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Analytic Investigation of Aerial Pickup Systems

by

P. S. Chase and J. L. Holmes

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Abstract

The characteristics and the results of analytic investigation of four inflight aerial pickup systems, the "Skyhook System", the "Towed Homing System", the "Long Line Circling System", and the "Two Plane Circling System", have been summarized and discussed. The factors determining the feasibility of these systems have been compared in an effort to determine which is most suitable for various applications at the present time, and whether any might prove more promising with future development work.

There is no "best system" for all applications and comments are made regarding the usage to which each is most suited. A meaningful comparison may be made for the case of inflight pickup of humans if the present state of development of each system and its ultimate potentiality for this use are considered. The comparison shows that the "Two Plane Circling System" is best developed at the present time and is suitable with minimum further effort for inflight pickup of humans. The "Skyhook" offers an intermediate possibility as far as the amount of further development required but will be suitable for alternate applications. The "Long Line Circling System" is the least well developed but holds the greatest potential for many possible situations of human pickup.

In addition, the application of these systems to the operation of dunked sonar has been investigated, since the possibility of thus utilizing the performance of fixed wing aircraft for such operations was considered attractive.

Introduction

The limitations of systems of aerial pickup for cargo, gliders, and human subjects which were developed during and prior to World War II have been discussed in Ref. 1. These systems involved a boom-stabilized line and acceleration limitation by cable pay-out or elasticity. Although this type of pickup was developed to operational capability, it was felt that further investigation might yield other means of transferring a human from the ground into a flying fixed wing aircraft. Converto-planes were eliminated from the study.

From the proposals, Refs. 2 and 3, and the morphological investigation of aerial pickup systems previously made, Ref. 1, four systems arose that were considered as the most promising for further study of feasibility: chronologically in order of analysis, the "Skyhook System", and "Towed Homing System", the "Long Line Circling System", and the "Two Plane Circling System". Analytic investigations of the first three of these systems have been completed and have previously been presented as Refs. 4, 5, and 6. No phase of operation of the Two Plane Circling System was considered to involve sufficient complexity to require analytic investigation.

In this report, the characteristics of the above systems and the results of the analytic investigations pertaining to the feasibility of the systems have been summarized. Experimental investigations conducted by other contractors are considered. A comparison has been made to show the most suitable and promising system for various applications, in view of the present state of the art and of the possibilities of further developmental effort.

A brief investigation has also been made of utilizing these pickup schemes in conjunction with dunked sonar units. The results of this investigation appear in Appendix I.

Summary of Characteristics and Results

The factors determining the feasibility and desirability of an inflight aerial pickup system might be outlined as follows:

1. Complexity of equipment
   a. In aircraft or towed by aircraft
   b. Initially on ground or dropped to ground
2. Aircraft maneuvers and requirements.
3. Certainty and ease of contact
4. Characteristics of flight of object picked up
   a. Trajectory
   b. Acceleration
5. Operation under non-optimum conditions
   a. Visibility
   b. Wind
   c. Areas with obstructions
6. Additional Problems (if any)

Each of the four pickup systems will be discussed considering these factors.

A. Skyhook System

The operation of the Skyhook System may be described as follows: An aircraft, in level flight, intercepts a stationary, vertically suspended cable at the ground end of which is attached the pickup load. On contact, the load is drawn into the air, and the upper end of the cable is attached to a winch in the aircraft and drawn in. The cable may be initially suspended by a balloon or other device.

The complexity of equipment required in this system, while fairly great, is not so unattractive that immediate applications of this scheme cannot be foreseen. On the aircraft, a yoke is required to guide the cable into the attachment slot. Also, a device to seize the cable and draw it into the aircraft for attachment to a winch is necessary. On the upper portion of the cable a series of "knots" is required to hold the cable in the attachment slot after contact and a helium or hydrogen-filled balloon provides a suitable means of holding the cable in its stationary vertical position. The cable and balloon together with the balloon inflating mechanism, and harness for the load, must be dropped on a separate pass by the aircraft or must already be available on the ground. Conventional balloon inflating techniques require considerable time to fill a balloon large enough to lift the required amount of cable; however, assembly time on the ground might be greatly reduced by the use of a packaged, pre-inflated balloon or by a very rapid, automatically actuated hydrogen generator.

The only aircraft maneuver required by the Skyhook System is a straight and level flight path, with a steep climb after contact beneficial to improving the trajectory of the load. Any reasonably large aircraft that can fly in level flight at 125 knots or less, and that can be equipped with a winch, is suitable for this system. A single engine aircraft, in which the yoke could be attached to the wing, would lessen the danger of hitting the cable with the propeller, but would make contact slightly more difficult than with a multi-engine aircraft with a center mounted yoke.

