4.14. ANALYSIS AND CLASSIFICATION OF BIRD FLIGHT AND ECHO DATA OBTAINED BY RADAR.

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SUMMARY

The large scale movements of birds observed on the plan position indicator of a surveillance radar cannot be resolved to give the identity and size of single birds unless the bird movements are sampled by a high resolution radar capable of isolating and examining individual bird echoes.

Radar flight and echo data is required for the study of bird movements, for gauging the bird strike threat, for estimating bird size and for possible identification of bird species. Detailed information of target parameters is also needed for designing new bird radars or adapting old ones, or in planning for their operational use.

A large amount of flight and echo data can be obtained from a high resolution tracking radar during a two minute period of bird tracking. Thousands of such radar engagements are made in the course of Spring and Autumn bird migration so that the potential accumulation of such data is enormous.

How can this data be analysed, classified and catalogued for rapid retrieval and effective use?

It is the contention of the authors that there is not yet a single neat solution to this problem, but using a large number of examples from the Nato-Gibraltar Bird Migration Radar Study they consider this question in terms of the bird strike threat. Particular attention has been paid to the specification of the amplitude variation of the bird activity modulation components over the whole two minute period of the echo signal record.

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1 INTRODUCTION

Radar methods which enable the present and predicted positions and velocities of aircraft which are hundreds of miles from the radars to be estimated with great accuracy in all weathers are unable to define whether they are friend or foe or to gauge their physical dimensions. Spectacular echo displays seen on the PPI's of military and air traffic control radars have been correlated with the known passages of migrating birds but in general it is impossible to state whether each echo represents five or fifty birds let alone their physical dimensions or species.

The identification of an uncooperative target by radar is generally a very difficult task but the discovery by Davenport (1) and the doppler records of Lanyon (2) showed a bird modulates its echo intensity and generates doppler spectra by wing flapping. These results suggested methods of identifying single birds. As far as the bird strike hazard is concerned the fact that an estimate of a bird's physical dimensions can be obtained from its radar wingbeat frequency goes a long way to enable the threat to be judged (3). Species with wingbeat frequencies above 20Hz are unlikely to prove a serious threat in Europe, but species with wingbeat frequencies below 10Hz are potentially dangerous.

Birds and aircraft are fortunately not often in conflict except when they use the same airspace near airfields, or when low level missions are flown; usually thousands of metres in height separate them. Consequently it is almost as important to know the height of bird movements as to track their flight through a region.

Echo and flight characteristics of birds are also required for studying the movements of birds and their threat to aircraft, and they are also required in planning the design or modification of radars and in their operation. There are numerous ways of obtaining echo and flight information but one that satisfies many requirements is to use a high resolution tracking radar to separate a specific bird from unwanted targets and then obtain from it the desired information for analysis.

Such data can be recorded onto a multitrack magnetic tape recorder which can be either a digital or instrumentation recorder. In our case an instrumentation recorder was used to record data in analogue form as this method was fully compatible with the radar outputs and analysis equipment. Data was recorded for approximately two minutes for each individual bird echo and each reel of tape gave a running time of over 3 hours. Several thousand such records were obtained of representative samples of all species observed on the radar day and night during Spring and Autumn migration as described in a recent paper (4). This collection of recorded tapes occupy several hundred hours of running time and it is obviously impractical to run through such records each time some item of information is needed. An attempt must therefore be made to analyse, classify and catalogue the records in such a way that makes a quick reference possible. If the records are on standard magnetic tape then the analysis, classification and cataloguing can be programmed to suit the particular user such as:- radar designer, air traffic manager, radar operator or ornithologist.

It should be emphasised that such a catalogue is not a replacement for the long recordings of raw data but a means of quick reference to where specific characteristics may be found. In many cases specific information will require a re-analysis

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to be made from the original recordings.

In the examples given in this paper we have attempted to formulate some pages of a possible catalogue using data obtained from our Nato-Gibraltar Bird Migration Radar Study. Initially long hand methods are useful for exploring the analysis problems, but the bulk of data can only be processed by making full use of analogue and digital computation.

Although the radar study of sight identified birds on local and migratory flight is essential for the detailed classification of species a great deal of the radar data obtained is from birds flying out of range of human sight such as during the hours of darkness. Information from these latter sources is also vital in building up our knowledge of bird radar echo returns and flight characteristics. In our examples we concentrate on unidentified birds on nocturnal migration but we also include some examples of records obtained on raptors in daylight.

2 RADAR DETAILS

The X-band (wavelength 3 cm) high-resolution automatic tracking radar used at Gibraltar has a range of approximately 5 nautical miles on a Herring Gull (*Larus argentatus*). The diameter of the resolution cell at a range of 1000 metre is 15 metres approximately, and the range and angular precision are 3 metres and 0.2 milliradian respectively.

Radar (slant) range, azimuth (bearing) angle and elevation angle data were continuously obtained from a bird being tracked and this information was sent electrically to an analogue computer which converted polar into cartesian data. The cartesian output of the computer gave the position of the bird in true height above a ground plan scaled in ground range Northings and Eastings. Ground range Northings and Eastings and height were continuously recorded onto multi-track magnetic tape for storage purposes and subsequent analysis. The radar echo signal and accurate digital time (referenced to GMT or Zulu time) were also continuously recorded. An additional track was used to carry team-leader and operator conversations which were a vital part of the acquisition, lock-on and follow sequence of each bird engagement. We found that a lively description of the engagement was of great benefit when making an analysis.

The range performance of the radar was calibrated on a metallized sphere of known echoing area (carried by a balloon). Records of wind velocity at different altitudes and other essential weather data were made throughout each day by the Meteorological Unit of RAF Gibraltar.

At Gibraltar an ATC surveillance radar was used to locate the high-resolution radar on to the centre of a migratory movement and then the radar operator methodically scanned through an assigned target position in elevation. However the echo patterns on the PPI of some broad front movements were so homogeneous that it was not feasible to pick out centres. On those occasions it was usual to estimate the migratory heading and concentrate on approaching targets; periodically scanning in elevation to obtain the migration height band. When a suitable target was found (ie one that would auto-follow clear of other targets and clutter and provided good echo and flight data) all radar data outputs were switched to record on tape. During migration large numbers of birds could be acquired without accurate "putting-on" information and about 50 birds or so were tracked (for not less than 2 minutes per track) per watch. The acquisition procedure was generally more difficult to carry out on diurnal movements because then birds tend to fly in bunches and sometimes a great deal of operator skill was required. A frequent cause of wasted records were birds joining a selected single bird part-way through the recording.

3 ANALYSIS

After representative samples of data from species moving in narrow or broad front movements have been obtained by the operations mentioned above it is necessary to analyse the data.

We shall not dwell in great detail on the analysis of "raw" radar records as we have already described some of our methods in previous papers (5). Some aspects of previous work such as estimating echoing area (6), a parameter which is worth cataloguing, have been left out in order to concentrate on other features such as the comparison of the characteristics of a number of birds of the same species.

As several of our previous papers were written about results taken on a high-resolution C-band (5cm wavelength) radar in Wales it is worth pointing out differences we encountered using the X-band radar in Gibraltar. Generally we engaged targets at Gibraltar at about 1/3 the range obtained in Wales. Consequently at Gibraltar the change in slant range was often twice as much in percent change of range as in Wales, and the change of elevation angle on radial targets was sometimes 10 times as much and the change of azimuth angle was sometimes 3 times more than in Wales.

3.1 Flight Characteristics

The heights and tracks of four birds with similar wingbeat frequency spectra are shown in Fig 1. The first number before the oblique sign is the bird engagement run number and the second number and the letter refers to the particular magnetic tape on which that run was recorded. This quartet of flight observations were done on the same August evening and approximately within one hour of each other, viz: run 158 was started at 20 hours 7 minutes 15 seconds Zulu and run 178 was ended at 21 hours 19 minutes 27 seconds Zulu.

The vertical and horizontal scales on the ground plan position diagram Fig 1 are given in terms of ground range Northings and Eastings respectively, and the position of the radar is marked. All the tracks are approximately straight. Runs 158, 160 and 163 are crossing tracks, but run 178 is a radial track. In all cases the birds are receding from the radar. The percentage change in radar (slant) range is as low as 13% approximately for run 160 and as high as 72% approximately for run 178. Corresponding to these radar range changes there are changes in echo intensity of approximately 2dB and 9.5dB, respectively.

The height versus time diagram is shown in Fig 1 for the four birds. All birds were observed at fairly constant heights between 1500 and 3000ft. As the engagement runs are accurately timed and the ground range scales are carefully calibrated it is possible to calculate the ground velocities of runs 158-178 and they range from 27 to 34 knots. Air speeds of from 18 to 23 knots can be estimated from wind velocities occurring at the appropriate heights and at that time.

The heights and tracks of five birds with similar wingbeat frequency spectra but different from above are shown in Fig 2. This quartet of flight observations were done on the same October evening between approximately 19.30 - 20.00 hours Zulu. The most interesting feature of these characteristics is the effect of different wind velocities with different heights. The wind speeds ranged from approximately 20 knots at 4000ft to approximately 29 knots at 7000ft in height. The effect of wind velocity on runs 103 and 113, which were at the lowest heights, is that their ground and air speeds are approximately the same and equal to

28 knots, whilst the effect on run 114, the bird flying at 7000ft, was for ground and air speed to differ considerably, viz: 14 knots and 33 knots.

At this point it is again worth mentioning that the catalogue can be as brief or detailed as the user requires. In the catalogue developed for the Nato-Gibraltar Bird Migration Radar Study and used as a "specimen" catalogue in this paper factors of importance in radar design and operation are included. For example, previous studies have shown that the average echo signal varies with aspect, but no systematic effort has been made to relate properties of the BAM (ie Bird Activity Modulation) waveform with aspect. It is not known yet how the modulation index changes with aspect or whether the loss of the fundamental wing beat frequency component and enhancement of harmonics of the BAM wave which can occur can be strongly correlated to aspect. Important factors necessary to tackle this problem have been catalogued; they are an estimate of the bird's aspect at the start of the engagement and the total angular change in aspect (vertical and horizontal) which occur during the run, and the mean and standard deviation values of the BAM waveform.

3.2 Echo Characteristics

The echo characteristics have been obtained from the tape recordings made of the radar automatic gain control (AGC) and they are analysed in a variety of ways. The amplitude response and bandwidth of the AGC system was also measured at the beginning and end of each migration period in order to check its performance.

Amplitude versus time records (BAM waveforms) have been made over the complete run using an ultra-violet paper recorder. In Fig 3, BAM waveforms with wing beat frequencies of 3.5, 5.0, 6.9, 12.1 and 14.6 Hz are compared. These records can be made at various paper speeds permitting the BAM waveform record to be expanded where necessary for comparison purposes, Figs 4-10. The waveform record is examined for whether the waveform is a simple quasi-sinusoidal wave or a complex one, and whether the wave is a continuous one such as generated by relatively continuous flapping as 95/5C in Fig 3 or periodically interrupted by quiescent periods produced by closed wing pauses or glides, such as 99/11C and 86/7B in Fig 3 (with a suitable radar it is possible to clearly distinguish between the flat quiescent period produced by a closed wing pause and the wobbly quiescent period produced by a bird gliding with outstretched wings). As the wing flapping and pause cycle can be used in the identification procedure it is worth while specifyir and including in the catalogue. The appropriate values for the 2 minutes of run 95/11C in Fig 4 are average number of flaps per wing cycle = 22, standard deviation = 10, while the average pause period per wing cycle = 1.5 seconds, standard deviation = 0.7 seconds. The flap and pause periods of BAM waveforms can sometimes be examined more effectively by selective filtering. The method adopted in this paper for presenting the AGC waveform as an amplitude variation with time used a low pass filter cutting off at approximately 35Hz. This is shown for run 86/78 in Fig 11A. For Fig 11B an additional filter has been used anc only frequencies between 10-35Hz are shown in the amplitude/time waveform. For Fig 11C the high pass filter was replaced by a low pass filter which only allowed frequencies up to 4Hz to pass.

A noticeable feature of the radar bird studies of night migration in Wales was that the majority of results were of echo signals of fairly constant intensity and modulation index, but this was not so at Gibraltar. As the fluctuation characteristics affect a number of factors such as target detection range, the variations in mean level and standard deviation of the evelope of the BAM waveform are considered over the entire observation record and specified. The AGC voltage was recorded on a B and K level recorder with a long time constant of several seconds to remove the high frequency components of the BAM waveform and leave the waveform envelope. These envelope records have been used with a minicomputer programme to obtain average value and standard deviation of the BAM waveform envelope. A single figure of merit, Pearson's coefficient of variation equal to the standard deviation/average value ratio, has been used to specify the absence or presence of fluctuation or a low level of modulation. A description of the specification and the values associated with different BAM waveform envelope shapes is given in Appendix A. Generally, BAM waveform envelopes which fluctuate relatively violently such as run 103/9C in Fig 12 have a high standard deviation/average ratio 10.2/24.9 and a high coefficient of variation 42%, while waveform envelopes which have relatively less fluctuations as run 116/9c in Fig 12 have a low standard deviation/average ratio 3.5/14.5, and a low coefficient of variation 23%.

Fourier analysis of the BAM waveform has been carried out using time compression analysis technique and amplitude/frequency spectrum diagrams are illustrated in Fig 13 for birds generating wing beat frequencies of 3.3, 4.9, 6.9, 8.2, 10.3, 11.7 and 14.6 Hz and for groups of similar spectra Fig 14-20. A key parameter in the catalogue is the fundamental frequency component of the BAM waveform as this component corresponds to the wing flapping frequency of the bird. The presence of harmonics of the fundamental component as in Fig 15 are also important in establishing the fundamental component accurately. In our catalogue the width of the fundamental frequency response is measured at the 1/2 power points as this width can be used to indicate wing beat frequency variations.

Another way of looking at variation in wing beat frequency over the entire 2 minute record has been mentioned in a previous paper (5). This is the intensity modulated frequency/time diagram shown in Fig 21. The amplitude/frequency fluctuations used to produce the spectrum diagram are used to intensity modulate ultra-violet sensitive paper and make a plot of frequency on the vertical axis. The horizontal axis is in terms of observation time from the start of the record for a period of one minute. This diagram enables any variations of wingbeat frequency to be revealed over the duration of the record, and it also shows up periods when the fundamental or harmonics of the BAM waveform fall to a low level or are absent. The intensity modulated frequency/time diagram shown in Fig 21 of run 105/11C indicates that the frequency variation of the fundamental is less than 5%.

Another check on variation of wing beat frequency versus time is shown for six of the seven groups of birds by the diagram given in Fig 22. The fundamental wing beat frequency components of the spectra of the 24 birds have been accurately measured at 12 second intervals. In each case the mean wing beat frequency of one bird of a group is given to indicate the frequency scale.

4 CLASSIFICATION

The Bird Radar Flight and Echo Data Tables, Fig 23 to Fig 29 are one method of classifying some of the information obtained by radar from a 2 minute observation of a bird. Each sheet contains tabulated information on a different species but (for the purposes of the paper) in order to compare species with what are considered to be similar species, 4 birds are tabulated on each sheet. A collection of such tables would be the basis for a quick reference catalogue.

The chief factor used here for labelling a species is the fundamental component of the Fourier spectra of the bird activity modulation waveform. In most cases the fundamental is easy to obtain but it can be absent for part of the record as we have mentioned in a previous paper (5) and it is then necessary to calculate the fundamental from the harmonic components of the BAM waveform. Other complications can arise if the beat and pause sequence of wing activity has a quasi-repetitive periodicity and an example of such species is given in the tables.

(Bruderer (7) advised us that many of his records taken in Switzerland possess these characteristics).

The classification using the table in Fig 23 as an example is as follows:

1) Date of making the observations record.

2) Tape Record: the first number before the oblique sign is the bird engagement run number and the number and letter after refer to the particular magnetic tape on which that run is recorded.

3) Run Time: the top set of numbers refer to the start of the engagement and the bottom set of numbers to the end of the run. Time is referenced to Zulu time in hours, minutes and seconds.

4) Spectra: the fundamental, with the 2nd and 3rd harmonics where present, of the BAM waveform are recorded together with the 3dB spread of the fundamental component.

5) Other Spectra Components: These frequency components may be generated by the bird, ie if it generates a quasi-repetitive flap and pause wing sequence, or it may indicate a radar or processing fault condition.

6) Wingbeat Cycle: This is a record of the average and standard deviation in seconds of the whole wing cycle, both flap and pause.

7) Number of Flaps: The average number of flaps of the wing, the standard deviation and the range in the number of flaps over the full 2 minute run. These parameters apply only to birds that flap and glide or flap and pause.

8) Pause: the average, standard deviation and range in seconds of pause or glide duration is given together with the number of pauses that occur in a 2 minute observation run on a bird.

