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# A Comparison between Two Methods of Analysis of Oscillatory Pressure Measurements, One Method Requiring the Use of a Tape Recorder

*by*

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# A COMPARISON BETWEEN TWO METHODS OF ANALYSIS OF OSCILLATORY PRESSURE MEASUREMENTS, ONE METHOD REQUIRING THE USE OF A TAPE RECORDER

by

A. W. Moore

B. L. Welsh

SUMMARY

Two methods for analysing oscillatory pressure distributions are compared. In one, a Digital Transfer Function Analyser is used on-line to measure the in-phase and in-quadrature components of oscillatory pressure signals with respect to a given reference signal. In the other method the pressure signals are recorded on magnetic tape, then the recorded signals are analysed on a digital computer at a later time.

Oscillatory pressures were produced by oscillating a model wing in a wind tunnel. Pressure transducers were mounted in the model at six chordwise stations and the responses from the transducers were measured by both of the above methods for a range of frequency and Mach number. A comparison of the results shows that for the conditions achieved in the tests, there is no significant loss of accuracy in magnitude when the oscillatory pressure signals are recorded on magnetic tape for later analysis, and that the measurement of phase angle is accurate to within $1^{\circ}$.

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## 1 INTRODUCTION

With steady flow, pressure distributions in a wind-tunnel test can be determined by piping the pressures from numerous stations on a model to a transducer mounted outside the tunnel. It has been shown[1] that a similar system can be used to measure sinusoidal oscillatory pressures of small amplitude provided proper allowance is made for the transfer functions of the pressure leads: but this system cannot be relied on for the measurement of large amplitude non-sinusoidal pressure fluctuations. Pressure signals with a high harmonic content will be encountered in an investigation of dynamic stall due to commence shortly at RAE Teddington. It is planned to measure these oscillatory pressures by installing 20 miniature absolute pressure transducers in a model having a 15 cm chord. On-line sequential analysis of the numerous oscillatory pressure signals would be time-consuming and costly from the point of view of tunnel running time alone. An alternative method has been developed in which the signals are recorded on magnetic tape, and then the recorded signals are analysed at a later time on a digital computer to give information such as instantaneous pressure distributions with corresponding instantaneous lift coefficients and pitching moment coefficients.

Whether the signals are recorded by multiplexing onto a single channel of a tape recorder or by using a multi-channel tape recorder the factors involved in the reproduction of the signals, e.g. the playback speed, the amplification of the system, phase shifts, etc, must all remain constant. In other words, the transfer function of the record and playback system should be constant. The opportunity arose during some recent experimental measurements, primarily designed for another purpose[2], to test out the planned scheme for recording and analysing the oscillatory pressures, and to check the accuracies particularly with regard to the phasing between channels. This was possible because in addition to results being obtained by analysing recorded signals with a digital computer, the pressure signals were analysed on-line using a Digital Transfer Function Analyser. The results from the two methods of analysis are shown to be in very good agreement for all cases considered. These include some conditions where the pressure signal is significantly non-sinusoidal due to the presence of a shock-wave in the vicinity of the pressure tapping. A brief outline of the experimental arrangement and on-line analysis is given in sections 2 and 3. The computer analysis is described in section 4 and the comparison between the results from the two methods is discussed in section 5.

At the completion of all the tests the tape recorded signals are fed into an analogue to digital interface to a Honeywell H516 computer where they are processed to give equivalent components to those obtained on-line using the DTFA, thus providing a direct comparison between results.

## 3 EQUIPMENT

### 3.1 The DTFA

The instrument used was a Solartron Digital Transfer Function Analyser type JM 1600, incorporating a Remote Reference Synchroniser type JX 1606.

In many applications, a sinusoidal signal from a function generator contained within the instrument would be used to excite the system under test. The phase of this signal would be used as a prime reference, and it is against this that signals from the test would have to be resolved into their components. For the present test, however, the model was excited independently, its displacement being regarded as the prime reference. The remote reference synchroniser was used to synchronise the phase of the function generator to that of the model displacement. Digital multiplier and integrator circuits resolved the output signals from the pressure transducer into their respective in-phase and in-quadrature components with respect to the fundamental, or various harmonic, frequencies of the displacement signal. The outputs are displayed simultaneously by an in-line numerical display. The instrument has a phase resolution of $0.05^{\circ}$ for frequencies up to 160 Hz.

### 3.2 The tape recorder

The tape recorder used was a CEC type VR 3300. The instrument records and replays using frequency modulated amplifiers giving it an operational frequency range from 0 to 20 kHz. Fourteen recording/replay channels are available and the tape speeds can be varied discretely from 15 to 60 in/s.

## 4 COMPUTER ANALYSIS OF THE MAGNETIC TAPE

The H516 program which controls the reading of the tape uses the priority-interrupt mode of operation. In this mode the outputs from the tape recorder are fed into the computer via an analogue to digital converter, but the conversion does not start until a priority-interrupt message is received. Ideally this would be generated from a marking pulse recorded at a convenient point on the reference signal. The equipment necessary to produce a suitable pulse is still being developed, so in the present case the interrupt was generated manually during the playback of each batch of signals. On receipt of this signal the tape is scanned at a pre-set rate for a specified number of scans, sample-and-hold amplifiers being used to prevent phase shift between channels. Since only six transducers were used in the present tests, there were sufficient channels on the tape recorder for all the required information to be recorded on a single tape. In this situation various other modes can be used to read the magnetic tape into the computer, but the priority-interrupt mode was chosen because this will be essential for the analysis of the results from the planned experimental programme for the measurement of instantaneous pressure distributions on an aerofoil oscillating through stall, when synchronised tape recorders will be required to record all the signals simultaneously. Useful experience in the operation of the system in the priority-interrupt mode could thus be gained. Furthermore, to check the programme which will be used in the future tests, routines for the evaluation of instantaneous lift and moment, rates of change of incidence, etc, were included as indicated in Fig.2 but these will not be discussed as they are not relevant to the present purpose.