The accuracy of flight required to ensure contact is high, depending of course on the width of the boom on the aircraft, and on the length of the "knotted" section of the suspended cable. Hitting the cable with any part of the aircraft except the yoke will doubtless effect disastrous motion of the load from the ground and endanger the aircraft.

The analytic investigation of trajectories and acceleration for this system concerned only configurations using steel cable. Subsequent experiments by another contractor were performed solely with nylon cable, largely as a matter of safety to the aircraft. Trajectories predicted with the steel cable are satisfactory with an initial trajectory angle (with the ground) of the order of 90°. Trajectories have an oscillatory nature, the bad effects of which can be damped or overcome by use of longer cables or an aircraft climb after contact. With the use of such an aircraft climb, and a configuration with 500 feet of steel cable, with a flight speed of 125 knots, the minimum altitude on the first downswing of the load is about 300 feet, approximately 2800 feet from the pickup point. If higher speeds or shorter cables are used, there is the danger that the load will swing above the aircraft; since the boom is located on the forward part of the aircraft, this is not a satisfactory condition. The trajectories exhibited in the experiments performed with nylon cable appeared to be of about the same nature, with initial trajectory angles of perhaps 70° to 80°.

Accelerations on the load in the Skyhook System can be kept reasonably low. With the use of nylon cable, the maximum acceleration for various configurations involving human-weight loads, has been experimentally determined to be in the 6-10 g range (including adverse wind effects). By use of small (1/8") steel cables and lengths of 500 feet with an airspeed of 125 knots, the predicted maximum acceleration for comparable loads falls below 6 g, with a significant acceleration lasting over a period of about 1.5 seconds. Increasing cable diameter or airspeed and decreasing length would tend to increase the accelerations.

The Skyhook System is not well suited to operation under restricted visibility conditions. Without a visible reference point on the ground, as well as a visible upper section of cable, contact would be difficult to accomplish. Even with a cable lighted over its whole length, for night operation, the loss of perspective would make correct alignment and altitude adjustment very difficult. The presence of wind will require more lift from the balloon to maintain the desired length of cable in the air. The aircraft is assumed to make its approach in an upwind manner. An increase in acceleration of several g may be expected if the cable is inclined about 30° from the vertical. Trajectories should not be much changed, except that the aircraft will actually be flying closer to the ground for the same length of cable, hence the minimum value of altitude of the load on the first downswing will be somewhat less.

This system is well adapted to pickup over most types of terrain. Pickup, even out of a small clearing surrounded by obstacles of heights up to several hundred feet is possible. The limiting factor is the altitude of high obstacles since the aircraft is originally flying at a height of only several hundred feet.

A problem peculiar to the Skyhook System is that of the motion of the section of cable between the aircraft and balloon after contact. The upper end of cable is likely to pull out of the balloon soon after contact, and snap back toward the aircraft. When nylon cable is used, the damage potential of this part of the cable is not great, unless it engages more or less securely some portion of the aircraft before the cable is firmly attached in the "eye" of the yoke.

The applications for this system include air-sea rescue and transfer of personnel and the pickup of mail or small quantities of cargo. The degree of safety for human pickup and the complexity of equipment and operation involved are offset by the short reel-in time, and ability to function from extremely small areas such as ship decks, life rafts, small clearings, etc. Further development work for specialized applications is clearly warranted.

B. Towed Homing System

The operation of the towed homing system may be described as follows: an aircraft in straight and level flight towing a cable with a homing device at the end, flies so as to pass over a target. The homing device guides itself to the target and there automatically makes attachment to a load reposing on the ground. The load is drawn into the air, due to its attachment to the cable, and is subsequently reeled into the aircraft.

For ideal operation of the system, a homing device is required at the end of the towed cable. It is doubtful whether contact can be accomplished by relying on aircraft maneuvers alone to guide the cable end to the target. Such a homing device would probably consist of a paravane, automatically directionally controlled by radar reflections, etc. from the target. In addition, an increase of drag of the load after contact, or an addition of lift, is necessary to give a satisfactory trajectory. This can be accomplished by another piece of equipment or by the ability to change the angle of attack of the homing paravane so as to provide upward instead of downward lift.

On the ground, a rig to permit contact is necessary, consisting of a harness for the load, and a length of cable so strung as to permit attachment of the end of the towed cable, as well as the target for the homing device. This equipment in rescue problems would not be available on the ground, and would have to be dropped on an initial pass by the aircraft, and then assembled.

The only aircraft maneuver required by the Towed Homing System is (aside from the initial equipment-dropping pass) a straight and level flight path, with a steep climb after contact beneficial to improving the trajectory of the load. Any reasonably large aircraft that can fly in level flight at 125 knots or less, and that can be equipped with a winch is suitable.

With a well developed homing head, contact should be relatively certain. Of course, the aircraft must maintain a flight path that will pass as close as possible over the target. There is a certain danger involved in placing a heavy moving object, the homing head in this case, in the vicinity of the load, particularly if the load is a human.