9) Bird Activity Modulation: Using the method described in the analysis and in Appendix A, K Pearson's coefficient of variation is used to indicate the quality of modulation. The average value and standard deviation is also given so that it is possible to gauge whether the poor quality of modulation is due to a low mean or to fluctuations in the BAM waveform.

10) Aspect: The top row of figures and letters give the estimated azimuth aspect of the bird at the start of the observation run: viz: 017 degrees from tail-on aspect in the horizontal plane. Angular changes $\Delta \phi$ and $\Delta \theta$ are the aspect changes in horizontal and vertical planes occurring during the 2 minute run.

11) Track: The top word gives a very approximate description of whether the ground plan track is straight or not, the second word tells whether the bird was approaching or going away from the radar and the last word whether the track was radial to the radar or crossing.

12) Range: The number is the radar (slant) range in yards at the start of the run. The change of radar range Δ R as a percentage of the start range is also given.

13) The top number is the radar azimuth angle at the start of the run and is the change of bearing angle occurring during the run.

14) The top number is the radar elevation angle at the start of the run and is the change in the elevation angle during the run.

15) The track heading is the mean bearing obtained by the radar operator during the run.

16) Estimated speeds are given in knots with the top figure being the ground speed and the lower figure is the air speed which allows for wind speed and direction.

17) The height is given at the start and end of flight and an indication is given whether or not the bird was flying at a constant height.

5 DISCUSSION AND CONCLUSIONS

Methods of analysing, classifying and cataloguing data obtained from individual birds in flight have been demonstrated, such methods can be orientated to suit the user's requirements. The catalogue can be used as a repository of generalised information as a reference to specific magnetic tape records and kept in the form of a book of tables or in a computer store.

The fundamental wing beat frequency component of the BAM spectrum extracted from those points of the echo signal modulated by wing flapping has been chosen as the key characteristic. This parameter is employed because it is fairly easy to obtain from echo signals of birds. Ambiguities can occur in determining the fundamental wing beat frequency component, because it may be absent in part of the engagement record or because the first components in the BAM wave spectrum may be due to the quasi-repetitive flap and rest wing activity of some species. Both conditions can be detected and resolved.

An abbreviated "specimen" catalogue has been given for species with wing beat frequencies of approximately 3.3 Hz, 4.9 Hz, 6.8 Hz, 8.6 Hz, 10.1 Hz, 12.1 Hz and 14.5 Hz. In order to give the reader some idea of the comparison possibilities, flight and echo characteristics have been tabulated for groups of 4 or 5 birds linked by a common wing beat frequency. The data for each bird was obtained from magnetic tapes holding thousands of bird runs taken during the Nato-Gibraltar Bird Migration Radar Study (a study designed to sample broad and narrow front bird movements, day and night, during Spring and Autumn).

In processing the results it was found yet again that the wing beat frequency component of the BAM wave spectrum can be remarkably constant for birds on migration. The frequency deviation in the worst case of the 29 runs used in the catalogue was a standard deviation of approximately 4% for the birds in the nominally 4.9 Hz group.

However many quite different species have approximately similar wing beat frequencies and so a consideration of some other features such as the relative durations of the flap and pause periods of the BAM waveform must be investigated if further selection is needed. There is an interesting example in the catalogue where further selection is possible. This is for the four birds grouped under the nominally 8.6 Hz wing beat frequency where the average wing cycle per unit period is 8.6 and 8.7 seconds for two of the birds and 2.6 and 2.9 seconds for the other two birds, whilst the average pause/wing cycle/run is 2.7 and 2.8 seconds for two birds and 0.51 and 0.78 for the other two birds. Hence in this selection using the fundamental wing beat frequency as the criteria the flap and pause periods of two birds selected are very different from the other two birds.

On several of the flight and echo data sheets it has not been possible to show beat/pause figures as it was not feasible to obtain these from the 2 minute records of bird returns.

The surveillance of birds invading controlled airspace requires a knowledge of their position, path and speed; a knowledge of their dimensions would further aid decision making of the bird strike hazard. It is our contention that the systematic classification and cataloguing of bird flight and echo information obtained by radar as suggested in this paper will be necessary both in the study and real time surveillance of airspace and airfields.

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APPENDIX A

SPECIFICATION OF THE AMPLITUDE CHARACTERISTICS OF THE BIRD ACTIVITY MODULATION WAVEFORM OVER THE 2 MINUTE OBSERVATION RUN.

It was pointed out in a previous paper (7) that the echo signal from a bird consists of at least two components, an averaged or mean signal component and an amplitude modulated component. Both the components affect the range performance of a radar; speaking very generally a bird generating fairly constant components will be able to be tracked further in range than a bird generating fluctuating components. Furthermore it may not be possible to extract the wingbeat frequency or its harmonics if the modulation component is small or marred by violent fluctuations.

The BAM waveform can be specified like any other amplitude modulated signal by the degree of modulation or the modulation index. Such a specification is most convenient to realize and use if the degree or depth of modulation remains fairly constant during the two or more minutes whilst the bird is being tracked. This was not the case at Gibraltar and consequently it was necessary to provide a means of specifying the amplitude characteristics of the whole observation run.

There is no reason at all why the BAM waveform should not be specified in terms of average modulation index and standard deviation of modulation index, but we decided however to tackle it in another way, one that appears easier to evaluate and use in a catalogue. A characteristic we want to evaluate for comparison purposes is one that specifies the BAM waveform for the complete run.

We can do this by looking at the variations in the mean value and standard deviation of the envelope of the BAM waveform over the entire two minutes. The average and standard deviation of the BAM envelope can be obtained electrically by rectifying and filtering out the wingbeat frequency components of the BAM waveform with the result shown in Fig 12.

The mean value enables a comparison to be made as to whether the depth of modulation is great or small, and the standard deviation as to whether the modulation is fairly constant or fluctuating during the observation run. For quick reference purposes a single definition which focusses attention on the quality of the BAM waveform is:

$$\text{Karl Pearson's coefficient of variation } (v) = \frac{100 \times s\ \%}{\overline{X}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where s = sample standard deviation

$\overline{X}$ = sample average or mean value.

The quality of the BAM waveform will generally be poor if the coefficient of variation is large, whether this is due to a small depth of modulation or violent fluctuations in modulation. Indeed, if the modulation index is fairly constant the value of the standard deviation and the coefficient will be small.

Alternatively it is sometimes easier when using direct electrical methods to obtain the root mean square (rms) value of the BAM waveform envelope than its standard deviation (but it must be rms value integrated over the observation time). The fluctuation characteristics of an electrical waveform is given by form factor defined by:

$$\text{Form Factor (F)} = \frac{\text{rms value}}{\overline{X}} \qquad \text{..................(2)}$$

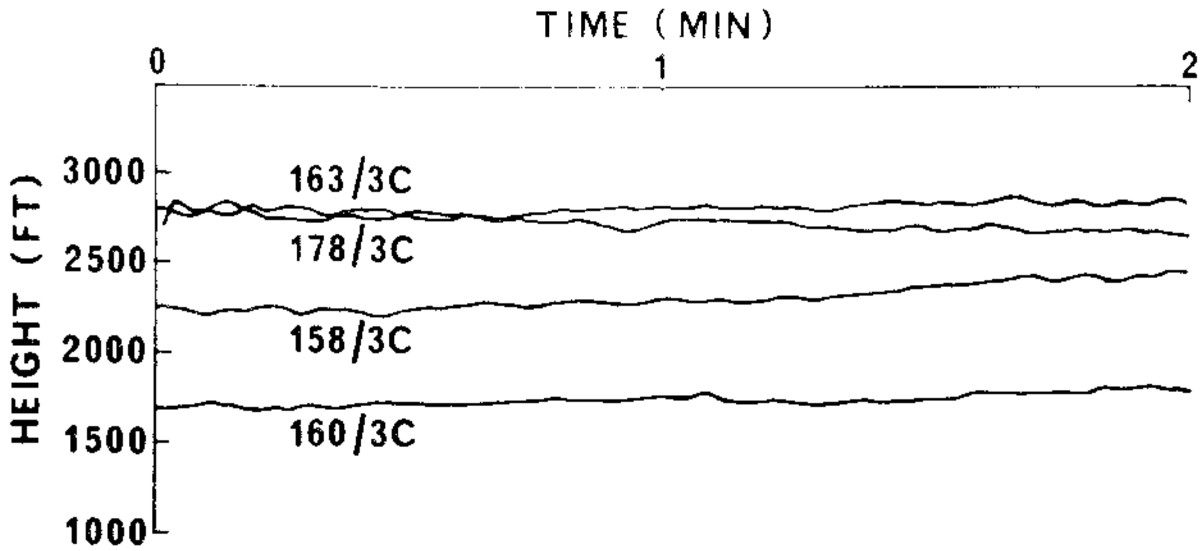
$$\text{and Pearson's coefficient (v)} = \left[F^2 - 1\right]^{\frac{1}{2}} \times 100 \qquad \text{..................(3)}$$

Some idea of the effects of variations on the BAM waveform amplitude can be seen by looking at Fig 30. In these cases well known periodic functions have been used such as full-wave rectified sine, sawtooth, 50/50 rectangular and half-wave rectified sine waves for the envelope shape function, although in practice the envelope will be more likely to be an aperiodic or random function. The periodic functions are easily approximated and enable a comparison table to be drawn up:

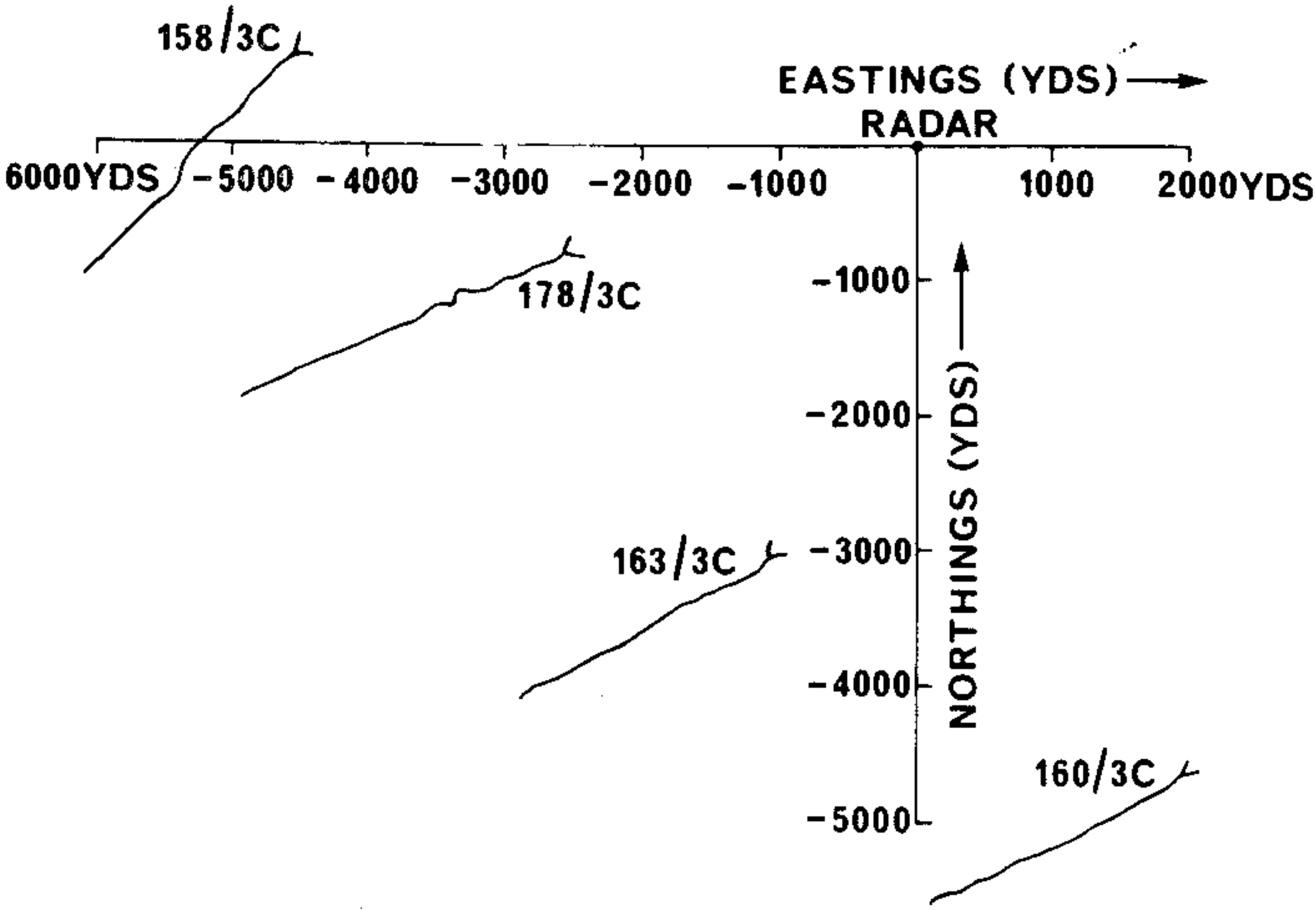
Waveform	Full-wave	Sawtooth	50/50 Rectangular	Half-wave Rectified
RMS Value	0.707	0.577	0.707	0.5
Average $\bar{x}$	0.63	0.5	0.5	0.138
Form Factor	1.110	1.154	1.414	1.572
Coefficient of Variation	48%	58%	100%	121%

We can see from the values given in the table that form factor and coefficient of variation increase together. However it is not always possible to estimate, by comparing waveform envelopes such as shown in Fig 30 by eye, whether one waveform will have a larger coefficient of variation than another. Usually it is necessary to evaluate the waveforms numerically. In practical cases waveform envelope shapes are much more difficult to estimate by eye than the periodic waveforms shown.

It is important to remember that the use of a single factor such as Pearson's coefficient of variation must be used, as with all generalisations, with care. For example it is essential to compare similar beat and pause or beat and glide species or similar continuously flapping species.

