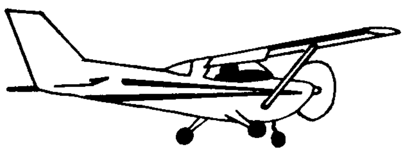
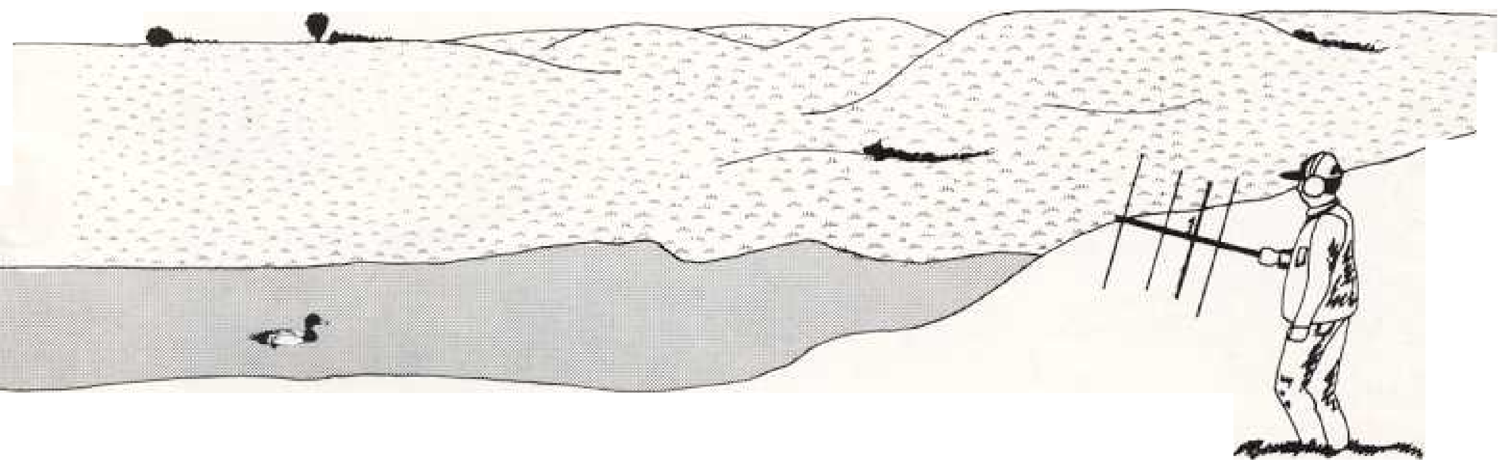
Resource Publication 140

MAY 1981

Procedures for the Use of Aircraft in Wildlife Biotelemetry Studies





Fish and Wildlife Service

U.S. Department of the Interior

PROCEDURES FOR THE USE OF AIRCRAFT IN WILDLIFE BIOTELEMETRY STUDIES

By David S. Gilmer
Lewis M. Cowardin
Renee L. Duval
Larry M. Mechlin
Charles W. Shaiffer
V. B. Kuechle

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Resource Publication 140
Washington, D.C. • 1981

Preface

Much of the knowledge and experience acquired by biologists who have used aircraft in biotelemetry studies has been inadequately documented. Procedures have been largely passed on by word of mouth between researchers. Consequently, little information is available in the literature to persons interested in these methods. In the present work we have attempted to assemble, in a logical sequence, guidelines that will aid the biologist who plans to use aircraft for tracking radio-marked animals. The information provided here is based on extensive testing of equipment and methods during telemetry studies of waterfowl in Minnesota, North Dakota, and California. Although our experience has been primarily with waterfowl, we believe that most of the information presented here could apply equally well to biotelemetry studies of other kinds of animals. Developments in new electronic technology, including the use of satellites for tracking animals ranging over vast areas, hold great promise for revolutionizing telemetry studies. However, these capabilities are not yet available to most wildlife biologists. In the meantime, the methods described in this paper will provide guidelines for the use of aircraft in biotelemetry studies.

Procedures for the Use of Aircraft in Wildlife Biotelemetry Studies

by

David S. Gilmer,[1] Lewis M. Cowardin, Renee L. Duval,[2]
Larry M. Mechlin, and Charles W. Shaiffer

U.S. Fish and Wildlife Service
Northern Prairie Wildlife Research Center
Jamestown, North Dakota 58401

V. B. Kuechle

Cedar Creek Bioelectronics Laboratory
University of Minnesota
Bethel, Minnesota 55005

Abstract

This is a report on the state of the art methodology and on questions that arise while one is preparing to use aircraft in a biotelemetry study. In general the first step in preparing to mount an antenna on an aircraft is to consult with a certified aircraft mechanic. Aircraft certification is discussed to provide background information concerning the role of the Federal Aviation Administration (FAA) in regulating the use of biotelemetry antennas on aircraft. However, approval of any specific design of antenna mount rests with local FAA authority. Airplane and helicopter antenna attachments are described. Performance of the receiving antenna system is discussed with emphasis on how variables as aircraft type and antenna configuration may influence reception. The side-looking vs. front-looking antenna configuration and the VHF vs. HF frequency band are generally recommended for most aerial tracking studies. Characteristics of receivers, transmitters, and antennas that might influence tracking are discussed. Specific topics such as calibration of receivers and transmitter quality control are considered. Suggestions in preparing for and conducting tracking flights that will improve overall efficiency and safety are presented. Search techniques, including procedures for conducting large and specific area surveys as well as methods to improve and evaluate search efficiency, are discussed. A concluding section considers special topics such as low-level operations and the use of helicopters. Diagrams of antenna mounts, equipment check-off lists, and antenna test procedures are included as appendices.

Aircraft have played an important role in wildlife management and research for over three decades (Crissey 1949), and are currently being used with increased frequency as a vehicle for tracking a wide variety of radio-marked animals (Cochran 1965, 1972; Graber 1965; Cochran et al. 1967; Kolenosky and Johnston 1967; Seidensticker et al. 1970; Mech et al. 1971; Dunstan 1974; Mech 1974; Hoskinson and Mech 1976; Kirby et al. 1976; Storm et al. 1976; Gilmer et al. 1977; Judd and Knight 1977; Weeks et al. 1977; Winter et al. 1978; Cederlund et al. 1979). The ability of an aircraft to rapidly survey large or inaccessible areas gives it an advantage over other mobile tracking units. In addition, the reception of radio signals from an airborne platform is enhanced because of the nearly line-of-sight relation between transmitter and receiver.

Procedures for the use of aircraft in tracking operations were described by Kolenosky and Johnston (1967), Seidensticker et al. (1970), Mech et al. (1971), Mech (1974), and Dunstan (1974). These procedures dealt mostly with ways in which an aircraft can be equipped with receiving antennas and used to search for radio-marked animals. Optimum search procedures are largely dependent on terrain and habitat features and animal mobility, as well as on equipment and type of aircraft. Experience of the observer–pilot crew is also an important factor (Hoskinson 1976).

[1]Present address: Wildlife Research Field Station, U.S. Fish and Wildlife Service, Route 2, Box 5210, Dixon, California 95620.

[2]Present address: U.S. Fish and Wildlife Service, Lloyd 500 Building, Suite 1692, 500 N.E. Multnomah Street, Portland, Oregon 97232.

The intent of the present report is to supply biologists with guidelines for conducting airborne biotelemetry operations and provide a basis for making decisions regarding the installation of antennas, aircraft certification, telemetry system characteristics, preflight planning and safety considerations, search techniques, and methods for evaluating search efficiency.

Aircraft Certification

Most investigators conducting telemetry studies do not have access to permanently assigned aircraft but must charter or lease available aircraft during the field season. Consequently, it is desirable that a suitable antenna system be quickly and easily attachable to an aircraft without requiring permanent structural alteration. It is imperative that the antenna and mounting bracket not interfere with aircraft controls, reduce the strength of the airframe, or adversely affect flight characteristics.

United States Federal Aviation Administration (FAA) Regulations require that any major alteration to an aircraft be accomplished in accordance with technical data approved by the FAA Administrator. Two methods of approval are (1) the Supplemental Type Certificate program and (2) field approval by an airworthiness inspector at a General Aviation District Office. Attachment of tracking antennas to an aircraft would generally be considered a major alteration. However, it is possible that tracking equipment could be classified as a minor alteration depending on the shape of the antenna assembly, its weight, and placement. Aircraft with attached biotelemetry antennas, of the types described in the present paper were operated in accordance with the terms of a Special Airworthiness Certificate (FAA Form 8130-7) in the Restricted Category for a special use as described in FAA Regulations 21.25 (2)(b). For biotelemetry operations the special use would be "Forest and Wildlife Conservation."

When a decision is made to use aircraft in tracking operations, several steps should be followed to obtain FAA certification of the aircraft. As a first step, the biologist should consult with an FAA Certificated Airframe Mechanic at a local airport (preferably the Fixed Base Operator providing the aircraft) to discuss antenna requirements and the feasibility of mounting antennas on available aircraft. If the mechanic considers the desired antenna system to be a minor alteration, he is authorized to approve the equipment for use on an aircraft.

If the antenna system is classified as a major alteration, the mechanic will prepare the appropriate request (FAA Form 337) for authorization of this alteration. The form, which is usually prepared for a specific aircraft, describes how the equipment is installed and removed, what type of hardware is required, material specifications, and weight and balance data. The FAA General Aviation District Office serving the area reviews these forms. If the antenna system meets preliminary FAA requirements, the mechanic is notified and requested to arrange for an FAA representative to inspect the installation on the aircraft.

