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ARROW 2 FLIGHT TEST INSTRUMENTATION

RD 88

ANALYZED

A PRELIMINARY EVALUATION OF THE OVERALL ACCURACY OF AN I.R.I.G. FLIGHT TEST INSTRUMENTATION SYSTEM

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ANALYZED

AVRO AIRCRAFT LIMITED

RESEARCH & DEVELOPMENT (AIRFRAME)

PROJECT ARROW 2 FLIGHT TEST INSTRUMENTATION

REPORT No. RD.88

FILE No.:

No. OF SHEETS 20

TITLE: A PRELIMINARY EVALUATION OF THE OVERALL ACCURACY OF AN I.R.I.G. FLIGHT TEST INSTRUMENTATION SYSTEM.

Classification cancelled / Changed to UNCLASS
By authority of AVRS
Date 27Sept96
Signature [signature]
Unit / Rank / Appointment AVRSS

Approved by: [signature]
E.J. Lynch,
Assistant to Chief Experimental Engineer.

Date: July 30, 1958.

AVRO EA 1368

PREPARED BY [signature] T.A.Stenning
Flight Test Instrumentation Engineering Supervisor
DATE July 24th, 1958.

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AVRO AIRCRAFT LIMITED
RESEARCH & DEVELOPMENT (AIRFRAME)

REPORT NO. RD.88

SHEET NO. 1 of 20

PROJECT

ARROW 2 FLIGHT TEST INSTRUMENTATION

DATE July 24, 1958.

PREPARED BY T.A. Stenning

SUMMARY

The total errors are analysed arising from the use of an I.R.I.G. magnetic tape F.M. and P.D.M. data acquisition system, by Avro, in the Arrow flight test program. The basic I.R.I.G. system is unlikely to introduce errors greater than ± 1.1%, but other equipment, and operating procedures will introduce additional errors. The total errors are not likely to exceed 3% if "in situ" calibrations are possible, nor 6% if such calibrations are impossible, and are likely to be appreciably less than these figures.

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CONTENTS

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1. INTRODUCTION

Since the I.R.I.G. system of instrumentation recording and reproduction was first proposed and accepted for use on the Arrow aircraft, much discussion has ensued as to the probable accuracy of the overall system, from input to the transducer to output of the reproducer equipment in either analog or digital form.

This report represents an attempt to assess this accuracy in the light of our own and other companies' experience with similar equipment, taking into account not only the basic accuracies of the various components, but also our methods of operating the system.

The author is well aware of the limitations of the present approach to the problem. Similar systems have been in use or in design in the U.S.A. over the past year or so, yet in discussion with instrumentation personnel at such forums as the I.S.A. symposium in New York this year, such opinions as are offered as to overall accuracy are felt to be unsupported by any concrete tabulated evidence, if indeed such concrete evidence is obtainable at all.

Without a detailed, statistical investigation of transducer performance, supported possibly by a fact-finding tour of the establishments using the equipment in question, the opinions expressed in this report, while representing the best of our knowledge within Avro, can have only a limited validity.

2. TERMS OF REFERENCE

The limits between which the data acquisition process will be examined are defined by the actual physical input into the transducer at one end, and the actual presentation of data for analysis at the other.

Thus, no account is taken of, for example, "position-error" in pressure transducers used to measure airflow, or of inadequate temperature compensation of strain gauges.

Similarly, the data acquisition process is considered complete when a Sanborn record is presented to the Flight Test Engineers, or a digital tape and/or punched cards are presented to the Computer Section.

Throughout the test it is found more convenient to refer to "error" rather than "accuracy", since errors can more logically be summed, evaluated, etc.

A distinction also is made between errors which occur as a percentage of "measured value" (MV) and those which are related to "full-scale", (FS).

3. ACCURACY OF THE SYSTEM COMPONENTS

3.1 The Transducer and Signal Conditioner

For the purpose of this report, one particular type of transducer, the unbonded strain-gauge pressure transducer, will be taken as a typical case. This is one of the more common types, and generally speaking, its basic accuracy is representative of the average.

3.1.1 Basic Errors

By this is meant the errors (deviation from linearity, hysteresis, and scatter) which it is either impossible or uneconomical to correct for at some stage in the data reduction process. Hysteresis and scatter, for example, cannot by their nature, be compensated for, while non-linearity, as it turns out, is small in relation to the overall accuracy

3.1.1 (continued)

of the system, and the complexity of a multi-point calibration is not warranted.

