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INVESTIGATION OF THE VISUAL REFERENCE REQUIREMENTS FOR PILOT CONTROL OF GLIDING PARACHUTES FOR LAND LANDING OF SPACECRAFT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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INVESTIGATION OF THE VISUAL REFERENCE REQUIREMENTS FOR PILOT CONTROL OF GLIDING PARACHUTES FOR LAND LANDING OF SPACECRAFT

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INVESTIGATION OF THE VISUAL REFERENCE REQUIREMENTS FOR PILOT CONTROL OF GLIDING PARACHUTES FOR LAND LANDING OF SPACECRAFT

By James E. Burkett

SUMMARY

A test program has been completed which investigated the problems associated with pilot control of a gliding-controllable parachute for land landing a spacecraft. The program was directed toward the parasail parachute with the following characteristics: an L/D of 1; desent rate of 30 ft/sec; and turn rates to 20 deg/sec. Wind drift determination, visual selection of a landing area, and obstacle avoidance were the major problems investigated during the program. Methods of testing included helicopter simulation of the parasail parameters and scale model air drops of an actual parasail. The scale model testing included movie camera investigation for preliminary pilot visual requirements determination and later a television system for pilot control investigations. A variety of test subjects were used to get different opinions on the system tested and the landing techniques used. It was found that with a system which gave the controller a view of a large percentage of the landing zone attainable and a simple reticle, landings could be successfully accomplished with visual control up to altitudes of 10 000 feet, providing the selected landing zone had a sufficient number of clear landing areas and that wind and visibility conditions were within acceptable limits.

INTRODUCTION

General

The Manned Spacecraft Center, in keeping with the overall responsibility for manned spaceflight operations, including landing and recovery, has given attention to the spacecraft systems and operational aspects of providing the capability of a land landing at the termination of a spaceflight mission. Such a capability at this point in spacecraft system development falls into the category of "desirable but requiring advances in the state-of-the-art of landing system design and operation." Over the past 2-3 years investigations have been made of several methods of providing spacecraft with a descent system which will allow pilot visual control and maneuverability during the landing phase. These investigations have included such systems as paragliders, gliding parachutes, rotor systems, winged bodies, et cetera. Of these, the gliding parachute family of descent systems has shown great promise when considered for use in the semi-ballistic spacecraft shapes currently utilized for the NASA manned spaceflight programs. Specifically, the controllable parachute known as the "parasail" has received the most attention and has been developed and tested as a landing system in combination with a Gemini-sized spacecraft to the point where the operational aspects of landing such a system could profitably be investigated. This report gives the results of an operational test program to determine the visual reference requirements for pilot control of gliding parachutes.

Mode of Operation

The gliding parachute family of descent systems have relatively low L/D capability. This range of L/D for different types of systems is approximately 0.7 to 2.0 with L/D 1.0 to 1.2 more readily available (parasail). Thus the maneuvering range of a spacecraft with such a system is limited and this results in an operational constraint. If the L/D were large enough to overcome any errors in the reentry trajectory of the spacecraft, then a point landing could be made at a preselected site (airfield) contingent on local weather and winds. L/D of the order 3.0 to 4.0 would be required to provide this capability. (Other problems associated with high L/D such as high horizontal landing velocity are not considered here.) Low L/D (0.7 to 2.0) such as the parasail system provides have resulted in a mode of operation called the "Zone Landing Concept." This concept is defined as follows: "The capability of a spacecraft and its system to reenter to a point in the atmosphere from which a land landing can be made at any of a number of places within a selected but unprepared zone by avoiding existing obstacles." Thus, a zone is preselected which has a high percentage of clear and relatively flat terrain, the spacecraft pilot under visual control with ground guidance as required, selects the best attainable landing area, determines the winds, and flies to that area to make an into-wind landing with the lowest possible horizontal velocity.

Test Program Objectives

The Landing and Recovery Division initiated a program to study the operational aspects of using a controllable parachute for land landings. This program includes an investigation of those areas associated with pilot control and is currently being directed toward the parasail parachute.

The program objectives were as follows:

1. The pilot display required to fully utilize the capability of the parasail system.

2. The capability of the system to maneuver into areas of various sizes.

3. The altitude at which visual control can be obtained.

4. The effect of wind drift on parasail landing operations.

TEST PROGRAM DESCRIPTION

The test program to determine the requirements for a visual reference system to fully utilize the capabilities of a gliding parachute system for landing a spacecraft consisted of three phases.

Phase I

The first phase was a preliminary investigation into the view of the ground required and a determination of the adequacy of the resolution attained with that view. This phase consisted of taking movies from non-gliding parachute drops, helicopter descents, and scale model parasail drops.

Phase II

The second phase was a preliminary investigation into the size of landing area attainable and the amount of clear area required within the capability of the parasail, plus further investigation into the field of view and resolution required. A controller was introduced at this point and helicopters were used for parasail simulation.

Phase III

The third phase extended the investigations of Phases I and II to an actual parasail case. A scale model spacecraft with a parasail parachute and a television camera to simulate pilot view was used for Phase III tests.

DESCRIPTION OF TEST VEHICLES AND SYSTEMS

Phase I

Nongliding parachute drops.- A metal container was fabricated which contained a parachute and a movie camera aimed straight down. The container was weighted such that the descent rate was approximately 30 ft/sec.

Helicopter descents.- Four movie cameras were mounted to a rack which was attached to the cargo floor of a UH-1 helicopter and extended outside the cargo door. The cameras were mounted so that their view was straight down from the helicopter. (See fig. 1.)

Parasail drops.- During parasail development tests, three movie cameras were mounted in a $\frac{1}{3}$-scale Gemini space vehicle. The cameras were mounted such that one was looking forward, one aimed straight down, and one at an angle forward of straight down. The latter camera could be adjusted to different angles prior to drop. The vehicle was suspended in the three-point Gemini configuration from a 24-foot parasail parachute.

Phase II

For Phase II, three types of helicopters were used, the H-13, H-19, and H-34. A 6-foot fibre optics bundle was used to give a view of the ground which used a lens at one end of the bundle to establish the field of view and a lens at the other end as an eyepiece. Figure 2 is a photo of the fibre optics bundle attached to the H-13 helicopter. A disc of Mylar with scribed lines was placed between the fibre optics bundle and the eyepiece for use as a reticle. Different reticles (examples of which are shown in fig. 3) were evaluated during the test program. During a portion of the test program, the look angle of the field of view lens could be changed during flight from straight down to 60° forward of straight down. A movie camera with the same size lens and at the same look angle as the bundle was used to record the descents. In addition to the fibre optics bundle, other tests were made with a closed circuit television placed in the cargo compartment of an H-19 and descents made with the test subject viewing the TV monitor. An overlay was placed on the TV monitor to serve as a reticle. Different lenses were also used on the TV camera. A vane attached to a protractor card was used to give the helicopter pilot a reference to simulate the proper glide angle for the parasail. The card was free-swinging and balanced to remain horizontal regardless of helicopter attitude.