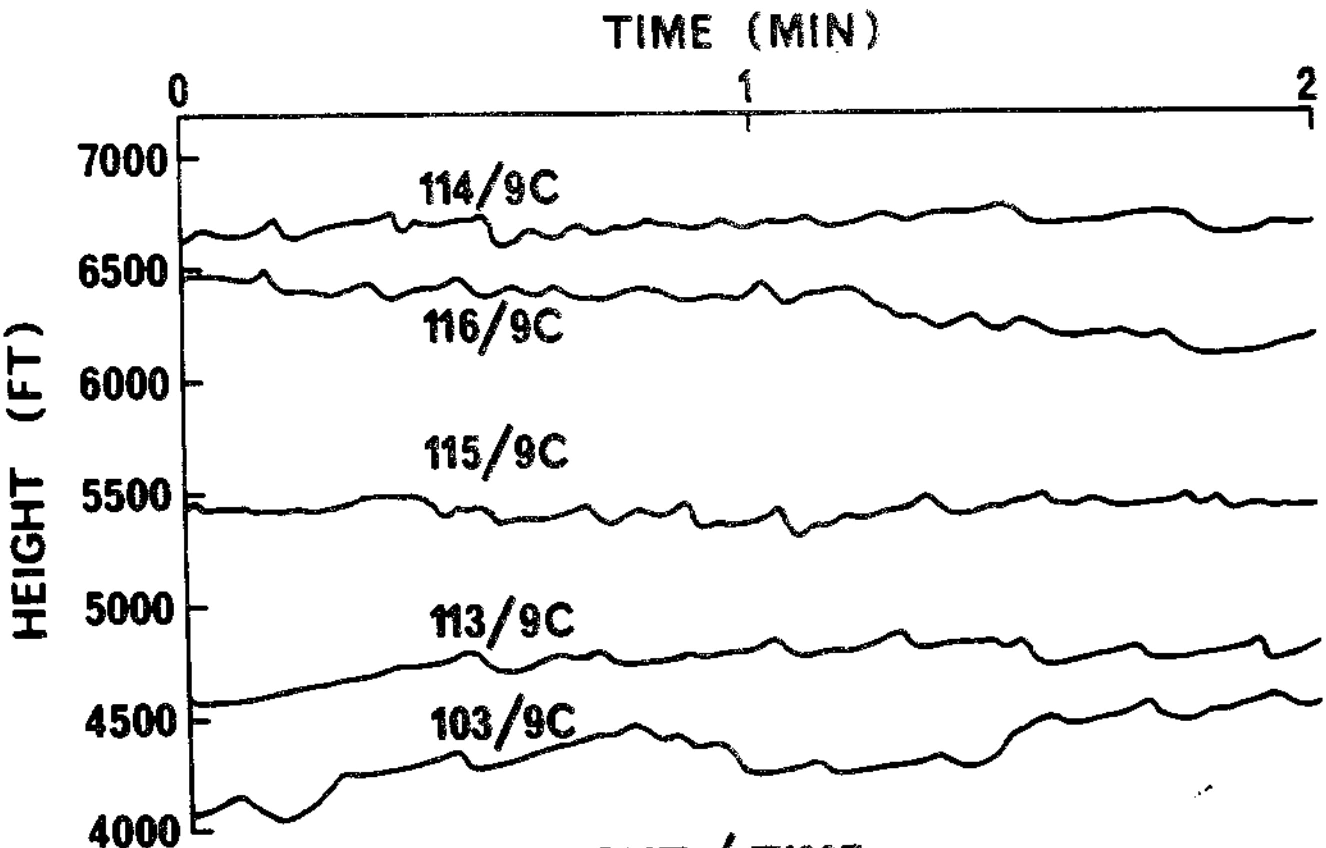


HEIGHT / TIME

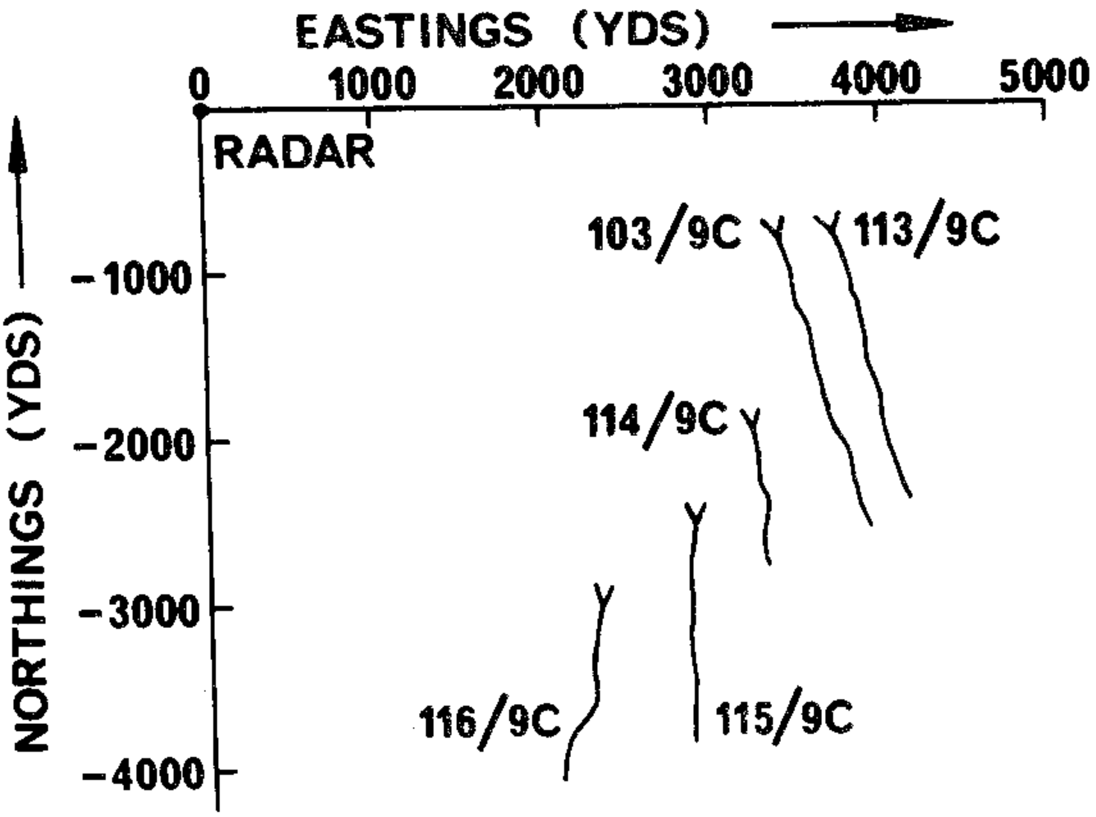


PLAN POSITION OF TRACK

FIG. 1



HEIGHT / TIME



PLAN POSITION OF TRACK

FIG. 2

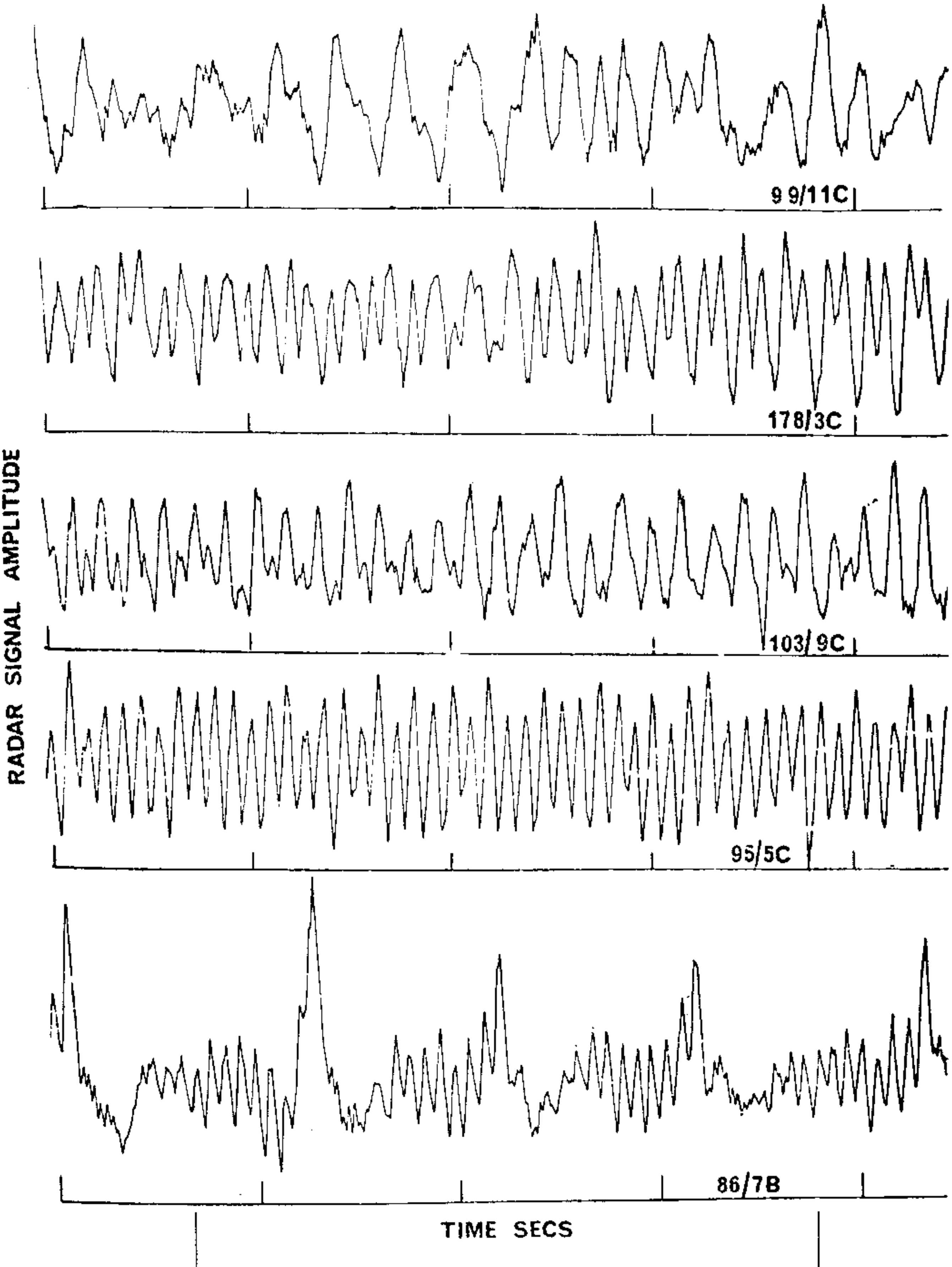


FIG. 3
COMPARISON OF DIFFERENT
BAM WAVEFORMS

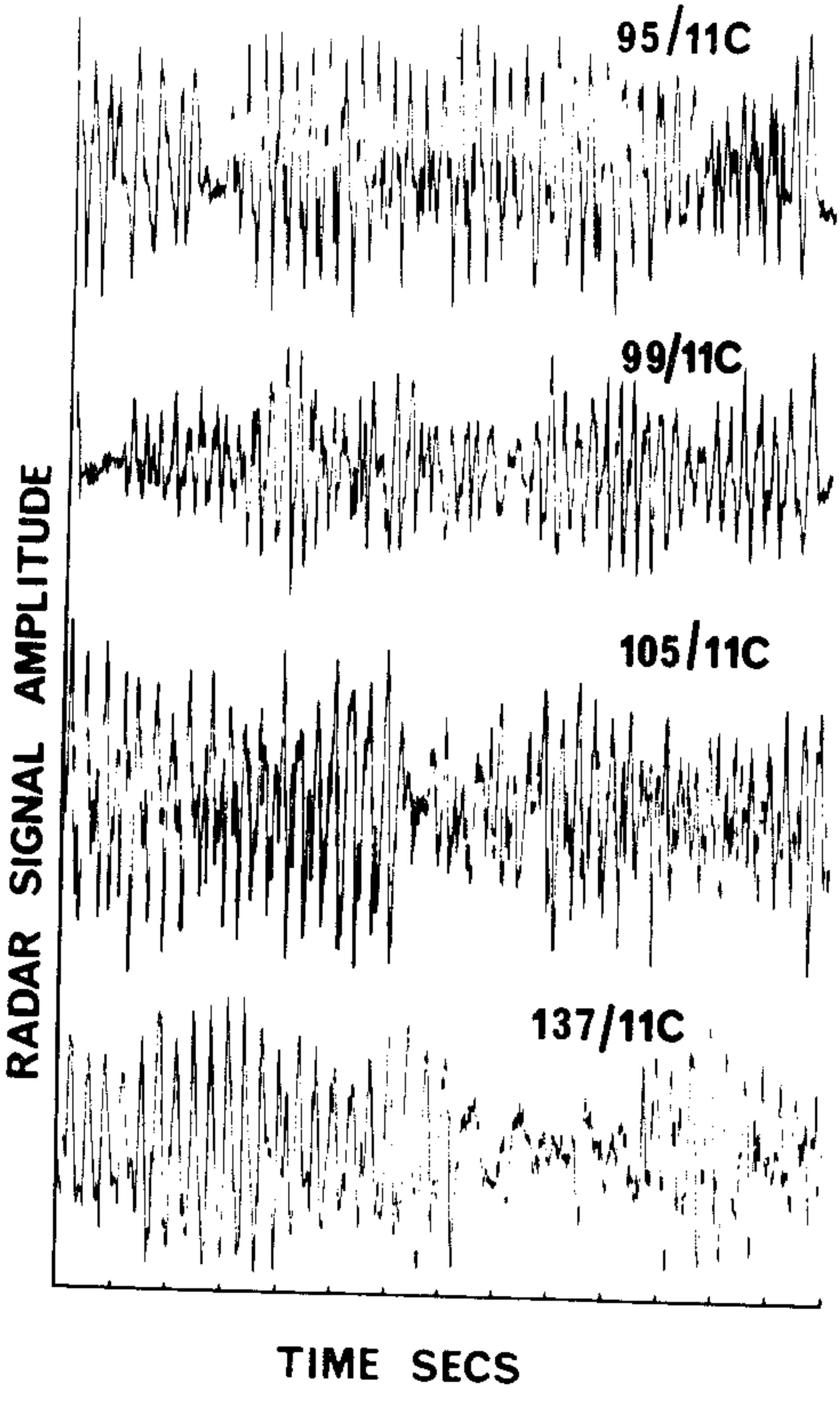


FIG. 4
COMPARISON OF SIMILAR BAM WAVEFORMS

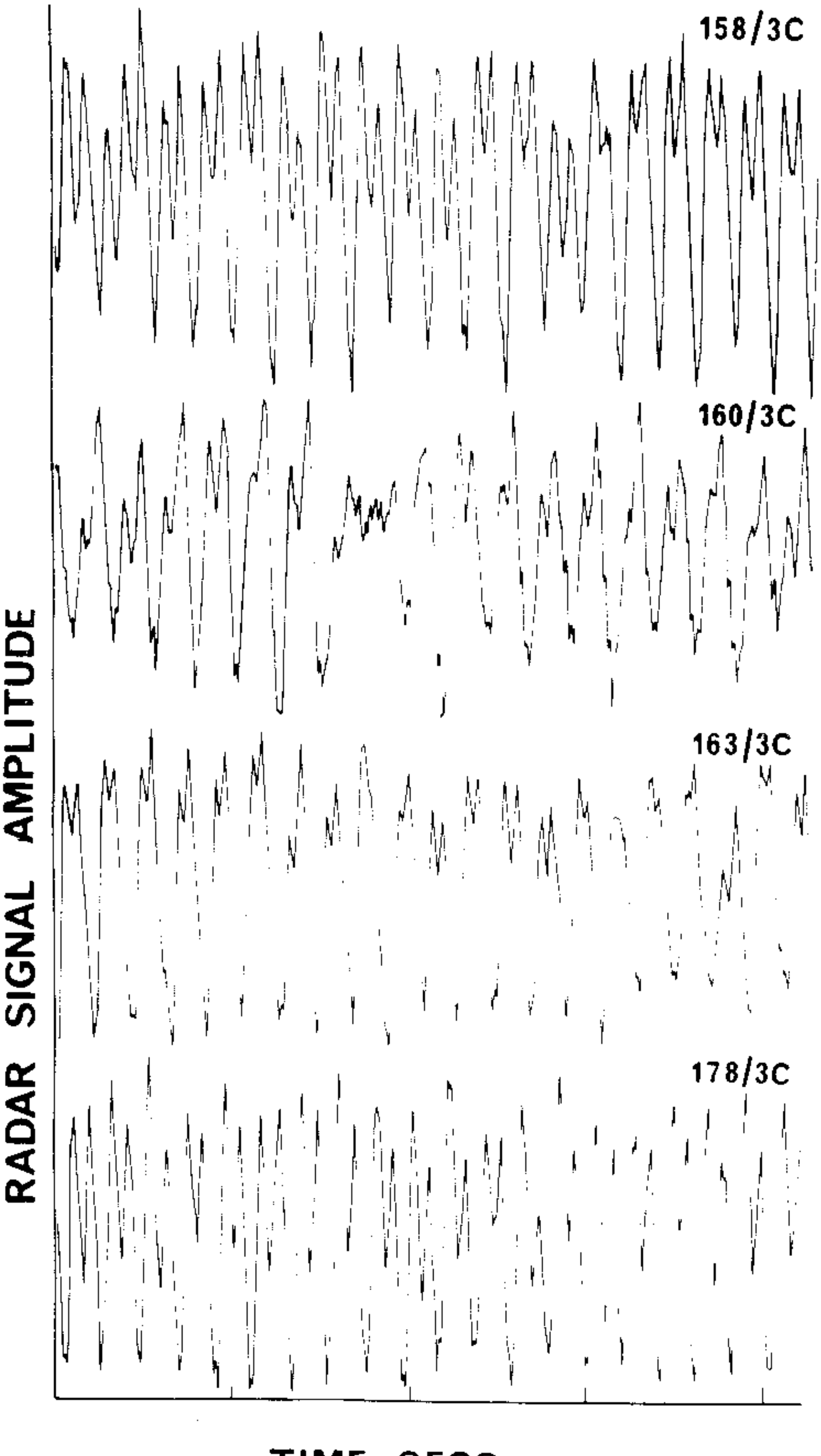


FIG. 5
COMPARISON OF SIMILAR
BAM WAVEFORMS

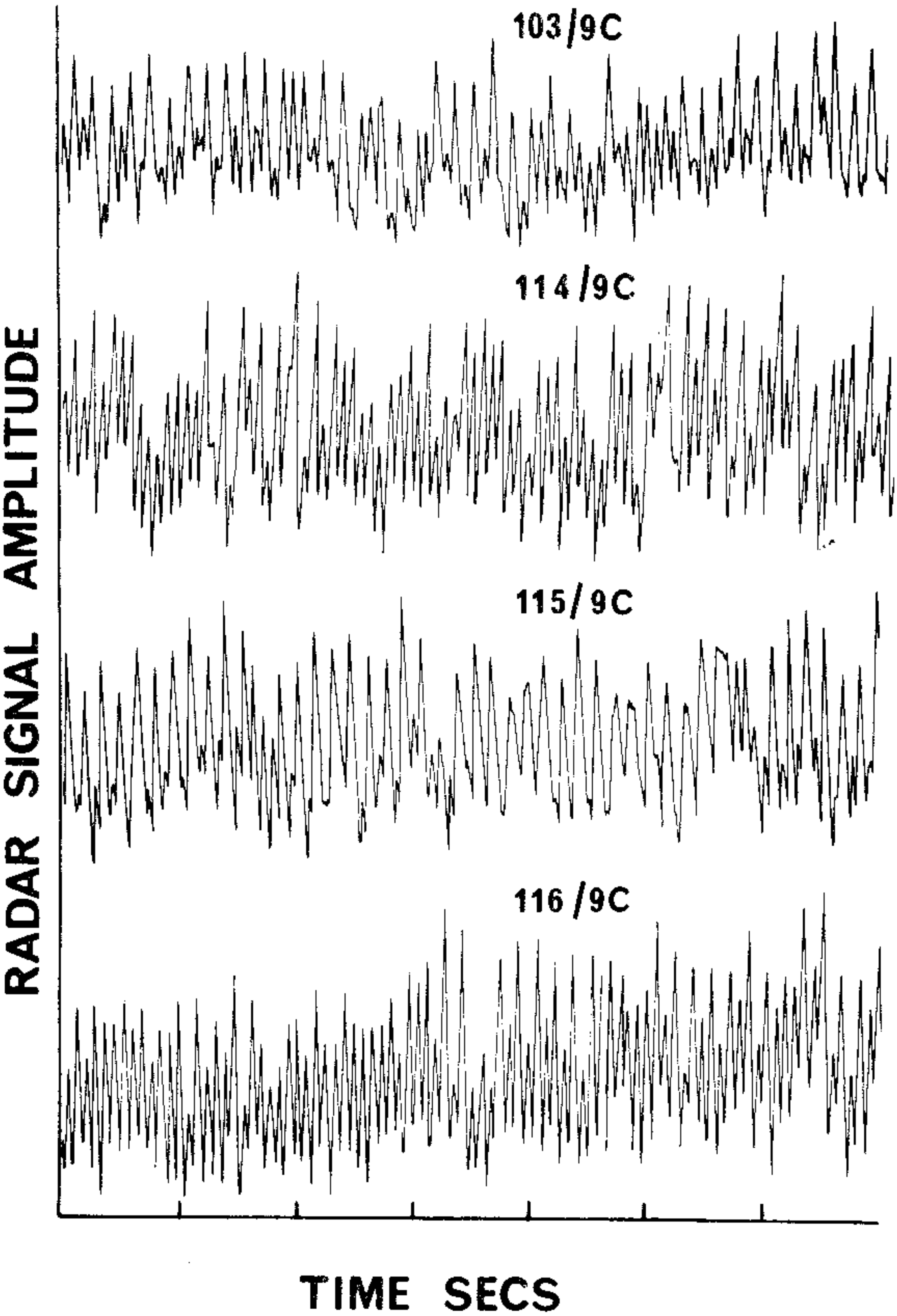


FIG. 6
COMPARISON OF SIMILAR
BAM WAVEFORMS

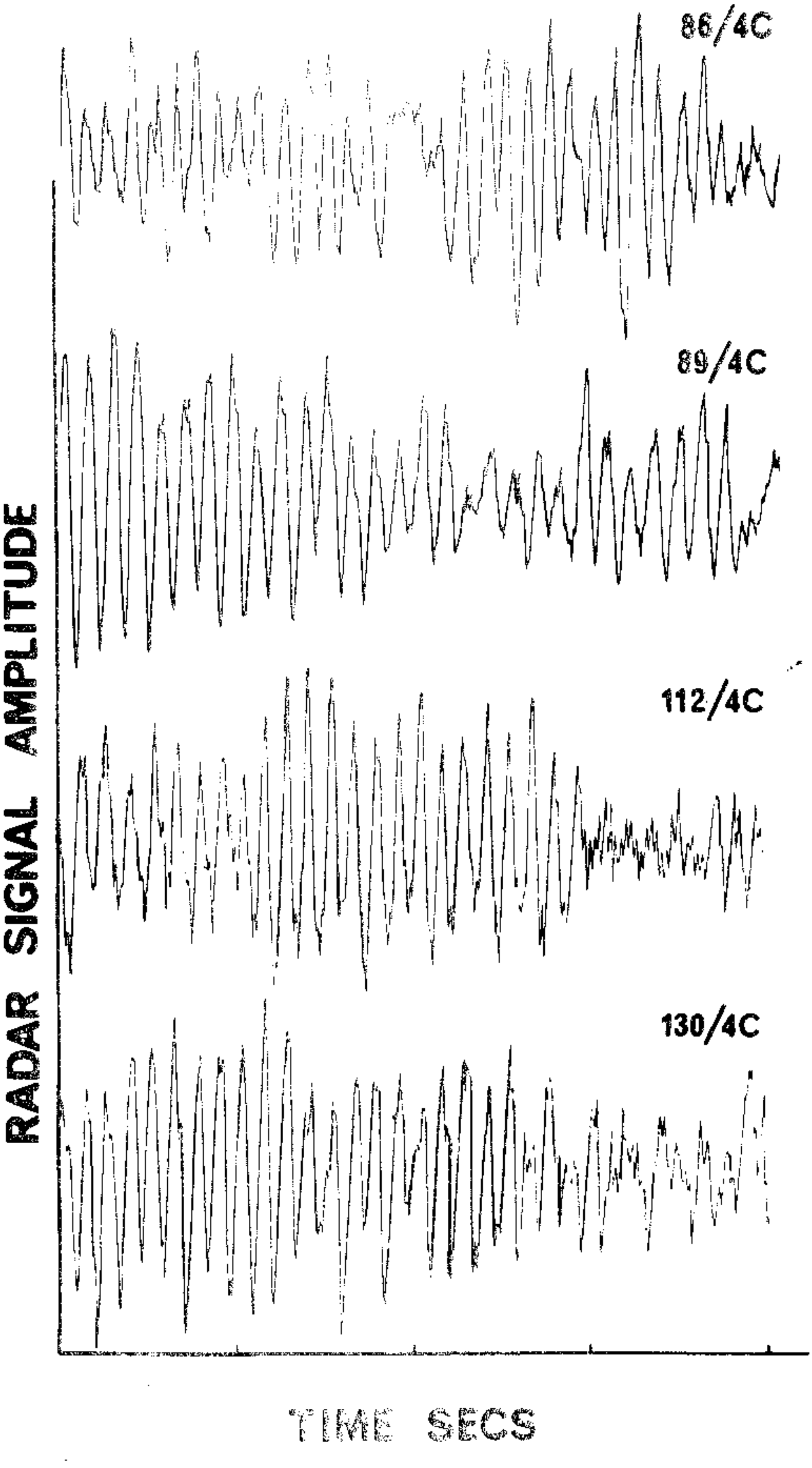


FIG. 7
COMPARISON OF SIMILAR BAM WAVEFORMS

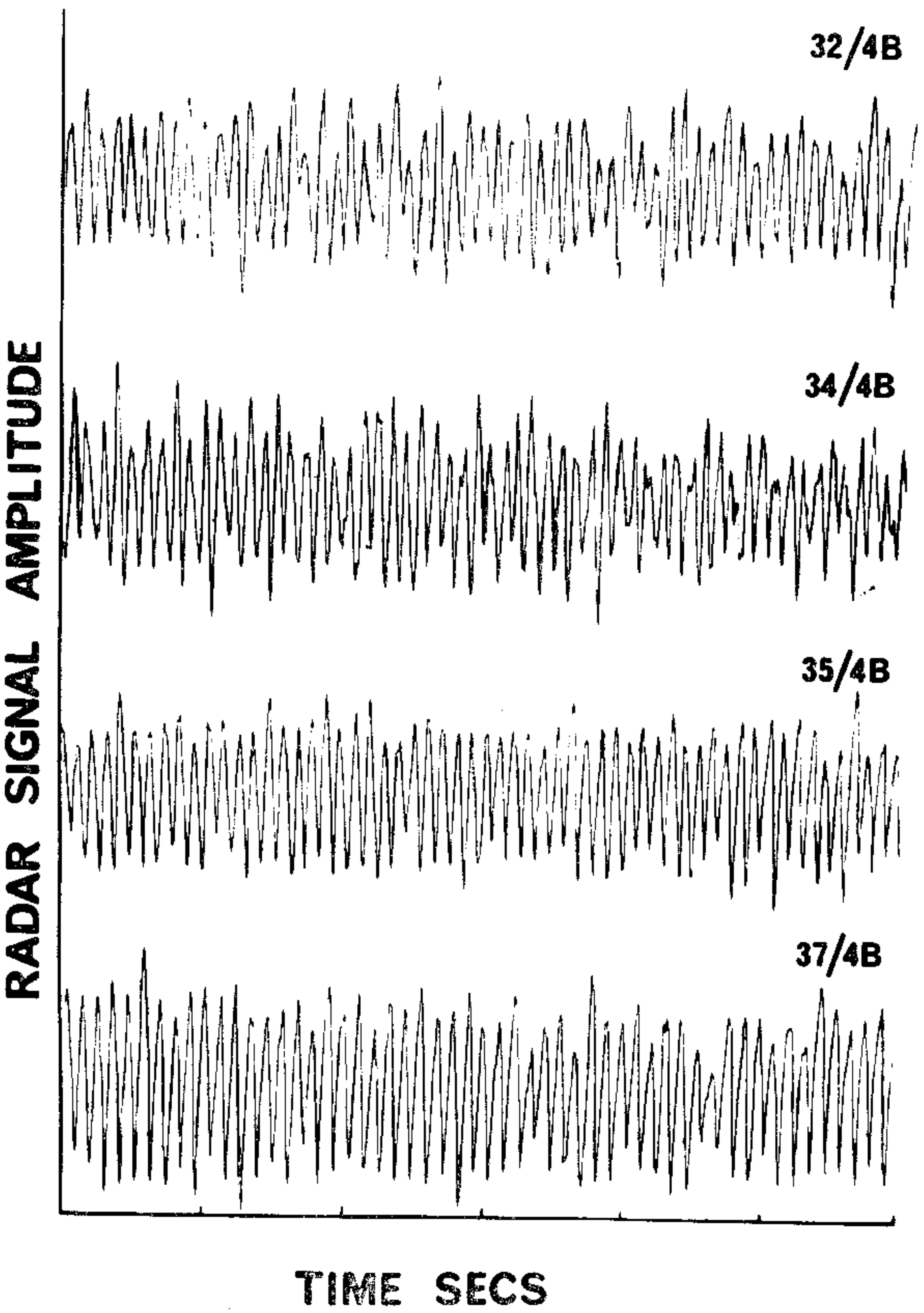