The results of the analytic investigation of the flight path of the load in this system reveal that both trajectories and accelerations are suitable for human pickup. Trajectories may be made safe by use of cable on the order of 1100 feet in length, together with a lift or drag device actuated at contact, in conjunction with a climb by the aircraft after pickup. For a typical satisfactory configuration, the initial trajectory angle (from the ground) is 33^{o}, while the altitude of the load at 1000 feet from the pickup point is 250 feet. The oscillatory nature of trajectories, which may result in an inopportune return of the load to the ground in some cases, may be overcome by use of long cables, a device producing additional drag or lift on contact, and an aircraft climbing maneuver.

The accelerations of the load resulting in the towed homing system are high, although not necessarily too high for human endurance. The greater danger appears to be that the predicted load will exceed or come quite close to the rated breaking strength of the cable. The peak acceleration for the case previously mentioned is 20 g. For a special configuration, the predicted acceleration peak has been reduced to 7 g. Most configurations having reasonable accelerations give values near the peak for a duration of approximately 0.5 seconds. Use of longer cables and of a heavier load initially on the towed cables tend to reduce the acceleration. Reducing aircraft speed also reduces the acceleration.

The Towed Homing System could be made operable under conditions of restricted visibility if the target point could be located by radar from the aircraft. The aircraft must fly only reasonably close over the target point, allowing the homing head to make the final accurate contact. In the presence of wind, the system should still be operable. A flight either directly upwind or downwind should permit the same straight approach trajectory. Over reasonably smooth terrain, or over water, the "ground effect" on the homing-head paravane could be used to aid altitude control in this system. However, the system is not suited to areas with obstructions near the pickup point.

The complexity of equipment required in this system, both in the air and on the ground immediately casts doubt as to the desirability of this system. However, it is a logical extension of the conventional (All American Aircraft) system which would eliminate proximity of the aircraft to the ground. In addition, analytically, it was necessary to essentially solve the trajectories and accelerations of this system as one phase of the Skyhook problem.. Applications which would warrant the effort required to perfect this system are not apparent at this time and further development is not recommended.

C. Long Line Circling System

The operation of the Long Line Circling System may be described as follows: an aircraft equipped with a very long cable, causes one end of this cable to be placed on the ground, either by "bombing" it in or by reeling out the full length of cable, and by a series of tightening circling maneuvers allowing the end to drop to the ground. The aircraft takes up a circling pattern to maintain the cable end stationary while the load is attached. Pickup is effected by the aircraft coming out of its circle into a straight climbing pattern.

The Long Line Circling System is basically simple as far as equipment required is concerned. Only a very long length of cable (8,000 feet or more), should be required, together with an initial load including the pickup harness and (ideally) a device for automatically staking the cable end to the ground. No equipment is required at any time on the ground and the need for a separate pass by the aircraft is non-existent.

The aircraft maneuvers required by this system are rather complex. The initial cable-placement maneuver might consist either of a dive- or level-bombing run, or of an initial circling pattern of large radius, quickly changed to a circle of small radius, not necessarily about the same point. If the bombing run technique of placement is used, it is then necessary to take up a circling pattern at a small radius to keep the cable end where it was placed. If the circling method of placement is used, the aircraft should be in or near the desired circling pattern when the cable end hits the ground.

The circling pattern necessary to keep the cable end stationary on the ground and to maintain a small angle of the cable at the ground with the vertical is probably not easily maintained by many operational aircraft. An aircraft capable of maintaining a one-minute turn at an airspeed on the order of 100-110 knots, without loss of altitude, should be satisfactory for this system if 10,000 feet of cable are used. Still longer lengths of cable might permit the employment of less maneuverable aircraft.

Contact of the cable with the load, in this system, is made entirely at the discretion of personnel on the ground. There are no dangers presented by the chance of a partial or undesired contact. If the cable is not automatically staked to the ground as it drops, subsequent operation of the system may be facilitated by so doing (pretensioning) at the time of attachment of the load. It is, of course, necessary to initially place the cable end on the ground reasonably close to the target point, so that contact may be effected quickly and easily. Techniques for accurate placement, either by the bombing or circling method, remain to be developed experimentally.

The flight path of an object picked up by the Long Line Circling System has not been analyzed directly. However, on the basis of experimental results and logical thinking, it appears that no dangerous trends should be exhibited by the trajectories. The only requirement is that the object leave the ground without dragging, at an angle sufficient to clear any obstructions in the immediate vicinity. The controlling factor of the initial trajectory angle is, of course, the angle of the cable at the ground when tension reaches a point sufficient to cause motion of the load. If the aircraft, by its circling configuration, causes the angle of the cable to be reasonably close to the vertical, and if pretension is used, mainly to prevent dragging along the ground, the initial trajectory angle of the load will be most acceptable. The subsequent flight path of the load should be characterized by a gradual rise to the equilibrium position associated with a straight flight path of the aircraft. If the aircraft has chosen a circling position which will give a good initial trajectory angle, this subsequent equilibrium position will be several thousand feet above the ground, even without allowing for a climb of the aircraft.