Phase III

The same $\frac{1}{3}$-scale Gemini vehicle and parasail as in Phase I tests was used for Phase III testing. The only change being that a television camera replaced the three movie cameras. The television camera was mounted so that the look angle could be changed from straight down to 45° forward of straight down. For all but two of the drops, the television camera was aimed 30° forward of straight down and a 5.7 mm lens was used, having a field of view of 84° fore and aft and 65° side to side. The landing system consisted of a parasail which could be controlled via radio link from a remote ground controller. The control system was nonproportional being only capable of either full control line travel or neutral, resulting in control positions of full right turn, full left turn, or straight ahead with turn rates of 20 deg/sec. No control trimming capability was provided. The landing gear contained honeycomb to absorb impact loads but was not intended to simulate the landing dynamics of the Gemini SC. The drop vehicle was weighted to 400 pounds which resulted in a descent rate of approximately 20 ft/sec. It should be noted here that this descent rate does not correspond to the operationally desired descent rate which has been determined as not lower than 30 ft/sec for the parasail system. This desired descent rate results from a trade off between the requirement to attenuate as much of the spacecraft forward horizontal velocity as possible during an into-wind landing and to provide an operationally reasonable wind limitation such that the spacecraft will not land with a backward velocity. Both a high forward velocity or a relatively low backward velocity would probably result in spacecraft tumbling or unacceptable landing gear design criteria for landing on unprepared terrain. A parasail with an L/D 1.0 will travel on a 45° glide slope in a no-wind condition (horizontal and vertical velocities equal). Thus the horizontal velocity equals the maximum surface wind velocity which can be attenuated without landing backwards. Hence the maximum surface wind velocity is an operational constraint of which 30 ft/sec (17.8 knots) is considered acceptable. It was necessary to accept the 20 ft/sec descent rate for these tests due the fact that the increased weight required to cause the 24-foot parasail to descend at 30 ft/sec would have the following detrimental effects: (1) ground handling would have been more difficult; (2) impact shock attenuation would have required a greater amount of shock material than deemed practical; (3) the design strength of the available parachute would have been exceeded; (4) canopy shape on the particular size parasail used for these tests was found to change if a higher descent rate was used, resulting in an unacceptably lower L/D capability. The parasail was suspended in the three-point Gemini configuration with a split front riser and the apex of the parasail pulled down. The vehicle was attached to the H-19 and UH-1 helicopters on specially constructed mounts which utilized a modified bomb rack for releasing the vehicle. The parasail was deployed by a static line from the helicopter attached to the parasail bag. A television receiver was placed in a van on the ground to give the controller a view of the landing area with a reticle as shown in No. 1 in figure 3. The point where the lines converge represents the point directly beneath the spacecraft. The short dashed lines represent 15° increments forward of straight down with the third one being over the no-wind landing point. The no-wind landing point is the point the spacecraft would land if there were no wind and the spacecraft was allowed to fly in a straight line. A photograph in figure 4 shows the vehicle in flight, while figure 5 is a photo of the vehicle attached to the UH-1 helicopter. Figure 6 is an internal photograph of the control van showing the TV monitor, parasail control box and the video tape recorder.

TEST PROCEDURES

Phase I

Nongliding parachutes.- The containers with the movie cameras and the nongliding parachutes were dropped from a UH-1 helicopter at altitudes to 10 000 feet over the Fort Hood Military Reservation.

Helicopter descents.- During the nongliding parachute drops, a helicopter attempted to follow the parachutes descending. Of the four cameras attached to the helicopter, two contained color film and two contained black and white film for comparison over the same terrain. Two different lenses were used on each set of cameras for resolution comparison.

Parasail drops.- The movies from the onboard cameras were taken during parasail development tests which were not specifically for Visual Reference System tests. The vehicle was dropped from an H-19 helicopter at altitudes to 4000 feet over Ellington AFB. The parasail was remotely controlled from a point on the ground with the controller watching the chute. The angle of the adjustable camera was set prior to each flight.

Phase II

This phase introduced a man into the system and several test subjects were used as controllers. The tests were conducted over uninhabited areas near Ellington AFB, and consisted of helicopter descents simulating the parasail parameters. The helicopter would climb to the desired altitude, 5000 feet for the H-13 and H-19 and 10 000 feet for the H-34, and establish a 2000 fpm descent with a 45 degree glide angle. The test subject would then use the view through the optical system to determine wind drift and select a landing area. Instructing the helicopter pilot to make the necessary turns, he would maneuver the helicopter to the selected landing area. The helicopter pilot made flat rudder turns at rates of approximately 20 deg/sec and terminated the descents at approximately 500 feet above the ground. The descents were made into zones with various percentages of clear areas in order to determine the wind effect and ability to maneuver into small landing areas.

Phase III

Phase III was performed in two parts. Part I consisted of air drops at Ellington AFB from low altitudes and Part II consisted of air drops at the Fort Hood Military Reservation from high altitudes.

Part I.- Preliminary drops were made from altitudes to 4000 feet at Ellington for familiarization and practice in wind drift determination plus preliminary evaluation of the system. Due to the limited area of the drop zone around Ellington, the vehicle was released upwind of the intended target such that a nongliding parachute would reach the target. The controller was instructed to determine wind drift and its effect on his ground track and to land the vehicle at a specific point for these tests. The controller was in the NASA Tower watching the TV monitor while a second person was in the drop zone with the ground control transmitter. The controller would radio commands to the person in the drop zone who would then control the vehicle. This second person was used for safety so that in the event the TV failed, he could take over control visually and land the vehicle near the target.

Part II.- At Fort Hood the task of the controller was different in that he was instructed to select his landing point after the vehicle was released from the helicopter. For these tests the television and the controller were in a van in the drop zone where he controlled the vehicle directly. In the event of television malfunction he could control the vehicle by observing it from outside the van. Three types of tests were performed at Fort Hood, all from 10 000 feet. The first for each controller was to fly to a preselected area with the wind unknown. The second was to select an area after release and fly to it. The third was to simulate "breaking out" of an overcast and used two controllers, the first to control the vehicle to 2000 feet above the ground and the second to take over at that point, select a landing area, determine wind drift, and land in the area.

Throughout the last two phases of the program, different test subjects were used as controllers to get a variety of opinions on the systems.

RESULTS AND DISCUSSION

Phase I

The movies taken in Phase I gave a preliminary look into the field of view required and the orientation of the field of view. They further gave an indication of the resolution that could be expected from a downward looking system with the various lenses used. From these tests it was found that the best field of view would be one that encompassed the entire area attainable using the parasail, and that some angle forward of straight down gave the most desirable line of sight. Considering the glide capability of the parasail and a nominal wind, a 30° angle was selected for further testing. The 5.7 mm lens was found to be the most desirable to give the field of view required. This lens is approximately equal to 85° from fore to aft and 65° from side to side. Although this was not quite the desired field of view, it was considered adequate for testing. Lenses available with larger fields of view caused an excessive amount of distortion at the periphery of the lens. During this phase it was also determined that a helicopter could be used to simulate the parasail descents.

Phase II

The lenses were again varied to verify the findings in Phase I. Although the smaller angle lenses (less than 5.7 mm) presented somewhat better resolution, it was found that the area restriction was too severe. Even with the capability of changing the angle of the lens in flight, it was not possible to accomplish the landing task satisfactorily. Locating a suitable landing area could be accomplished with a movable lens; however, the problem of determining wind drift was found to be extremely difficult and consumed an excessive amount of time. The field of view required is one which encompasses at least the area directly beneath the spacecraft and the no-wind landing point.

Reticle requirements were studied during this phase and several patterns were investigated. Of the reticles tested, it was found that a simple, uncluttered presentation was best for wind drift determination. The reticle should define the point directly beneath the spacecraft and the no-wind landing point so that these can be used as a reference for landing progress. Cross hairs were used to determine relative motion and radials emanating from the straight down point aid in determining direction of drift.

