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A Preliminary Investigation of BIRD CLASSIFICATION BY DOPPLER RADAR

Prepared for:

National Aeronautics and Space Administration
Wallops Station
Wallops Island, Virginia 23337

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RCA | Government and Commercial Systems
Missile and Surface Radar Division | Moorestown, N.J. 08057

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This study was conducted by RCA, Missile and Surface Radar Division, Moorestown, New Jersey for the National Aeronautics and Space Administration, Wallops Station, Wallops Island, Virginia under Order No. P-52, 456.

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BIRD CLASSIFICATION BY DOPPLER RADAR

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FOREWORD

This report presents the results of a preliminary study of the application of doppler radar to the classification of birds. The desirability for improvements in bird classification stems primarily from the hazards they present to jet aircraft in flight and in the vicinity of airports. A secondary need exists in the study of bird migration. Since most migration takes place at night, it is difficult for ornithologists to make accurate estimates of annual variations in populations of particular bird species.

The target return from a doppler radar is a signal whose frequency is proportional to the relative velocity between the radar and the target. In principle, the wing body and tail motion of a bird in flight will reflect signals which, when analyzed properly, may present a "signature" of wing beat pattern which is unique for each bird species.

Although the results of this investigation did not validate the feasibility of classifying bird species, they do indicate that a more thorough investigation is warranted. Certain gross characteristics such as wing beat rates, multiple bird patterns, and bird maneuverability, were indicated clearly in the results. Large birds with slow wing beat rates appear to be the most optimum subject for further study with the X-band doppler radar used in this investigation.

Charles Vaughn of NASA Wallops Island, Virginia. Collecting Bird Signatures with RCA Model 4019 Doppler Radar.

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1. INTRODUCTION

The capability to detect and identify birds in flight which can not be visually seen because of their long range, darkness, or cloud cover is desirable for a number of reasons. Foremost of these is the threat which large birds or flocks of birds pose to jet aircraft in the vicinity of airfields and in flight. In this application the requirement is to separate the birds into two classes, those which are a hazard and those which are not. This separation can be made if the size, number, and density of birds can be estimated.

Refinements of bird classification which would preferably identify particular bird species in flight would be of value to the study of bird migration. In addition to the separation of birds into species or at least a small group of species, an estimate of the number or density of the birds is desirable for making estimates of bird species populations. This latter goal is of particular importance to the assessment of the effects of known or unidentified ecological factors, either man made (pollution) or natural, on bird populations.

A preliminary investigation of the application of doppler radar to bird classification has been conducted. A doppler radar provides the relative range rate (radial velocity) of a target with respect to the radar. As a bird flies the wings, tail and body of the bird will have a particular motion pattern which, when viewed by a doppler radar, will produce a complex doppler signature. This signature is, in principle, unique to most individual bird species since few birds have identical flight patterns. This investigation has sought to determine if the signatures provided by recording the output of an RCA hand held doppler radar (HHTR-4019) on a group of bird targets of opportunity at Wallops Island, Virginia show efficient distinctive characteristics to warrent an extensive investigation of this technique.

2. TECHNICAL DISCUSSION

2.1 Bird Flight Characteristics

A detailed study of the characteristics of birds in flight which are useful in their identification was not possible during this brief study. However, the principal parameters have been assessed in general terms from references 1 to 5.

Radar Cross Section

Bird dimensions fall in the "Mie" region in which the scattering cross section oscillates about a mean value as wavelength changes (4). Because of this it is difficult to predict the effective cross section variation of a given bird based on its size. The measured range of cross sections reported is from .18 to 600 cm^2 as the type of bird and its aspect changes (1, 4).

Air Speed

The ground speed of birds in flights varies greatly depending upon wind conditions but the range in air speed can be expected to reach a normal limit of about 50 knots (1) or about 26 meters/sec for birds in migration. Birds of prey are commonly timed at over 45 meters/sec. during an attack.

Wing Beat Rate

Typical wing beat rates for a representative set of birds are summarized in Table 1 (6)

Type	WBR (Beats Per Second)
Sparrow	13
Duck	9
Crow	3-4
Stork	2
Pelican	1-1/16

TABLE 1. TYPICAL WING BEAT RATES

The wing beat rates of eighty birds related to their air speed in level flight is reported in (3). The maximum WBR was 30/sec and the maximum air speed given is 29 m/sec although 97 percent are below 27 m/sec and 25 beats/sec.

Wing Beat Pattern

Birds have distinctive flight patterns which can be used to separate them. Many large birds do very little flapping and simply glide and soar with very little wing motion while others such as ducks and geese flap continuously. The smaller birds often have a wing beat pattern which is characterized by a short period of flapping followed by coasting. Many of these birds fly a trajectory which consists of a series of vertical arcs.

2.2 Doppler Radar Characteristics

A doppler radar operates in a manner to produce a signal proportional to the relative velocity of the radar and the target. The doppler frequency output f_d is

$$f_d = \frac{2 V_R}{\lambda} = \frac{2 V_R f}{c} \tag{2-1}$$

where V_R = relative velocity of radar and target

$\lambda = c/f$ = wavelength of radar carrier

f = radar operating frequency

c = velocity of light

The RCA Hand-Held Tactical Radar (HHTR) Model 4019 used in the experiment reported here operated at X-band (8.75 GHz) and thus had an output frequency of 58 Hz per one m/sec. target velocity.

The RCA HHTR-Model 4019 radar is primarily designed as a surveillance radar to detect and track moving vehicles,animals and men. The output is brought out through audio amplifiers to a headset worn by the operator. A target is detected by the audio output with a frequency corresponding to its relative velocity. If the target is not moving, it cannot be detected.

A principal feature of the radar is the characteristics of the audio output which permits the identification or classification of the target. The motions of the arms, legs and torso of a man when running, walking and crawling for example, produce a doppler output to the radar operator which strongly correlates with the actual sound or the visual image of the man as he moves.

This audio output can be analyzed with a spectrum analyzer and recorded on a time-frequency plot. The spectrogram, as it is called, will show a pattern on which the motion of the various parts of the target can be identified. An example is shown in Figure 2-1 of a man walking and running. The return from the torso constitutes the largest signal and shows the mean velocity of the man. Slight up and down movements of the torso doppler return are caused by the irregular walking speed as one steps from one leg to the other. The leg and arm motions produce excursions about the torso return corresponding to the added or subtracted rate of motion.

2.3 Optimizing Doppler Radar Parameters For Bird Classification

In order to extract the unique wing, tail and body motion characteristics of a bird in flight the radar must be able to resolve both time and frequency details in the doppler return within a wing beat period. The resolutions* in time and frequency are reciprocally related to each other. That is, if a resolution of T seconds is desired in the time domain the corresponding resolution in frequency is 1/T.

*Resolution in this context refers to the ability to discriminate between two adjacent point targets of equal strength.