The acceleration of the load may be controlled by the amount of pretension used; the maximum force exerted on the load should equal the breaking strength of the line used for pretensioning. Acceleration may be thus limited to 2 or 3 g and satisfactory trajectories still result.

Under conditions of restricted visibility, the Long Line Circling System still has possibilities of application. Such conditions would probably require the "bombing" method of cable placement, with radar, infrared, etc., used for finding the target point. Establishing and maintaining a circle about an invisible point would be extremely difficult, hence radar again might be used. Additional instrumentation in the aircraft, specifically, a tensiometer giving the cable tension at the aircraft, might also make possible the establishment and holding of the desired circling flight path, even with the reference point invisible.

Wind has a most unsatisfactory effect on this system. Since the aircraft in its circling configuration cannot maintain its circle in the presence of wind by flying at constant airspeed, the aerodynamic drag on the cable will change markedly as the aircraft varies its airspeed to keep in the desired circle. As a result, rather large fluctuations in tension and angle of the cable at the ground between the upwind and downwind portions of the circling pattern will occur. It is possible for a section of the cable to lie along the ground during the downwind portion, only to rise and give excessive tension during the upwind section of the flight path. If the aircraft flies in a pattern which gives an angle of the cable with the vertical at the ground which is reasonably small, the cable should never drag on the ground, but the tension may be expected to vary by a factor of 2 or more, with a wind in the 10-15 knot range. A wider range of these fluctuations in tension can be permitted by having the cable end initially staked to the ground; however, in winds of over 25 knots, the system is probably impractical.

The Long Line Circling System should be operable in areas with high obstructions nearby, provided that the aircraft can take up and maintain a circling pattern giving a small angle of the cable with the vertical at the ground. Since the altitude gain experienced by the load is on the order of several thousand feet (for sufficiently long cables), it is the initial trajectory angle attainable which is the limiting factor in clearing any obstruction.

This system is the least developed of those which have been attempted experimentally. The amount of pilot skill required and the long reel-in time are fundamental disadvantages of this system (cable length as such is not). However, it holds great promise of furnishing a simple, reliable method of inflight pickup. The analytic investigation of this system has furnished an understanding and optimism regarding its capabilities beyond those demonstrated in preliminary experiments. For applications requiring safe and surreptitious pickup of personnel, this scheme is probably the most promising investigated. Further development work is definitely warranted if the best general solution to this specific problem is desired. If developed, it would also be useful for a variety of other pickup applications.

D. Two Plane Circling System

The operation of the Two Plane Circling System may be described as follows: two aircraft, towing between them a span of cable to the center of which another length of cable is attached, take up a circling pattern. The aircraft fly in the same circle, but with one 180° removed from the other. The length of cable attached to the cable span will hang straight down, and the aircraft may maneuver their circle about so as to place the end of this cable at the desired point on the ground. The load is attached to the cable end, and pickup is accomplished by the aircraft climbing while still in their circling pattern. When sufficient altitude is reached, one aircraft cuts free from the span of cable, and the other aircraft reels in the cable and load.

This system was not investigated analytically, since there was no phase of its operation which appeared complex and of which a better understanding appeared necessary.

The immediately obvious disadvantage of this system is that it requires two aircraft and the coordination of their movements in addition to the actual pickup operation. The cable assembly towed by the aircraft is not particularly complex, and no equipment is necessary on the ground. The idea of two aircraft, attached together by cable, and hence limited in their relative motion, undergoing a long flight to the site of the pickup operation, presents a number of possible deterrents to successful completion of pickup, aside from the fact that the effort required is doubled for the same operation. A system in which the aircraft are initially uncoupled would improve the situation and could utilize an existing system of inflight coupling near the pickup site.

A formation take-off by the aircraft, if initially coupled, is necessarily required in this operation. As far as the circling portion of the system is concerned, the radius of turn may be easily adjusted to an appropriate value for the aircraft used merely by changing the length of the cable span between the aircraft. Experimental tests with this system show that a small amount of pilot practice with the system enables all necessary maneuvers to be performed in a satisfactory manner.

The end of the vertical portion of cable can be placed at the target point as accurately as the skill of the pilots permits. If a short length of cable is allowed to rest on the ground, small variations in the circling pattern of the aircraft will not move the cable end while attachment of the load is being made.

Trajectory and acceleration of the load in the Two Plane Circling System ideally might be considered as perfect. The trajectory is vertical, or near vertical, depending only on the skill of the pilots, to as high an altitude as desired. Accelerations of the load can be non-existent, if the aircraft go into their climbing pattern gently.