A typical figure for these basic errors is ± ½% of full scale, measured as deviation from the best straight line. The 10% and 90% points of the transducer range (on the best straight line) are allocated output values in the Lab. calibration, and these are the values which are passed on to the Computer Section for data reduction.

3.1.2 Drift

Drift in transducers takes two forms, - change of zero, (bridge unbalance for zero physical stimulus), and change of slope, (rate of change of bridge unbalance with change of stimulus). Since many of our transducers are installed in areas where it is impractical to apply an accurate known physical stimulus without extensive breaking down of equipment, drift must be accepted as part of the "uncalibratable" error in the system in many cases. Certain strain-gauge pressure transducers have a further unfortunate feature in that the calibration changes with exercise, i.e., a series of calibration cycles will produce different slopes and zero outputs until the transducer "settles" to a final established line. In flight there is no means of telling whether the transducer has settled on its established calibration when any particular measurement is taken.

Finally, in the case of the earlier C.E.C. pressure transducers, the zero output is considerably affected by the torque loading used to seal it in its adaptor. A recommendation has been made as to the torquing limits to be observed during assembly - (the minimum torque being determined by the requirement to obtain a pressure tight seal and the maximum by the requirement to maintain the "free" zero output to within 1/4% of full scale).

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3.1.2 (continued)

This type of transducer is being eliminated from future systems, but a number of them are installed in aircraft 25203, in which the first I.R.I.G. system will operate, and it is not considered realistic to rule out the possibility of about ½% in zero error being caused by faulty installation technique.

Table 1, below, summarises the transducer errors discussed in 3.1.1 and 3.1.2.

TABLE 1 - TRANSDUCER ERRORS

TYPE OF ERROR	% F.S.	% M.V.
Basic:- Hysteresis, Scatter, Non-Linearity	½%	
Drift of Basic Calibration with Time (zero & slope)	1%	1%
Shift due to lack of exercise (zero & slope)	1%	1%
Zero shift due to installation torque	½%	
Total	3%	2%

(This implies a possible total error of 3% to 5% F.S. according to the amplitude of the signal). As to the applicability of the above analysis to other types of transducer, some of the factors involved are:-

Thermocouples and "Stick-on" or "Bolt-on" Resistance Bulbs:-

Changes of heat transfer characteristics due to local distortions, contamination, etc.

Strain Gauges

"Creep" of gauge due to inadequate curing of adhesive, - adequate curing cycles are not always achievable on actual aircraft structures.

3.2 Signal Conditioning

Under this heading are included all the operations necessary to condition the "raw" signal from the transducer for entry into either the voltage controlled sub-carrier oscillators or the P.D.M. commutators.

For entry into the V.C.O.s we must have a signal of a nominal level in the order of ± 2½ V.D.C., thus some form of amplification, and sometimes demodulation is required on low level channels.

For P.D.M., the input level is ± 7½ millivolts, and no amplification is generally required, although it may occasionally be necessary to demodulate an A.C. signal.

In most cases, the signal conditioners are located upstream of the point at which the calibration voltages are inserted into the system; this means that they form, in effect, an extension to the transducer itself, and any inherent errors in the conditioner units must be considered as part of the transducer error.

In the cases where "active-element" signal conditioners, (phase sensor, etc.) are employed, however, the calibration is inserted upstream of the conditioners.

3.2.1 "Passive Element" Conditioners

The general method of operation is as follows:-

A signal conditioner is designed to match the nominal output of the transducer over the dynamic range required, with provision for sufficient adjustment of balance and sensitivity to cover any normal variation between individual transducers. The transducer is calibrated in the laboratory before installation, together with its associated conditioner unit, the conditioner being adjusted to give the required zero and full-scale outputs to the V.C.O.s or commutators with the nominal polarizing voltage on the transducer. The conditioner adjustment potentiometers are then locked, and the unit identified as being

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3.2.1 (continued)

adjusted for use with its own particular transducer. Thence forward, the transducer and its conditioner-unit form a "package" with a unique calibration function, which can be used for scaling purposes in the computer or by the personnel setting up the analog readouts.

Since calibration reference voltages are put in downstream of the transducer/conditioner package, the only justification for subsequent re-adjustment of the conditioner is the application of a calibrating physical input at the transducer.