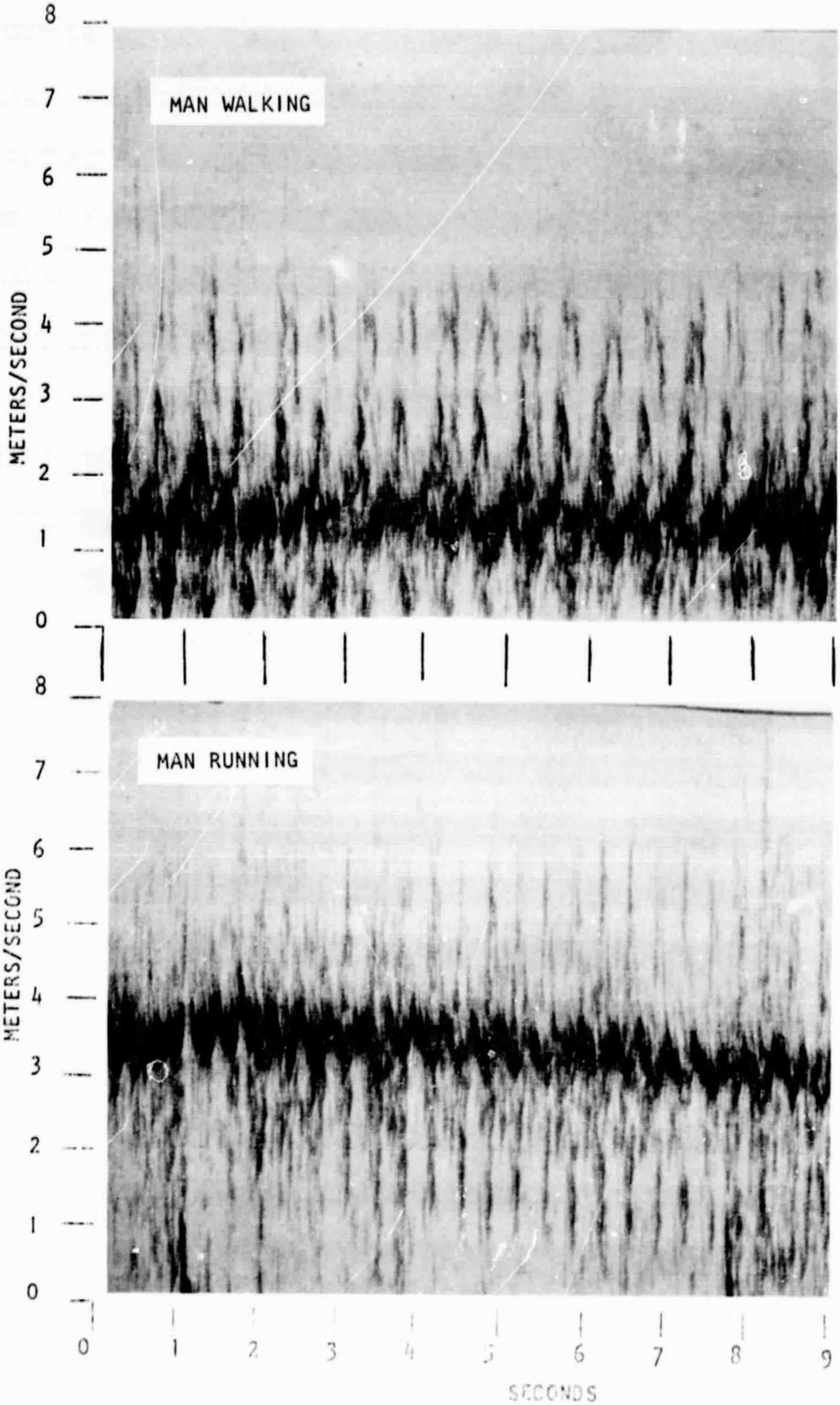

FIGURE 2-1 SPECTROGRAM OF SINGLE MAN WALKING AND RUNNING

Therefore, if we wish to resolve the maximum WBR of 30 beats per second into resolvable phases a time resolution of much less than 1/30 seconds is required. It can be argued that a wing beat period should be divided into about 10 or more segments in order to separate the principal phases of the beat pattern. (A diagram showing 12 phases is developed in reference (5)). This would suggest a required time resolution of about .003 seconds and a corresponding frequency resolution of 300 Hz. In addition, the frequency coverage must be sufficient to encompass all velocities of interest and doppler excursions. For fine resolution of a wing beat pattern the number of frequency resolution elements covering the doppler excursion of the wing and body motion should be at least as great as the number of time resolution elements. It can be estimated that the radial velocity of the wings of a small bird flapping at a rate of 30 per second will be about 3 meters/sec relative to the birds body. If 3 m/sec. of velocity coverage represents a minimum of ten 300 Hz frequency elements, the doppler scale becomes 1000 per meter/sec.of velocity. The radar operating frequency corresponding to this can be found by applying equation (2-1) and solving for f.

$$f = \frac{c\ fd}{2\ V_R} = \frac{3 \times 10^8 \text{m/sec}\ \ 1000\ \text{Hz}}{2 \times 1\ \text{m/sec}}$$

$$f = 150\ \text{GHz}$$

This frequency is well into the area of millimeter wave radar and it is apparent that the foregoing idealized specifications can not be met with practical radar parameters.

The foregoing time resolution should not be confused with the resolution in the time domain of a pulsed radar which is the reciprocal of the bandwidth of the transmitted pulse and is thus not directly related to the carrier frequency of the radar.

A reduction by an order of magnitude in radar operating frequency (to X-band) provides a time-frequency resolution fairly well matched to the WBR of a Crow (3-4 beats/sec.) for the purposes of resolving fine details. Good signatures can be expected for WBR's from 4 to 6, fair signatures for WBR's to 10 and marginal to poor signatures for WBR's beyond 12 to 13.

3. FIELD TESTS AND RESULTS

3.1 Field Data Gathering

The RCA HHTR-4019 radar was used to collect the doppler returns from bird targets of opportunity at Wallops Island, Virginia. The field data were taken by Charles Vaughn of NASA, Wallops Island during June and July of 1972 and were recorded on a Lockheed portable tape recorder. A second track was used to record comments on the motion and descriptions of the targets. This gave a running account of the field data which was essential to the later data reduction.

3.2 Data Reduction - Spectrum Analysis

The data recorded on the Lockheed recorder was first transferred to an Ampex FR-100 tape recorder which was equipped with a tape position counter. This permitted the selection of precise positions on the tape for analysis.

Spectrum analysis was performed with a Kay Electric Co. Sonograph Missilyzer. Although this particular instrument is not in the same class as some of the digital FFT spectrum analyzers available today, it has the advantage of providing a hard-copy spectrogram and its coverage is reasonably well matched to the RCA HHTR-4019 radar.

All of the data on one reel of tape from the Lockheed recorder was processed in the analyzer. The most representative examples from these data have been included in this report.

3.3 Radar Characteristics

The RCA Handheld Radar used in the testing is a light weight, high performance, high reliability, ruggedized, tactical surveillance radar. Battery operated, this all-solid-state radar is designed for either one-man hand-held deployment, or for tripod or vehicle pintle mounting when automatic sector scanning is desired.

The radar detects, locates, and tracks moving personnel and vehicles. Ranging extends from 0 meters eliminating the near range void characteristic of conventional radars. Ranging accuracy of 8 meters was field demonstrated with trained operators. Aural and visual outputs permit surveillance of terrain area up to 3000 meters from operator. The "look listen" feature permits continuous monitoring while ranging on a particular target.

A nominal 12 hours of uninterrupted service is provided in the detection mode from a pair of rechargeable nickel cadmium batteries.

The aural output of the radar is normally presented to the operator by a set of headphones. Filters for ear compensation are built into the audio amplifier for best operator performance. A modification was made to the radar used to obtain data on birds. The audio doppler was brought out of the radar before filter compensation to provide clean signatures to the FM tape recorder.

Radar Specifications are:

Modulation....................................Pseudo-Random Code
Phase Shift Keyed

Detection Range.............................0-1500 meters On 0.5 m target
0-2500 meters on Vehicles

Location Range..............................2500 meters dependent on target size

Range Resolution	25 meters (0-2500 meter range only)
Range Accuracy	8 meters nominal
Primary Power	12 volts DC, internal rechargeable nickel cadmium batteries external 24VDC Source
Weight	
Receiver/Transmitter	7.9 lb with batteries
Total System	14 lb.
Dimensions	
Receiver/Transmitter	13 in x 9 in x 4 in

3.4 Results

3.4.1 Spectrogram Charts

The data are generally presented in two ways on the spectrograms, with a wideband filter and with a narrow band filter. Each complete analysis chart* has a maximum time-bandwidth product of 500 Hz x 24 sec. = 12,000. In the narrow band filter case the filter bandwidth is 2 Hz so there are 250 frequency resolution elements along the frequency or velocity axis. There are 48 time resolution elements each of 0.5 seconds along the time axis or about one per 1/4 inch. In the wide band mode the frequency resolution is 20 Hz and there are 25 elements across 500 Hz (8.6 m/sec.). Each freq uency element in this case is about 1/6 inch. The corresponding time element is about 1/40 inch.

3.4.2 Distortion Effects

In many cases of large signal strength the signal saturated in the radar receiver. This caused the generation of harmonic signals which appear on the charts as traces which duplicate the exact path of a low frequency signal but at a multiple of its frequency.

*Only a section of the spectrogram charts are shown

The relatively long settling time of the narrowband filter caused the display to appear streaked in this mode.

3.4.3 Bird Flight Spectrograms

Large Birds

Figures 3-1 and 3-2 show the charts taken of a laughing gull in various maneuvers. In this chart and the following, the maneuvers of the bird when possible are indicated on the chart. A particular good segment (in inset of Figure 3-1) showing the definition of wing beat pattern is magnified and reproduced on Figure 3-3 together with that of a gull-billed tern. Although these magnified records are not optimized, they do indicate the type of signatures one would expect when the radar and analyzer parameters permit resolution of the separate phases of the wing beat. By studying similar patterns and correlating them with a film taken of the bird in flight one should be able to identify particular parts of the doppler signature which can be used to classify the bird.

Figure 3-4 is a record from a snowy egret taken in continual flight from a puddle in front of the radar. The strong vertical traces on the charts show the points when the range gate of the radar was changed. Each range gate interval covers a radar range of 25 meters.

A gull-billed tern is shown in Figure 3-5 and 3-6. One interesting segment here is the lower frequency track between the eleventh and thirteenth second mark. The target strength and maneuverability suggest a large insect.

Small Birds

Figure 3-7 is the track of a butterfly which was judged to be about one-half the size of a monarch butterfly. Its maneuverability is much greater than that shown by any bird. Its target strength at 25 meters was somewhat of a surprise.

