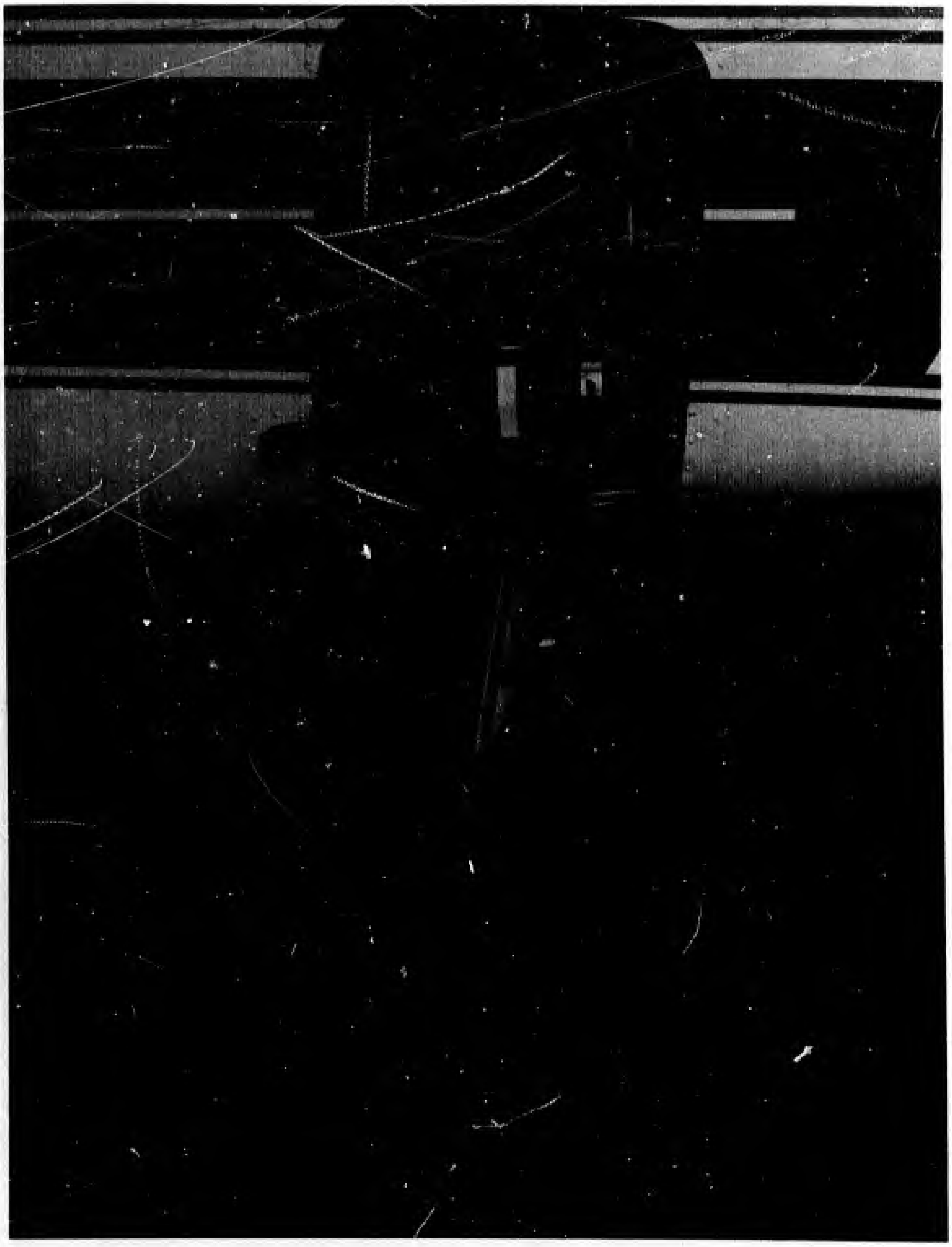


Figure 2. Cessna 182 Equipment

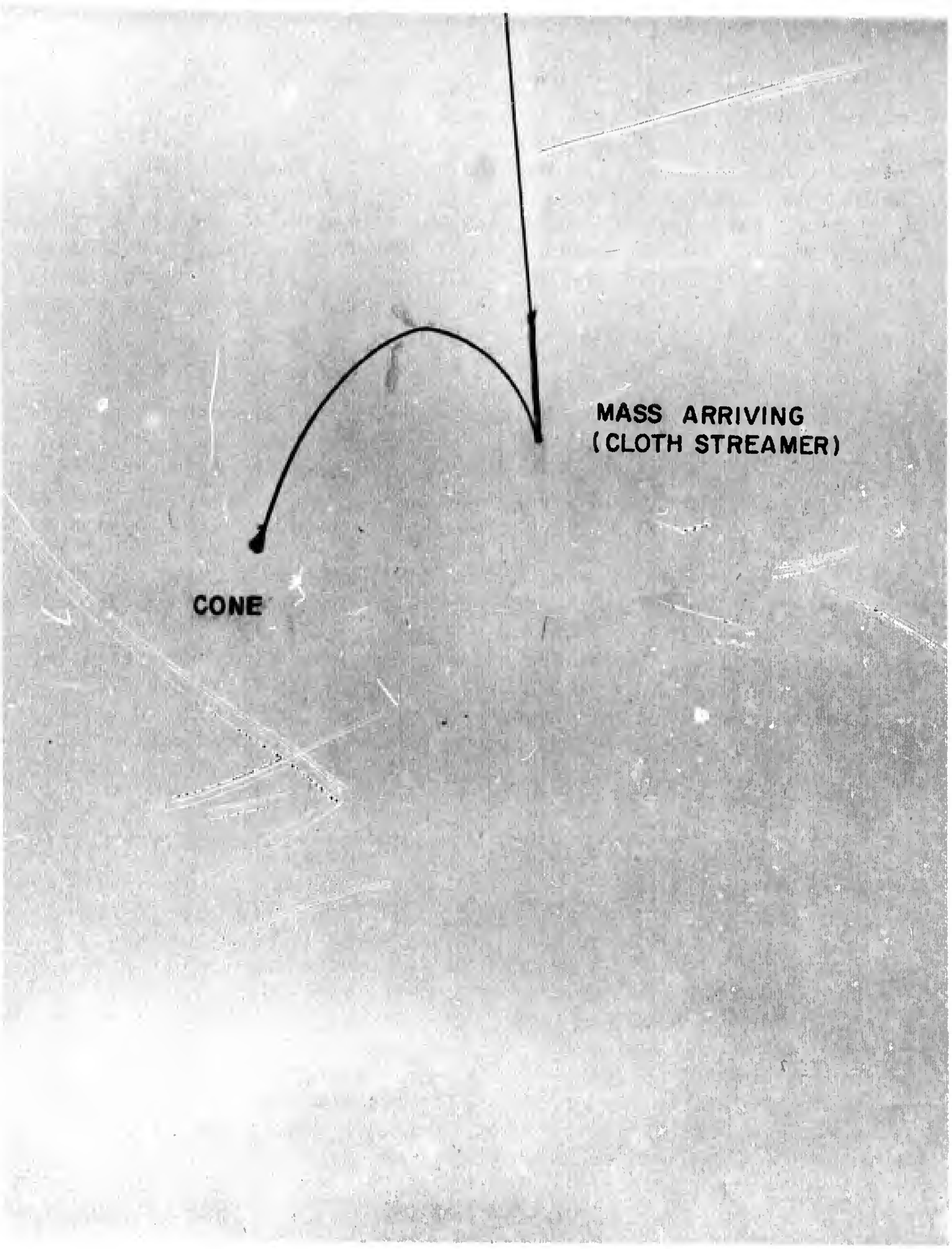


Figure 3. Mass Arriving at Cone

c. Delivery Methods

(1) Double-Line Free-Fall*

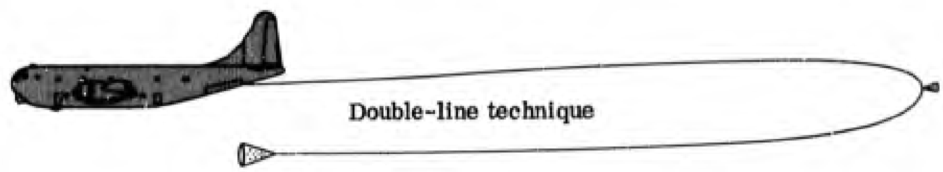
The double-line free-fall maneuver was performed by holding the cone in the aircraft and deploying 2000 feet of line in a long loop. Initially, knots developed between the two lines until a small sliding cone (Figure 2) was used to deploy the line and deployment of the line was made at higher airspeeds (110 mph) to maintain higher tensions on the line. A large cone was then level-bombed from approximately 900 to 1000 feet over a double theodelite tracking system and a typical trajectory of the cone is shown in Figure 4. Immediately after dropping the cone, a constant bank orbit was started to hold the line in a stalled condition.

The classic orbit delivery required approximately one orbit to stall the line and the cone's location was unpredictable. (During high winds, the cone often appeared downwind of the aircraft's flight path). The double-line free-fall technique apparently halved delivery time (time from release to line-in-vertical-stall position) and consistently placed the cone near the target. The technique will be optimized for minimum time and minimum line length with a goal of delivering the mass with a near zero velocity component near the target and then quickly lowering the cone to the ground before the wind can