This type of calibration is only practicable in a limited number of cases, e.g., differential and static pressure, control surface angles, etc.,

When this type of calibration is done, it is valid to adjust the conditioner to compensate for any drift of the transducer which may have occurred since its latest laboratory calibration. Otherwise it must be assumed that neither the transducer nor the conditioner-unit have drifted, and any actual drift in either contributes directly to the overall system error. Setting up of the signal conditioner in the course of laboratory calibration can be assumed to be done to an accuracy 0.1% F.S., using the available laboratory standards.

A signal conditioner built with .05% precision resistors should hold its setting, under all environmental conditions, to within .2% of full scale.

In the case of the "in-situ" calibration, however, it would not be realistic to assume the same level of accuracy as can be achieved in the laboratory, particularly when a number of such calibrations have to be carried out in a limited time.

The probable error in this case is obviously somewhat imponderable. One of the factors affecting the static and differential pressure transducer calibrations, for example, is the adiabatic heating

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3.2.1 (continued)

effect due to raising the reference pressure in the pitot-static system and in the connecting tubing to the pressure reference. This causes a slow variation of the reference pressure which makes it difficult to read the vernier scale of the manometer with the accuracy of which the instrument is theoretically capable. Slight vibration of control surfaces, trailing edge distortion, and back-lash in the transducer linkage, all contribute errors to the calibration of control surface angle potentiometers.

In the writer's opinion, calibration done under these conditions should not be expected to be within better than 1% of full scale.

3.2.2 <u>"Active Element" Signal Conditioners</u>

The essential difference between these conditioners, (D.C. amplifiers, phase sensors, etc.) is that the calibration reference will be inserted upstream of the conditioner, so that the conditioner itself is within the correction loop of the system. They do not, therefore, have any direct error contribution to the system, and will be discussed as part of the correction loop in a subsequent para.

Summarising, we have now reached the point when conditioned signals are fed into the recording system, which from this point on is self-correcting.

In the case of channels to which it is impossible or impractical to apply an "in-situ" calibration, the signal going into the recording system has in it errors due to transducer and signal conditioner aberrations amounting to a possible maximum of:-

3% - 5% F.S. (Due to the Transducer)
0.3% F.S. (Due to the Conditioner)
(See Fig. 1)

3.2.2 (continued)

In the case where a physical calibration before and after flight is used, we still have an uncertainty in the transducer output amounting to ½% due to scatter, hysteresis, etc., although it is valid to assume that the 1% F.S. and 1% M.V. errors due to change of calibration with exercise will be reduced to, say, .2% each, while the error due to the original installation can be eliminated. To these errors must be added an imponderable error due to setting-up the signal conditioner under operational conditions to which we have assigned an arbitrary value of 1% of full scale. Thus, in the case of an "in-situ" before/after flight calibration, we can assume that the voltage going into the recording system proper, represents the physical input to the transducer to within 1.7% to 1.9% full scale, depending on signal amplitude.

3.3. Electrical Parameters

Where actual electrical signals from an electric system, (damper, fire control, radar, etc.,) are being measured, the situation is, of course, somewhat better. The difficulty here, from the point of view of assessing accuracy, is to decide where the electronic system finishes and the recording system begins. Generally speaking the electrical signals to be measured are in the form of amplitude modulated A.C. carriers. . In some cases the onus is on Flight Test Instrumentation to convert these signals to D.C. and sometimes the conversion is done by the electronics contractor in his own equipment, and with devices the accuracies of which are as yet unknown. It is valid, in either case, to regard the demodulating device, (a phase sensitive demodulator) as performing the function of a transducer, and in the case of the Avro designed devices, the drift under the specification environmental test conditions, can be considered to be of the order of 1% full scale, for a given attenuation adjustment.

3.2.3 (continued)

Substituting this value for the transducer error, we have a possible degradation of data into the recording system of 2%, since it is assumed that the attenuation has to be adjusted at the output from the phase sensitive demodulator during set-up of the system, and the usual allowance for set-up under operational conditions must be made.

4. THE RECORDING SYSTEM PROPER

Inasmuch as both the F/M and P.D.M. sub-systems contain correction loops, it is logical to consider as a whole that portion of the overall system which is covered by these loops. We will therefore consider the recording system proper as beginning at the point at which calibration reference signals are inserted.

In most cases, this point is downstream of the signal conditioners. However, in the few cases where the signal conditions are of the active element type, e.g. D.C. amplifiers, these devices are brought within the correction loop by inserting the calibration reference upstream.

