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STUDY OF GUIDANCE TECHNIQUES FOR AERIAL APPLICATION OF AGRICULTURAL COMPOUNDS

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16. Abstract

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FOREWORD

This report contains the results of a literature survey study of guidance techniques for aerial application of agricultural compounds. The survey was conducted for the Langley Research Center under the technical direction of Mr. William E. Howell, Avionics Technology Research Branch - Flight Electronics Division, and his alternate, Mr. James C. Young.

At the Lockheed-Georgia Company, the study was performed under the cognizance of J. M. Spencer, Manager of the Electronic Systems Department. J. D. Caldwell served as study manager with P. B. A. Dimmock and R. H. Watkins performing the technical functions.

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A literature and product search study was conducted in accordance with the statement of work to identify candidate systems for further evaluation of suitability in meeting specified accuracy requirements for a swath guidance system in an agriculture aircraft. Further examination of identified systems reduced the list of potential candidates to a single category, i.e., transponder-type systems, for detailed evaluation. Within this category three systems were found which met the basic accuracy requirements of the work statement and were further evaluated against the specified requirements. These three systems include Flying Flagman (Del Norte), Electronic Flagging (Motorola) and Raydist Director System (Teledyne). In addition to evaluating the systems against the specified requirements, each system was compared with the other two systems on a relative basis. The conclusions supported by the analyses showed the Del Norte system to be the most suitable system currently available to meet the requirements contained in the statement of work.

INTRODUCTION

The primary objective of this study was to determine how well current electronics technology could match the guidance requirements for aerial application of agricultural compounds.

The flying involved in the airborne application of compounds is unique. It has some aspects of a military low-level strafing attack and some aspects of aerobatics. The pilot is operating a highly maneuverable machine a few feet off the ground with his attention devoted to steering the aircraft, dispensing of materials, and maneuvering to effect turns and avoid obstacles. The operational requirements of a swath guidance system must not therefore intrude, except in a minor way, with demands for pilot attention.

Swath guidance systems must have certain special properties to make them suitable for this application. A swath-to-swath guidance accuracy on the order of 1 meter is required from the system itself in order to provide a viable system after the error introduced by a pilot's ability to fly the steering information is overlaid over the system's inherent accuracy. Because of the highly maneuverable situation of the application, steering information must be presented in near real time which places a limit on the averaging of signals to improve accuracy. This requirement placed a 250 millisecond lag on the study. Another major requirement placed on the study was cost. Cost was considered in a broad sense covering not only the acquisition cost but also cost in terms of equipment reliability and the availability of a support organization to keep equipment operational. A low initial cost system would be a poor bargain for an operator unless backed up with these other important considerations. The above technical considerations plus others provide the study baseline.

Scale of operation can also modify judgement of the suitability of a system. Where a low-to-moderate cost system with the proper credentials might be entirely satisfactory for a small-to-medium scale operator working on crops, the same approach could provide an unsatisfactory answer to the needs of a large-scale operator whose job involved huge forested acreage.

With the desired system qualities in mind, the study was initiated by an electronics technology literature survey to develop candidates for study and analysis. Information was obtained by contacts with vendors, by visits, through the Lockheed Dialog Data Bank System, and through our own local resources in the Technical Information Department. Descriptions were developed by an iterative process mostly by telecon with the manufacturers. Data on such considerations as accuracy, range, frequency, complexity/reliability/maintainability, noise, lag, antennas, cost, size, weight, and power requirements were compiled. Some of the potential candidates were discarded at this time when it became obvious they would not survive the filtering process.

The survivors of the literature search then became the basis for developing a matrix with the surviving candidates on one axis and system features on the other axis.

An analysis was made of the systems contained in the matrix to determine their ranking as to meeting requirements of the swath-guidance application. The candidates most closely meeting the criteria were then selected for a more detailed investigation to bring out their strengths and weaknesses. Writeups containing the results of these investigations were then made. On the basis of these results, choices and recommendations were made.

LITERATURE AND PRODUCT SEARCH

A literature and product search was conducted to identify potential candidate systems and to obtain information pertinent to the overall requirements. This search was conducted during the first phase of the study and was continued throughout the study as required to explore specific areas in more detail. The following general means were used in conducting the search.

- Lockheed-Georgia Electronics Division resources
- Vendor telephone contacts
- Visits to vendor facilities
- Lockheed-Georgia Technical Information Department

Engineering personnel within Lockheed-Georgia's Electronics Division have been deeply involved in the guidance systems for C-5, C-141 and C-130 aircraft, as well as systems for other airborne applications, and thus have acquired a background of knowledge and reference material. This resource was utilized in selecting various systems and equipments for consideration and further evaluation when appropriate.

Telephone contact was made with various pertinent equipment manufacturers; these included:

Litton	- inertial systems
Honeywell	- precision inertial systems
Motorola	- Mini-Ranger and Electronic Flagman
Del Norte	- Flying Flagman
Texas Instruments	- Global Positioning System
Spectra Physics	- laser tracking system
LMSC	- Laser Doppler Velocimeter

Data was obtained from each of these with the exception of Spectra Physics whose system was said to be in development and technical information was being withheld pending filing of patent disclosures and for safeguarding of other propriatory interests. Further examination showed the transponder type systems to be the most likely candidates in respect of accuracy. A visit was made to Motorola to review the operation and accuracy of the Mini-Ranger system on which their Electronic Flagman system is based. This included information on the system operating principles and operation of the actual equipment in the laboratory and field. Only one prototype of the Electronic Flagman had then been made and this was examined in the laboratory. The main unit consists of the fundamental ranging circuits of the Mini-Ranger incorporated with a computer for the course calculations. A visit was also made to Del Norte to review their Flying Flagman equipment. Several production units were being manufactured at the time and a completed unit was undergoing final acceptance tests prior to delivery to a customer.

Lockheed-Georgia's Technical Information Department facilities were used to review trade journals, seminar and symposium proceedings and various institute publications to obtain articles, abstracts and bibliographies. The Lockheed DIALOG system was used to obtain a listing of articles and papers related to the study being conducted. This system, operated by the Lockheed Missile and Space Company, is an information system which contains 110 different data buses (subject categories) which are constantly updated. In response to an input of key words, titles, authors or contract numbers, the system provides listings of abstracts and bibliographical data on related publications, articles and programs. A Report Bibliography was also obtained from the Defense Documentation Center via the Defense Research On Line System (DROLS) administered by this agency. Lockheed, as a defense contractor, has access to the use of this information system containing about one million reports. Abstract data on these reports is cataloged in three data base areas: reports, work units (contract and in-house) and program planning.

SELECTION & ANALYSIS OF POTENTIAL CANDIDATE SYSTEMS

In selecting a list of candidate systems or equipment for further evaluation in agricultural aircraft operations, an accuracy requirement of ± 1 meter, swath to swath, imposes a very stringent constraint on choices. Coupling this with a parallel requirement of low acquisition, operating and maintenance costs presents an even more severe constraint. A large number of systems and concepts were examined, however, the stated requirements very rapidly reduced the choices for further evaluation. Table 1 contains a matrix of general parameters of characteristics of several systems which were examined in more detail. Included in the list are several navigation aid (NAVAID) systems, inertial navigation systems (INS) and transponder-type systems. Excluded from the list were several other systems which were examined, such as map matching and laser range finding, and eliminated.

The systems which are shown in this matrix fail to meet the accuracy requirements, except for the transponder-type systems, but have been included because they represent the current state-of-the art in navigation. The accuracies depicted reflect systems which were basically developed, and are undergoing continuing improvement, to satisfy requirements for medium and long range navigation of civil, commercial and military aircraft. Many of the systems are part of larger networks to provide global coverage. Thus, the accuracy requirements imposed are less stringent than those imposed on agricultural aircraft operations which are local in scope.

As can be seen from Table 1 the majority of systems for accurate position fixing are in the NAVAID category. They are typically long range systems capable of providing accuracies between 1.6 km (1 mile), for the older systems, to 10 meters (25 feet) for the latest systems still in development. They are used to "update" or position fix an aircraft dead reckoning navigation system, such as an inertial navigation system, to bound the position error. Inertial system performance degrades with time and requires periodic position updates to provide small terminal navigation errors. A typical mission of this type would be a transoceanic flight of a commercial aircraft with VOR/DME position update prior to landfall.

None of the NAVAID type systems available approach the 1 meter swath-to-swath accuracy requirements for agricultural applications. Any which did would also require a dead reckoning system to keep navigation and steering information current between position fixes. The last three system types on the chart (Table 1) are the only ones which were considered suitable for further investigation. Two of these system types, the satellite-based Global Positioning System (GPS) and inertial navigation systems (INS), do not meet the accuracy requirements required by this study, however, they do provide accuracies which appear compatible with large scale operations where swath-to-swath accuracies may be less stringent. A more detailed

POTENTIAL CANDIDATE SYSTEMS

SYSTEM TYPE	LORAN-C	OMEGA	DIFFERENTIAL OMEGA	RADAR	JTIDS RELNAV	GPS	INS	TRANSPONDER
VOLUMETRIC COVERAGE	1200 NM., TO GROUND	GLOBAL, TO GROUND	100-200 NM, TO GROUND	UNLIMITED	LINE-OF-SIGHT	GLOBAL, TO GROUND	WORLDWIDE	LOCAL
SIGNAL RELIABILITY	FAIR 100 KHZ	FAIR (10-14 KHZ)	FAIR (10-14 KHZ)	MODERATE (5-16 GHZ)	HIGH (L-BAND)	HIGH (1230; 1575 MHZ)	NOT APPLICABLE	HIGH
COORDINATE INFORMATION	ABSOLUTE TWO-DIMENSIONAL POSITION (LAT - LONG)	ABSOLUTE TWO-DIMENSIONAL POSITION (LAT - LONG)	RELATIVE TWO-DIMENSIONAL POSITION (X, Y COORDINATES)	RELATIVE RANGE / BEARING TWO-DIMENSIONAL POSITION (R, θ)	RELATIVE TWO-DIMENSIONAL POSITION & VELOCITY (X, Y COORDINATES)	ABSOLUTE TWO-DIMENSIONAL POSITION (LAT, LONG, HEIGHT & VELOCITY)	ABSOLUTE TWO-DIMENSIONAL (LAT LONG)	RELATIVE TWO-DIMENSIONAL (RANGE & X-Y COORDINATES)
ACCURACY	1500 FT, 95% PROB. (PREDICTABILITY) 50-300 FT (REPEATABILITY)	1-2 NM (RMS)	1100-1900 FT.	VARIABLE	UNDER OPTIMUM CONDITIONS 100 FT CEP CONSIDERED LIKELY	25 FT HOR. POS 35 FT. VERT POS 0.1 KNOT VELOCITY. (ASSUMES HIGHEST PERFORMANCE RCVR & 24 SATELLITE CONF.)	0.1 NM/HR TO 2 NM/HR (2σ) (TIME DEPENDENT SYSTEM ACCURACY)	3 METER POSITION ACCURACY 1 METER SWATH-TO-SWATH REPEATABILITY
APPLICATION VERSATILITY	AIR, SURFACE, MED DISTANCE, WEAPON DELIVERY	AIR, SURFACE, UNDERWATER, LONG DISTANCE, STEERING SIGNALS	AIR, SURFACE UNDERWATER, SHORT DISTANCES, TERMINAL	INTERMITTENT POS FIX, WEAPON DELIVERY RANGE	AIR, SURFACE, MED DIST, COLLISION AVOIDANCE, WEAPON DELIVERY	AIR, SURFACE, SPACE, LONG DIST, TERMINAL, WEAPON DELIVERY	WORLD WIDE AIR, SURFACE, UNDERWATER, STEERING SIGNALS	LOCAL NAVIGATION, STEERING SIGNALS, RANGE
USER EQUIPMENT COST	MODERATE	LOW ($40-50K)	LOW	HIGH	MODERATE	MODERATE TO HIGH	MODERATE TO HIGH ($150-250K)	LOW ($50-60K)

JTIDS RELNAV = JOINT TACTICAL INFORMATION SYSTEM - RELATIVE NAVIGATION
GPS = SATELLITE-BASED GLOBAL POSITIONING SYSTEM
INS = INERTIAL NAVIGATION SYSTEM

TABLE 1

discussion of these systems is included in the next two sections. The transponder type systems, shown in the last column of the matrix represent the only type of system identified by the literature and product search which merited further evaluation to meet the specified requirements. More detailed information on the other NAVAID type systems included in the matrix is available from many literature sources, however, a good summary of performance characteristics and limitations of these and other systems is presented in the Spring 1977 issue of NAVIGATION (Journal of the Institute of Navigation) magazine, pp 48-58. The basic format and much of the content of the matrix (Table 1) was extracted from this article.

GLOBAL POSITIONING SYSTEM

The Global Positioning System (GPS/Navstar) is a current development program. The system is not operational; equipment is not available for evaluation.

The principle of the system is to determine the receiver's position anywhere on the surface of the earth from measurements obtained from four of a set of twenty-four satellites. Currently one satellite is in orbit with promise of the launch of two more in 1980. Receivers have been designed and prototypes produced and tested using the one satellite and an "inverted range" at Yuma Proving Ground.

The receiver locks on to the signal from a satellite and determines the range between the satellite and receiver. The received signal contains data defining the parameters of orbit of the satellite and the complete set of parameters defining the orbit of all the other satellites. Based on this information the computer is able to select the set of four satellites offering the optimum geometry at the current time. By measuring the range to each satellite and knowing each's instantaneous position the receiver computer is able to solve for its position and determine its clock error.

Using the four satellites and the high precision frequency mode the system is theoretically capable of giving position accurate to 10 meters (30 feet) under worst case conditions. The Department of Defense is responsible for the development of the GPS and may limit the availability of precision signals and thereby the GPS accuracy to civil users to 100 meters. This accuracy is also dependent upon the motion of the receiver and the use of 1 second smoothing of the position data. Nonuniform motion such as making continuous turns will considerably degrade the system accuracy. To compensate for this and to feed the vehicle motion changes into the receiver an Inertial Navigation Unit is used on high maneuver aircraft. Knowing the satellite position and velocity with respect to the receiver and the changes in aircraft motion the computer is able to calculate the shifts in received frequency and maintains frequency tracking throughout maneuver. Antenna observation due to vehicle parts coming into the direct path of the satellite will still cause loss of signal strength and possibly lock. The GPS system is, in essence, a precision position fixing system, capable of good accuracy when in steady motion. Continuous change in flight path such as those in small area agricultural use introduce problems requiring an independent navigation system to eliminate.

Since only prototypes of the receivers have been constructed the only prices available are "design to" costs. For a multichannel receiver designed for high dynamics operation this goal is $25,000. Assuming that the receiver would not need external aids from devices such as an Inertial Navigation Unit there would be changes required to a standard GPS receiver system to allow its use in agricultural aircraft. A separate pilot entry panel and instrument would be required to allow the system to be referenced to the initial swath, enter the chosen swath width, index the swaths and display steering information to the pilot. Changes to the computer program and additional interface modules would also be required. These additional items will probably add some $10,000 to the receiver cost goals.

A good description of GPS operation, signal characteristics and testing is in Summer 1978 NAVIGATION.

INERTIAL NAVIGATION SYSTEMS

Commercially available inertial navigation systems provide navigation accuracies of the order of 2 nautical miles per hour in standard airline operation. These systems normally supply cross-track deviation and track angle error, to separate flight director computers, instruments, and autopilot system to provide steering and horizontal situation information to the pilot. The steering signals are referenced to the great circle path between two way-points defined in latitude and longitude. When installed on a light aircraft the system weight, including inverters to supply 400 c/s power, is approximately 160 lbs. and the cost $150,000.

Inertial system's biggest advantage is that they are self-contained and do not depend on external sources of signal which require placement, maintenance and a source of power. Inertial systems are capable of worldwide navigation and steering without external aids to within the 2 nautical miles per hour. An inertial system does, however, require 15 to 20 minutes of ground alignment, with power on, prior to moving the aircraft and is not able to align at latitudes greater than 78°.

The largest system error source is velocity error since the system normally has no external reference inputs to estimate this error. If an independent measure of velocity or position is available, techniques such as Kalman filtering can be used to reduce both velocity or position errors. However this is a more sophisticated and expensive system than in normal commercial operation.

More accurate self-contained inertial systems are available; one example being the Honeywell SPN/GEANS system. This is capable of operating up to 10 hours with system errors of the order of 1/10 nautical mile per hour without external updates. The cost of this system being about $250,000.

Velocity or drift error is the principal disadvantage of any inertial systems when used in applications of this nature. (Ref. No. 14) Operational Aspects of Inertial Guidance in the 1975 Province of Quebec Spruce Budworm Control Program describes a Litton Aero Products systems usage in this application. Typical velocity errors averaging 0.25 ft/sec were measured during this program over some 600 missions. If a system has a 0.25 ft/sec velocity error when flying over a known point and flies for 20 seconds along a line, turns in 20 seconds, and flies back down a parallel line to pass abreast of the original point, 60 seconds of time will have elapsed and the position error will be 15 feet (providing the velocity error remains constant during the interval). This example is typical of a swath to swath flight over a 160 acre field.

