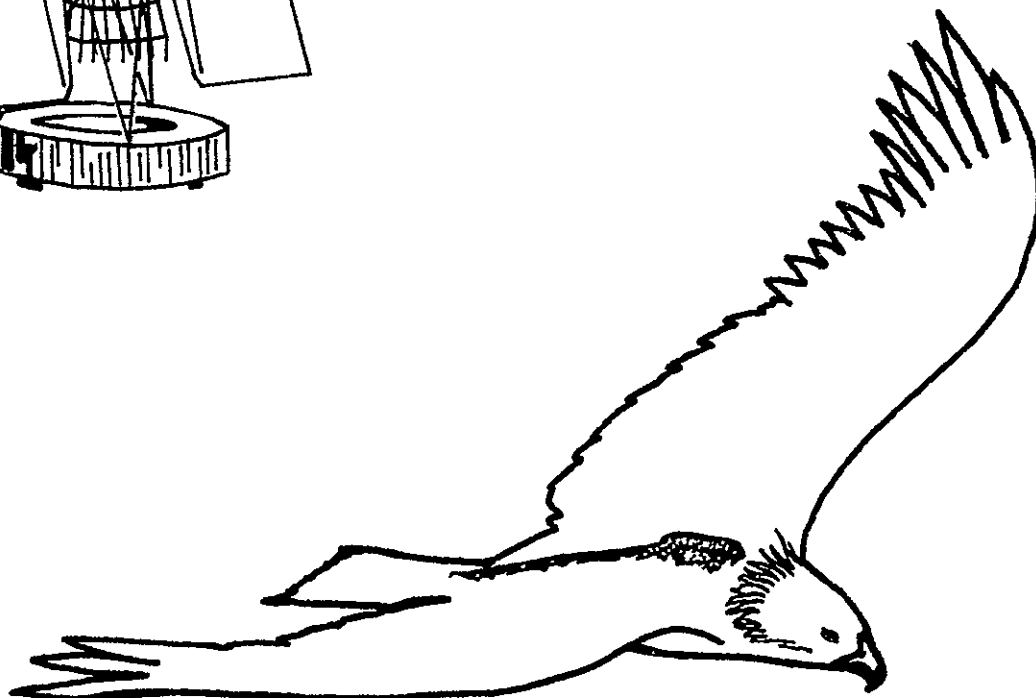
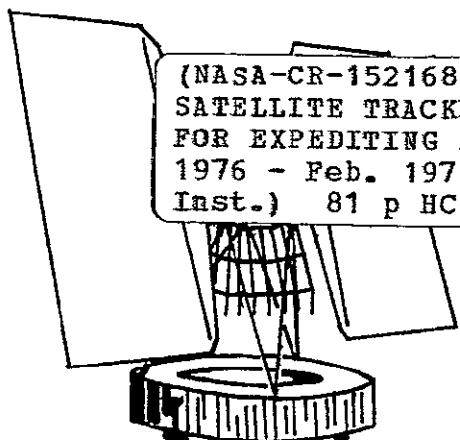


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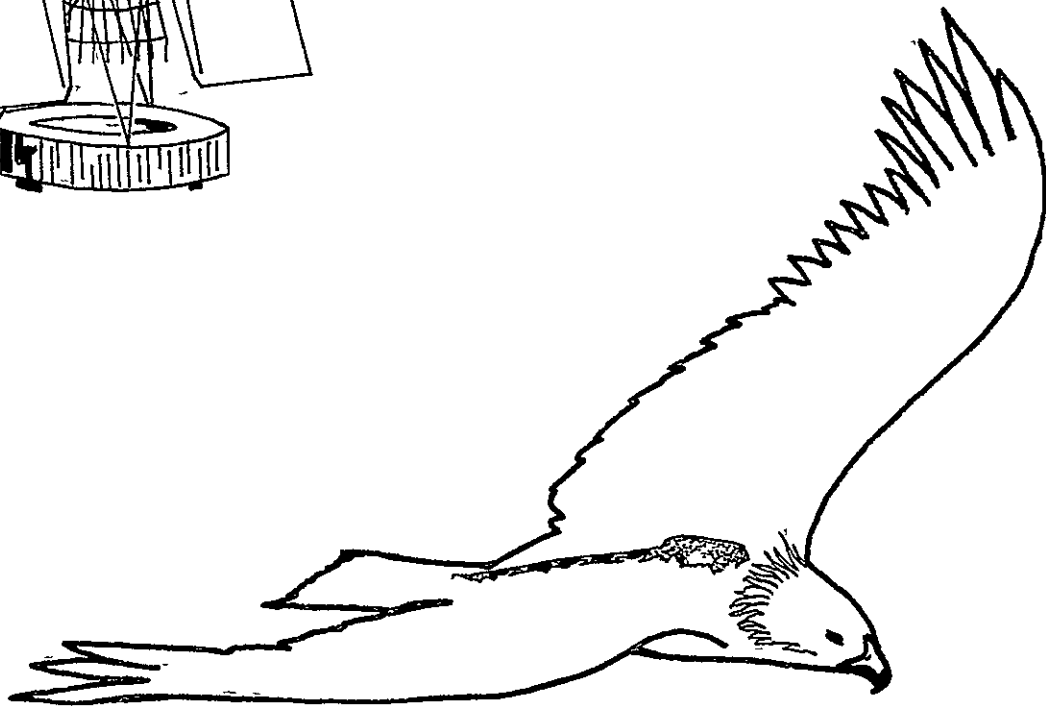
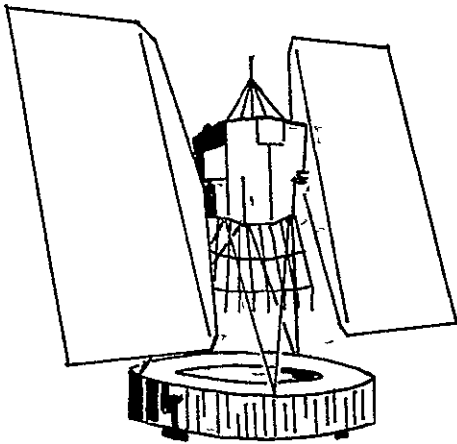
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**ASSESSMENT  
OF NEEDS FOR  
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AND SUGGESTIONS  
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Environmental Research Institute  
Box 156 Moose, WY 83012

ASSESSMENT OF NEEDS FOR SATELLITE  
TRACKING OF BIRDS AND SUGGESTIONS FOR  
EXPEDITING A PROGRAM

FINAL REPORT

Covering the period March 1976-February 1978

NASA Grant Number NSG-2157

Dr. Frank C. Craighead, Jr.

## ABSTRACT

Results of animal-instrument interphase work indicate that large free-flying birds can be successfully instrumented with radio packages comparable in weight to satellite-transmitter packages. The 401 MHz frequency proved satisfactory for a combination of satellite and ground tracking of migrating birds. Tests run for nearly a year with the Nimbus 6 satellite and a miniaturized, one-watt prototype RAMS transmitter produced encouraging results in regard to location accuracy, frequency of contact with satellite and use of whip antennas. A future program has been recommended with priority given to development of six operational transmitters for feasibility experiments. Estimated costs ranging between \$50,000 and \$250,000 have been suggested for this phase. Several proposed feasibility experiments have been outlined based on field experience and present limitations of a stage by stage developing telemetry system. Various satellite tracking projects that could be moulded into a future program by interested scientists and user-agencies have been suggested and briefly described. When operational transmitters based on our prototype are available, feasibility experiments can be conducted. Seeking funds from various sources must be a continuing process to maintain momentum for a full scale program of satellite tracking of birds.

The NASA Technical Officer for this grant is:

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## CREDITS

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## 1. INTRODUCTION

The objective of this research has been to advance toward the ultimate goal of tracking and monitoring migrating birds by satellite. This has required the further development and testing of the necessary equipment, experimentation with package harnesses and attachment methods and the comparison of performance of various frequencies.

The first organized attempt to consider the feasibility and to examine the potential of satellites for tracking and monitoring wild animals was a conference sponsored jointly by the Smithsonian Institution, The American Institute of Biological Sciences (AIBS), and the National Aeronautics and Space Administration (NASA) in May 1966. In 1969 the National Academy of Sciences (NAS) assembled a panel of scientists to look anew at the foundation of space biology. Wildlife behavior and ecological relationships were part of the agenda. Recommendations were made for a program for satellite tracking of free-ranging animals. One result of this meeting was a cooperative program in which an elk (Cervus canadensis) was tracked and monitored by the Nimbus-3 satellite (Craighead, Craighead, Cote, and Buechner 1972). This feasibility experiment was quickly followed by another to monitor a black bear's (Ursus americanus) winter den (Craighead, Craighead, Varney and Cote 1971).

Subsequently, various meetings led to workshops on wildlife monitoring by satellite. A NASA/AIBS Santa Clara conference on wildlife monitoring was held 24-27 April 1973 at the Ames Research Center, Moffett Field, California. It was followed by a Santa Cruz workshop in September 1973. The purpose of these meetings and the subsequent report was "to show the importance of our wildlife resources and to show that their management, conservation and rational use are national goals, based on laws, treaties,

and agreements binding between the United States and other countries as well as upon agencies of the State and Federal levels" (Anonymous 1973). The report stresses that State and Federal agencies have established programs for which information is needed on habitat, censusing, migration, movement, location, physiology, and behavior of animals and their populations.

Further impetus was given to animal satellite tracking and monitoring by the Easton, Maryland workshop on Satellite Data Collection User Requirements held 18-20 May 1975.

The National Academy of Sciences biology panel recommended (1) that NASA offer the community its services for liaison and information dissemination; (2) that a common data processing and standardization effort be established; (3) that NASA institute a program to develop and standardize in situ sensors; (4) that NASA support the development of recoverable packages; and (5) that NASA consider the Santa Cruz report on wildlife movement and tracking systems (Wolff et al. 1975).

The 1973 Santa Cruz report treated the development needs and application of technology to various satellite tracking programs. Two systems, RAMS and Omega/OPLE, were selected by consensus as having the greatest capability and best specifications for locating and monitoring animals and their environments.

The Random Access Measurement System (RAMS) uses the Doppler location technique (G. Balmino et al. 1968). It transmits at predetermined intervals as compared with an ordered system such as IRLS which responds to an interrogation from the satellite. A decided advantage is that RAMS permits numerous experiments at low cost using simple data collection equipment. The RAMS system aboard the Nimbus-6 satellite can handle

up to 1000 platforms (i.e. bird transmitters) per orbit. This permits large scale studies of migrating birds on a worldwide scale (Cote, DuBose and Coates 1973).

The aim of the transmitter development was to obtain an electronic package that would be as small as possible and one needing little or no modification when fastened to the smallest as well as the largest animal that could be feasibly studied. This approach would tend to standardize equipment and eliminate duplication. Our development of the Nimbus 6/RAMS DCP one-watt transmitter (Varney and Pope 1974) weighing 56 g and compatible with Nimbus satellite frequencies (401 MHz) has been an effort to expedite the program and to follow the recommendations of the Santa Cruz report. The bulk of this current report deals with a continuation of aspects of this work which are prerequisite to practical and successful feasibility experiments and to future development of a comprehensive and significant program of satellite tracking and monitoring of wildlife, specifically migrating birds.

The general conditions under which satellite tracking would be most productive as well as specific problems amenable to solution by satellite tracking and monitoring have been well covered in the paper "Satellites for Research on Free-roaming Animals", (Buechner et al. 1971), and in the Santa Cruz and Easton, Maryland workshop reports.

One paper has been published to date as a result of this grant: "Progress Toward Tracking Migrating Raptors By Satellite", (Craighead and Dunstan 1976). Abstract: The ultimate objective of this radio-tracking research is to track and monitor migrating birds by satellite. It is envisioned as only a part of a much broader program of satellite biological and ecological data collection (Wolff, Cote and Painter 1975).

The future need and demand for satellite tracking and monitoring of birds will very likely be focused on waterfowl and ocean birds, but large raptors, such as the Bald Eagle (Haliaeetus leucocephalus) and Golden Eagle (Aquila chrysaetos) provide ideal subjects for initial experiments. Current efforts are directed toward conducting successful feasibility experiments with these birds. Some specific objectives include equipment development and testing, animal-instrument interphase or attachment methods, evaluation of various feasibility-tracking experiments with raptors and suggestions for expediting a future program.



## 2. ANIMAL-INSTRUMENT INTERPHASE-ATTACHMENT METHODS AND TECHNIQUES

It is obvious that the attachment of an electronic package to an animal is basic to acquiring position/location and other pertinent information. The method of attachment selected depends on the animal's characteristics, but it must be done with care so as not to harm the animal or introduce an unacceptable physiological or behavioral variant. Such aberrations will degrade the value of any data acquired (Anonymous 1973). The smaller the gear for attachment to an animal the greater the number of species on which it can be effectively used. The package size varies with transmitter power, life, size, encapsulation and harnessing requirements. A program was conducted to test and evaluate various transmitter-attachment methods with the realization that the final satellite package itself might weigh between 100 and 200 grams.