appreciably drift the system. After the mass was retrieved on the ground the pilot immediately converted his flight path from a constant bank angle to a constant radius turn (accounting for wind). The ease of this maneuver was demonstrated when 27 consecutive orbits were flown in a 15 knot wind. The ground observer held the cone during the orbits and the line never touched the ground (Figure 5).

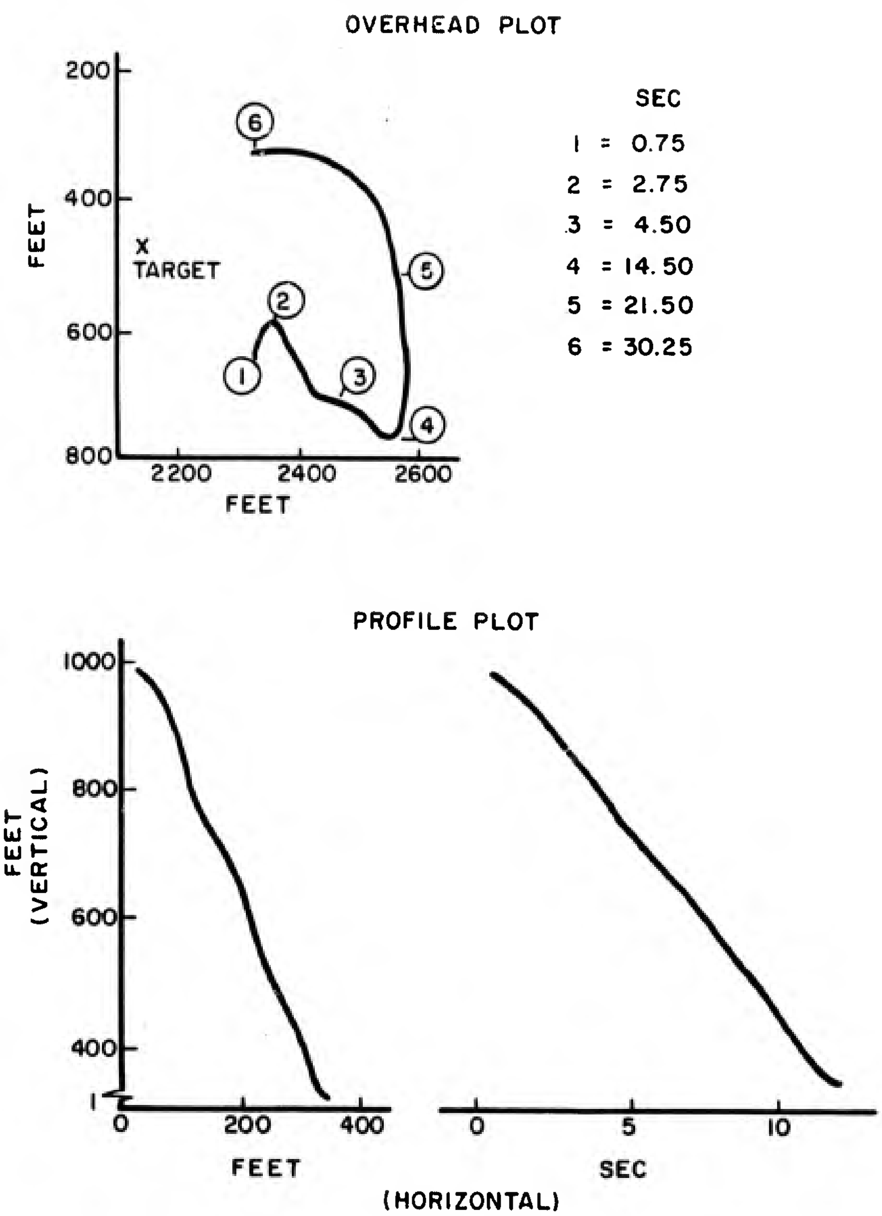
(2) Skip-Bomb*

This delivery was executed using the same technique as the double-line free-fall method except the cone was replaced with a ten-pound shot bag, the delivery was made from 300 feet altitude and only 1500 feet of line was initially deployed. The aircraft was flown straight and level over a ground target and the shot bag dropped to the target. Immediately full power was applied and a tight climbing spiral started while 500 feet more line was deployed. The only problem with this type of delivery may be inadvertently striking the ground man with the dropped mass. Two deliveries were within 70 feet of the target and accuracy should improve rapidly with practice. The flight path was offset from the target so that the pilot could continuously see it; the mass impacted between the target and the aircraft's position over the ground. This technique was similar to the Ground Anchor Recovery-Delivery System (G.A.R.D.S.) single-line deployment concept except that the line is deployed double and not secured to the ground (Reference 11).