If the installation passes the field inspection, an FAA Form 8130-7 is issued for the aircraft. Certification of several aircraft should be requested, to insure that an authorized aircraft is always available when tracking operations are scheduled. The pilot of the aircraft is usually responsible for insuring that all safety and procedural requirements are followed whenever the antennas are attached.

If the FAA inspector feels that the antenna installation is too complex to approve in the field and will require evaluation by FAA engineers, he will provide guidance on this procedure.

This outline of the sequence of events is provided so that the biologist has some idea of the requirements. The important point is that the biologist should consult with a qualified airframe mechanic as the first step in using telemetry antennas on any aircraft.

The ultimate purpose of the certification procedure is to protect the pilot and tracking crew. Should an accident occur and the insurance inspector determine that proper certification was not obtained, the insurance policy on the aircraft may be voided.

Aircraft owned, leased, or rented by the U.S. Government and by State agencies are considered "public aircraft" and are not required to obtain airworthiness certification for alterations caused by mounting tracking antennas. However, aircraft owned and operated by the U.S. Department of the Interior (DOI) are required to obtain certification for alterations caused by mounting tracking antennas. Furthermore, tracking installations on DOI aircraft are subject to approval by the Office of Aircraft Services. We strongly recommend that the above certification procedures be followed, regardless of aircraft ownership.

Regulations governing aircraft certification procedures in foreign nations may be different from those in the United States. Appropriate regulations or authorities should be consulted in each situation.

Considerations for Antenna Mounting

The primary criterion for the design of a mount for a biotelemetry antenna on an aircraft is the development of a safe, secure system that satisfies airworthiness requirements. Of secondary importance is positioning the antenna so as to reduce any distortion to its directionality and sensitivity.

The size of the receiving antenna depends on the frequency and gain requirements of the equipment. Because higher frequency (VHF and UHF) equipment requires smaller antennas, it is more desirable for use on aircraft than low band (HF) equipment. Yagi antennas designed to receive signals at frequencies as low as 140 MHz are practical for use on aircraft, but lower frequency yagis are often unwieldly and usually require loop antennas. Our experience in tracking from an aircraft is based primarily on 164 MHz equipment which is commonly used in a wide range of telemetry studies. Frequencies in this band are assigned to some government agencies within the DOI, including the Fish and Wildlife Service. The primary antenna described in the present paper is the yagi mounted in a side- or forward-looking configuration. Judd and Knight (1977) and Seidensticker et al. (1970) reported on the use of a single antenna mounted through the belly of an aircraft, and Whitehouse and Steven (1977) described a monopole array that can be permanently installed on aircraft.

To attach the antenna to the aircraft, we designed a bracket that clamps to the wing strut of a high-winged aircraft (high-winged aircraft were generally better suited than low-winged aircraft for tracking work). This design enables the user to mount the antenna on most Cessna aircraft and to adjust the antenna in several axes (Fig. 1 and Appendix A). A simplified but less versatile mount was used on a Piper Super Cub.

Our antenna attachments were approved by the local FAA General Aviation District Office for specific aircraft. This approval does not insure that a similarly designed attachment would be approved by other FAA offices or meet more restrictive FAA guidelines.

Brackets made of aluminum stock with heliarc welds were attached by slipping the cuff over the wing strut and fastening it with bolts on the trailing edge of the cuff (Fig. 1 and Appendix A-1). Neoprene or naugahide padding was used to avoid scratching the paint on the wing strut. The bracket must be correctly positioned by sliding it up and down the strut, before the bolts are tightened. The shaft can be extended or retracted as desired after the bracket is secured.

On the basis of electronic tests, we considered the side-looking antenna correctly positioned when the tips of the middle antenna elements were about 15 cm below the leading edge of the wing and 30 cm forward of the wing. Right and left antennas are positioned similarly unless variations are needed to achieve a desired effect, such as a combination of forward- and side-looking configurations.

Coaxial cables can be led directly from the antenna to an air intake on the leading edge of the wing. A screen or filter may have to be removed from the intake pipe to allow the cable to be retrieved through the air vent in the cockpit. If air intakes are not conveniently located on the wing, the cable can usually be routed into the cockpit through a sliding window (Super Cub) or the door opening. If the cable is carefully placed, the seal around the door usually does not crimp the cable when the door is shut.

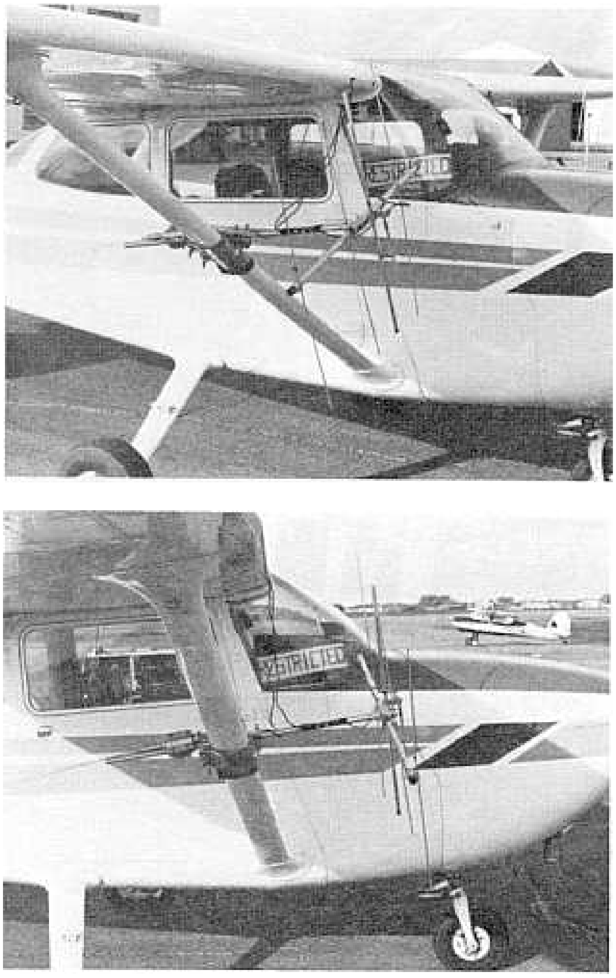


Fig. 1. Correct position of side-looking yagi antenna mounted on a Cessna 172. Front quarter view (top), side view (bottom).

Cables should be routed into the cockpit and secured so that they do not interfere with the pilot's activities or the aircraft controls. An experienced person usually requires only about 15 min to attach left and right antennas, route cables, and load equipment.

The design of an antenna mounting for a helicopter requires additional considerations of the variable wind and vibration forces that may exert pressure on the mounted structure. The proximity of main and tail rotors to the antenna necessitates that the structure be rigid and secure.

Fig. 2. Side- and forward-looking yagi antenna system designed for use on a helicopter (Bell 206B Jet Ranger). Rear quarter view (top), front quarter view (bottom).

The helicopter antenna mounting we used was designed for the Jet Ranger (Bell 206B) with high skids. It consisted of a single steel boom mounted forward of the fuselage, securely guyed and carrying both forward- and side-looking yagis (Fig. 2 and Appendix A-2). Coaxial cables were led into the cockpit through the door.

Performance of Receiving Antenna Systems

The directional pattern of an antenna mounted on an aircraft influences the efficiency and accuracy of tracking. We determined antenna patterns only for yagi and loop antenna systems commonly used in biotelemetry studies; tests of a wide range of receiving antenna systems, such as dipole and monopole arrays (see Whitehouse and Steven 1977) were not our intent. Furthermore, our test procedures were not conducted on an "antenna test range" designed for precise evaluations. Costs required to insure elimination of all potential errors are prohibitive. Nevertheless, we believe that our results provide a basis for considering the characteristics of several antenna systems. Accuracies of our measurements are well within tolerances acceptable in field studies. We examined five principal variables:

- Frequency—midfrequency of the transmitter–receiver system (30 MHz loop and 164 MHz yagi).
- Aircraft type—make and model of the aircraft used (Cessna 172, Cessna 180 with floats, Piper Super Cub PA-18).
- Antenna configuration—antenna orientation with reference to the direction of flight (side-looking, forward-looking).
- Antenna tilt—angle (depressed) measured between the horizontal and the antenna beam for the yagi side-looking configuration (0°, 15°, and 30°).
- Altitude—aircraft height above ground level (AGL); tests were conducted at 300, 600, and 900 m.

All tests were made with wing strut mounts (Fig. 1). Data runs were made with the aircraft flying in a level attitude.

Before airborne tests were conducted, static tests were made on the ground to determine the best way to position the side-looking yagi array relative to the aircraft wing. Readings of voltage standing wave ratio (VSWR; an index of the mismatch of a line of load—the higher the mismatch, the higher the standing wave ratio; if a load is properly matched, the standing wave ratio is 1) were lowest when the antenna was positioned with the top of the elements about 15 cm below the undersurface of the wing and about 30 cm forward of the leading edge of the wing (see also AVM Instrument Co. 1979). No significant improvement in VSWR was noted until the antenna was removed so far from the vicinity of the wing that safe attachment was precluded.

To facilitate the measurement process with AC-powered test equipment, we conducted the airborne tests in reverse, i.e., the transmitter was in the aircraft and the receiver was on the ground. The antennas normally used for receiving remained on the aircraft and were used as the transmitting antennas. Procedures used in these tests are described in Appendix B.