This system is not particularly applicable to conditions of restricted visibility, since the relative position of the aircraft must be held reasonably close to 180° across the circle. In addition to the danger of having two aircraft following the same flight path under poor visibility conditions, this relative positioning of two aircraft with respect to the center of the circling pattern would probably require extensive instrumentation.

It is possible that, with two aircraft controlling the position of the vertical section of cable, this position may be held quite stationary even in the presence of wind. It is also possible to allow the whole system to drift with the wind, if this wind is not too large.

The Two Plane Circling System is applicable to picking up loads (of limited weight) from any type of terrain, regardless of obstructions in the area. All that is necessary is a small open area, large enough to permit dropping in the cable and raising up the load. The low rate of ascent possible with this system minimizes the danger even of contact with obstructions in the surrouding area.

The main probable cause for failure in this system would be the breaking of the span of cable between the aircraft. The most apparent way of causing the cable to break is for the aircraft to increase their radius of turn until the tension in the span cable mounts to an unmaintainable degree. A tensiometer giving the cable tension at the aircraft would be a useful instrument to prevent this type of failure. However, little or no trouble of this type was encountered in experimental work with this system with operational aircraft. Some difficulty was encountered on take-off with the full length of cable extended, a necessary but unrealistic condition of the experiments. Take-off without initial connection between the aircraft would eliminate the likelihood of cable breakage due to dragging along the runway and facilitate take-off from aircraft carriers.

This system is without a doubt the best developed and most easily operated of those studied. Its inherent simplicity, reliability, and safety, recommend it for most conceivable pickup operations. However, the facts that two aircraft and consequent coordination are involved and that restricted visibility operations will be difficult make it less attractive than the Long Line Circling System as a method of surreptitious rescue work. The relatively little development effort required to perfect this scheme for application as a general utility pickup system seems small in relation to the possible return.

Comparison of Systems

A condensed comparison of the four systems of aerial pickup considered is presented in Table I. It may be seen that the Two Plane Circling System is superior to all except in two respects: operation under restricted visibility conditions. and, most important, the fact that it requires two aircraft. In spite of the high degree of operational development of this system at the present time, the two aircraft requirement,

TABLE I

Comparison of Pickup Systems on Feasibility Factors

	Skyhook	Towed Homing	Long Line Circling	Two-Plane Circling
No. of Aircraft Required	1	1	1	2
Equipment Simple	No	No	Yes	Yes
Assembly Reqd. on Ground	Yes	Yes	No	No.
Cable Length Reqd.	500 ft.	1100 ft.	8000-10,000 ft. or more?	5000 ft between aircraft
Special Training and Practice Reqd. for Pilot	Little	None	Most	Little
Most Aircraft Acceptable	Yes	Yes	No?	Yes
Initial Trajectory Angle	70-90^0	35^0	? >40^0	90^0
Eventual or Minimum Load Alt. at distance from pickup	300 @ 3000 ft.	250 ft @ 1000 ft.	? 1000 ft @ 2000 ft.	As high as desired
Max. Acceleration (optimum)	~5 g	7-20 g	1-3 g	0-1 g
Operable with restricted visibility	Doubtful*	Yes*	Yes*	Doubtful*
Operable with Wind	With low wind	Yes	With low wind	Yes
Operable over all terrain	Yes	No	Yes	Yes
Operable in closed-in areas with very high obstructions nearby	No	No	Possibly	Yes
Feasibility Established by Experiment	Yes	No	No(Yes**)	Yes
Amount of Further development necessary	Some	Much	Much	Almost none

*Additional Instrumentation Required
** With light aircraft only.

which effectively doubles the effort required for the pickup operation, may make this system undesirable in comparison with a one-aircraft system with satisfactory characteristics.

No such system has even approached the present degree of development of the Two Plane Circling System. However, the Long Line Circling System has offered, and still offers, the best potentialities of any one-aircraft system considered. Its low acceleration and potentially excellent trajectories seem to place it far above the two other one-plane systems. However, the results of experiments conducted with the Long Line Circling System have not been particularly favorable, except where light aircraft were used. It does appear, however, that with highly maneuverable operational aircraft experimental results should be obtained proving the feasibility of the system. Extremely long cable lengths (well over 10,000 feet) might allow the operation to be performed successfully with most operational aircraft. In view of the great range of conditions allowable for successful pickup with this system as visualized at its best, further development work should certainly be justified if a one-aircraft pickup system is desired.

The Skyhook and Towed Homing Systems have certain limitations. In both, rather exacting accuracy is required for contact and successful pickup. It is far easier and safer for contact on the ground to be made between two relatively stationary objects (as in the Long Line Circling and Two-Plane Circling Systems) than between two objects, one of which is in motion at rather high speed. Further, the accelerations of the load resulting from the Skyhook and Towed Homing Systems, while not excessive, would, for example, probably be too great for an injured human to endure. Also the height of trajectories several thousand feet from the pickup site in these two systems is limited by the initial altitude of the aircraft, which would usually be somewhere below 1000 feet.