4.1 The Correction Loops

4.1.1 P.D.M. Sub-System

Two channels of every P.D.M. commutator are allocated to the function of zero and full-scale reference. For zero reference, the two switch poles which form the channel input are shorted together, and on picking up the resultant zero signal from the tape, the P.D.M./P.A.M. conversion units of the ground playback equipment are automatically balanced to give zero voltage out, irrespective of the actual pulse-width received.

For the full scale reference, the two switch poles of the full scale reference channel are supplied with a precision voltage derived by a chain of precision resistors, from the same source which supplies D.C. polarisation to the transducers.

4.1.1 (continued)

This reference voltage will be $7\frac{1}{2}$ millivolts when the transducer polarisation is at its nominal level, and will vary in proportion to any variations in the latter.

When the full scale signal recorded on the tape is picked up in the Ground Station, the P.D.M./P.A.M. conversion units are automatically adjusted to give the nominal full scale output voltage, even if the input reference voltage has drifted from its nominal figure of $7\frac{1}{2}$ M.V.

Thus it can be seen that the loop will correct for the following aberrations:-

1. Variation of polarising voltage to the transducers. (As long as the transducer signal conditioner combination maintains the correct ratio, at full scale, between polarising voltage, and output voltage, the ground station will put out the correct full scale signal).

2. Errors in conversion from pulse-amplitude output of the commutator to pulse width.

3. Drift in the P.D.M. amplifiers which precede the P.A.M./P.D.M. conversion.

4. Low frequency, (1-2 cps) variation in tape speed between recording and playback, ("wow").

5. Reconversion in the ground station from P.D.M. to P.A.M.

The errors which the loop will <u>not</u> correct are:-

1. Noise, either on the signal or due to the deterioration of the switch.

2. Error in the full scale reference which alters the ratio between it and the polarising voltage, i.e. drift in the reference resistors with temperature, ageing, etc.

4.1.1 (continued)

3. Drift in the "Holding Amplifiers" which maintain the signal level between one channel sample and the next. (The correction loop will also apply a false correction to self-energising channels, such as thermo -couples or aircraft system voltages, if the polarising voltage of the bridge-type transducersdrifts).

If a clean, precision voltage is presented to the commutator, (assuming for the present we have no switching noise), and the D.C. output of the ground station is compared with the commutator input, it is claimed that the overall sensitivity of the correction loop is such that, within reasonable variation of the five "correctible" aberrations listed above, the overall error will not exceed 0.5% of full scale. This is based on the separate specifications for the airborne and ground equipment.

First, conversion from commutator input to pulse width output is specified as accurate to 1% full scale. It is further specified that the P.D.M. ground station will correct all information to within 0.5% with reference to the full scale and zero reference pulse widths. Now ideally, this means that, although the full scale reference pulse width on the tape may vary from its nominal value, in microseconds by as much as 1%, if all the information pulse widths are corrected with reference to it, the final data is within .5%, i.e., the sensitivity of the correction loop.

Assuming that the reference voltage, which is derived from 3 x .05% resistors in series, is accurate to within 0.15%, the overallerror should not exceed 0.65%.

In practice, however, no user of similar equipment will claim accuracies of this order.

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4.1.1 What, then, are the factors which degrade the accuracy of the P.D.M. sub-system to the level of 2% to 1½%, which is the best that is claimed for it in practice? Part of the degradation is no doubt due to the fact that the signal conditioner is often included in the system, whereas it is outside the correction loop and is strictly speaking, a part of the transduction circuitry. It has already been shown that errors in setting up may contribute 1% to the overall error, which would bring the overall figure up to 1.65% full scale.

In the course of current investigation into the operation of the P.D.M. (Ascop) system at present in use, precision voltages are to be fed into the airborne equipment, to be recorded, played-back and measured in the ground station. This will give an indication of how close to the specification figures for accuracy the Ascop equipment approaches.

Tests already carried out by feeding the P.D.M. output of an Ascop commutator - keyer assembly through a translator into the Millisadic digitiser, (no tape recording) gave a scatter of 0.7% and a maximum drift of 2.1% F.S. The Ascop is claimed to be a 2% system overall, (including tape recording), so that in this case the specification is not met. (In fairness to G.E.C./Ascop it must be stated that the digitising of translated P.D.M. was not contemplated in the original system and Avro was advised against it. The translated P.D.M. from the Ascop ground station has recycling spikes on the analog trace which have to be filtered before the analog data can be digitised).