Since an inertial navigation system is normally operating for long times (8 hours) with an accuracy requirement of 2 nautical miles per hour the entry of waypoints and other position data is normally possible only to 0.1 minute of position. This represents an ability to define position with an accuracy of ± 600 feet. Litton changed the computer program in the 1975 operation to allow data entry and position resolution to 60 feet and improve the numerical integration techniques. But this limited the least discernible crosstrack deviation also to, at best, 60 feet and a simple crosstrack meter with ± 750 feet full scale was used as a steering aid. It may be possible to reduce the least significant bit of position information down to 1 foot and further increase the data update rate within the computer but this would also require refinement of the accelerometer and velocity data. Also a technique could be developed, similar to that used by some radio systems, to define the initial leg of the area to be treated by flying over and operating an "event marker" at the start and end of the initial path. This could also remove, to some extent, the effect of velocity error since the "positions" as defined by the event marker would include any current velocity errors and only changes in velocity error during the application would introduce errors in swath-to-swath distance. This technique, in missions covering a considerable area, and therefore elapsed navigation time, would require repeats of the initialization depending on the accuracy required; certainly at each reload, if overall accuracy approaching 1 meter is attainable by using better resolution and improved processing.

The normal control and display unit (CDU) is used for all data entry on an inertial navigation system. This unit has been developed for the normal navigation use and has multiple displays selected by a switch and a keyboard entry panel. Operation of this unit needs considerable understanding of the system operation, training and practice in operation. Entry of the data for the treatment area is principally defined by coordinates in latitude and longitude of the area with a separate entry for swath width. This is ideal for large areas such as forests where the necessary coordinates may be obtained from accurate maps and whose boundaries are not visually well defined. For small fields, such as the typical 160 acre example, whose coordinates are not readily referenced to latitude and longitude and whose boundaries are readily discernible this is a wasteful task. The system does require a fairly accurate entry of the coordinates at which alignment is performed in order to operate accurately. Normally this is required to ± 0.1 minute of latitude and longitude, i.e., approximately ± 600 feet. Once alignment has been achieved and the appropriate data loaded to define the treatment area the system is able to provide steering signals from take-off to the start of the first run. Here the mode of operation of the system is transitioned from normal navigation to the swath-to-swath mode. At the point the load runs out the system is triggered to retain this location. By resuming the normal navigation mode steering signals to the reload base may be obtained and upon completion of loading the system is able to steer back to the point to resume the partially completed run.

The chief advantage of an inertial system lies in the self-contained abilities. No external signals or references are required to operate the system once alignment has been completed. Thus the system is able to operate in remote areas and other large areas of varying terrain where line of sight systems are at a disadvantage. Similarly the system can operate under all atmospheric conditions where radio signals suffer from varied attenuation and propagation directly affecting their accuracy. There is no need to place transponders at various locations to cover the desired treatment area with the associated problems of access and replacement of power sources.

In summary, inertial systems are not currently capable of meeting the 1 meter swath-to-swath accuracy requirements. They are expensive to purchase ($150,000) and operate and require considerable training and expertise in operation. They have been successfully used in forest treatment where accuracy requirements are less stringent and the area large and best defined by map coordinates. In these remote areas, their self-contained abilities predominate and the use of multi-engined aircraft with several crew members allows the system to be used with advantage.

EVALUATION OF TRANSPONDER TYPE SYSTEMS

The results of the various investigations and evaluations reduced the choice of suitable candidates to those with transponder-type systems. This reduction in choices resulted primarily from the inability of other type systems to meet the basic accuracy requirement of ± 1 meter swath-to-swath repeatability accuracy. This very stringent constraint requires continual aircraft position measurements on the order of one to three meter accuracy and continuous processing of this data to generate steering signals to provide repeatability within one meter.

Three equipment manufacturers were found who have developed systems suitable for agricultural aircraft operations. These companies, Del Norte, Motorola and Teledyne Radist-Hastings, were selected for further evaluation because each had carried development at least through the prototype stage and demonstrated the required capability. In the case of Del Norte, the leading candidate, several production systems have been delivered and are in use. Other potential candidates with similar systems were eliminated because the development status of each appeared further behind. The following sections contain descriptions of the three leading candidate systems along with comments on suitability for the stated requirements.

DEL NORTE FLYING FLAGMAN

General

The Flying Flagman equipment manufactured by Del Norte Technology, Inc. is a range/range positioning system derived from their Trisponder distance measuring equipment. The basic Flying Flagman system consists of a set of airborne equipment which continually measures the distance to each of two ground transponders. This range information is processed to provide position information to the pilot and to continuously compute and display pilot steering information. The system operates at X-band frequency (8.8 to 8.9 GHz) and is thus limited to line-of-sight operation.

Two ground transponders are typically located up to 40 km (25 miles) apart to form the base leg of a triangle used to compute aircraft position by trilateration. The microprocessor within the airborne equipment continuously computes steering information relative to the track selected by the pilot. This steering information is displayed on a localizer type instrument to enable the pilot to fly a selected track between two end points which may be as much as 80 km (50 miles) apart. The system provides for flying offsets to this track in either direction, with the offset distance being selectable from 1/3 meter (1 ft.) to 3045 meters (9990 ft.). The transponder power and antenna gains are sufficient to provide tracking at distances up to 80 km, providing radar line-of-sight between the aircraft and the two ground transponders is maintained.

The system has been designed for aerial agricultural operations and as such provides "one-button-operation" for most of the operations. Most of the system controls are set on the ground before starting an operation, with checkout of the equipment through its built-in test circuits requiring less than one minute. The remote transponder locations do not have to be surveyed. The ground station transponders can be set up and turned on within a few minutes. The system can be oriented simply by flying between the remote transponders or by setting a known baseline length into the microprocessor via controls on the control panel.

A time sharing feature, standard on all systems, allows up to four aircraft to use the same two ground transponders simultaneously. The two transponders used for a specific operation can be selected from four preset transponder codes with panel switches. Additional codes up to a total of 96, can be selected in-flight by making control panel switch changes. The basic system provides for parallel offset tracks, however, other patterns are available through optional equipment. A "material-out-point" feature allows a pilot to mark any point he wishes so that he can return to that point to resume spraying, dusting, or fertilizing.

The Del Norte Flying Flagman system currently sells for about $50,000 for a basic uninstalled system consisting of two ground station transponders and airborne equipment. According to Del Norte, most systems in use utilize three ground transponder stations at a cost of about $6,000 for the additional station.

Optional accessories, such as the racetrack pattern control and lite-bar steering indicator sell for $850.00 each. To date, approximately 25 to 30 systems have been delivered with an additional 15 to 20 systems on order. The company appears to have an on-going program to continually improve and/or modify the equipment, based on feedback from the users as well as their own investigations. A more detailed description of the equipment, along with operational procedures and capabilities is given in the following paragraphs.

Equipment Description

The Flying Flagman system was developed from the Del Norte Trisponder positioning equipment. Brochures describing the characteristics and operation of these transponders is included as Addendum A-2 through A-5. A tabular description of the Flying Flagman equipment is included in Figure 1. System characteristics are shown in Figure 2.

Figure 1

Flying Flagman - Equipment Description

Airborne Equipment

Steering Indicator....	7.62 cm (3 in.) Panel Mounting
Pilot's Control Box...	14.6 x 7.6 x 14 cm (5-3/4 x 3 x 5½ in.)
DDMU Control Box......	14.6 x 15.2 x 15.2 cm (5-3/4 x 6 x 6 in.)
DDMU Main Frame.......	12.7 x 25.4 x 48.3 cm (5 x 10 x 19 in.)
Master Transponder....	15.2 x 26.7 x 35.6 cm (6 x 10½ x 14 in.)
Antenna...............	6.4 cm (2½ in.) Hemispherical Omni (Standard) 360° azimuth x 20° elevation coverage; 7 db gain
Weight................	Approximately 18 Kg (40 pounds) installed, depending on aircraft type
Power Requirements....	4½ amps at 24 Vdc (23-30 Vdc) 7½ amps at 12 Vdc (11-30 Vdc)

Ground Equipment

Ground Transponder....	15.2 x 26.7 x 35.6 cm (6 x 10½ x 14 in.)
Weight................	7 Kg (15 pounds) not including power source
Power Requirements....	0.7 amps (max.) at 24 Vdc
Antenna (Standard)....	180° azimuth x 5° elevation coverage; 15 db gain
Antenna Weight........	0.5 Kg (1 pound)

Figure 2

Flying Flagman - Characteristics

Frequency....................	8.8 to 8.9 GHz
Range.......................	114 M (300 ft.) to 80 Km (50 mi.)
Temperature..................	0° to 55° C (32° to 130° F), (non-condensing)
Accuracy	± 3 M (± 10 ft.) at 80 Km (50 mi.)
*Repeatability................	Less than 1 M (3 ft.)
Swath Width..................	Selectable from 1/3 M (1 ft.) to 3048M (9990 ft.)
Swath Length.................	Up to 80 Km (50 mi.) (Depends on antennas and orientation)
Patterns.....................	Single and Multiple Parallel Track (Standard); Racetrack (Optional)
Number of Parallel Swaths....	1 to 99
Headings.....................	0° to 360°
Applications.................	Spraying - Seeding - Dusting - Fertilizing - Photogrammetry - Aerial Surveys - Mineral Surveys - Search and Rescue
Information Output...........	Raw data continuously; position data as desired; ASCII (serial) data format for recording optional; visual display for pilot.
Update rate..................	Minimum of two updates per second
Vehicles.....................	Airplanes and helicopters

*Repeatability is based on "static-type" laboratory conditions; not guaranteed by Del Norte since it can vary with operation.

A basic Flying Flagman system consists of two ground transponders and a set of airborne equipment. The ground transponders, operating at X-band frequency are radar line of sight limited but have some very definite advantages over non-line-of sight systems and even over lower microwave frequency (C-band) systems. The reduction in microwave component and antenna size resulting from operation at X-band provides a ground transponder which weighs about 7.5 Kg (16 pounds) including antenna.

These transponders are located as high above ground level as possible, such as on top of grain elevators or water tanks, TV towers, tall buildings, ridges, etc. The unit is mounted in a weatherproof container, which means it can be permanently mounted and left unattended when connected to an optional power supply using 115 Vac. For remote locations or for installations where power is not readily accessibly, automobile type storage batteries can be used. According to Del Norte, a typical system in use will have two ground stations positioned from 12 to 25 miles apart. Additionally, most of the systems in use utilize three ground stations since the addition of this third station provides two additional baselines, all of which can be established by selecting pre-set codes on the control panel. Once a ground station is set up and activated it remains in a quiescent (receive only) state until an interrogation is received. The transmitter portion is then activated and remains on until interrogations are no longer received. A newer version of the Flying Flagman currently in the field contains a "time-saver" circuit which turns the receiver on once each minute for a period of 8 to 10 seconds when no interrogations are being received. Work is also underway to use solar panels to supplement the power source.

A time-sharing adapter on the airborne equipment permits simultaneous operation with up to four separate airborne systems. This limitation is established to provide any interrogating transponder with a minimum of two updates per second, since any transponder can actually handle many more than four different interrogators per second. Each airborne system processes either 16 or 64 replies per second from each of the two ground stations it is netted with. The data rate used by the Digital Distance Measuring Unit (DDMU) is selectable by the system operator (pilot) via the system control box. For most operations, according to Del Norte, most pilots usually leave the data rate set at 16 per second.

A family of antennas is available for use with each ground station transponder, however, all the systems delivered to date by Del Norte have been of the same type. This antenna provides coverage of 180° in azimuth and 5° in elevation, with a gain of 17 db. The airborne antenna in use on all systems provides 360° azimuth and 20° elevation coverage, with a gain of 7 db. Both antennas are horizontally polarized. These antennas, along with 1 KW peak power outputs for both the airborne and ground transponders provide operation up to 80 Km (50 mi.) when radar line-of-sight is maintained. In fact, the ± 3 M accuracy in distance measurement specified for the system is at a range of 80 Km. It was reported that operation in the Casa Grande area of the Southwest was achieved at ranges of 125 to 150 Km with ground station transponders located on plateaus some 1500 meters high to achieve the necessary line-of-sight.

The steering indicator supplied as standard with the airborne equipment is a localizer display type instrument whose functions are described in the section on system operation. This instrument, normally mounted on the instrument panel of the aircraft, has been ruggedized and packaged in a weatherized container, and is available for mounting outside the cockpit in front of the windscreen. This allows the operator to monitor the instrument with a minimum of eye and head movement. Also available as an option at a cost of $850.00 is a "Lite-Bar" steering indicator described in figure A-6 of the Addendum section.

The equipment contains built-in self test and monitoring circuits which enable the operator to check out the equipment quickly, following a check list. Procedures are supplied in the manuals for troubleshooting and isolation of a failed circuit card or part. Del Norte guarantees to repair and return a failed part or to replace it with a duplicate within eight hours after receipt of the failed part.

A Del Norte spokesman said that each Flying Flagman system is system tested, temperature cycled, retested, stripped down for inspection, tested again and then flown in the company's aircraft for checkout prior to delivery to the customer. According to Del Norte literature the warranty provided with the Flying Flagman system covers a period of one year, parts and labor, with normal operation and maintenance of equipment. Installation is done by a licensed mechanic, provided by the buyer, who works under the supervision of a Del Norte representative. A typical installation was stated to take approximately eight hours. Concerning the type of approvals needed, Del Norte says that approval from the Federal Communications Commission (FCC) to operate the transponder and a new weight and balance entry in the aircraft log book to comply with Federal Aviation Administration (FAA) regulations are all that is required. Del Norte offers a free ground school at its factory facility for pilots and mechanics to learn the operation and maintenance of the system.

System Operation

The basic operation of the system is derived by the continuous processing of range information between the airborne equipment and two ground station transponders. This processing is done in a microprocessor, which is part of the airborne equipment, to provide steering between two designated points on the ground, established as part of the procedure of orienting the system, and then to provide steering for flight paths parallel to this line. The two ground stations in use serve as the baseline of a triangle which includes the aircraft distance from each ground station. The microprocessor, using this baseline distance, continuously computes the location of the aircraft, located at the triangle apex, relative to the reference ground stations. It then computes steering to fly the aircraft along selected paths within the operating area permitted by the geometry of the layout.

In order to meet the specified position accuracy of ± 3 M the angle intersection between the aircraft and the reference stations must be maintained between 30° and 150°. The area of coverage represented by this geometry is illustrated in Figure 3. For a spacing between stations of distance "d", the shaded portion of circle A_1 with radius equal to this spacing "d" is the area which can be covered by an aircraft operating within line-of-sight of the stations. The area depicted by A_2 represents the area which can be covered by re-orienting the antennas of T/R-1 and T/R-2. It can be seen from this figure that each point on the circle perimeter forms an angle of intersection of 30° with the reference stations T/R-1 and T/R-2 while each point on the perimeter of the "football" shaped intersection forms an angle of intersection of 150° with the reference stations. Thus the shaded portions A_1 and A_2 represent the limits of operation for a given baseline length between two ground stations. Further examination of this figure will show that the minimum operating distance from the baseline is approximately 0.1 times the baseline length (i.e., the perpendicular distance from the baseline to the "150° line" on the figure) while the maximum distance from the ground stations is 2.0 times the baseline length.