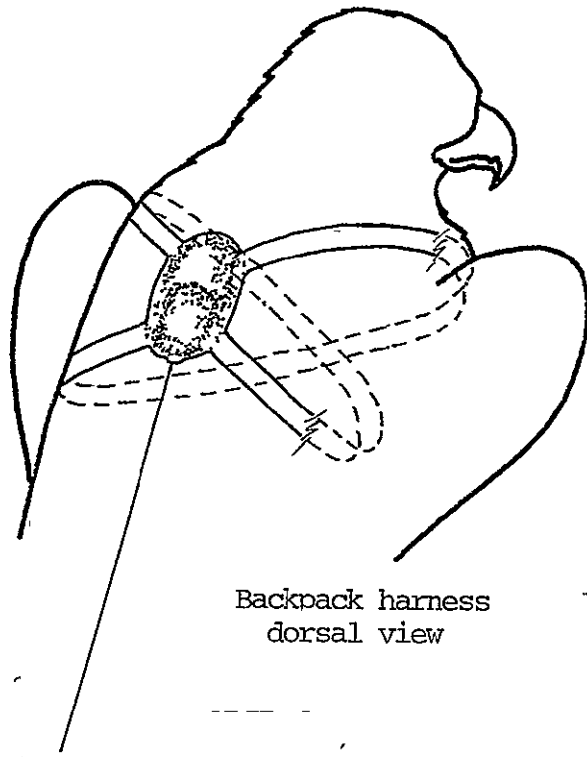
In order to test and evaluate various transmitter-attachment methods, a combination 148 MHz and 462 MHz bird-telemetry system was acquired and put into operation. Basically, it consisted of a 148 MHz system (Beaty 1972) with a UHF to VHF converter on the UHF antenna. The miniaturized transmitters weighed 2.8 g.

Four approaches to instrumenting or harnessing were tried: transmitter attachment to the tarsus (tarsometatarsus), attachment to the rectrices or tail feathers, the backpack harness (Dunstan 1972), and the backsack attachment. Each of the four methods has advantages for some species of birds, and one may be favored over the other depending on objectives.

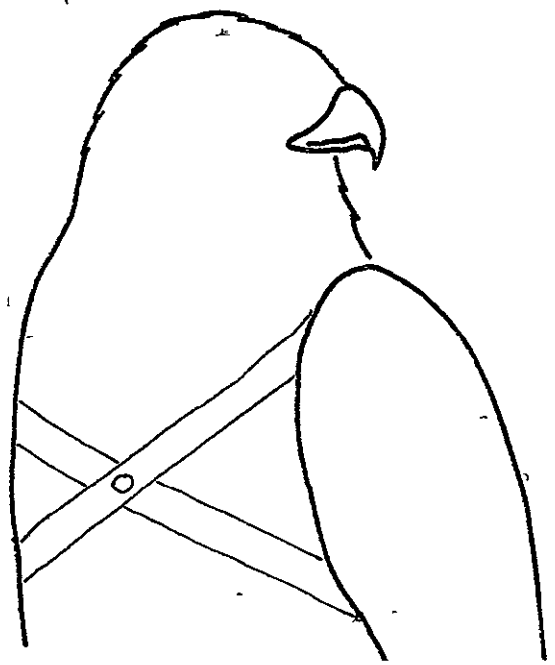
### 2.1 BACKPACK HARNESS

The backpack harness (Fig. 1) as designed by Dunstan (1972), a modification of earlier such body attachments, was used in this study

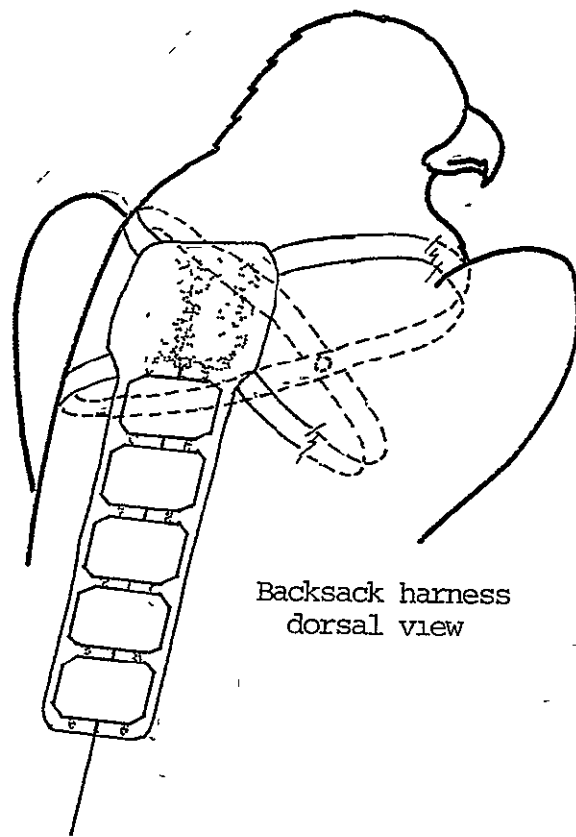
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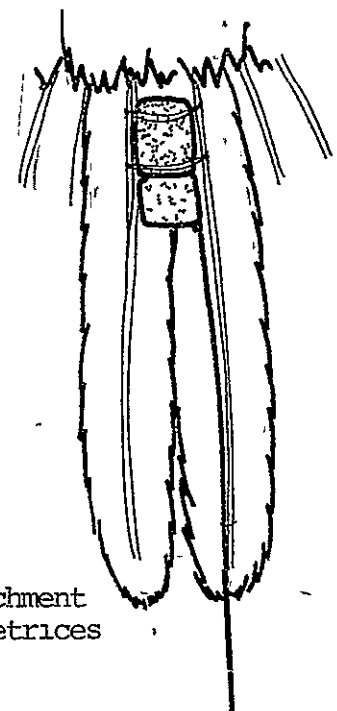
Backpack harness  
dorsal view



Ventral view of  
harness attachment



Backsack harness  
dorsal view



Tailfeather attachment  
ventral view of retrices

Fig 1

on Ravens (Corvus corax) and Golden Eagles (Aquila chrysaetos). The transmitter, power source and transmitting antenna were either embedded in perm dental acrylic (Hygienic Dental Mfg. Co., Akron, Ohio) or sealed in layers of epoxy to waterproof them and to prevent breakage. Neck and body straps of both nylon and tubular teflon were used to form the harness. The present weight of a satellite transmitter package is in the neighborhood of 100 g. Total weight will, of course, vary with battery requirements. It seemed logical that weights ranging between 100-200 g could best be carried by a bird when attached to the back. The maximum package weight used on Ravens was 45 g. A wild Golden Eagle successfully carried a 180 g package while nesting.

## 2.2 BACKSACK HARNESS

Radio packages prepared as backpacks (Figs. 1,2) were sewn within a "backsack" made of AIV-16 Fabric (Cooley, Inc., Pawtucket, Rhode Island) or Saflag fabric (Safety Flag Co. of America, Pawtucket, Rhode Island). The backsack reduces the possibility of transmitter antenna breakage and also serves as a color marker before and after battery failure. Straps made of 1 or 1.4 cm wide tubular teflon (ribbon style 8476, Bally Ribbon Mills, Bally, Pennsylvania) were centered and embedded with acrylic into the ventral surface of the package. The straps formed a harness for use on Bald Eagles (Haliaeetus leucocephalus), Golden Eagles and other large birds.

The transmitter package was positioned on the sack material and sewn in place along the sack edges and across the harness straps with heavy dacron thread. The transmitter antenna was sewn in place between the material (Fig. 2). A nylon tape No. 7407 M11-T-5039E, Type III (Bally

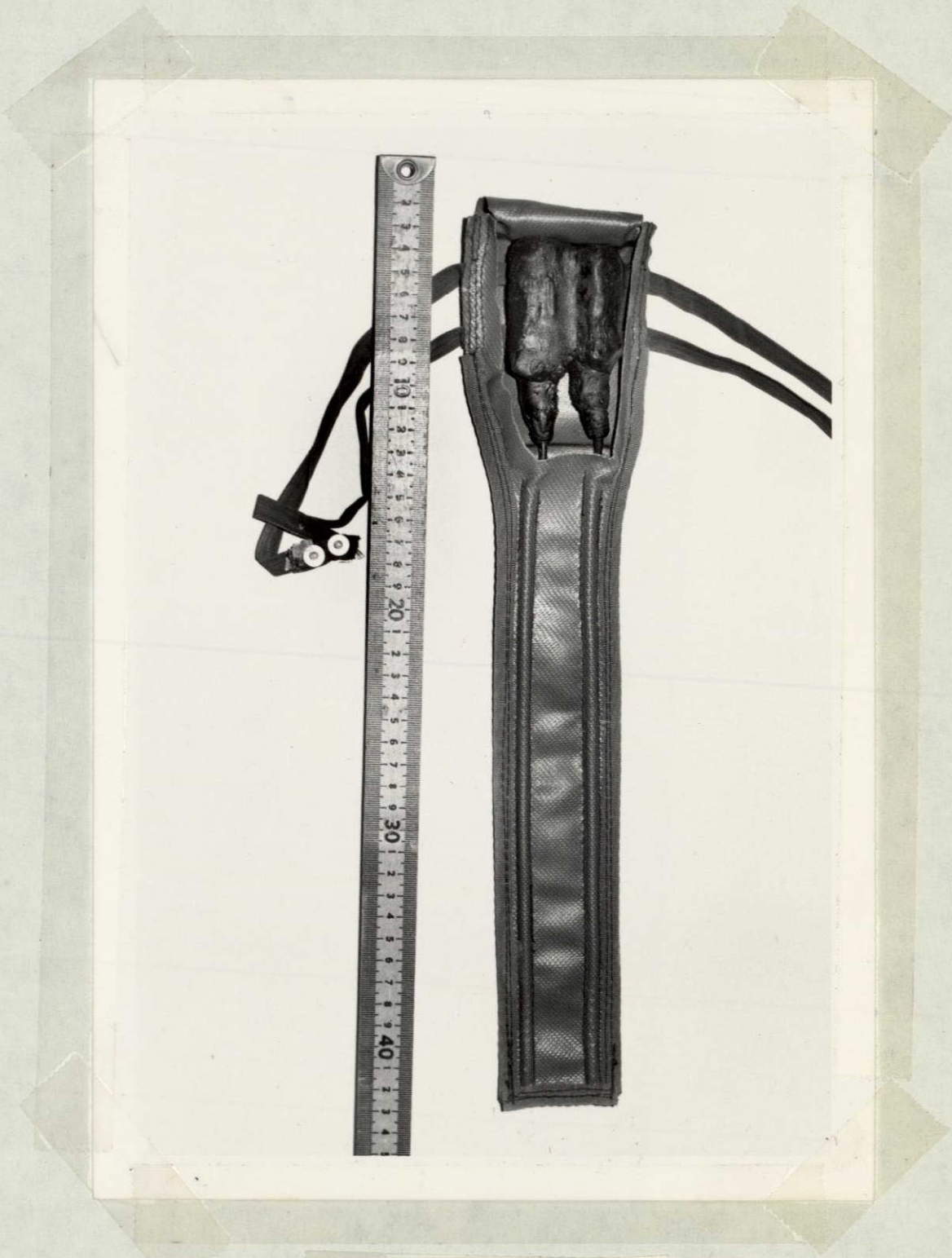


Fig. 2

Backsack Harness

Ribbon Mills), was sewn along the edge of the backpack to minimize fraying and separation. Additional tough light-weight materials could be used and experimentally tested.

When placed on the eagle, the two straps were passed around the body so that they crossed and were joined at the midline of the breast (Fig. 1). Straps and harness fit were adjusted to allow for growth of nestlings and molt and body size changes in full-grown eagles. Straps were joined with various suture material for short-term use and with pop rivets for long-term use.

The total length of the backpack was 41 cm and the width of the portion covering the antenna was 5.3 cm. The total length of the backpack varies with the length of the transmitting antenna, which is related to the transmission frequency. The 222 MHz transmitters had 30.4 cm antennas, the 148 MHz transmitters 24 to 30 cm antennas. The size of the sack covering the power source and transmitter varied in width from 9.5 to 10.5 cm depending on the size of the batteries used. The weight of the backpack was also related to type of batteries used and ranged from 60 to 180 g. The theoretical transmitter lifetimes for the 222 MHz transmitters were from 14 to 33 months. Some actual lifetimes are still to be determined as the work on some birds continues.

The use of solar cells to recharge transmitter batteries has been increasing and is being perfected. Solar panels kept the batteries recharged on the IRLS equipment used to track elk (Craighead et al. 1972). They have been used successfully on turkeys (Meleagris gallopavo) and mule deer (Odocoileus hemionus), (Patton, Beaty and Smith 1971). Solar cells have been tested with 30 g, 400 MHz transmitters designed for use on Herring Gulls (Larus argentatus), (Williams 1973). The antenna sheath

used to prevent antenna breakage by Golden Eagles could readily be used to house solar cells for recharging of satellite-transmitter batteries as depicted in Fig. 1, thus assuring longer life at reduced weights. This is an area for further development and experimentation and may be essential to obtaining long life with light weight packages.

Radio transmitter backsacks were placed on two adult female Golden Eagles, four nestling Golden Eagles, and four nestling Bald Eagles. All birds carried the backsacks well and neither the young nor the adults showed adverse reactions to the presence of the backsack. The marked adult female Golden Eagles continued to kill prey and feed young after tagging. Golden Eagle nestlings with backsacks were fed by unmarked adults at the same rate as prior to tagging and adults showed no unusual behavior in relation to tagged nestlings. The Golden Eagle nestlings fledged and dispersed from the parental ranges well within the time ranges for the same activities of other unmarked young. The tagged-nestling Bald Eagles were fed regularly by the unmarked parents and also fledged and dispersed from the home ranges within the time limits for other unmarked young in the study areas. Different colored backsacks were used on adult and nestling Golden Eagles.

Occasionally the adults and young preened the antenna portion of the sacks and the harness straps. During preening the antennas were not sharply bent and the force of pulling was absorbed by the entire harness. The distal portion of the sack, including the antenna, sometimes slipped from the middle of the back to either side along the flank, but most of the time the sack remained toward the middle of the bird's back. Scapular feathers often covered the anterior portion of the sack, but the distal half was visible.