Some deterioration in the data is also caused by the limited "bandwidth" of the tape, particularly at speeds of 10 and 15 ips. This means that the leading and trailing edges of the pulses are not as sharply defined on the tape as they are at the outputs of the differentiating amplifiers. This shows up as a 20 cps jitter which increases with the number of playbacks, due to smearing of the oxide coating of the tape.

4.1.1 (continued)

Summarising, within our definition of the recording system as beginning at the point where the calibration references are inserted, (thus neglecting setting-up errors) it is believed that, pending actual "in-flight" evaluation, we should allocate a value of 1% to the "closed-loop" system.

4.1.2 F/M Sub-System

Virtually the same considerations apply to the F/M sub-system as to P.D.M.

Normal input into the F/M section is via the voltage controlled sub-carrier oscillators, which convert the $\pm 2\frac{1}{2}$ V D.C. signal from a signal conditioner into a deviation from a centre frequency.

The linearity of the V.C.O.s selected for the airborne I.R.I.G. system is established by evaluation tests at the specification environmental conditions as being within $\frac{1}{2}$%, (from best straight line).

The deviation sensitivity drift, and centre frequency drift over long periods are acceptable in the sense that they are well within the correction capabilities of the ground station.

The discriminators in the I.R.I.G. ground station are of the servo-controlled type. On receipt of a "flag-signal" which is recorded on the tape when the calibrate function is activated, electro-mechanical servos, operating over a period of 1 second, automatically reset the discriminator outputs to conform to chosen zero and full scale values. When zero volts is fed to the V.C.O., the resulting frequency deviation is nominally plus $7\frac{1}{2}$% but will actually vary slightly from this value. At the same time, the discriminator receives a zero flag signal, and the balance of the output amplifier is automatically reset so that, until the next calibrate signal arrives,

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4.1.2 (continued)

the actual frequency output of the V.C.O. at that instant will result in zero output from the discriminator. The same process occurs when a full scale reference voltage is put into the V.C.O., except that in this case it is the amplifier gain which is reset.

When the signal conditioner consists of a D.C. or A.C. amplifier, the calibrate reference is put in upstream of this, so that the signal conditioner drift is corrected along with the V.C.O. etc.,

Long term drift of the V.C.O.s is within 2%, and any amplifiers used will have the same specification. Tape speed control, and where necessary, flutter compensation, maintain the relation between recording and playback speeds to within .1%, but it should be noted that a .1% variation in tape speed, will cause a frequency deviation at the discriminator input of $\frac{0.1 \times 100}{2 \times 7.5}$ or 0.67% of bandwidth, i.e., 0.67% of full scale voltage at the output. However, there is little point in evaluating and summing these separate errors, since the discriminator outputs are corrected with reference to the calibrate inputs into the V.C.O.s, (or into their preamplifiers). Thus, as in the case of the P.D.M., it is the accuracy of the reference voltages, plus the sensitivity of the correction loop, which determines the overall error of the system. Again, the manufacturer's claim (for the correction loop), is for .5% or better, but even less experience is available in the F/M field than in P.D.M., on which to base an estimate of practical accuracy achievable. A figure of 1% is believed to be the best guess.

5. DIGITISATION

Our only digital facility at present available is the Millisadic, a slow-medium speed device with a proven accuracy, (precision voltage in, to digits out), of ± 0.1%. Further digitising equipment will be acquired later, with higher speed capabilities, but of the same order of accuracy, (10 bit binary, 1024 levels).

5. (continued)

The difficulties of digitising translated P.D.M. data, due to the presence of recycling "spikes" between consecutive channel samples, will not occur with the later P.D.M. equipment which employs a "non-return to zero" technique. As long as the Millisadic is used, however, there will still be phase distortions caused by attempting to digitise higher frequency data than that for which the device was originally intended. This can be overcome by "time-base" expansion, (i.e. playing back the analog tape at a slower speed), if digitising of high frequency data does become a problem. We will, therefore, assume that the digitising process by itself introduces no more than ± 0.1% full scale error.

6. OVERALL SYSTEM ERROR

Fig. 1 is an attempt to present the cumulative errors of the system in graphical form. The chart covers two methods of operation of the system, (with and without physical calibration) but only one type of transducer, the unbonded strain-gauge pressure sensor is considered. Also, the errors shown are the cumulative sums of the probable maximum errors of each stage of the system.