LAYOUT GEOMETRY — OPERATING AREA

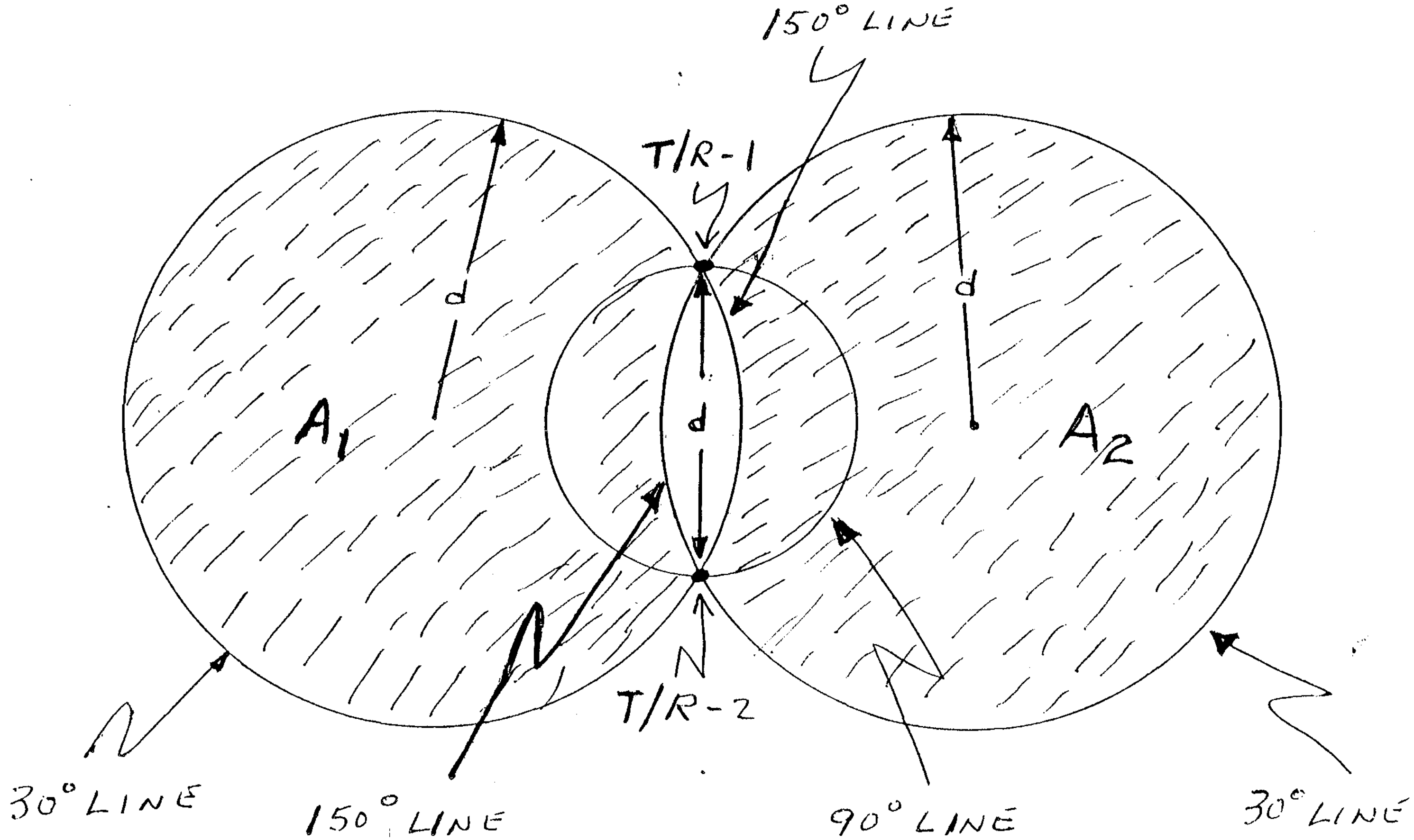
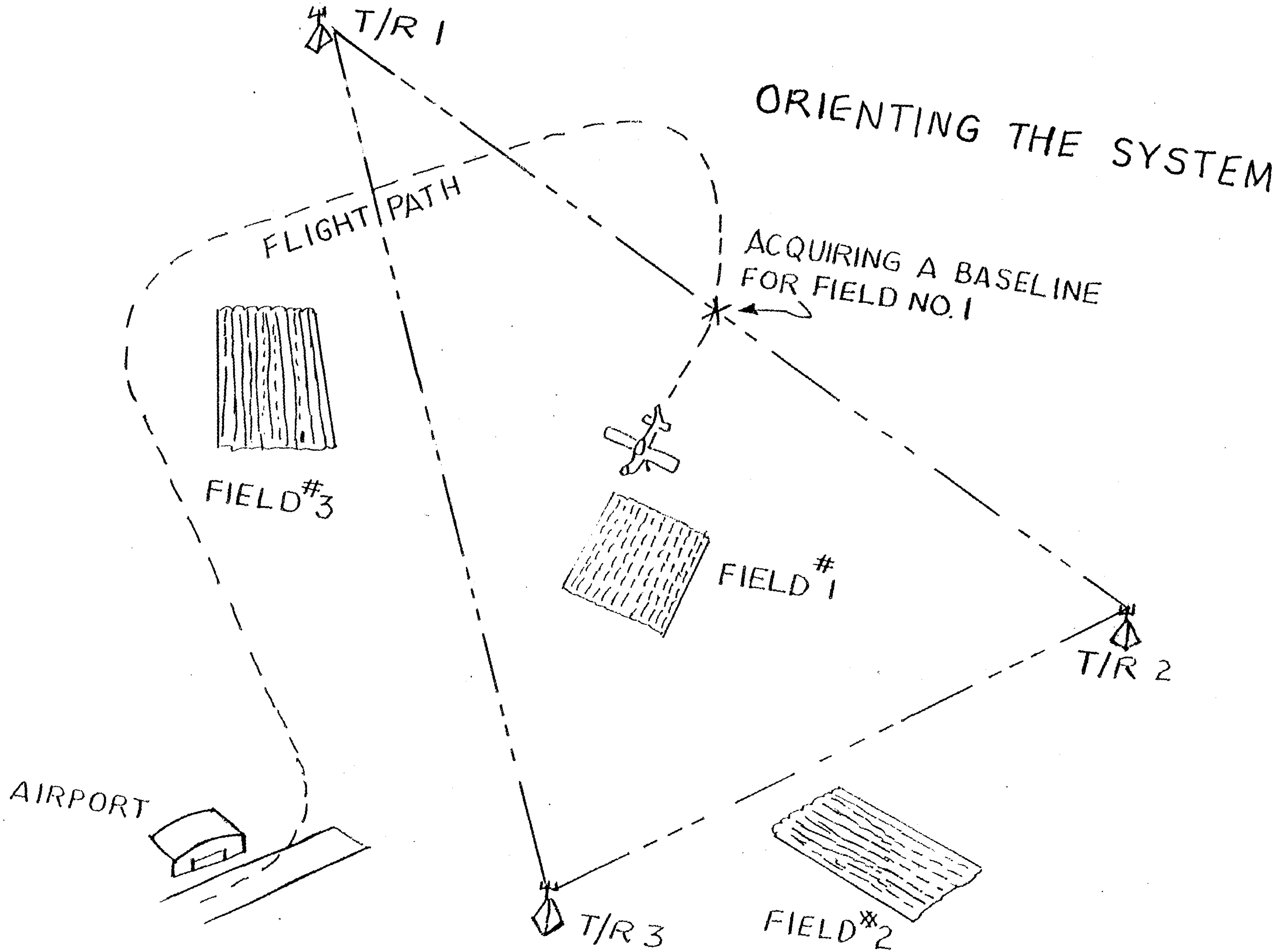


FIGURE 3

The above analysis shows that the ground stations should be located so that the work areas are on one side or the other of the imaginary baseline connecting them. The system will then function within the specified accuracies as long as the aircraft is between 0.1 and 2.0 times the baseline length. For example, for a baseline length of 20 Km, this operating area will be between a distance of 2 Km and 40 Km from the baseline.

Once the ground stations have been placed in position the length of the baseline between them must be established. This can be accomplished by flying the aircraft across the line between the two stations. The appropriate switches are set on the control panel and as the aircraft crosses the line between the stations the distance measurements, which will be at a minimum, will be recorded automatically by the system as the baseline length. Once this distance is established, it will remain in the microprocessor memory for as long as 30 days or until changed by the operator. This baseline length is available for display to the operator or for recording on magnetic tape. If the ground transponders are not moved or if they are relocated at a later date to the same positions the baseline length can be manually inserted by the operator without having to fly across the baseline again. Figure 4 illustrates this basic operation of orienting the system and also shows how the use of a third ground transponder can increase the number of available baselines from one to three.


ORIENTING THE SYSTEM
T/R 1
FLIGHT PATH
ACQUIRING A BASELINE
FOR FIELD NO. 1
FIELD #3
FIELD #1
T/R 2
AIRPORT
T/R 3
FIELD #2

FIGURE

After the baseline has been acquired, the next step is to establish the "job" baseline. This operation is depicted in Figure 5 and is accomplished by making a visual pass over the beginning and end points of the first run. As the aircraft passes over the desired starting point, the pilot presses the P_1 button on the control panel and presses the P2 button while passing over the end point. The microprocessor then computes the distance between these points and establishes their positions relative to the ground stations even though aircraft heading and course may have changed during the pass. It next generates a network of grid lines parallel and perpendicular to the line defined by P_1 and P_2. The parallel lines of the grid are offset by the swath width selected for the operation.

Beyond this point the procedure becomes a "one-button" operation. The operation hits the control button, makes a 180° turn and heads back toward P_2. The system computes and displays left-right steering information on the vertical bar of his indicator to bring him over P_2 on a course in line with P_1. As the aircraft approaches P_2 the horizontal bar of his indicator will be displaced on the top section of the display. When the aircraft is within 0.8 Km (0.5 mi.) of P_2 this horizontal bar will start closing toward the zero posi-tition and will be zeroed just as the aircraft passes over P_2. At the same time, an amber bulls-eye on the indicator will illuminate and stay lit for approximately two seconds. Having passed over this point the pilot simply maintains the heading dictated by the left-right steering pointer of the indicator. As the aircraft

PARALLEL TRACKS

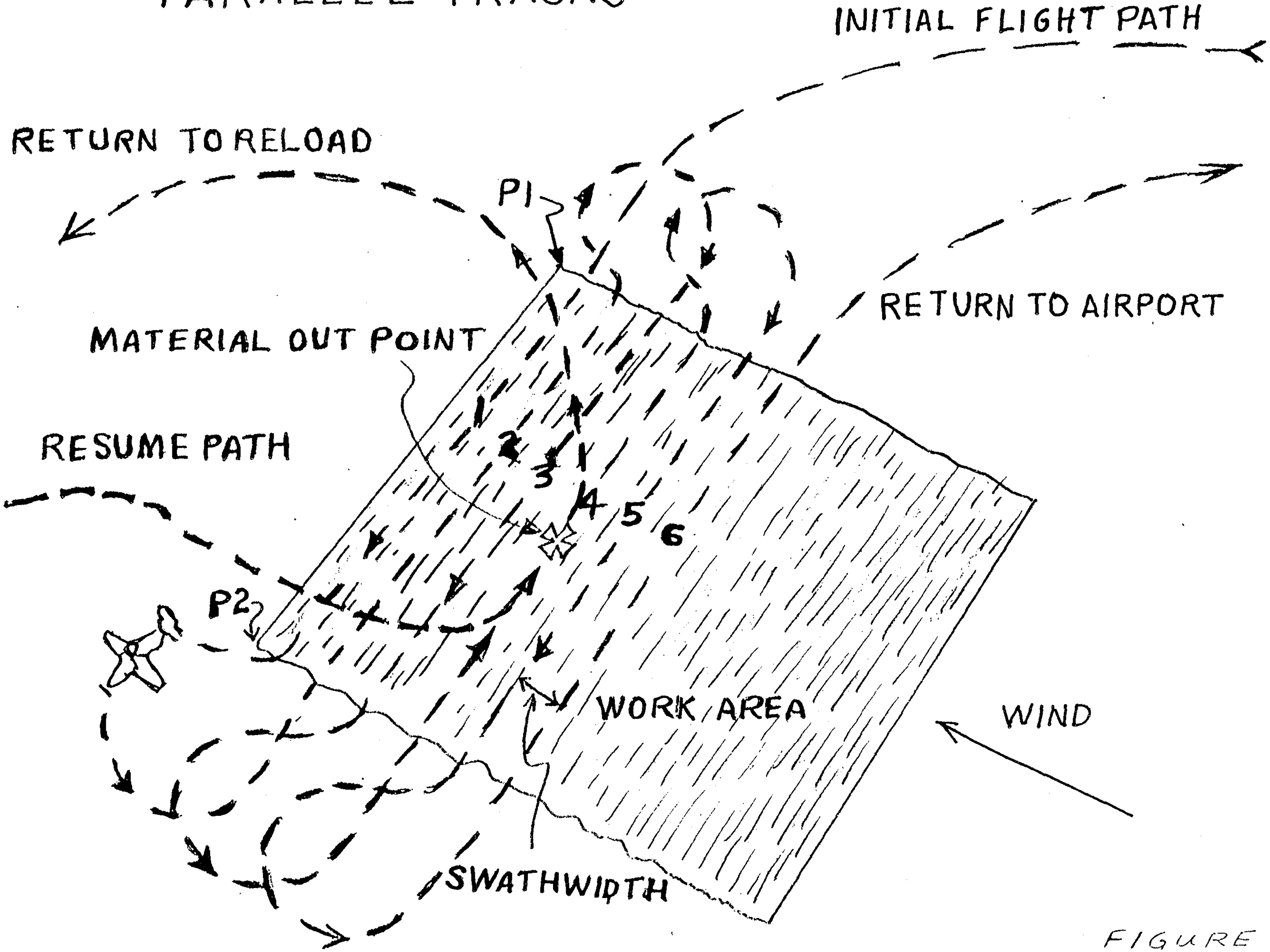


FIGURE 5

approaches within 1/2 mile of P_1 the horizontal pointer will go full up and then will move back toward the zero position, reaching it just as the aircraft passes over P_1 and as the amber bulls-eye again illuminates for two seconds. At this point, the pilot hits the control button and the system automatically generates the data necessary for the next run on a track parallel to the present track but in the reverse direction and offset by the pre-selected swath width.

The pilot now proceeds to make a 180° turn and follow the steering information to bring him back to the starting point of the next pass. During this turn he can press a button on the control stick which will decrease the left/right steering pointer sensitivity by a factor of 10 to 1, i.e., from 23 meters (60 ft.) to 230 meters (600 ft.). When the button is released the sensitivity changes back to the original value. This capability has been tested and found to provide a sort of funnel effect which enables the pilot to more accurately bring the aircraft over the new starting point with the proper heading. As the aircraft is maneuvered through the 180° turn and brought back to the starting point by the next run, the horizontal bar and amber light function as previously described.

The system also provides a material-out feature which allows the pilot to accurately denote the location at which it occurs, assuming it happens in the middle of a run. To accomplish this action, the pilot presses the control button at the point where he breaks off the run and the system stores the location of the designated point. As depicted in Figure 5 the pilot returns to reload and then resumes the run by following the steering information displayed on his indicator. All the steering features and amber light operation described above operate to guide the aircraft back to the material-out point.

Figure 6 shows a typical racetrack pattern which is available as an operational accessory at a cost of $850.00. A brief description of this option is described on page A-7 of the Addendum section. Figure 7 illustrates how the system can be used to obtain data for determining the shape and/or area of a particular work area.

Conclusions - The Del Norte system, of all the systems investigated, appears to be the single system which meets or exceeds the various requirements imposed. Swath-to-swath accuracy requirements, excluding operator response, can be met. System lag time of 0.5 seconds for simultaneous use by four aircraft can be improved to the specified lag time of 0.25 seconds when used by two aircraft simultaneously, and can be improved even more for single aircraft use. Acquisition costs, though higher than desired, appear reasonable. A lease arrangement might ease this problem somewhat, although Del Norte does not currently appear to be receptive to this approach. Maintenance and troubleshooting procedures and equipment turn-around times seem adequate. Simplicity of operation coupled with an ongoing effort to improve equipment operation indicate an understanding of agricultural aircraft operation. Reports from equipment users to date indicate a high degree of success in meeting operational requirements.