Three marked eagles (two of which were marked under BLM contract 525 CO-CT 5-1013) were later captured and appeared to show no adverse effects from the tagging. One fledgling Golden Eagle wore a backpack for 11 weeks before being recaptured. A second recaptured Golden Eagle had worn a backpack for 53 days after fledging. Neither bird showed any damage to skin, feathers or the backpack. However, both were in poor physical condition when captured. One had pathogenic trichomonads (Trichomonas gallinae) and had lost considerable weight. The second was not diseased but had lost considerable weight, apparently from lack of food. It is not unusual for fledglings to lose weight due to poor foraging conditions or ability. One nestling Bald Eagle fitted on 23 July 1974 with a backpack with no transmitter was found shot in Iowa in December 1974, 624 km from the Minnesota test site. The feathers, skin and backpack of this bird were otherwise undamaged when examined.

Evidence indicates that the radio transmitter backpack works well on nestling, fledgling and adult eagles. Antenna breakage is minimized and after the transmitter power source fails, the backpack acts as a color marker for continued use. More than one transmitter with separate antennas can be placed in a backpack. The use of two transmitters will become important when monitoring both location and physiological parameters. It is also possible to combine a slow pulsed transmitter (1 per min) for satellite tracking with a more rapidly pulsed transmitter (1 per sec) for location from the ground. This combination, or a single transmitter timed to switch to a more rapid pulse rate for ground tracking, would facilitate global location via satellite during migration, yet permit ground observations for behavioral and recapture studies. For example, the post-nesting-season range of an immature Red-tailed Hawk (Buteo borealis) instrumented and tracked in this study embraced 125 square miles

and measured 19 miles at its longest dimension. This fall hunting range contrasted in size to nesting territories of mature birds in the same area measuring from 1.8 square miles to less than one square mile (Fig. 3). The relation of this immature bird to adults was observed and hunting behavior was recorded (Craighead, F. Jr. 1975).

The weight of the current demonstration RAMS transmitter is 56 g. The smallest available battery pack capable of operating it weighs 33 g, antenna and harness about 10 g. The package without encapsulation thus weighs in the neighborhood of 100 g. A 99 g lithium battery pack would increase the weight but provide an estimated operating time of eight months as opposed to about three. Due to weight considerations the backpack and backsack harnesses appear to be the first choices for satellite feasibility experiments. The backsack has the drawback that it is not readily dropped or released when the package is no longer functioning. Using materials that disintegrate when exposed to sunshine should permit ultimate release at a roughly precalculated time. This can be accomplished by the use of such material to sew the four attachment straps together where they join at the bird's breastbone.

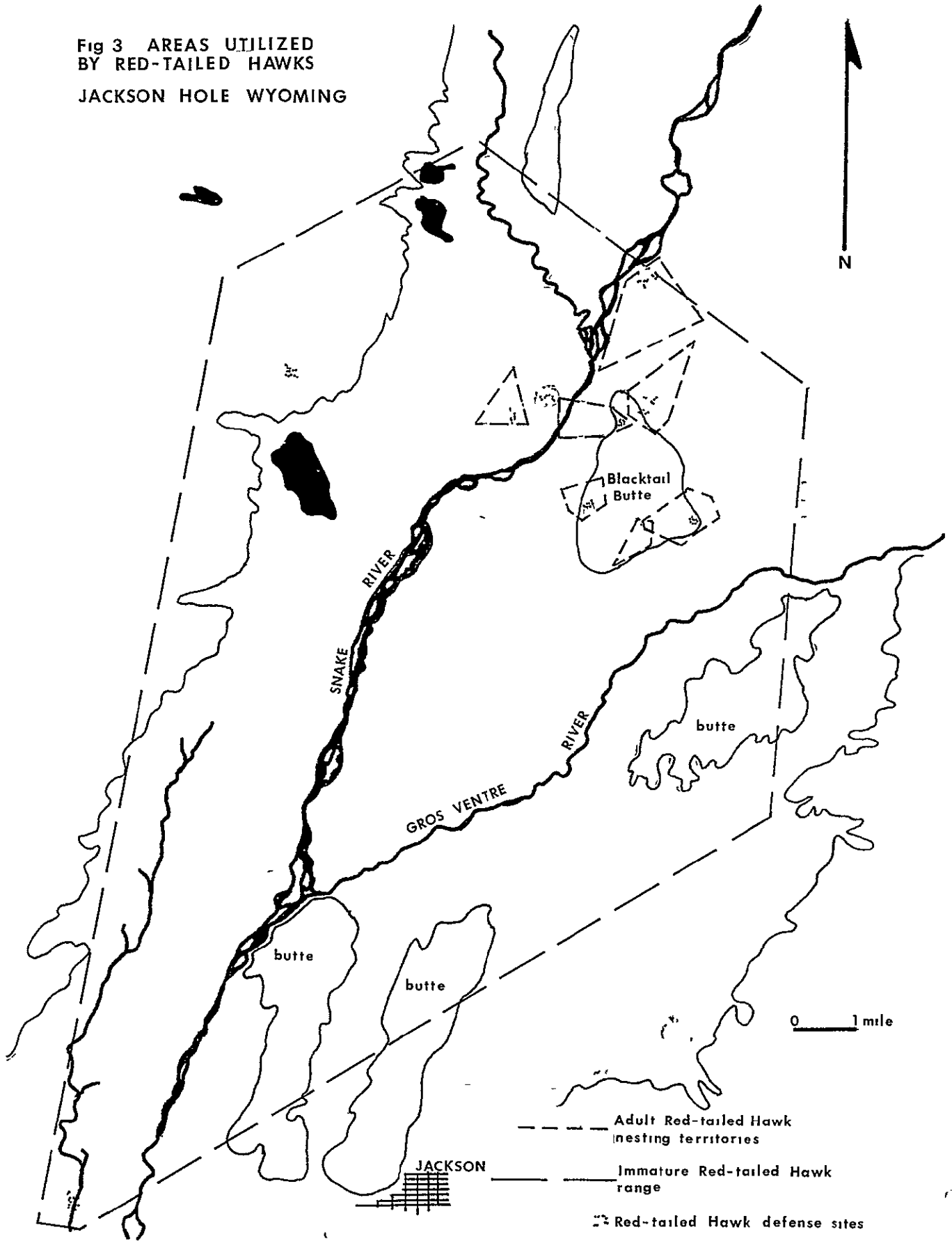
### 2.3 TAILFEATHER ATTACHMENT

Various types of tailfeather attachments (Fig. 1) have been tried with a variety of birds (Bray and Corner 1972; Dunstan 1973). The tailfeather attachment falls off when the bird molts--both an advantage and a liability. Its operational life is limited to periods between molts, and its use is not feasible just before molting. Sooner or later the transmitter is dropped and the bird is free of any encumbrance, a decided asset.

For the tail attachment a 4.3 g lithium battery (2.80 volts) was



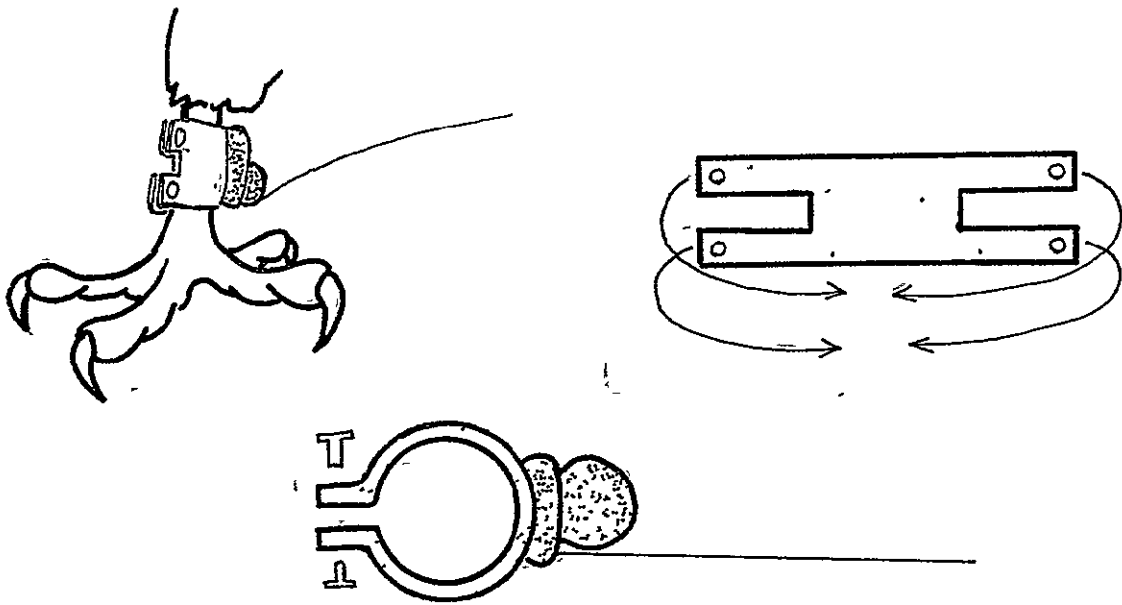
Fig 3 AREAS UTILIZED  
BY RED-TAILED HAWKS  
JACKSON HOLE WYOMING



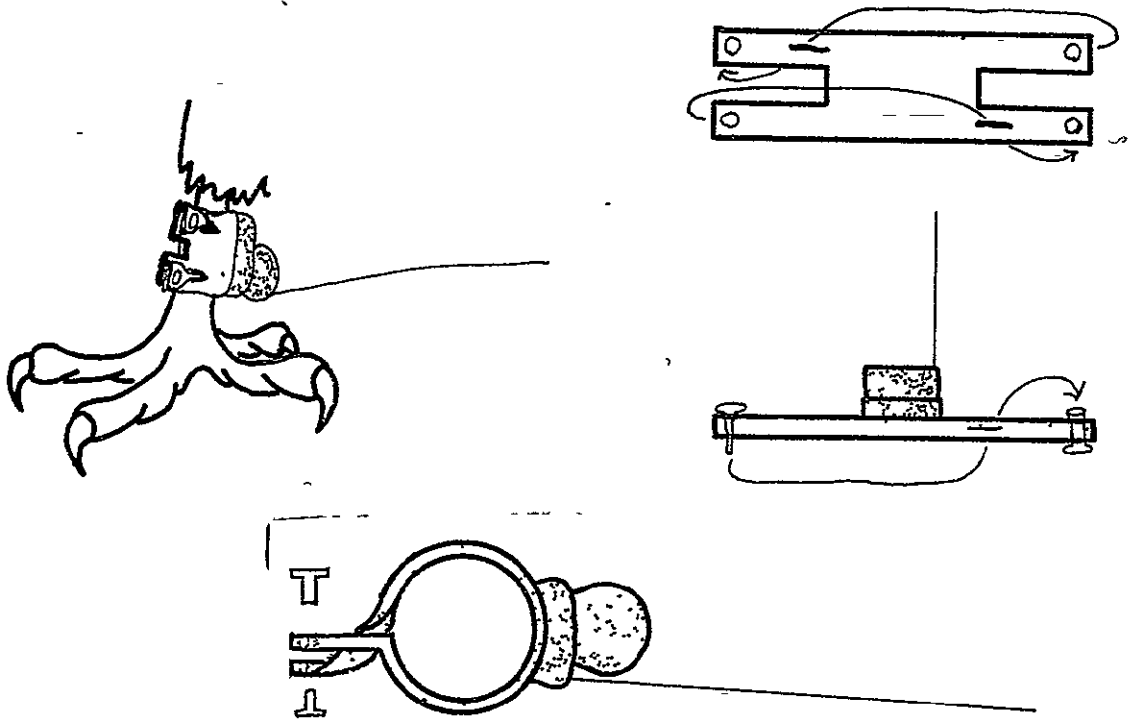
glued to the 2.8 g miniature transmitter using fast drying epoxy. Two strands of heavy dental floss were tied around the transmitter and knotted so as to leave eight loose ends or four ties. These were used to secure the transmitter to the two inner tail feathers. Two square knots were tied around the shaft of each feather, one above the other. The transmitter rested against the ventral surfaces of the feather shafts, and the knots were tied on the dorsal side. Prior to being placed on a bird, the transmitter dental floss wrapping and battery were covered with several coats of epoxy. While the more permanent tail attachment was being secured, either the bird was hooded or its head and eyes were covered with a stocking. This had a calming effect and minimized struggling. In some cases the task was made easier by lightly binding the bird's wings to its sides using several wrappings of cheesecloth or towel. With the bird immobilized, the transmitter was quickly tied to the two central tail feathers about 4 cm below the point of feather insertion. Each tie on both the ventral and dorsal side of the feather was epoxied--a precaution found necessary to prevent slippage. The antenna was tied to the shaft of one tail feather about 5 cm from the tip of the feather. This knot also was coated with epoxy to prevent breaking or untying when picked at by the bird. The antenna length was as near one quarter wavelength as feasible but varied with the subject. Shortening the antenna length reduced operating range in proportion to the reduction. The antenna extended between 2.5 and 12.5 cm beyond the end of the tail. The whip antenna varied from 24 to 30 cm in length.

#### 2.4 TARSAL ATTACHMENT

The tarsal attachment (Fig. 4) was prepared by cutting an unrolled pattern of leather to fit around the leg of the species of bird to be



Tarsal attachment  
flat-type joint



Tarsal attachment  
jess-type joint

Fig 4

instrumented. The transmitter with attached battery was epoxied to the leather. Two snaps permitted rapid attachment or removal. When the transmitter was to be kept on the bird for an extended period of time, a drop of epoxy was placed on each snap. Most tests were made with trained birds that could be released for varying periods of time and then retrieved. The tarsal transmitter assembly was readily snapped on the subject's leg while the bird was sitting on the gloved hand. Hooding the hawks simplified the task. The tarsal attachment was used or tested with a variety of birds--Ravens, Red-tailed Hawks, Prairie Falcons (Falco mexicanus) and Horned Owls (Bubo virginiana).