*Suggested by J. Simons
*Suggested by B. Dixon



A. Maneuver



B. Trajectory of Cone

Figure 4. Double-Line Deployment

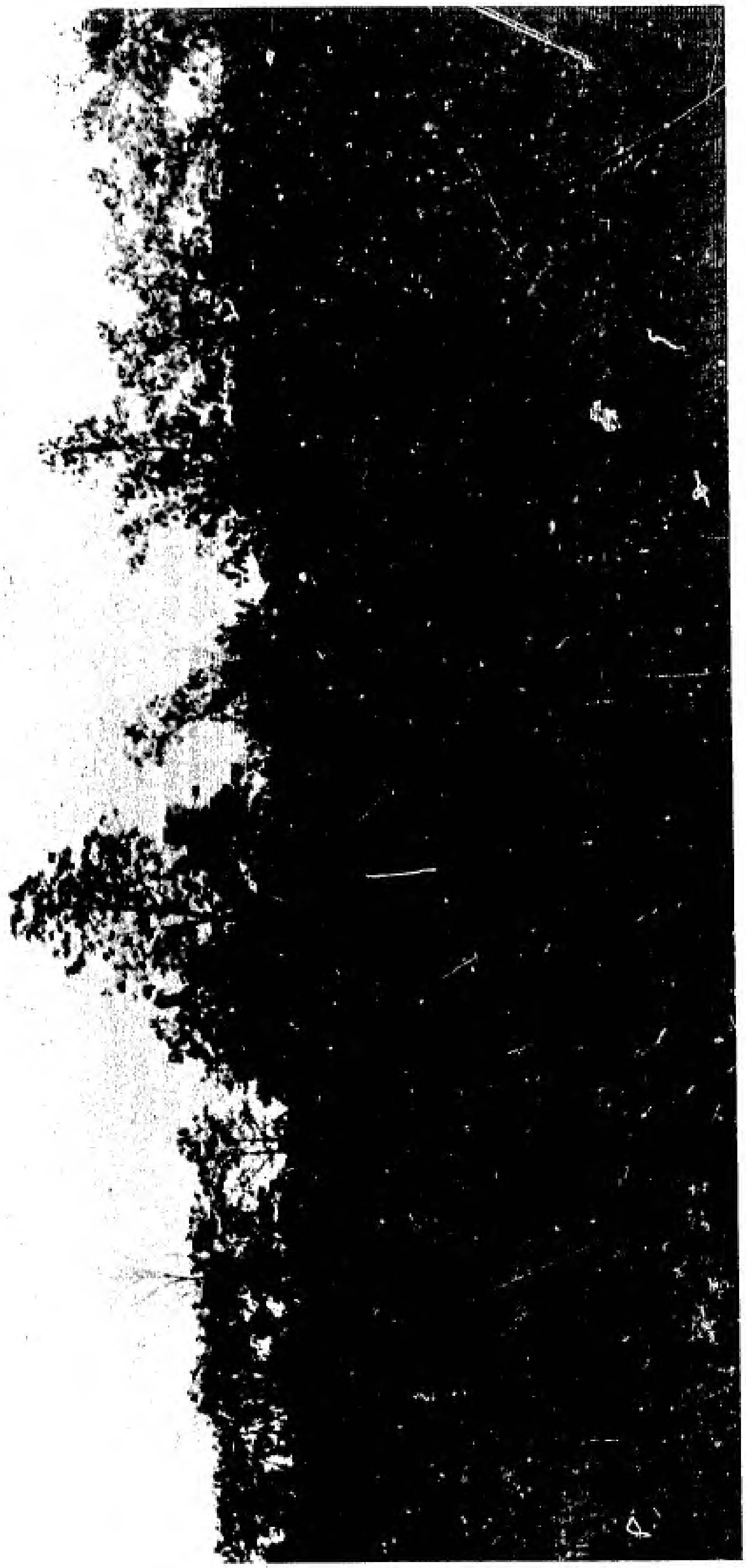
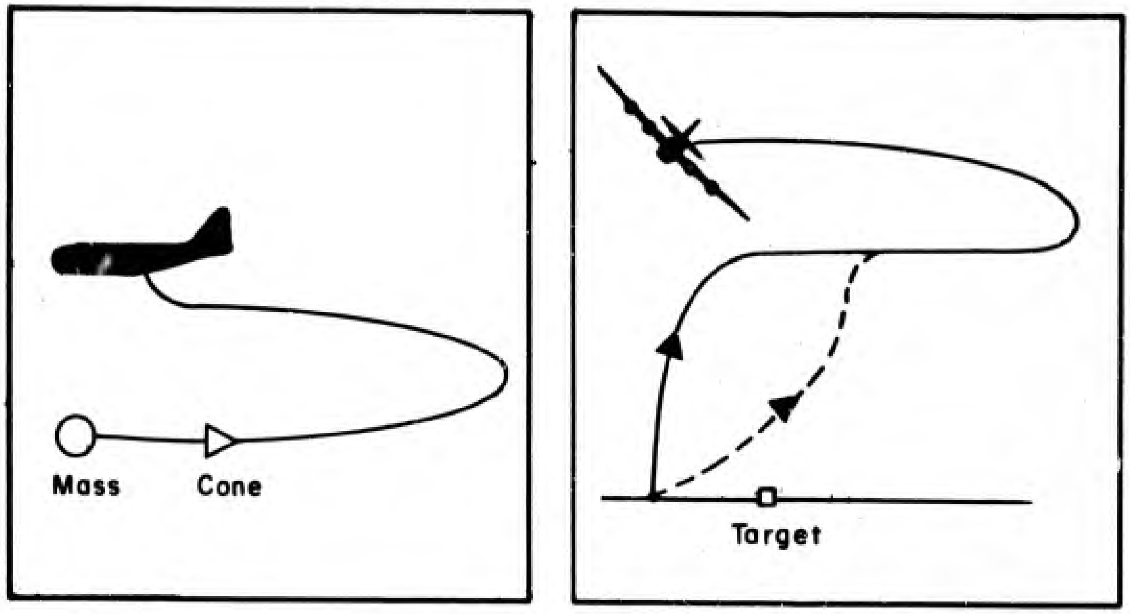


Figure 5. Hand Holding of Cone

(3) Double-Mass, Double-Line*

The cone mass was fixed 1 to 200 feet above a mass, the line was deployed double, both masses were then level-bombed toward the target as the aircraft entered its orbit.

Improved delivery accuracy was attained by free-falling the mass to a point near the target, then the aircraft circled until the airborne cone arrived near the target. The cone was then placed on the ground by reeling out line or descending the aircraft (Figure 6).



a. Release

b. Delivery

Figure 6. Double-Line, Double-Mass Delivery

d. Pickup Method

Four 20-pound tires were tied to the line during successive launches on 15 November 1968 (Figure 7 a). The first two trials, (one tire, two tires) resulted in vertical launches. The three-tire load departed at about 30 degrees from the vertical and the four-tire load at about 55 degrees. All launches were smooth and the tires ascended without any ground contacts. The half loop of circling line gradually unwound after the aircraft departed its orbit and the line described a single arc to the aircraft which flattened as the mass was held. The astonishing ease of the maneuver (pilot flew straight and level into

* Suggested by J. Simons

a. Launch of Tires

Figure 7. Circling-Line Pickups

the wind while the ground man held the mass until the line exerted an upward pull) prompted the authors to consider this maneuver as a second milestone (the first being the double-line delivery maneuver) and to publish this report. Immediately it was decided to man-rate a rescue application and on 29 November 1968, three successful pickups of a 45-pound Fulton-suited dummy (Figure 7 b) were performed. The suit was very stable at launch and only rotated after moving in trail behind the aircraft.