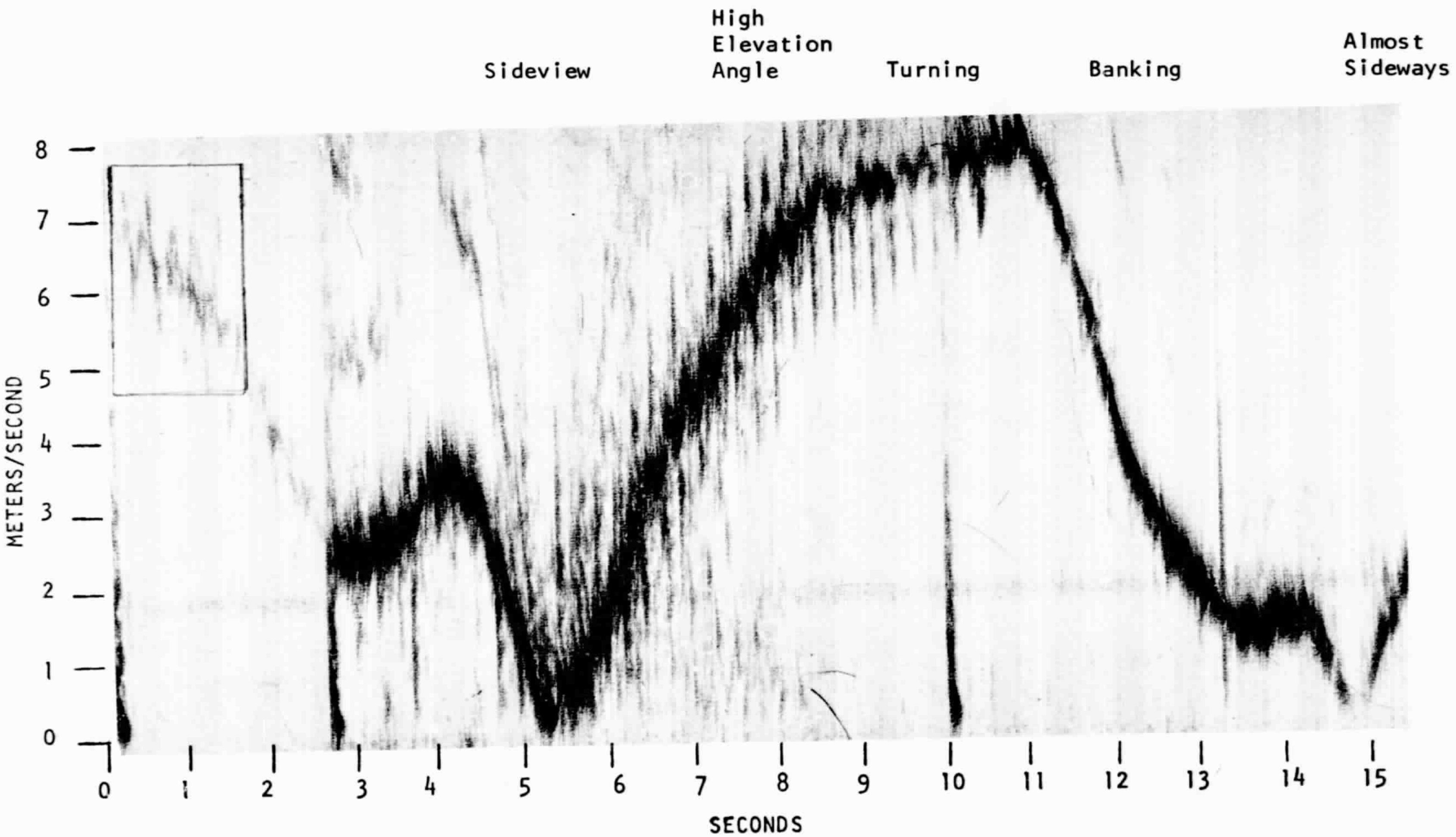

FIGURE 3-1 LAUGHING GULL, WIDEBAND FILTER

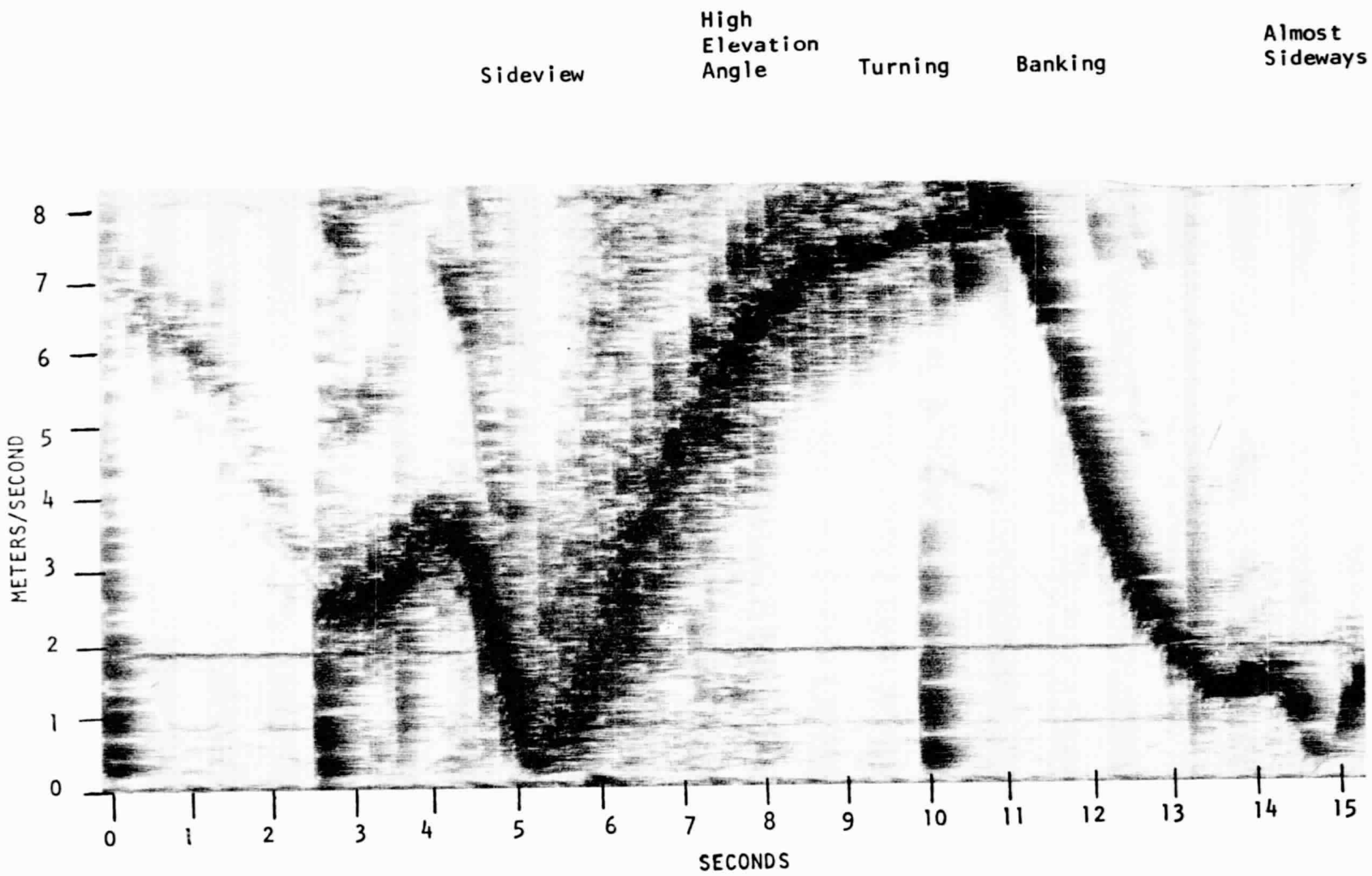

FIGURE 3-2 LAUGHING GULL, NARROWBAND FILTER

FIGURE 3.3a LAUGHING GULL

FIGURE 3.3b GULL-BILLED TERN

FIGURE 3.3 MAGNIFIED WING BEAT PATTERNS

Taking Off and Flying Away

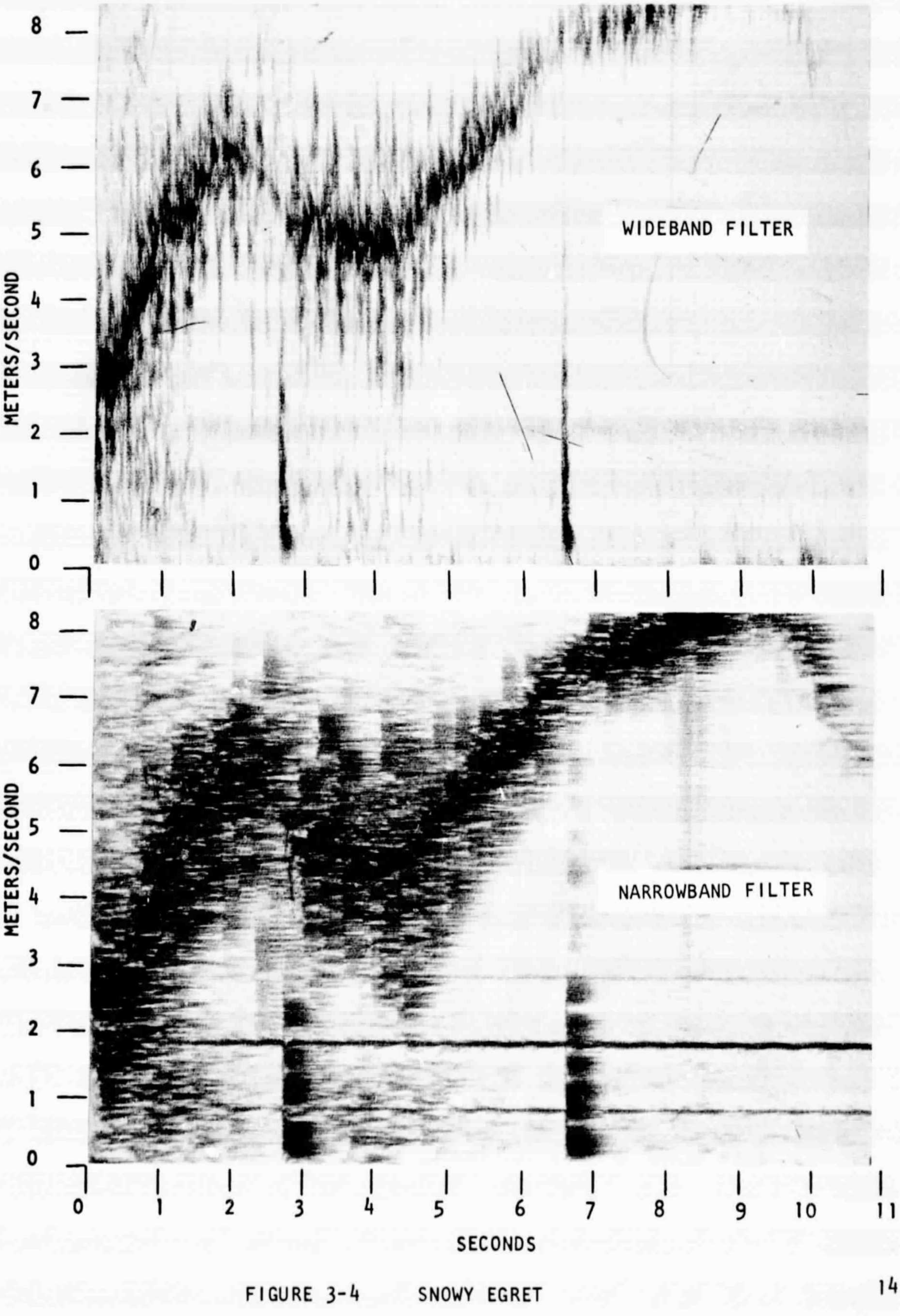

FIGURE 3-4 SNOWY EGRET

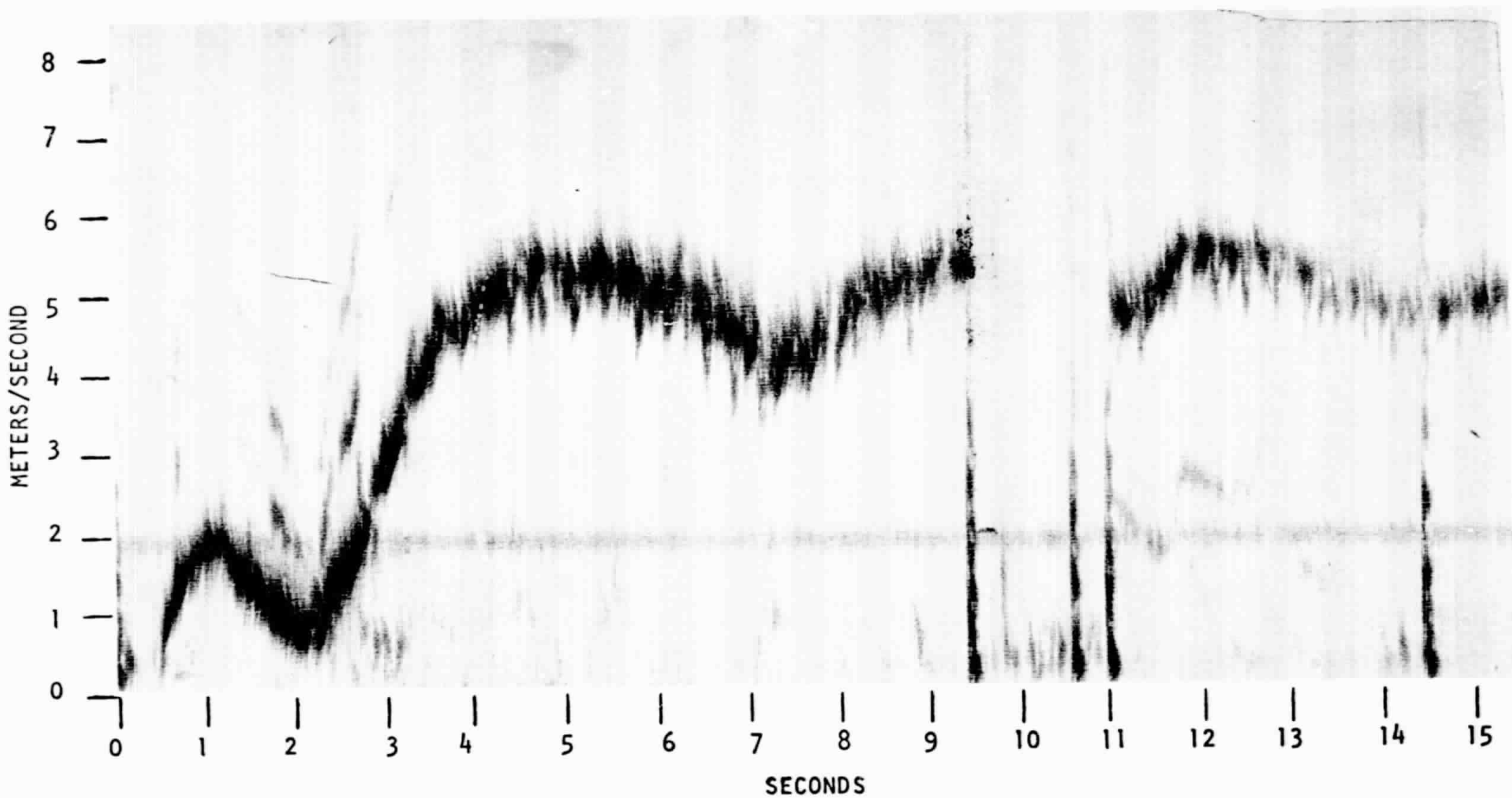

FIGURE 3-5 GULL-BILLED TERN, WIDEBAND FILTER

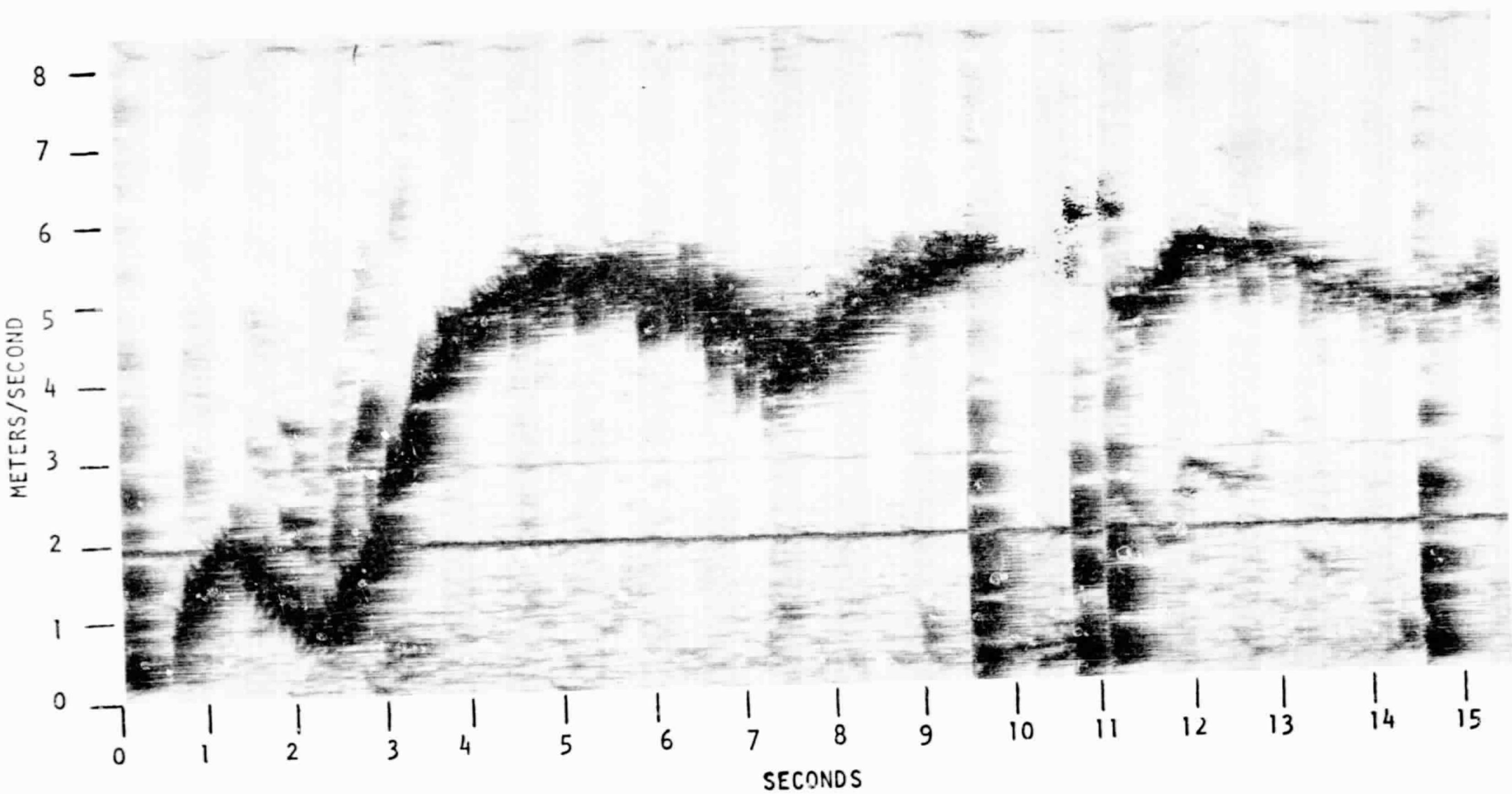

FIGURE 3-6 GULL-BILLED TERN, NARROWBAND FILTER

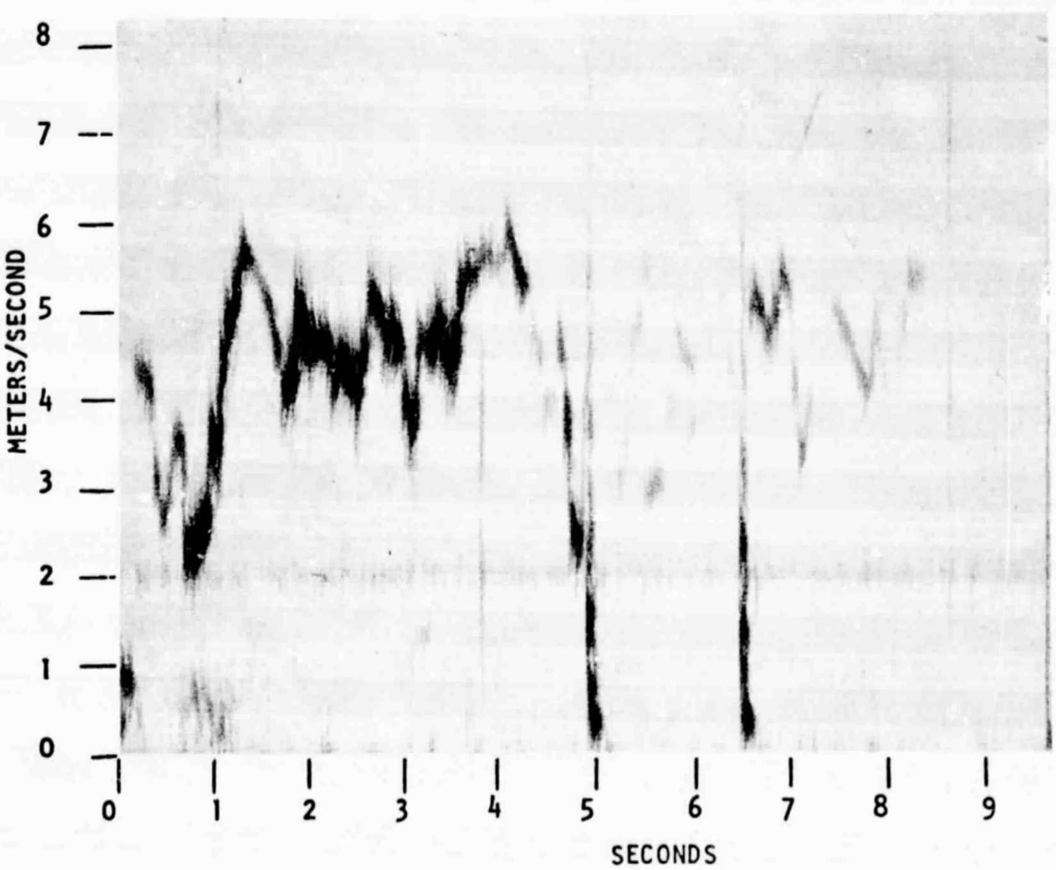

FIGURE 3-7 BUTTERFLY

Figures 3-8 and 3-9 show the returns from two separate red-winged blackbirds skimming over the marsh. Because of range and angle coverage limits in the radar, two birds are not evident on the charts.

Figure 3-10 shows a boat-tailed grackle. The wing beat rate was about 6 per second in the region of good resolution from the fourth to sixth second mark.

Barn swallows are shown in Figures 3-11 and 3-12. Of particular note here is the large maneuverability indicated for this bird. It should be noted that the doppler signature will be largely independent of range as long as an adequate signal-to-noise ratio is obtained. Radial velocity changes will not be range dependent. A wing beat rate of about 6 per second is evident for the barn swallow, which corresponds to published data.

Multiple Birds

Figures 3-13 and 3-14 show particularly good examples of multiple bird tracks, in this case of glossy ibis. About 20 birds were visually seen in the case of Figure 3-13 but it is apparent that all were not captured in the surveillance volume. In this case an advantage of the narrowband filter is apparent since the multiple birds can be resolved better in frequency than they can in time.

Figure 3-14 shows another group of glossy ibis this time about eleven were counted and all were flying the same general trajectory. The result is a generally broad spectral track without resolution of individual birds.