RACETRACK PATTERN

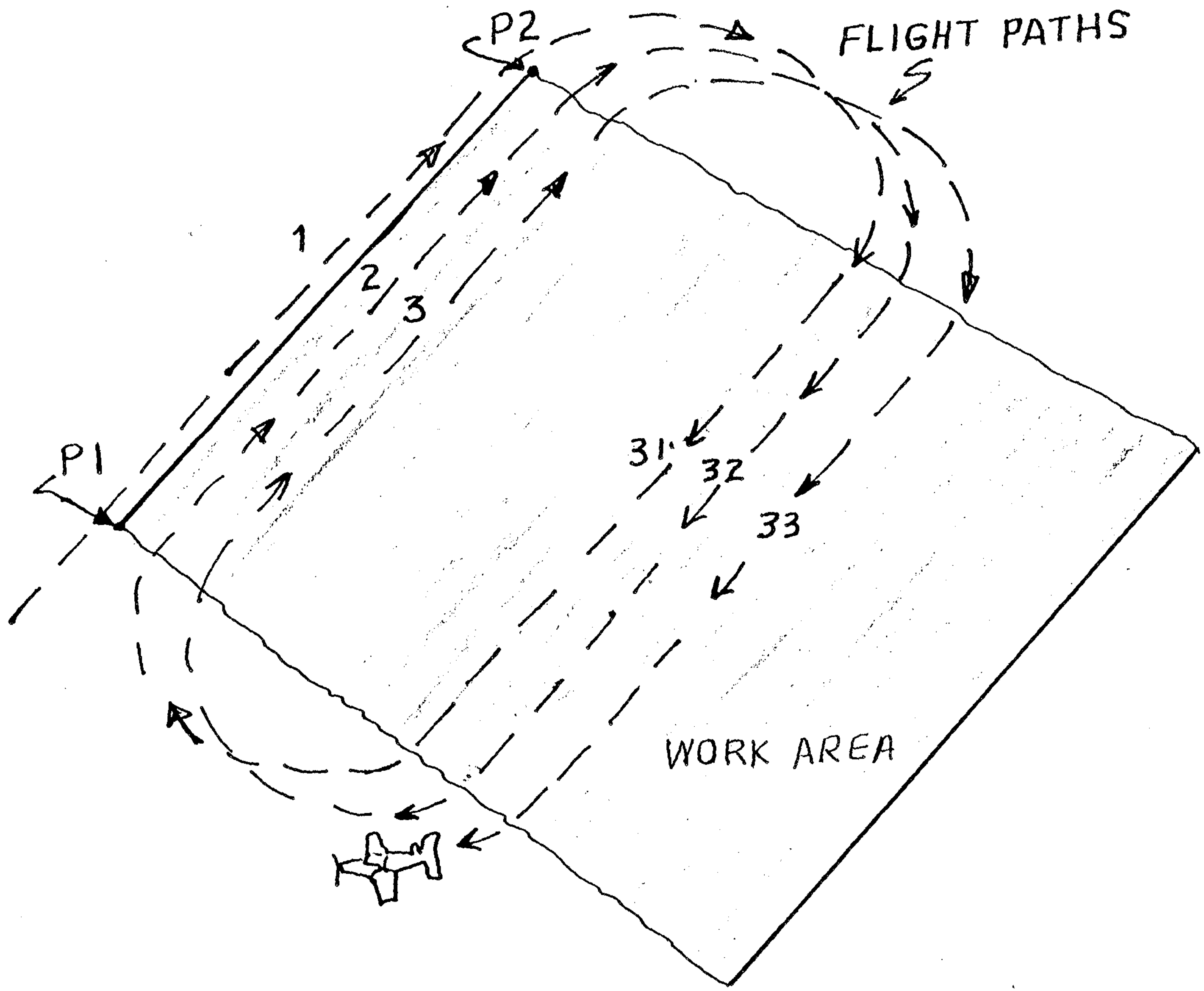


FIGURE 6

MEASURING THE AREA

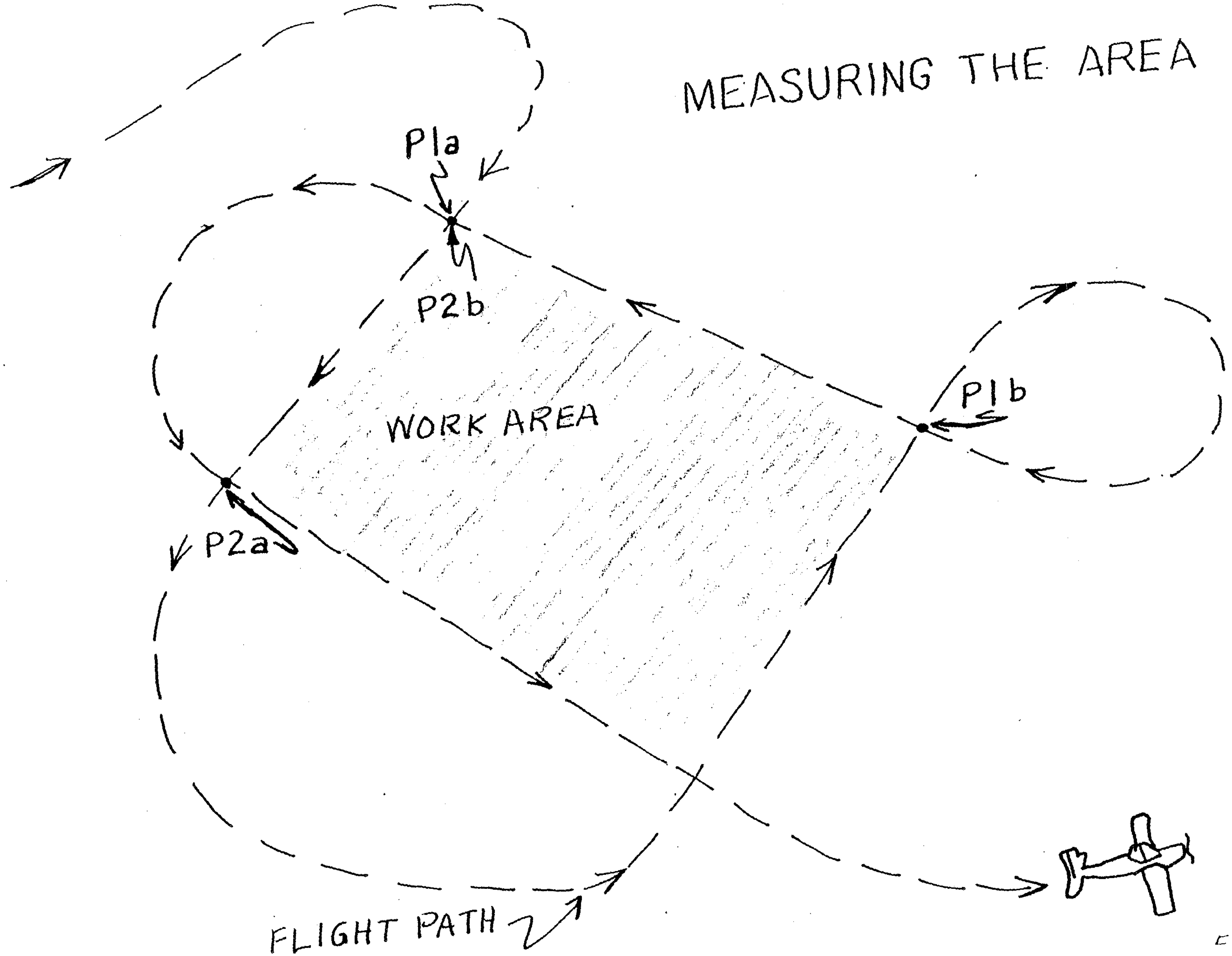


FIGURE 7

MOTOROLA MINI-RANGER AIRBORNE SYSTEM

The Motorola "Electronic Flagging" system was developed from their basic Mini-Ranger III positioning determining system. The basic theory of operation of the system is identical to that of Del Norte Flying Flagman system except for the following differences:

1. The Motorola system operates at C-band (5.4 to 5.6 GHz) while the Del Norte system operates at X-band (8.8 to 8.9 GHz).

2. The Motorola system uses an antenna with 75° azimuth x 15° elevation coverage on the ground station transponders of its standard configuration. This limitation on azimuth coverage (compared with 180° azimuth coverage for the Del Norte system) reduces the effective coverage to a wedge shaped area approximately 1/3 the size of the circles defined in Figure RHW-3 for a given ground station spacing.

3. The overall loop gain of the standard Motorola system provides for coverage of up to 37 Km (20 n. mi.) in range compared to 80 Km for the Del Norte system. This range limitation dictates a maximum spacing between ground stations of approximately 10 nautical miles, thereby reducing the effective area of coverage to considerably less than that of the Del Norte system. Increased range can be obtained by using more

directive antennas on the ground transponders, however, these antennas must be reoriented after the baseline length is established. The locations of the ground stations can be manually entered, the same as in the Del Norte system, so this measurement would only have to be established once for a given pair of locations.

4. Determining the baseline length with the Motorola system is accomplished by flying directly over either reference station as contrasted with the method used with the Del Norte system which requires only that the aircraft fly across the baseline at any point.

Because of the similarities between the Motorola and Del Norte systems, a detailed description of the Motorola has not been included. Included in the Addendum section (A-8 and A-9) are two comprehensive data sheets which describe the system very concisely. It should be noted that the section on reference station geometry describes a case which would require ground station antennas with azimuth coverage nearly double the 75° coverage of the standard system antennas to achieve the coverage depicted.

The primary reason for not including more detailed information and analysis of the Motorola system is that Motorola appears to have abandoned its efforts to market this system to any extent. Any efforts at further development, at best, are being done on a "low key" level.

One very significant set of test data obtained on the Motorola Mini-Ranger Tracking System serves to reinforce the basic distance-measuring and repeatability (swath-to-swath) accuracies of the Motorola and Del Norte systems. General Dynamics conducted a series of test utilizing the Motorola Mini-Ranger Tracking System and the M35-A Truck as the tracking target at the Yuma Proving Grounds Inverted Range on 5 October 1978. The purpose of the tests was to evaluate the accuracy and repeatability of the Mini-Ranger System for support of Truth Data generation of the Navy ship tests to be conducted at San Diego Harbor and the San Clemente Island range. According to a General Dynamics Interoffice Communication dated 16 October 1978 the test results showed that a . . . "statistical comparison of Mini-Ranger range measurements with laser Truth data generated ranges validated Motorola's claims of a 1 meter system for the MRS III for static and dynamic environments (to 20 m/sec)." Because of the similarities in operational theory between the Motorola and Del Norte airborne systems, and because of identical distance measuring and repeatability accuracies claimed by both, these test results lend credibility to the capabilities claimed for both systems.

TELEDYNE HASTINGS - RAYDIST SYSTEM

Teledyne has two basic versions of its RAYDIST Radiolocation system for use in position finding. Both versions, DRS-H and DRS-T, are non-line of sight continuous wave (cw), phase comparison systems with different characteristics. These systems have been in use for several years in a variety of operations, principally maritime in nature. Published Teledyne literature claims ranges in excess of 400 km (250 mi.) during daylight and 240 km (150 mi.) at night over sea water for the long range versions, which utilize 38 m (100 ft.) antennas. Ranges of 120 km (75 mi.) or more can be achieved using antennas of 18 m (47 ft.) length.

The DRS-H system, when operated in a range/range configuration for airborne positioning, utilizes two ground stations and one mobile station in the aircraft. Aircraft position is continuously computed by trilateration in the same basic manner as done by the Del Norte and Motorola systems except that the distance measurements are made using phase comparison techniques. In this mode (i.e., range/range), up to four aircraft can simultaneously use the same two ground stations for continual positioning data.

The DRS-H system can also be operated in a hyperbolic mode by utilizing a third ground station to provide two hyperbolic base lines. In this mode no transmitter is required in the aircraft equipment, and the limit of four simultaneous users is removed. The position accuracy achieved is nearly as good as that of the range/range mode (better intersections are obtained with the circular patterns of the range/range mode), however, the coverage area is reduced over that of the range/range system.

The DRS-T system is an expansion of three-station hyperbolic DRS-H and utilizes a minimum of four ground stations to provide improved geometry and additional lines of position while maintaining non-saturability. As with the three-station DRS-H system, no transmitter, only a receiver, is required in each user aircraft.

For all the Radist system configurations, positioning accuracies of less than 3 meters (10 ft.) and repeatabilities of ± 1 meter (3 ft.) are claimed. These figures along with stated sensitivities (resolution) of 1/3 to 1/2 meter are comparable to the capabilities claimed by the Del Norte and Motorola.

To provide aircraft steering information of the type required for agricultural operations an additional "black box" called a Director system is required in the aircraft. This unit processes position data to provide steering to fly a large number of different patterns which can be programed for the unit. According to Teledyne literature, the absolute accuracy of a Raydist system is typically improved to standard deviations of 1.5 meters by the addition of the Director system and additional lines of position.

Because of its capabilities, the Raydist system was analyzed for suitability in airborne agricultural operations. When examined on its own merits, it has capabilities which would satisfy very stringent ag aircraft operation requirements. However, when compared with a system of the Del Norte or Motorola type, it appears to provide very little, if any, improvement in accuracy or repeatability. Descriptive literature on the various Raydist configurations is included in the Addendum Section (A10-A18) in lieu of an extensive description here. Instead, only those factors which are pertinent to its use for airborne agricultural uses are discussed. Suitability in this area appears to be impacted in four major areas: complexity, size and weight, cost and antenna requirements. Each of these areas is discussed below.

Complexity - The complexity of the Director system is not one which detracts from its capabilities. It is simply a matter of excessive capability for ag aircraft operations. The Raydist Director system was designed for a variety of uses and applications, and thus has outputs and information which are not needed for ag aircraft operations but are necessary for other applications.

Size and Weight - The weight of airborne equipment required for the DRS-H range/range system is approximately 60 kg (135 pounds) as compared with 18 kg (40 pounds) for the Del Norte airborne hardware. Operating in the hyperbolic mode as a DRS-H or DRS-T system removes the need for an airborne transmitter (17 kg, 37 pounds), however, the required aircraft equipment still weights about 45 kg (100 pounds). The equipment weight of a typical ground station is from 34 to 113 kg (75 to 250 pounds), excluding power source and depending on antenna configuration. This compares with a weight of about 7 kg (15 pounds), excluding power source, for a Del Norte type ground station.

Cost - The cost of a DRS-T system consisting of four ground stations and 1 set of airborne equipment is approximately $104,000 which consists of about $47,000 for ground stations and $57,000 for airborne equipment. Leasing this equipment for a 30 day period costs approximately $7,000. The cost of a basic Del Norte system (2 ground stations and 1 airborne set of equipment) is approximately $50,000. Cost of each additional Del Norte ground station is $6,000.

Antenna requirements - Assuming that the Raydist equipment could be redesigned to tailor it for ag aircraft usage at a reduction in complexity, cost and weight, the antenna requirements resulting from operation in the low frequency band would remain. The antenna used with each Raydist ground station for long range coverage is a 38 meter (100 ft.) sectional aluminum antenna weighing 120 pounds. The guys and ground system weigh 39 kg (85 pounds). In addition some 75 meters (200 ft.) of clearance around the base of this antenna is required for guying. For medium range operation, an 18 meter (47 ft.) antenna is used which consists of a 13 meter (35 ft.) telescopic aluminum whip with two 2-meter (6 ft.) extensions. The weight of this antenna system, including 2 kg (5 pounds) for guys and ground system, is about 14 kg (30 pounds).

The Weyerhaeuser Company in Washington state is currently evaluating the Raydist system, using helicopters, for use in fertilizing large tracts, up to 260 square kilometers (100 square miles), of forest area. While the results of these tests are not known, informal feedback on the program indicates that system range and clearance for antenna guying are problem areas.

In conclusion, the Raydist system, in its present configuration, appears less suitable for ag aircraft applicantions than the Del Norte or Motorola type systems.

CONCLUSIONS AND RECOMMENDATIONS

The literature and product search conducted during this study period and the subsequent analyses and evaluations revealed a single, commercially available system which appears to satisfy virtually all the specified requirements of the contract statement of work. This system is the Flying Flagman manufactured by Del Norte Technology, Inc., Euless, Texas.

Although the available Del Norte test information consists of laboratory testing plus their own "sell-off" flight testing of each individual system, the system is so similar to the Motorola unit that further flight testing does not appear worthwhile. The Motorola tests conducted at the Yuma Proving Grounds verify that this type transponder system is capable of the level of accuracy required.

Del Norte does not currently have any sort of leasing arrangement for its Flying Flagman equipment, and appears to be unreceptive to such an arrangement at this time. Informal feedback from the Del Norte marketing office indicates that financing and payment is a problem for some system users since several systems have been returned recently because of inability to meet payment requirements. An examination of ways to make the system more affordable to potential users appears needed.

REFERENCES

1. Interoffice Communications, General Dynamics Electronics Division, Ft. Worth, Texas, "Mini Ranger Test at YPG," 16 October 1978.

2. J. F. R. Gower, R. L. Grasty, B. M. Oliver, "Experiments with a Standard Inertial System," Geological Survey of Canada, Ottawa K1AOE8, Canada.

3. G. J. King, "The Use of Aircraft in Agriculture," Canadian Farm Economics, Volume 13 No. 2.

4. Norman B. Akesson, Wesley E. Yates, "The Use of Aircraft in Agriculture," Food and Agriculture Organization of the United Nations, Rome 1974.

5. "The Role of Inertial Navigation in Aerial Survey and Special Applications," Litton Aero Products, 21050 Burbank Blvd., Woodland Hills, California 91364, April 1976.

6. "Handbook for Agricultural Pilots," U. S. Dept. of Agriculture, National Agricultural Library, 303997.

7. "Agricultural Aviation Research," NASA Conference Publication 2025, a workshop held at Texas A&M University, October 19-21, 1976.

8. "Navigation" Journal of the Institute of Navigation, Summer 1978, Vol. 25, No. 2.

9. "National Plan for Navigation," U. S. Department of Transportation, Washington, D.C. 20590, NTIS, Springfield, Virginia 22161, Nov. 1977.

10. Glancey, B. M. et. al., "Evaluation of an Electronic Guidance System for Aircraft Used to Apply the Bait in the Imported Fire Ant Program," Florida Area Southern Region, Agricultural Research Service, USDA, Gulfport, Mississippi, 39501.

11. "Decca System Looks Good for Large-Scale Ag Operations" American Aviation, August 1966.

12. David A. Walker, "Track Guidance in Aircraft Spraying," Br. Crop Prot. Counc. Monogr. No. 11, 1974.

13. "Long-Range Navigation Systems," Business and Commercial Aviation, April 1979.

14. G. Boivin, S. T. DeCamp, "Operational Aspects of Inertial Guidance in the 1975 Province of Quebec Spruce Budworm Control Program, paper presented at the Fifth International Agricultural Aviation Congress (1975) Kenilworth, Warwickshire, England.

15. "A Comparative Performance Analysis of Modern Ground-Based, Air-Based, and Satellite-Based Radio Navigation Systems," Navigation: Journal of the Institute of Navigation Vol. 24, No. 1, Spring 1977.