The Skyhook System has had its feasibility under certain conditions established by experiment. However, some further development work would be required before the system could be considered safe for human pickup. No experimental work has been conducted with the Towed Homing System. To make this latter system at all practical, extensive development of the homing feature would be required.

Conclusions

Four aerial pickup systems have been investigated: the Skyhook System, the Towed Homing System, the Long Line Circling System, and the Two-Plane Circling System. Analysis has been made of applicable sections of these systems where pertinent. While all systems appear to be feasible for pickup operation (and even for human pickup), there is no universally best system and the characteristics and stage of development of each naturally determines the most satisfactory for specific applications.

The following conclusions appear warranted:

1. The Two-Plane Circling System offers the safest and most readily available means of aerial pickup. If there is no objection to the use of two aircraft in a particular application and if the conditions for pickup will allow the necessary coordination between these aircraft, this system is generally

satisfactory. Little development effort is required to ready this system for human pickup. Very little pilot training would be required and modifications to aircraft should be slight.

2. The Long Line Circling System appears to offer the best ultimate solution to a variety of aerial pickup situations. In addition, it embodies the use of only one aircraft and places the responsibility for coordination in the hands of a single person. However, further experimentation, particularly with highly maneuverable aircraft is required to establish the degree of feasibility for human pickup. Considerable pilot training may be required but additional relatively simple instrumentation should make the operation easier. Still it offers the only real possibility for pickup under restricted visibility conditions. This system, well developed, should have such advantages over other single aircraft systems for certain applications that further development is recommended.

3. The Skyhook System, while at a further stage of development than the Long Line Circling System, has certain limitations in its application. The hazard associated with pickup by this system is greater than with the Long Line Circling or Two-Plane Circling Systems. Also the equipment on the ground necessary to raise the cable is somewhat complex.

This situation is unimportant for operation from shipboard or at a maintained base and could be minimized in other instances by the development of an automatically inflating balloon package. Little pilot training is required and the short reel-in time involved might furnish a definite advantage for human pickup in cold atmospheres. For certain applications this system is sufficiently promising to warrant the development effort required to perfect it.

4. The Towed Homing System has been previously suggested by several sources as an interesting possibility but upon detailed examination does not appear attractive. Analytic consideration of this system, however, contributed to the solution of the Skyhook System and the results were considered worthy of inclusion. In view of the general unattractiveness of this scheme, no further development at this time is warranted.

APPENDIX I

DUNKED SONAR APPLICATIONS

Introduction

It has been proposed that the Long Line Circling System should be an interesting means of combining the performance of fixed wing aircraft with an airborne dunked sonar system. The search speed might thus be increased in addition to lengthening the search arm. Good flight endurance on station would also result, and the fact that the aircraft is removed from the vicinity of the water surface should reduce spurious noise input.

Consideration of such systems should also include the Two Plane Circling System but obviously would not include the Skyhook or Towed Homing Systems.

The study made here is not purported to be a system analysis of this type of arrangement, but rather a collection of pertinent comments relating to the major considerations which are apparent. The degree of feasibility of operation is indicated.

Existing Sonar Systems

The possible sonar systems for use fall into two groups, existing ones and those proposed or under long range development. The existing systems are the AQS-2 Helicopter or Lighter-than-Air Dipped or Towed Sonar, the AQS-4 Helicopter Dipped Sonar, and the AQS-6 Helicopter Dipped Sonar. An additional proposed system which is related is the Omni-directional or Echo-Ranging sonar. The ranges of characteristics of these systems which are important, are summarized below:

Range: Several thousand yards (narrowed by sea state, etc.)

Transducer Weight: From less than 100 to approximately 700 lbs.

Size: As large as a 20" diameter cylinder 48" long

Power Required: From 300 to a few kilowatts

Cable Length: A few hundred feet

Transducer Operating Depth: Up to 300 ft. (adjustable)

Allowable Transducer Movement: Two or three knots horizontally and essentially none vertically

Allowable Shock Loading: Essentially none.

Considering these characteristics in order, the range of such systems is not particularly attractive, since it is of the order of magnitude of the aircraft circling pattern required and the primary use for sonars of this type is as a convoy screen. To maintain a screening operation under many conditions would thus require flight patterns which would overlap. For area search this range would require frequent dipping and transfer to a new site, which could be achieved by the Two-Plane Circling System, but which would be somewhat slow with the Long Line Circling System due to the time required to assume the proper pattern. For contact investigation the same comment applies.

The transducer weight and size can be accommodated by either system. However, it will be seen that the transducer is not the only piece of equipment which must be suspended at the end of the cable.