## 2.5 DISCUSSION

The tail attachment proved to be quite suitable for raptors and Ravens. However, this package weighed under 10 g--transmitter 2.8 g, battery 4.3 g, harness less than 2 g. With the maximum amount of miniaturization available from present advanced technology, the RAMS transmitter could be reduced to 20 g and could conceivably be used to track Golden and Bald Eagles using the tailfeather attachment. The tail assembly was received well by all subjects. After a little initial preening, the transmitter was largely ignored and had no noticeable effects on flight performance. However, comparison of flight performance when the transmitter is attached to one rather than to two tail feathers should be explored. The tarsal attachment proved largely unsuccessful for raptors as the birds often bent, twisted and even completely broke off the whip antennas. It was quite useful and convenient for instrumenting birds for periods of tracking lasting only a few days. It should prove more useful for waterfowl, but winter use with freezing conditions would definitely present problems. Completely waterproofing

any of the transmitter packages may prove to be a problem with waterfowl and ocean birds. This is an area that would benefit by further research and development. Better or improved waterproof encapsulents have much wider use than in animal telemetry and thus might be a suitable subject for NASA funding.

The backpack and backsack harnesses are the logical choices for most situations where RAMS satellite transmitters will be employed. The models used were within the weight allowances determined for birds of between 3-5% of body weight (Anonymous 1973). Adult Bald and Golden Eagles weigh in the neighborhood of 5,000 to 7,000 g. The largest backsack used, 180 g, is between 2.6% and 3.6% of the eagle weights. The current demonstration RAMS transmitter package is also within this weight range.

### 3. FIELD TESTS OF 400+ MHZ TRANSMITTERS (NON-SATELLITE) AND COMPARISONS WITH PERFORMANCE OF OTHER FREQUENCIES

The Nimbus-6/RAMS DCP one-watt transmitter transmits on a frequency of 401 MHz. It transmits a one second message to the satellite once per minute. This is adequate for satellite-animal position location. However, for optimum performance of both long distance (1100 km) and local tracking of migrating birds a switch from the signal of one second per minute to one with a fast enough pulse rate (60 per min) for ground tracking would be desirable. In order to evaluate the 400 MHz frequency for short range ground and aerial tracking we conducted field tests and also tracked free-flying birds (Craighead 1975). This frequency was compared with other frequencies used in tracking animals for location accuracy and for distance received. Tests were conducted under operating field conditions using the equipment available for each system. Overall accuracy of results was influenced by such conditions. These were not engineer designed or controlled tests using accurate meters, gauges, etc., but reflect the variables that biologists encounter while actually tracking and monitoring.

#### 3.1 EQUIPMENT

The following equipment was used in comparing the various UHF and VHF frequencies tested:

##### Receivers:

148 MHz ten channel receiver, Freq. stability, (Center freq.)

+/- 100 Hz.

400 MHz receiver as above with 400 MHz converter for antenna.

150 MHz three channel receiver, 150-151 MHz range, Sensitivity-140 dbm,  
freq. stability, 2 kHz drift.

220 MHz receiver, 12 channels, 220-222 MHz, Sensitivity-140 dbm,  
freq. stability less than 2 kHz.

#### Antennas:

148 MHz two-element beam, hand-held, stowable. Gain 6.5 dB minimum.

Half power beam width 20-75 degrees. Front-to-back ratio 14 dB.

148-150 MHz, four-element yagi, modified.

220 MHz, eleven-element yagi, gain 13.2 dB. front-to-back ratio  
20 dB, one half power beam width 48 degrees.

220 MHz five-element yagi.

400 MHz eleven-element yagi with converter.

#### Transmitters:

148 MHz, sealed metal case, power in three volts.

400 MHz, power in three volts.

150 MHz, power in one and one-half volts.

220 MHz, PF falcon single stage, power in one and one-half volts,  
Golden Eagle two-stage, power in three volts

### 3.2 ACCURACY TESTS

All transmitters were mounted on cardboard boxes placed on the ground. Transmitters were positioned so that the transmitting antenna was parallel to the ground and broadside to the receiving antenna for best reception under field conditions. All receiving antennas were at a height of 2.25 meters above the ground. The receiving antennas were at an elevation 52 meters below that of the transmitting antennas. The distance (line-of-sight) was 4.5 km (2.8 mi). All tests were for the peak signals; not the nulls.

Accuracy was determined by receiving the signal and turning the

receiving antenna left; then swinging right past maximum signal to fade out, and back left to fade out past the maximum signal. The angle between fade out points (the angle of signal reception) was determined by measurement and listed as + or - from maximum signal. Accuracy as used here is the number of degrees which the receiving system was in error from the actual known position of the transmitter. The error was determined by an observer using a headset and/or a meter.

### 3.3 ACCURACY RESULTS

Eight transmitters were tested with various combinations of antennas (Table 1). The 400 MHz equipment was excellent, had a narrow fade (angle of signal reception) and had accuracy to pinpoint a transmitter to at least  $\pm 6$  degrees.

The 148 MHz transmitters were average, perhaps because the best transmitters had already been used on birds and were not available for tests. Range was average compared with the 150 MHz single battery, less than the 150 MHz dual battery, equal to the 200 MHz single battery unit for Prairie Falcons (PF) and less than the 220 MHz two stage unit for Golden Eagles (GE). The two-element beam hand-held stowable antenna had a reception angle-width of about 30 degrees and an accuracy of  $\pm 8$  degrees or better. This is slightly greater width than for the four-element yagi.

The 220 MHz PF single battery transmitter and equipment was as accurate as the 400 MHz equipment with the five-element antenna, and more accurate than all other equipment with the eleven-element antenna. Range was also best with the eleven-element.

The 220 MHz two stage equipment had slightly greater fade and better pinpointing than other equipment. This is probably due to the



TABLE 1: ACCURACY TESTS OF UHF AND VHF GROUND-BASED TELEMETRY SYSTEMS

Transmitter	Angle of Signal Reception (in degrees)	Accuracy (degrees of error)
400 MHz, ch 5	$\pm 15-18$ <sup>a/</sup>	$\pm 6$ <sup>a/</sup>
148 MHz, ch 5	$\pm 25$ <sup>b/</sup>	$\pm 6-8$ <sup>b/</sup>
	$\pm 30$ <sup>c/</sup>	$\pm 8$ <sup>c/</sup>
150 MHz, single battery ch 1, 3.5	$\pm 25$ <sup>b/</sup>	$\pm 6-8$ <sup>b/</sup>
	$\pm 30$ <sup>c/</sup>	$\pm 6-8$ <sup>c/</sup>
220 MHz single-stage ch 2, 3	$\pm 12$ <sup>d/</sup>	$\pm 4-6$ <sup>d/</sup>
	$\pm 18$ <sup>e/</sup>	$\pm 6-9$ <sup>e/</sup>
220 MHz 2-stage slow pulse	$\pm 15$ <sup>d/</sup>	$\pm 4-6$ <sup>d/</sup>
	$\pm 20$ <sup>e/</sup>	$\pm 6-10$ <sup>e/</sup>
220 MHz 2-stage faster pulse	$\pm 15$ <sup>d/</sup>	$\pm 4-6$ <sup>d/</sup>
	$\pm 20$ <sup>e/</sup>	$\pm 6-10$ <sup>e/</sup>

<sup>a/</sup> 11-element yagi with converter for use on 148 MHz receiver

<sup>b/</sup> 4-element yagi

<sup>c/</sup> 2-element beam

<sup>d/</sup> 11-element yagi

<sup>e/</sup> 5-element yagi

fact that it is a stronger transmitter being tested at the same distance as the others.

#### 3.4 DISTANCE TESTS

All transmitters were mounted on cardboard boxes as for the accuracy tests and placed within 0.5 m of the ground but not flat on the ground. Receiving antennas were 2.25 m above the ground in line-of-sight.

The procedure was to move away from the transmitters and test range and signal strength at intervals of 0.1 mile. The audible signals were monitored using maximum tuning and gain and with the receiving antennas aligned for peak signal reception. Three categories of reception were used. Good was easily heard by the observer with a headset and included all the area out to the point at which the signal was difficult to hear. From this point the signal was classified as Faint until it was almost inaudible. Very Faint indicates that the signal could be detected only if the receiver was perfectly tuned, the antennas oriented properly and the ambient noise level very low.

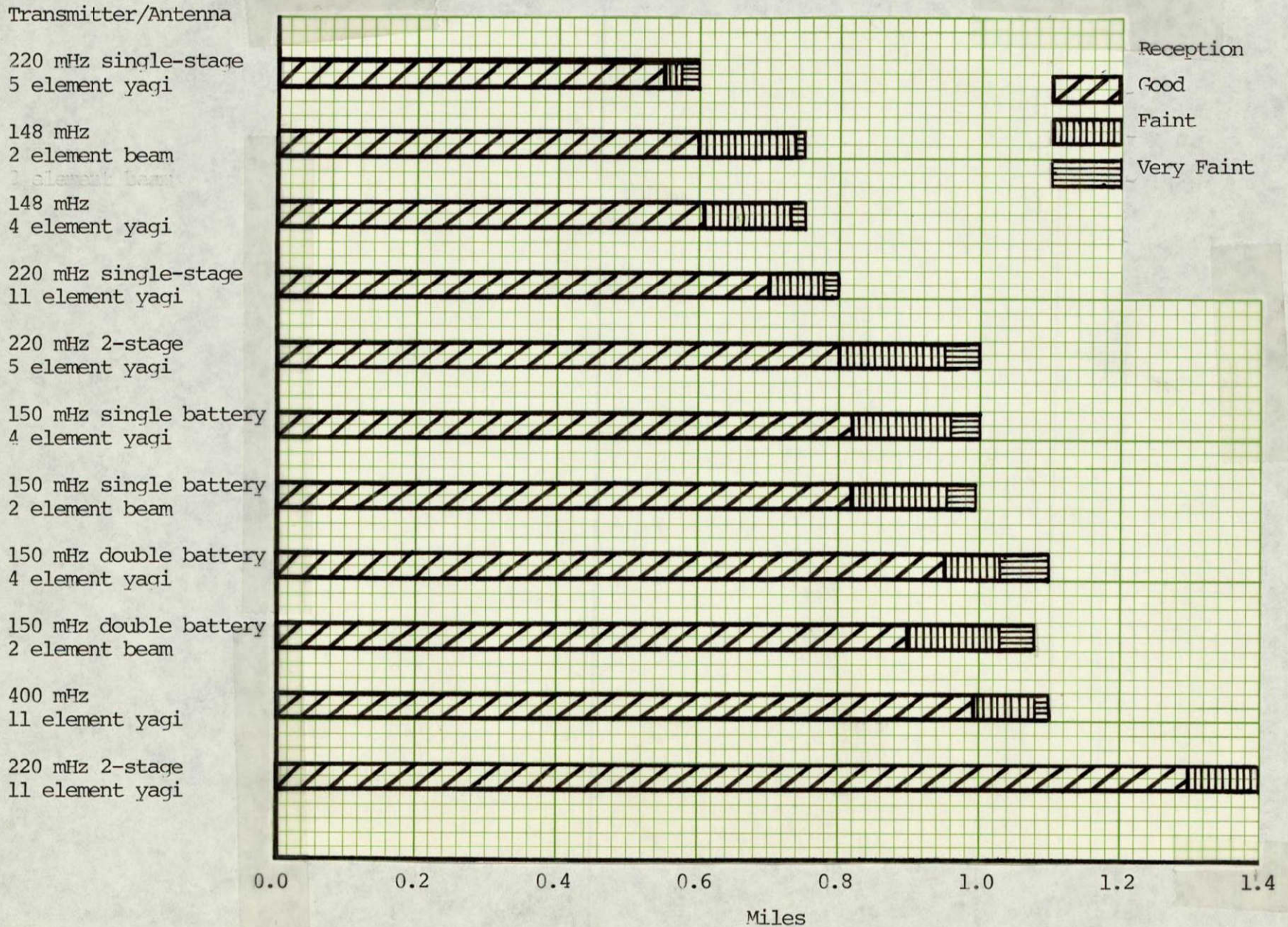
#### 3.5 DISTANCE RESULTS

Eleven tests were run with various transmitter receiver combinations (Figure 5). The 220 MHz single battery unit with the five-element antenna dropped out first, probably because the lead-in wire was not exactly measured to the frequency. It was approximately 7 m long.

The 148 MHz transmitter with either the two-element beam antenna or the four-element yagi dropped out next. Both receiving antennas seemed to work about equally well.

The 220 MHz PF (prairie falcon) single stage transmitter with eleven-element antenna dropped out third.

Fig. 5 DISTANCE TESTS OF UHF AND VHF GROUND-BASED TELEMETRY SYSTEMS



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The 150 MHz double battery (3.0 volts vs. 1.5 volts) transmitter dropped out fifth. The yagi antenna performed slightly better than the two-element beam.

The 400 MHz transmitter with the eleven-element antenna and converter dropped out sixth and may have been received for a greater distance if the pulse rate had been faster.

The 220 MHz GE (golden eagle) two-stage transmitters dropped out last and were still detectable but in the "faint" category at 1.5 miles (Fig. 5). One would expect these two-stage (2 transistor) units to outperform the single stage units.

Additional testing could be done if a line-of-sight distance of 40 miles was feasible and transmitters were suspended more than 2 m above the ground. Vertical height of either the transmitting or receiving antenna is very important in distance tests and range increases dramatically as either is raised above the ground.

### 3.6 OTHER TESTS AND DISCUSSION

Tests using 32 MHz transmitters were not conducted in this series of tests but transmitters on this frequency were used operationally in tracking elk and grizzlies for thousands of tracking days. The performance of this frequency using comparable tracking systems was compared with the other field tested systems and a judgement decision formulated.