FIG. 8
COMPARISON OF SIMILAR BAM WAVEFORMS

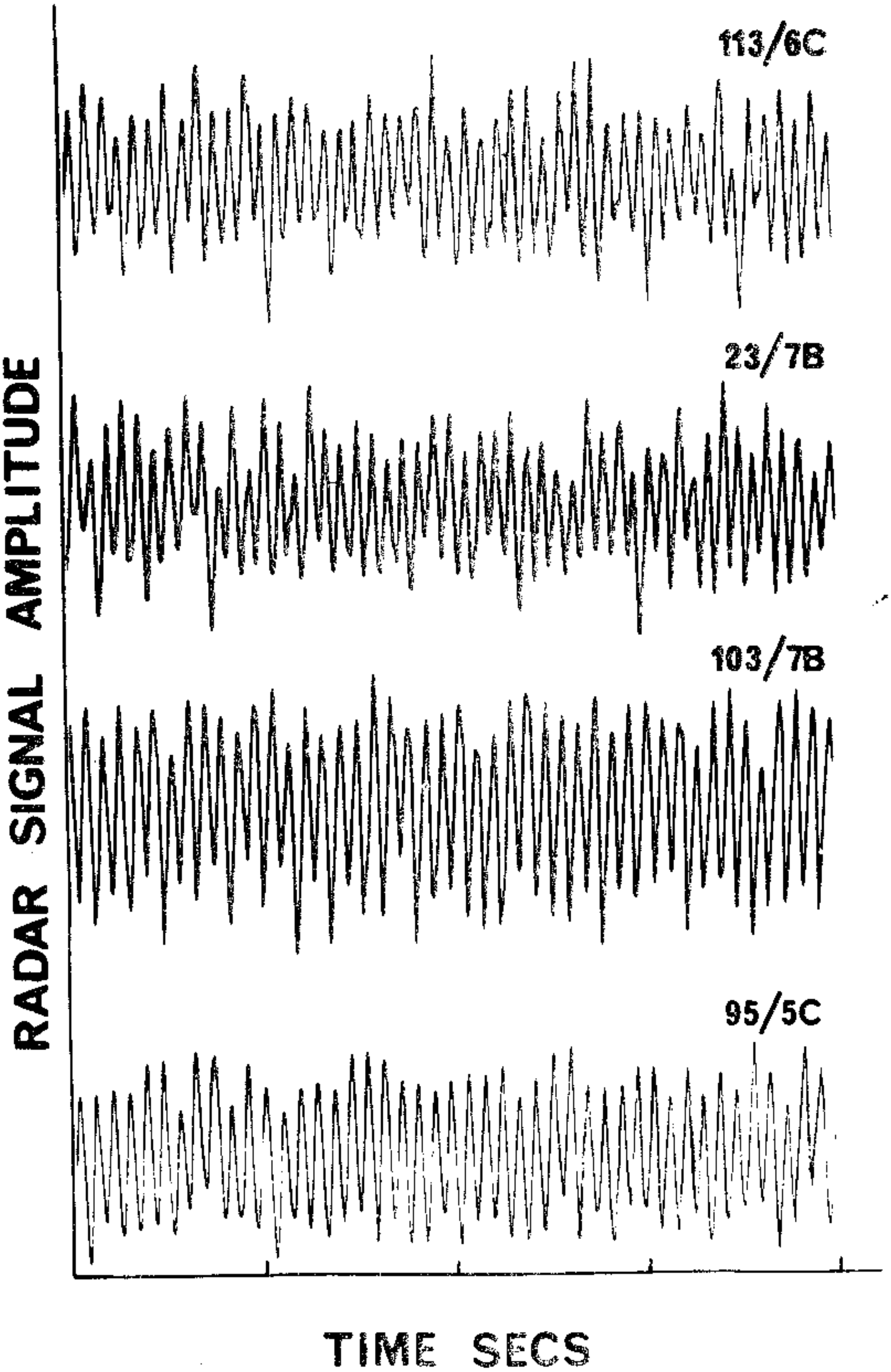


FIG. 9
COMPARISON OF SIMILAR BAM WAVEFORMS

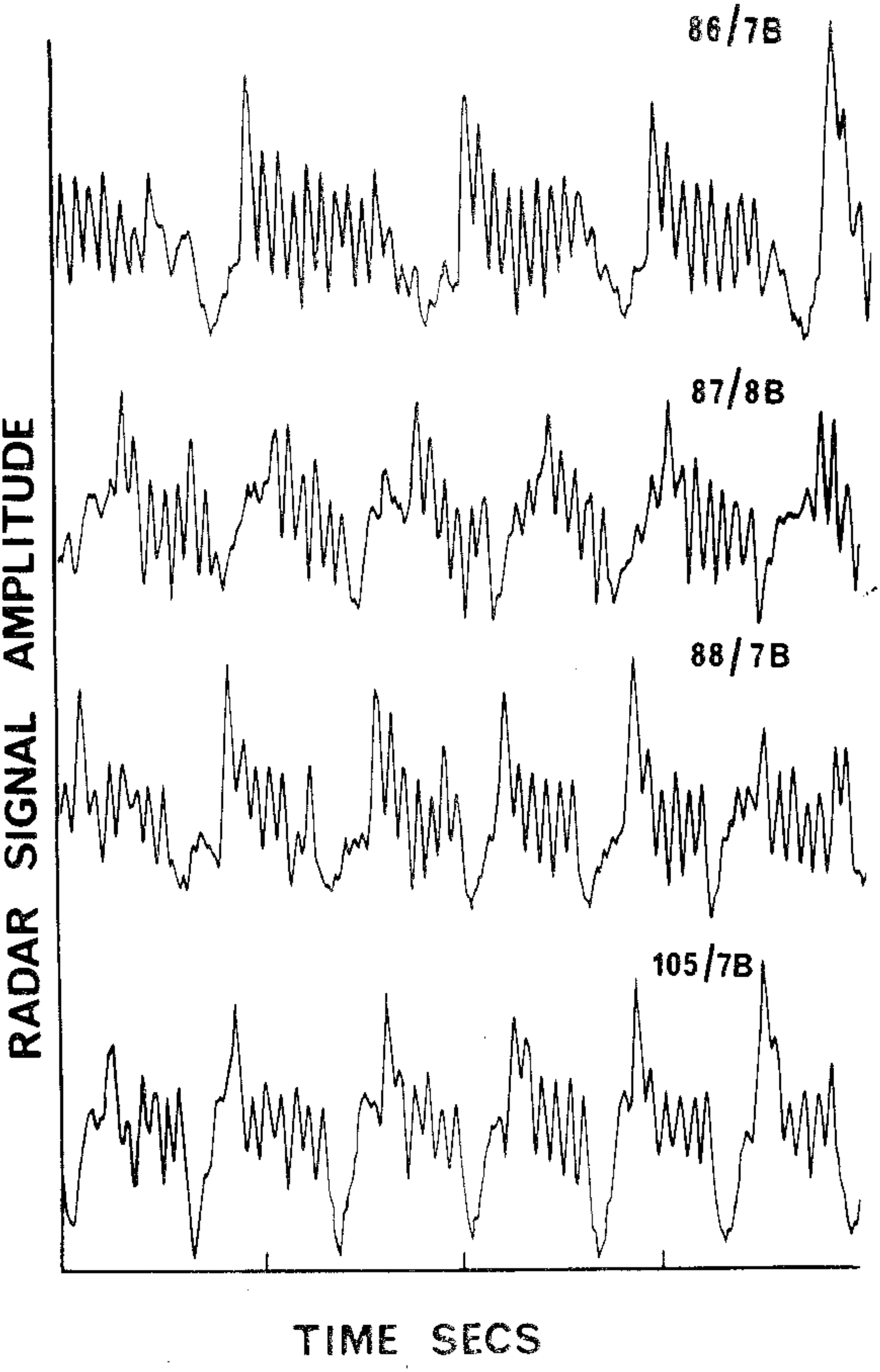


FIG. 10
COMPARISON OF SIMILAR BAM WAVEFORMS

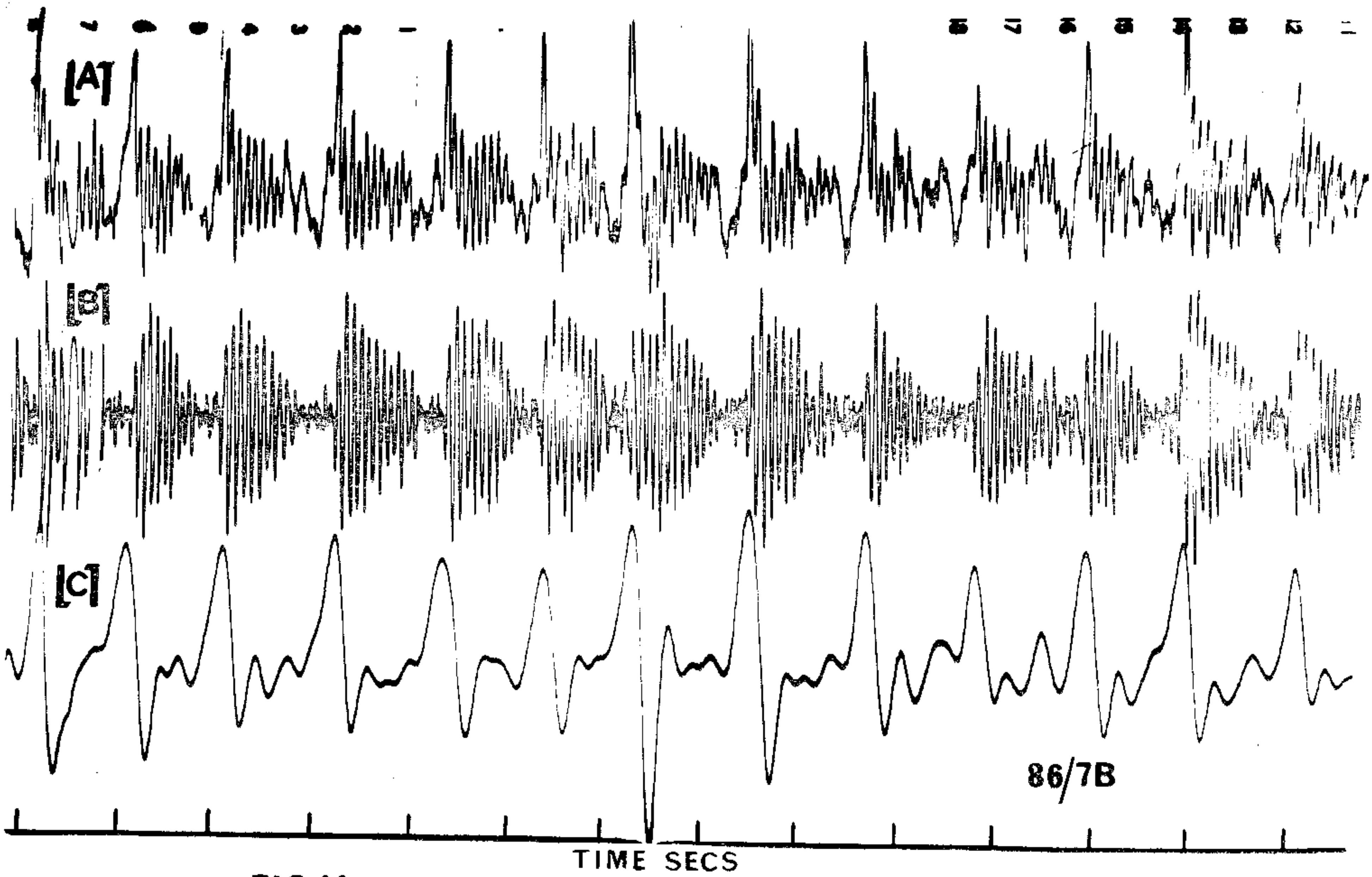


FIG 11 TYPICAL BAM WAVEFORM AFTER FILTERING

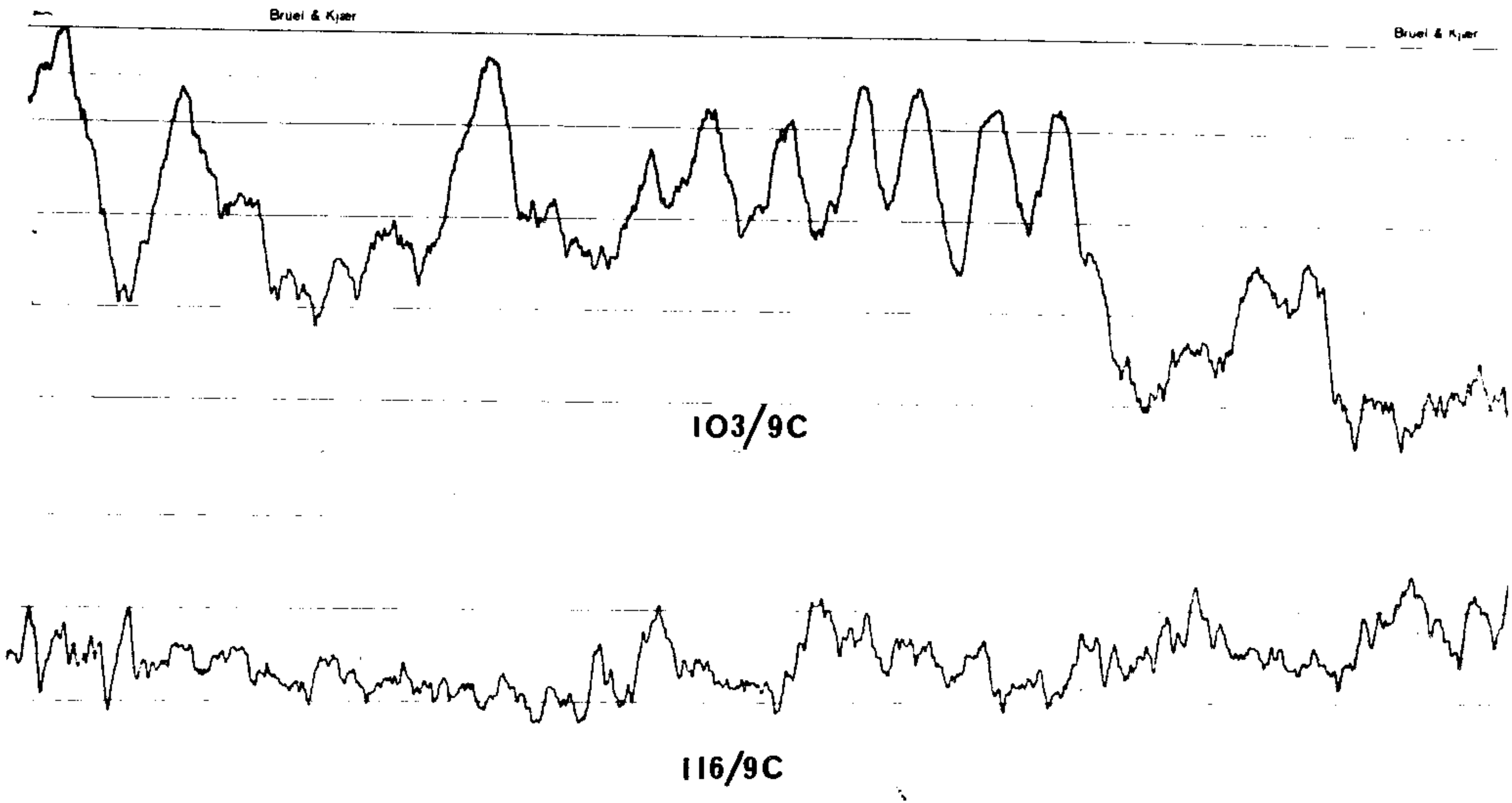


FIG. 12 B.A.M. WAVEFORM ENVELOPES

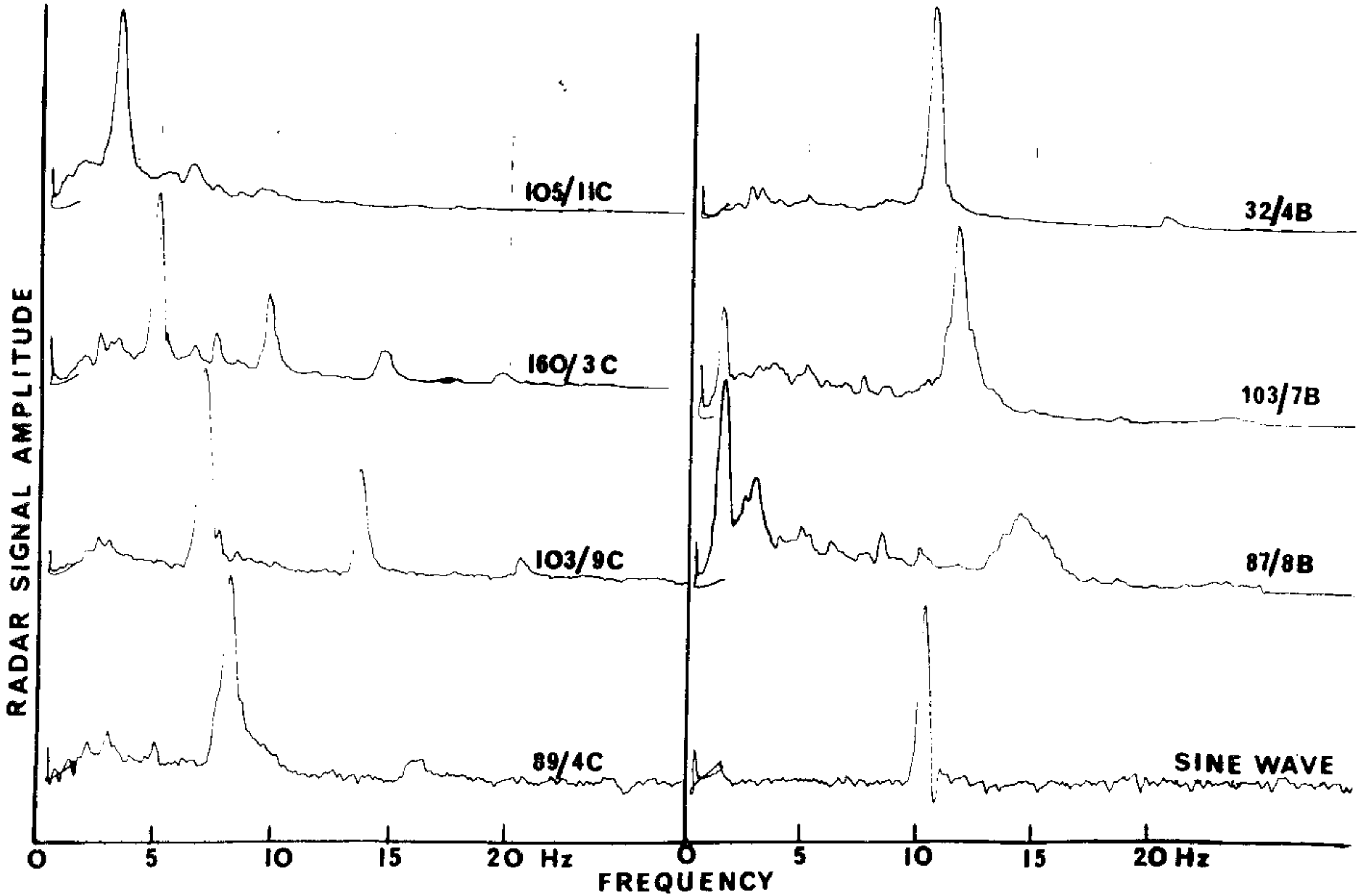


FIG 13 SELECTION OF BAM SPECTRA

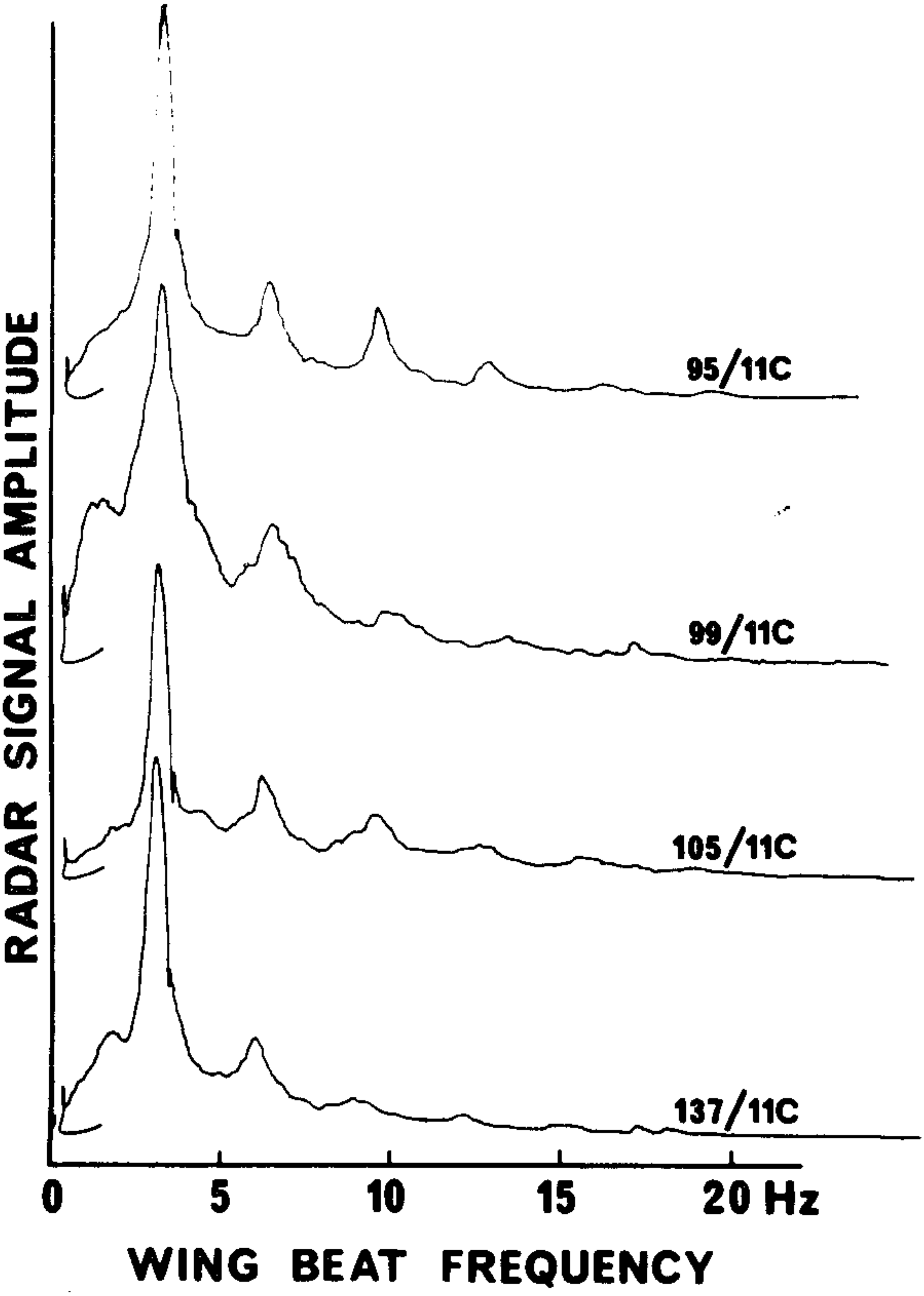


FIG. 14
COMPARISON OF SIMILAR SPECTRA

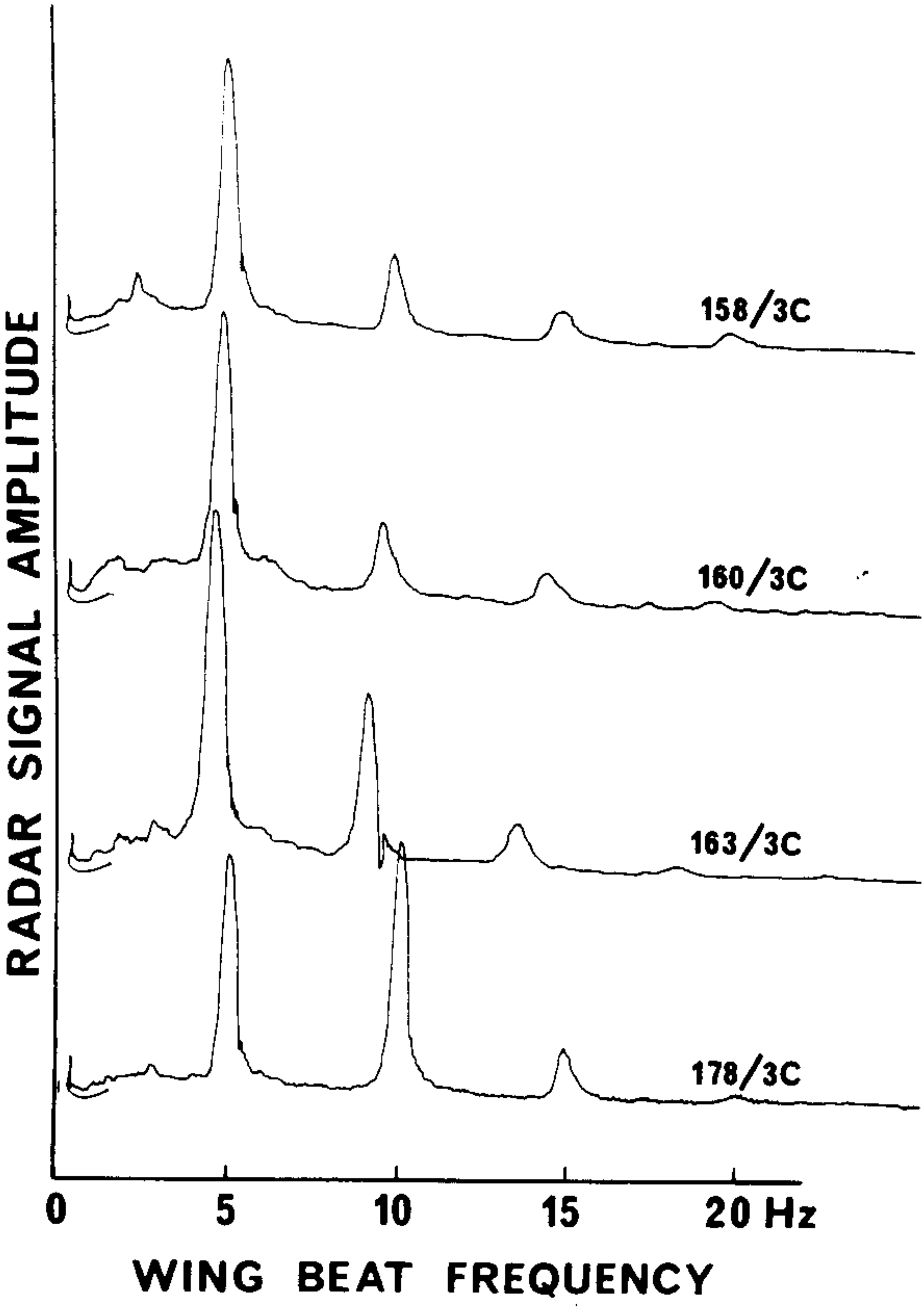


FIG. 15
COMPARISON OF SIMILAR SPECTRA