All measurements were relative: an arbitrary standard level was chosen and all measurements were compared with this level. This technique eliminates the need for an absolute standard, eliminates any inaccuracies that may arise in the receiver system, and tends to reduce sight errors. The antenna patterns are the same for relative or absolute measurements. It is

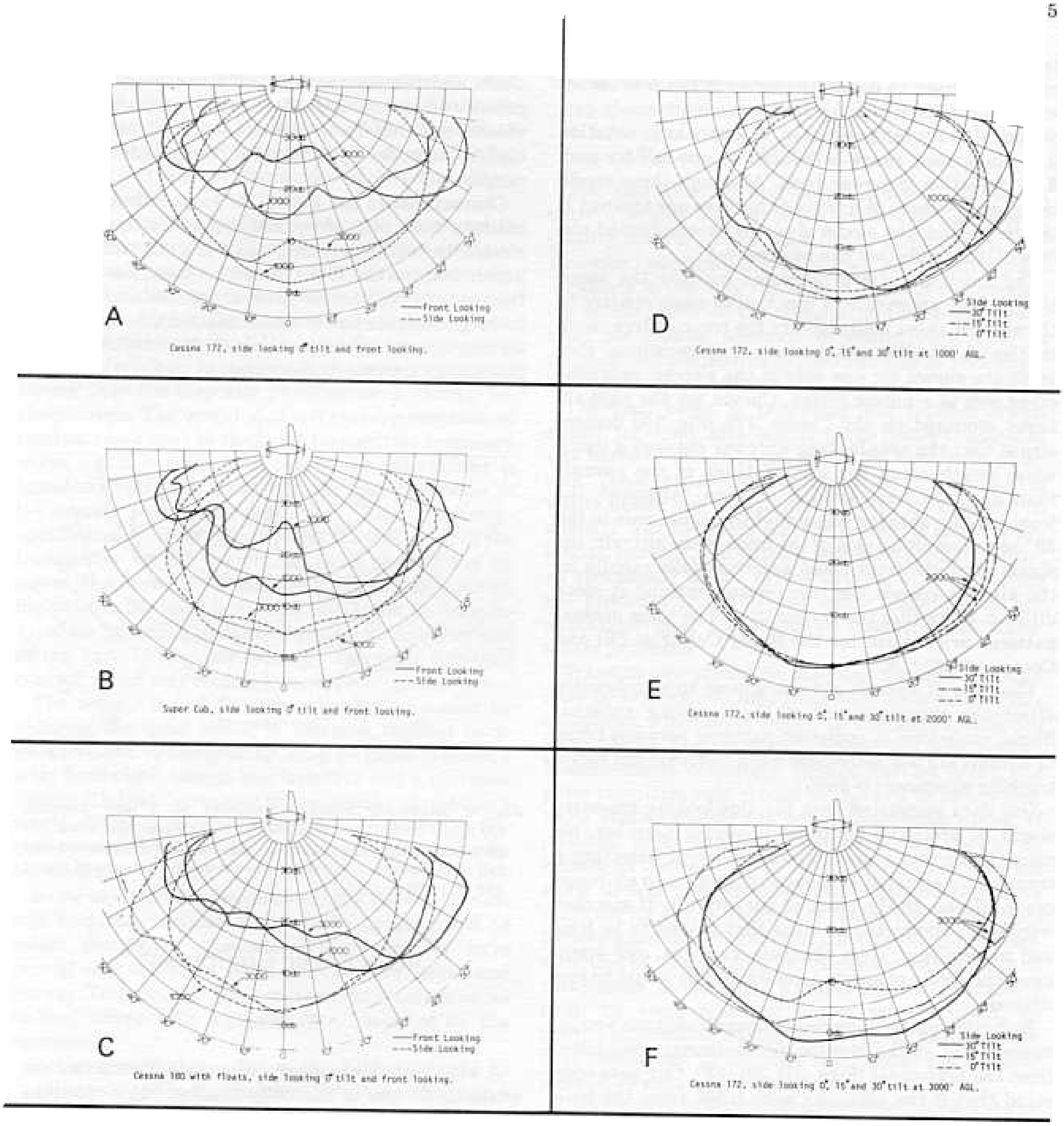


Fig. 3. Receiving antenna patterns of a yagi array system (164 MHz). Readings were not obtained within the sector 20° either side of the nose and tail of the aircraft. Aircraft were flown at altitudes of about 300, 600, and 900 m AGL.

the sensitivity of the antenna system in any given direction in relation to its maximum sensitivity that is important in determining placement and tracking procedure. This sensitivity is indicated in decibels (db), a power ratio term (db = 10 log [power received/maximum power received]).

The results of antenna tests are plotted in Figs. 3 and 4. The degrees on the outer arc indicate the angular bearing measured from a line perpendicular to the flight path. The numbers on the inner arcs indicate the decibels below the maximum level for that test. These curves can then be used to indicate the antenna pattern. The half-power points (i.e., 3 db) on a pattern are commonly used to define the antenna beam or sector width, since path loss for free space is inversely proportional to the range squared. If logarithmic notation (i.e., db) is used, range is reduced by one-half for each 6 db reduction in power level. Although these conditions are not those of free space because one antenna is on the ground, the model gives an uncomplicated picture of the trends that can be expected.

The antenna pattern diagrams indicate the sensitivity of the antenna as a function of angle relative to the aircraft. Also indicated are the comparative sensitivities of the different antenna configurations. Patterns are shown for one side of the aircraft only; the other side is a mirror image. Curves for the yagi antenna mounted on the Cessna 172 (Fig. 3A) demonstrate that the side-looking antenna surveys a much wider swath along the ground track of the aircraft than does the front-looking antenna. Although the front-looking antenna has a slightly higher gain in the 30° sector on either side of the front of the aircraft, the signal strength from these antennas falls rapidly as the aircraft passes the transmitter, making it more difficult to localize the transmitter. The same general patterns are evident for the Super Cub (Fig. 3B) and Cessna 180 (Fig. 3C).

The type of aircraft did not appear to significantly affect the characteristics of the receiving antenna. Slight variations in radiation patterns between types of aircraft are not detectable when conventional radio-tracking equipment is used.

Our data suggested that the side-looking antennas would be preferred for tasks involving searches, because there was a greater probability of detecting a transmitter situated at maximum ground to air range perpendicular to the track of the aircraft. If searches were to be conducted in areas that tended to be long and narrow (e.g., river channels, canyons, and drainages) the choice of antenna configuration would be less critical.

Radiation patterns varied as aircraft altitude was increased and as the side-looking antennas were tilted from the horizontal (Figs. 3D, 3E, 3F). Our data indicated that if the antennas were tilted from the horizontal, the radiation pattern was expanded but the gain was reduced. Optimum amount of tilt depended to some extent on altitude. Average radiation patterns improved somewhat as tilt was increased from the horizontal. The optimum tilt was about 15° when altitude was 300 m AGL. The maximum gain was not increased at altitudes higher than 300 m AGL. However, our tests were conducted in open areas without obstructions between transmitting and receiving antennas. Higher altitudes would probably increase sensitivity if the transmitters were located in a forested or mountainous region. Considering safety, visual detection of animals, time required for aircraft climb and descent, and disturbance to animals and persons on the ground, the 300-m level probably provides a suitable flying altitude for most work unless higher altitudes provide for increased detection ranges.

Characteristics for a 30-MHz loop antenna (Fig. 4) indicate that this array and frequency are less desirable for aerial tracking than the yagi array and higher frequencies. If the researcher must use this low-frequency range because of other constraints, the side-looking configuration or a combination side- and front-looking system would probably be the best choice, for the reasons previously described.

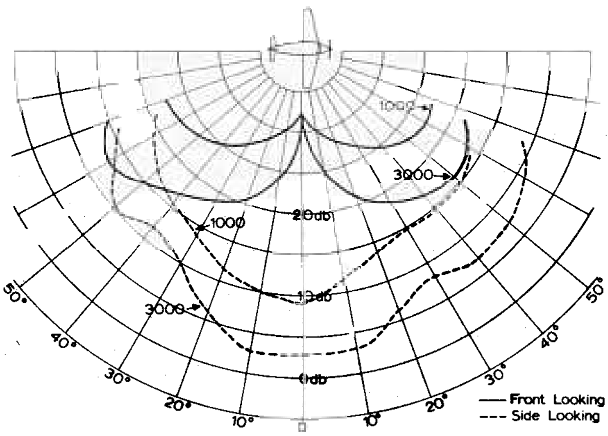


Fig. 4. Receiving antenna patterns of a loop antenna (30 MHz) mounted on a Super Cub. Readings were not obtained within the sector 20° either side of the nose and tail of the aircraft. Aircraft was flown at altitudes of about 300 and 900 m AGL.

Electronic Equipment

Receivers

A wide variety of makes and models of receivers are available for use in telemetry studies. Most receivers are of either a continuous-tune or frequency-synthesized design. Many of the early receivers were of the continuous-tune type, where tuning was accomplished as in a car radio. As a means of providing a finer tuning capability, receivers were developed with detent tuning where one knob was used to step-tune a part of the band and a continuous fine-tune knob was used to tune across the step. The accuracy of the frequency setting of the continuous-tune receiver was a function of dial backlash, dial resolution, and temperature dependence of the oscillator frequency. These variables generally reduced the dial accuracy of the continuous-tune receiver. In spite of these difficulties, this type of receiver is effective in two situations: (1) when transmitter frequency drift makes the use of other receivers impractical, or (2) when one wishes to search an entire frequency band without regard to specific frequencies (i.e., the exact frequencies of the transmitters are unknown).