In field use it takes a great deal of time and tracking experience to learn all the little idiosyncrasies of a radio tracking system. The directivity varies with terrain, attachment methods, subject activity, equipment configuration and other variables. Nevertheless, the impressions obtained in using and comparing the different systems are that the range at which signals could be received was more consistent

with the 32 MHz frequency than with the others. Signals could be picked up with hills and low mountains intervening. Transmission and reception were better than line-of-sight. When transmitters were low (1-2 m) above the ground) signal range and directivity were more consistent on 32 MHz. Signal directivity as well as range was excellent in line-of-sight and ground-to-air with the higher frequencies. Terrain absorption seemed to be proportionately greater with the higher frequencies. Directive "bouncing" or signal reflection was proportionately greater with the higher frequencies.

In very rugged country shielding effect or signal reflection could at times make position location and tracking quite difficult when using a 400 MHz frequency, but change of receiving position tends to eliminate errors. A very decided advantage of the 400 MHz frequency is the very small transmitting and receiving antennas that are used. A UHF frequency permitting small receiver and transmitter antennas appears to be suitable not only for satellite tracking but for many applications of ground-to-ground location while tracking migrating birds.

The 400 MHz frequency has been used to study movements of Herring Gulls (Williams, 1974). The performance of this UHF system versus VHF systems are summarized by Lawson et al. (1976). They found the range of the telemetry system to be limited primarily by the radio horizon; strong signals were received at a distance of 84 km and the system was effective through 1 km of forest and over low hills. In their experience, "the range of comparable 150 MHz and 432 MHz systems is similar in light forest and low hills and the latter is superior for open water or flat country", (Lawson et al. 1976, p. 362).

#### 4. TEST RESULTS OF NIMBUS 6/RAMS DCP TRANSMITTER

Before feasibility experiments could be conducted on free-flying raptors it has been mandatory to test the RAMS breadboard transmitter designed by Varney and Pope (Varney and Pope 1974) with the Nimbus 6 satellite. The opportunity to do this occurred in 1977 and stationary tests were run from January 28 through November 21, 1977. The proposed experiment and some of the results are presented in the following pages under status Report and Experiment Proposal.

The location results from a transmitter having less than optimum frequency stability are encouraging. (NASA frequency specifications for the Nimbus 6 require no more than a 4 Hz drift in 15 minutes.) Hopefully, the present NASA frequency specifications which are difficult to obtain with small transmitters will be relaxed in order to permit biological monitoring of a wider range of animals. The average error for location was 19 km (12 mi) and the frequency of contact with the satellite using a whip antenna was quite good. Research and development on antennas done by Georgia Tech. under a NASA contract may be applicable in improving antenna performance. The test results indicate that with minor modification, transmitters for field use can be constructed and a feasibility experiment carried out on free-flying migrating birds. Location accuracy can be improved but is more than adequate for many migration and movement studies under consideration. Computer programming will be essential for data reduction and analysis but sufficient data is available from the fixed position tests to complete this step prior to conducting a feasibility experiment with the Nimbus 6 satellite.

#### 4.1 EVALUATION OF OSCILLATOR STABILITY ON RAMS LOCATION ACCURACY: EXPERIMENT PROPOSAL SUBMITTED TO NASA (1/3/77)

##### 4.1.1 Objective

To test a breadboard DCP transmitter built as part of a NASA-sponsored study (ARC work order A-91082A) with the Nimbus-F Random Access Measurement System to determine typical location accuracy.

##### 4.1.2 Background

The Environmental Research Institute (Moose, Wyoming) is sponsoring or conducting several development and research efforts which will eventually lead to the use of satellite data collection and location systems in ecological studies of birds and small mammals. Instrument packages weighing 100 grams with a volume of 30 cm<sup>3</sup> would be practical for use on large raptors or waterfowl. Reduction of size and weight by another factor of 10 would allow use of such equipment on passerine birds. Battery life for instrument packages should be from several months (minimum) to a year.

With such severe size, weight, and power constraints, it may be extremely difficult to design instrument packages that comply with specifications such as those of the present RAMS system. Providing sufficient oscillator stability is one of the most difficult problems to solve. Antennas for a bird-carried package will probably be limited to simple whips or dipoles.

Presently operational RAMS data collection platforms use temperature-compensated oscillators with considerable thermal insulation or close thermal coupling to relatively constant temperature sea water, or else active thermal control such as oscillator or crystal ovens. Such techniques are capable of providing 1 part in 10<sup>8</sup> frequency stability for 15 minutes, but are considerably more bulky or require more DC

power than allowable in equipment suitable for use on birds. It is likely that oscillator stability and location accuracy will be tradeoffs that should be considered if very small instrument packages are to be used in future systems.

#### 4.1.3 Transmitter Performance

The breadboard transmitter which will be used for the test has performance characteristics outlined by Varney and Pope and included above. They are typical of those which could be obtained with reasonable confidence in a unit which is extremely small and has low average DC power consumption.

The transmitter as described in the report has been modified by the addition of logic circuitry which provides bit sync, frame sync, ID, mode bits, and dummy data (system clock). The logic is presently configured to turn the transmitter entirely off between transmissions to minimize DC power requirements. The oscillator stage is turned on 1 second before transmission to allow the carrier to stabilize. The adequacy of this mode of operation will be evaluated during the test.

The frequency/temperature slope of the oscillator is relatively high ( $150 \text{ Hz}/^{\circ}\text{C}$ ), but temperature changes during the 15 minute satellite overpass time can be held to small values with thermal insulation. Experiments will be conducted with various amounts of insulation to determine the minimum amount required under typical outdoor conditions.

The short term stability, frequency drift during the 1-second transmission, and spurious output signals from the transmitter have been checked. All appear to be satisfactory.



#### 4.1.4 Test Methods and Setup

The package will be located on the roof of the Ford Aerospace and Communications facility in Palo Alto, California (latitude  $N37^{\circ}25'39''$ , longitude  $W122^{\circ}06'06''$ , elevation 60 ft.) from approximately January 3 to February 28, 1977. DC power will be provided by a laboratory-type power supply. The transmitter will be connected to a quarter-wave vertical whip antenna on a quarter-wave diameter circular ground plane. RF power at the antenna input connector is 1.0 watt. The package will transmit for 1 second at 62 second intervals continuously.

GSFC will be contacted by telephone during the first few days of operation to verify that transmissions are being received by the satellite. Thereafter, periodic mailing of location data to Palo Alto is requested.

Various ID codes may be used for the package if desired in order to check the effect of initializing conditions in the location computation algorithm. Presently assigned IDs are 0004<sub>g</sub> and 0602<sub>g</sub>.

#### 4.1.5 Use of Data Obtained

The primary objective of the proposed test is to obtain engineering data on typical location accuracy which could be obtained with the RAMS system, under field conditions, when using a transmitter with less than optimum performance. This information is expected to be useful while making design tradeoffs and system performance allocations when preparing for experiments using extremely miniature equipment in the future.

A secondary goal is to demonstrate the operation of a partially miniaturized transmitter in response to the expressed interest of several

potential user agencies; such demonstrations provide credibility for development efforts thus far and often assist further development by stimulating user interest and support.

We do not anticipate that the transmitter will be used in its present state of development for any operational experiments. Permission to conduct the proposed test will not be interpreted as a type approval of the equipment by GSFC if satisfactory results are obtained. If any manuscripts are submitted for publication which discuss the use of the transmitter with the RAMS system or results of the test, an advance copy will be provided to GSFC for review for accuracy.

Joel R. Varney  
F. C. Craighead Jr.  
3 January 1977

#### 4.2 STATUS REPORT: RAMS TRANSMITTER LOCATION ACCURACY TEST

This report briefly summarizes the results (to date) of a location accuracy test in which the Nimbus-6 Random Access Measurement System (RAMS) is determining the apparent position of a transmitter with less frequency stability than RAMS specifications. The objective of this test is to evaluate the feasibility of using transmitters that are extremely small and have restricted performance capabilities in satellite doppler location measurement systems (see the following experiment proposal).

##### 4.2.1 Transmitter Description

The transmitter used in the experiment is described by Varney and Pope 1974. It is a breadboard transmitter that was partially miniaturized during a previous study program for the Environmental Research Institute. Thick-film fabrication methods were used. Data circuitry has been

added to the transmitter which generates RAMS-compatible identification and synchronization codes, along with high-resolution temperature sensing and encoding circuits. Two of the system's four available telemetry words are used to transmit temperature data with 0.02°C resolution.

The transmitter meets RAMS system specifications for RF output power, modulation format and phase accuracy, and spurious frequency emissions. It uses an oscillator, however, which is less stable than the 1 part in  $10^8$  per 15 minutes specified by NASA. The transmitter frequency changes 3 parts in  $10^7$  per °C, which is expected typical performance for a very small, low DC power consumption transmitter with minimal thermal insulation.

The antenna used for the majority of the time during the experiment has been a quarter-wave vertical whip mounted on a square ground plane which measures 13 inches on a side ( $\frac{1}{2}$  wavelength). Data is presently being taken with a smaller ground plane (4 inches square).

#### 4.2.2 Experimental Configurations

The transmitter was placed in operation on the roof of the Ford Aerospace facility in Palo Alto, California on January 28, 1977. Location data has been received nearly continuously since then, with short periodic interruptions to make changes to the equipment setup.

The following configurations and operating modes have been used:

- Transmission for 1 second at 62 second intervals using the larger antenna ground plane.
- Continuous transmission with the larger antenna ground plane.
- 1 second transmissions with a HP8660 frequency synthesizer replacing the transmitter oscillator.
- 1 second transmissions with the smaller antenna ground plane.

### 4.2.3 Data Analysis

Analysis of the location data is in progress; Only a limited sample has been reduced at the present time. Factors that have been examined to some extent are:

- Ways of identifying inaccurate location data (high two-pass velocity, low standard error values, noisy data)?
- Effects of transmitter ON-time on location accuracy.
- Temperature and oscillator stability effects on location accuracy.
- Location accuracy differences between day and night passes.
- Percentage of possible messages received by satellite.

The RAMS data printouts from GSFC are being entered on a magnetic disk for storage and later computer processing. Location errors for each experiment configuration will be plotted and compared, and regression plots will be made of location error versus factors such as temperature change during a pass, number of messages received, goodness of fit (SE or F values), and other parameters.

### 4.2.4 Preliminary Results

A number of preliminary results have been obtained from the sample of data examined thus far:

#### 4.2.4.1 Antenna adequacy

The frequency of contact with the satellite when using the vertical whip antenna is satisfactory. Up to 15 messages have been received on overhead passes. Sufficient messages for a location calculation were generally received for at least 4 passes per day (2 noon passes and 2 midnight passes). Slightly reduced coverage is expected with the smaller ground plane, but the difference has not yet been determined from the data.

#### 4.2.4.2 Location accuracy obtained

After eliminating obviously bad locations (high two-pass velocity, poor fits, etc.), typical one pass location errors with the internal transmitter oscillator were 4 miles for night passes and 20 miles for day passes.

#### 4.2.4.3 Oscillator turn-on effects on location accuracy

No significant difference in location accuracy has been observed between the continuous transmission mode (oscillator always on) and the 1 second per minute mode (oscillator turned on 2 seconds before the transmission). Any location accuracy effects caused by oscillator warm-up time are small compared to other sources of error.

#### 4.2.4.4 Temperature effects on location accuracy

Temperature changes during the time the satellite is in view of the transmitter are the primary source of location error. Typical temperature change during a night pass (determined from telemetry data) was  $0.015^{\circ}\text{C}/\text{minute}$  with typical location error of 4 miles. During day passes, the temperature change increased to  $0.1^{\circ}\text{C}/\text{minute}$  and typical location errors increased to 20 miles. Estimated transmitter frequency changes during a 15 minute pass corresponding to the measured temperature changes are 34 Hz at night and 225 Hz during the day.

Eliminating the frequency changes by operating the transmitter with the oscillator replaced by a frequency synthesizer (frequency drift  $\leq 3$  parts in  $10^8$  per 24 hours) reduced the average one-pass location error to 1.8 miles, and the two-pass error to 2.4 miles.

#### 4.2.5 Discussion

The results obtained thus far are very encouraging, and indicate that the accuracy of RAMS location data from a transmitter with comparatively low frequency stability is acceptable for many applications. Average error for combined day and night passes is on the order of 12 miles, which would be quite satisfactory for animal or bird behavior studies where large daily movements occur.

The frequency of contact with the satellite obtained while using a simple linearly-polarized whip antenna (instead of circular polarization) is also very encouraging. Similar simple antennas are the most preferable for transmitters for animal behavior studies, and the results indicate that use of such antennas should be practical.

#### 4.2.6 Future Plans

Sufficient data has been accumulated to satisfy the main objectives of the experiment. Work remaining to be done consists primarily of data reduction and analysis.

An additional experimental task that is planned for the near future is to make measurements of transmitter frequency during satellite overpasses for later comparison with location accuracy results. This will allow the effects of frequency drift on location accuracy to be more accurately established than is possible from temperature telemetry data alone.

J.R. Varney

11 November, 1977

#### 4.3 DATA SHEET INFORMATION

Information from a typical data sheet is shown in Table 2. The locations are more accurate at night than in the day because the temperature changes are usually less. The locations for March 3, 1977 are used here to illustrate location data. On orbit 8479 at 6 hours and 48 minutes the most likely location was calculated to be in error by 7.34 km (4.56 mi). The signals (1 sec duration at 62 sec intervals) produce two locations where two orbit lines are bisected (Balmuno et al., 1968). The transmitter is at one of these two intersections. These intersections are normally several hundred miles apart on the surface of the earth. Knowledge of the previous position of the transmitter can be used to eliminate the ambiguous location. In this case (Table 2) it was 3616 km (2247 mi) in error, hence was eliminated as a probable transmitter location. Other locations for the same day were as follows:

Orbit 8472	17 hrs 47 min:	29.35 km (18.24 mi) error
Orbit 8473	19 hrs 29 min:	40.55 km (25.20 mi) <u>error</u>
Orbit 8474	21 hrs 20 min:	15.40 km (9.57 mi) error
Orbit 8479	6 hrs 48 min:	7.34 km (4.56 mi) error

Even the greatest error revealed here of 41 km (25 mi) would provide valuable data on a bird migrating over a long distance as for example from the Arctic to the subtropics. The most accurate location of to within 7.34 km is close enough that if a bird such as a bald eagle were stopping over in flight it might be possible to visually locate it knowing the habitat the species prefers. If the bird were carrying an additional standard tracking transmitter (3 g) on the same or a different frequency, it could be located and observed even if the error was the greatest shown for March 6, 1977; that is, 41 km.