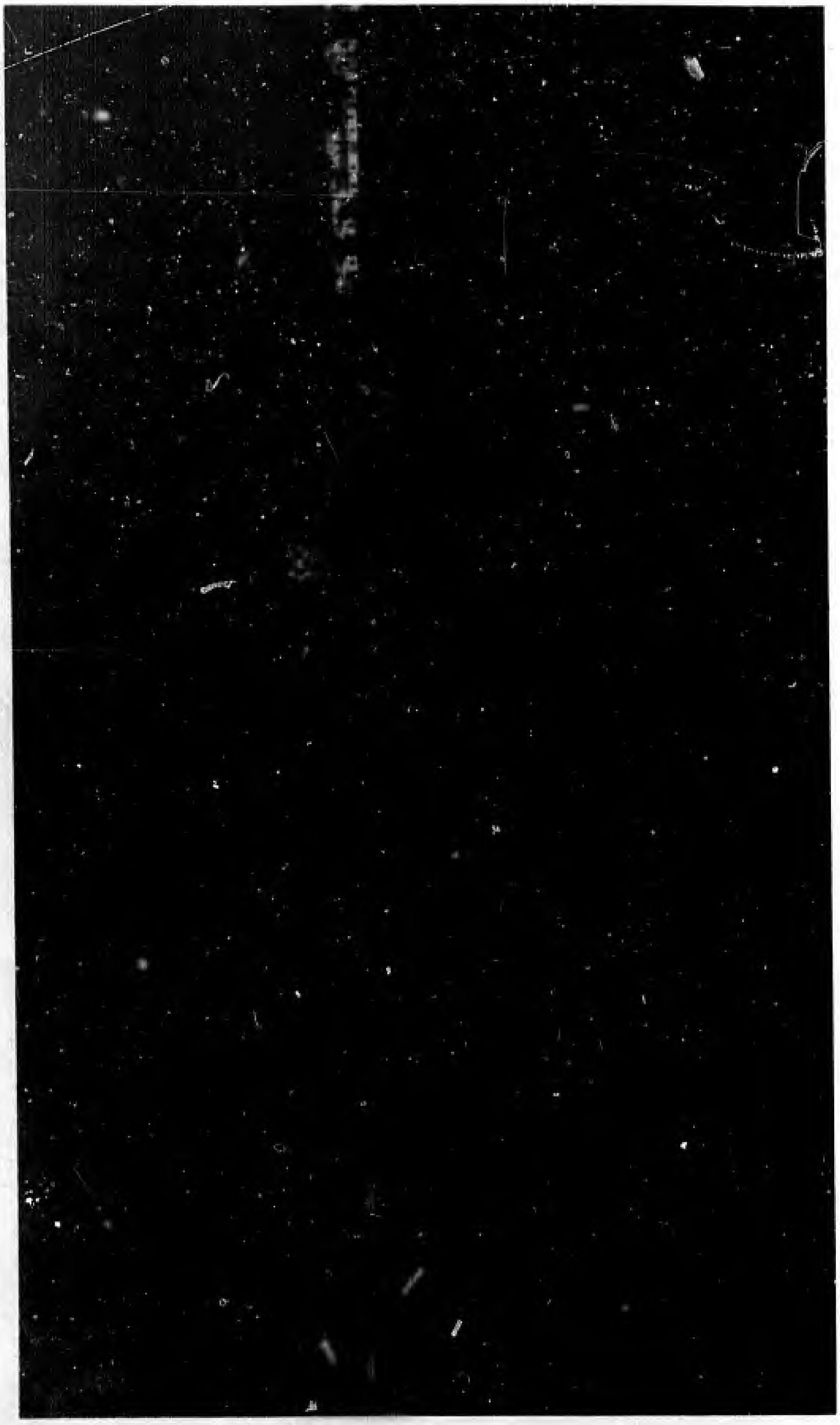


Figure 7. (Continued)

SECTION III

FUTURE EFFORTS

General improvement efforts will continue through 1971, and will concentrate on the contribution of three major components - aircraft, line, and remote mass.

1. LLL SIMULATOR

The simulator shown in Figure 8 was installed in a 50-foot high engine test cell at WPAFB in December 1968.

The main element of the simulator is a 20-foot radius long boom that deploys lines through a movable eyebolt. It is being used to quantitatively relate line length, line tension, airspeed, radius of turn and altitude; to propose new delivery techniques; to examine potentially hazardous maneuvers; and to explore systematically new techniques that were discovered in flight trials. Existing theodolite tracking facilities at WPAFB are being used to track inflight deliveries and these data will be used to validate some of the simulator results.

2. FLYING LINES*

Flying lines are being designed by the Air Force Materials Laboratory that should increase LLL loads by factors of 3 to 10. The intent of this program will be to develop lines (braids, tapes, ribbons, etc.) that will have a higher strength to weight ratio than current fiber forms and will be of such a design (see examples) as to provide more lifting surface to the air flow and enhance streamlining when directed into the wind. Through the use of yarns having a high degree of elasticity the lines will flatten when wound under tension on a spool, and will take an airfoil shape at the load levels anticipated during use. Fibers which have a potential, based on strength, elasticity, and density, in this application include polypropylene, nylon 6-6, Dacron, Lycra, etc. Approaches to forming airfoil configured lines would include not only the use of weaving and braiding techniques, but also mixing of inelastic fibers (Dacron, glass, etc.) with elastic fibers (Lycra) and rubber yarns to obtain the proper shaping of the material. These specially designed materials are intended as the replacement for parachute cord which is round.