Descents were made into areas with various amounts of clear landing areas. These tests provided information as to size of area required and amount of clear area needed within the zone of capability. Approaches were made into areas that contained less than 50 percent clear area within the initial field of view at 10 000 feet. At 10 000 feet with the optical system tested, large clearings, groups of trees, and roads and streams could be distinguished. However, during descent, fences, powerlines, and similar, less easily defined local obstacles could not be seen until it was too late to avoid them. The inability to see these obstacles was due to at least a 50 percent light loss in the fibre optics. It is believed that a system specifically designed to provide a pilot's view of the ground for spacecraft landing would eliminate this problem and provide the resolution necessary for distinguishing these objects. It was found that wind drift could be determined and a landing area selected within limitations of the helicopter. Visual control could be accomplished from 10 000 feet, although wind drift was difficult to determine at altitudes above approximately 6000 feet.

It should be noted that exact simulation of the parasail parameters could not be made with the helicopters flown under manual control. During the descents, the descent rate would vary within ±500 ft/min of the desired descent rate and the glide angle varied as much as $\pm 15^{\circ}$ of that desired. Pilot technique and experience was an important factor in the simulation. Also the fact that the descents were terminated from 300 to 1000 feet above the ground made exact landing spots difficult to determine. However, the results of the testing gave an insight into the problems involved and a preliminary look at not only the view and reticle required but also the size of area that could be attained and techniques for using the system.

During the course of the helicopter simulation a closed circuit television system was used to investigate the resolution obtained and determine its suitability for further testing on an actual parasail. A TV was placed in the cargo compartment of an H-19 and descents made from 6000 feet show that the TV presentation actually provided better resolution than the fibre optics except that it did not show color. Flights at 10 000 feet in a C-119 showed that the resolution to 10 000 feet was adequate for further testing.

Phase III

Part I.- The drops during Part I, as stated before, were primarily for familiarization with the system and practice in wind drift determination, and consisted of 18 drops using 4 different controllers. The weather for these tests was clear skies with surface winds varying from 10 knots (17 ft/sec) to 20 knots (34 ft/sec) with gusts and winds at drop altitude as high as 40 knots (68 ft/sec). These high winds exceeded the no-wind forward glide capability of the parasail in that 20 ft/sec was the greatest forward speed attainable. The controller's ability to perform the task of landing at a specific point was largely a function of the magnitude of the wind. As experience increased and familiarity with the peculiarities of the parasail increased, the controller was able to land within approximately 200 yards of the desired target. At the higher winds and while flying into the wind, the view of the ground was not adequate to show the landing point. A technique to solve this problem was to make 90° turns cross wind to locate the landing point and then turn back into the wind just prior to touchdown. Typical ground tracks are shown in figures 7 to 10.

Part II.- Thirty drops of the $\frac{1}{3}$-scale parasail were made at Fort Hood during Part II, again with four different controllers. The weather during these tests varied from clear skies and light and variable winds to broken clouds and surface winds to 15 knots. A problem resulting from weather conditions was fogging of the television lens at lower altitudes. This was alleviated by coating the lens with glycerin to prevent condensation from forming. Results of the test program show that the optics used in the television system can give the astronaut an adequate presentation of the ground to control the parasail to a suitable landing area. The resolution of the system is such that at 10 000 feet altitude, roads, streams, groups of trees, buildings, and large clear areas can be defined. Wind drift is difficult to determine at the altitude due to low relative motion across the ground. At altitudes below 6000 feet, wind drift can be readily determined and landing areas can be selected. Below 500 feet it is again difficult to determine wind drift when in an open area due to lack of land reference points. Also, some local obstacles are difficult to see with the television due to lack of contrast and loss of light. Examples of these obstacles are power lines, flat boulders in neutral shade soil, and fences. As stated before, it is believed that most of these obstacles could be seen with a system having color and better contrast as was shown from the movies of earlier $\frac{1}{3}$-scale tests where color film was used in the recording camera.

In several drops the controllers were instructed to purposely fly into areas that were predominantly undesirable due to trees and other obstructions. It was found during these tests that satisfactory landings could be made into zones that had only 40 percent of the total area acceptable as a landing area. Advanced recovery planning for mission use has shown that landing zones can be selected which provide acceptable landing areas well in excess of the 40 percent attained at Fort Hood. Also, landings were made into areas as small as 150 yards square. Figure 11 is a map of the Fort Hood area showing the landing sites and a circle representing the area attainable from 10 000 feet under a no-wind condition. It should be noted that the terrain is not typical of that expected in a landing area that may be selected for an actual land landing mission, but represents a variety of terrains and conditions.

In general, the controllers after several drops were able to determine wind drift, select a landing area, and control the vehicle to that area. Except for instances where wind drift near the ground was difficult to determine due to lack of reference point, they were able to land into the wind. Typical ground tracks of the Fort Hood tests are shown in figures 12 to 15.

In the course of the tests, several factors were brought out that indicated areas that require improvement prior to further testing. As stated before, wind drift was difficult to determine near the ground when no land reference points were available. It is therefore recommended that in areas where gound guidance and advice is available the approach to the landing area should be selected such that turns are not required below 500 feet except to miss local obstacles. For landings without ground guidance a compass or heading indicator should be included in the SC so that the vehicle could be turned into the wind prior to touchdown as determined either by using the last wind obtainable by reference points or obtained from a ground meteorology station. An altimeter should be included to give the pilot an indication of height above the ground and thus maneuvering time remaining.

Another factor involved in wind drift determination is parasail trim. Throughout the test series, various degrees of turn were "built into" the parasail due to misrigging. Since a straight course could not be maintained, wind drift determination was extremely difficult. The control system was such that when the system was activated, full turn was attained and when released the control lines returned to a neutral position. A proportional control system or one with a trim capability would allow the controller to trim the system to straight flight.

These tests did not exactly duplicate the design parameters of the parasail due to weight limitations of the vehilce and the parachute tested. The desired descent rate was 30 ft/sec whereas the actual descent rate attained was approximately 20 ft/sec. This reduced descent rate lowers the capability of the system to negate the wind component; however, it increases the descent time and therefore gives the controller more time to determine wind drift and select a landing area. The system was hampered by a degradation in presentation due to the inherent resolution problem of using a non-color television system. Resolution and thus obstacle detection could be greatly improved with the use of a clear optical system rather than a television camera. It was demonstrated however, that even with the shortcomings mentioned above and the lack of altitude and heading references, the landing task could be accomplished successfully. Any improvement to the system would add to the overall capability of the parasail, simplify the pilot task requirements and thus improve the accuracy of the landings.

The parasail has the capability of variable L/D, although this capability was not used during this test program. Very little testing has been done to evaluate the effects of variable L/D except that of closing both turn vents simultaneously and thus reducing the L/D. The advantage of having a variable L/D would be the capability to reduce forward motion just prior to landing and thus reduce the chances of tumbling. Further testing of visual reference systems and operation landing problems should include a variable L/D capability so that the potential of the parasail concept can be fully investigated.

CONCLUSIONS AND RECOMMENDATIONS

It was demonstrated that with the Visual Reference System tested, wind drift could be determined, a suitable landing area selected, and that a gliding parachute can be controlled to the selected area. It was further shown that visual control can be established at altitudes to 10 000 feet and wind drift readily determined at altitudes below 6000 feet.

It is recommended that a system to be used for visual reference in conjunction with a controllable gliding parachute should include the following:

1. A field of view that would encompass as much of the attainable landing area as practical. (Min $\pm 30^\circ$ to side, 10° beyond no-wind point, and 30° behind straight down point.)