For the present analysis, the number of scans is such that 24 points per cycle are digitised for 10 consecutive cycles. After the frequency of the reference signal on playback has been accurately measured, the desired scan rate of 24 times the basic frequency is set up on the A-D interface to the computer. The physical independence of the tape recorder and the equipment determining the rate of scan is an unsatisfactory feature of the method. For instance, if the tape speed varies whilst the data are being read, then a phase shift between consecutive cycles occurs such that the 24 scans during the later cycle will be made at a different part of each cycle from the first 24 scans. An incorrect mean value will result when the data are averaged. The procedure is being modified for future tests so that it will be possible to use one of the recorder channels to record a suitable pulsed signal of the required frequency, which is locked to the reference signal. The pulsed signal will then be used on playback to drive the A-D interface. The digitised integer values (for which 16384 is equivalent to 1 volt) are fed into an array in the computer in which the first value is the first point from channel one, the second value is the first point from channel two and so on until the first point from the last specified channel is reached; the next value in the array is the second point from channel one and so on until the array is completed with the last point from the final scan.

The program for the analysis of the data calls up a series of subroutine or subprograms, each one performing a separate part of the analysis, e.g. one subroutine checks the cycle-to-cycle consistency of input data and obtains mean values with corresponding standard deviations over the 10 cycles read in, another sorts the data into a convenient form, and so on. Since the actual parameters of the subroutines are specified only in the calling program it is a relatively simple matter to change items such as the number of cycles to be read in. The first operation is to convert the data back to volts and to average over 10 cycles. During the averaging process each item of data after the first cycle is compared with the appropriate current mean value, and if the new value is outside given limits then it is rejected, replaced by the existing mean value and an error message is printed on the line printer. Any serious phase shift in scanning positions is quickly detected and an intermittent malfunction of a transducer will also be indicated. In general it will not be practicable to monitor all the signals from the pressure transducers, so it is advantageous to get an indication of malfunction: the mean values over the 10 cycles are evaluated with corresponding standard deviations. The computer then waits whilst the error messages, if any, are examined. If the input data are deemed acceptable, a signal from an on-line teletypewriter restarts the program; but if there is something amiss then a different batch of cycles can be read in, or the program can be stopped.

The averaged data are next sorted into a matrix form; the rows of one matrix given the instantaneous chordwise distribution of the signals from the pressure transducers at each 24th part of the cycle, and the columns give the variation around the cycle at each chordwise station; the model displacement is put into a separate single column matrix. At this stage the data represent only the oscillatory parts of the signals. These values in volts are printed out together with corresponding matrices of standard deviations over the 10 cycles. During the wind-tunnel tests the mean level of each signal is recorded on a data logger. These values are read into the computer on paper tape so that the oscillatory and mean parts of the signals can be recombined.

The oscillatory part of the signal which is fed to the recorder has a zero mean value, but it is possible for a dc drift to occur when the signal is passed through the record and replay amplifiers of the tape recorder. The oscillatory signal read by the computer may therefore have a non-zero mean value. To allow for this, the mean value of the digitised oscillatory signal is calculated, then this is appropriately added to or subtracted from the true mean value as recorded by the data logger. The adjusted mean is added to the digitised oscillatory part so that the true absolute oscillatory signal is obtained having the required dc mean value*. To convert the values in volts to non-dimensional ratios of instantaneous static pressure to stagnation pressure, each signal is multiplied by a suitable factor. This includes a previously determined factor for the gain of each amplifier $A_1$ to $A_7$ shown in Fig.1, and also includes a gain factor for each channel of the tape recorder as determined from an initial analysis of recorded calibration signals. The displacement during a cycle is converted to instantaneous angles of pitch in radians.

Since the priority-interrupt signal has no fixed phase relationship to the recordings on the tape, the A-D conversion for different analyses does not usually start at the same point in the cycle of motion. However, it is convenient to refer each analysis to a standard cycle starting with the model in its mean position, so the rows of the matrices are re-ordered such that the maximum displacement of the model occurs on the sixth row (i.e. at the quarter-cycle point). It should be noted that with 24 digitised points per cycle, the possibility remains for a variation of up to $15^{\circ}$ in the position of the digitised points with respect to the desired reference signal. This is allowed for in the final step in the analysis, which is to analyse the data into Fourier components. The Fourier analysis is carried out on the assumption that the cycle begins with the model precisely in its mean position, i.e. it is assumed that the first scan occurs at $\pi/12$ of the cycle. Hence Fourier analysis of the model displacement signal gives the phase difference between the desired digitised reference motion and the actual digitised motion. Suitable allowance for this phase difference can then be made in the Fourier analysis of the pressure signals to give their phases and magnitudes with respect to a standard reference motion. This enables direct comparison to be made between results from separate analyses. The Fourier series is truncated after the seventh harmonic, but this is more than sufficient for comparison with the results from the DTFA, the useful frequency range of which

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*It should be noted that this procedure is not necessary for the comparison with the DTFA analysis in which only the oscillatory parts of the signals are processed, but it is an essential feature for future tests in which the results are to be integrated to derive the instantaneous lift and pitching moment.

does not extend beyond 160 Hz. The results are printed out as Fourier cosine and sine coefficients, and in corresponding polar form.

In order to calibrate the recording and playback system, calibration signals from a common source with amplitude maintained accurately at one volt rms were recorded simultaneously on each channel of the tape at frequencies used in the wind-tunnel tests, nominally 20 Hz, 40 Hz, 60 Hz. Initial analysis of the recorded calibration signals using the above method showed that the phase shift between channels was less than $0.5^{o}$. The gain factors for each channel were determined from the amplitudes and were found to be insensitive to frequency over the range used.

## 5 COMPARISON BETWEEN RESULTS FROM THE TWO METHODS

The basic difference between the two methods is that on the one hand the DTFA is used on-line during the tunnel run to analyse directly the output from each transducer, whilst on the otherhand the outputs are recorded on magnetic tape at some time during the run and these recorded signals are analysed at a later time on a digital computer. It should be noted that the on-line measurements are made sequentially, i.e. the output from the first transducer is analysed to give the first harmonic with respect to the model motion, then the output from the second transducer is analysed, and so on for the six transducers, and finally the process is repeated for every successive harmonic required. When the tape recording is made, all six outputs are recorded simultaneously. It was therefore essential from the point of view of comparing results that conditions remained constant over the period during which the on-line analysis was made. The DTFA was usually set to integrate for 100 cycles, so at the lowest frequency used, each of the three harmonics measured was obtained in approximately 5 seconds. With allowance for switching time the longest continuous period required to obtain the on-line results at the 6 stations was therefore about 3 minutes. Although the rig did not produce inexorable motion, careful monitoring of the model amplitude showed no appreciable fluctuations during the operation of the DTFA. The very good agreement between the two sets of results is indeed a confirmation of the constancy of conditions.