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* Written by Mr. J. Ross

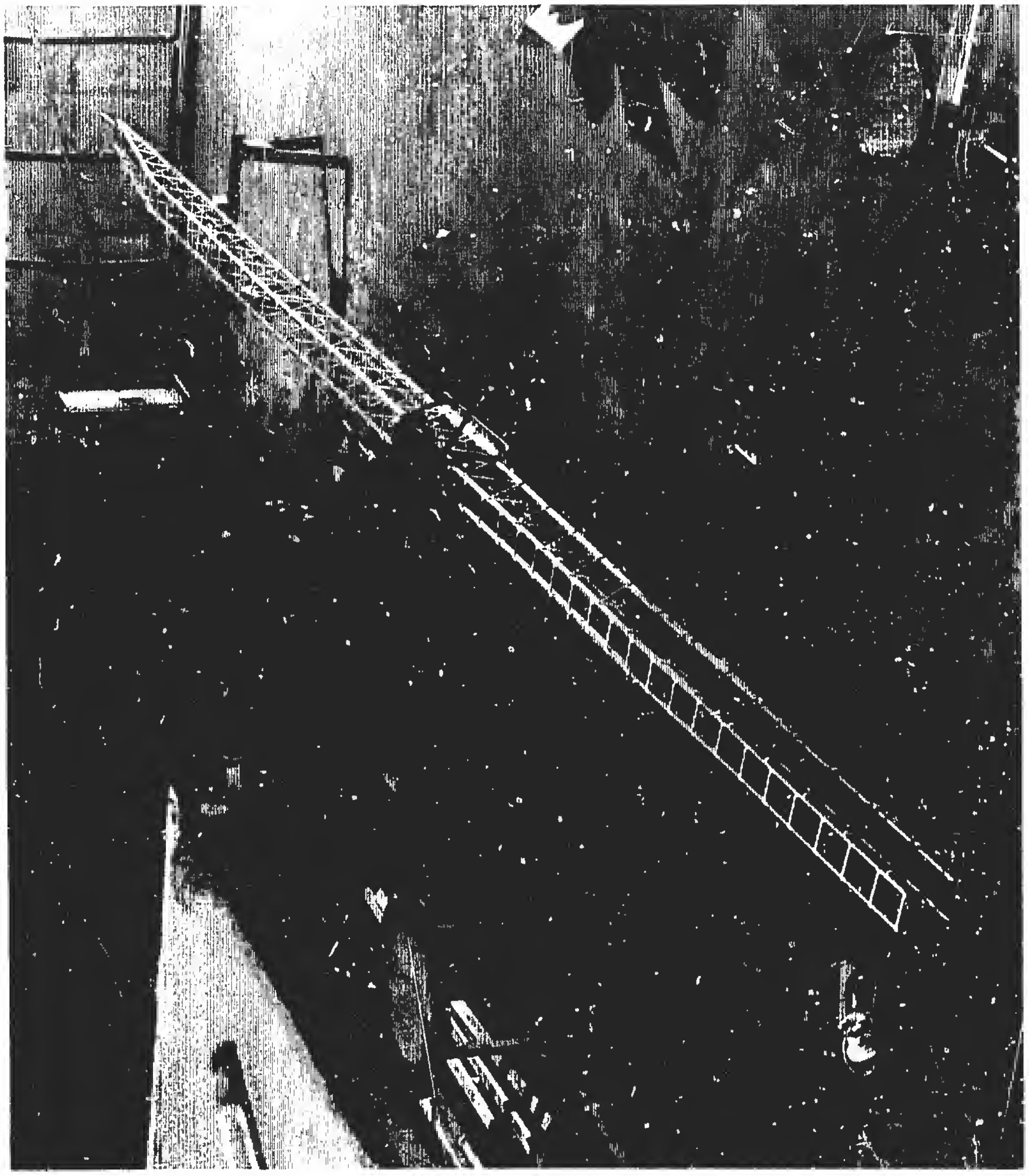
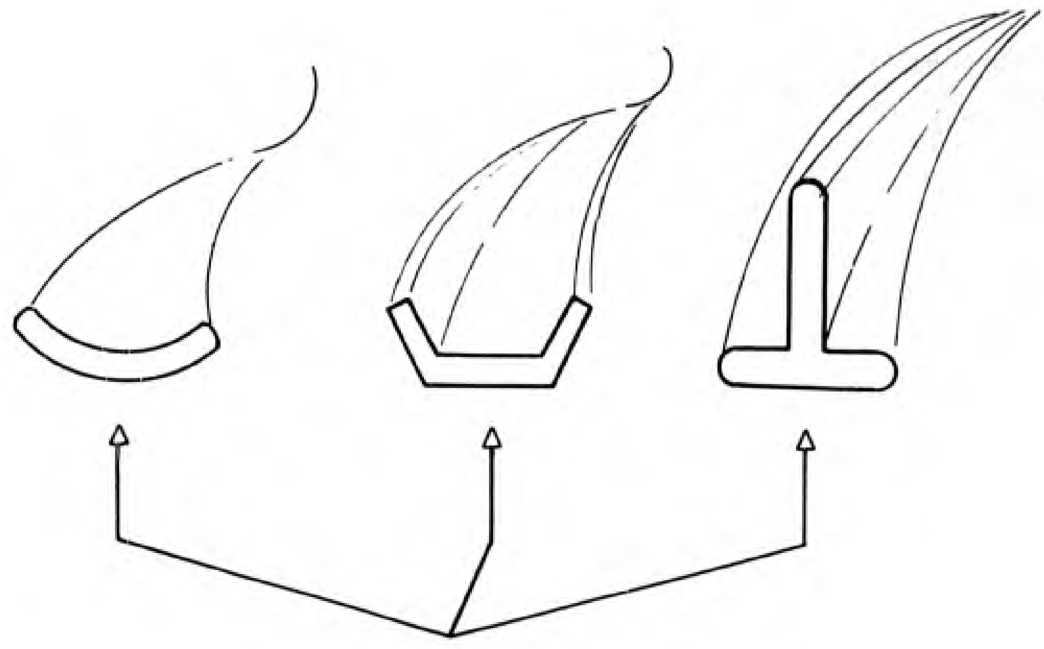


Figure 8. LLL Simulator



A contractor will insert hard wire into the hollow core for studies requiring electrical current from aircraft to mass. Automobile tow, wind-tunnel and inflight tests will be used to explore flying-line factors.

3. CONVAIR C-131B

In early 1969, a C-131B will fly with a side-firing laser (IBM's RASCOR) coupled to the aircraft's autopilot. With a passive reflector held by the ground observer, the laser should lock on the reflector and present slant range information to the autopilot. The autopilot will have a manual mode (absolute slant range presented on a vertical needle over the attitude indicator) and a fully automatic mode, including a barometric hold on altitude. The aircraft will be flown in a constant bank mode or constant ground radius mode, depending on the LLL requirement.

4. AUTO LLL SYSTEM

Automatic systems are needed to loiter over a point, linear (road or boundary line), or area target under low visibility conditions and to accurately control height and position. The literature stresses the inability to continuously loiter above a fixed ground position. This was the factor that terminated most efforts during the twenty years of limited circling-line endeavors. The problem is especially germane to