2. Resolution sufficient to define major obstacles at altitudes to 10 000 feet and local obstacles at lower altitudes in time to avoid them.

3. A simple reticle showing the no-wind landing point and the point directly beneath the vehicle plus a cross hair arrangement for wind determination, similar to reticle 1 in figure 1.

4. An altimeter and compass or heading indicator.

A need for further testing is indicated which, in addition to including an altimeter and heading indicator, should include the following:

1. Proportional control and/or trim capability for the parachute.

2. Study of the effects of variable L/D.

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Figure 1.- UH-1 helicopter showing camera attachments.

NASA
S-63-17512

Figure 2.- H-13 helicopter with fibre optics bundle and glide angle indicator.

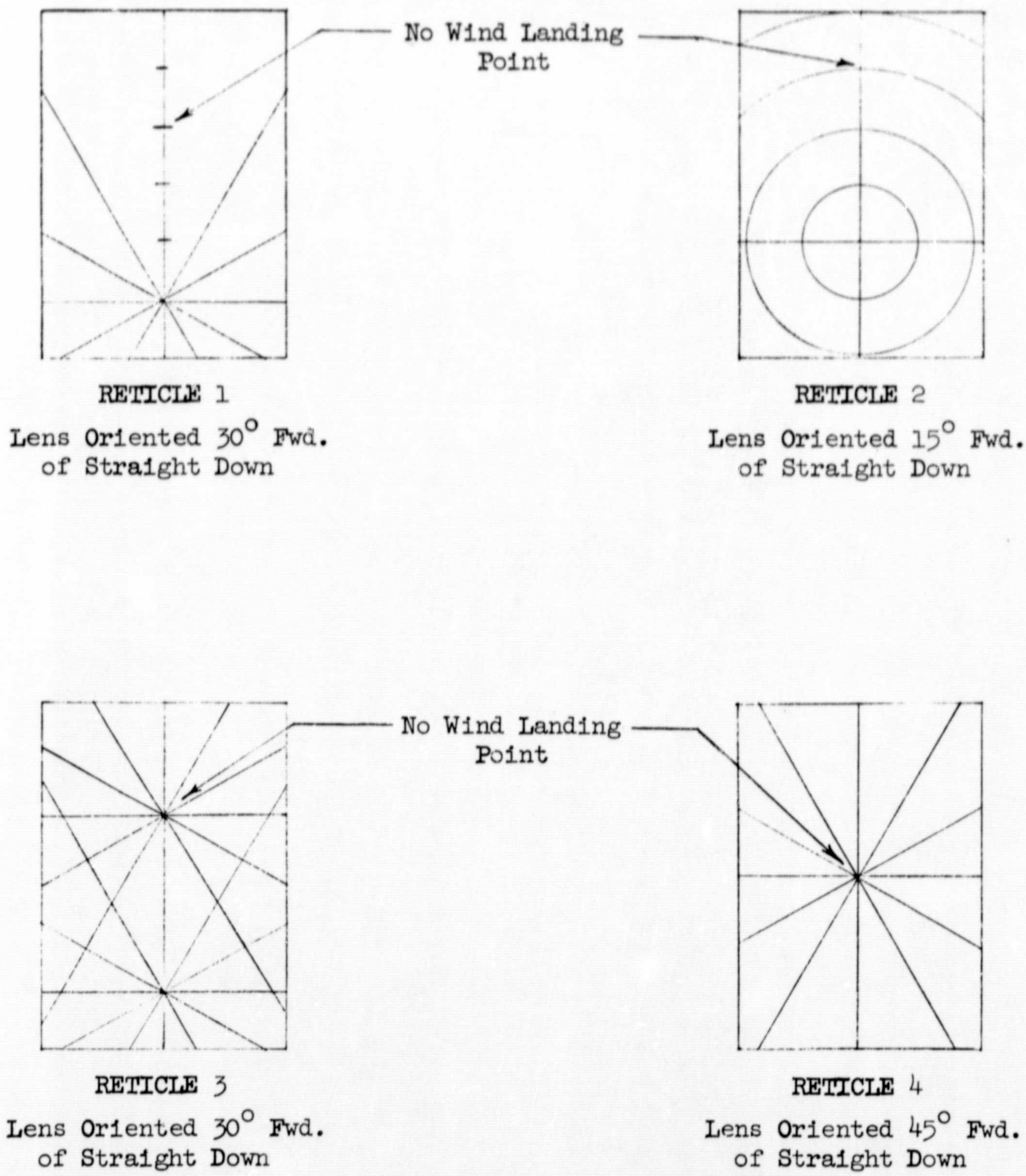

Figure 3.- Examples of reticles investigated.