The results are presented in Tables 1 to 3. Each table contains, for a given frequency, the values of the in-phase and in-quadrature components of the pressure signal from six chordwise stations for a range of Mach number. It can be seen that apart from four isolated cases 20 Hz, M = 0.75, x/c = 0.4;

40 Hz, M = 0.4, x/c = 0.0125; 40 Hz, M = 0.85, x/c = 0.40; 60 Hz, M = 0.85, x/c = 0.05) the results are in excellent agreement. This is clearly illustrated in Figs.3 and 4 which show the results obtained by the indirect analysis plotted against the results measured on-line by the DTFA. For exact agreement, the points should be on a line making an angle of $45^{\circ}$ with the axes. Apart from the previously mentioned four inconsistent results, Fig.3 shows that the in-phase components lie along the desired line. However, in Fig.4 the in-quadrature pressure components show a linear variation which is slightly rotated from the $45^{\circ}$ position. The discrepancy would be explained by a consistent error of about $1^{\circ}$ in the phase angle determined by one of the methods. This gives no measurable effect on the in-phase component because the phase angles were mostly less than $30^{\circ}$ in magnitude.

The tests in which pressure signals were recorded were all made with the model oscillating about zero incidence with amplitudes up to $1^{\circ}$. Most of the resulting oscillatory pressures were nearly pure sinusoids, but some conditions were chosen so that a shock wave passed over one transducer during the cycle, in which case the resulting pressure fluctuation was far from sinusoidal. Examples are shown in Fig.5. For one such case, four different batches of 10 cycles were analysed; and for a second case at a smaller amplitude, three different batches were analysed in order to test repeatability. It can be seen from Table 4 that consistent results are obtained from each analysis.

The second and third harmonics for the two cases as determined by the direct method are also included in Table 4. With $0.5^{\circ}$ amplitude it is again clear that there is good agreement between the respective values obtained from the DTFA and from the recorded signals. With $1.0^{\circ}$ amplitude the agreement is not as good, but it might be noted that of all the tests made at Mach number M = 0.825 the results for $1^{\circ}$ amplitude with fundamental frequency 41 Hz showed by far the largest discrepancies between values of the fundamental obtained by the two methods.

## 6 CONCLUDING REMARKS

The main purpose of the work is to examine the use of a method for the measurement of oscillatory pressures, in which the oscillatory signals are recorded on magnetic tape and analysed at a later time on a digital computer. Comparison with results measured on-line with a Digital Transfer Function Analyser shows, for the range of frequency, Mach number and amplitude of the tests, that there is no significant loss of accuracy in magnitude when the indirect method is used and that the measurement of phase angle is accurate to within $1^{\circ}$.

With regard to the tape recorder (CEC VR 3300) it is found, from analysis of suitable recorded calibration signals, that the gain factor of each of the seven channels required for the present tests is insensitive to frequency in the range 20 Hz to 60 Hz, and the phase shift between channels is less than $0.5^{\circ}$.

The analysis for the indirect method described in the text presumes that the electrical characteristics of the recording channels are initially unknown, and provides a method for determining and accounting for the transfer function of each channel. Moreover, the method includes a correction for any dc drift that might occur in the record and playback process. In principle, any number of harmonic components of the pressure responses can be evaluated provided sufficient points are digitised per cycle of oscillation. The Fourier analysis is truncated after seven harmonics in the present case for which 24 points per cycle are digitised.

An obvious advantage in using a tape recorder is that the recorded signals can be re-analysed with more points per cycle if a particular response is found to have interesting features. The responses of the pressure transducers were fed both to the DTFA and to the tape recorder after amplification by amplifiers designed to give negligible phase shifts. It was verified that the phase shifts were zero, but lengthy calibrations were necessary prior to the commencement of the tests in order to determine the gain factors of each of the seven amplifiers for ten available settings per amplifier. It should be possible with the indirect method to record calibration signals via these amplifiers, so that the phase shifts and gains due to the complete system could be automatically calculated and accounted for in the computer analysis.

The measurement of oscillatory pressures by the two methods has enabled valuable experience to be gained both in the on-line use of the DTFA and in the development of an indirect method necessary for the planned investigation of dynamic stall due to commence shortly.

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## Table 1

COMPARISON BETWEEN RESULTS MEASURED ON-LINE BY THE DTFA AND RESULTS FROM ANALYSIS OF THE RECORDED SIGNALS

Frequency of oscillation = 20 Hz*

Values of the oscillatory part of $p/Ho \times 10^2$

| Transducer position x/c | M = 0.75, amplitude $1^o$ | | | | M = 0.825, amplitude $1^o$ | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 5.11 | 5.19 | 1.27 | 1.23 | 4.41 | 4.39 | 1.30 | 1.26 |
| 0.05 | 4.07 | 4.15 | 1.01 | 0.96 | 3.76 | 3.63 | 1.16 | 1.14 |
| 0.10 | 3.07 | 3.12 | 1.05 | 1.03 | 3.03 | 2.99 | 1.45 | 1.42 |
| 0.20 | 2.30 | 2.35 | 0.56 | 0.52 | 2.83 | 2.79 | 1.22 | 1.19 |
| 0.40 | 1.41 | 1.15 | 0.04 | 0.04 | 5.55 | 5.49 | 0.73 | 0.71 |
| 0.90 | 0.41 | 0.40 | -0.25 | -0.11 | 0.24 | 0.24 | -0.18 | -0.18 |

| Transducer position x/c | M = 0.85, amplitude $1^o$ | | | |
|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 3.89 | 3.84 | 1.15 | 1.10 |
| 0.05 | 3.27 | 3.28 | 1.08 | 1.02 |
| 0.10 | 2.54 | 2.55 | 1.28 | 1.25 |
| 0.20 | 2.21 | 2.20 | 1.00 | 1.01 |
| 0.40 | 2.33 | 2.33 | 1.01 | 1.00 |
| 0.90 | -0.23 | -0.19 | -0.42 | -0.38 |

* All the frequencies quoted are nominal values.