The power required to operate the sonars is not excessive but in present installations where the line lengths are of the order of a few hundred feet or less, the line loss is a large fraction of the power supply. For this reason and because of considerations of cable weight and strength, it does not seem possible to furnish the sonar with power from the airplane in the circling systems under consideration.

The possibility of flying in the Long Line Circling System with small cable tension and small aircraft radius appears to be lessened as the cable weight is increased. A ten-thousand-foot cable containing two copper conductors, capable of furnishing a power supply of only a few hundred watts, and a steel cable for strength in lifting has been considered. The results of analysis of a few situations of flight for the Long Line Circling System with this cable are shown in Fig. 1. It will be seen that large tensions, and consequently large horizontal forces, at the bottom of the cable result for easy flight attitudes. In the Two-Plane Circling System this problem does not exist. However, considering these factors, it will apparently be necessary to consider a self-contained power supply at the bottom of the cable. Such a supply and the associated platform might weigh from several hundred to a thousand pounds depending on the requirements.

Additional considerations regarding cable length involve the possibility of microphonics, capacitance, and impedance, which must be faced in transmitting signals from the sonar to the aircraft. It might be more expedient to use a radio transmitter located at the bottom of the cable.

The transducer operating depth and allowable movement present additional difficult problems to be surmounted. The range of depth over which operation is required must probably be met by lowering the transducer from a buoy on the surface to the desired depth of operation, since accurate control of this feature in the circling systems will be impossible. Furthermore, the requirement for little vertical motion will make prohibitive even the motion of the transducer introduced by a surface buoy,due to wave action. It would seem, therefore, that the transducer must be able to maintain a fixed depth by other means. The requirement for horizontal movement of only 2 or 3 knots will be difficult to maintain in either the Long Line Circling or Two-Plane Circling Systems without the use of some restoring force such as that provided by a sea anchor. A sea anchor of reasonable size will compensate for horizontal forces imposed by the component of cable tension. The combination of the above requirements would appear to be satisfied if the cable from the aircraft in either system were attached to a surface buoy equipped with a sea anchor to limit its motion. However, a simple means of limiting the vertical motion of the transducer is not readily apparent.

Almost without exception the above sonars will not withstand the water entry shock which is associated with the Long Line Circling System. The Two-Plane Circling System offers a greater likelihood of being able to gently lower a sonar into the water, even drifting with the surface wave train if necessary to eliminate the possibility of waves striking the transducer. The inherent frailty of the transducer elements might be overcome by suitable shielding and shock absorbing devices but such features would involve considerable additional complexity and would require retracting such devices after immersion.

Additional problems associated with the above sonars, except for the Omni-directional sonar, concern the necessity for maintaining or knowing the orientation of the transducer in order to obtain a bearing on the target.

Summarizing, it appears that no existing sonar equipment could be used without modification, with either the Two-Plane Circling System or the Long Line Circling System.

Long Range Development Possibility

If a particularly long range sonar were available, the use of the Long Line Circling or Two-Plane Circling Systems would be more attractive as a means of utilizing fixed wing aircraft performance in a usable operational system. The attractive feature would be the ability to make very rapid area searches or investigation of contacts in a fashion where neither helicopter nor lighter-than-air type aircraft could compete. The additional complexity of maintaining a platform at the bottom of the cable, on which a power supply, transmitter, and orientation furnishing device could be mounted with associated motion limiting gear, such as a sea anchor, would perhaps be justifiable in terms of performance which might result. Transducer protection from physical shock and adjustable depth control would also be required. The probable weight of such a system at the bottom of the cable would be between 1000 and 2000 lbs. The size could be very large but the requirements of storage in the aircraft and withdrawal from the water must be met. A convenient means of limiting the vertical motion of the transducer is not apparent but the Two-Plane Circling System would provide a good possibility of limiting vertical movements to rather slow steady motions rather than the short, jerky movements which would be characteristic of a transducer supported directly from a surface float. There is some possibility that a sub-surface float from which the transducer could be lowered, loosely linked to a surface float, would provide a workable system. To raise or lower such an array would require a steel cable of perhaps 3/16" or 1/4" diameter. Ten thousand feet of 1/4" cable would weigh over a thousand pounds.

Conclusions

It is concluded from the considerations mentioned that there is no sonar system in existence today which may, without extensive modification, be dunked by the Long Line Circling or Two-Plane Circling Systems. However, there is a possibility that the performance which might be possible with a sonar system particularly designed for use with either of these aerial pickup systems would be sufficiently attractive so that the complexity resulting could be tolerated. The Long Line Circling System is the least likely to succeed and the Two-Plane Circling System offers reasonably good possibilities. In this application the Two-Plane Circling System does not seem to be particularly objectionable and, in fact, would offer a hunter-killer type of operation where one plane made the attack after localizing, while the other retrieves the sonar. In the Long Line Circling System it is difficult to conceive how the single aircraft could effectively search and kill.