Frequency-synthesized receivers were developed to improve frequency stability. All frequencies originate from a single quartz crystal, which has excellent temperature and time-frequency stability. The frequencies are stepped across the band with a digital control, usually at intervals of 1 KHz. Most frequency-synthesized receivers also have a fine-tune control that allows tuning over the step and provides some overlap between steps. The operator of a frequency-synthesized receiver must tune to the exact transmitter frequency if the signal is to be detected. When the receiver is tuned to a particular frequency, the operator knows he is exactly on that frequency. The frequency-synthesized receiver requires that the frequency of the transmitter remain within the band pass of the receiver. If it is suspected that the transmitters are drifting outside the band pass, this drift must be compensated for by tuning to digital frequencies on either side of the expected frequency or by using the fine-tune control, which may cause a loss of operator efficiency.

The sensitivity of a receiver can be increased by reducing the band width to decrease thermal background noise. A compromise must be made between a wide bandwidth that is less sensitive and a narrower bandwidth that increases the probability of missing a signal. Thus, as the bandwidth is narrowed, the frequency stability of the transmitter and receiver becomes more critical.

Some new receiver designs include a memory circuit and frequency scanner that can be programmed to select designated channels. These features have proved very useful for aerial searches (see Search and Survey Techniques). The programmed receiver tunes to each channel for a "dwell time" selected by the operator.

Before a receiver is used in the field, it should be "calibrated" to the transmitters, which are fitted on a mock-up animal. This procedure should be repeated when the transmitter is fitted to the animal, just before the animal is released. For each transmitter, the frequency indicated on the receiver should be recorded, along with the transmitter frequency provided by the manufacturer. This procedure will indicate whether the receiver tends to read high or low and will be useful in calculating "corrected" frequencies that increase probability of signal detection.

A log book should be maintained for each receiver, indicating the date of purchase, repair work done, calibration information, serial numbers, modification, and any other information that may be useful in the maintenance and operation of the unit.

Transmitters

The dependability and performance of the transmitters largely determine the success of the project. Quality control in the selection of components, construction, encapsulation (potting), and testing pays dividends in the long run. Few biologists can oversee the construction of the transmitters they use. However, the careful selection of components such as crystals and transistors is the first step in creating a dependable transmitter.

The final steps in producing the finished transmitter, including attachment of the battery, antenna, and harness, and potting, should be done with great care. These steps should be completed at least several weeks before the transmitters are to be attached to animals. The batteries and the materials used for antennas, harness, and potting should be of high quality, all thoroughly tested before batches of transmitters are produced. An untested minor modification has sometimes been the source of unanticipated transmitter problems.

Transmitters should be accepted for field use only after laboratory and field tests have been successfully completed. Final tests should be conducted when the transmitters are completely assembled and potted. Measurements of battery voltage, current drain, and pulse repetition rate should be checked to insure that these characteristics are within acceptable limits. If possible, units should be energized and allowed to remain on the shelf for at least several days, because some defects may develop after transmitters have operated for only a short time. Three other tests help to determine the reliability of the transmitter: (1) construction of temperature vs. frequency curves for each transmitter, to indicate if a unit is subject to excessive drift; (2) some measurement of power output, to predict transmitter range; and (3) range checks under field conditions, to simulate transmitter range under essentially actual field situations.

Careful records should be maintained for each transmitter indicating the type of transmitter, materials used in potting and in the construction of harness and antenna, other characteristics of the transmitter, and the results of each test.

Antennas

There are many types of antennas in use for transmitting and receiving. A discussion of the design and characteristics of several important antennas used in biotelemetry work was presented by Amlaner (1980).

Antenna elements and booms are constructed of aluminum tubing and have a finite fatigue life due to flexing stresses which may be accelerated by vibration caused by use on aircraft. It is recommended that only new antennas be used on aircraft and that after one field season the antenna should be assigned to ground use only.

Equipment costs may appear to be a major expenditure of project funds. Nevertheless, the expenses of capturing animals and monitoring them usually represent an investment in cost that exceeds the expense of transmitters, receivers, and other electronic gear. The biologist should attempt to obtain only high-quality equipment that is designed to accomplish the objectives of the research. If funding is limited, quantity rather than quality should be sacrificed. Telemetry projects are expensive and should not be attempted unless adequate funding is available.

Preflight Preparations

A prerequisite for the safe and efficient use of aircraft in biotelemetry studies is careful preflight preparation. Preflight work should include at least four items: (1) planning the tasks to be accomplished during the flight; (2) discussing the flight with the pilot; (3) assembling the equipment needed; and (4) checking out all electronic gear.

A first step in planning the flight is the procurement of adequate maps of the area to be searched and the travel routes to and from the area. We recommend two sets of maps of the study area: one small scale (large area coverage) and one large scale. Aeronautical navigation charts show topography, prominent landmarks, and major road networks, and may be suitable for large area coverage. Large-scale maps of the study area should clearly define topographic features and other landmarks. Detail not required for position location is often confusing and should be eliminated. U.S. Geological Survey 7.5′ quad sheets, photo-reduced as necessary, may serve as good large-scale maps. A clearly defined grid coordinate system should be superimposed on the maps. Our experience has indicated that the Universal Transverse Mercater system (U.S. Department of the Army 1958) is ideal for biotelemetry projects. The large-scale maps of the study area should be produced in adequate numbers to allow the observer to record notes directly on the map and then file this map as a permanent record.

The area to be searched for radio-marked animals should be defined before the flight. If a large area is to be covered it may be desirable to designate units that can be effectively searched within an allotted time, considering en route time. The duration of the search should be estimated so that the adequacy of power supplies for the receivers and other portable electronic equipment, such as transceivers, can be determined. Alternate power sources should be carried if battery-powered equipment is operated over extended periods. Primary power sources should be fresh and fully charged at the start of an operation. Most receivers with an external power connection can use power derived from the aircraft if it is equipped with a 12-volt electrical system.

An up-to-date list of transmitter frequencies should be prepared. The last location of each animal should be recorded because it may be useful as the starting point for a later search. Previous movement patterns of animals should be considered when data on such movements are available. Data forms that enable the investigator to record information thoroughly and accurately, but with little writing, will allow more time for observation and receiver operation. All maps and data forms should be designed for convenient use in the confined space of the cockpit. Forms should be designed for lap-size clipboards, and maps should be usable while folded.

At some point in the preparation phase, the observer and the pilot should discuss the mission: the overall objectives; altitude requirements and maneuvering procedures; and hand signals between observer and pilot, if they are to be used. Operations in or near Restricted Areas (e.g., National Parks and Refuges), Military Operating Areas, and military bombing simulation routes (IR routes) should be considered and the appropriate authorities consulted. The local FAA Flight Service Station can provide guidance on who should be contacted. Travel routes to and from the study area should be defined. An alternative airport should be identified in the event that a return to the departure point is not feasible. A complete weather briefing should be obtained from the nearest aviation weather facility. The effect of weather on a survey should be considered.

Ground crews that will operate in coordination with the search aircraft must be briefed and rendezvous points and communication plans clearly established. An alternate means of communication between air and ground crew should be developed for use in case of radio failure.

The use of an equipment inventory, based on a checklist (Appendix C), is the best way to insure that all required items will be aboard the aircraft during the operation. Items such as pencils, cameras, and film can be easily overlooked until they are needed. If operations are conducted during cold weather or over rugged or remote regions, it is advisable to carry a survival kit if this equipment is not normally carried in the aircraft.

The final phase of the preflight preparation is a check-out of all electronic equipment. The antennas should be mounted and double checked for security and to insure that all cables are properly connected. The installation should be inspected by the pilot. If antennas are tunable, final adjustments should be made for optimum performance. Tracking crews should know how to operate complex electronic equipment before the flight. Training sessions for this purpose are highly beneficial. A test signal strategically located at the airport or on the study area should be used to insure that the receiver system is functioning properly.

The overall concern is to conduct a successful flight in the safest way possible. Attention to details is important. Adequate planning may require one or more hours for each hour of flight. Contingency plans should be prepared for any probable situation.

Search and Survey Techniques

The methods and equipment used in aerial searches depend on the design and purposes of the particular study undertaken. We discuss some of the various approaches that may be used and provide specific illustrations from waterfowl studies. The number of marked animals present on an area at any one time and the size of the area greatly influence the techniques to be used. Monitoring large numbers of individuals over a large area, particularly if the species studied is highly mobile, usually requires scanning receivers (described earlier). The species studied also influences the procedure used because some animals are confined to particular habitats, at least at some stage of their life. One of two techniques is usually employed: the biologist either goes directly to a specific area (last known location, specific habitat) to initiate the search, or searches a large area in some systematic fashion.

Searching Specific Areas

Search methods developed for specific tasks have been described by Kolenosky and Johnston (1967), Seidensticker et al. (1970), Mech et al. (1971), Cochran (1972, 1965), Dunstan (1974), Mech (1974), Hoskinson (1976), and Hoskinson and Mech (1976). In many studies the investigator may have reason to believe that an animal is more likely to be in one area than in another. Even for highly mobile animals like waterfowl, it is reasonable to begin a search at the last known location of the bird. Other information, such as the fact that a bird is nesting or has a brood, may further modify the search pattern. Once radio contact is made, the exact location must be determined.

The following instructions for locating and pinpointing waterfowl are based on our experience with birds that had been equipped with 164 MHz back-mounted transmitters having an air to ground range of about 9.6 km. We used a scanning type receiver designed and built at the Cedar Creek Natural History Area, Bethel, Minnesota, and a switch box that allowed the tracker to listen to one or both wing-mounted yagi antenna arrays.