First, the term "probable maximum" error should be defined as the error which is not likely to be exceeded, but no statistical evidence can be offered as to the percentage probability of the error being exceeded. Secondly, the probability that the errors in all stages of the system will be the probable maximum in the same, (most adverse), direction at any particular instant is obviously not very high.

The chart states, in effect, that there is a probability, (not very large) that any particular measurement will be as much as 6.4% F.S. in error (at full scale), if the transducers are not calibrated after installation, as against 3% F.S. if physical calibration is carried out sufficiently often to eliminate any appreciable drift in the transducer. To assign a numerical value to these probabilities, as has been stated before, would require an extensive study outside of scope of the present report.

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7. DISCUSSION AND CONCLUSION

7.1 Accuracy Requirements of the Arrow Flight Test Program

Accuracy requirements of the Arrow Program have been stated by various Agencies at various times, and have been revised on occasion to take account of assumed limitations of transducers and recording systems.

It seems, however, that there are broadly two orders of accuracy which will be called for as the program progresses.

(a) A limited number of parameters, mainly in the "Air Data" category, but also including such measurements as control surface angles, etc. must be known to an accuracy of the order of ¼% if the computations which are to be based on them are to have significant value. These quantities will not always be required to this accuracy. They are acceptable at a lower order of accuracy when used merely as reference data for systems testing, for example. But it should be noted that a 1% error in differential pressure is equivalent to 2% in I.A.S., which combined with a 2% error in fuel consumption can give a 4% error in range. Equivalent errors in air temperature, engine pressure ratio, etc. can make reduction of range data to standard conditions quite valueless. Again, at high I.A.S., a 1% change in elevator angle, (say $\frac{1}{2}^{o}$) has a very considerable effect on the normal acceleration applied to the aircraft. It is also believed, though on less well documented evidence, that evaluation of the Integrated Electronics System, which is in itself a high accuracy analog system, demands something better than an equivalent analog measuring system if quantitative measurements are to be worth while.

(b) A greater number of parameters, mainly concerned with system functioning, (temperatures, pressures, flow rates, etc.) are believed to be acceptable at an accuracy of the order of 5%,although in most cases, 2% has been requested.

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7.2 Capabilities of the Instrumentation System

The capabilities of the system, as will be seen from Fig. 1, vary from 3% to 6%, according to whether or not an in-situ, between-flight physical calibration is carried out. As it happens, the type of parameter mentioned under 7.1 (a) above is generally amenable to physical calibration, and would have to be made so, in any case.

The overall error figure of 3% represents the maximum error likely when such calibrations are done under operational conditions.

1% of this error is contributed by the recording system and 1% by setting-up procedures, the remaining 1% being due to a combination of hysteresis, exercise effects and digitising.

It is possible that a large part of the 1% setting-up error could be eliminated if, say, one were allowed to spend 15 minutes calibration time on each parameter, to have exclusive use of the aircraft during calibration periods, and use of laboratory type equipment, but even if this were done, the total error can hardly be reduced below 2% which still does not meet the requirement of 7.1 (a). Better transducers are required if accuracy is to be improved beyond this point. It appears, in fact, that if the requirements of 7.1 (a) are insisted upon, the I.R.I.G. system must be supplemented by either a direct reading photo panel, or in the case of the Electronics System signals, an airborne digital recording system. The capabilities of such a system will be discussed in a later report, but briefly, the gains are not all due to the recording system. Given the possibility of recording to an accuracy of 0.1%, (digitising the outputs of the transducers, or signals from the Electronics System), it becomes worth while to take special measures, for a few parameters, to ensure more accurate set-ups, and it also becomes worth while to use special transducers, which would not be justified when tied into a 1% recording system.