## Table 2

## COMPARISON BETWEEN RESULTS MEASURED ON-LINE BY THE DTFA AND RESULTS FROM ANALYSIS OF THE RECORDED SIGNALS

Frequency of oscillation = 40 Hz

Values of the oscillatory part of p/Ho × $10^2$

| Transducer position x/c | M = 0.4, amplitude $1^o$ | | | | M = 0.6, amplitude $1^o$ | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 1.86 | 2.08 | 0.61 | 0.65 | 4.55 | 4.46 | 1.44 | 1.37 |
| 0.05 | 1.26 | 1.27 | 0.36 | 0.35 | 2.88 | 2.92 | 0.86 | 0.86 |
| 0.10 | 0.87 | 0.88 | 0.26 | 0.24 | 1.95 | 1.96 | 0.75 | 0.77 |
| 0.20 | 0.59 | 0.60 | 0.08 | 0.08 | 1.38 | 1.35 | 0.33 | 0.33 |
| 0.40 | 0.34 | 0.35 | -0.04 | -0.04 | 0.80 | 0.79 | 0.00 | 0.01 |
| 0.90 | 0.16 | 0.14 | -0.11 | -0.11 | 0.36 | 0.34 | -0.17 | -0.15 |

| Transducer position x/c | M = 0.7, amplitude $1^o$ | | | | M = 0.8, amplitude $1^o$ | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 4.98 | 5.03 | 1.90 | 1.82 | 4.59 | 4.58 | 2.11 | 2.10 |
| 0.05 | 3.65 | 3.69 | 1.42 | 1.34 | 3.77 | 3.78 | 1.97 | 1.93 |
| 0.10 | 2.51 | 2.55 | 1.30 | 1.27 | 2.79 | 2.79 | 2.15 | 2.11 |
| 0.20 | 1.89 | 1.90 | 0.66 | 0.63 | 2.79 | 2.79 | 1.72 | 1.70 |
| 0.40 | 1.07 | 1.07 | 0.10 | 0.07 | 1.21 | 1.21 | -0.14 | -0.14 |
| 0.90 | 0.41 | 0.41 | -0.18 | -0.17 | 0.42 | 0.42 | -0.27 | -0.25 |

Table 2 (concluded)

| Transducer position x/c | M = 0.825, amplitude 1° | | | | M = 0.825, amplitude 0.5° | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 4.10 | 4.12 | 2.06 | 2.00 | 2.10 | 2.06 | 1.06 | 1.03 |
| 0.05 | 3.37 | 3.38 | 1.93 | 1.90 | 1.72 | 1.70 | 0.95 | 0.92 |
| 0.10 | 2.31 | 2.40 | 2.27 | 2.12 | 1.19 | 1.19 | 1.10 | 1.09 |
| 0.20 | 2.42 | 2.41 | 1.92 | 1.90 | 1.21 | 1.20 | 1.01 | 0.99 |
| 0.40 | 5.60 | 5.71 | 1.72 | 1.67 | 2.99 | 3.00 | 0.51 | 0.53 |
| 0.90 | 0.31 | 0.30 | -0.38 | -0.35 | 0.15 | 0.15 | -0.17 | -0.16 |

| Transducer position x/c | M = 0.85, amplitude 1° | | | |
|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 3.58 | 3.60 | 1.81 | 1.81 |
| 0.05 | 2.94 | 2.92 | 1.75 | 1.71 |
| 0.10 | 1.99 | 1.97 | 1.93 | 1.92 |
| 0.20 | 1.82 | 1.79 | 1.64 | 1.63 |
| 0.40 | 2.59 | 2.29 | 2.08 | 1.86 |
| 0.90 | -0.04 | -0.03 | -0.70 | -0.72 |

Table 3

COMPARISON BETWEEN RESULTS MEASURED ON-LINE BY THE DTFA
AND RESULTS FROM ANALYSIS OF THE RECORDED SIGNALS

Frequency of oscillation = 60 Hz

Values of the oscillatory part of $p/Ho \times 10^2$

| Transducer position x/c | M = 0.4, amplitude $1^o$ | | | | M = 0.6, amplitude $1^o$ | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 1.88 | 1.89 | 0.82 | 0.80 | 3.70 | 3.69 | 2.12 | 2.09 |
| 0.05 | 1.18 | 1.18 | 0.41 | 0.40 | 2.49 | 2.48 | 1.37 | 1.37 |
| 0.10 | 0.79 | 0.80 | 0.28 | 0.27 | 1.58 | 1.58 | 1.09 | 1.09 |
| 0.20 | 0.56 | 0.56 | 0.06 | 0.05 | 1.20 | 1.20 | 0.50 | 0.50 |
| 0.40 | 0.34 | 0.33 | -0.11 | -0.11 | 0.72 | 0.74 | 0.03 | 0.04 |
| 0.90 | 0.14 | 0.14 | -0.20 | -0.19 | 0.31 | 0.31 | -0.22 | -0.21 |

| Transducer position x/c | M = 0.7, amplitude $1^o$ | | | | M = 0.8, amplitude $1^o$ | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 4.16 | 4.18 | 2.91 | 2.93 | 3.48 | 3.48 | 3.34 | 3.28 |
| 0.05 | 3.01 | 3.03 | 2.19 | 2.20 | 2.69 | 2.68 | 3.04 | 3.00 |
| 0.10 | 1.85 | 1.88 | 1.83 | 1.81 | 1.47 | 1.46 | 2.82 | 2.79 |
| 0.20 | 1.57 | 1.58 | 0.99 | 0.98 | 1.79 | 1.75 | 2.46 | 2.43 |
| 0.40 | 0.99 | 0.99 | 0.18 | 0.18 | 1.40 | 1.40 | 0.00 | -0.01 |
| 0.90 | 0.41 | 0.42 | -0.24 | -0.23 | 0.47 | 0.48 | -0.35 | -0.32 |