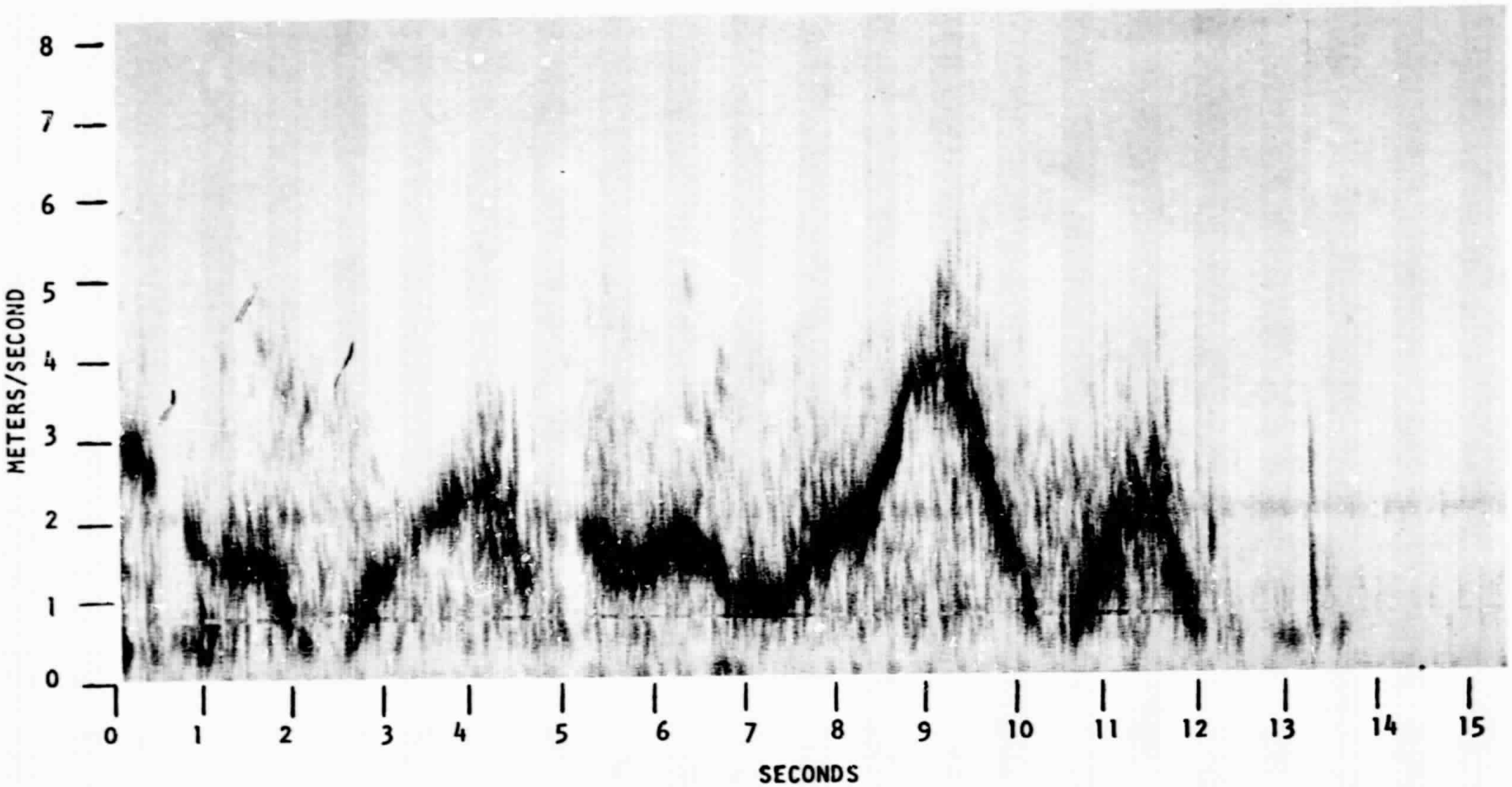

FIGURE 3-8 RED-WINGED BLACKBIRD, WIDEBAND FILTER

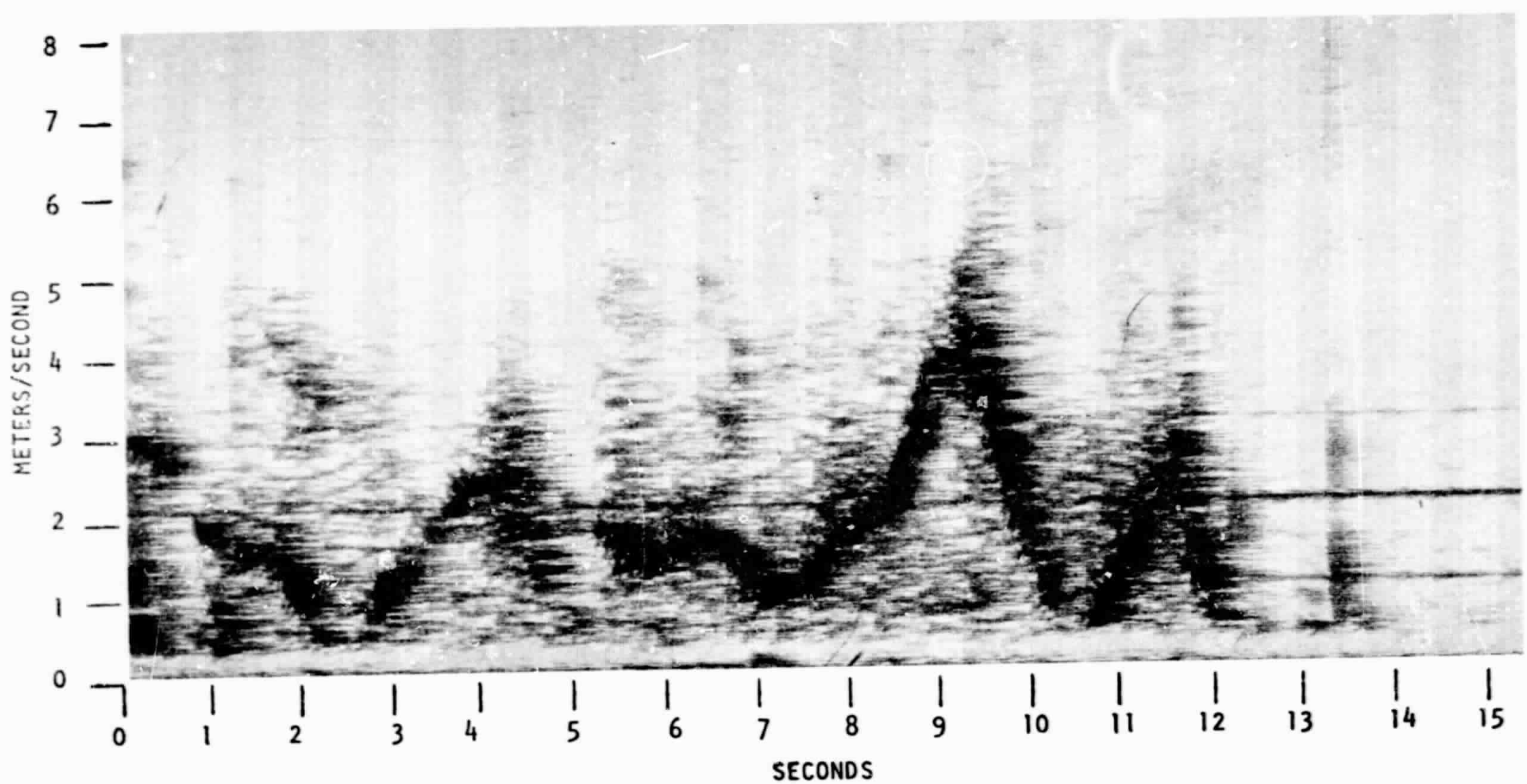

FIGURE 3-9 RED-WINGED BLACKBIRD, NARROWBAND FILTER

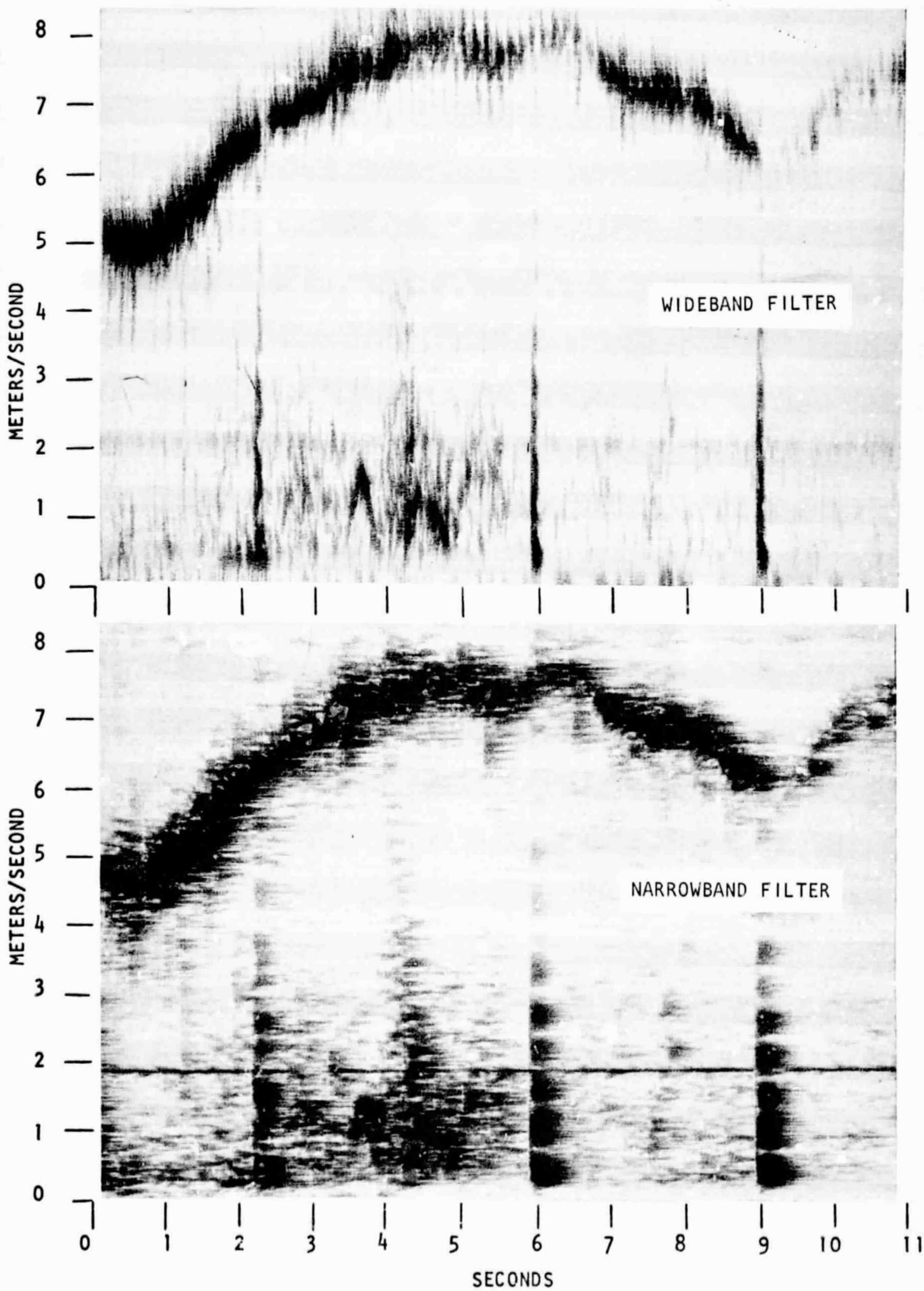

FIGURE 3-10 BOAT-TAILED GRACKLE

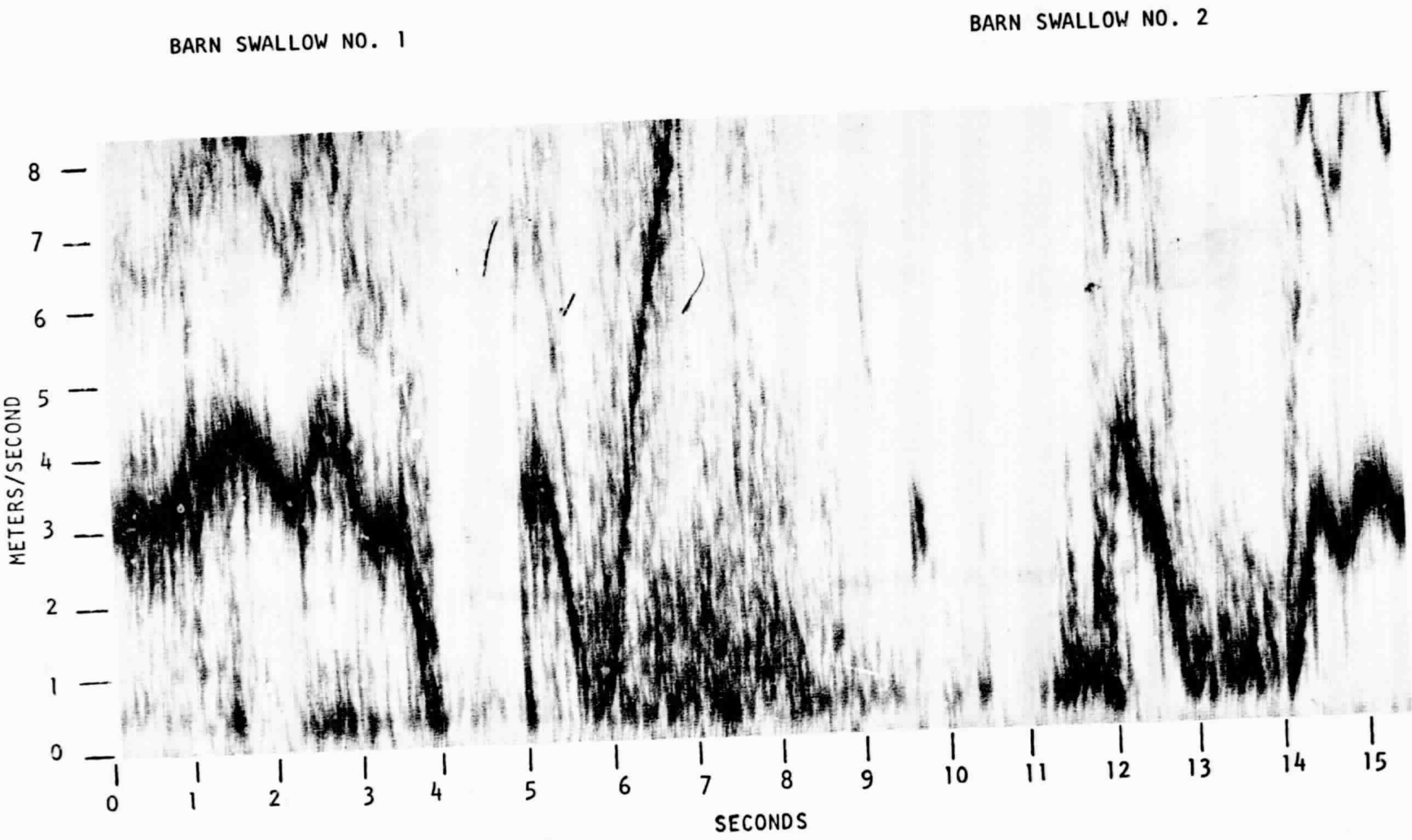

FIGURE 3-11 TWO BARN SWALLOWS, WIDEBAND FILTER

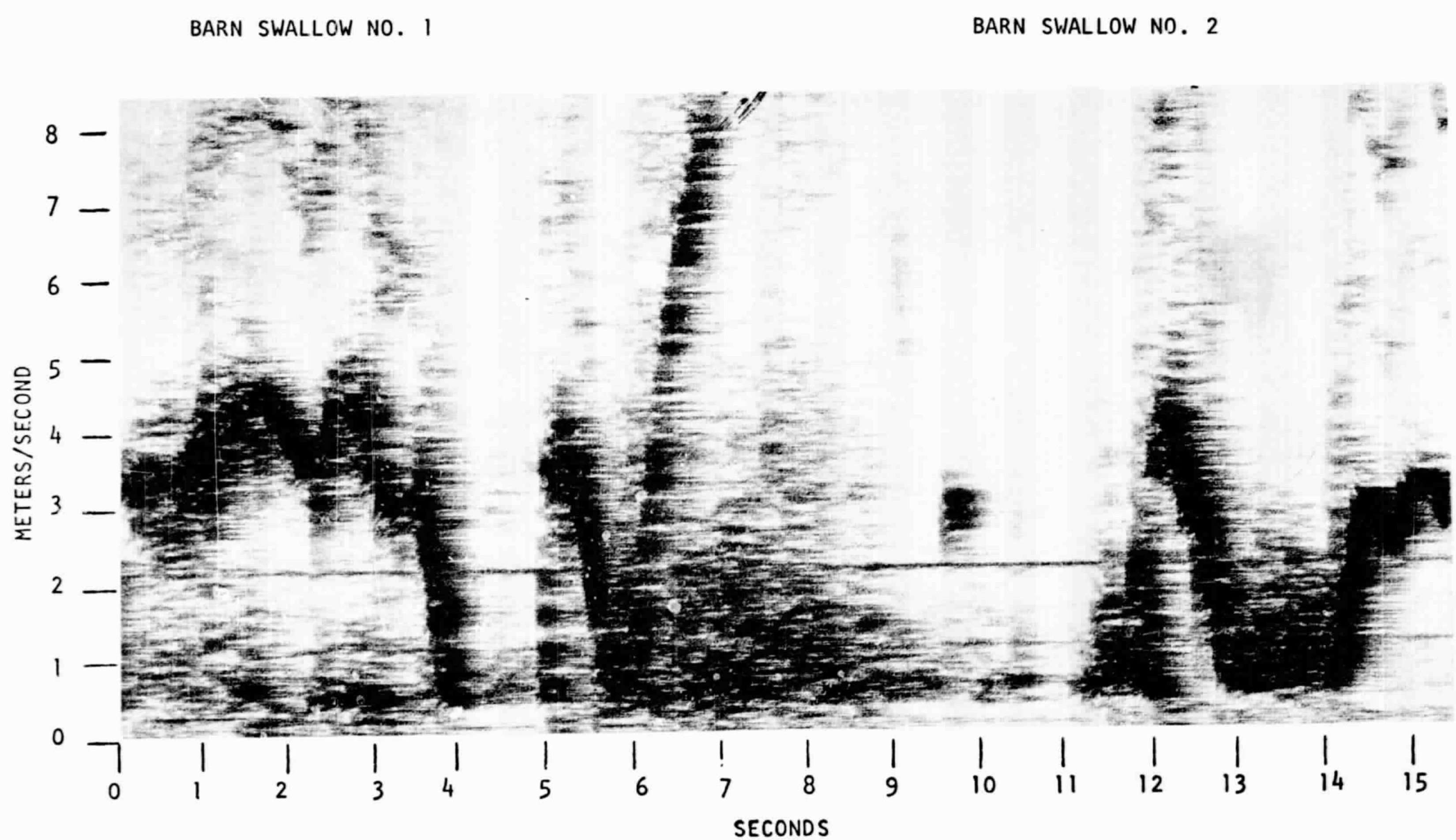

FIGURE 3-12 TWO BARN SWALLOWS, NARROWBAND FILTER

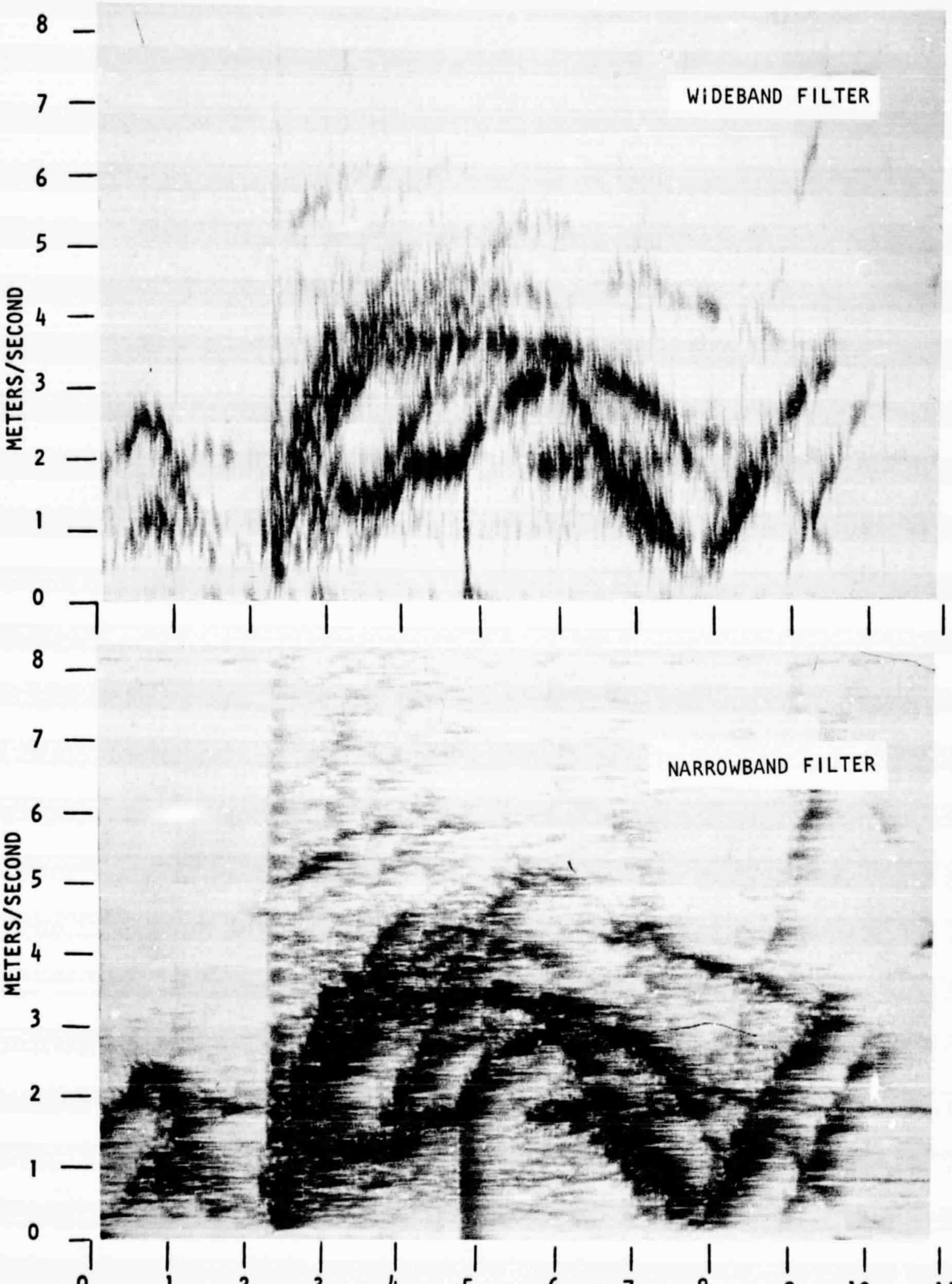

FIGURE 3-13 GROUP OF GLOSSY IBIS

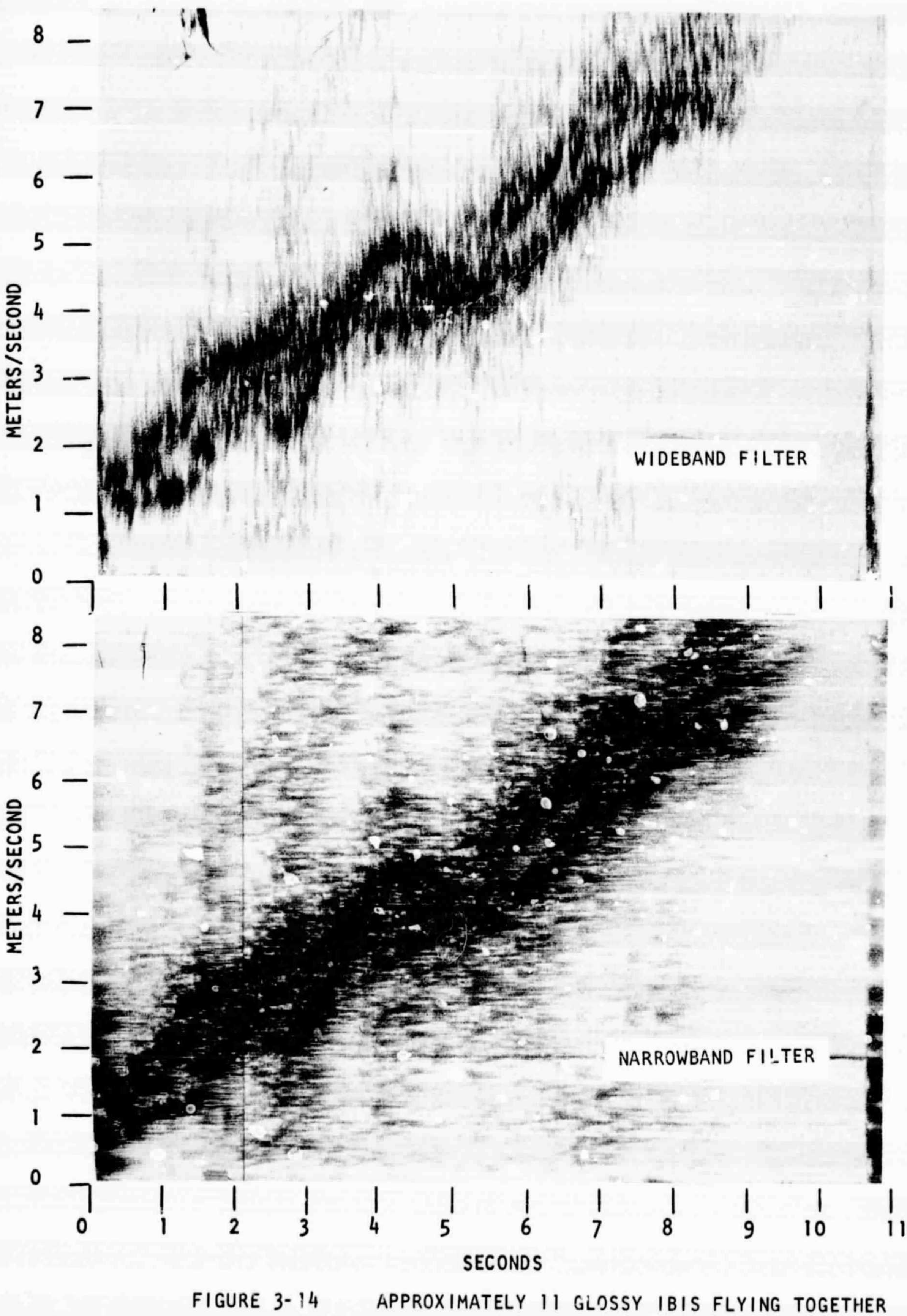

FIGURE 3-14 APPROXIMATELY 11 GLOSSY IBIS FLYING TOGETHER

4. SUMMARY AND CONCLUSIONS

The results of this initial study indicate that a doppler radar operating at X-band can provide a valuable tool for the identification of birds. Although the radar frequency is not sufficiently high to do fine doppler discrimination on small birds with very rapid (greater than 10 per second) wing beat rates, it can provide signature data on large birds that could cause hazards to aircraft. The results of the study show that:

- Wing beat signatures can be resolved for wing beat rates less than 3 per second.
- Wing beats are resolvable up to 10 per second.
- Bird flight maneuvers are clearly indicated.
- Individual tracks in a small flock of birds are distinguishable.