In conclusion it appears that the Two-Plane Circling System could be used to dunk a rather complex sonar array if sufficient development work on the sonar and motion limiting apparatus are undertaken. A careful operational evaluation of the potential of such systems should be undertaken before the attractiveness of such an application is assumed.

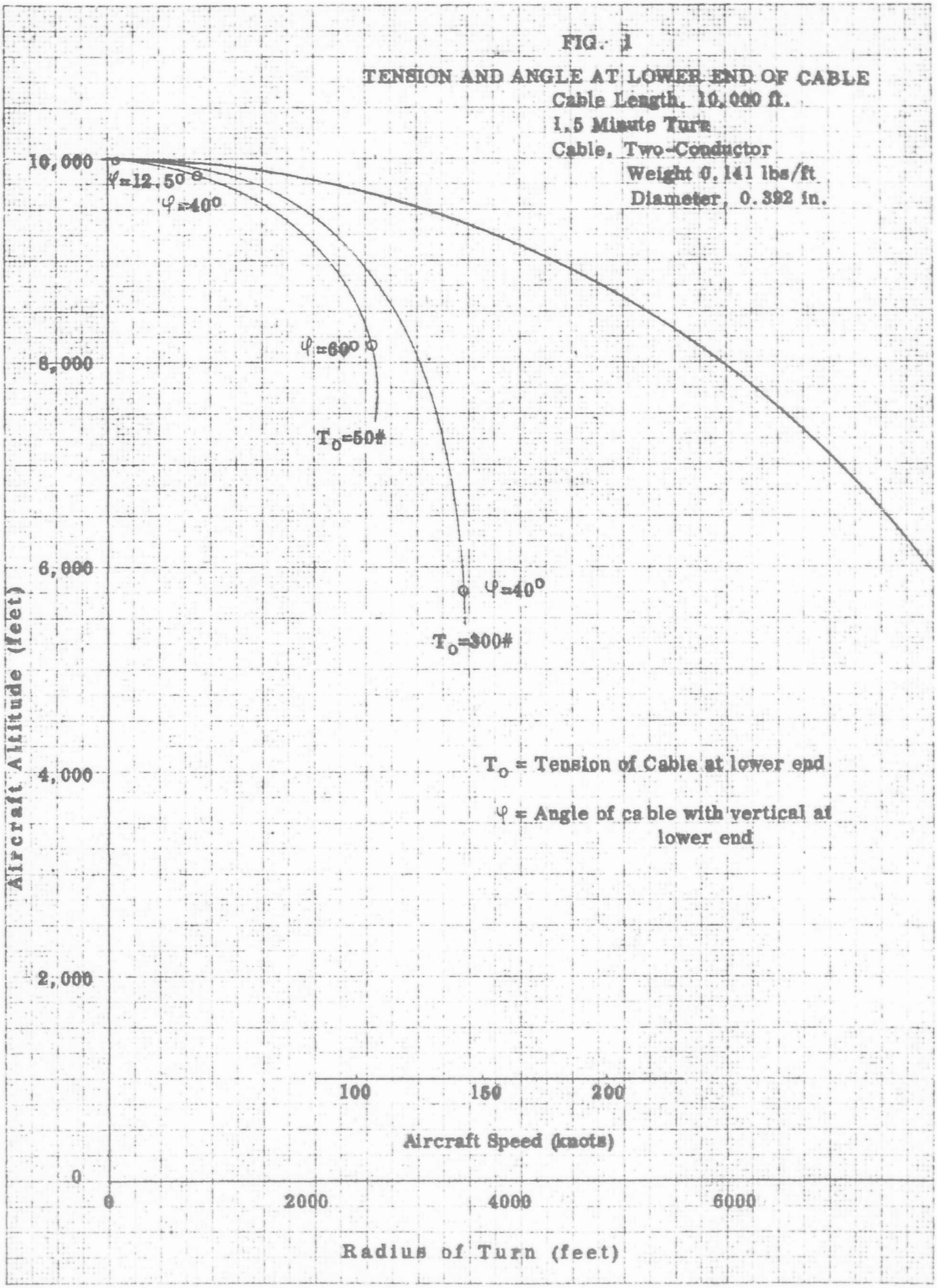
FIG. 1
TENSION AND ANGLE AT LOWER END OF CABLE
Cable Length, 10,000 ft.
1.5 Minute Turn
Cable, Two-Conductor
Weight 0.141 lbs/ft
Diameter, 0.392 in.
φ=12.5°
φ=40°
φ=60°
T₀=50#
φ=40°
T₀=300#
T₀ = Tension of Cable at lower end
φ = Angle of cable with vertical at lower end
10,000
8,000
6,000
4,000
2,000
0
Aircraft Altitude (feet)
100
150
200
Aircraft Speed (knots)
0
2000
4000
6000
Radius of Turn (feet)

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