Table 3 (concluded)

| Transducer position x/c | M = 0.825, amplitude $1^\circ$ | | | | M = 0.825, amplitude $0.5^\circ$ | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 2.96 | 2.96 | 3.08 | 3.03 | 1.48 | 1.47 | 1.58 | 1.56 |
| 0.05 | 2.23 | 2.21 | 2.84 | 2.80 | 1.13 | 1.14 | 1.43 | 1.41 |
| 0.10 | 1.05 | 1.03 | 2.65 | 2.60 | 0.50 | 0.49 | 1.34 | 1.32 |
| 0.20 | 1.15 | 1.13 | 2.52 | 2.48 | 0.50 | 0.54 | 1.31 | 1.28 |
| 0.40 | 4.14 | 4.16 | 3.56 | 3.54 | 2.62 | 2.62 | 1.73 | 1.71 |
| 0.90 | 0.42 | 0.43 | -0.49 | -0.47 | 0.21 | 0.21 | -0.26 | -0.23 |

| Transducer position x/c | M = 0.85, amplitude $1^\circ$ | | | |
|---|---|---|---|---|
| | In-phase ×(-1) | | In-quadrature | |
| | Recorded | DTFA | Recorded | DTFA |
| 0.0125 | 2.45 | 2.52 | 2.62 | 2.49 |
| 0.05 | 2.19 | 1.83 | 2.05 | 2.29 |
| 0.10 | 0.70 | 0.74 | 2.17 | 2.09 |
| 0.20 | 0.65 | 0.68 | 1.85 | 1.77 |
| 0.40 | 1.02 | 1.02 | 3.19 | 3.05 |
| 0.90 | 0.33 | 0.32 | -1.00 | -0.97 |

Table 4

FOURIER ANALYSIS OF DIFFERENT PARTS OF THE RECORDED RESPONSE FROM A TRANSDUCER WITH A SHOCK WAVE OSCILLATING ABOVE IT

Values of the oscillatory part of p/Ho × $10^2$

(a) Frequency = 40 Hz, amplitude $1^o$

| Harmonic number | In-phase component | | | | In-quadrature component | | | |
|---|---|---|---|---|---|---|---|---|
| | Batch 1 | Batch 2 | Batch 3 | Batch 4 | Batch 1 | Batch 2 | Batch 3 | Batch 4 |
| 1* | -5.59 | -5.60 | -5.62 | -5.61 | 1.86 | 1.72 | 1.77 | 1.80 |
| 2 | 2.24 | 2.17 | 2.18 | 2.21 | 1.32 | 1.39 | 1.35 | 1.35 |
| 3 | -0.63 | -0.65 | -0.66 | -0.63 | -0.29 | -0.39 | -0.28 | -0.31 |
| 4 | 0.97 | 0.90 | 0.95 | 0.96 | 0.08 | 0.20 | 0.13 | 0.14 |
| 5 | -0.37 | -0.37 | -0.34 | -0.35 | -0.28 | -0.36 | -0.26 | -0.28 |
| 6 | 0.22 | 0.25 | 0.27 | 0.23 | 0.02 | 0.08 | 0.01 | 0.03 |
| 7 | -0.20 | -0.21 | -0.21 | -0.18 | -0.11 | -0.18 | -0.12 | -0.13 |

(b) Frequency = 40 Hz, amplitude $0.5^o$

| Harmonic number | In-phase component | | | In-quadrature component | | |
|---|---|---|---|---|---|---|
| | Batch 1 | Batch 2 | Batch 3 | Batch 1 | Batch 2 | Batch 3 |
| 1* | -2.97 | -3.01 | -2.97 | 0.49 | 0.49 | 0.55 |
| 2 | 1.23 | 1.23 | 1.26 | 1.31 | 1.30 | 1.22 |
| 3 | 0.12 | 0.05 | 0.05 | -0.67 | -0.67 | -0.62 |
| 4 | -0.11 | -0.06 | -0.22 | 0.14 | 0.19 | 0.17 |
| 5 | 0.11 | 0.06 | 0.02 | -0.11 | -0.11 | -0.11 |
| 6 | -0.07 | -0.11 | -0.04 | 0.01 | 0.03 | 0.07 |
| 7 | 0.05 | 0.08 | 0.05 | 0.01 | 0.00 | -0.02 |

Comparison between two methods of analysis for the conditions above

| Harmonic number | case (a), $1^o$ | | | | case (b), $0.5^o$ | | | |
|---|---|---|---|---|---|---|---|---|
| | In-phase | | In-quadrature | | In-phase | | In-quadrature | |
| | mean recorded | DTFA | mean recorded | DTFA | mean recorded | DTFA | mean recorded | DTFA |
| 1* | -5.61 | -5.71 | 1.79 | 1.67 | -2.98 | -3.00 | 0.51 | 0.53 |
| 2 | 2.20 | 2.04 | 1.35 | 1.21 | 1.24 | 1.24 | 1.28 | 1.20 |
| 3 | -0.64 | -0.74 | -0.32 | -0.19 | 0.07 | 0.03 | -0.65 | -0.61 |

* Fundamental frequency is denoted harmonic number 1

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| 3 | K. G. Moreton<br>G. S. Smith | The use of miniature transducers in the measurement of fluctuating pressures on small aerofoils.<br>(In draft) |