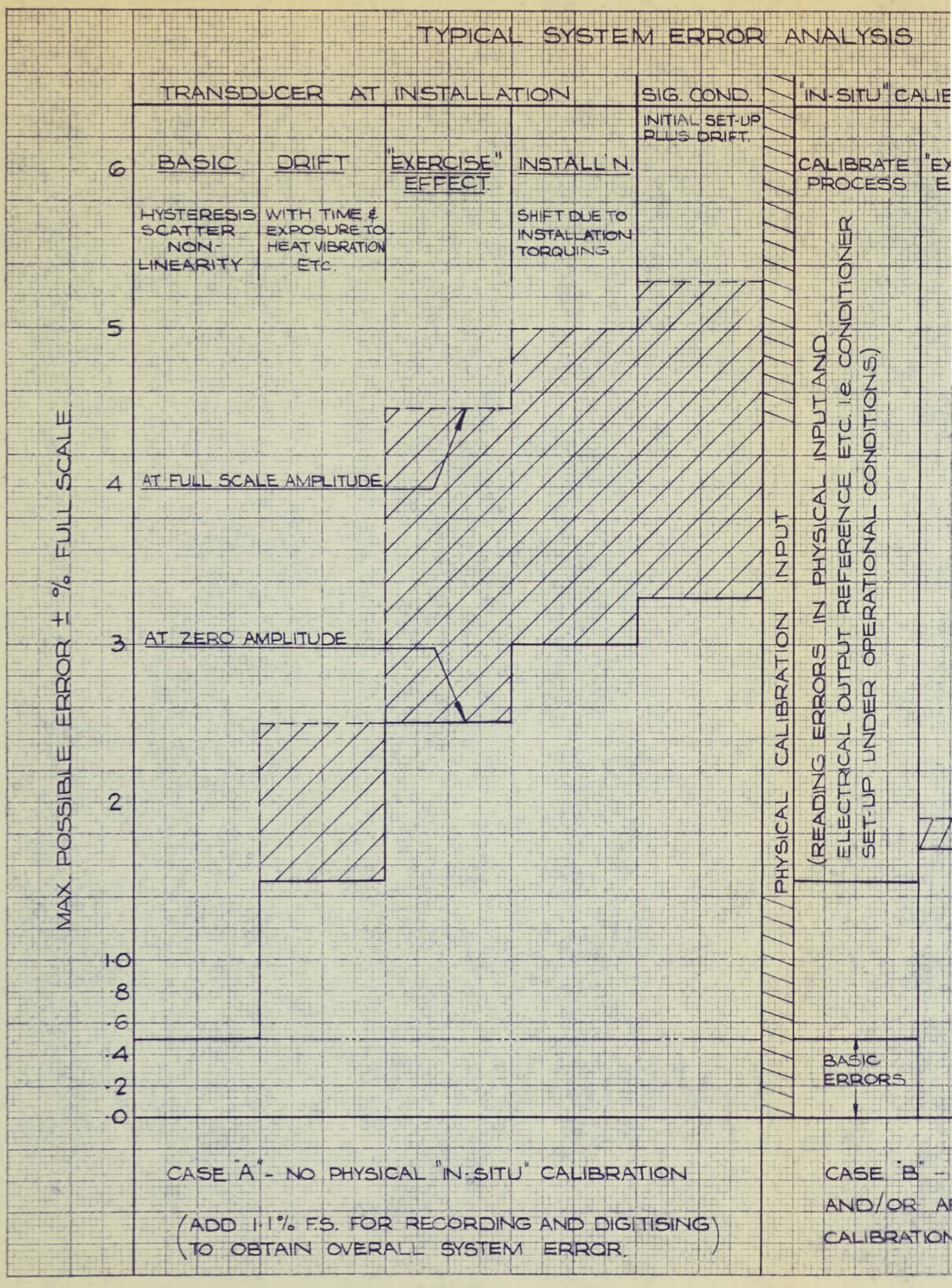
Summarising the position then, it can be said, firstly, that by the use of special transducers and the expenditure

7.2 (continued)

of a great deal more time and trouble in calibration, it would be possible to push the accuracy of the I.R.I.G. system, for certain selected quantities, to a little over 1%. (Such a claim has been made for Project Datum, after three years development work on an instrumentation investigation, per se, not on an operational flight test project). However, since the selected quantities referred to are actually required to an accuracy of ¼%, the improvement from 3% to, say 1.¼%, while commendable in itself, is probably not worth the extra effort and delay to the Flight Test Program which would be involved. The figure of ¼% is obtainable, for Air Data at least, by the use of a photo panel, but at the expense of much increased labour and time in data reduction.

Secondly, for systems testing, the 3% accuracy obtained by between-flight calibrations of the transducers is certainly acceptable, while the 6% figure is marginal. The 6% figure is, however, mostly due to poor transducer characteristics, does not apply to all transducers, and will doubtless be improved as better transducers become available. For example, the installation torquing errors referred to in 3.1.2. have already been eliminated from transducers now being received, and a check of zero levels when the aircraft systems are broken down for any purpose would eliminate part of the long term drift error. It should be noted, however, that present Flight Test Programming policy does not allow systems to be broken down solely for instrumentation calibration.