The receiver operator begins the search with the switch box in the "both" position to cover the area on both sides of the aircraft (side-looking antennas) and the RF gain (adjustment for the sensitivity of the receiver) at the maximum position (signal strength may decrease when switch boxes of certain designs are used in the both position). Aircraft altitude was usually between 150 and 300 m AGL. If no signal is received at the last known location, a search of the local area is begun by flying transects separated by 1.6 to 3.2 km over the area until the signal is received or the available time is used up. (Although our measurements are given in the metric system, the English system is used in field work because of the convenience of using road networks, which are based on the rectangular land survey system commonly used throughout most of the United States.)

When the signal is received, the operator changes the control switch from the both position to the left and then to the right antenna to determine the direction of the transmitter from the aircraft. After the direction has been verified, he returns the switch to the both position and the aircraft is flown in the direction of the transmitter. This should cause a signal null (very little or no signal will be heard). As the aircraft gets closer to the transmitter, the signal strength increases until the operator can no longer null the signal. The aircraft is then close enough to start pinpointing the location.

The operator changes the switch box from the both position to the left and then the right position to determine the side of the aircraft on which the transmitter is located. If, for example, the transmitter is to the right of the aircraft, the operator chooses a section of land over which the pilot must make a right 360° turn with a 1.6-km radius. As the aircraft is making its turn, the switch is repeatedly transferred back and forth from the left to right antenna. If the signal remains strongest on the right antenna, the transmitter is within the 1.6-km circle. If the signal is stronger from the left antenna, the aircraft must move 1.6 km to the left and repeat the circling procedure. Once the location has been identified as inside the 1.6-km circle, the operator must reduce RF gain and volume on the receiver and have the pilot circle around various landmarks such as wetlands, stock dams, and brushy areas inside the 1.6-km radius. He then switches back and forth from left to right antenna, and should hear a strong signal from the right antenna and a weaker signal from the left side. As long as the transmitter is kept on the right side of the aircraft, he will receive a weak signal from the left side because that antenna is receiving the signal from the back of the antenna. When the signal strength (with the RF gain turned down), is about the same on both antennas while the aircraft is banked about 30° and in a 360° turn, the right wing of the aircraft should be pointing at the transmitter location.

The location determined in this manner is the best estimate of the location of the animal. In our application of the technique we frequently need greater precision, such as the location of a nesting hen, or visual contact with the bird to determine its status. The tracker in the aircraft then gives the ground crew a location where it can probably receive the signal, the bearing to the transmitter, and a description of landmarks and access routes. Once the ground crew picks up the signal, the aircraft proceeds to the next animal. Occasionally the animal moves while the ground crew is making its approach; assistance from the aircraft may then again be required.

Use of HF Loop Antennas in Searches

Bi-directional loop antennas characteristic of HF tracking gear require different techniques than those normally employed with directional yagi antennas. Some biologists have successfully used an HF system with a forward- and aft-looking loop in combination with a left- and right-looking loop. Both antennas were hooked into a switch box (W. E. Berg, personal communication). Experience was critical in obtaining good results with this system. Signals were often detected at greater than expected ranges by monitoring only the outside loop while the aircraft was in a turn.

Searches Over Large Areas

Some types of studies, especially those that require marking a large number of animals over a large area, frequently require different search techniques than those described above. These techniques may also be required when the original contact cannot be made by the specific area method because of the high mobility of the marked animal. Wide area searches are usually made by flying a pattern of parallel flight transects and using a scanning receiver. We have used the following procedures to determine the most efficient search design. Width of the transect is determined by the maximum signal range that can be reliably detected for the weakest transmitter of those to be used in the field. Signal range is measured perpendicular to the aircraft track and parallel to the ground. To determine the number of animals that can be searched for, the operator uses the equation $NC = MD \times 3600/SR \times GS$, where NC = Number of channels programmed; MD = Minimum parallel detection distance (miles, kilometers, or nautical miles; units of distance and speed used for MD and GS must be consistent); SR = Receiver scan rate (seconds/channel); and GS = Maximum ground speed of aircraft (miles/hour, kilometers/hour, or knots). Minimum parallel detection distance (*MD*) is measured parallel to the aircraft ground track and within the transect through an area over which the signal can be heard (Fig. 5). The shape of this area is related to the antenna receiving patterns discussed in an earlier section (Figs. 3 and 4). Test flights should be conducted to determine the values of signal range and *MD* for specific transmitters and receiving systems. Data obtained in tests flown to evaluate waterfowl telemetry equipment in September 1978 and April 1979 (Cessna 172, side-looking yagi antennas, 15° tilt) showed that an *MD* of 8.0 km occurred along the aircraft ground track (Fig. 5). Transect width for the example diagrammed in Fig. 5 was set at 9.6 km; signal range was determined to be 4.8 km. These characteristics are specific for the equipment we used in the test and may not accurately reflect the performance of other systems. The approximate relation between *MD* (km) and signal range (km) is shown in the

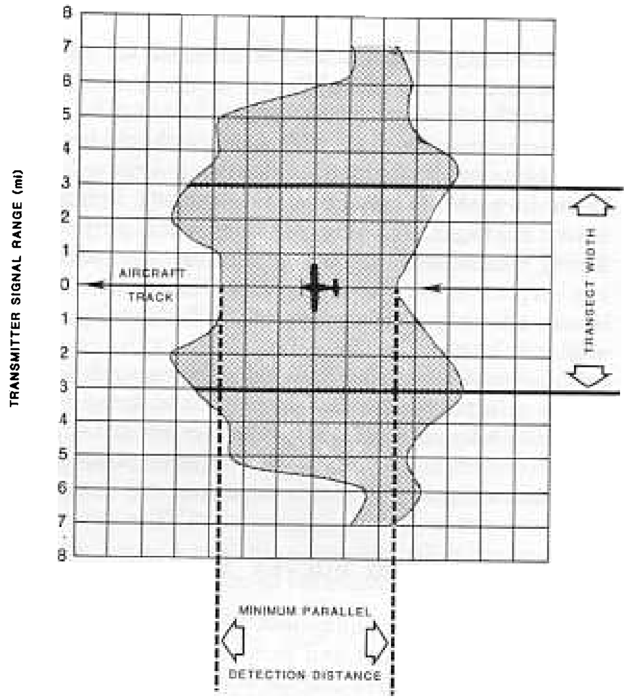


Fig. 5. An example of a signal reception pattern of a Cessna 172 with side-looking, 15° tilt yagi antennas flying at 300 m AGL. The shaded portion represents the area in which the transmitter signal can be reliably detected. In this example the minimum parallel detection distance was 8.0 km. The transect width was established at 9.6 km.

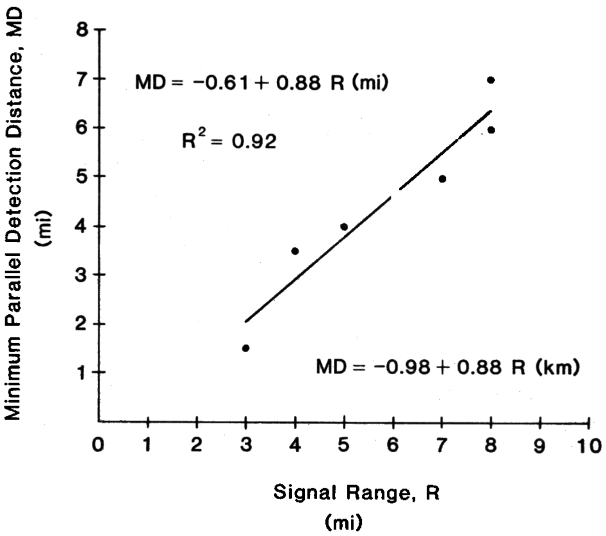


Fig. 6. Relation between minimum parallel detection range and signal range.

equation: $MD = 0.88\,R - 0.98$, where $R =$ signal detection range (Fig. 6).

The minimum receiver scan rate that was effective in our tests was 2-sec dwell on each channel (pulse rate of the transmitters was about 100 pulses/min). We estimated the maximum ground speed of the aircraft to be 193 km/h. This gave us a calculated capability of monitoring 75 channels. Another variable that determines the number of animals that can be handled in a search, but that is not in the above equation, is transmitter frequency drift. This problem may require the investigator to program two or three channels with a spread of frequencies around each transmitter in the search area. Experience with the transmitters and receiving system will help resolve this problem.

We found that this procedure formed a logical basis for planning the search of a large area, but there are often variables that have not been taken into account. Transmitters with excessively low range, greater than normal drift, or in certain locations (e.g., under water, in a den) can invalidate results from the basic equation. Results vary from day to day because of atmospheric conditions or radio interference; different observers also differ in their ability to hear weak signals and in their skill and experience in handling the equipment.

Probability of Finding an Animal Present in the Area Searched

Because of the variables discussed above, the investigator can seldom assume that an animal that was not located by radio signal was absent from the search area at the time of the search. Some measure of tracking efficiency therefore becomes highly desirable, and may be mandatory if the objectives of some studies are to be met. We have adopted and modified a mark-recapture technique first described by Hewitt (1967), who used it to estimate population density of breeding blackbirds. The method relied on an observation to mark a territory rather than the actual capture and marking of the bird.

In our adaptation of the technique, two tracking aircraft were flown, one as close behind the other as was safe and practical. If a radio-marked bird was heard by the observer in the first aircraft, the bird was treated as a marked individual. The observer in the second aircraft treated the signal from an animal heard by the first aircraft as a recapture and any other signal received as the capture of an unmarked individual. Data derived by this technique yield an estimate of the number of birds with functional transmitters present on an area, as well as separate estimates of the tracking efficiency of the two aircraft.