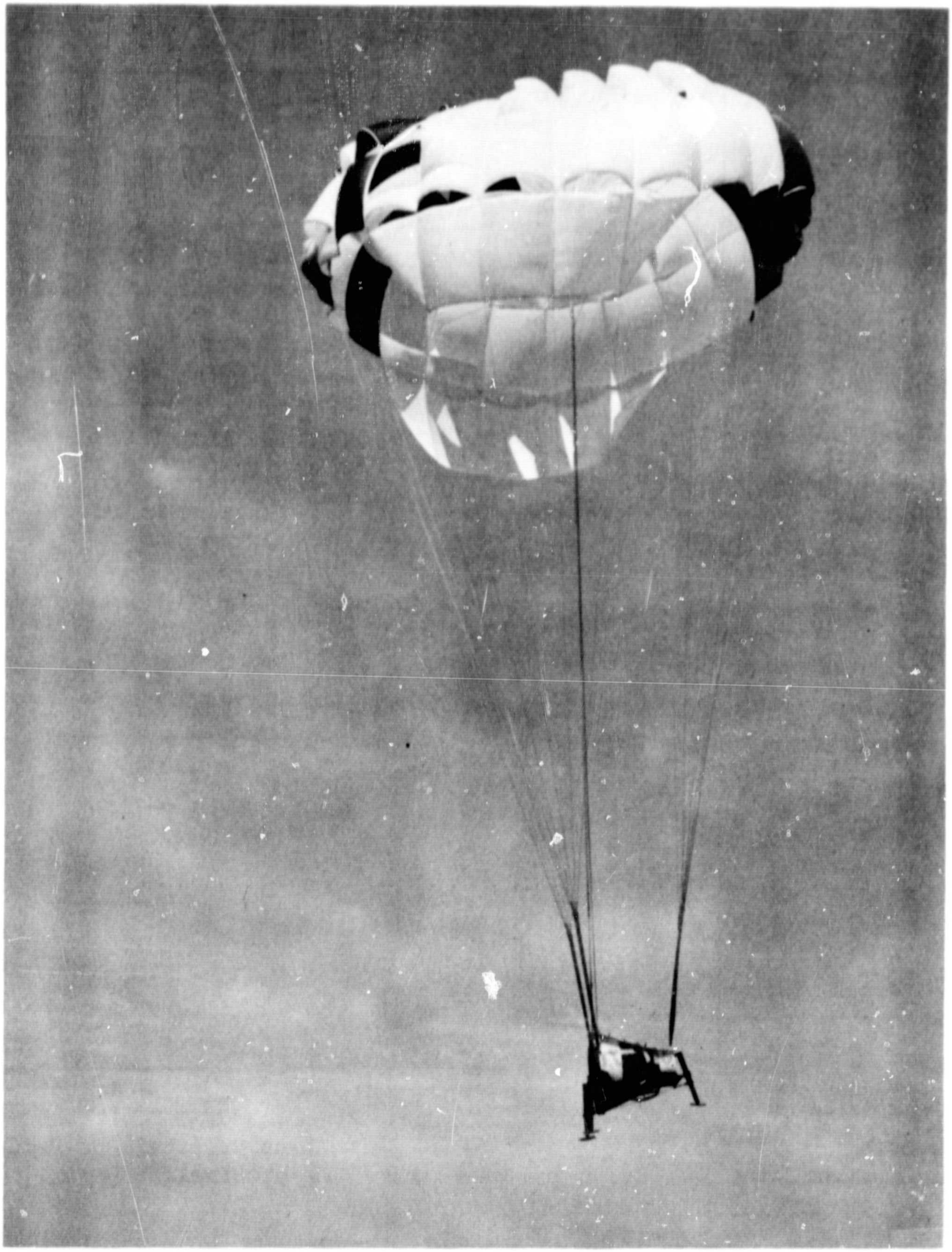

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Figure 4.- $\frac{1}{3}$-scale Gemini parasail vehicle with TV camera.

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S-64-24389

Figure 5.- $\frac{1}{3}$-scale Gemini vehicle attached to UH-1 helicopter.

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Figure 6.- Internal view of Parasail control van showing TV monitor, control box, and video tape recorder.

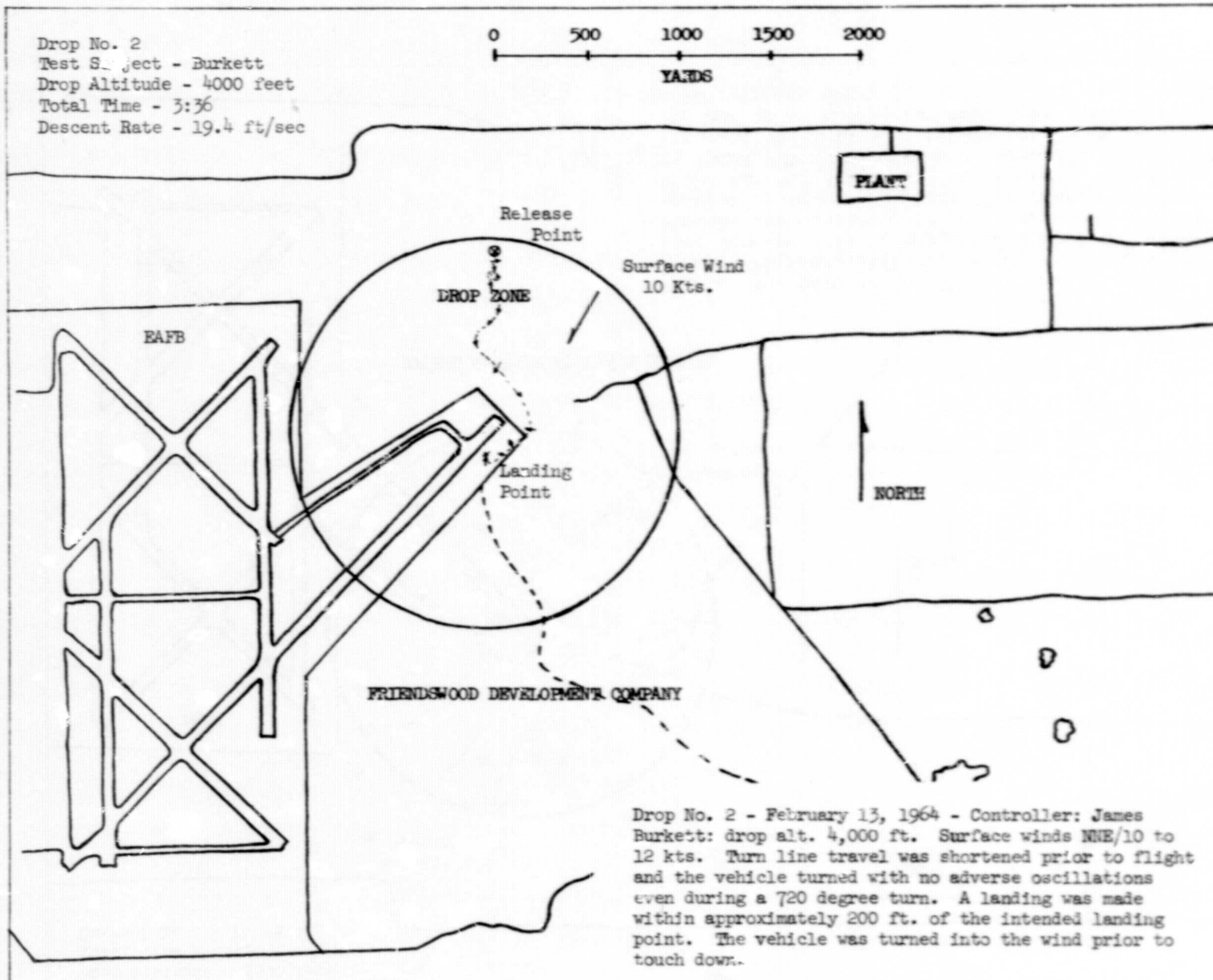


Figure 7.- Typical ground track (Ellington Air Force Base).