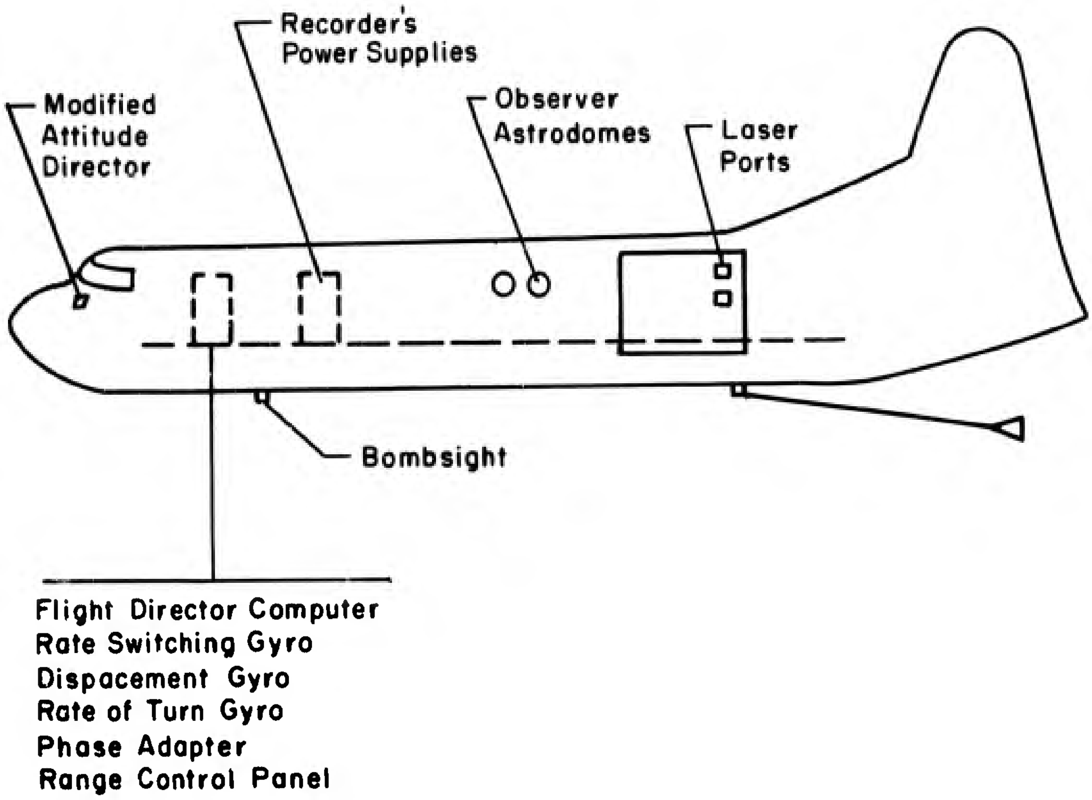


Figure 9. C131B Long-Line Aircraft

human engineering flight research because of the pronounced lag term (delay) between aircraft and mass motion; dramatic display/control reversals and apparent lack of control (the cone may move in several undesired directions); unusual forward/side/down flight control relationships (e.g., increasing bank drops the cone, extending the system vertically, shortening it horizontally); and the multi-task interdependence of pilot, reel operator, and ground observer tasks. This triple task must be unburdened with auto or semi-automatic control for missions requiring loitering above the ground. The in-house-developed VFR nonintegrated system for the C-131B aircraft will probably consist of inputs from a fixed altitude, laser derived slant range, and tracking error by the reel operator. A VFR integrated system would feed aircraft line and wind factors into an air data computer which would drive the autopilot and the reel. An IFR integrated system would add radio altitude and cone or ground homer signals to the computer.

These systems should be developed for loiter under day, night, and weather conditions. The VFR nonintegrated system being tested in 1969 in the C-131B could serve as the major input to these systems.

5. CONTROLLABLE MASS

An Army radio-controlled target drone will be lifted by a Cessna U206 in 1969. After moving into a trail position, the unpowered drone will be flown to a loiter position by the reel operator as the CESSNA starts to orbit the site. Over the (Figure 10) target, the drone will either be stalled or its recovery parachute deployed. Later, the parachute will be released, and the drone returned to its trail position and towed to base.

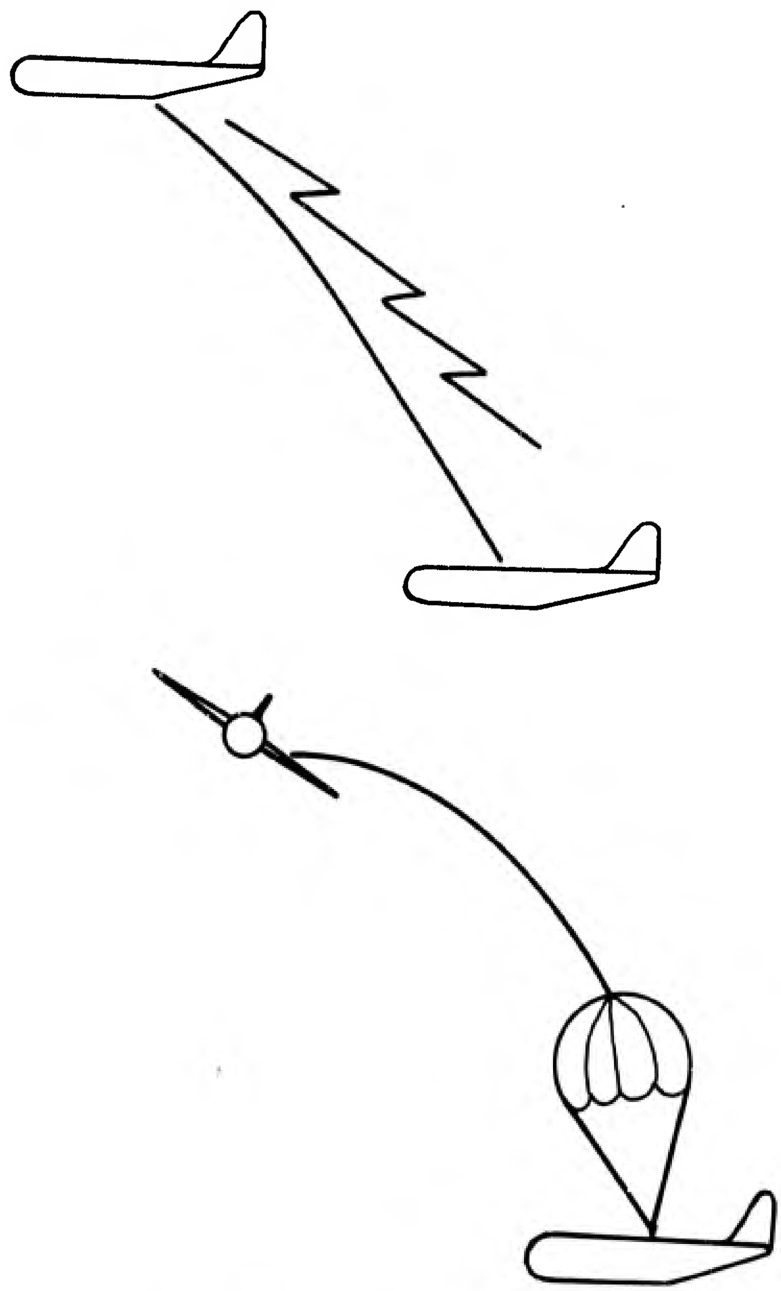


Figure 10. Radio-Controlled Drone

6. LIFTING SURFACES

Some method is desired to increase the rate of ascent of a heavy payload being retrieved from the long-line loiter circling maneuver. An aerodynamic device could be attached to the tow line in such a way that it creates lift when the retrieval maneuver begins and assist the initial stages of pulling the payload into the air. The configuration could develop into a thick delta wing with about a 45-degree sweep, with a large rudder. The lifting capabilities of delta wings at low speeds and the absence of severe stall characteristics are both factors which recommend this shape.

The 12-inch model (Figure 11) shown below was flown on the LLL simulator in January 1969. The device was attached to the line, and it quickly lifted into a trial position. Early tests suggest that radius of rotation and place of attachment for the shape are important for determining its lifting ability.