16. "Agricultural Aviation Research" Proceedings of Workshop held at College Station Texas, 19-21 October 1976, NASA-CP-2025.

17. "The Benefits of Improved Technologies in Agricultural Aviation," NASA-CR-157051.

18. "Airplane Guidance Report Bibliography," prepared by the Defense Documentation Center, Alexandria, Virginia, for the Lockheed-Georgia Company.

19. Roberts, J. R. et. al., "Comparison of Spray Programmes in Quebec and New Brunswick Forests," National Research Council, Canada, 1977.

20. "Navigation for Airplanes," DIALOG search 23 May 1979, Lockheed-Georgia Company.

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A D D E N D U M

DEL NORTE'S

FLYING FLAGMAN

POSITIONING EQUIPMENT

For

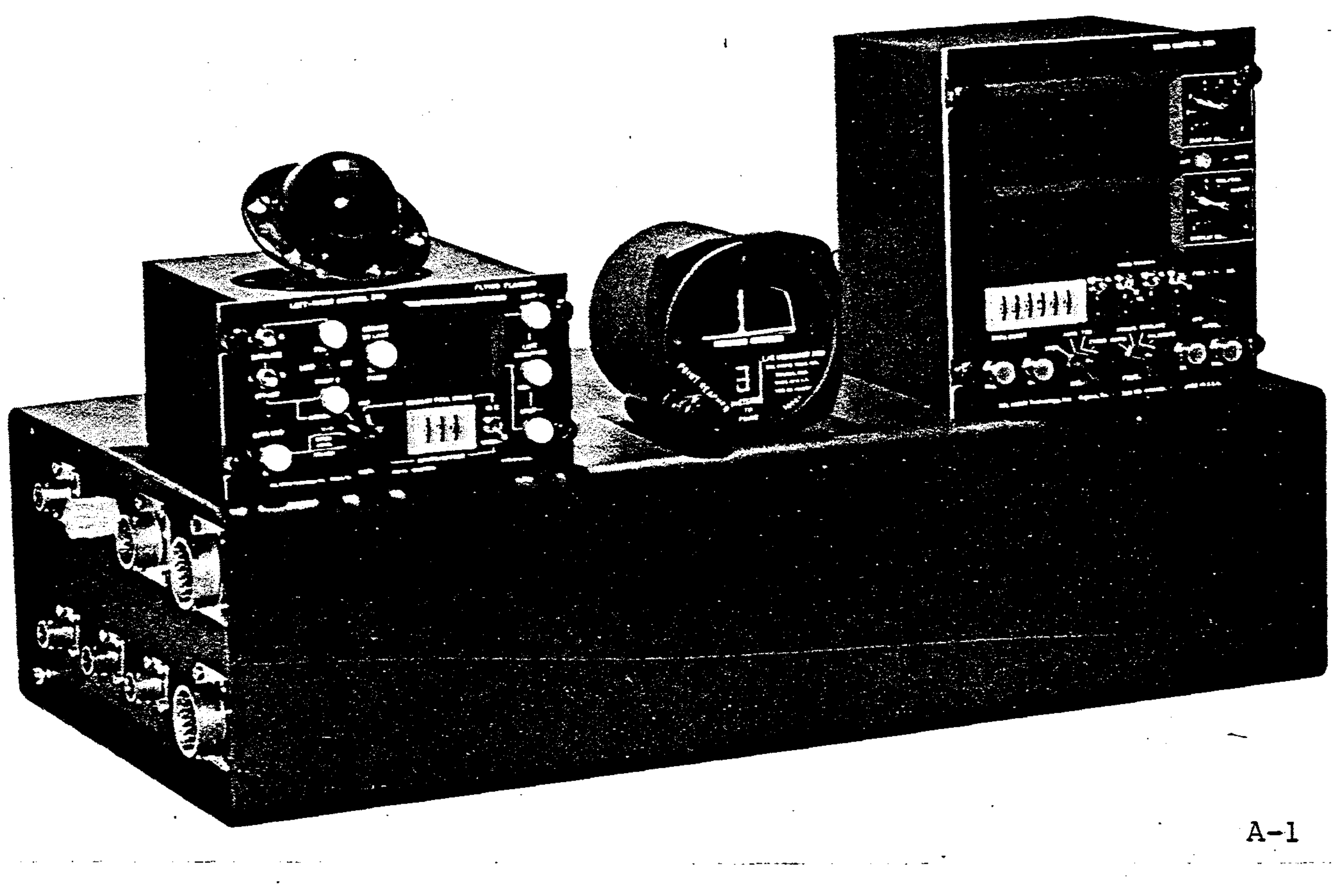
AGRICULTURAL OPERATIONS

AERIAL SURVEYS

SEARCH AND RESCUE

PHOTOGRAMMETRY

ETC.



DEL NORTE

STATE-OF-THE-ART

SPECIAL TRISPONDER FEATURES

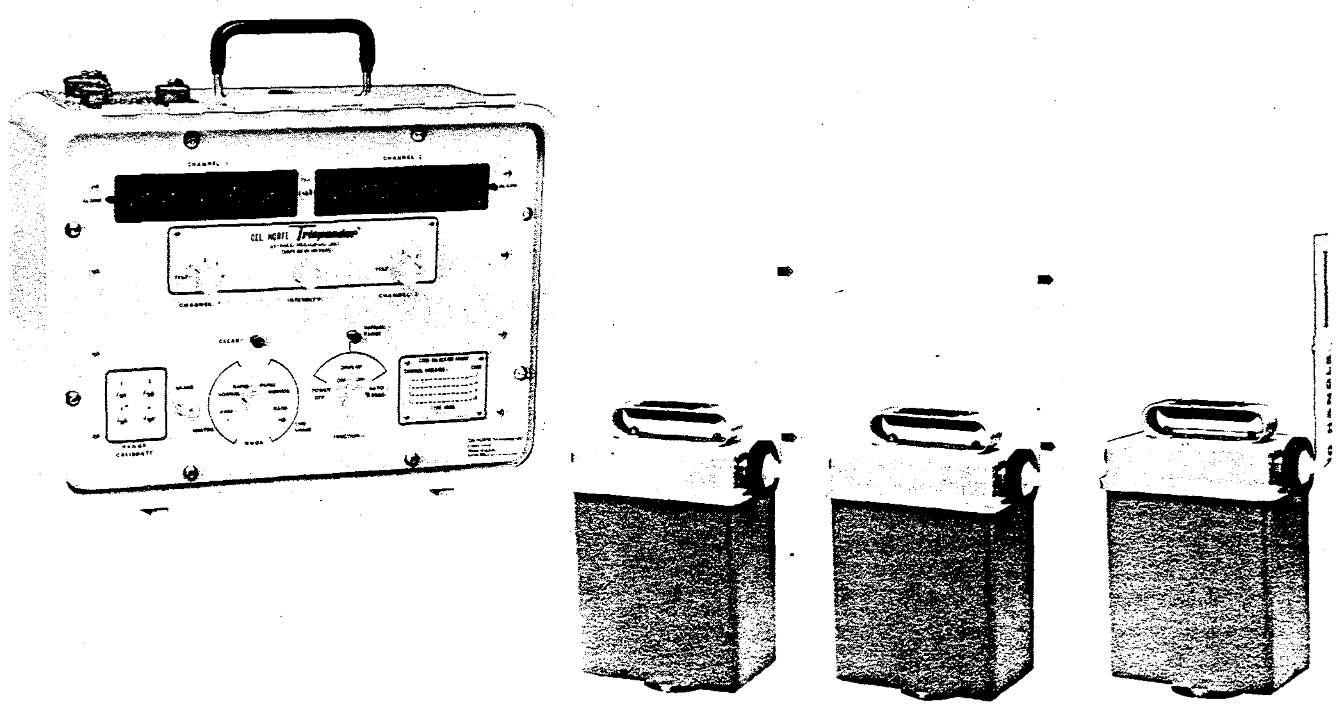
For the past eight years, all Trisponder® positioning systems have utilized the PRI (Pulse Repetition Interval) method of identifying the proper remote stations and, in turn, encoding and decoding all signals. This method has proved to be very successful in accurately measuring distances. Del Norte has, after approximately 4 years of field experience, implemented a further refinement of the PRI coding method in order to enhance the overall system operation.

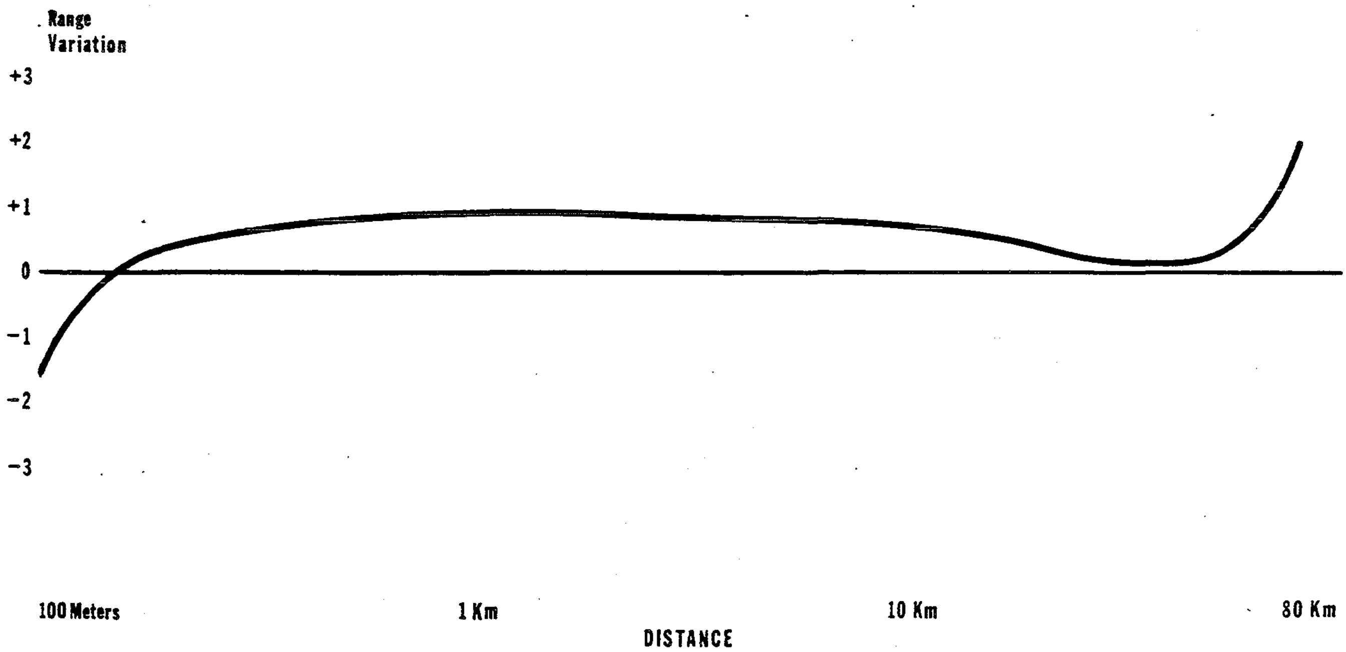
It has become obvious through these years of experience that there were other strong factors involved in being able to maintain the system accuracy as demanded by field operations. One of these is signal strength variations caused by operational conditions. Rain, high humidity, phase cancellation areas, and relative remote station location, i.e., one unit nearby and one far away, will cause these variations. Another factor is a highly congested radar environment and, finally, the ability to accurately determine a practical velocity of propagation.

Controlling these two major outside influences (unwanted RF signals and variation in signal strength) are items that must be accomplished through technology internal to the electronic system—automatically—since they present too many variables to an operator. In like manner, experience and actual field testing is demanded from any manufacturer in defining and reducing to practicality the velocity of propagation.

Literally volumes have been written on this subject. Laboratory tests can be made in an attempt to duplicate field operating conditions. However, a test range is required if empirical data is to be obtained. As a result of Trisponder field experience and testing, the Trisponder system produced today contains the most advanced capabilities available.

Within the Trisponder, the PRI generation and detection circuits are controlled by temperature





compensated crystals that are precise to the extent that 1 meter accuracies are possible. In actual operation, the Master T/R under control of the Distance Measuring Unit (DMU) generates a series of pulses using these precision circuits. Each Remote T/R, having its own particular PRI, will receive the interrogations from the Master and through its own detector circuits will test the incoming signal to determine if it is the proper code.

After successful tests (the incoming pulses from the Master must line up with the particular PRI to which each Remote is set), the Remote will generate (with the same precision as its detection circuits) that same PRI series of pulses back to the Master. The Master will then begin to detect the incoming signals from the Remote. After passing these tests, the Master instructs the DMU to perform "distance" calculations and output the valid information. In this manner, the logic circuitry, through which all signals must flow, performs the decisions as to their "validity".

Only identified, valid pulses are used to establish range data. Large variations in pulse amplitude (or signal strength) occur in these pulses. Excessively strong signals can cause the receiver to be over-driven or weak signals to go undetected, and frequently this does occur in other systems. These variations in signal strength are manifested by unstable data or the complete loss of data at a most critical time.

Del Norte's answer to this undesirable variation in pulse strength is Synchronized Pulse Amplitude Control (SPAC). Within the Trisponder, the amplitude of only a valid signal is expressed as a voltage and fed back to the receiver section of the T/R unit. This voltage is then used to control the receiver gain so that only the needed amplification is used. This allows the acceptance of weak signals that would otherwise be lost and likewise prevents saturation of the receiver. The sample-and-hold circuit controlled by the ranging signal decoding circuits permits automatic compensation to achieve quality range data. Even the non-technical operator is assured of valid range data without the necessity of costly and time-consuming post-operation analysis.

Separately from both the above safeguards, it is still vitally necessary to have the proper value for the velocity of propagation of the RF signals. Through years of worldwide experience it has been shown that you must go beyond lab conditions to accurately define the value of R in the equation D=RxT.

A test range has been established with irrefutable survey points providing various known distances out to 80km. This range has been used to establish, under true operating conditions, the velocity of propagation as used in the Trisponder system. It has also proven the effectiveness of the logic and amplitude control circuits. The above graph is typical of data accrued on the test range. It shows the Trisponder data to be well within our specified 3 meter accuracy.

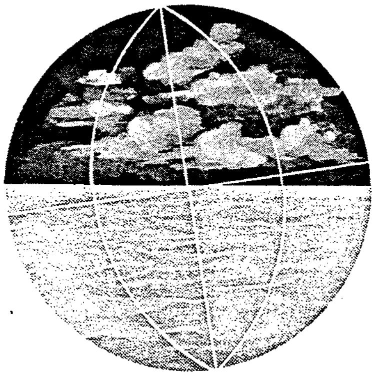
Benefits received by you from Trisponder systems are:

A. High immunity to noise capture.
B. Automatic compensation of data output and rejection of invalid data.
C. Increased stability of range data.
D. Coding accomplished without pulse ambiguity.

®Registered trademark of Del Norte Technology, Inc.

DEL NORTE Technology, Inc.

1100 Pamela Drive, P.O. Box 696, Euless, Texas 76039
Phone AC 817 267-3541



DEL NORTE

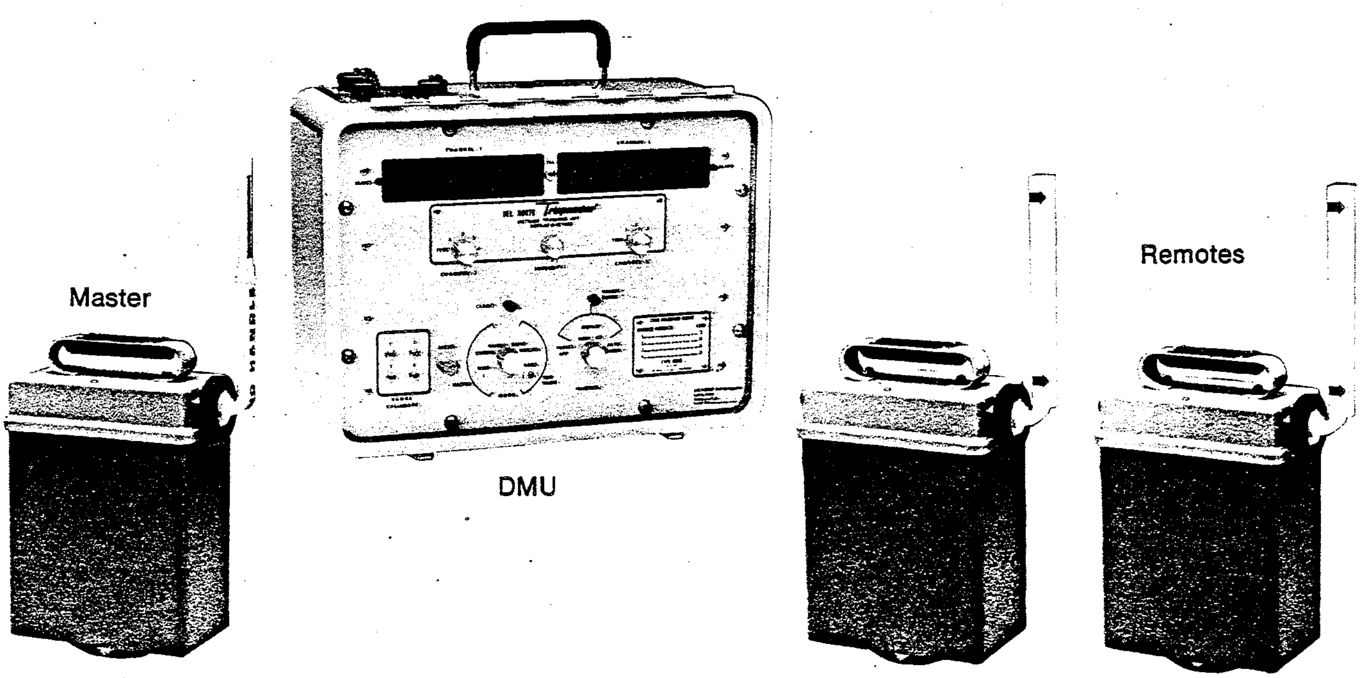
Trisponder®

with dual & multichannel control

for accurate positioning of air, sea, and land vehicles

- 80 km range
- 0.5 meter resolution
- ±3 meter accuracy
- battery operation
- field maintainability
- rugged waterproof construction
- measurements in feet or meters
- simple, automatic operation
- immunity to interference
- 10/100 sum digital averaging
- specialized gain control circuitry

Using advanced microwave and digital techniques, the Trisponder provides accurate line-of-sight distance information from a Master to two or more Remote stations. Distance is obtained by measuring the round-trip travel time of signals transmitted between the Master and Remote. Then, 10 or 100 path lengths selected by digital filtering are averaged to determine each distance displayed. Ranges are obtained in a matter of milliseconds, thus providing an accurate track of boats, trucks, helicopters, aircraft, and other moving vehicles. Optional accessories may be added to provide a wide range of sophisticated features.