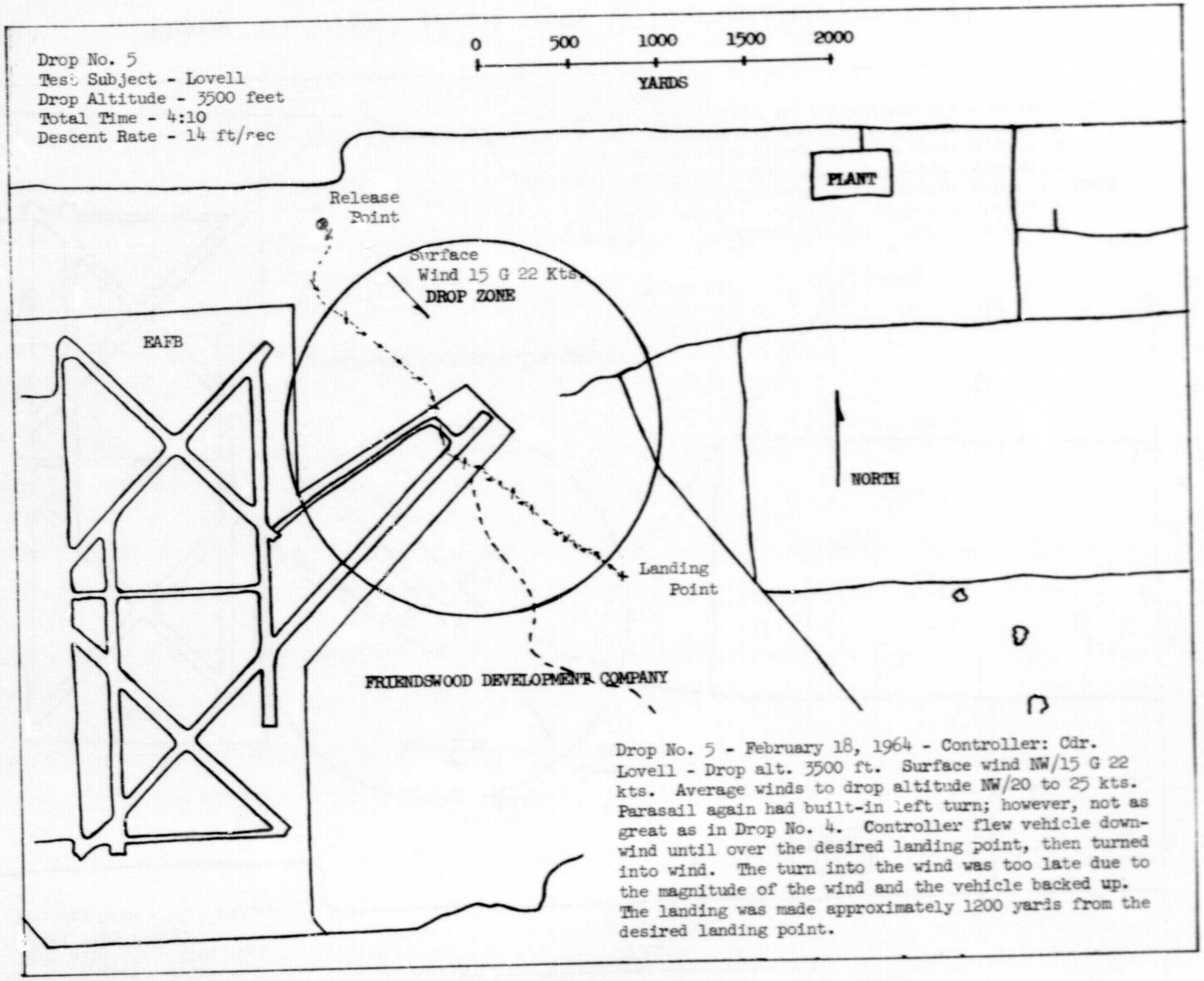


Figure 8.- Typical ground track (Ellington Air Force Base).

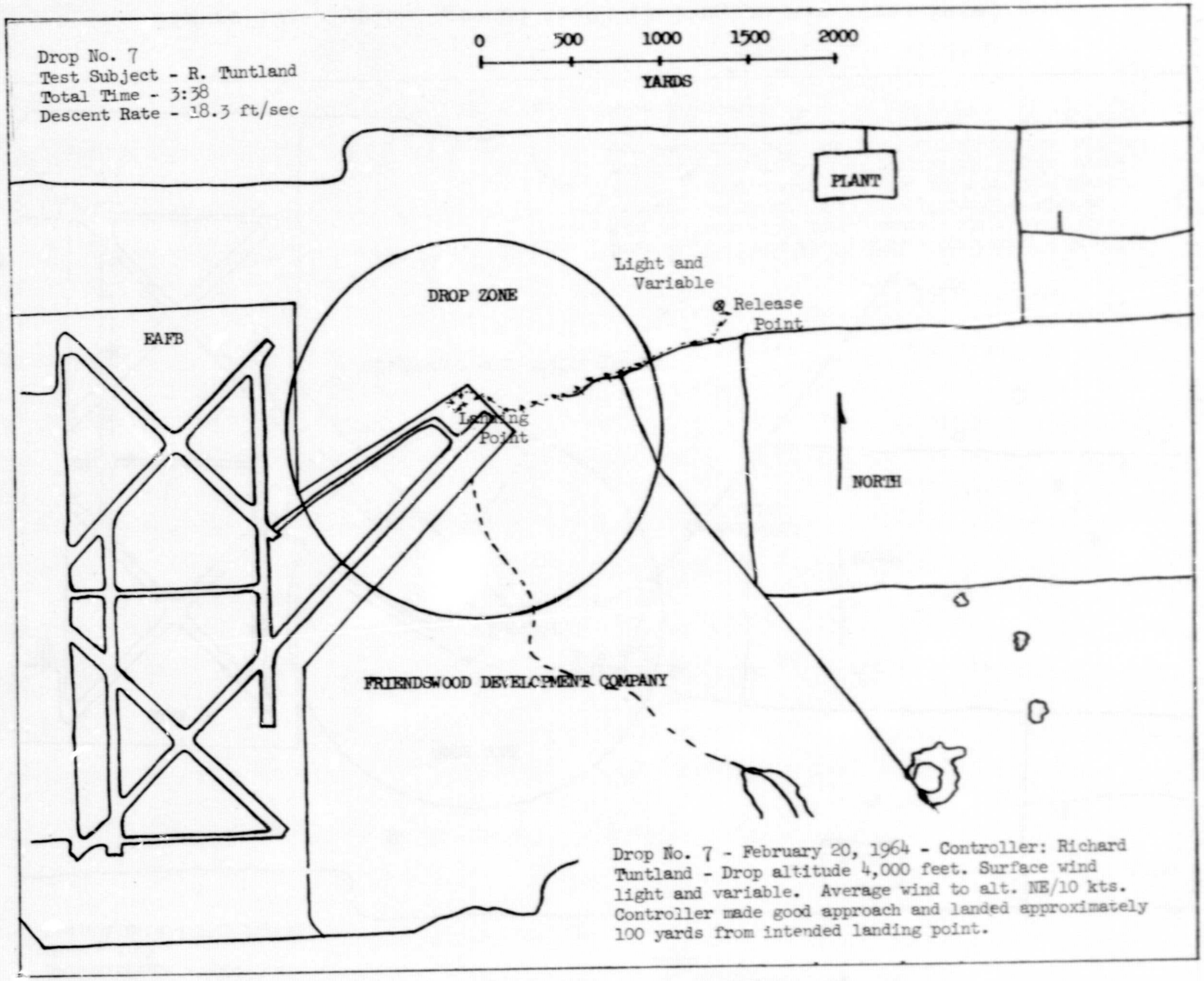


Figure 9.- Typical ground track (Ellington Air Force Base).