The vast literature describing mark recapture methods and their underlying assumptions was summarized by Otis et al. (1978). In the discussion that follows, we use the same notation they used for the two models presented—Mh ("capture probabilities vary by individual animal") and Mo ("capture probabilities are constant"). Model Mh seems most appropriate for the two-plane search. The model assumes that each member of the population has its own probability of capture, independent of all other members of the population. This assumption allows for transmitters of differing power and distance from the aircraft. The assumption of no difference between trapping occasions and no behavior response to trapping are also made. These assumptions may be met if the passes of planes 1 and 2 are close together and there is no movement of animals between passes and the first plane does not cause the animal to enter a den or some other area where the signal would be attenuated. The observers must also work independently of each other. In most applications of mark recapture methods, the marking of only a small portion of the population and the relatively few recaptures cause imprecise estimates of population size. In the two-plane search, a larger portion of the population may be "marked" by plane 1 and "recaptured" by plane 2; therefore, more precise estimates of the population size of radio-marked animals can be obtained.

During field work in 1978 on a study of breeding mallards (*Anas platyrhynchos*) in North Dakota, we used the two-plane search in an area where intensive preliminary tracking indicated the presence of 10 radio-equipped ducks. In two search trials, population estimates were 10.5 and 10.0. Efficiency of crews

Table 1. *Estimated number of transmitters in a test of the application of mark recapture methods with a two-plane search. There were 21 transmitters in an area 16.1 × 35.4 km (see Otis et al. 1978:15 for details of models and assumptions).*

Model[a] and parameter[b]		12.9-km spacing	19.3-km spacing: trial 1	2	3	4	5	6
Mh	M_{t+1}	20	16	17	19	18	20	20
	f_1	3	7	9	6	8	11	6
	$\hat{N}$	21.5	19.5	21.5	22.0	22.0	25.5	23.0
Mo	n_1	20	14	10	14	10	11	15
	n_2	17	11	15	18	18	18	18
	m_2	17	9	8	13	10	9	13
	$\hat{N}$	20.1	17.4	19.5	19.7	19.6	23.4	20.9
	$\hat{p}$	0.92	0.72	0.64	0.81	0.71	0.62	0.79
	$\hat{V}(\hat{N})$	0.15	2.63	6.13	1.05	3.14	8.50	1.24

[a]Model Mh—probability of capture different; model Mo—probability of capture equal.

[b]Model Mh: t = number of trapping occasions (in our study 2).

M_{t+1} = number of birds found 1 time by both planes.

f_1 = number of birds found by both planes.

$\hat{N}$ = estimated number of radio-marked birds $= M_{t+1} + \frac{1}{2}f_1$.

Model Mo: n_1 = number of birds found by plane 1.

n_2 = number of birds found by plane 2.

m_2 = number of birds found by plane 2 that were also found by plane 1.

$\hat{N} = (n_1 + n_2)^2/4\, m_2$.

$\hat{p}$ = estimated probability of finding a bird on a given flight $= n_1 + n_2/2\hat{N}$.

$\hat{V}(\hat{N})$ = estimated variance of $\hat{N} = \hat{N}[(1-\hat{p})^{-t} - t(1-\hat{p})^{-1} + t-1]^{-1}$.

varied from 30 to 80%. Because the actual size of the marked population in 1978 was not known, we designed a simulated test of the method during spring 1979. Twenty-one transmitters with an average ground to air range of about 9.6 km were placed at random in an area 16.1 × 35.4 km. A number of trials with different observers were flown along transects 9.6 and 12.9 km apart. At the 9.6-km spacing, all observers found all radios. The same was true at 12.9 km except for one trial (Table 1). By taking every other line, we simulated searches at 19.3-km spacing.

Although these results are preliminary, we believe that the two-plane search holds considerable promise for estimating the number of radio-marked animals on an area and for estimating the proportion of animals present on an area that an air crew can be expected to locate.

The tracking techniques described in this section are based on our experience with specific types of equipment used for tracking radio-marked waterfowl. Although they should furnish guidance for the design of radiotelemetry studies, each new study requires modifications and additional techniques. Successful use of aerial methods requires a thorough understanding of the capabilities of the system used, and this knowledge must be gained through both testing and operational experience. Knowledge of the species studied may greatly enhance the effectiveness of tracking efforts.

Special Considerations

Low-level Operations

If the survey requires continuous flight below a height of about 150 m AGL, additional details should be considered. The pilot should be experienced in low-level work, and both pilot and observer should be familiar with the area to be searched. Local FAA authority, sheriffs office, refuge managers, and game wardens should be notified of the approximate time and area of the survey. Helmets, fire retardant clothing, and boots should be worn during low-level work. Specific agency regulations concerning this type of work should be reviewed. Federal Aviation Regulations, part 91.79, concerning minimum safe altitudes, specify that except for landing and takeoff an aircraft should be operated so that in the event of a power failure the aircraft can be landed without endangering persons on the ground. Over congested areas (cities, towns, or settlements) aircraft should remain above an altitude of 300 m above the highest obstacle within a horizontal radius of 600 m of the aircraft. In other situations aircraft must remain at least 150 m AGL, except over water, where aircraft must remain at least 150 m from persons, vessels, or structures. Flight operations below 150 m may require FAA authorization.

Helicopters

The helicopter has proved to be highly effective because of its ability to travel at slow speeds, hover, and land at almost any site. The high cost of operation, relatively short cruising radius, and the limited availability of these aircraft prevent greater use in biotelemetry work. Sometimes reduced rates on helicopters can be obtained by contracting for a specified block of time or by sharing contract expenses with other agencies in need of helicopter services. Cruising radius (or on-station time) can be extended by the use of a pickup truck with a suitable fuel tank and transfer system that can be used for refueling the helicopter at rendezvous points.

Our experience with a Jet Ranger in prairie terrain showed that the most effective method for use of this aircraft was to search for a signal from an altitude of several hundred meters. When a signal was detected the helicopter was maneuvered downwind of the signal at an altitude of less than 15 m. Signal directionality was best determined when the helicopter, equipped with a forward-looking antenna, moved slowly upwind toward the signal, occasionally yawing left and right. This method provided precise locations of ducks on nests or in marshes, and we were often able to see birds or to land and collect additional data at nest sites. Some animals flee from a low-flying helicopter, and others attempt to hide. The tolerance of different species under different situations must be determined by experience.

When operating a helicopter in the vicinity of nesting raptors caution should be exercised as these birds may attempt to stoop on a hovering or slow-moving helicopter. The pilot should attempt to maneuver the helicopter so that it is above any raptors flying nearby.

Flight Characteristics and Icing Conditions

Tracking antennas mounted on the wing struts cause increased drag on the aircraft and result in a reduction of airspeed of about 5 to 7 knots in a Cessna 172. This factor should be considered, particularly during low-altitude operations. A good airspeed safety margin should be maintained and steep turns should be avoided. If icing conditions are encountered, ice may tend to build up on antenna elements before it forms on flight surfaces (W. E. Berg, personal communication). Small amounts of ice on the elements may cause them to flutter, thereby setting up serious vibrations.

Fatigue and Motion Sickness

Human fatigue is an important consideration when tracking operations are conducted from an aircraft. Two hours appear to be the limit that an individual can effectively monitor receiving equipment and do a satisfactory job of data recording, navigation, and other functions. Weather conditions play a large role: high temperatures and turbulence further reduce a person's ability to concentrate on the job at hand. If turbulence is severe, operations may have to be reduced or rescheduled. Flights should generally be started as early in the morning as practicable to avoid turbulence and thunderstorms that often develop as the day progresses.

Motion sickness may detract from the efficiency of the tracking operation. Although a few people suffer from chronic motion sickness, most can readily adapt to turbulent flying conditions. Certain motion sickness drugs are useful, but sometimes cause a temporary loss of navigation or tracking skill. Observers should not fly if they are suffering from an upset stomach. Many persons induce motion sickness by constantly turning their head during steep turns and other unusual attitudes. This situation commonly occurs when operators are photographing terrain objects. The head should be turned as little as possible; it should be held in a forward and upright position. It is better to move the eyes rather than the head (Federal Aviation Administration 1974). Some other preventive measures include opening air vents, loosening of clothing, and frequent visual reference to the distant horizon. Crew members in the back seat of the aircraft are subjected to increased gravity forces. The pilot should be informed if crew members experience discomfort.

To a large degree the comfort of the aircraft crew determines the success of the flight. The interest of the pilot in the goals and objectives of the project is important when the flying becomes repetitive and boring (see Hoskinson 1976). Patience and precision are often required to locate radio signals and data must be accurately and thoroughly recorded. Distractions to the crew may introduce errors that are difficult or impossible to correct after the flight is completed.

Acknowledgments

We thank pilots J. Engman, J. Goldsberry, M. Holcomb, R. Jackson, M. Meier, J. Peterson, J. Schubert, H. Simonson, and J. Wehler for their help in conducting test and tracking flights; J. Gulke, J. Heggenes, R. Reichle, R. Schuster, J. Sease, and J. Winters for assistance in the collection of data; I. J. Ball, R. J. Greenwood, R. E. Kirby, A. L. Kolz, L. D. Mech, K. D. Norman, C. Smith, and K. J. Reinecke (all of the U.S. Fish and Wildlife Service); W. E. Berg (Minnesota Department of Natural Resources); W. D. Garrett, J. W. Jutson, L. R. Langdon, and S. C. Peterson (Office of Aircraft Services, U.S. Department of the Interior), and F. L. Kellogg (Federal Aviation Administration, U.S. Department of Transportation) for providing helpful suggestions during preparation of the manuscript; A. M. Frank and D. H. Johnson for providing assistance in statistical analysis; R. Aurland and R. Braaten for help in design and construction of antenna mounts; and O. D. Georgen and F. L. Kellogg (both of the FAA) for helpful suggestions for improving the design of the antenna mounts.