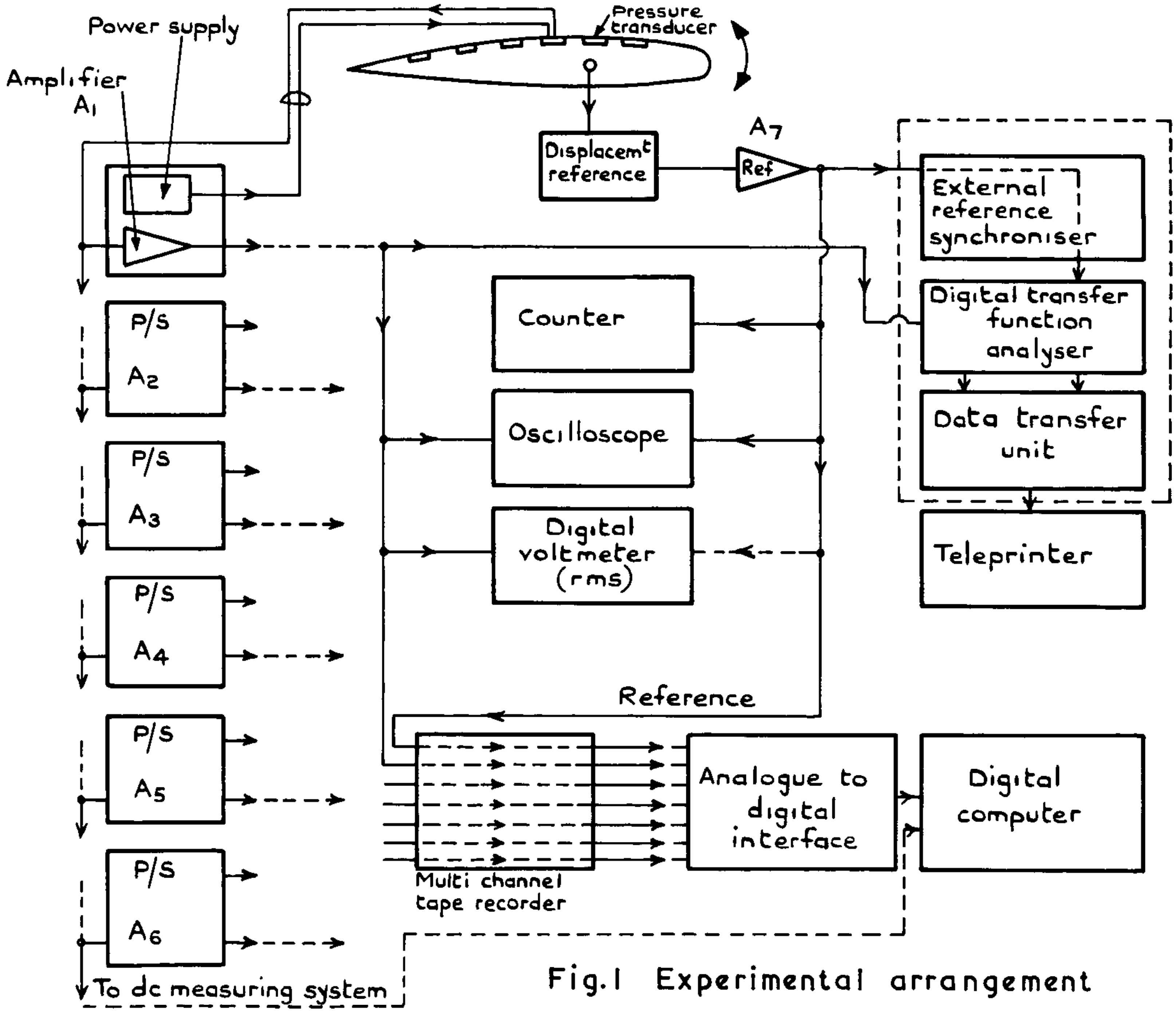


Fig.1 Experimental arrangement

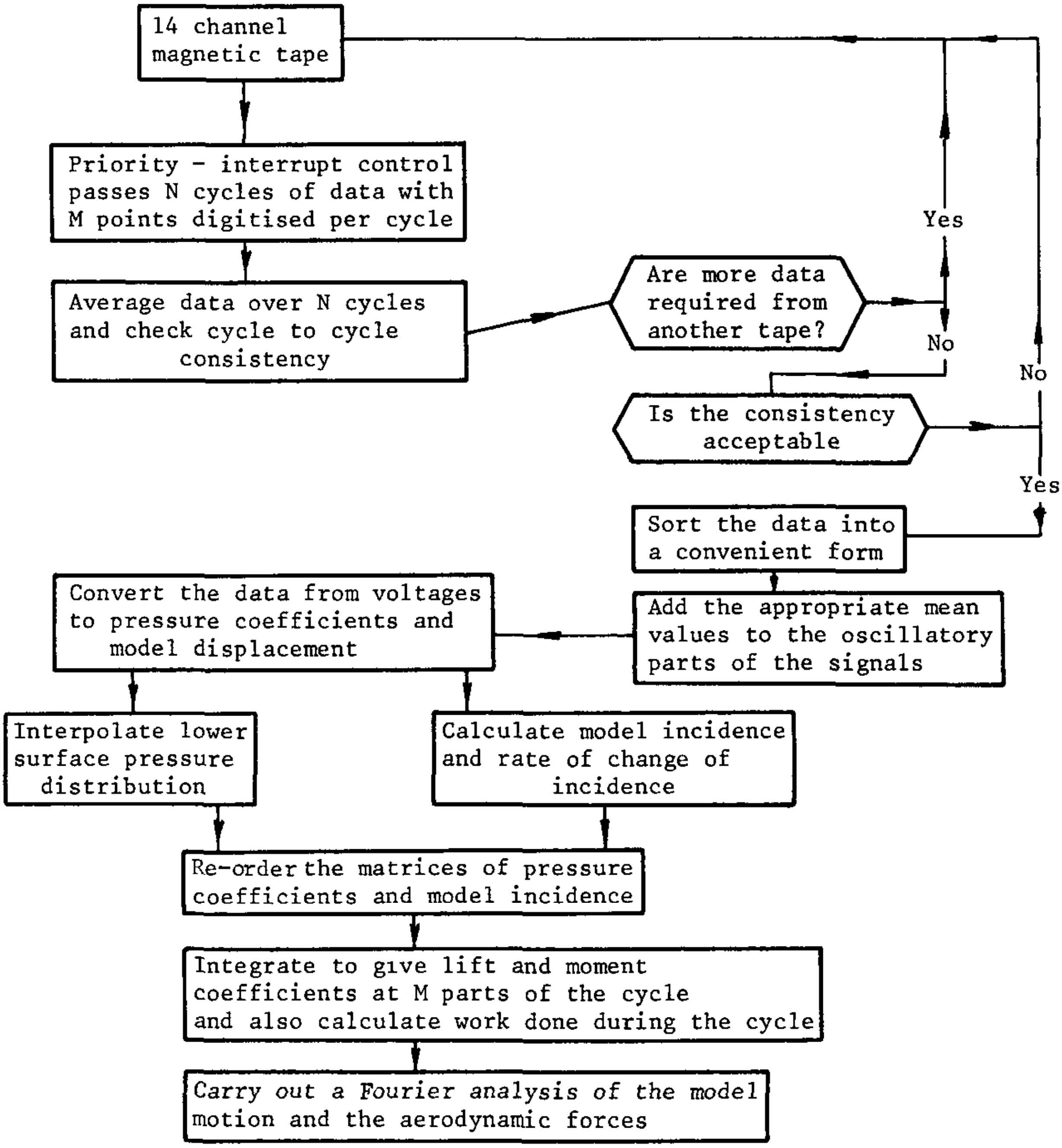


Fig.2 Flow diagram for the analysis on the H516 computer