DEL NORTE

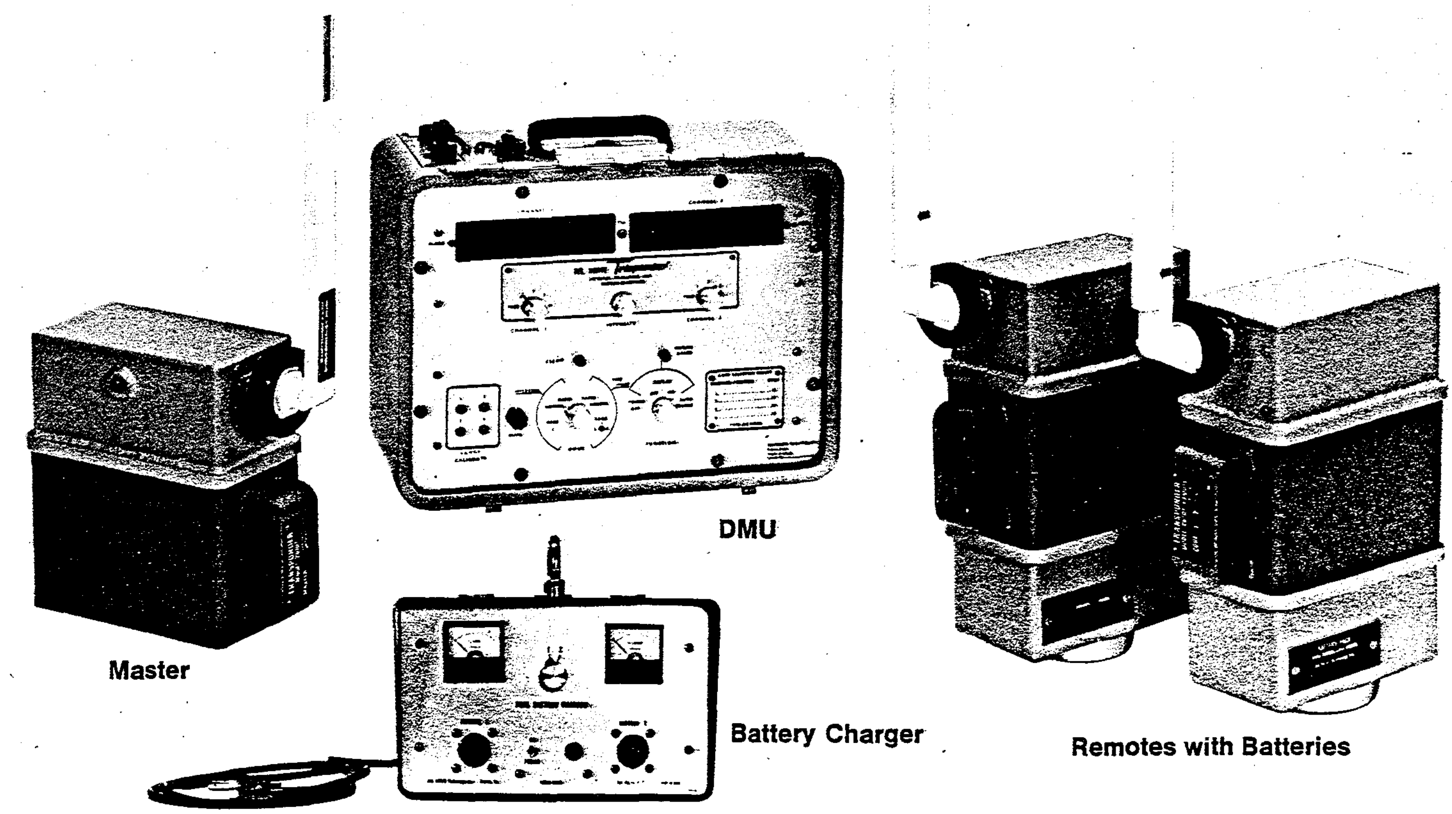
Trisponder SSX

All solid state transponders provide one-meter accuracy for improved position location

- **1 meter accuracy**
- **5 km range**
- **0.1 meter resolution**
- **self-contained rechargeable battery operation for remotes**
- **rugged waterproof construction**
- **100/1000 sum digital averaging**

With the introduction of all solid state transponders; Del Norte has once again brought the microwave positioning field another step forward. Yet this highly portable system is still easily maintained in the field. A solid state transmitter replaces the usual magnetron resulting in a much lower power drain. Self-contained batteries allow the remotes to operate some 10 hours before requiring a recharge.

Trisponder SSX also means instant on — no time delay for filament warmup. This makes the same simple automatic operation for which Trisponder is so well known, even simpler. Come to SSX for solid, dependable performance.



Master

DMU

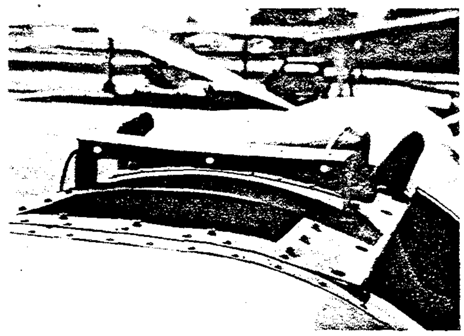
Battery Charger

Remotes with Batteries

DEL NORTE TECHNOLOGY, INC.
1100 Pamela Dr., Euless, Texas (817) 267-3541

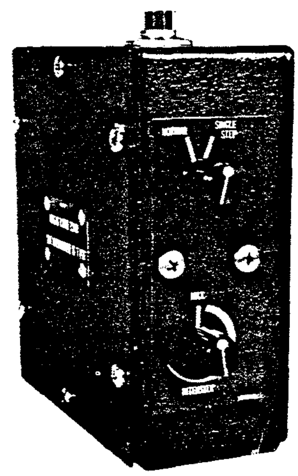
Optional Equipment

Lite-Bar Steering Indicator



The Del Norte LITE-BAR is an optional accessory used with the Flying Flagman system to provide easy-to-read steering information for night operations. It consists of a row of lights with green on the right, red on the left and amber center and end marker lights. The lights are housed in a flat waterproof enclosure normally mounted on the nose of the aircraft. The Del Norte LITE-BAR encourages pilots to keep their "heads out of the cockpit" while giving them the precise steering information they need. Depending upon mounting position on the cowling, the LITE-BAR may also be used for daylight operations.

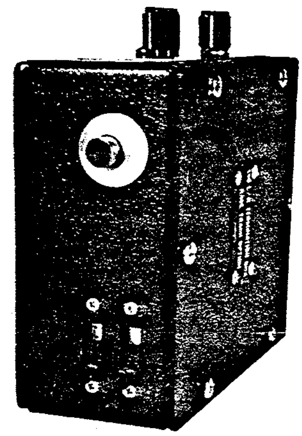
Chaining Program



The Del Norte CHAINING PROGRAM is an optional accessory used with the Flying Flagman system to provide a means of measuring regularly spaced intervals along a desired ground track. The interval is selectable between 50 feet and 9990 feet. An electrical signal is provided at the selected interval and may be used to fire a chaining stake, operate a camera, etc. An interval counter also is provided in the control box. The CHAINING PROGRAM may be used with any length swath and with any desired spacing between swaths within the normal operating limits of the Flying Flagman system. An electrical position output suitable for recording on magnetic tape is a standard feature. The CHAINING PROGRAM can be installed in both fixed wing aircraft and helicopters.

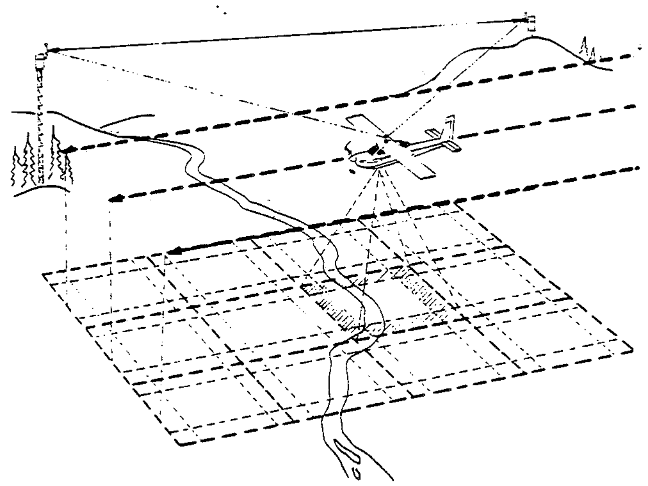
Racetrack Pattern Control

The Del Norte RACETRACK CONTROL is an optional accessory used with the Flying Flagman system to provide the pilot with a simplified means for flying a racetrack type of pattern. The equipment consists of a small control box on which the pilot can select the spacing between the opposite sides of the racetrack pattern. The RACETRACK CONTROL works with the Flying Flagman steering needle to provide guidance along the two sides of the racetrack pattern. A single push on the RACETRACK CONTROL button progressively moves the RACETRACK PATTERN across the field. This equipment is especially suitable for use with the larger, faster, turbo-powered aircraft because it increases their accuracy and efficiency by minimizing their non-production maneuvering time.



X-Y Orientation

The Del Norte Flying Flagman equipment has available an alternate method of system orientation. The X-Y ORIENTATION option provides a pilot with the ability to preset the location of up to four ground transponder locations and up to four operational points, using surveyed positions coordinates for these eight positions. Map coordinates may be used if less positional accuracy is acceptable. The Flying Flagman steering needle will then guide the pilot to any of the four operational points or between any two of them. The pilot may select and use any pair of ground transponders and may select different transponders at any time.



The ability to pre-program a specific ground track very precisely makes this option particularly suitable for the following types of work:

1. Geophysical Surveys
2. Photogrammetry
3. Laser or Photobathymetry
4. Forestry Surveys and Treatment

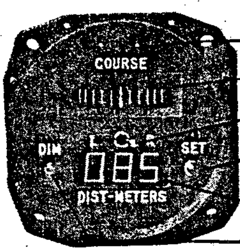
PRINTED IN USA

1M3-79-OD

Motorola Mini-Ranger Airborne System Operating Instructions

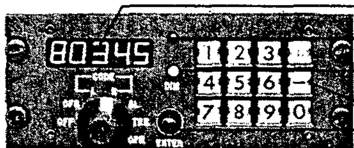
SYSTEM SET-UP

AUTOMATIC STEERING INDICATOR (ASI)



NOTE: ASI course deviation meter has 3 sensitivities: When both auto ranging lights are on, the scale is 300 m/div. with one light on the scale is 30 m/div. with both lights off the scale is 10 m/div.

CONTROL DISPLAY UNIT (CDU)



1. SYSTEM TURN ON

Make sure aircraft power is on. Turn function select switch on CDU to "OFS". The system warms up in one minute.

2. ENTER SWATH WIDTH

With function select switch in "OFS" position, first press the "CLR" key on the keyboard then the swath width (in meters). Press the "ENTER" button to record the swath width in memory. The entered numbers appear on the CDU digital display.

3. OFFSET DIRECTION

The offsets to the left of the direction in which the **initial track** is flown are entered as positive. Offsets to the right of the **initial track** direction are entered as negative. The "-" (minus) key must be pressed after the "CLR" key and before the offset distance.

4. ENTER REFERENCE STATION CODE NUMBERS

With function select switch in "CODE L" position press the "CLR" key, the code number of the left side station then the "ENTER" button. The left side is determined by looking from the work area to the baseline. Similarly with the function select switch in the "CODE R" position, the right side station code is entered.

5. ENTER BASELINE LENGTH - KEYBOARD METHOD

If the baseline length (distance between the two applicable reference stations) is known, it can be entered in the following way: Place function select switch in "BL" position, press the "CLR" key, press the keys corresponding to the baseline length (in meters), then press the "ENTER" button.

6. ENTER BASELINE LENGTH - FLY-BY METHOD

If the baseline length is not known, it can be entered by flying directly over either reference station. With the function select switch in the "BL" position, press the "CLR" key. With the aircraft directly over the reference station, press the "ENTER" button. The baseline length will appear on the CDU display.

7. ENTER DIRECTION OF INITIAL TRACK

With the function select switch in the "TRK" position; press the "CLR" key then align the aircraft down the track. Make sure the CDU alarm light is **off** and the characters E1 appear on the CDU display, then press the "ENTER" button near the start of the track, the characters E2 should then appear on the CDU display. Press the "ENTER" button again near the end of the track.

NOTE:
Do not press the "CLR" key between E1 and E2 entries.

The straight line defined by the two entries is the **initial track.**

NOTE:
Initial track can be flown at any angle to the baseline.

The system will not indicate the start or end of the track.

8. STEERING SENSE CONVENTION

The ASI meter sense switch controls the direction of the meter needle deflection. With the switch in the right position, the aircraft must be steered towards the needle to get on track when flying in the same direction as the initial track was flown. When flying in the opposite direction, it is necessary to place the switch in the left position for the meter to sense the same way.

INSTALLATION

1. RANGE PROCESSOR

Requires 12-30V, 100W DC power, is 18" X 5.5" X 17", weighs 25 lbs.

2. CONTROL DISPLAY UNIT (CDU)

Powered by connecting cable to Range Processor. Standard 5.75" X 2.25" X 7" aircraft instrument housing, weighs 2 lbs. Instrument panel installation as close to ASI as possible.

3. AIRCRAFT STEERING INDICATOR (ASI)

Controlled by connecting cable to Range Processor. Standard 3" diameter X 5" aircraft instrument housing, weighs 1 lb. Installed in or above instrument panel as close to operator's line of vision as possible without obstructing view.

4. RECEIVER/TRANSMITTER (R/T)

Connected to Range Processor with thick cable. Weighs 5 lbs. and must be located as close as possible to the antenna. 5.5" X 6.5" X 9.25". Connected to the antenna with a coaxial cable.

NOTE: Care must be taken to not bend the cable or connectors since this is the signal link from the antenna.

The R/T has two brackets to be used to attach it to the airframe.

5. ANTENNA

Connected to the R/T with coaxial cable, the antenna placement on the aircraft is critical. 8.5" long and about 2" wide and 0.5" thick. It must be mounted on the aircraft exterior in a position to maintain **line-of-sight** with **both** reference stations during operation. Loss of line-of-sight with either reference station will result in loss of steering information to the pilot. This is no problem if the signal loss is temporary, but prolonged loss of information will negate the use of the system. The antenna must be rigidly mounted on both ends of the attached mounting bracket.

MOTOROLA

Mini-Ranger Position Determining Systems
8201 East McDowell Road
Scottsdale, Arizona 85252
Telephone (602) 949-3181

SYSTEM OPERATION

1. SYSTEM OPERATION
With the function select switch in the "OPR" position, the steering indicator wil be centered on the initial track.

2. POSITIVE OFFSETS
To move one swath width to the left side of the **initial track** direction, press the "ENTER" button once.

NOTE:
The Function Select switch must be in the "OPR" position.

If the second track is flown in the opposite direction from the **initial track**, it will be necessary to change the "METER SENSE SWITCH" on the ASI in order to maintain the steering sense. Each time the "ENTER" button is pressed, the ASI meter will center one additional swath width to the left.

The CDU display will show the total number of offsets from the **initial track**, the **initial track** being offset 0.