A further report will discuss the capabilities of an airborne digital system, either as a complement to, or a substitute for, the I.R.I.G. analog system.



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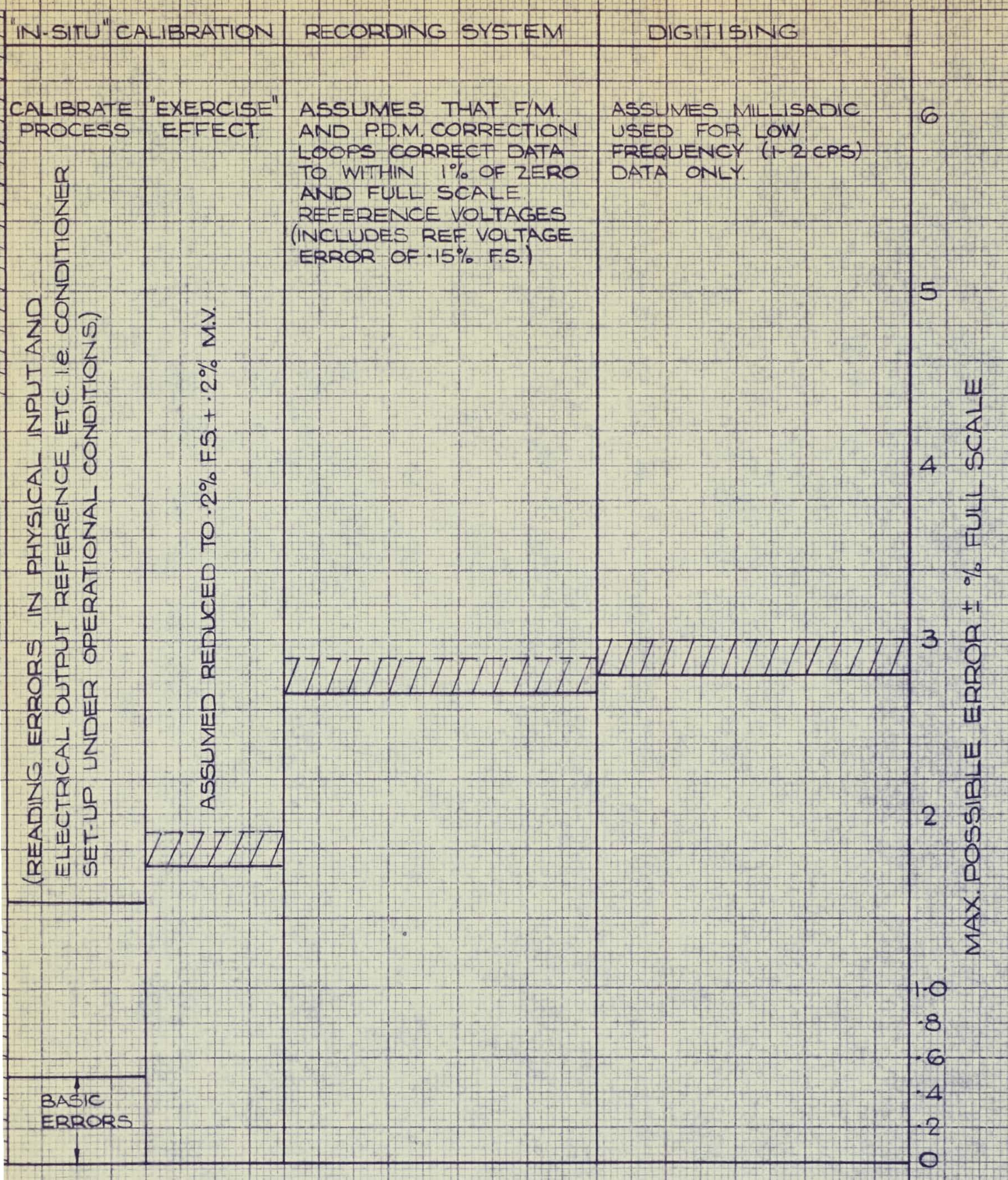
ANALYSIS — STRAIN GAUGE PRESSURE TRANSDUCERS



CASE "B" – PHYSICAL "IN-SITU" CALIBRATION BEFORE AND/OR AFTER FLIGHT – (ASSUMES NO DRIFT BETWEEN CALIBRATIONS AND MEASUREMENT.)

RPT NO RD 33 FIG 1