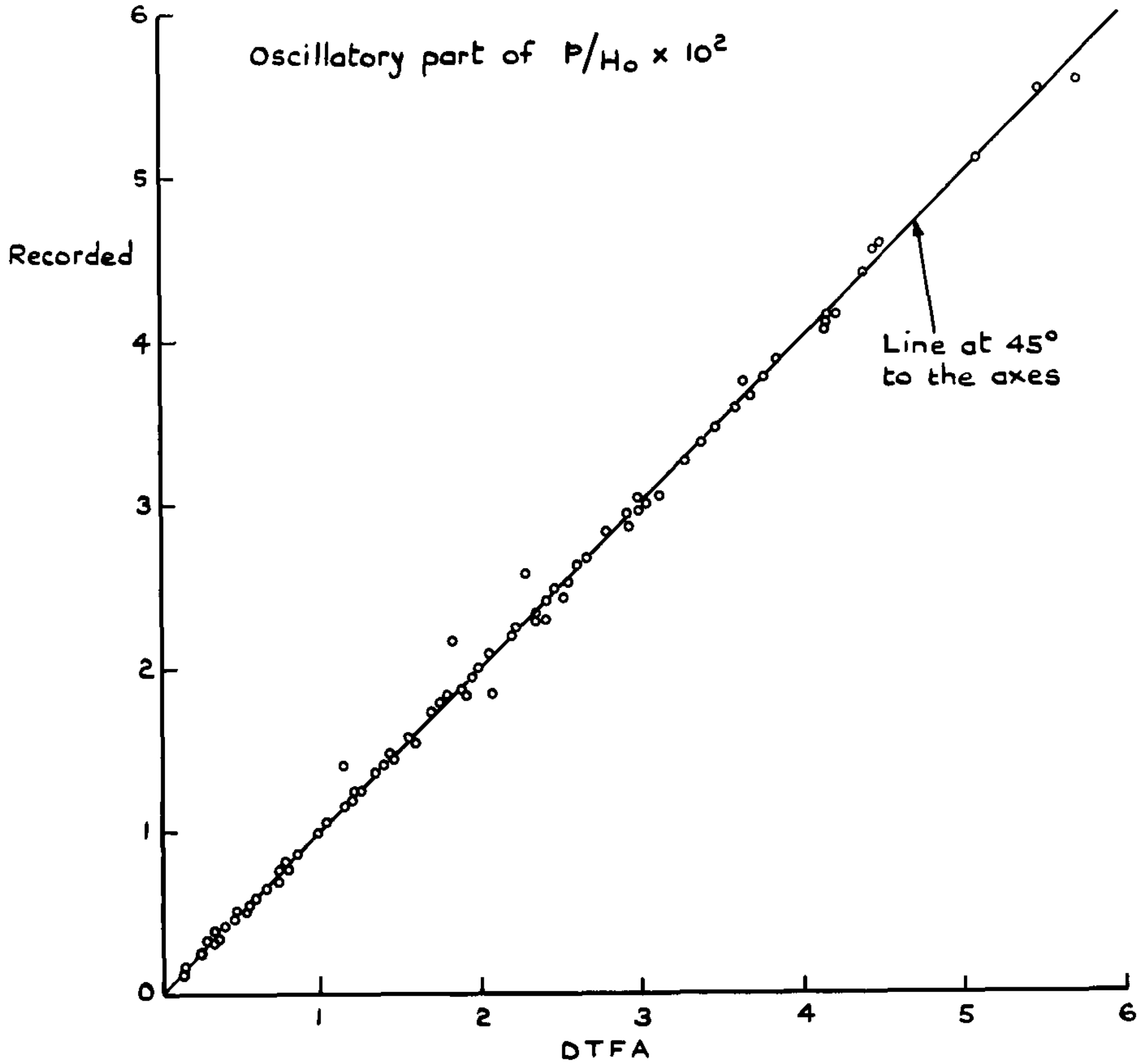


Fig. 3 Comparison between results from the two methods of analysis of the oscillatory pressure signals:
(a) Component in phase with the motion