3. NEGATIVE OFFSETS
To move to the right side of the **initial track** direction, it is necessary to enter a negative offset (see Item 3 of the System Set Up) and proceed as with a positive offset.

4. TO DECREMENT OFFSETS
If it is desired to offset in the direction opposite from that entered, press the "-" (minus) then the "ENTER" button (while the function select switch is in the "OPR" position). Both the "-" and the "ENTER" button must be pushed for each offset decrement desired.

5. TO CHANGE SWATH WIDTH
Turn function select switch to "OFS", press the "CLR" key, the new swath width (in meters) and the "ENTER" button. Turn the function select switch back to "OPR".

NOTE:
Press "-" key before the swath width entry for a negative offset.

6. DISTANCE TO INITIAL TRACK
Turn the function select switch to "TRK" to display the perpendicular distance from the current flight path to the initial track.

7. TO CHANGE INITIAL TRACK
Repeat No. 7 in System Set-up procedure. It may be necessary to change the offset sense if it is different from previous set up.

8. TO CHANGE BASELINE
Repeat steps 4 and 5 or 4 and 6 of the System Set-up procedure. It will be necessary to enter a new initial track.

9. POSITION "SET" FEATURE
To interrupt flight for reloading or refueling, press the "SET" button on the ASI to record the location in memory. To return to the location, use the ASI meter auto range feature: Once the meter needle is centered with the auto ranging lights off, the aircraft is on the right track. The ASI Digital Distance Display will display the distance to the "SET" point. When the aircraft gets within 5 meters of the "SET" point, the ASI Digital Display will go blank.

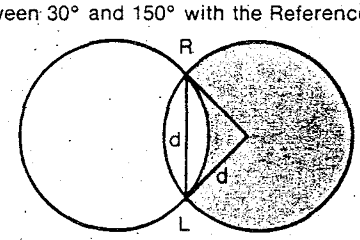
REFERENCE STATIONS

1. POWER REQUIREMENTS
Each reference station requires 24V DC and a maximum of 25W. This power can be provided by using two 12V lead-acid batteries in series or a 24/28V aircraft battery. In regular use each battery charge should last about 4 days.

2. RANGE
The standard 13 dB antennas can provide coverage for up to 20 nautical miles provided line-of-sight is maintained. This necessitates raising the R/T and/or reference stations a combined distance of 200 ft. above ground level to obtain full range. The omnidirectional antenna on the R/T has a 25° vertical pattern and the 13 dB sector antennas on the reference stations have a 75° azimuth and 15° vertical pattern. This necessitates some care in "aiming" the reference stations at the work area.

3. LINE-OF-SIGHT
The system works at C-band (5400-5600 MHz). It cannot "see" through obstructions or around corners. Loss of line-of-sight will result in a lost signal. Although the system will continue to function in this condition, it will not provide steering indication until the signal is reacquired. *SEE TROUBLESHOOTING SECTION FOR IDENTIFYING LINE-OF-SIGHT LOSS PROBLEMS.*

4. GEOMETRY
System reproducibility is rated at ±1meter. Each swath will be within 1 meter of the next. This error is noncumulative. In order to maintain reproducibility, the R/T must maintain an intersection angle between 30° and 150° with the Reference Stations.



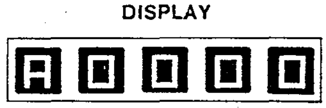
This diagram illustrates the pattern of the optimum geometric work area for the system. The line "d" between the two reference stations is the **BASELINE**. Its length can be between 200 yards and ten miles for the standard system. The limits of the optimum area of operation are defined by the circle whose radius is "d" as shown by the shaded region of the diagram. Each point on the circle's perimeter forms a 150° angle of intersection with the reference stations, each point on the perimeter of the football shaped intersection forms a 30° angle with the reference stations. Both intersecting circular areas can be covered from one pair of reference station sites but the stations must be aimed to cover either the left or the right area.

5. CODING
Each reference station has a code number between 1 and 4. These numbers identify the pulse code of the individual station. The system will work only with stations of different codes.

TROUBLESHOOTING

1. If the ASI cannot provide good steering information due to signal loss, both auto ranging lights come on and the word "OFF" appears in the ASI digital display.

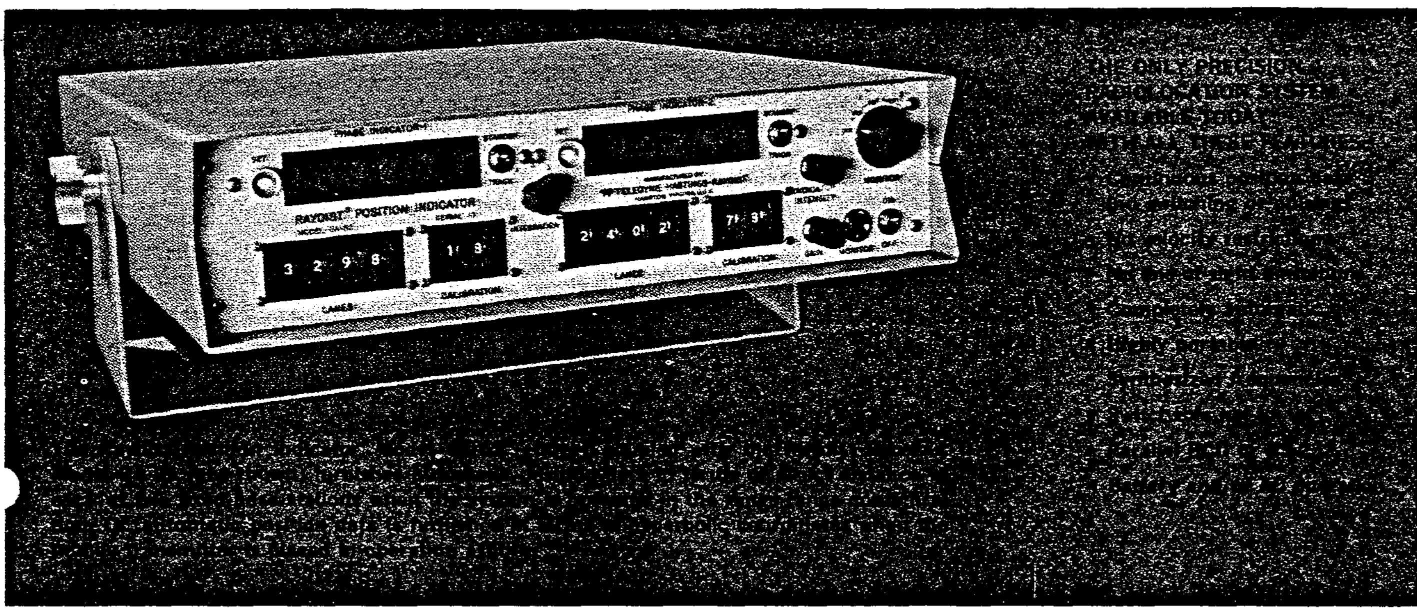
2. The CDU digital display will provide information on the specific problem, while in the "OPR" mode by displaying the following codes:

DISPLAY	PROBLEM	PROBABLE CAUSE
	Loss of signal from right side reference station	1. Loss of line-of-sight 2. Low batteries or power interruption
	Loss of signal from left side reference station	Same as above.

TELEDYNE HASTINGS-RAYDIST
Hampton, Virginia 23661 (804) 723-6531

RAYDIST DRS-H SYSTEM

Limited-User Range-Range, or Unlimited-User Hyperbolic System for Marine and Aircraft Use.



RAYDIST DRS-H SYSTEM

The new Raydist DRS-H System is a compact, lightweight, battery-powered radiolocation system which can be transported and installed in a matter of minutes in almost any location. This system has the same high accuracy and provides the same completely automatic operation as earlier Raydist Systems.

Virtually an all-weather system, the Long-Range DRS-H Raydist System operates over sea water at ranges in excess of 250 miles during daylight and 150 miles at night. The Medium-Range DRS-H Raydist System, utilizing the same electronic components as the Long-Range System, operates with a shorter antenna and lower transmitter output power to provide ranges up to 75 miles or more. Yet the entire system, complete with antennas* and batteries, can be carried easily in an automobile, aircraft, helicopter or small boat. Both systems are powered by two ordinary automobile batteries or other convenient 24-volt dc source. Solid-state inverters to provide 24-volt dc power from 115-volt ac power are available.

Raydist DRS-H provides a choice of two forms of position information; either range-range (circular) or hyperbolic coordinates. Both the range-range mode and the hyperbolic mode (along the base lines) provide sensitivities of 1/3 meter and over-all accuracies of a few meters. The choice of the type of operation depends on the user's specific application.

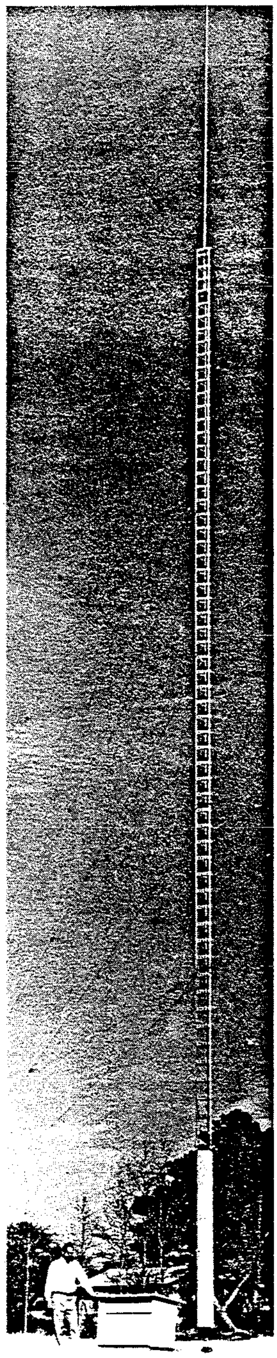
In the range-range mode, up to four users can operate simultaneously in the DRS-H System. Further, employing simple circular patterns, better intersections are obtained with a greater coverage area in the range-range mode. The range-range mode provides longer ranges seaward utilizing only two shore based stations. Transmissions occur only between the mobile stations and each base station. Therefore, the base station sites can be selected without concern for terrain or intervening coastline. To plot a position, one has only to swing two arcs, using the base stations as centers, and the two Raydist ranges as radii. The intersection of these two arcs provides an accurate position fix.

In the Hyperbolic mode, precision position data is available to an unlimited number of users simply by installing the mobile transmitter at a shore location. This provides two hyperbolic base lines, one between the shore based mobile transmitter and each of the two base stations. In this mode, a 22-inch "voltage probe" antenna can be employed on marine vessels or aircraft, eliminating many of the installation problems of larger antennas on small boats and aircraft. Since no transmission is required from the user vessel, the chance of interference with other user equipment is minimized.

The change from range-range to hyperbolic operation requires no equipment modification inside the base stations or the mobile equipment. The Raydist Position Indicator automatically provides either range or hyperbolic position data depending on the mode used. Thus, the user can change operational modes rapidly and economically depending upon specific work requirements.

By using single-sideband techniques, only two frequencies are needed. This feature conserves the radio frequency spectrum and also makes the system much less susceptible to interference.

*47-foot antenna



MOBILE EQUIPMENT

Lightweight Raydist mobile equipment consists of the Navigator, a CW Transmitter and a small Strip Chart Recorder. The Receiver measures 16" x 14" x 5" and weighs approximately 15 pounds. The CW Transmitter, usually located close to the antenna, measures 18" x 15" x 12" and weighs 37 pounds. The Strip Chart Recorder measures 7" x 8" x 17" and weighs approximately 15 pounds. Total power required is less than 7 amperes at 24-volts DC.

Modular construction permits immediate replacement of a faulty component in the field by relatively unskilled personnel. All solid-state electronic design and encapsulation techniques provide the highest degree of reliability.

Further important savings result from reduced transportation costs, reduced installation and maintenance time, and the elimination of complex data reduction.

RAYDIST BASE STATIONS

Each base station is a single unit which needs only to be connected to the batteries and antenna. The lightweight weatherproof unit measures 18" x 15" x 12" high and weighs only 45 pounds. The range of the system depends on antenna height and power output levels. Depending on the antenna installation, the system provides a medium-range operation up to about 75 miles or a long-range operation up to 250 miles or more.

The 47-foot antenna for medium-range operations consists of a 35-foot telescopi- aluminum whip with two 6-foot extensio. weighing 25 pounds. The guys and ground system weigh 85 pounds.

Power is supplied by two conventional automobile type storage batteries or other suitable 24-volt source. Long-range operation requires approximately 2½ amperes battery drain. For short ranges, the equipment may be operated at reduced output to conserve battery life.

Raydist long-range (100 feet) antenna installation with equipment shelter.

Raydist is available for immediate sale or lease for use anywhere in the world.
For information, write, phone, or cable:

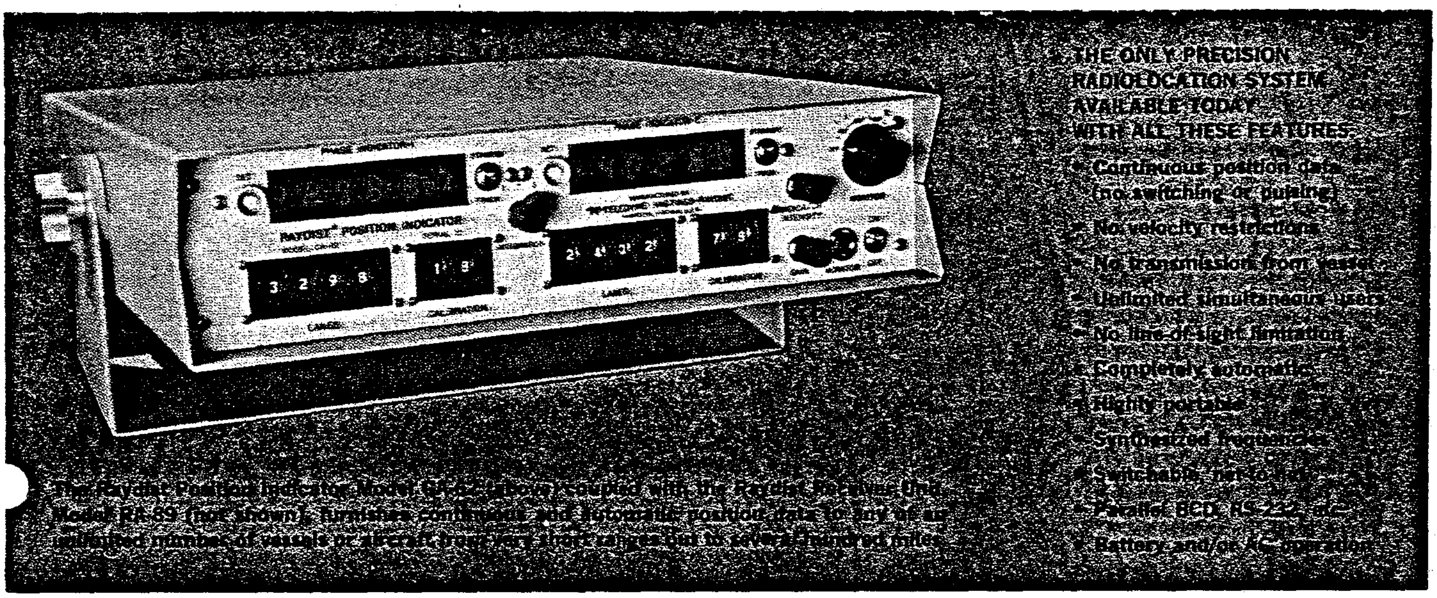
TELEDYNE
HASTINGS-RAYDIST

P.O. Box 1275, Hampton, Va. 23661 USA
Telephone: (804) 723-6531
TWX: (710) 882-0085 CABLE: HASTRAY

TELEDYNE HASTINGS-RAYDIST
Hampton, Virginia 23661 (804) 723-6531

RAYDIST "T" SYSTEM

Unlimited-User Precision Navigation and Radiolocation System for Marine and Aircraft Use.



RAYDIST "T" SYSTEM

The Raydist "T" Radionavigation System is specially adapted to accommodate an unlimited number of users operating simultaneously in the same network. It is capable of providing precise radiopositioning and radionavigation data continuously 24 hours per day with a sensitivity of approximately 0.5 meters, a repeatability of approximately 2 meters and a geographic accuracy of approximately 3 meters.

Unlike some other radionavigation systems, the Raydist "T" System is not limited to line-of-sight operations nor by vehicle speed, acceleration, or maneuvering. System accuracy is maintained well beyond line-of-sight and under all conditions of vehicle motion.

The Raydist "T" System determines position by the phase comparison of continuous-wave signals in the HF radio frequency band. To achieve the highest accuracy, the utmost reliability and freedom from line-of-sight limitations, Raydist utilizes two very narrow-band frequency allocations in the HF band. The base station network consists of two single-sideband stations and two continuous-wave stations. Additional stations may be added to extend the system or to provide additional coverage.