- A large flock of birds will appear as a broader spectrum and larger cross section than a single bird. Individual erratic movements by single birds will be resolvable.
- Rate of change of motion is useful in distinguishing large birds from small.

The analysis equipment used as not optimized in that the total expected doppler range of bird targets are not covered. The paper display and analyzer combination does not provide an adequate dynamic range to show fine features of a wing beat pattern.

5. RECOMMENDATIONS

Two avenues of additional effort on the use of doppler radar for bird identification appear worthwhile. The first is a more detailed analysis of the wing beat patterns of large birds (with low wing beat rates) using the RCA HHTR-4019 X-band radar as the sensor. The objective of this investigation would be to determine if particular species create time spectrum signatures which are in fact unique. Factors such as aspect angle both in elevation and flight direction would be included. In carrying out this investigation it is recommended that motion pictures of birds in flight be taken simultaneously with the radar signatures so that particular signature features can be correlated with flight phases. The study should concentrate on a variety of birds with similar wing beat rates and should include cases where the birds have identical wing beat rates and only the fine details of the signature can be used to separate them.

The other task would study the radar sensor-data reduction-display problem to define the feasibility, performance and projected costs of a bird classification system. The objective here would be to assess the economic and operational viability of a bird classification system in terms of its cost and performance factors. The study would consider a number of application areas such as in-flight and ground-based systems. The integration of other target features such as the time variation of target cross section would be included.

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ACKNOWLEDGEMENT

A number of people have contributed to this program. Charles Vaughn of NASA, Wallops Island, Virginia collected all of the field data on the birds using the RCA Model 4019 hand held radar and the Lockheed tape recorder. His expert identification of bird types while taking the data was essential. Robert Van Olst and Donald Dempsey of RCA were instrumental in the administration and initial conception of the approach and they together with Charles Vaughn provided helpful suggestions for the report. Finally, the aid of Edward Horton and Dave Berlin of RCA in processing the data under a very tight budget is appreciated.