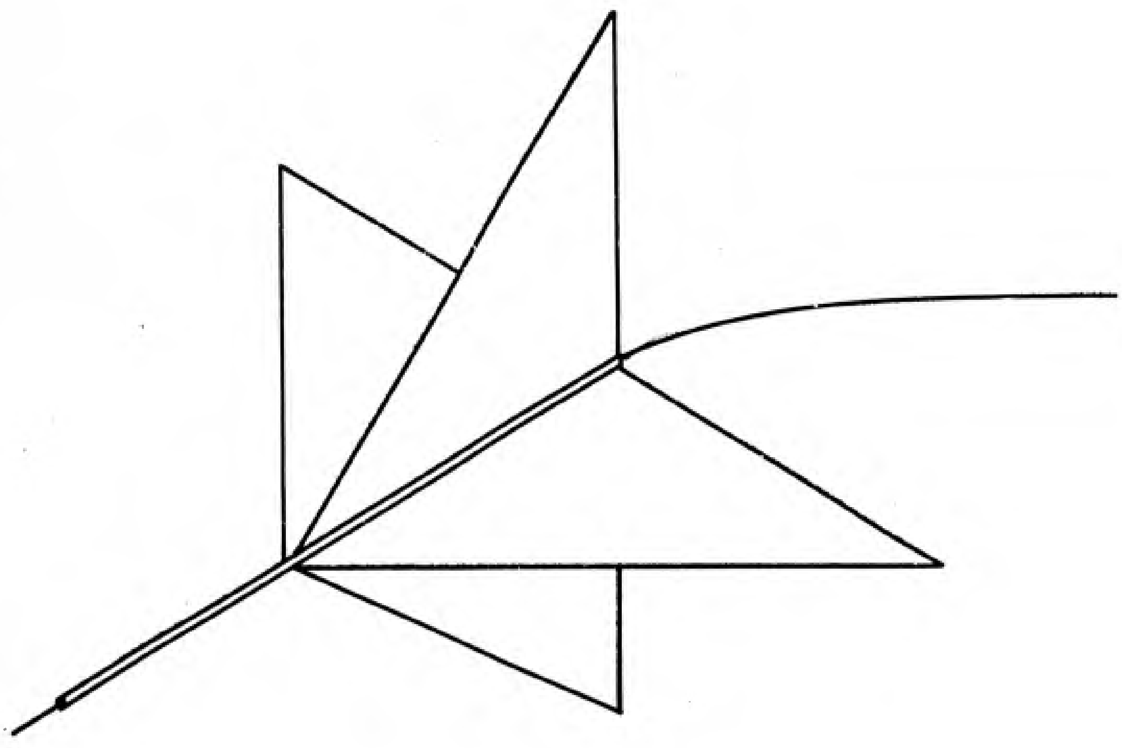


Figure 11. Lifting Surface Device

The device shows promise for retrieval and delivery of large masses. A 6-foot unit is being fabricated for future Cessna trials. The cone will be delivered to the ground and replaced with large (100 pounds) masses. The aircraft will then descend in orbit as line is layed on the ground and the lifting surface fixed to the line. The aircraft will then fly away, trail the device, and then the mass. Soft landings of the mass will also be attempted as depicted in Figure 12.

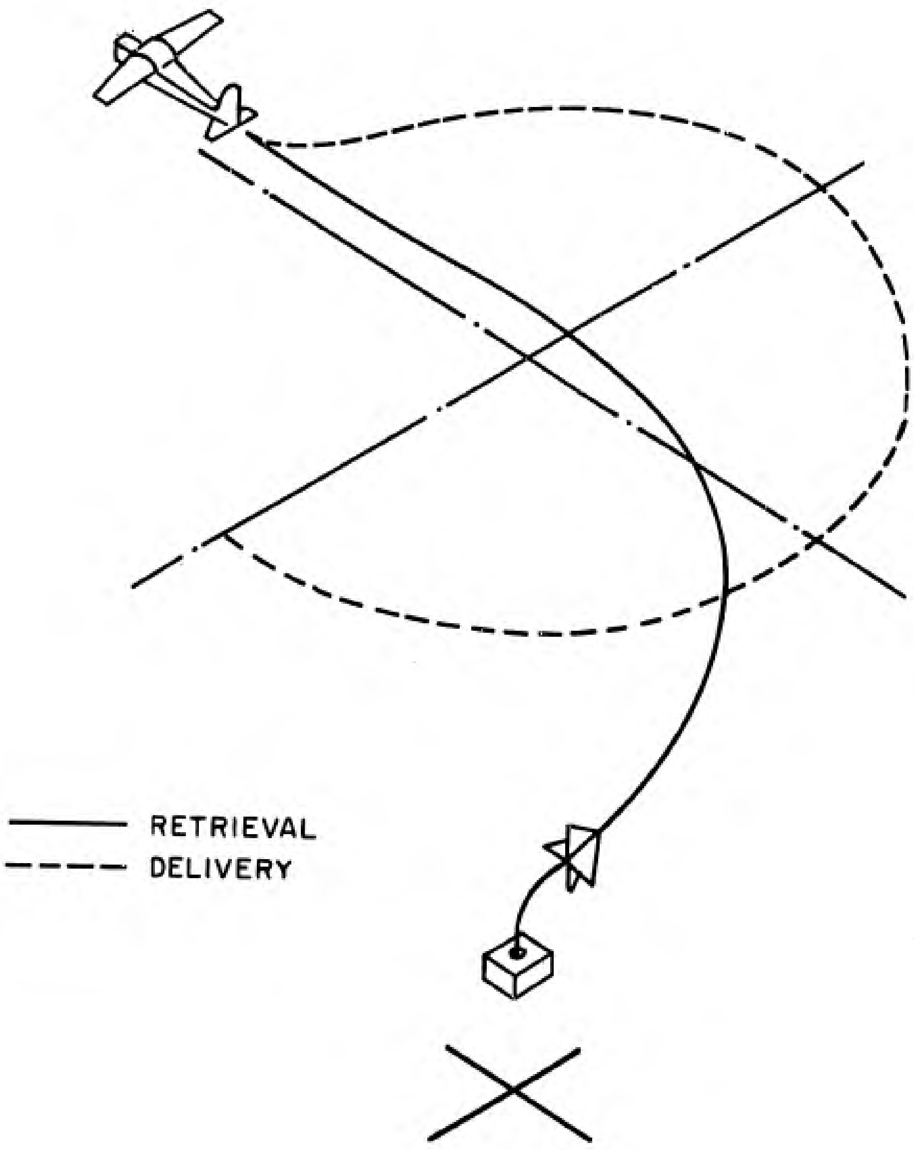


Figure 12. Lifting Surface and Heavy Masses

7. APPLICATIONS*

This section presents concepts for future systems.

a. Rescue

Two versions of a single pickup system for light aircraft will be man-rated in 1969. A system without a reel will be flown with a light aircraft and the pickup will be delivered by parachute. The LLL rescue kit will be designed to deploy from aircraft without any major modification to the aircraft. A with-reel system using an electro-hydraulic winch will also be man-rated for light aircraft. The reel will be designed for quick installation as a standby rescue unit. A heavy aircraft system will be man-rated for longer lines and will be designed for permanent installation.

Future vehicles could include free and podded multi-personnel (with lifting surfaces) pickup systems.