References

Amlaner, C. J., Jr. 1980. The design of antennas for use in radiotelemetry. Pages 251–261 *in* C. J. Amlaner, Jr., and D. W. MacDonald, eds. A handbook on biotelemetry and radio tracking. Pergamon Press, Oxford.

AVM Instrument Company. 1979. AVM radiotelemetry equipment and techniques manual. AVM Instrument Co., Champaign, Ill. 32 pp.

Cederlund, G., T. Dreyfert, and P. Lemnell. 1979. Radiotracking techniques and the reliability of systems used for larger birds and mammals. Rapport SNV PM 1136, Forsknings-station, Grimso, Sweden.

Cochran, W. W. 1965. Techniques in aerial telemetric studies of nocturnal migration of birds. Progress Report 1, National Science Foundation GB-3155, December 8, 1965.

Cochran, W. W. 1972. Long-distance tracking of birds. Pages 39–59 *in* S. R. Galler et al., eds. Animal orientation and navigation. National Aeronautics and Space Administration, Washington, D.C. NASA SP-262. 606 pp.

Cochran, W. W., G. G. Montgomery, and R. R. Graber. 1967. Migratory flights of *Hylocichla* thrushes in spring: A radiotelemetry study. The Living Bird 6:213–225.

Crissey, W. F. 1949. The airplane in fish and game work. Conserv. Dep., Albany. Fish Wildl. Inform. Bull. 4. 20 pp.

Dunstan, T. C. 1974. Location of a lost hawk by telemetry from an airplane. Hawk Chalk 13(3):38–42.

Federal Aviation Administration. 1974. Medical handbook for pilots. U.S. Govt. Printing Office, Washington, D.C. 74 pp.

Gilmer, D. S., R. E. Kirby, I. J. Ball, and J. H. Riechmann. 1977. Post-breeding activities of mallards and wood ducks in north-central Minnesota. J. Wildl. Manage. 41(3):345–359.

Graber, R. R. 1965. Night flight with a thrush. Aubudon 67(6):368–374.

Hewitt, O. H. 1967. A road-count index to breeding populations of red-winged blackbirds. J. Wildl. Manage. 31(1):39–47.

Hoskinson, R. L. 1976. The effect of different pilots on aerial telemetry error. J. Wildl. Manage. 40(1):137–139.

Hoskinson, R. L., and L. D. Mech. 1976. White-tailed deer migration and its role in wolf predation. J. Wildl. Manage. 40(3):429–441.

Judd, S. L., and R. R. Knight. 1977. Determination of grizzly bear movement patterns using biotelemetry. Pages 93–100 *in* Proc. 1st Int. Conf. Wildl. Biotelemetry, July 27–29, 1977. Laramie, Wyo.

Kirby, R. E., J. H. Riechmann, and M. E. Shough. 1976. A preliminary report on Minnesota's innovative 1973 waterfowl season. Wildl. Soc. Bull. 4(2):55–63.

Kolenosky, G. B., and D. H. Johnston. 1967. Radio tracking timber wolves in Ontario. Am. Zool. 7(2):289–303.

Mech, L. D. 1974. Current techniques in the study of elusive wilderness carnivores. Proc. Int. Congr. Game Biol. 11:315–322.

Mech, L. D., L. D. Frenzel, Jr., and R. R. Ream. 1971. Movements, behavior, and ecology of timber wolves in northeastern Minnesota. Pages 1–35 *in* L. D. Mech and L. D. Frenzel, eds. Ecological studies of timber wolf in northeastern Minnesota. USDA Forest Service, North Central Forest Experiment Station Research Paper NC-52. 62 pp.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildl. Monogr. 62. 135 pp.

Ramo, S., and J. R. Whinnery. 1962. Fields and waves in modern radio. John Wiley and Sons, New York. 576 pp.

Seidensticker, J. C., M. G. Hornocker, R. R. Knight, and S. L. Judd. 1970. Equipment and techniques for radio tracking mountain lions and elk. Idaho Coop. Wildl. Res. Unit, For. Wildl. Range Exp. Stn., Bull. 6. 20 pp.

Storm, G. L., R. L. Andrews, R. L. Phillips, R. A. Bishop, D. B. Siniff, and J. R. Tester. 1976. Morphology, reproduction, dispersal and mortality of midwestern red fox populations. Wildl. Monogr. 49. 82 pp.

U.S. Department of the Army. 1958. Universal transverse mercator grid. Technical Manual TM 5-241-8. U.S. Government Printing Office 1969-390-947/404. 66 pp.

Weeks, R. W., F. M. Long, J. E. Lindsay, R. Bailey, D. Patula, and M. Green. 1977. Freshwater fish tracking by aircraft. Pages 63–69 *in* Proc. 1st. Int. Conf. Wildl. Biotelemetry, July 27–29, 1977. Laramie, Wyo.

Whitehouse, S., and D. Steven. 1977. A technique for aerial radio tracking. J. Wildl. Manage. 41(4):771–775.

Winter, J. D., V. B. Kuechle, D. B. Siniff, and J. R. Tester. 1978. Equipment and methods for radio tracking freshwater fish. Agric. Exp. Stn. Univ. Minn. Misc. Rep. 152. 18 pp.

Appendix A

Construction of Antenna Mounts

The basic mount design we use to attach biotelemetry antennas to aircraft was developed about 10 years ago and was gradually improved through a series of modifications resulting in the designs described here. Other biologists have developed mounts that may be equally satisfactory. Illustrated in this appendix are designs for wing strut and helicopter mounts that were approved by local FAA authority. We emphasize that approval of these antenna mounts for our work does not insure that similar designs will be approved in other situations. Approval authority rests solely with the FAA inspector who is guided by his own judgment and current official directives and regulations.

We present the following diagrams so that other biologists will have adequate information to construct similar mounts or use this information as a basis to develop other designs (Figs. A-1, A-2).

A - 13/16" O.D. aluminum tubing

B - 1/16" flexible aluminum

C & D - 17/16" O.D. aluminum tubing

E,F,G,H,I,J,K & L - 1/8" aluminum plate

M - all bolts 5/16"

N - heliarc welds symbolized by ▬

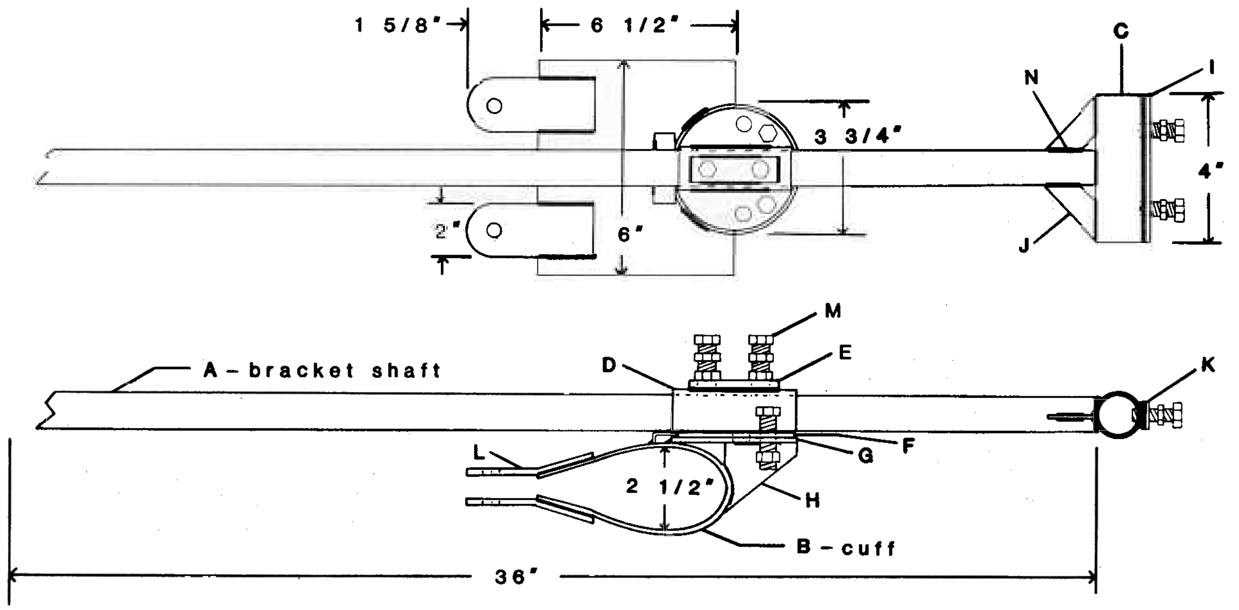


Fig. A-1. Schematic diagram of airplane wing strut yagi antenna mount. Measurements are provided in English units. Inside of cuff lined with padding to avoid scratching strut surface. All nuts and bolts should be certified for use on aircraft. These are available at any airport with repair facilities. Use lock nuts on cuff.