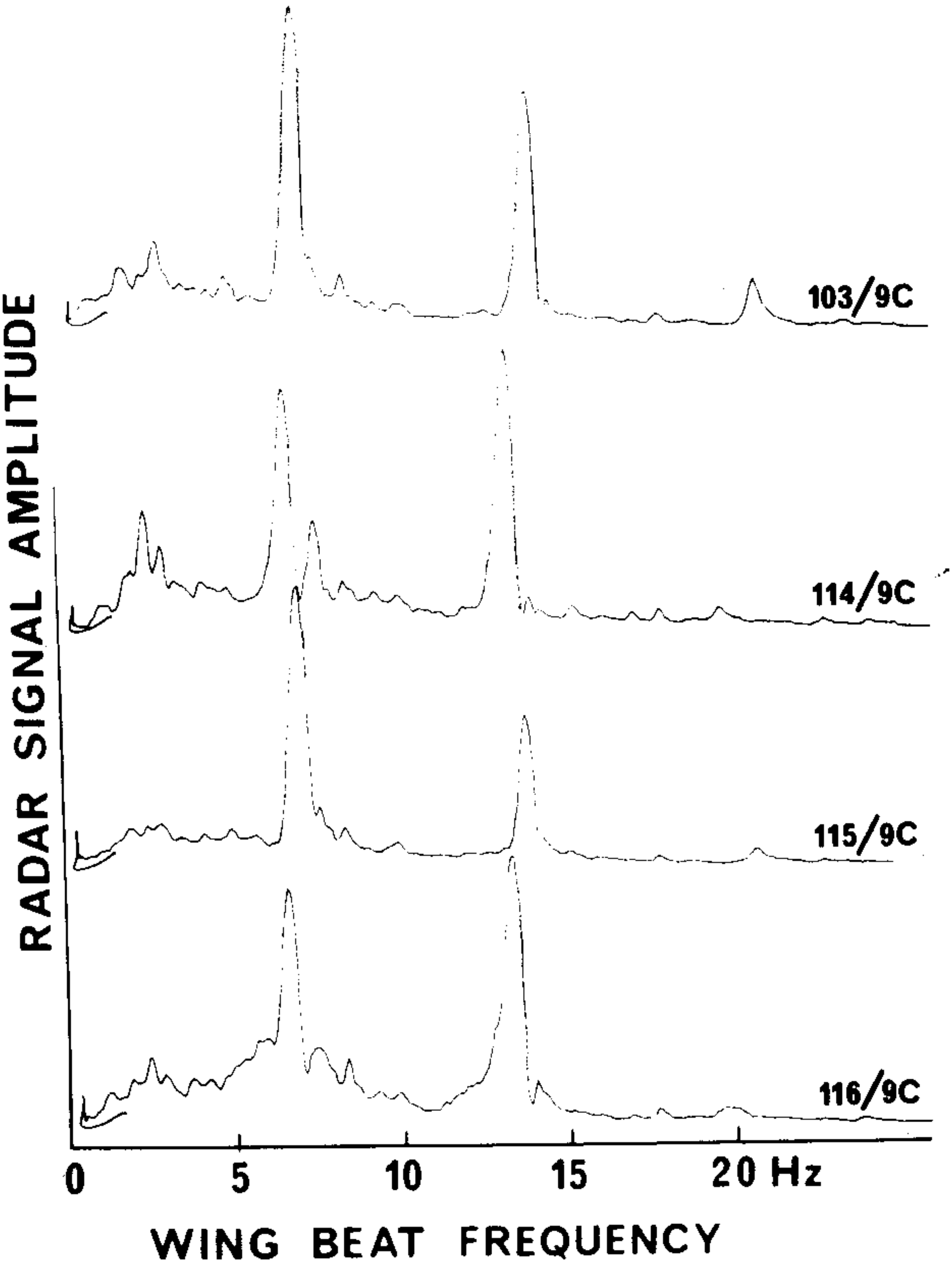


FIG. 16
COMPARISON OF SIMILAR SPECTRA

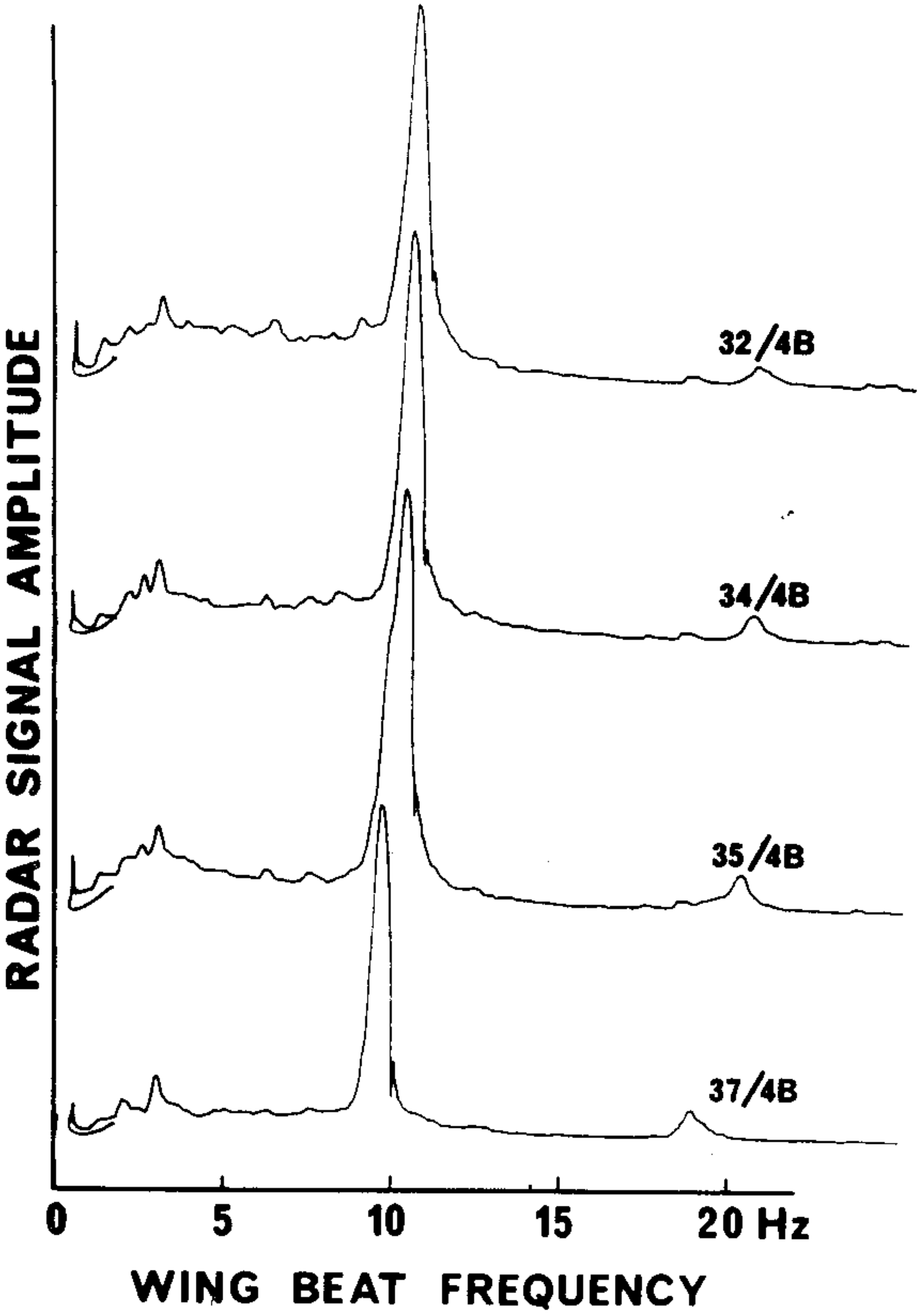


FIG. 17
COMPARISON OF SIMILAR SPECTRA

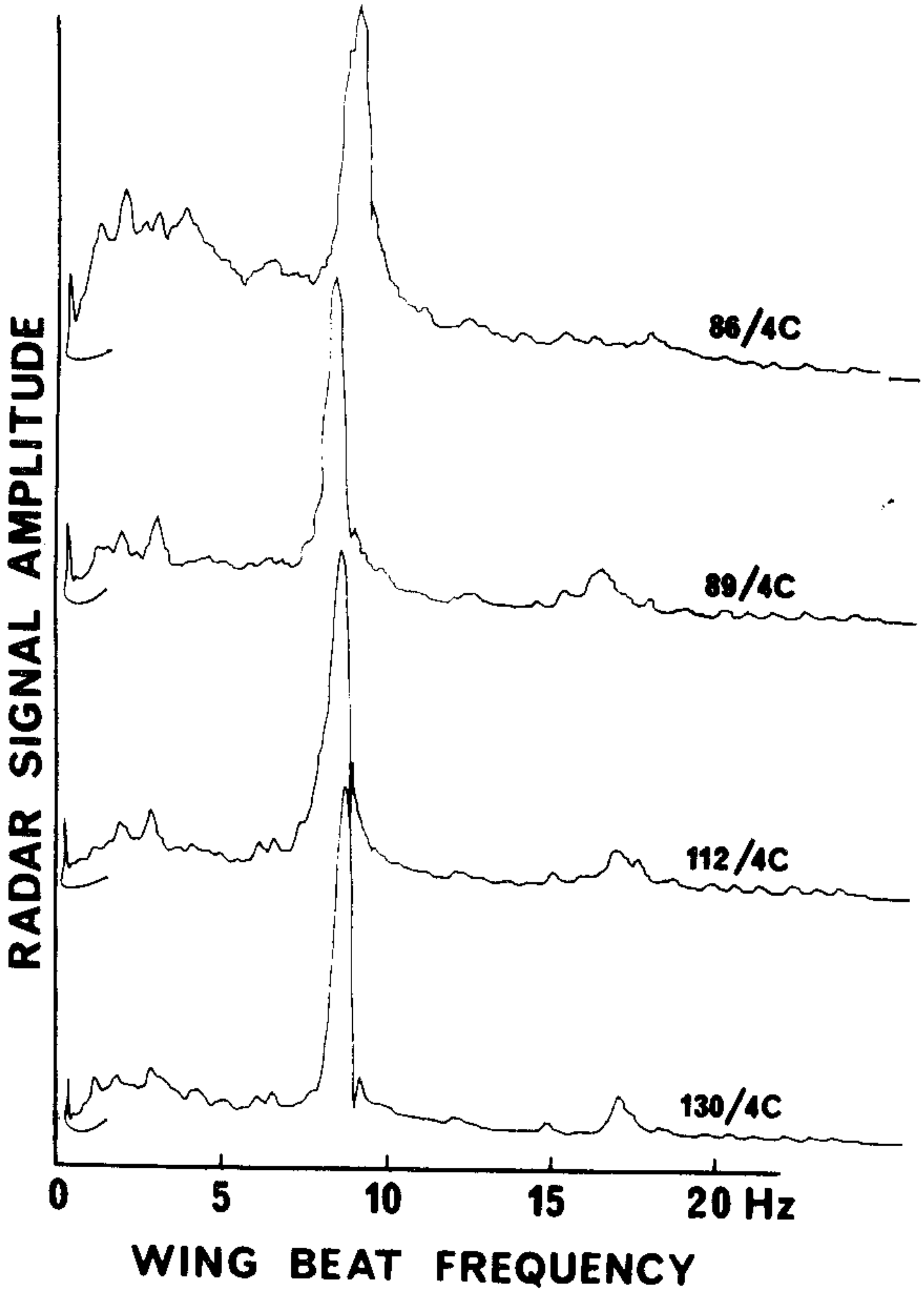


FIG. 18
COMPARISON OF SIMILAR SPECTRA

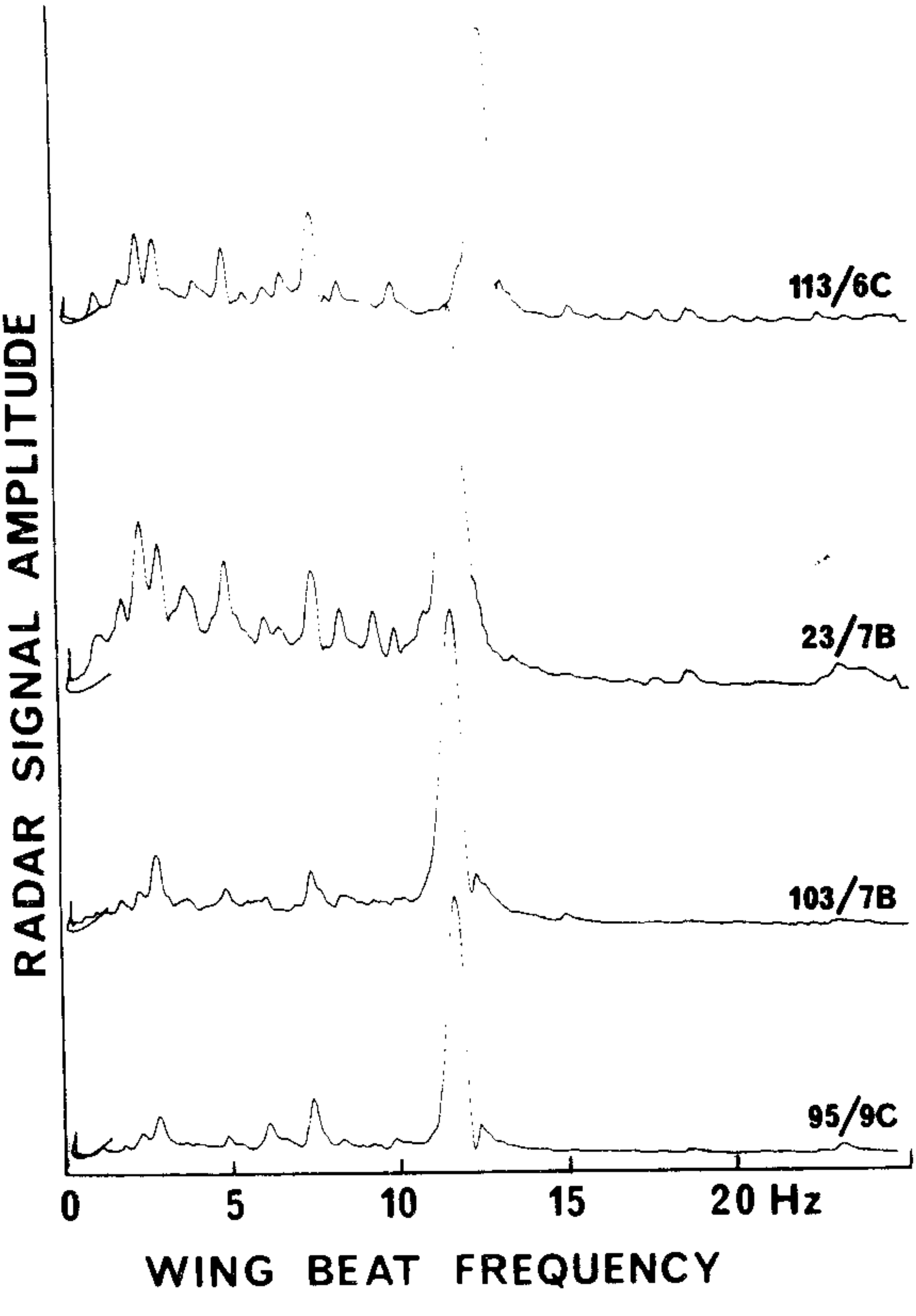


FIG. 19
COMPARISON OF SIMILAR SPECTRA

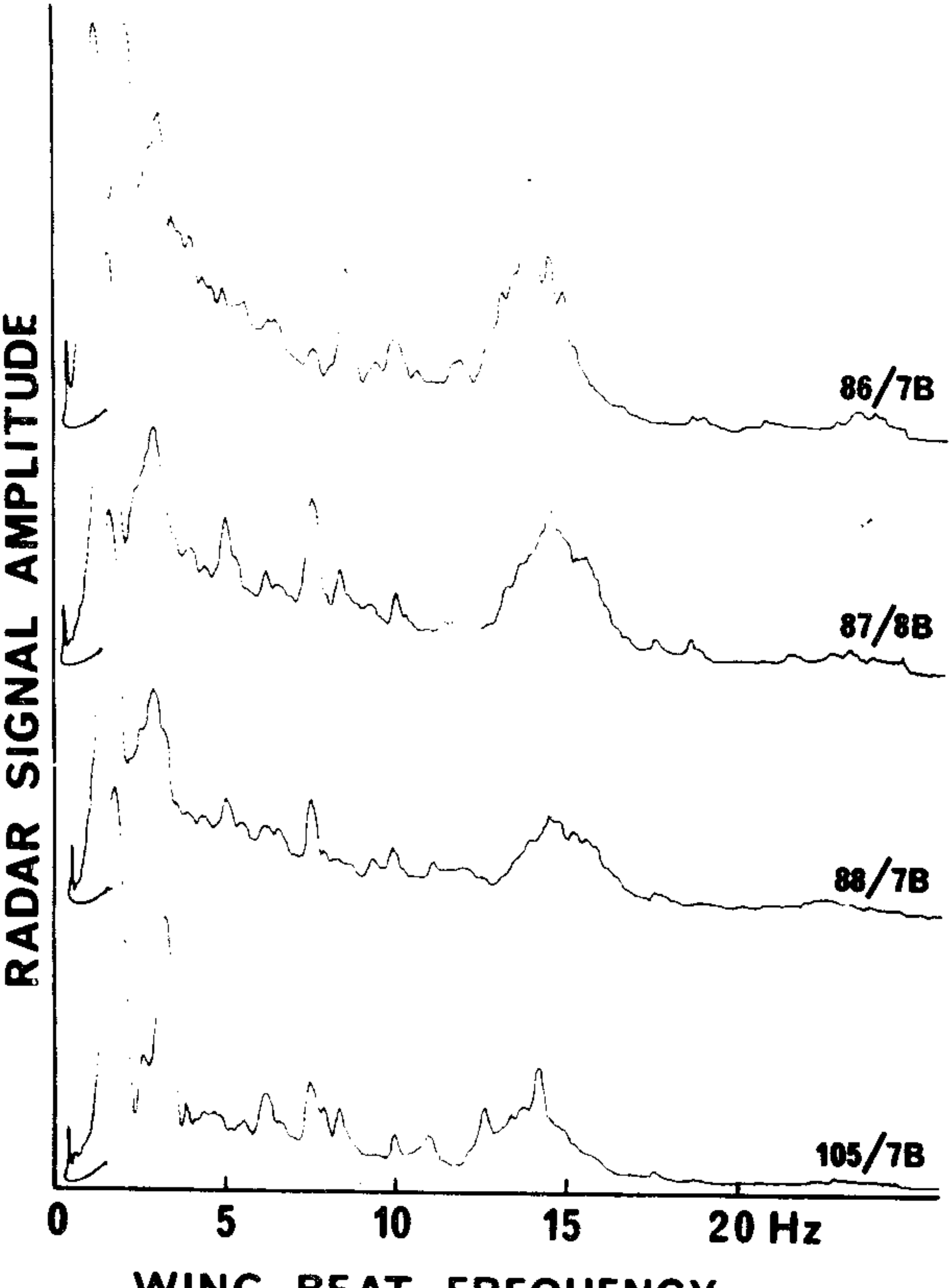
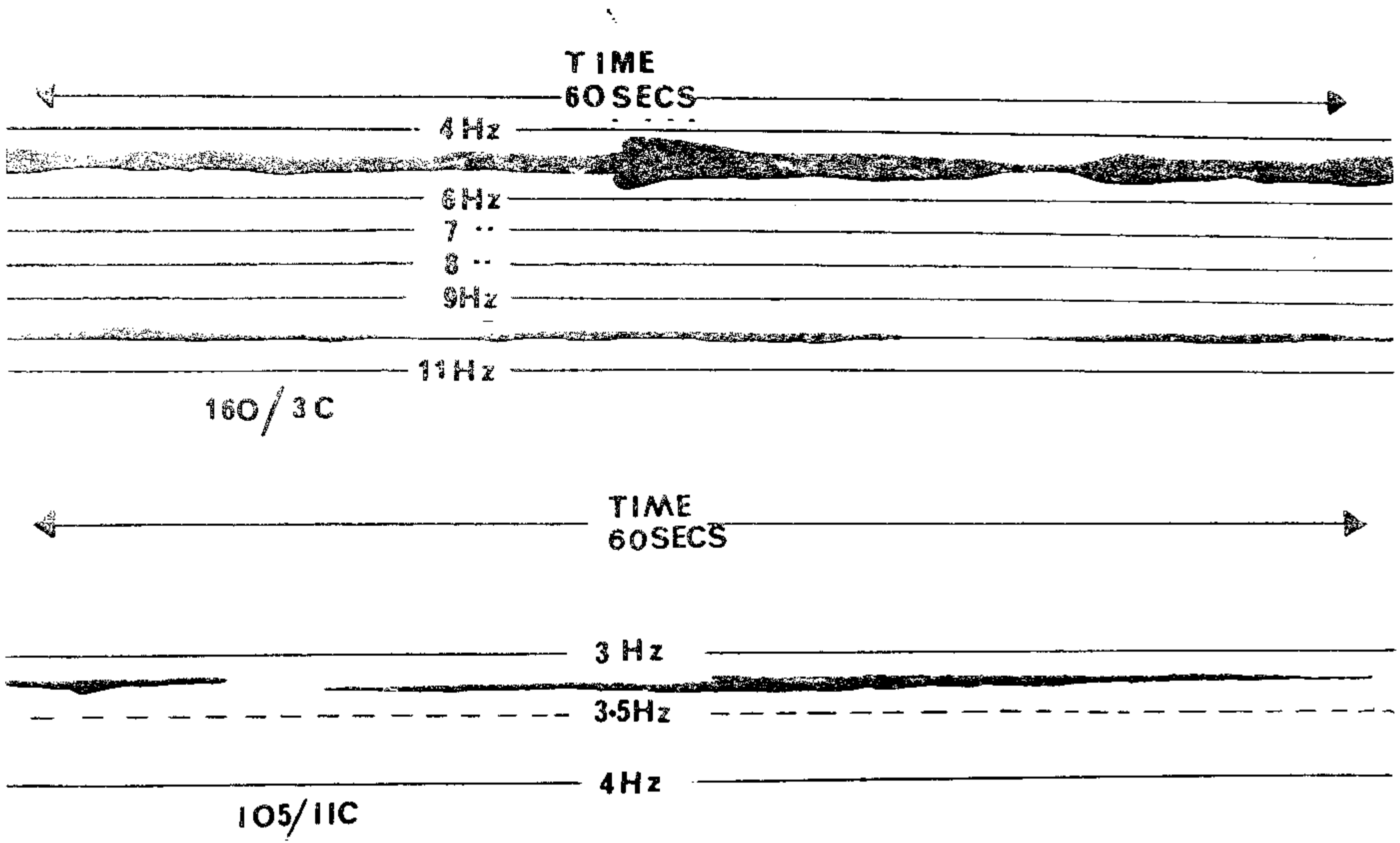


FIG. 20

COMPARISON OF SIMILAR SPECTRA



WINGBEAT FREQUENCY SHOWN AGAINST TIME

FIG. 21

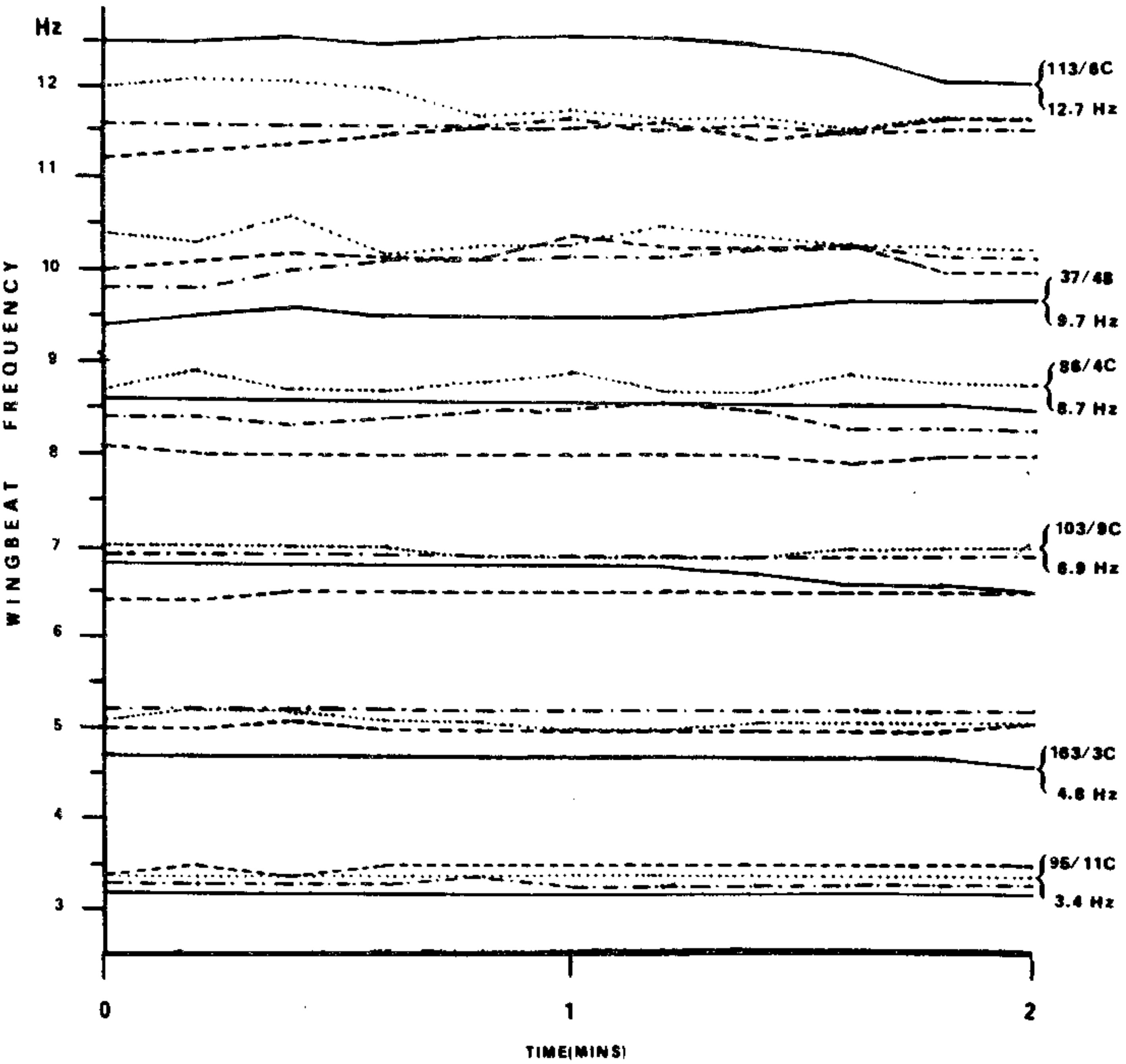


FIG 22
WINGBEAT FREQUENCY/TIME DIAGRAMS

FIG 23

BIRD RADAR FLIGHT AND ECHO DATA

1	DATE	13-9-72			14-9-72	