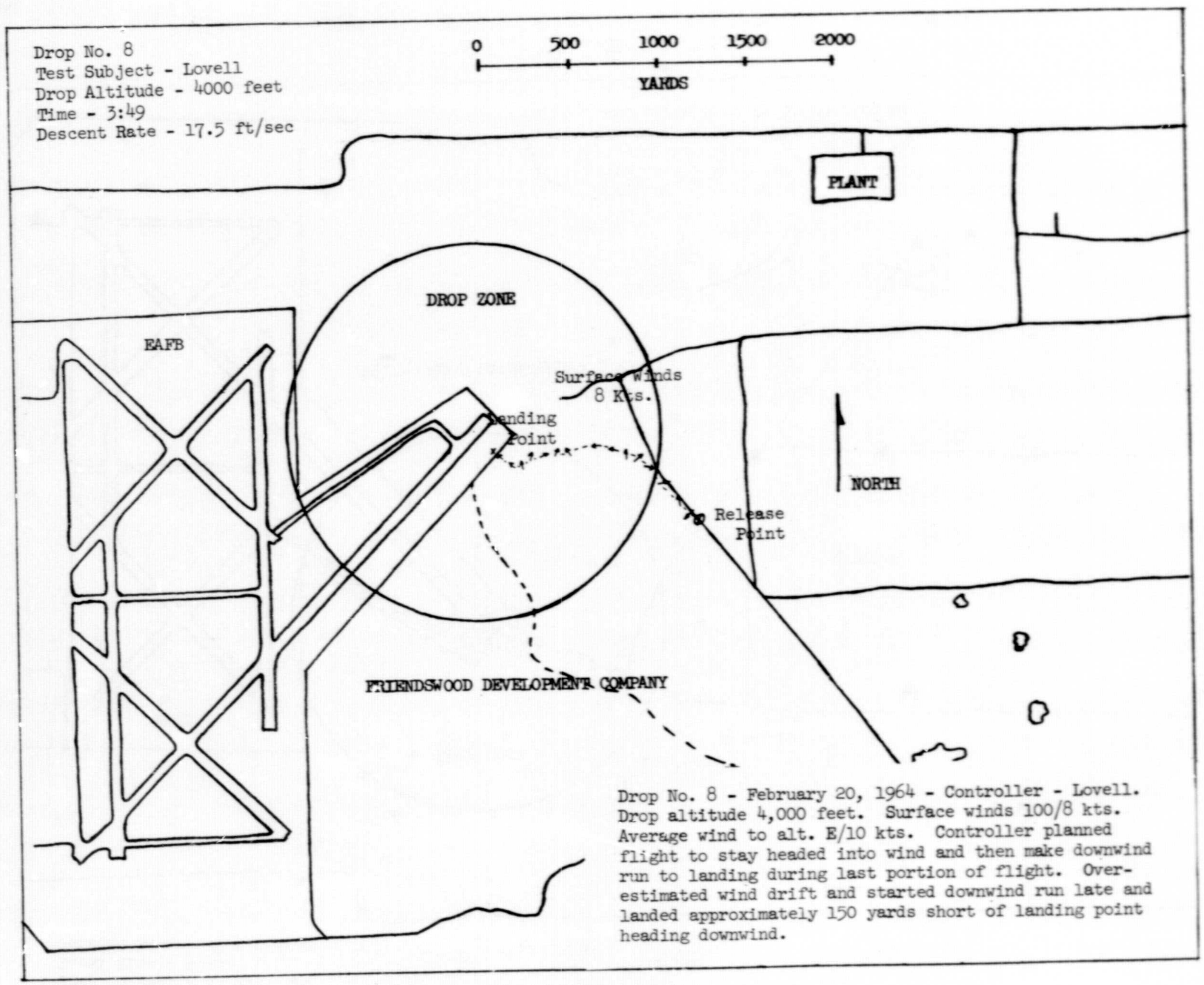


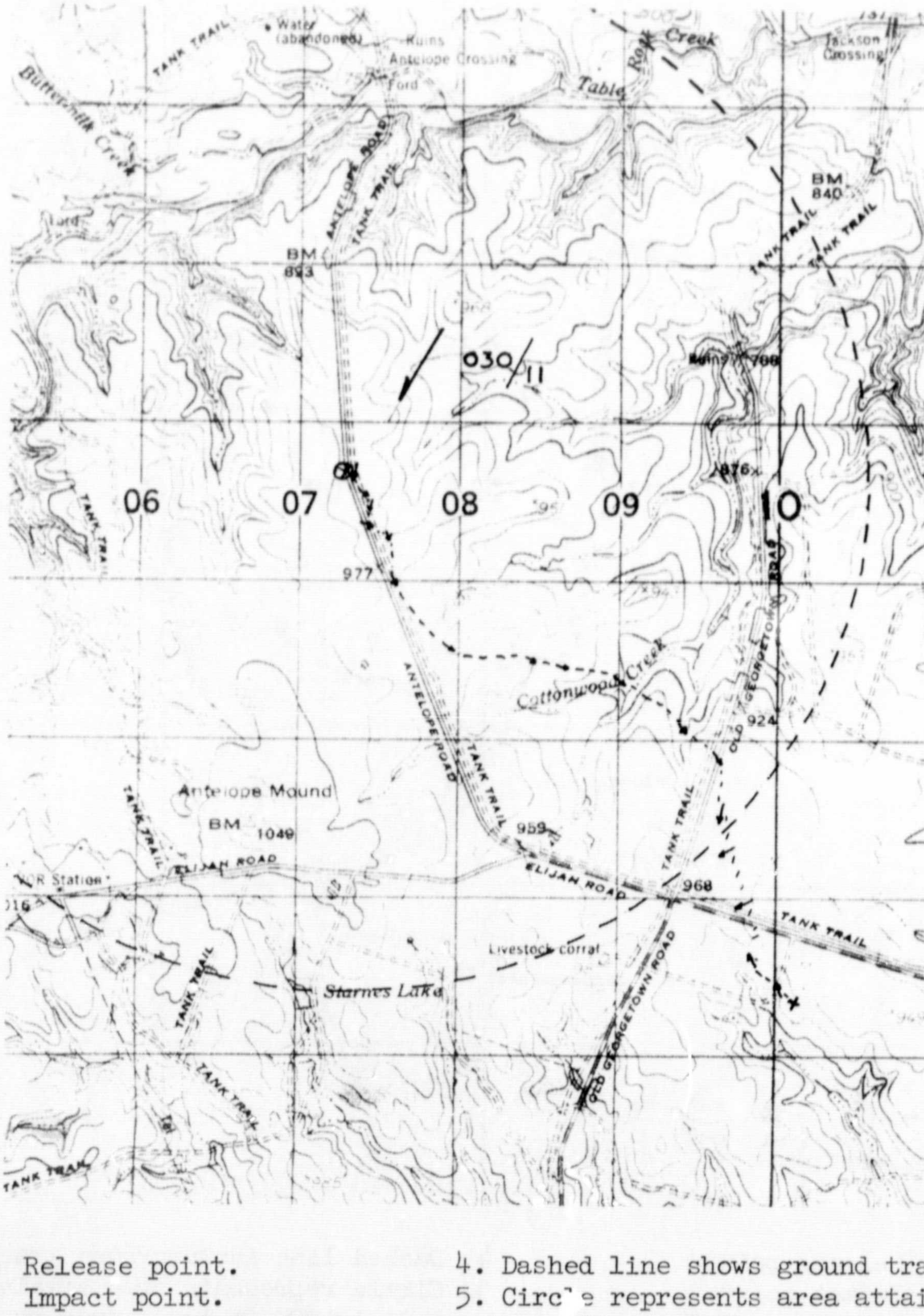
Figure 10.- Typical ground track (Ellington Air Force Base).

1. ⊗ represents landing points.
2. Large circle (10,000 ft radius) represents area attainable with no wind.
3. Shaded area denotes trees or undesirable landing areas.

Figure 11.- Map of Fort Hood showing landing points.