TABLE 2

## MODIFIED DATA SHEET

Date	Orbit No. Since launch	No. Transmissions Received This Orbit	Day Hours (Since Jan.)		Time in GMT		
			Minutes	Seconds	Milliseconds		
3/6/77	8479	13	65	06			
			One Transmission		48	02	908

Platform Id=0602

One pass position

Indicated preference\*

Lat Long

37.39 237.83

47\*---Most likely location based on curve fit (47% S.E.)  
The calculated location 7.34 km error (4.56 mi)

28.03 227.02

37<sup>2</sup>---Ambiguous location point 3616 km error (2247 mi)

Palo Alto Location

37.43 N latitude

237.90 E longitude

To obtain Pacific Standard Time  
subtract 8 hours.



#### 4.4 DATA MANAGEMENT

Data reduction and analysis even for a relatively short feasibility experiment is a tremendous task unless computer assisted. The development of a computer program or programs to retrieve, summarize and display pertinent data is a necessity. A report on computer programming and data reduction relative to the Nimbus 6/RAMS transmitter tests, though not a part of this report, will be completed by Joel Varney at a later date and made available to NASA.

## 5. FEASIBILITY EXPERIMENT POSSIBILITIES

Although further equipment development and testing will be required, we have now reached a point where we can consider various feasibility experiments with the Nimbus Satellite using a large instrumented raptor as the subject. The approximate 100-200 g weight of the RAMS transmitter package is well within the weight-carrying capacity demonstrated for Golden or Bald Eagles. The current weight precludes all but the backpack attachments, but this does not appear to offer any real deterrents. Whether a Bald or Golden Eagle is selected may well depend upon the time of year when experiments can be undertaken. Timing will depend upon a number of factors, one of which will be the construction and testing of two to six transmitters for field use in a feasibility experiment. The major objective will be to accurately track an instrumented bird or birds over a considerable distance for an extended period of time, perhaps a minimum of three months. Ideally the experiment not only should demonstrate the feasibility of satellite tracking, but also should provide information not hitherto available. It appears as though a non-game bird such as a Golden or Bald Eagle would be the candidate for a first experiment but large waterfowl or oceanic birds could be considered. User agency demand for future satellite tracking programs may well develop in the area of migratory tracking of waterfowl.

Numerous feasibility experiments are possible but only a selected few of the more promising are treated here on a tentative priority basis. Through the Environmental Research Institute we are continuing our efforts to conduct a first feasibility experiment.

## 5.1 GOLDEN EAGLE

1. The tracking of a mature or an immature Golden Eagle of the year (fledgling) from a far northern nesting site, perhaps within the Arctic Circle, would provide a long flight over a relatively short period of time (Fig. 6). A three month battery life would suffice though longer would be desirable. In 1976 a limited survey was made of nesting Golden and Bald Eagles in Alaska with the specific objective of locating active nests that could be readily reached on short notice (Fig. 7). Both the Golden and Bald Eagles tend to return to and use the same nest year after year or they switch to a nearby alternate nest site. The time for instrumenting an adult eagle would be mid-July to early September. Fledglings could be fitted with a transmitter in late August. Trapping methods for capturing adults have been worked out for practically any time of the year.

2. Golden Eagles as well as Bald Eagles regularly concentrate in very localized areas during winter months and in some cases in spring. Such concentrations are primarily related to sources of available food. Adult eagles of either species trapped and instrumented at concentration sites should provide migratory or dispersal data and shed information on where Golden Eagles come from or disperse to from such concentration sites as those in Colorado or Texas. These movements could be extensive or rather limited in length as compared to northern nesting migrants instrumented in the fall of the year.

James L. Rous, Non-Game Specialist, Office of Migratory Bird Management, U.S. Fish and Wildlife Service is with collaborators formulating a Golden Eagle management plan. He has expressed interest and suggested support for satellite tracking of eagles to obtain



Fig. 6 Fledgling Golden Eagle near Arctic Circle



Fig. 7 Bald Eagle nest: Alaska



information for management decisions. The Golden Eagle is protected by federal law, yet its predatory habits continually bring it in conflict with ranchers. There is growing pressure to develop management plans for this bird that take into consideration their actual or assumed predation on domestic lambs. This is an economic problem that in view of the eagles' protection can only be solved by obtaining factual biological data. One such situation that presents such a biologic-economic problem and lends itself to at least partial solution by satellite tracking is presented by Golden Eagle concentrations at spring lambing areas.

Near Dillon, Montana on the Helle and Christensen's ranches immature Golden Eagles concentrate during the spring lambing season. At this time (May) eagles take some lambs and they also feed on carrion, that is, lambs that have died at birth or from other causes. Currently some eagles are being trapped and marked with colored wing discs (patagial markers) as well as with leg bands. If one or more of these immature Golden Eagles were instrumented with a transmitter and tracked by satellite in a feasibility experiment some data on the concentration and dispersal of these eagles might be quickly obtained with good probability of more from an expanded program. The information would be most useful in fashioning a management program for these eagles, the cost might be less than using conventional methods and solutions to a predation problem of economic concern might be expedited. Funding for such a project should be readily available. The captured eagles would have to be instrumented in April-May thus the earliest date for instrumenting the birds would be 1979. It is possible that tested operational hardware will be ready by this date if there is early funding and an accelerated program of construction.



3. Intensive studies of nesting Golden Eagles and associated raptors have been carried out on the Snake River Birds of Prey Natural Area near Boise, Idaho. This area is under the jurisdiction of the Bureau of Land Management and the research is supported by this federal agency. Information is scarce yet desirable on the migratory movements of the adult nesting eagles as well as on the movements of fledglings. Satellite tracking of these birds could provide needed information for management of the eagle population on this federal preserve. Bureau of Land Management officials have expressed interest in helping to fund equipment development leading to satellite tracking.

#### 5.2 BALD EAGLE

The Bald Eagle, our national bird, was given protection under the Bald Eagle Act of June 1940. Numerous federal, state and private programs are underway to protect this bird and its habitat and to gather a wide range of information that will insure that it receives adequate protection. Data for management is needed on Bald Eagle movements and migration. Information has been and is being obtained through banding operations. Banding of eagles and other migratory birds falls under the jurisdiction of the U.S. Fish and Wildlife Service and the Canadian Wildlife Service. Since 1955 about 2000 Bald Eagles have been banded but as of August 1975 only 232 returns had been filed (Spencer 1976). Information on migration is thus slow in accumulating. It could be greatly speeded up and enhanced through a program of satellite tracking. Because of the Bald Eagle's national importance, large size, and migratory movements it is a suitable bird for one or more feasibility experiments in satellite tracking.



The majority of breeding Bald Eagles are found along the coasts of Alaska and western Canada. Estimates range between 30,000 and 50,000 birds (Spencer 1976). Southeast Alaska alone has an estimated breeding population of 8,000 eagles (King et al. 1972). Some 2,760 eagle nests have been located along 3,500 miles of surveyed coastline in southeast Alaska (Robards, F.C. and J.I. Hodges 1976). Both fledgling and mature Bald Eagles could readily be instrumented in southeast or northern Alaska but there would be less assurance of a long flight than would be the case with the Golden Eagle.

Bald Eagles, like the Golden Eagles, also form winter concentrations where food such as fish, wounded waterfowl and carrion are available. Capturing and instrumenting for satellite tracking can best be performed at or near nest sites or in the vicinity of winter concentrations.

Very little is known about the movements of West Coast Bald Eagles. One or more Bald Eagles concentrating along the Skagit River in Washington could be readily trapped, instrumented and its dispersal flight pattern monitored by satellite. A mature bird would probably move to a spring nest site. Such a project could be conducted cooperatively with the Washington Department of Game, the U.S. Fish and Wildlife Service, the Nature Conservancy and interested researchers. The optimum time for instrumenting would be December. Similar but much larger eagle concentrations occur along the Chilkat River, Alaska in the fall of the year. Here a cooperative project of trapping and marking could be worked out with the U.S. Fish and Wildlife Service. Bald Eagles could also be trapped and instrumented at a number of winter concentration areas throughout the U.S. such as McDonald Creek, Montana, along the Mississippi in Illinois or in the San Luis Valley of Colorado.



Eagles instrumented at winter concentrations could migrate anywhere from a few hundred to well over a thousand miles.

### 5.3 CARIBOU (Rangifer tarandus)

A feasibility experiment which could be conducted immediately and would provide data and experience for a transition from the present state of knowledge to future experiments with eagles is a caribou migration feasibility study. Production model transmitters are presently available from Handar Inc. weighing 135 g (transmitter plus digital encoding circuitry). With these electronic components a package weighing approximately 444 g (about 1 lb) or not over 906 g (2 lb) could be attached to a caribou in Northern Alaska and its migration route traced as an interim experiment.

The present RAMS transmitter weighing 56 g (Varney and Pope 1974) with a two-year battery life, waterproof encapsulation, antenna and harness would weigh between 1 and 2 pounds (Craighead, F.C. Jr. 1977) but is not in production; this transmitter will be further miniaturized as discussed in this report before going into production. A weight of 1 to 2 pounds is less than the weight of equipment we have successfully used to radiotrack grizzly bear (Ursus arctos), black bear, elk and mountain sheep (Ovis canadensis).

Biologists of the Alaska Department of Fish and Game have been consulted and they are eager to cooperate in such an experiment. More information is being sought on the migration routes and wintering areas of caribou. The Central Arctic herd, for example, has been steadily declining in recent years and a ground-based radiotracking study is being conducted by the Alaska Department of Fish and Game.



A satellite feasibility experiment would add valuable information to this study. Exploration and development of non-renewable resources has an adverse effect on the Central Arctic subpopulation in the form of interference by the pipeline with their movements and other behavior. Such effects should be studied in other herds that move over longer distances. Knowledge gained by a satellite feasibility study would set the stage for more detailed studies of caribou herds, would aid in management of these populations, and would provide a firm foundation for future experiments with birds. The Environmental Research Institute is currently preparing a proposal to secure funding for this project and is seeking NASA approval of the experiment. Caribou can, if necessary, be instrumented throughout the year but the late summer and the fall months would be the optimum time.

Various state and federal officials from a number of resource management agencies have been contacted concerning possible feasibility experiments with both eagles and caribou. More communication, discussion, and interaction will be necessary once a decision for an experiment is reached. It would be desirable if this could be a cooperative venture with a potential user-agency such as the Alaska Department of Fish and Game, the U.S. Fish and Wildlife Service, the Bureau of Land Management, and the U.S. Forest Service.



## 6. SUGGESTIONS FOR EXPEDITING A FUTURE PROGRAM

Even while work is progressing to produce a half dozen miniaturized transmitters for field use, and feasibility experiments are under way, there should be a sustained effort to organize a future program of satellite tracking of birds. A key to this is creating interest and obtaining support of user agencies and other organizations. User agencies that could benefit from a program of satellite tracking of birds and that have expressed an interest are:

The U.S. Fish and Wildlife Service, Dept. of Interior  
The Bureau of Land Management, Dept. of Interior  
National Oceanic and Atmospheric Agency, Dept. of Commerce  
National Marine Fisheries Service, Dept. of Commerce  
The Bureau of Reclamation, Dept. of Interior  
The U.S. Corps of Army Engineers, Dept. of Defense  
U.S. Forest Service, Dept. of Agriculture  
Various State agencies—for example, Wash. State Game and Fish Dept.  
Private Organizations such as: The National Geographic Society,  
Nature Conservancy, Eagle Valley Environmentalists, Inc.  
and the Environmental Research Institute.  
Researchers from various universities

Most of these have not only expressed interest in one way or another but have made tentative offers of financial help to support one or more phases of the pre-program efforts. Additional organizations that could benefit from satellite tracking of animals or utilize the telemetry system are mentioned in the Santa Cruz report.

New and improved data gathering techniques that will enable state and federal agencies to better carry out their responsibilities is desired by the above listed agencies. Tracking and remote sensing by satellite could expedite numerous research projects, provide information needed for management plans of migratory species, provide data for



Environmental Impact Statements and obtain critical information not now available on some endangered species. Of all the organizations listed the U.S. Fish and Wildlife Service would probably have the most to gain from a bird-satellite tracking program.

To date the status of our research and the results of experiments have been disseminated through technical papers, workshops, popular articles, slide lectures, movies, discussions and correspondence. More of this work is needed to inform potential users and to generate interest and confidence in the practicality of a satellite tracking program.

After feasibility experiments have been successfully carried out it is up to the user agencies to expedite and to finance their programs. Initially most of the support for such a program must of necessity come from federal and state agencies using appropriated funds. However, if NASA could support and help finance a number of "feasibility experiments" once the first one proves successful, it should provide tremendous impetus for getting a program going and it would tend to eliminate a gap of inactivity between a first experiment and later operational programs--a gap that otherwise seems inevitable.