2	TAPE RECORD	95/11C	99/11C	105/11C	137/11C	
3	RUN TIME	16-35-05 16-37-09	17-02-12 17-04-10	17-31-33 17-33-28	08-09-36 08-11-38	
4	SPECTRA	Hz	Hz	Hz	Hz	Hz
	fundamental	3.4	3.5	3.3	3.2	
	3dB spread	0.2	0.2	0.2	0.2	
	2nd harmonic	6.8	7.0	6.6	6.4	
	3rd harmonic	10.2	10.5	9.9	9.6	
5	OTHER SPECTRAL COMPONENTS PRESENT	Hz	Hz	Hz	Hz	Hz
6	WING CYCLE/ UNIT PERIODS	SECS	SECS	SECS	SECS	SEC
	av					
	sd					
7	No. FLAPS/WING CYCLE/RUN					
	av	22	14	31	17	
	sd	10	7	17	5	
	range	9-36	3-28	7-49	10-25	
8	PAUSE/ WING CYCLE/ RUN					
	av	1.5	1.5	2	3	
	sd	0.7	0.7	0.8	0.9	
	range	1 - 3	1 - 3	1 - 3	2 - 5	
	number	13	18	8	13	
9	BAM/RUN					
	coeff/var	31%	38%	41%	51%	
	average	22.5	19.8	16.4	19.4	
	sd	7.0	7.5	6.8	9.8	
10	ESTIMATED ASPECT (AZ)	017 TO	073 TO	005 TO	045 TO	
	Δϕ	-2	-20	-6	-2	
	Δθ	-18	-1	-4	-6	
11	TRACK	STRAIGHT RECEDING RADIAL	STRAIGHT TANGENTIAL	STRAIGHT RECEDING RADIAL	STRAIGHT RECEDING RADIAL	
12	SLANT RANGE (yds)	1800	4900	4700	3200	
	ΔR during flight	+78%	+6%	+31%	+68%	
13	BEARING (°)	228	300	223	178	
	Δϕ	+2	-20	-6	+2	
14	ELEVATION (°)	36	16	17	17	
	Δϕ	-18	-1	-4	-6	
15	MEAN TRACK HEADING	SW 232	SW 216	SW 216	S 183	
16	ESTIMATED SPEED (kt)					
	(ground)	21	25	28	30	
	(air)	25	27	29	31	
17	HEIGHT (ft)	3200 CONST	4000 CONST	4000 CONST	2800 CONST	
18	REMARKS					