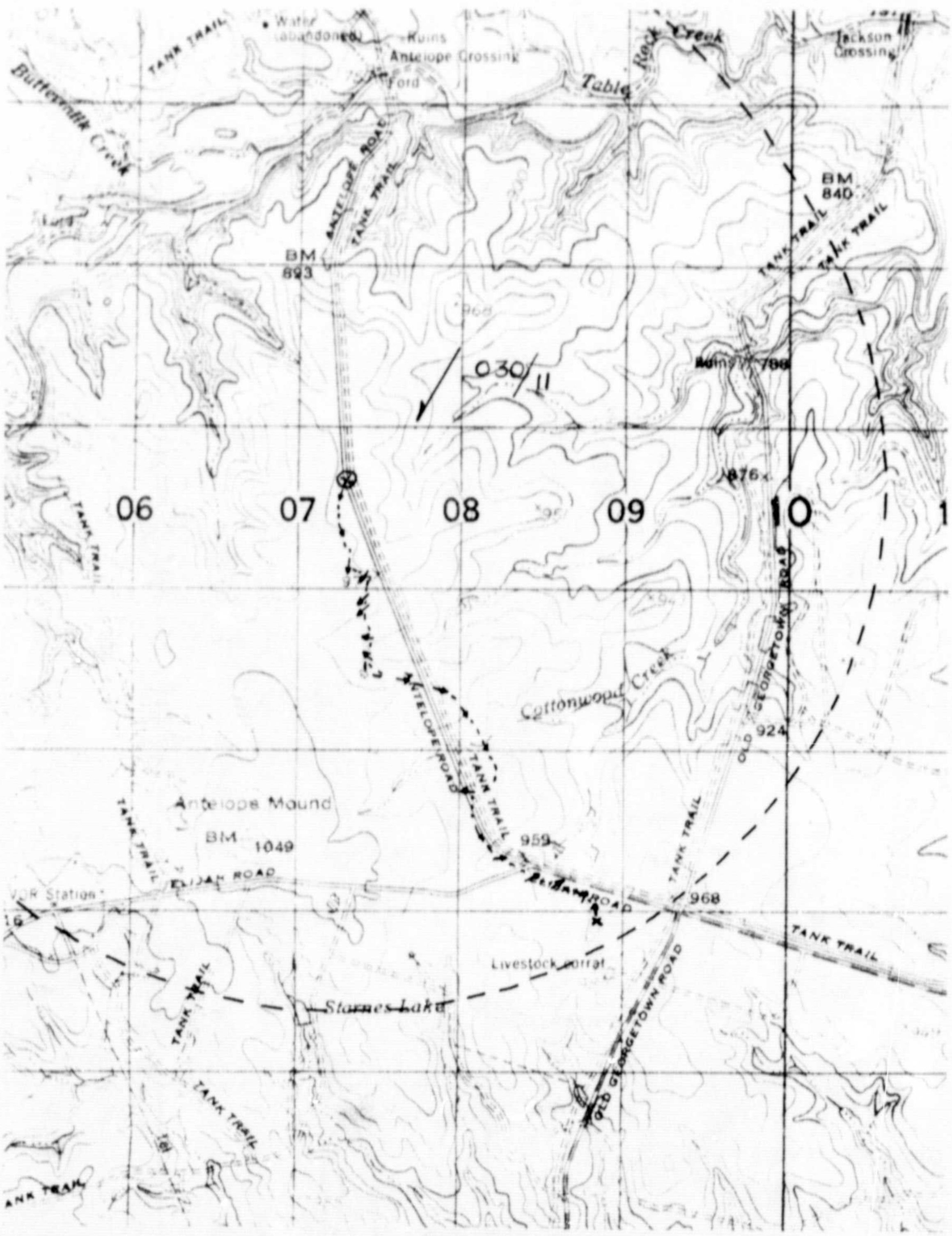
1. ⊗ Release point.
2. x Impact point.
3. ⟶ Direction of flight.
4. Dashed line shows ground track.
5. Circle represents area attainable from 10,000 feet altitude no wind.

Figure 12.- Typical ground track (Fort Hood Military Reservation).



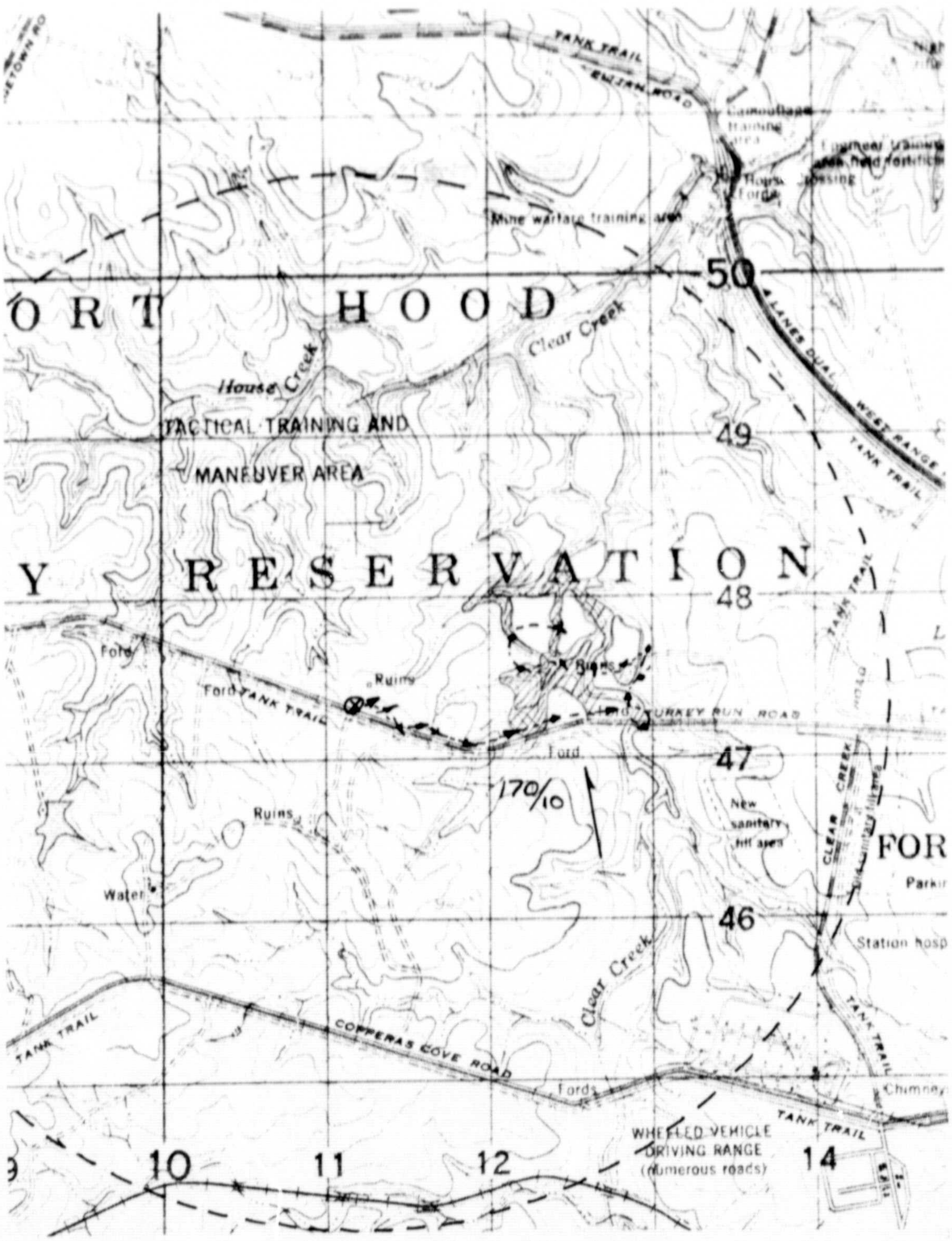
1. ⓧ Release point.
2. x Impact point.
3. ⟶ Direction of flight.
4. Dashed line shows ground track.
5. Circle represents area attainable from 10,000 feet altitude no wind.

Figure 13.- Typical ground track (Fort Hood Military Reservation).



1. ⊗ Release point.
2. x Impact point.
3. ⟶ Direction of flight.
4. Dashed line shows ground track.
5. Circle represents area attainable from 10,000 feet altitude no wind.

Figure 14.- Typical ground track (Fort Hood Military Reservation).



1. ⓧ Release point.
2. x Impact point.
3. ⟶ Direction of flight.
4. Dashed line shows ground track.
5. Circle represents area attainable from 10,000 feet altitude no wind.

Figure 15.- Typical ground track (Fort Hood Military Reservation).