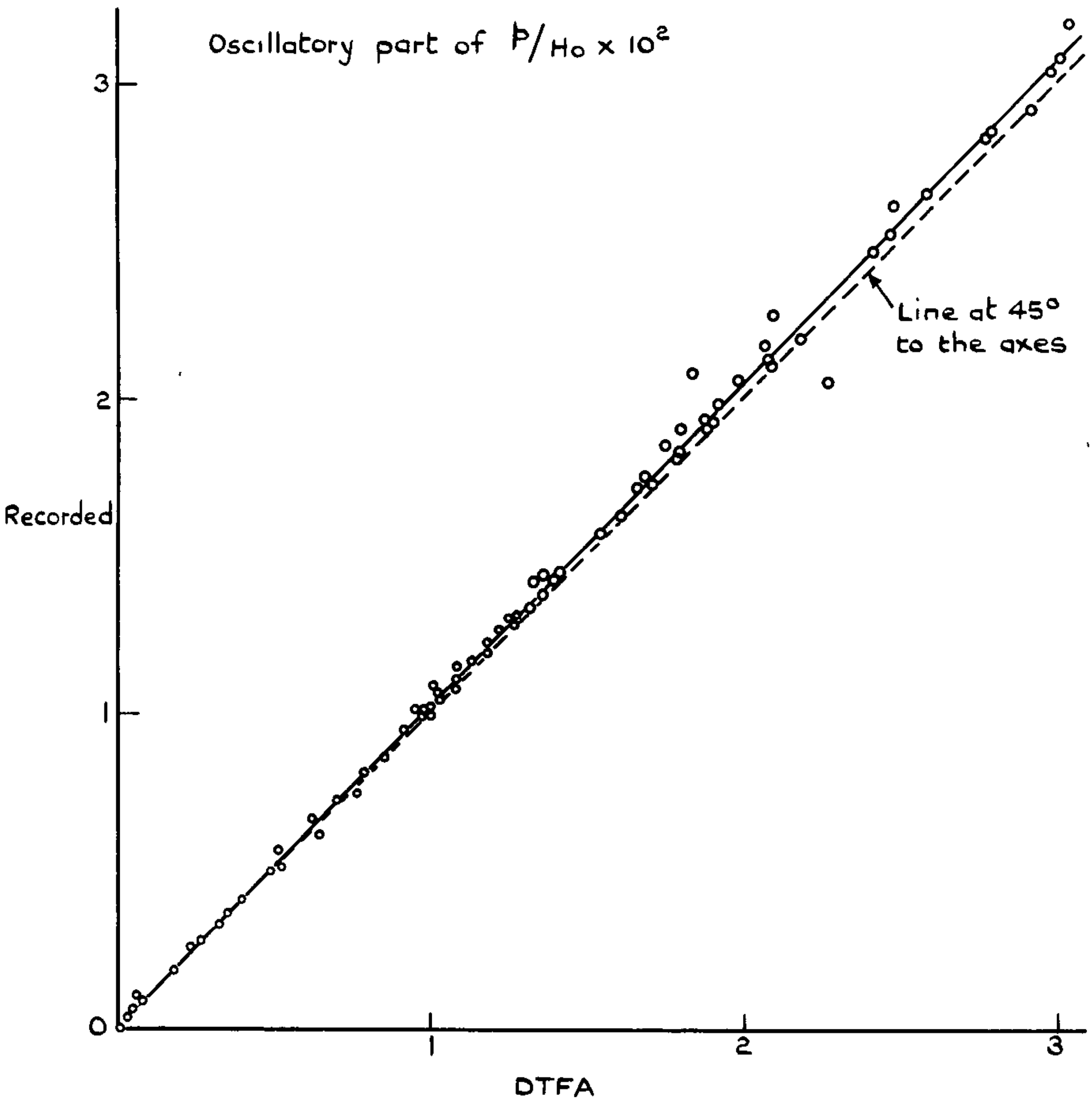


Fig. 4 Comparison between results from the two methods of analysis of the oscillatory pressure signals:
(b) Component in quadrature with the motion

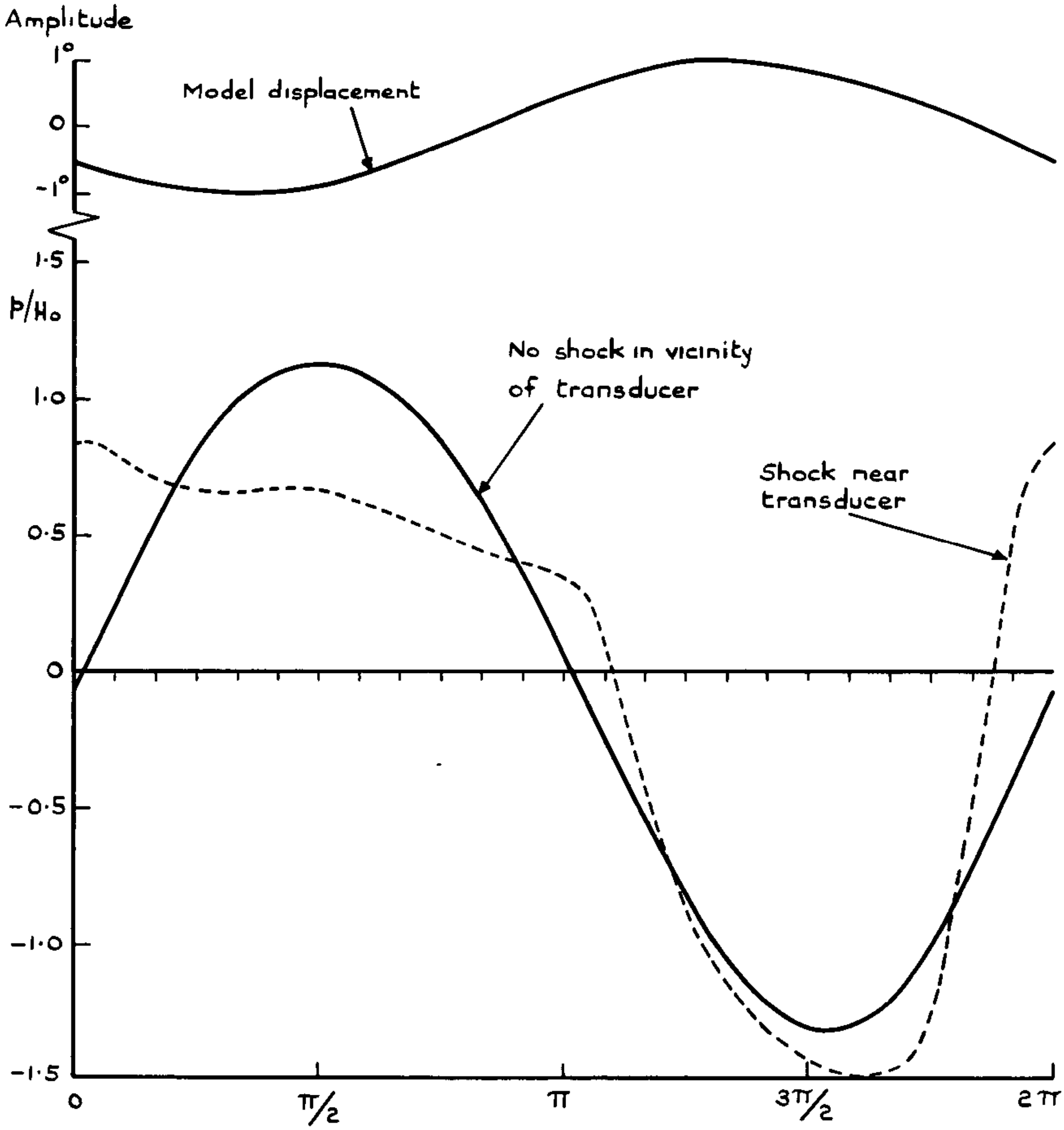


**Fig.5 Typical responses of the pressure transducers during one cycle of oscillation**

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## DETACHABLE ABSTRACT CARD

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Moore, A W — 518 5
Welsh, B L — 681 846

A COMPARISON BETWEEN TWO METHODS OF ANALYSIS OF OSCILLATORY PRESSURE MEASUREMENTS, ONE METHOD REQUIRING THE USE OF A TAPE RECORDER

Two methods for analysing oscillatory pressure distributions are compared. In one, a Digital Transfer Function Analyser is used on-line to measure the in-phase and in-quadrature components of oscillatory pressure signals with respect to a given reference signal In the other method the pressure signals are recorded on magnetic tape, then the recorded signals are analysed on a digital computer at a later time

Oscillatory pressures were produced by oscillating a model wing in a wind tunnel Pressure transducers were mounted in the model at six chordwise stations and the responses from the transducers were measured by both of the above methods for a range of frequency and Mach number A comparison of the results shows that for the conditions achieved in the tests, there is no significant loss of accuracy in magnitude when the oscillatory pressure signals are recorded on magnetic tape for later analysis, and that the measurement of phase angle is accurate to within 1°

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