FIG 24

BIRD RADAR FLIGHT AND ECHO DATA

1	DATE	15-8-72				
2	TAPE RECORD	158/3C	160/3C	163/3C	178/3C	
3	RUN TIME	20-07-15 20-09-12	20-12-44 20-14-42	20-24-31 20-26-31	21-17-28 21-19-27	
4	SPECTRA fundamental 3dB spread 2nd harmonic 3rd harmonic	Hz 4.9 0.8 9.8 14.7	Hz 4.9 0.8 9.8 14.7	Hz 4.8 0.8 9.6 14.4	Hz 5.0 0.8 10.0 15.0	Hz
5	OTHER SPECTRAL COMPONENTS PRESENT	Hz	Hz	Hz	Hz	Hz
6	WING CYCLE/ UNIT PERIODS av sd	SECS	SECS	SECS	SECS	SECS
7	No. FLAPS/WING CYCLE/RUN av sd range					
8	PAUSE/ WING CYCLE/ RUN av sd range number	SECS	SECS	SECS	SECS	SECS
9	BAM/RUN coeff/var average sd	31% 21.5 6.7	30% 16.6 5.0	40% 20.4 8.2	31% 19.5 6.0	
10	ESTIMATED ASPECT (AZ) Δϕ Δθ	076 TO -16 -3	084 HO - 074 TO 22 -1	054 TO -15 -6	014 TO -4 -9	
11	TRACK	STRAIGHT RECEDING TANGENTIAL	STRAIGHT CROSSING TANGENTIAL	STRAIGHT RECEDING TANGENTIAL	STRAIGHT RECEDING RADIAL	
12	SLANT RANGE (yds) ΔR during flight	4500 +28%	4500 +13%	3200 +44%	2900 72%	
13	BEARING (°) Δϕ	279 -16	157 +22	202 +15	255 -4	
14	ELEVATION (°) Δϕ	11 -3	9 -1	18 -6	20 -9	
15	MEAN TRACK HEADING	SW 223	WSW 243	WSW 242	WSW 256	
16	ESTIMATED SPEED (kt) (ground) (air)	30 21	28 19	27 18	34 23	
17	HEIGHT (ft)	2500 CONST	2100 CONST	3000 CONST	2900 CONST	
18	REMARKS					

BIRD RADAR FLIGHT AND ECHO DATA

1	DATE	20-8-72			21-8-72	
2	TAPE RECORD	86/4C	89/4C	112/4C	130/4C	
3	RUN TIME	19-30-05 19-32-06	19-47-49 19-49-50	21-33-16 21-35-13	19-41-15 19-43-15	
4	SPECTRA	Hz	Hz	Hz	Hz	Hz
	fundamental	8.7	8.2	8.6	8.8	
	3dB spread	0.7	0.6	0.8	0.7	
	2nd harmonic	-	16.4	17.2	17.6	
	3rd harmonic	-	-	-	-	
5	OTHER SPECTRAL COMPONENTS PRESENT	Hz 2 - 5	Hz 2 - 3	Hz 2 - 3	Hz 2 - 3	Hz
6	WING CYCLE/ UNIT PERIODS	SECS	SECS	SECS	SECS	SECS
	av	8.6	2.6	2.9	8.7	
	sd	5.1	0.9	1.8	4.2	
7	No. FLAPS/WING CYCLE/RUN					
	av	51	17	18	52	
	sd	39	6	14	32	
	range	9-148	2-27	4-52	18-123	
8	PAUSE/ WING CYCLE/ RUN	SECS	SECS	SECS	SECS	
	av	2.7	0.51	0.78	2.8	
	sd	2.4	0.53	0.73	2.0	
	range	0.5 - 9.0	0.15 - 1.0	0.2 - 2.2	0.5 - 5.5	
	number	12	14	11	12	
9	BAM/RUN					
	coeff/var	30%	43%	48%	31%	
	average	27.1	18.3	20.7	26.0	
	sd	8.2	7.8	9.9	8.0	
10	ESTIMATED ASPECT (AZ)	089 TO	012 TO	076 TO	084 HO - 083 TO	
	Δϕ	-1	+10	+10	13	
	Δθ	-5	-10	-5	-2	
11	TRACK	STRAIGHT RECEDING RADIAL	STRAIGHT RECEDING TANGENTIAL	STRAIGHT RECEDING TANGENTIAL	STRAIGHT - TANGENTIAL	
12	SLANT RANGE (yds)	4000	2700	4000	4500	
	ΔR during flight	+24%	+73%	+32%	15%	
13	BEARING (°)	251	238	284	275	
	Δϕ	-1	+10	-10	-13	
14	ELEVATION (°)	17	27	18	17	
	Δθ	-5	-10	-5	-2	
15	MEAN TRACK HEADING	WSW 246	W 263	WSW 247	SSW 211	
16	ESTIMATED SPEED (kt)					
	(ground)	15	24	23	19	
	(air)	11	10	13	23	
17	HEIGHT (ft)	3200 const	3700 const	3700 const	3900 const	
18	REMARKS					

1	DATE	22-4-72				
2	TAPE RECORD	32/4B	[illegible]	35/4B	37/4B	
3	RUN TIME	22-04-12 22-06-12	[illegible]	22-33-39 [illegible]	22-39-47 22-41-48	
4	SPECTRA fundamental 3dB spread 2nd harmonic 3rd harmonic	Hz 10.3 0.5 20.6 -	Hz 10.3 0.6 20.5 -	Hz 10.2 0.7 20.5 -	Hz 9.7 0.5 19.4 -	H
5	OTHER SPECTRAL COMPONENTS PRESENT	Hz 3.1, 6.2, 15.	Hz 3.1, 6.2, 14.	Hz 3, 6, 15.	Hz 3	H
6	WING CYCLE/ UNIT PERIODS av sd	SECS	SECS	SECS	SECS	SE
7	No. FLAPS/WING CYCLE/RUN av sd range					
8	PAUSE/ WING CYCLE/ RUN av sd range number	SECS	SECS	SECS	SECS	
9	BAM/RUN coeff/var average sd	27% 28.5 7.8	27% 29.2 7.8	22% 22.7 5.0	28% 19.0 5.4	
10	ESTIMATED ASPECT (AZ) Δφ Δθ	042 HO +18 2	038 HO +14 1	073 HO +16 1	088 TO -11 2	
11	TRACK	ZIG-ZAG APPROACHING TANGENTIAL	ZIG-ZAG APPROACHING TANGENTIAL	ZIG-ZAG APPROACHING TANGENTIAL	ZIG-ZAG RECEDING TANGENTIAL	
12	SLANT RANGE (yds) ΔR during flight	3700 -9%	3900 -6%	3900 +6%	5500 +11%	
13	BEARING (°) Δφ	211 +18	217 +14	216 +16	240 +11	
14	ELEVATION (°) Δφ	19 +2	20 +1	12 -1	15 -2	
15	MEAN TRACK HEADING	NNW 330	NNW 333	WNW 303	WNW 303	
16	ESTIMATED SPEED (kt) (ground) (air)	18 21	16 19	18 21	19 17	
17	HEIGHT (ft)	3600	4100	2300	4300	
18	REMARKS	CROSSWIND				

BIRD RADAR FLIGHT AND ECHO DATA

1	DATE	4/5/72		6/5/72	23/8/72	27/8/72
2	TAPE RECORD	142/6B	23/7B	103/7B	95/5C	113/6C
3	RUN TIME	21-17-00 21-18-59	23-37-04 23-39-04	21-42-19 21-44-20	21-10-53 21-12-53	21-32-52 21-34-52
4	SPECTRA fundamental 3dB spread 2nd harmonic 3rd harmonic	Hz 12.2 1.0 - -	Hz 11.8 1.0 - -	Hz 11.7 0.8 - -	Hz 12.1 0.7 - -	Hz 12.7 0.8 - -
5	OTHER SPECTRAL COMPONENTS PRESENT	Hz 1.3 to 6.8	Hz 1.6 to 6.2	Hz 2.6 to 6.6	Hz 1.7 to 7.0	Hz 1.5 to 7.0
6	WING CYCLE/ UNIT PERIODS av sd	SECS	SECS	SECS	SECS	SECS
7	No. FLAPS/WING CYCLE/RUN av sd range					
8	PAUSE/ WING CYCLE/ RUN av sd range number	SECS	SECS	SECS	SECS	SECS
9	BAM/RUN coeff/var average sd	 27% 26.3 7.1	 31% 27.0 8.3	 23% 22.6 5.3	 37% 17.2 6.4	 29% 20.4 5.9
10	ESTIMATED ASPECT (AZ) Δϕ Δθ	050 HO +5 +4	067 HO +13 +4	058 HO +17 +5	060 TO -10 7	056 TO -23 3
11	TRACK	curved approaching tangential	curved approaching tangential	curved approaching tangential	Straight Receding Tangential	Zig-Zag - tangential
12	SLANT RANGE (yds) ΔR during flight	6000 18%	5700 20%	4000 22%	3000 63%	4000 16%
13	BEARING (°) Δϕ	186 +5	207 +13	210 +17	286 -10	288 -23
14	ELEVATION (°) Δϕ	18 +4	17 +4	15 +5	18 -7	24 -3
15	MEAN TRACK HEADING	NNW 347	NNW 350	NNW 345	W 260	SSW 206
16	ESTIMATED SPEED (kt) (ground) (air)	 19 16	 24 20	 21 20	 29 18	 28 23
17	HEIGHT (ft)	5200 const.	5000 const.	3100 const.	2800 const.	4900 const.
18	REMARKS					

FIG 29

BIRD RADAR FLIGHT AND ECHO DATA

1	DATE	6-5-72				9-5-7
2	TAPE RECORD	86/7B	88/7B	90/7B	105/7B	87/8B
3	RUN TIME	20-40-59 20-43-02	20-45-58 20-48-03	20-51-16 20-53-16	21-47-47 21-49-48	21-12-4 21-14-4
4	SPECTRA fundamental 3dB spread 2nd harmonic 3rd harmonic	Hz 14.6 1.9 - -	Hz 15.0 1.4 - -	Hz 13.5 2.7 - -	Hz 14.4 1.8 - -	Hz 14.6 2.5 - -
5	OTHER SPECTRAL COMPONENTS PRESENT	Hz 1 to 6.8	Hz 1 to 6.3	Hz 1 to 7	Hz 1 to 8	Hz 1 to 6
6	WING CYCLE/ UNIT PERIODS av sd	SECS 0.96 0.12	SECS 0.75 0.07	SECS 0.60 0.09	SECS 0.63 0.07	SECS 0.78 0.08
7	No. FLAPS/WING CYCLE/RUN av sd range	8 2 5 - 12	6 1 5 - 8	5 1 3 - 6	6 ½ 5 - 7	7 1 5 - 9
8	PAUSE/ WING CYCLE/ RUN av sd range number	SECS 0.28 0.09 0.19 - 0.5	SECS 0.25 0.05 0.16 - 0.37	SECS 0.19 0.03 0.13 - 0.27	SECS 0.21 0.04 0.14 - 0.25	SECS 0.23 0.03 0.19 - 0.
9	BAM/RUN coeff/var average sd	29% 24.0 6.9	34% 23.4 8.0	37% 22.2 8.2	38% 21.0 8.0	39% 22.5 8.8
10	ESTIMATED ASPECT (AZ) Δϕ Δθ	045 HO +35 + 8	037 HO +26 +10	043 HO + 25 + 5	034 HO +20 + 5	031 T +30 1
11	TRACK	ZIG-ZAG APPROACHING TANGENTIAL	ZIG-ZAG APPROACHING TANGENTIAL	STRAIGHT APPROACHING TANGENTIAL	ZIG-ZAG APPROACHING TANGENTIAL	ZIG-ZAG APPROACH TANGENTI
12	SLANT RANGE (yds) ΔR during flight	3200 -17%	3800 -26%	3600 -14%	3400 -18%	3700 -12%
13	BEARING (°) Δϕ	230 +35	213 +26	213 +25	205 +20	110 -28
14	ELEVATION (°) Δϕ	21 +8	25 +10	28 +5	23 +5	21 +1
15	MEAN TRACK HEADING	N 354	N 350	NNW 340	NNW 338	N 355
16	ESTIMATED SPEED (kt) (ground) (air)	24 28	24 28	21 24	18 21	26 30
17	HEIGHT (ft)	3500/3900 CHANGE	4800 CONST	5100 CONST	4000 CONST	4000/360 CHANGE
18	REMARKS					

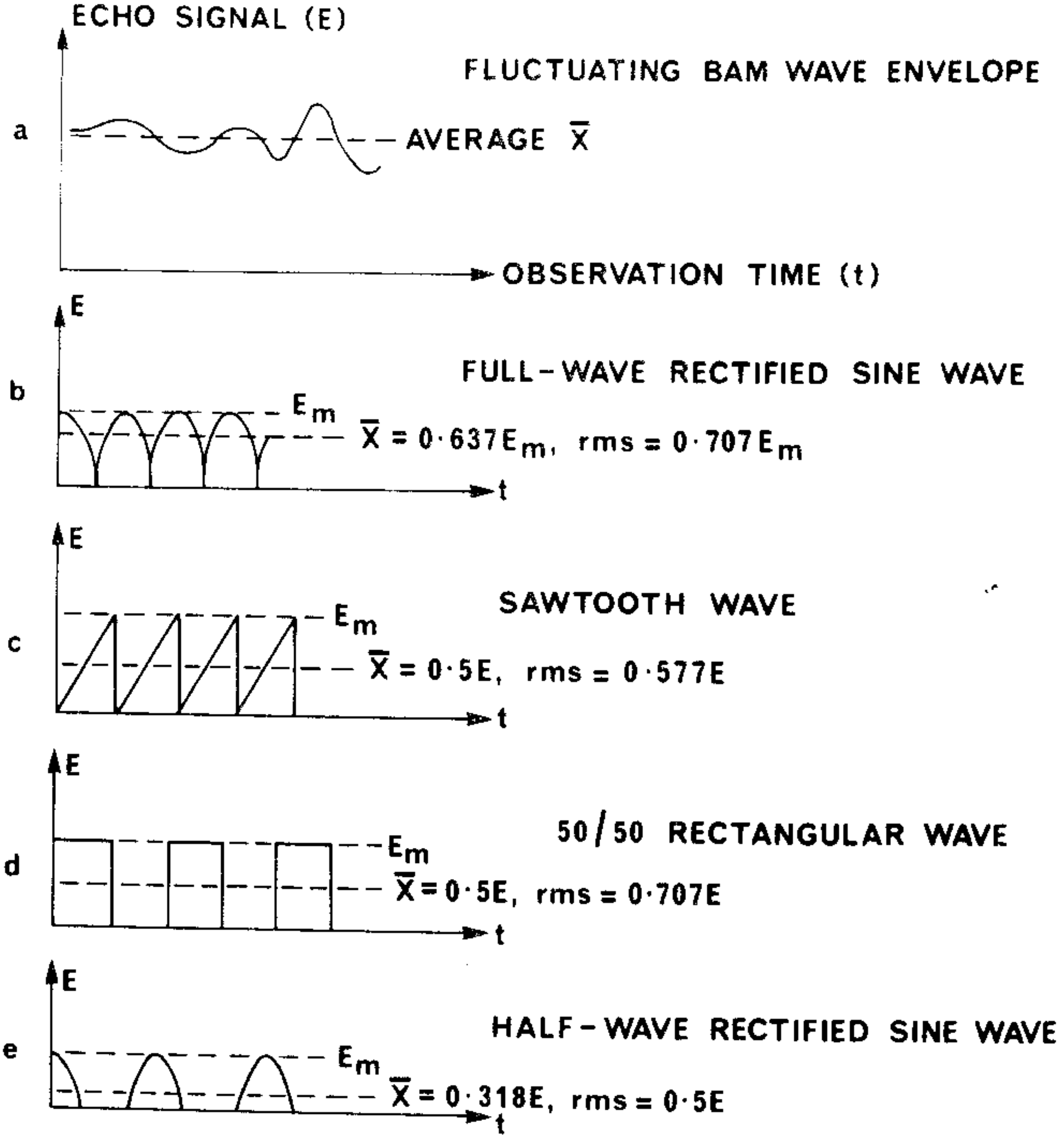


FIG. 30

BAM WAVEFORM ENVELOPE VARIATIONS