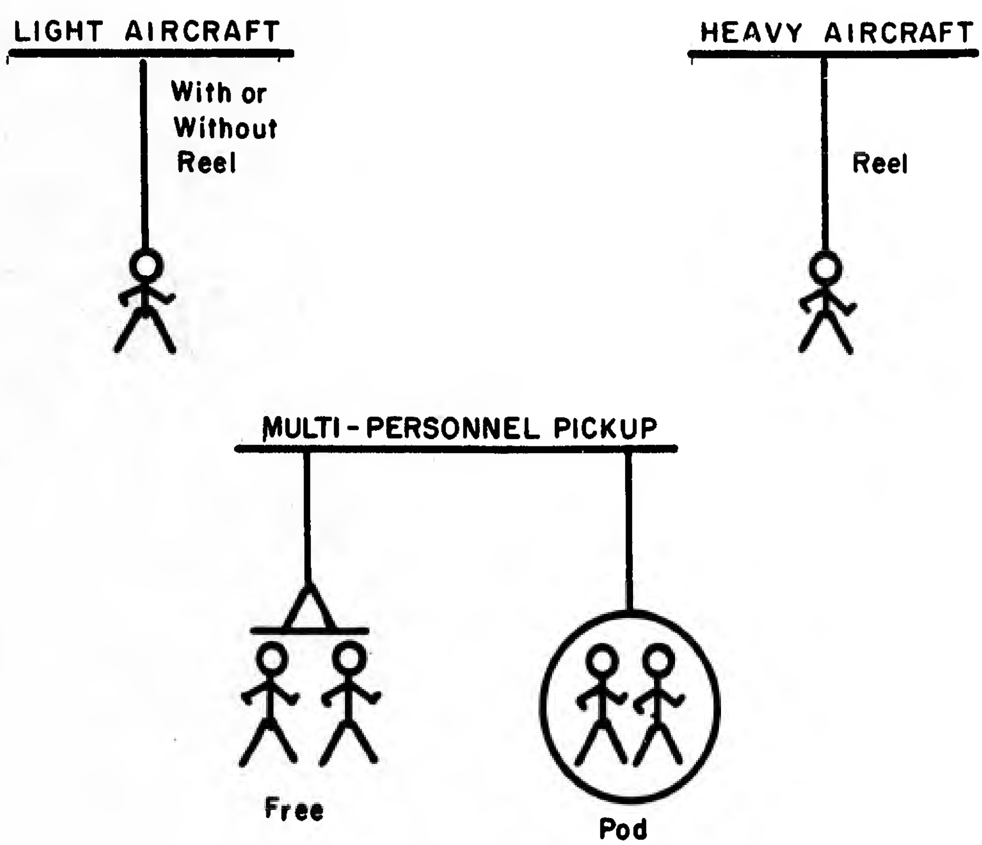


Figure 13. Pickup Designs

* Reference 12 includes several classified applications.

b. Communications

A long phone system will be tested and documented in 1969. A hot mike and headset in the cone will be dropped to the ground observer. An existing army field phone unit has been ordered for the test. A polyethylene or nylon line with a hard wire core may be used to secure the transmissions. Recommendations for a communication kit will be made for eventual use by commando, covert Forward Air Controller, rescue and special Military Advisory Groups (Figure 14).

c. Supply

The retrieval-delivery (supply) places or retrieves large masses at low speeds or retrieves small masses at high speeds with jet aircraft. The launch (retrieval) has proven to be the quickest LLL development and the mass size may only be limited by line strength and tow power.

Delivery sizes would be paced by flying line and lifting surface developments. Kits could be designed for pylons for jets and reciprocals to serve as helicopters for special lift missions.

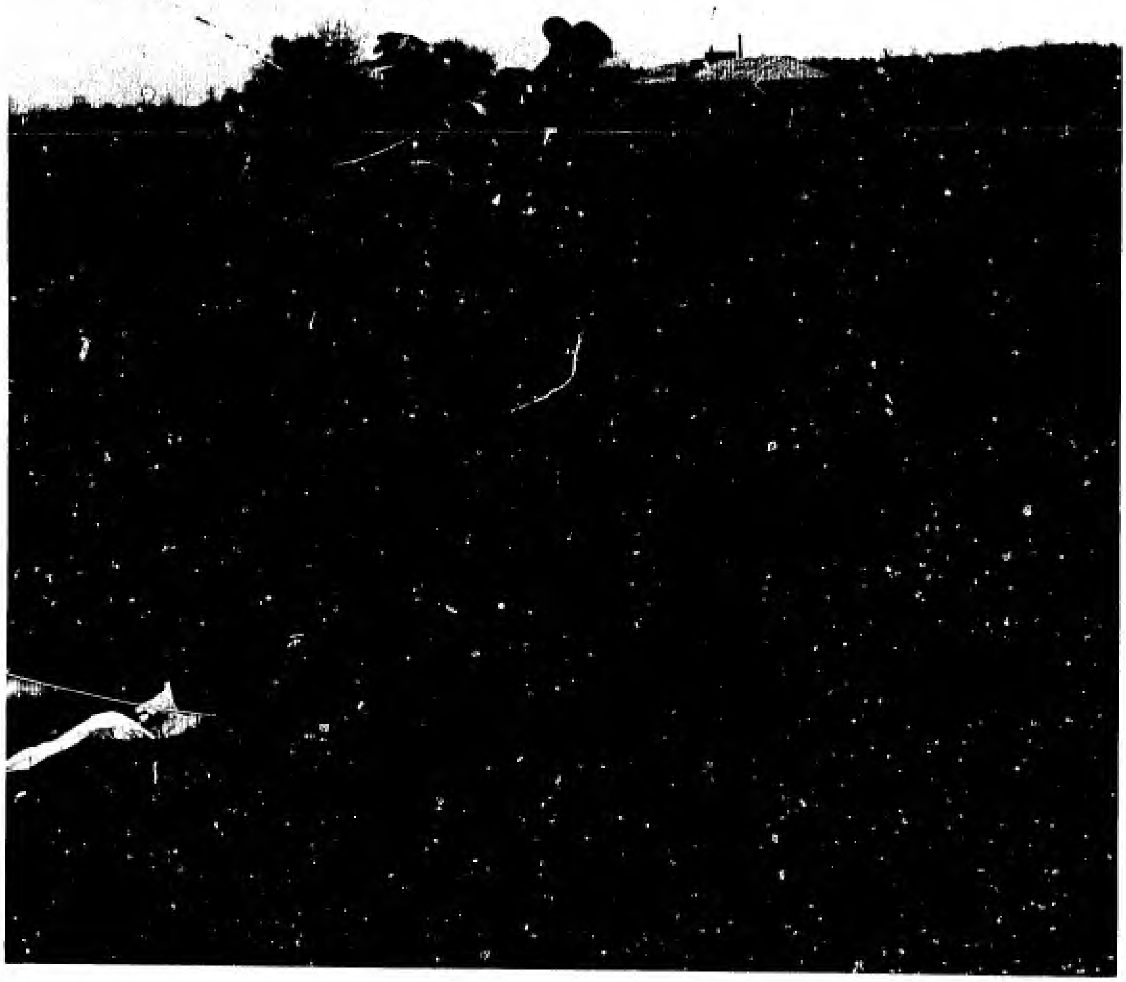


Figure 14. Communications

SECTION IV

CONCLUSIONS

This report is concerned with the development of a new technique. Historically, the Air Force Commander has had a choice of zero-velocity (helicopter) or forward velocity (aircraft) systems for accomplishing his missions. These new long-line techniques will offer him simultaneous zero-high velocity systems.

The significant combat success of the AMRL side-firing concept has established the on-pylon turn as a maneuver for Air Force strike tactics. The purpose of the free-fall and circling-line technique is to place a well-controlled mass at the center of that maneuver.

Starting in 1948, the Air Force, Navy, Industry and NASA studied and curtailed their short efforts because of vertical bounce (yo-yo) of the mass, elliptical motion of the mass, difficulty in maintenance of a constant radius turn, and the effects of wind and turbulence on the mass (References 3-9).

It is critical to the understanding of this report to note that AMRL has avoided many of these problems by using free-fall techniques for delivery and straight tow techniques for launch. The circling-line concept (except for a controllable mass or automated system) has been limited to a method of loitering after delivery and before launch.

The LLL technique may be used to perform rescue and supply missions. Both missions could be performed by a single aircraft. Such mission flexibility would significantly enhance a field commander's overall capability without enlarging his aircraft inventory.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Deputy for Limited War Aeronautical Systems Division Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

Maneuvering techniques for fixed-wing aircraft positioning a towed mass near the center of an on-pylon are discussed. Free-fall and circling-line techniques were improved and several applications demonstrated. Successful ground launching of 100-pound masses with the system prompted a decision to man-rate it for air to ground pick-up of personnel. New delivery and retrieval methods are discussed.

Future efforts involving longer lines and heavier masses are discussed in terms of flying lines, lifting surfaces, a long-line loiter (LLL) simulator, and a large cabin aircraft.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rescue						
Supply missions						