#### 6.1 INTERESTED FIELD RESEARCHERS

In order to help expedite a future program of satellite monitoring of migrating birds various field biologists were contacted to determine their interests. Their names, addresses and a brief proposal abstract are listed. Only those working with large birds are included and these serve merely as a sample. The field biologists have been categorized according to subject bird of interest to them. The projects, though in many cases proposed by individuals, would have to be done in collaboration with NASA and in cooperation with a federal or state



agency. Long proposals or those somewhat duplicating others have been shortened.

#### 6.1.1 Golden Eagle

Frank C. Craighead, Jr., F. Lance Craighead, David Mindell,  
Environmental Research Institute, Box 156, Moose, Wyo. 83012.

To Instrument Nesting Golden Eagles in the Far North to Determine Migratory Patterns and to Instrument Eagles at Winter Concentrations and at Spring Lambing Concentrations to Determine Dispersal Patterns.

This would be a follow up to one or more successful feasibility studies as recommended for this species and could include instrumenting of eagles whose nesting sites are disturbed by oil and gas or other activities on the North Slope to evaluate their response and their ability to relocate and renest.

J. Michael Lockhard, Research Associate, Chihuahuan Desert Research Institute, 800 North Bird Street, Alpine, Texas 79830. To Determine the Migratory Routes of Golden Eagles Wintering in the Trans-Pecos Region of Texas.

Frank Lance Craighead and Thomas C. Dunstan, Environmental Research Institute, Moose, Wyo., and others. To Develop a Cooperative Program of Satellite Tracking of Golden Eagles Migrating To and From the Snake River Birds-of-Prey Natural Area in Idaho.

An interrelated study of nesting raptors and prey species has been completed on the Snake River Birds-of-Prey Natural Area. It has been supported by the Bureau of Land Management, the agency that administers the natural area. Little information has been gathered on the migration of nesting Golden Eagles. Such data is needed for developing and



expanding management plans. A research program of satellite tracking of eagles could be carried out by contracts with the administering agency that has expressed an interest in funding such a project in part or whole.

H.G. Swartz, Professor and Chairman, Biological Sciences Program, University of Alaska, Fairbanks, Alaska 99701. Use of Satellite Telemetry in Tracking Winter Migration of Alaskan Golden Eagles.

Most of the large population of Golden Eagles moves out of Alaska in the winter but we do not know where they tend to end their southern movement. Possibly they go as far as those western sheep-raising states now embroiled in controversy and it is important to find this out. Adults and young of Golden Eagles, as of all species, may be expected to behave somewhat differently with respect to some features of migration and this is an important aspect of migration studies.

The foregoing projects are only a few of the many research activities involving Golden Eagles. Most of these in one way or another could benefit from satellite monitoring. A comprehensive and illuminating program could be worked up among federal, state and independent investigators, perhaps coordinated through the Non-Game Specialists, Office of Migratory Bird Management, U.S. Fish and Wildlife Service.

#### 6.1.2 Bald Eagle

Numerous active field researchers have expressed an interest in using satellite tracking techniques to determine the migratory movements of both nesting and wintering (concentrations) of Bald Eagles. A very informative program could be jointly planned, coordinated, and carried out on the Bald Eagles of western U.S., Canada and Alaska. The following listing of Bald Eagle projects, many of which could be integrated, is an example of what might be done for other large bird



species as well.

Thomas C. Dunstan, Assistant Professor, Western Illinois University, Macomb, Illinois 61455. The Location of Migrating Bald Eagles From the Chippewa National Forest by Satellite Tracking.

Bald Eagle banding studies were begun on the Chippewa National Forest, Minnesota, in 1963 under the direction of John E. Mathisen, U.S. Forest Service. Since then studies on nesting ecology, population dynamics, breeding behavior, and migration have been conducted by government staff, university personnel and students. To date 94 breeding pairs have been identified and 274 young eagles have been banded. However, migration data is accumulating very slowly despite banding, color marking and standard radio telemetry studies. Good data on dispersal and movements up to 640 km (400 mi) from the breeding range have been gathered but little is known about the daily flights or movements over long distances. Banding data has proven that Minnesota eagles from one to three years of age migrate up to 2,720 km (1,700 mi) from the Chippewa but nothing is known about the location of the birds between banding and recovery. The use of satellite tracking and data collection systems would provide much needed information about the movements of migrating Bald Eagles that would complement the data already gathered about the Chippewa population. The satellite system could provide information about direction and rates of migration flights as correlated with weather. Other information such as the location of wintering areas, food habits of wintering eagles, habitat use during migration, and mortality will enable us to provide a 365 days-a-year management plan for one of the most important breeding populations remaining in the



48 contiguous states.

Peter E. Nye, Endangered Species Unit, Wildlife Resources Center, Delmar, New York 12054. Bald Eagle Satellite Tracking Studies on Bald Eagles Wintering in New York State.

The concentration of Bald Eagles wintering in Southeastern New York may be the single largest wintering concentration in the Northeast United States. Up to thirty eagles utilize this area and it is unknown where these individuals are coming from and whether or not they emanate from one general breeding area or many. No banded or color marked individuals have been sighted or recovered during the winter on this area. The area offers an excellent opportunity to utilize satellite tracking to gather data invaluable in protecting the species and its habitat during the entire life cycle. Furthermore, by obtaining information regarding the habits of individual Bald Eagles over an entire year, populations and the overall biology of these birds can be closely monitored, and significant insight into Bald Eagle behavior, problems and protection may be gained. Ecological relationships of these birds have been conducted on this area for three consecutive years so there is a substantial background to augment and help interpret the findings of satellite telemetry.

Jonathan M. Gerrard, 954 15th Ave. S.E., Minneapolis, Minn. 55414 and Douglas W. A. Whitfield, Department of Botany, University of Alberta, Edmonton, Alberta T6G2E8. Use of Satellites To Monitor Day-to-Day Movements of Bald Eagles During Migration.

The large numbers of Bald Eagles nesting in Saskatchewan and our



present studies which show that some of these birds migrate as far south as Texas, New Mexico, Arizona and California makes these eagles ideal subjects for tracking by satellite. Our studies of Saskatchewan Bald Eagles over the course of the past 11 years have provided the essential background for the proposed study. Thus recent surveys have revealed about 4,000 breeding pairs of Bald Eagles in this Canadian province. This population is stable and reproductively healthy. Detailed studies of habitat and of breeding and post-fledging behavior have already been performed (Gerrard et al. 1975). Banding and wing-marking studies have provided some information with regard to the migratory pattern of these birds. Thus, after fledging in August, the young eagles spend 4-8 weeks in the vicinity of their nest before leaving to migrate southward. The eagles go south across the plains of southern Saskatchewan into Montana and North Dakota. Some birds will continue south reaching as far as Missouri, Texas or southern California by mid-winter. Others appear to remain farther north in areas of Montana and South Dakota. One bird, an apparent exception to the usual pattern, migrated to Alaska. While we know in general terms the migration pattern of these eagles, we know very little of the specifics of the day to day movements of individual birds. Such information is critical to the rational management and preservation of a population of birds which covers such a large area during the course of its annual migrations. The long distances covered by these migrating eagles, some of it in areas where there are few roads, means that satellite tracking is the only feasible method of following their migration. Thus, following the completion of feasibility studies satellite tracking of Saskatchewan eagles which winter in the mid-western and



western United States could provide much needed information on the day to day movements of birds of this important species.

Terrence N. Ingram, Executive Director, Eagle Valley Environmentalists, Inc. To Track By Satellite Bald Eagles Wintering Along the Mississippi River.

Movement and migration data are needed for the preservation and management of eagles wintering in the Midwest, specifically in southwestern Wisconsin along the Mississippi River and along the Wisconsin River. Eagle Valley along the Mississippi in Wisconsin has had up to 150 eagles concentrated in a 170 acre area on a single day. Satellite tracking could provide information on the movement of these birds and on their relation to reservoirs as well as to river habitat.

Richard L. Knight, Non-Game Biologist, Washington Department of Game, Seattle Regional Office, 509 N. Fairview Ave., Seattle, Washington 98109. Satellite Tracking of Bald Eagles Wintering Along the Skagit River, Washington.

In winter, Bald Eagles concentrate along the Skagit River in Washington to feed on dead and dying salmon. Although these birds convene in a very restricted area their places of origin are unknown as is their dispersal pattern and migration routes to nesting sites. Information on movements is needed for developing management plans.

Spencer B. Beebe, Northwest Representative, The Nature Conservancy, Northwest Office, 1234 N.W. 25th Ave., Portland, Ore. 97210. Satellite Tracking to Gather Ecological and Movement Data on Bald Eagles Wintering on the Skagit River Bald Eagle Natural Area.



Information on the concentration and dispersal movements of eagles wintering along the Skagit River, Washington, is needed for management plans. Eagles in the natural area preserve are protected, studied and viewed by the public. A cooperative program between State and Federal agencies and private organizations utilizing satellite tracking would provide useful and now unavailable information for protection and management of the eagles.

Christopher Servheen, 235 E. Sussex Ave., Missoula, Montana 59801.  
Feasibility of Satellite-Tracking Wintering Bald Eagles on the Skagit River, Washington.

Movement patterns of Bald Eagles on the west coast of North America are unknown, as are the biology and movements of subadult (age 1-4 years) Bald Eagles in spring and summer. Color-marking and traditional radiotracking research is limited in this area by inaccessability, weather conditions, rugged terrain and the lack of observers in remote areas. Current patagial marking work on the wintering population on the Skagit River in western Washington provides a firm basis for future satellite tracking research. Techniques and expertise needed to mount satellite radiotracking packages on Bald Eagles is now available, as are captive eagles to test harnessing techniques.

Alan R. Harmata, 13217 County Road #15, Wellington, Colo. 80549.  
To Determine the Breeding Grounds and Identify Migration Routes of Bald Eagles Wintering in the San Luis Valley, Colo.

Between mid-December and mid-February each year 250-300 Bald Eagles reside in the San Luis Valley and along the Rio Grande River. Since only two pairs of Bald Eagles are known to summer in Colorado, it is safe to assume that these birds are migrants from farther north.



However, their nesting areas are not known. The winter food supply for San Luis Valley Bald Eagles is broadly based. Large waterfowl populations on two National Wildlife Refuges, fish in the Rio Grande, domestic and wild carrion (cattle, sheep, deer and rabbits) on farm and pastureland, and rabbits are utilized by the Bald Eagles. This prey base has been supporting 200-300 eagles. There is thus a high probability that radio instrumented birds will return the following year. Satellite tracking would enable migration routes, critical habitats (staging areas in migration), and breeding areas of a particular wintering population to be identified. Migration speeds and weather influences can be studied. Tracking of eagles with known pesticide levels may help to identify areas where pesticide poisoning is a problem.

Mark Stalmaster, Graduate Student, Department of Biology, College of Science, Utah State University, UMC 53, Logan, Utah 84322. Satellite Tracking to Gather Data on the Movements of Bald Eagles to and from the Nooksack River Winter Concentration.

Satellite tracking of the Nooksack River Bald Eagles, Washington, about 50 miles northwest of the Skagit River winter concentration would provide information not now available. Movement data of this concentration in relation to that of Skagit River birds would be of considerable interest as well as valuable for management purposes. Migration data would fill gaps in a two year study in which population numbers, distribution, habitat use, and effects of human disturbance on behavior were assessed.

David K. Garcelon, Route 1, Box 327, Eureka, Calif. 95501.  
Determining the Migratory Paths and Wintering Areas of Nesting California



Bald Eagles and Bald Eagles Re-introduced to the Channel Islands.

Satellite telemetry would provide vital migratory and movement data on nesting and re-introduced Bald Eagles. With the data researchers could take steps to protect the migratory pathways and wintering areas. There is a good possibility that Bald Eagles re-introduced into the Channel Islands of California will travel south to winter in Mexico. The ability to follow their movements by satellite would give knowledge of exact wintering areas and allow the determination of survival rates while they are in Mexico. Some funds may be available from the Technology Transfer Office of NASA at Humboldt State University in Arcata, Calif.

David S. Shea and B. Riley McClelland, Glacier National Park.

Satellite Tracking of Bald Eagles in Glacier National Park.

Bald Eagles will be trapped and marked in Glacier National Park using power snares and padded jaw traps. Satellite tracking would enable their subsequent movements to be followed.

It is obvious from the various projects suggested for satellite tracking of Bald Eagles in western U.S., Canada and Alaska that a coordinated program of satellite tracking would provide data not now available but essential for management of this species. Work toward developing such a program could begin now, and if funds are available could become operational once a successful feasibility experiment has been conducted.

#### 6.1.2 Other Raptors

Due to present transmitter weights the first feasibility experiments



as well as a subsequent User-Satellite-Monitoring Program will have to be directed toward large birds. However, further miniaturization is possible utilizing current thin-film and thick-film techniques. The present RAMS transmitter weighs about 56 g and the overall package will weigh under 200 g. With the maximum amount of miniaturization available from present advanced technology, the RAMS transmitter could be reduced to 20 g (Varney and Pope 1974). This and other developments in the field of electronics should eventually make it possible to instrument medium sized birds, those ranging between 1000 g and 2000 g. In this category will fall some of the medium sized raptors such as the American Rough-legged hawk (Buteo lagopus s. johannes), the Gyrfalcon (Falco rusticolus), and endangered species such as the Peregrine Falcon (Falco peregrinus). The smaller transmitter will also permit a program of satellite tracking of waterfowl the size of some of the larger ducks. These medium-sized birds constitute an important segment of the avian population. They include most of the waterfowl managed for hunting purposes and most of the diurnal and nocturnal raptors. Satellite tracking can provide valuable information on migratory movements of these birds that will be invaluable in their preservation and management.

Frank C. Craighead, Jr., F. Lance Craighead and others, Environmental Research Institute, Box 156, Moose, Wyoming 83012. To Determine the Migratory Patterns of Tundra Nesting Peregrine Falcons (Falco peregrinus tundrius) and to Track Birds of This Endangered Species to Southern Wintering Grounds.