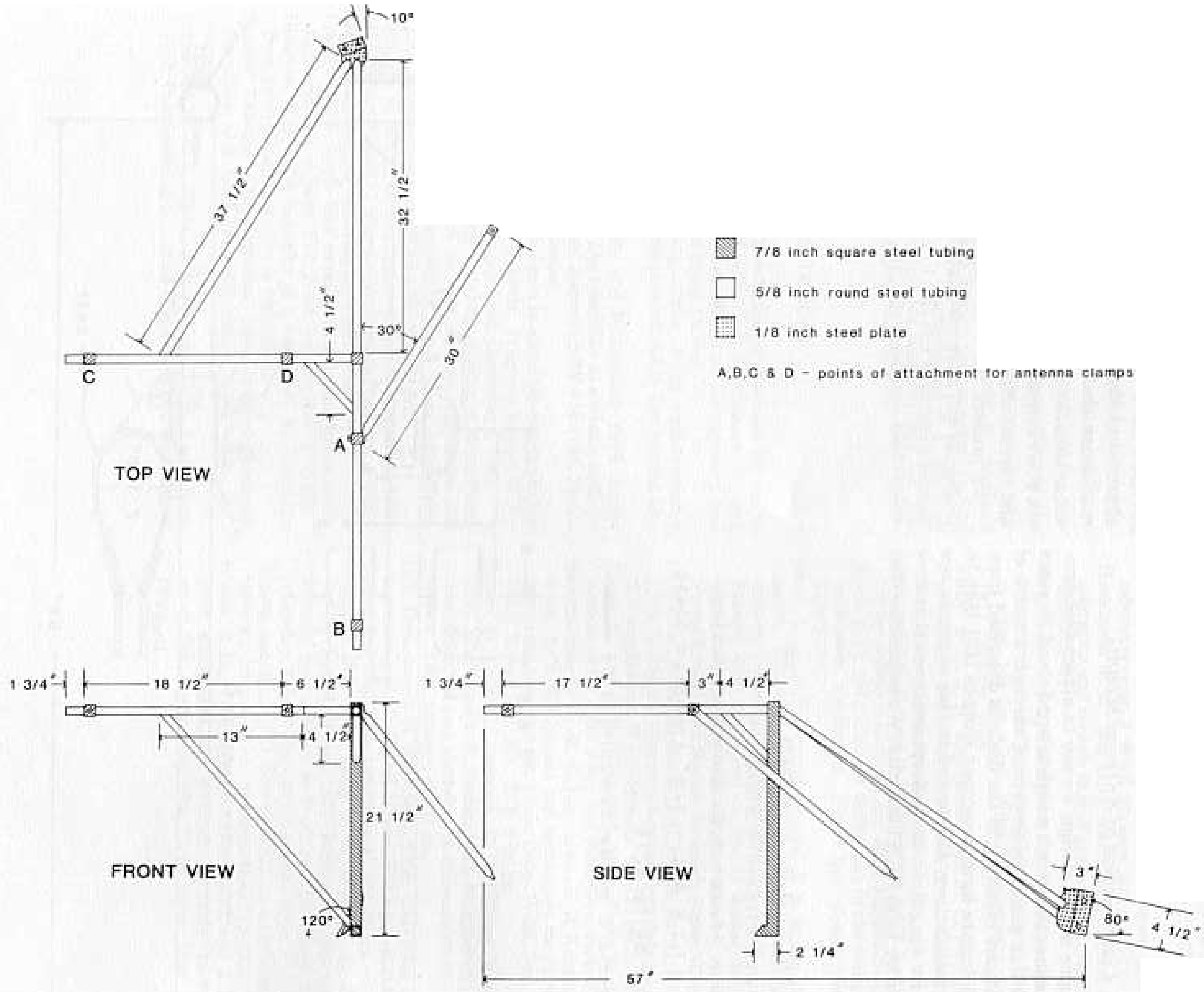


Fig. A-2. Schematic diagram of helicopter (Jet Ranger) yagi antenna mount. Measurements are provided in English units. All nuts and bolts should be certified for use on aircraft. These are available at any airport with repair facilities.

Appendix B

Antenna Test Procedures

The reversal of the transmitter and receiving antennas is always valid because the reciprocity theorem states that in linear systems the antenna pattern for reception is identical with that for transmission (Ramo and Whinnery 1962:558).

The transmitter located in the aircraft was crystal controlled, battery powered, and regulated to keep the output constant. Either of two antennas were selected by switching the antenna cables at the transmitter.

The signal was received by a quarter-wave ground plane antenna located on the ground and was fed into a receiver through a calibrated attenuator (Fig. B-1). The signal output level was displayed on an oscilloscope and voltage meter. The signal frequency was monitored with a frequency meter, and drift was compensated by using the receiver's fine-tune control. Tests indicated that the signal frequency could vary ± 500 Hz before the signal level changed more than ± 1 db. The calibrated attenuator was used to maintain the output at a constant level. Using this technique, one can easily maintain calibration and eliminate nonlinearities in the system. Tests were not conducted on a specially designed antenna range. Many variables affect the results and may prevent the exact duplication of our findings.

A signal from a calibrated signal generator was switched to set the reference gain level of the system at the start and completion of each run. Although little gain adjustment was needed the receiver was adjusted to keep the output constant for a given input signal level.

To make comparisons between different altitudes and antenna configurations for each aircraft, we normalized all measurements to the maximum value for that aircraft. No comparisons were made between antenna gains on different aircraft because the gain variation would probably be masked by variation in transmission conditions and because we had no way to insure the calibration of the system between aircraft. The comparison between antenna patterns on different aircraft is valid because the comparison is a relative one. The shape of the gain pattern is not dependent on the signal amplitude at the antenna.

A distance correction was made to compensate for the loss in signal level due to the changing distances the signal had to travel as the aircraft moved toward and away from the receiver site.

Free space corrections were used. Although strictly speaking these equations are valid only between antennas in space, air to ground transmissions closely approximate these conditions, especially at lower frequencies where atmospheric attenuation is low.

The actual power received at the antenna (P_r) is equal to:

$$P_T - P_L + A_G$$

where P_r = received power in decibels (db); P_T = transmitted power (db); and P_L = path loss = 20 (log aircraft to receiver antenna distance/distance from aircraft to receiver antenna at its closest point).

A_G = Antenna gain (db)
db = $10 \log P_1/P_2$ where P_1/P_2 is a power ratio.

Rearrangement of terms yields the following equation:

$$A_G = P_r + P_L - P_T$$

Because P_r and P_T are held constant and P_L can be calculated, the antenna gain is a constant. Since the angle to the aircraft is also known, the antenna pattern can be determined.

Tests were conducted near Jamestown, North Dakota, and Cambridge, Minnesota. The test areas were chosen because they had a good network of intersecting roads, which allowed easy and accurate determination of aircraft position (road intersections were

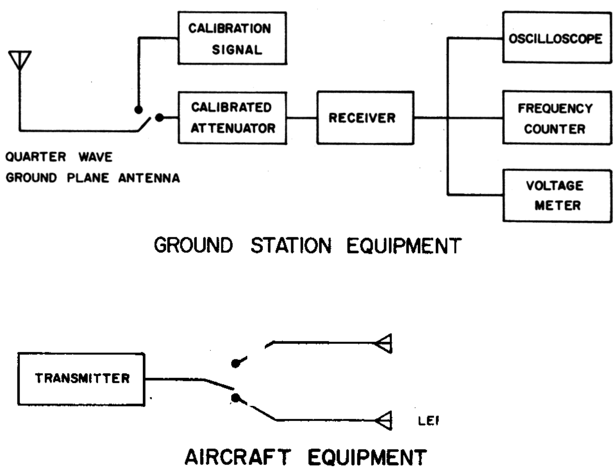


Fig. B-1. Equipment used to obtain electronic measurements during tests of antennas mounted on aircraft.

used as reference points). Intersections occurred at each 0.8-km interval at Jamestown and at 1.6-km intervals at Cambridge. The distance from the receiving site to the flight path was 3.2 km at Jamestown and 3.5 km at Cambridge. As the aircraft flew along the test transect it reported its position by two-way radio each time it crossed a road intersection. The receiving station then recorded the corresponding attenuation level for that point. For all except loop antennas, two runs were made for each configuration and altitude tested. The readings were then corrected for distance (path loss), normalized to a reference level, and plotted. The curves drawn were for the best fit to the data points.

Problems were encountered with vertical wind gradients, which caused variation in altitudes; the average of two runs decreased this error. Also, the pattern is not highly dependent on altitude. We would expect the error caused by the estimated ±30-m variation in altitude we encountered to be small. Errors due to crosswinds are a greater problem because they cause the aircraft to "crab" and therefore have a direct effect on the pattern. The only compensation we had for crosswinds was to average runs from opposite directions. Although errors attributable to crosswinds are difficult to measure, we do not believe the crosswind effects have significant influence on the antenna patterns.

Appendix C

Equipment Checklist

List of animals to be located during flight (also notes on frequency drift)
Map of last known animal locations (also consider recent movement patterns if known)
Blank maps and data forms
Clipboard
Pencils, pens
Camera and film (if desired)
Communication radio (air to ground)
Test signal transmitters
Timepiece to calibrate aircraft clock
Operational receiver
Backup receiver
Auxiliary power supplies
Headphones
Switch boxes
Extra coaxial cable (proper length and connectors)
Antennas and mounts, with coaxial cable attached
Padding for mounts
Tool kit for mounting antennas:
- adjustable wrenches
- screwdriver
- slip-joint pliers
- electrical tape
- extra bolts, nuts, washers
- multimeter
- "Restricted Category" signs (if required)

Procedural Checklist

Attach mount with antennas to aircraft (adjust as necessary)
Run coaxial cables into cabin
Hook up switch boxes and receiver
Test system: make sure switch box is functioning correctly
Review flight plan with pilot
Pilot recheck antenna mounts
Tune antenna (as necessary)
Check receiver battery voltage
Scanning receiver:
- check programmed frequencies
- check dwell time
- check appropriate mode switches

Place "Restricted Category" signs near cabin door (if required)