Each station is assembled as a single, portable unit which needs only to be connected to batteries and to an antenna. Long-range stations employ 100-foot vertical aluminum antennas and 100-foot radial ground systems. All stations are 100% solid-state and are designed to operate unattended for long periods of time. The very low cost and small size of the base station electronics permit the installation of complete duplicate electronic units at each of the four transmitting sites so that in the event of malfunction, network operation can be restored immediately by simply switching to the alternate unit.

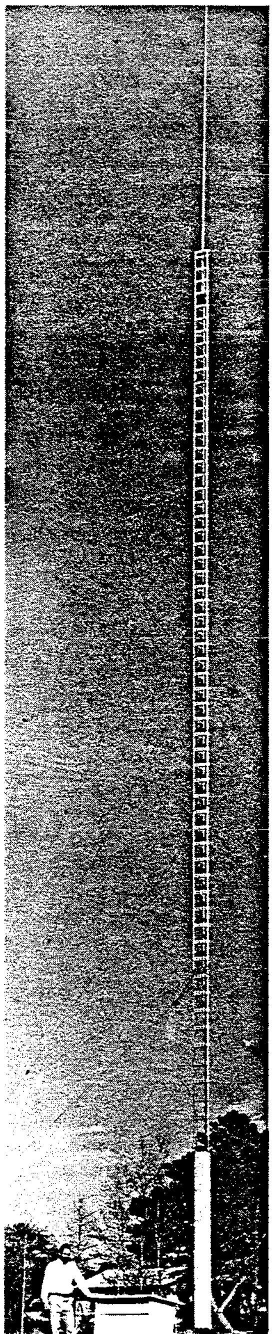
The Raydist "T" System allows up to four independent lines of position (LOP's) to be determined simultaneously. Use of these additional LOP's provides confirmation of position, increased reliability, and in many cases, lane identification.

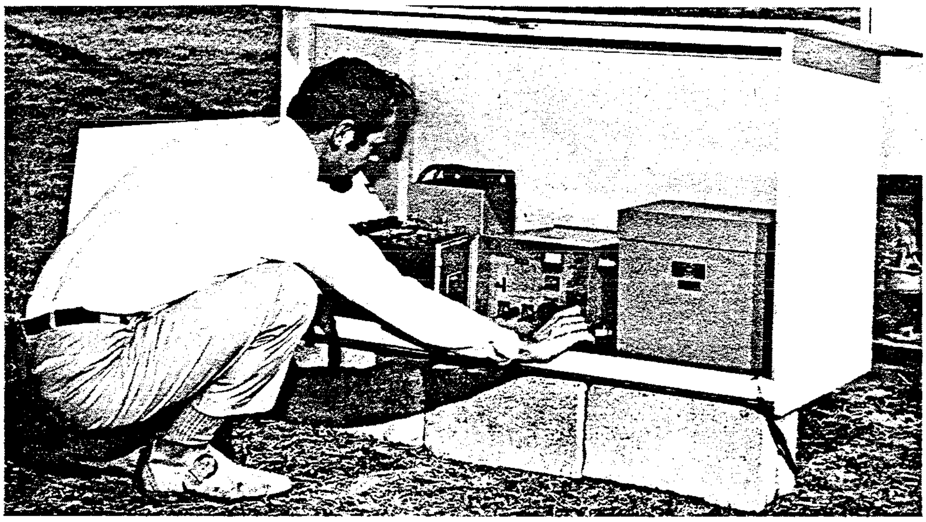
The Raydist "T" System now has been in wide use for a number of years. The Chesapeake Bay Raydist "T" System has been in operation since 1970. The National Oceanic and Atmospheric Administration (NOAA) has used Raydist "T" extensively aboard NOAA vessels RUDE and HECK for wire drag operations.

The U.S. Coast Guard has evaluated Raydist "T" and concluded that "...a properly configured Raydist "T" System can provide an excellent precision location system suitable for Coast Guard use in most any area of operation served by buoys."

The U.S. Army Aeromedical Service has employed Raydist "T" since 1971 aboard helicopters engaged in testing a pilot's flying capabilities under various test conditions.

Raydist "T" has also been used extensively by the U.S. Navy Mine Countermeasurers Helicopter Squadron (HM-12). Operations have been conducted in the vicinities of Norfolk, Va., Charleston, S.C., and San Diego, CA., the Gulf of Mexico, the Philippines and Hawaii, as well as in actual minesweeping assignments in North Viet Nam and in the Suez Canal.





MOBILE EQUIPMENT

The lightweight Raydist "T" mobile installation consists of the Receiver, Position Indicator, Strip Chart Recorder, and a small antenna. The Receiver measures approximately 16" x 14" x 5" and weighs approximately 16 pounds. The Position Indicator measures approximately 16" x 14" x 4" and weighs approximately 15 pounds. The Strip Chart Recorder measures 7" x 17" x 8" and weighs approximately 15 pounds. Most installations utilize a vertical whip antenna or a smaller "voltage probe" antenna.

Total input power at 24 v. d-c is approximately 1.8 amperes so that the entire shipboard installation may be solely battery operated for extended periods of time or may be operated continuously from an a-c converter.

The complete installation may be made easily and quickly, in many cases, less than an hour.

BASE STATIONS

Each base station is packaged as a single, lightweight, weatherproof unit which needs only to be connected to an antenna, ground system and a 24 v. d-c power source. These highly-portable base stations are equally well-suited to both short and long range applications, up to 250 miles or more, depending on the type of antenna used and adjustment of power output levels.

The 47-foot antenna for medium-range operations consists of a 35-foot telescopic aluminum whip with two 6-foot extensions weighing 25 pounds. The guys and ground system weigh 5 pounds. For long-range operations, a 100-foot sectional aluminum antenna weighing 120 pounds is used. The guys and ground system weigh 85 pounds.

Power may be supplied by two conventional automobile-type storage batteries, a thermo-electric generator, or from a 115/230 v. a-c to 24 v. d-c converter. For short ranges, the equipment may be operated at reduced output to conserve battery life.

Raydist long-range (100 feet) antenna installation with equipment shelter.

DIGITAL & OPTIONAL ACCESSORIES

Raydist is available for immediate sale or lease for use anywhere in the world.
For information, write, phone, or cable:

TELEDYNE
HASTINGS-RAYDIST

P.O. Box 1275, Hampton, Va. 23661 USA
Telephone: (804) 723-6531
TWX: (710) 882-0085 CABLE: HASTRAY

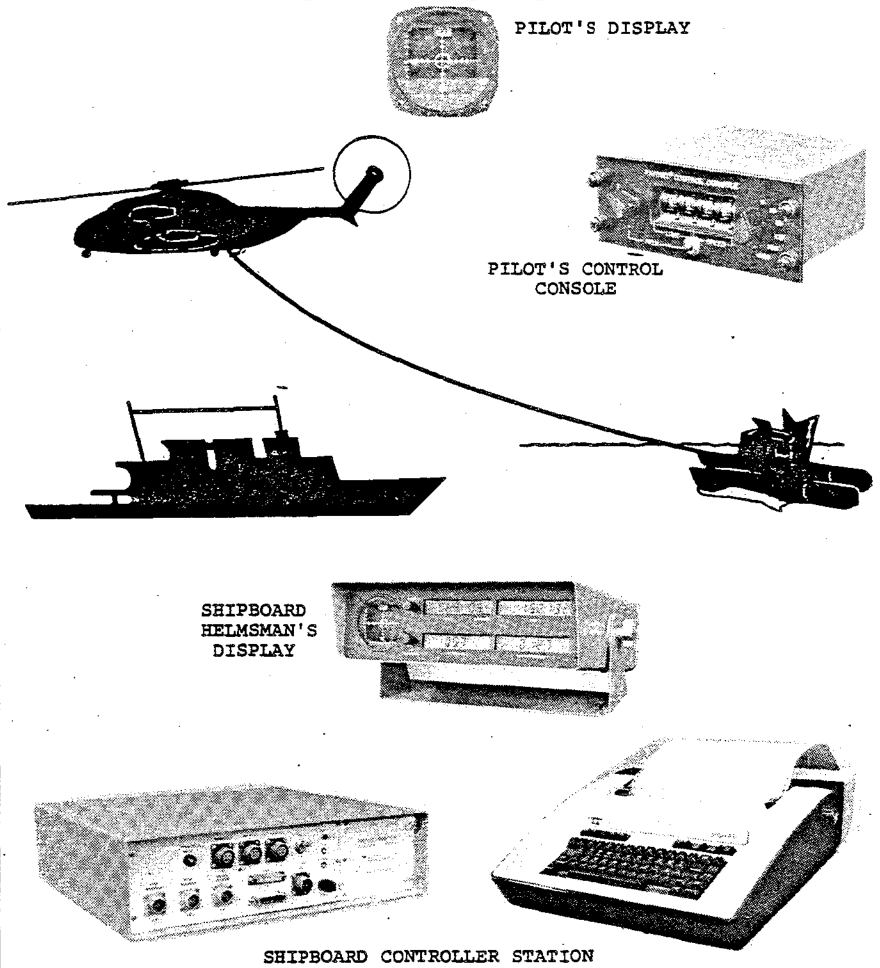
Printed in U.S.A.

TELEDYNE
HASTINGS-RAYDIST

DS-373

Raydist Director System

Microcomputer guidance system for airborne and marine operations.



- FULL CONTROL at Director's station
- Illuminated pilot's or helmsman's display
- Complete capability for survey patterns including "dogleg" courses
- Pre-plot and post-plot capabilities
- Deviation from desired track and speed
- Continuous position data relative to survey area inside or outside area
- Undistorted plot of "track made good" to any desired scale
- Information to helmsman and survey chief easily tailored to individual requirements
- Director System will accept external inputs and will output total real time data to an automatic track plotter, printer, remote indicator, paper tape punch, or magnetic tape recorder.

Raydist Director System

The new Raydist Director receives data from any Raydist Navigator to provide fully automatic guidance information to the survey chief, helmsman, or pilot. The system can be used for surface or airborne operations for hydrographic, geophysical surveys, magnetometer surveys, gravity surveys, mine sweeping operations, airborne agricultural operations, search and rescue missions, etc. The unit contains a built-in microcomputer, and can be programmed ashore or afloat to provide complete guidance information and recording data in any form.

The shipboard controller's station includes the Director, containing the microcomputer and program cassette, and the teleprinter which provides a permanent record of all input/output data. In the airborne version, a compact panel instrument gives the pilot a heads-up display of deviation from the desired survey line, deviation from a desired speed, relative position in or out of the survey area, plus controls for line number and operating speed, illumination, and L/R sensitivity.

In the shipboard version, the variably illuminated helmsman's indicator displays deviation from the desired course line, bearing of the desired course line, deviation from the desired speed, time of day, line number (and line segment where "dogleg" courses are involved), and time remaining before the next turning point.

RAYDIST DIRECTOR SYSTEM

SPECIFICATIONS

	DIRECTOR	TELEPRINTER	HELMSMAN'S DISPLAY	PILOT'S DISPLAY	PILOT'S CONTROLLER
INPUTS	Incremental signal from Raydist Navigator	Director and keyboard	Director	Director	Director
SIZE	5½"H X 19"W X 14"D	5½"H X 18"W X 21½"D	4"H X 14"W X 8"D	3½"H X 3½"W X 6"D	2"H X 5"W X 4"D
WEIGHT	23 lbs.	30 lbs.	9 lbs.	7 lbs.	2 lbs.
POWER	2 amp @ 28 vdc	115 vac, 50/60 Hz	28 v, 0.3 amp	28 v, 0.25 amp	28 v, 1 amp

USAGE

As an automatic guidance and real time plotting system for practically any type of survey or reconnaissance mission where a desired survey pattern is required; with the highest degree of accuracy, efficiency, and safety.

INPUTS

The Director accepts position data from any Raydist Navigator or Position Indicator operating in any of the several Raydist configurations (DRS-H, T, TRAK III, etc.). Access to the minicomputer is provided through the teleprinter keyboard and program cassette.

OUTPUTS

A permanent printout of all input/output data is provided at the terminal while the heads-up display gives the pilot or helmsman all the information necessary to steer the vessel or fly the aircraft. The plotter output is available as a real time aid in evaluating the progress of the survey.

The Raydist Director System is designed for use in any of the several Raydist System configurations and can easily be adapted to existing systems.

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POSITION FINDING SYSTEMS & EQUIPMENT DATA

NAME AND MODEL	The Raydist DRS-H System
MANUFACTURER	Teledyne Hastings-Raydist Hampton, Virginia 23661 (U.S.A.)

OPERATING CHARACTERISTICS

PRINCIPAL APPLICATION	Hydrographic Surveys, Channel Surveillance, Dredging Operations, Buoyage Maintenance, Aerial Surveys, Photo Mapping, Oil Well Location, Drilling Operations, Ecological Studies, Marine Life Studies.
OTHER USES	Buoy tending, check/implant aids to navigation, search & rescue.
NORMAL PLOTTING TYPE(S)	range-range.
OPTIONAL PLOTTING TYPE(S)	Hyperbolic, Hyperbolic-Elliptical, and HALOP
TRANSMISSION TYPE	CW (AO) and SSB (A2h).
MEASUREMENT TYPE	Continuous phase measurement. Two or more position coordinates in lanes. Lane width approximately 45 meters in areas of best geometry.
FREQUENCY	1600 to 4500 kilohertz.
SPECTRUM USAGE	Typical system requires only two narrow band frequency allocations, one occupying 150Hz and a second occupying 1.4kHz.
EQUIVALENT SPECTRUM USAGE	Continuous operation of CW and SSB stations.
APPROXIMATE RANGE	DAY: 500 kilometers; NIGHT: 250 kilometers over sea water.
RESOLUTION	0.01 lane (Approximately 1/2 meter in areas of best geometry).
TYPICAL ACCURACY	Repeatability approximately ±0.02 lanes (approximately ±1 meter). [redacted] Accuracy not affected by vehicle speed.

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LANE WIDTH	Approximately 45 meters in areas of best geometry.
USERS PER SYSTEM	Up to 4 in range-range mode. Unlimited number in hyperbolic mode.
SUSCEPTIBLE TO STATIC OR SKYWAVE	Low susceptibility to static and skywave due to continuous signal transmission and very narrow band characteristic of system. Skywave (if present) fluctuates very rappidly and is readily filtered out.
PRESENTATION OF DATA	(1) visual digital display; (2) electrical digital output (BCD, RS232, etc.); (3) printed paper tape; (4) punched tape; (5) magnetic tape; (6) track plotter; (7) lane follower (left/right); (8) strip chart line recording.
MANUAL/AUTO	Automatic tracking.
AUTO-STEERING, ETC.	Manual or automatic steering can be provided through a programmed computer so that a predetermined pattern can be undertaken with automatic control of the vessel through an auto-pilot.
AMBIGUITIES	One per lane.
HOW RESOLVED	(1) Continuous operation from a known starting point; (2) Use of redundant Raydist data and computer program; (3) Satellite system to resolve Raydist lane ambiguity.
TIME TO TAKE FIX	Instantly and continuously available.
SPECIAL CHARTS	Circular grid charts for range-range operations or hyperbolic charts for hyperbolic operations can be drawn by hand or by suitably programmed digital plotters.
AVAILABILITY OF DATA	100% duty cycle. No pulsing, no time-sharing, no synchronization of stations.
SPECIAL FEATURES	Electronics housed in light weight aluminum cases; easily transported by one man in rugged padded shipping cases. All powered from 24VDC or commercial AC power with suitable DC converters. Long range operations with low input power.

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COUNTRIES/CONTINENTS	Raydist systems are in extensive use in all continents. Use includes Arctic, Temperate, and Tropical areas.
SPECIFICATIONS	Designed to withstand environmental extremes of temperature, humidity, and vibration using the latest encapsulation techniques. Modern electronic circuitry using only silicon semi-conductor and integrated circuit construction. Exclusive use of top quality proven components provides high reliability and low maintenance. Base stations can be used for hyperbolic operation without modification. System provides specified accuracy at all speeds, including supersonic.

PHYSICAL CHARACTERISTICS OF LAND BASED EQUIPMENT

NUMBER OF STATIONS TRANSMITTING	Two stations per system in the range-range or three stations per system in hyperbolic. Additional stations may be used to provide additional coverage or redundant data.
OUTPUT POWER TO ANTENNA	CW: 40 watts average; SSB: 10 watts average.
TRANSMITTER PRIMARY POWER	CW transmitter 5 amps @ 24 volts DC; SSB transmitter 2.75 amps @ 24 volts DC.
NUMBER OF OPERATORS FULL TIME	None. All base stations operate unattended. No network synchronization required.
RADIO PATH BETWEEN LAND BASED STATIONS	None in range-range mode. Baseline transmissions required in hyperbolic mode only.
WEIGHT OF EQUIPMENT PER CHAIN (Including Power Supplies)	Complete Long-Range System (2 ranges) packed for air shipment (including antenna towers) 1192 lbs. (540 kg). For hyperbolic operation, an additional antenna tower is required.
PORTABLE READILY	Yes.
TIME TO SET UP CHAIN	1/2 day per station (3 men).

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