Breeding populations of Peregrines have completely disappeared in the eastern U.S. and have drastically declined from the West (Hickey 1969).



Nesting populations of Peregrines in Alaska are definitely on the decline; chlorinated hydrocarbon pesticides picked up in wintering areas are implicated (White and Cade 1971). Some remedial measures might be possible if the wintering grounds of this endangered species in South America could be pinpointed by satellite tracking (Craighead and Dunstan 1976).

Numerous researchers in the U.S. and Canada are working on projects to help save the Peregrine Falcon and many have expressed interest in satellite tracking of Peregrines once the technology is available. A cooperative program along these lines could be conducted with members of the Raptor Research Foundation Cornell Laboratory of Ornithology, Federal agencies including the Canadian Wildlife Service and others.

H.G. Swartz, Professor and Chairman, Biological Sciences Program, University of Alaska, Fairbanks, Alaska 99701. The Use of Domestic Bred Peregrines in Determining Migration Routes and Wintering Areas Using Satellite Technology.

This proposal is essentially the same as that proposed by Craighead (above) to determine migration routes, wintering areas and possible areas of pesticide contamination, but with the use of domestic bred birds. This should alleviate any problems involved in using the young of an endangered species, particularly those whose health may be already impaired by heavy pesticide loads. It is possible that subgroups of Peregrine populations winter in highly specific locales, for example, a particular wetland complex. Other countries might be willing to impose local bans which might have a rather substantial good effect in lowering pollution



burdens acquired during the winter even though those countries refuse to place nationwide pesticide bans.

Richard Glinski, Staff Research Biologist, Arizona State University, Department of Zoology, Tempe, Arizona 85281. Satellite Tracking of Gray Hawk Migration Between the United States and Northern Mexico.

Satellite tracking of Gray hawks (Buteo nitidus) would not only provide valuable data on this bird's migration and residence in Mexico, but also would demonstrate to the people and officials of Mexico that the United States recognizes the value of non-game birdlife. This may help to instill a sense of wildlife heritage in the minds of people whose culture still is preoccupied with poverty.

Frank C. Craighead, Jr. and Lance Craighead, Environmental Research Institute, Moose, Wyo. 83012. To Satellite Track Migrating Raptors to Determine Their Effect on High Rodent Populations.

Raptors such as the diurnal American Rough-legged hawk and the nocturnal Short-Eared Owl (Asio flammeus) through migration and winter concentration help regulate high rodent densities. These birds nest in the far north and in fall and winter move southward stopping to feed on rodents where the population densities are high and readily available. In their winter migratory movements many of these birds each year fan out over large expanses of the northern U.S.. Satellite tracking would help to understand yearly migration patterns and would aid in evaluating the effect of these raptors on undesirable high rodent populations--specifically Microtus.

Both species, the owl and the hawk, nest in the far north and



could be readily instrumented with excellent assurance of long, though interrupted, migratory flights.

#### 6.1.4 Seabirds

Lance Craighead, Wildlife Ecologist, Environmental Research Institute, Box 156, Moose, Wyo. 83012. The Satellite Tracking of Seabird Migration Routes and Location of Wintering Areas With Respect to Disturbances, If Any.

A feasibility study could be conducted on a large pelagic seabird such as an albatross or the Magnificent Frigate Bird (Fregata magnificeus). A bird such as this would test the satellite telemetry capabilities over long distances of open ocean with such concomitant problems as periodic exposure to salt water and the effects of the transmitter weight on a bird that spends a major portion of its time in the air. In addition it would provide previously unavailable information on migration, daily movements, speed and areas utilized at different times of the year.

Once a miniaturized version of the RAMS transmitter has been developed the scope of seabird studies could be expanded tremendously. Little is known of migration routes and wintering areas of pelagic seabirds such as the Alcids or of long range migrants such as some Larids and Stercorarids. Endangered species such as the Short-tailed Albatross (Diomedea albatrus) could be followed and better managed for protection. Satellite tracking may be the only means of acquiring such information across thousands of miles of open ocean. Jaegers, for example, are valuable indicator species of the health of arctic ecosystems and their numbers and distribution could be made more meaningful if their life cycle could be elucidated further via satellite telemetry.

Such a program could involve experiments such as the monitoring



of various species in the bird communities nesting on islands in the North Eastern Gulf of Alaska where oil and gas development is taking place. The response of various birds to documented disturbance in some locations and their subsequent resettling success or failure could be learned with satellite telemetry. An evaluation of the disturbance could be made and remedial measures taken.

Donald W. Sparling, Department of Biology, University of North Dakota. Use of Satellite Telemetry to Follow the Oceanic Movement of Laysan Albatrosses (Diomedea immutabilis) or Black-footed Albatrosses (Diomedea nigripes).

#### 6.1.5 Waterfowl And Other Birds

The following has been abstracted from correspondence and material furnished by: Harvey K. Nelson, Assistant Director, U.S. Fish and Wildlife Service, U.S. Department of Interior, Washington, D.C., and:

David S. Gilmore, Wildlife Biologist, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, North Dakota 58401. The Tracking of Waterfowl Using Satellite Technology.

The U.S. Fish and Wildlife Service is responsible for research on, and management of, migratory birds such as swans, cranes, ducks, geese and other species. Treaties with Mexico, Canada and Japan established this responsibility. The United States is now developing Migratory and Endangered Species Agreements with the Soviet Union. New and improved research and management tools and techniques are needed and continually sought in order to better manage large mobile populations of these birds. Satellite tracking and monitoring of waterfowl could be of inestimable value in carrying out waterfowl-management responsibilities,



nationally and on a worldwide basis. In time the major application of satellite tracking may be in the field of waterfowl management. The Fish and Wildlife Service has expressed an interest in such a program in various ways but has recognized that the miniaturized equipment is not yet available nor the techniques worked out via satellite-feasibility experiments. Harvey Nelson and David Gilmore both have expressed an interest in satellite technology and the use of a RAMS transmitter for waterfowl. No attempt has been made here to outline a program as this is beyond the scope of this report.

Swans, cranes and even geese are sufficiently large that they can be seriously considered for feasibility experiments should a number of these studies be approved by NASA. A program of satellite tracking of these birds could be initiated once present sized operational transmitters are available.

William Sladen, Johns Hopkins University, MD. has been studying the Whistling Swan in collaboration with various agencies. Banding research has received a high priority and could well be augmented by satellite tracking.

The Whistling Swan has been carefully protected for over 70 years (Sladen 1969). It breeds in the high arctic tundra where man has had little influence on its environment until the present. Over one half of North America's Whistling Swans spend their winters on the estuaries of the Chesapeake Bay and Currituck Sound in Maryland, Virginia and North Carolina. Very little is known about the speed or even the routes of migration across the U.S.A. and Canada, but they do pass over heavily congested areas of human populations and cross important airline routes. Since the loss of a Viscount Airliner in Maryland in 1962 as a result of a collision with swans, there has been a growing



awareness of the potential hazard of these swans and other large waterfowl to aircraft.

The Air Force Office of Scientific Research (1966) stresses the need for biological studies of bird movements; satellite tracking has great potential in solving the problems of bird/aircraft collisions. The Canadian Wildlife Service instigated a study in 1967 to study the local and migratory movements of the Whistling Swan. A program of satellite tracking would fit in well with these studies centered at the Chesapeake Bay Center for Field Biology.

The U.S. Fish and Wildlife Service has undertaken a program of reestablishing nesting Aleutian Canada Geese (Branta canadensis leucoparia) on islands where they once nested. A radiotracking program is being conducted by John Martin, Aleutian Islands, N.W.R., Box 5251, FPO, Seattle, Wash. 98791. When reintroduced birds migrate south after the breeding season it is important to know where they and the juveniles go so that measures can be taken to protect them. Satellite tracking could be a valuable aid in this management project (Craighead, F.C., Jr. 1975).

Stanley Temple, University of Wisconsin, Department of Wildlife Ecology, Madison, Wisconsin 53706. To Instrument Young Whooping Cranes (Grus americana) Raised in Sandhill Crane (Grus Canadensis) Nests.

A program is underway to place eggs of endangered Whooping Cranes into Sandhill Crane nests to increase the numbers of Whooping Cranes. A satellite tracking experiment would enable these young birds to be instrumented just before fledging and followed on migration routes and wintering grounds. Protection could be given en route and in wintering areas and the behavior, survival and subsequent reproductive



success of these birds could be assessed.

As indicated earlier in this report the suggested program is only a sampling of the interest, need and possibilities of satellite tracking of birds. Thus many interested and capable investigators have not been mentioned nor could all of them be included here. It is hoped and assumed that this suggested program will stimulate efforts to organize and expand such a program. It is regretted that some biologists who may have submitted abstracts of satellite tracking projects are not included. A fire destroyed a completed report and much of the reference material. This report is a rewrite without benefit of former correspondence and references.

## 6.2 DISCUSSION

Some of the proposed projects also provide situations suitable for one or more feasibility experiments should circumstances make this desirable.

In all of the suggested satellite tracking projects, movement studies of the birds are emphasized. However, a vast and varied amount of data on the ecology of numerous species can be secured. The complexity of the studies will vary with objectives and funding. Migration flights can be correlated with simultaneous weather data from Tyros satellites. Migration routes and stop-over or staging areas can be related to habitat and physiographic features using Landsat multi-spectral imagery. Critical habitat for some species can be delineated more specifically than presently possible. Information can be accumulated to shed light on bird orientation and navigation. The potential for research on and management of migratory birds using satellite technology is tremendous, almost unlimited, once a tested miniaturized system is available at reasonable cost.



## 7. PROGRAM PRIORITIES AND ESTIMATED COSTS

The Report on 1973 Santa Cruz Summer Study on Wildlife Resources Monitoring concludes (p. 53) that microminiaturization of the RAMS and the Omega/OPLE systems is necessary before the potentials of satellite monitoring of a wide range of species can be realized. The first phase of the microminiaturization process has been completed as detailed previously in this report in the section entitled ~~Test Results of Nimbus 6/RAMS DCP Transmitter.~~

Though further microminiaturization of transmitter circuitry is desirable and possible, the limiting factor on animal tracking and monitoring by radio and particularly satellite tracking is battery size and life. Lithium cells currently provide the most power for their weight but are more bulky than mercury cells. Research toward developing more powerful batteries per unit of weight should be encouraged. It could give a tremendous impetus to the use of telemetry systems in conducting wildlife and ecological research and it would have wide application in other fields. If NASA could support basic research toward designing new types of batteries or improving others it would be a contribution with wide reaching effects and benefits.

### 7.1 MICROMINIATURIZATION PHASE

As a continuation of this research we envision three additional phases as suggested by Dave Beaty of Telonics, Inc. necessary to develop readily available operational hardware for raptors, waterfowl and comparable sized birds:

The first of these is miniaturization of the existing hardware into a configuration that is compatible for later production



and which will perform with the required precision. The result would be 2-6 prototype, pre-tested transmitters ready to put on free-flying birds in the field.

We have solicited two estimates of the costs of this stage of microminiaturization. Telonics, Inc. of Mesa, Arizona has studied the requirements for some time and estimate that 1½-2 engineers and one support technician along with supporting clerical and documentation personnel could produce 2-6 transmitters in 8-12 months. Telonics total cost estimate is below \$50,000. They are prepared to submit a detailed cost breakdown and supportive information as hardware requirements are specified and sponsoring agencies commit their interest. Handar Inc. of Santa Clara, Calif. has a 65 g transmitter that has been used on Polar Bears in a 4530 g (10-11 lb) package excluding harness. This package as presently available, could be reduced to 444 g (approx. 1 lb). A ball park estimate by Handar of the costs of further miniaturization to the desired 100-200 g package is \$250,000 and would take in excess of one year of development. However, Handar is not interested in further development work in this area. A recurring charge for transmitters in quantities of 20-50 would be about \$3,000-\$4,000 each.

## 7.2 PRODUCTION ENGINEERING PHASE

This phase consists of polishing the technology developed in the course of producing 2-6 transmitters for actual satellite tracking of large birds. This next phase would be "to establish producibility engineering and cost effectivity of volume production of the transmitters", without expending or committing large amounts of funding. It includes preproduction documentation, the fabrication of a number of transmitters in close accordance to that documentation and full testing of those units.



### 7.3 INITIAL PRODUCTION

The final phase of the program would utilize the data base acquired by the earlier work to actually produce transmitting systems in production quantities as determined by the sponsoring agencies and users.

This phase includes production and sustaining engineering as well as technical reporting and labor. Present demand for production quantities is in the area of 75-250 unit runs, but with availability of the item and increased public awareness the demand can be expected to increase considerably. Each unit fielded would result in a net savings to the user agency in manpower and equipment cost as well as in increased and hertofore unavailable data.

### 7.4 DISCUSSION

The completion of this program resulting in a lightweight, accurate satellite/animal telemetry system will require the concerted effort of interested engineers and field biologists over a period of several years. The initial contract for microminiaturization development should be awarded to an engineering firm with implied responsibility for close association with personnel conducting the field tests and with an expressed interest in continued effort through subsequent phases of the program. Telonics, Inc. have established themselves as leaders in the field of animal telemetry equipment, are dependable and resourceful, are interested in development as well as production phases, and have come up with reasonable yet realistic cost estimates. Joel Varney, whose long time interest and extensive experience encompasses the technical and biological areas of concern, should be consulted throughout. This should also be the case with NASA engineers such as Chuck Cote



and biologist Paul Sebesta.

Feasibility experiments should be conducted on species whose biology will provide a wide spectrum of the problems that the system will eventually encounter. The Environmental Research Institute is interested in seeking funding from public and private agencies to complete phase 7.1 (microminiaturization) and to conduct a first feasibility experiment as discussed earlier.



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