flight conditions. Wingbeat "signature" alone does not of course enable hundreds of different species to be identified individually by radar, but an estimate of physical dimension (vital in the bird strike problem) is possible (6). There is little difficulty at all in sorting out finches from duck, duck from geese and geese from gulls if the radar can be used to resolve one or two birds at a time. Further classification of species is also possible using a logic based upon geography, population, time of day and season. While further analysis of the content of long BAM records for harmonic content and wing pause, flapping and glide duration and occurrence extends the possibility of better identification. In the latter cases, flight conditions and echo linearity must be known.

BAM Waveforms and Spectra of Released Mallard

The BAM waveform and chief frequency components of the mallard, run C2, released on 21-3-69 is shown in Fig 8A. Signal amplitude along the vertical axis and time of flight along the horizontal axis are plotted for a 6 second duration of the radar echo signal record. The top waveform is the BAM waveform after passing unaffected through a 0-40 Hz lowpass filter. The bottom waveform is the same waveform after all frequency components have been removed except the fundamental component centred on 6.5 Hz and components lying close to it within a band 6-7 Hz. The waveform above the fundamental is that of the second harmonic components of the complex BAM waveform lying between 12-14 Hz. Above the second harmonic waveform is the third harmonic components waveform, which lie between 18-21 Hz. Filtering is a convenient method of simplifying a complex waveform and it is explained briefly in Appendix A. Unfortunately at the time it was not possible to make the bandwidths of the fundamental and harmonic bandpass filters large enough or of equal bandwidth and consequently it is not possible to compare envelope fluctuations of the complex and harmonic waveforms in detail. Looking at the complex BAM waveform for the whole 6 seconds we might guess the signal had some periodic components but it would be difficult to resolve them without analysis. A consideration of the harmonic waveforms show their amplitudes rise and fall in a complicated way and that maxima and minima in one harmonic waveform does not always follow its relative.

A better way of investigating the frequency content of a complex BAM waveform is to plot its spectrum by means of an electronic spectrum analyzer. The frequency spectrum of a mallard, run C2, is shown in Fig 8B. The echo signal is plotted along the vertical axis and frequency along the horizontal axis. Four spectra of the BAM waveform record taken at 5 second intervals are plotted one above the other on the left-hand diagram, Fig 8B. A spectrum averaged over the whole duration of the echo record is shown in the right-hand diagram. We see from the right-hand diagram that the analyzer has resolved the whole complex BAM record into fundamental and second and third harmonic components, and the fundamental has the greatest amplitude. A look at the left-hand side diagram confirms the results of filtering that the fundamental and harmonics components are not always present together as shown for the average for the whole record, but any of them may be at a minimum. However in spite of the complexity of the BAM waveform and the occasional loss of the fundamental it is possible to measure the fundamental as 6.5 Hz, which is the average wing beat frequency of mallard measured with a calibrated cine-camera when cruising in level flight.

there are no even harmonics. The transient response of the fundamental filter is similar to that obtained of the pulse sine wave, but the delay and rise time of the third harmonic is now only a fraction of a second because the filter bandwidth is 3 Hz. The effect of an even more complex waveform, a pulsed sawtooth waveform is shown in Fig. 14C. The ideal sawtooth wave has both odd and even harmonics and the relationship between amplitudes is unity, 0.5 and 0.33 for fundamental, second and third harmonics as shown in Fig. 14C. The pulse response is most pronounced for the narrowest bandwith and least for the broadest bandwidth of the third harmonic filter.

Thus we find that a relatively narrow bandwidth delays the pulse and slows down the rise time more than if a wider bandwidth is used. In the case of the bird waveforms under consideration it would have been preferable to use similar bandwidths for fundamental and harmonic filters so that delay times would have been approximately the same. A wider bandwidth of at least 3 Hz for the fundamental and 2nd harmonics would have reduced rise time distortion too, but unfortunately the bandwidths of the tunable filters used in these experiments were not adjustable. Poor transient response does not affect the filtering out of the spectra, but makes it difficult to compare the fluctuation characteristics of fundamental and harmonic waveforms.

APPENDIX B(1)

CORRELATION

Correlation is a mathematical method of computing the degree of similarity between two quantities. Electrical quantities, such as voltage waveforms used in communications, radar and medical diagnostic equipment are particularly convenient, because waveforms can be easily manipulated with respect to time. Auto-Correlation is a method of correlating a waveform with a time shifted replica of itself, and Cross-Correlation is the process of correlating two waveforms which may have come from different origins. The theory and practice of correlation measurements employing electrical waveforms are well explained in a book by Bendat and Piersol (8).

The Auto-Correlation Function $\emptyset(\tau)$ of a waveform $x(t)$ is given by the expression:-

$$\emptyset(\tau) = \overline{x(t)\ x(t+\tau).dt} \quad \ldots\ldots\ldots\ldots (1)$$

and if the waveform $x(t)$ is a continuous function it can be written

$$\emptyset(\tau) = \lim_{T\to\infty} \int_{-T}^{+T} x(t).x(t+\tau).dt \quad \ldots\ldots\ldots\ldots (2)$$

where τ is the delay time, T is the integration or averaging time and

$$0 \leqslant \tau < T$$