NEW DEVELOPMENTS IN COCKPIT HUMAN INTERFACES

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Abstract

The paper presents past and present work on the use of new interfaces between the pilot and his cockpit. In particular are considered Touch Sensing Displays, Helmet Sights and Direct Voice Input.

I. Introduction

Traditional pilot cockpit inputs have been made in the form of switches, control columns and hand controllers which push, pull and rotate, and more recently the use of push buttons which allow for much easier interaction with software controlled systems. The displays have been primarily electro mechanical, except perhaps for the head-up display and some radar displays which have been examples of CRT displays used in various cockpits for many years, but newer cockpits are showing increasing use of CRT displays for the portrayal of cockpit and sensor information. Fig 1 shows the rear seat of Tornado, in which the two CRT displays are clearly visible. This is taken from a mockup, with some of the more sensitive areas blanked out, but is an example of an aircraft which is flying quite successfully with CRTs for many of its system display functions. There still remains the basic question of how the pilot interacts with this cockpit. He can certainly see what he wants to do, but beyond this he can feel, he can touch, he can look directly at, he can talk, and he can listen, and he can certainly press things in the traditional way. Which of these are most important to the pilot? Undeniably, all! *En passant*, it is important to note that 'feel' is relevant not only in the sense of tactile displays but in the straightforward aspect that a pilot should be able to differentiate his control functions clearly by feel - a point on which I do not want to dwell as it is fairly self evident, but readily forgotten with rows of identical switches or press buttons even behind the pilot's hips. A pilot looking out of the cockpit does not want to have to look back in to check what he is doing with system controls near his left hand, they need to be instinctively differentiated by feel. However, today I want to introduce some specific areas of pilot cockpit interaction in the research stage - some of which have in fact been around for some years, but are still new as far as general application is concerned. These are touch sensing displays, helmet sights, and direct voice input.

II. Touch Sensing Displays

If a pilot can see a point in the cockpit that needs to be designated, what better way than to point at it. In this way he already presses buttons and switches, but a touch sensing display offers a new dimension to this capability. It can be looked upon as a very large and flexible keyboard, as an extremely simple designation medium, or as a means of interacting with pictorial displays in a completely new way.

Fig 2 illustrates a traditional display with multi-function keyboard. Would it not be easier to touch the legends directly on the display for effect rather than have to work out which key beneath to press? Also, given the freedom of the whole display area, can one not design a better presentation of the legends?

Used as a keyboard, the keys can be large, even large enough and sufficiently spaced for ease of pressing without errors in difficult cockpit vibration conditions; the key can have the legend clearly within it so that there is no parallax and confusion; and within modern cockpits demanding some degree of multi moding the legend can be changeable depending on the moding of the key. These factors are difficult to produce cheaply on keyboards but are all readily available on the touch sensing CRT if the CRT and its symbol generators are already available in the aircraft. The key in a keyboard should also have good tactile feel. This aspect is not so readily achievable with a touch sensing display. Ground based systems, in common with many hand calculators, can overcome this deficiency in their keyboards with audio feedback, *ie* a 'bleep' when the key is pressed sufficiently. It is not so readily apparent that there will be room on the audio channel of an aircraft for such a feature in a cockpit. Consequently good visual feedback on the display will be vital to overcome this tactile deficiency.

A basic question on the use of such touch sensing displays is the accuracy with which the pilot can designate a point on the display. For simple keyboarding, the effective area of the keys on the display can be much larger than the equivalent in a fixed array of keys elsewhere in the cockpit, and hence the accuracy need not be as good as when pressing a button. However, for designation tasks the pilot must indicate to the system that an item of interest exists at a specific point in the display and the accuracy has to be much higher than for keyboarding. In radar displays for example, two items of interest, in this case radar returns, may be close to one another and one is to be differentiated from the other in designation. Interaction with a pictorial display is, in terms of accuracy requirements, simply an extension of 'designation' in that a point in the pictorial display has to be touched to achieve a certain effect. However, in terms of system control, this offers completely new possibilities which are illustrated later.

The final accuracy achieved by the pilot in touching the displays is affected by vibration, steady manoeuvre, and the basic accuracy of the touch sensing measurement system. To take the last one first, we are in the early days of equipment development and there has been no great incentive to increase the measurement accuracy of the systems, in that the present accuracies are perfectly adequate for most ground based tasks. The systems used in our research have an active area on the display of 163 by 124 mm, and allow a resolution of 2.7 mm, that is, two presses with the finger

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2.7 mm apart will be differentiated by the system. The effect of steady g is difficult to measure other than in flight or a centrifuge and our research has not yet proceeded that far. However, plans are being laid to put our equipment into a centrifuge which will constitute an exciting further phase to our research. In flight, pilot feedback on the use of keyboards is distinctly relevant to touch sensing displays in that they favour using certain keyboards by using the fingers to support the hand at the edge of the keyboard and then to operate the keyboard with the thumb. This imposes limitations of reach from the edges, and could be more difficult with the increased area of touch sensing displays. It is premature to make judgements in this area without experimental work, and it has been noted as an area for concern and further study, and in fact some of the present experimental tasks are being undertaken with this technique.

The effect of turbulence, either in military aircraft in low altitude high speed flight or in civilian airliners in flight or landing in difficult conditions has certainly been the subject of research, partly for the simple reason that man rated vibrators with good frequency response for such human factors work have been readily available to us. Experiments have been conducted on the accuracy of designation on simple displays with the subject being vibrated. The first experiment was performed under contract at British Aerospace at Filton, and used a low level of vibration appropriate to modern military aircraft. Vibration was in the vertical axis, and a display and ejection seat was used in such a way as to approximate to a typical cockpit task. In fact two display locations were used, one at chest height ahead of the subject, and one down by the left thigh to represent two possible locations in the cockpit. The vertical vibration level used was 0.1 rms g, and this proved to have little effect on the pointing accuracy which was 3.6 mm mean radial error on both the high and low display positions. These accuracies did not include the basic accuracy of the touch sensing system, as in this early experiment the technique used was a simulation of the touch sensing system where the pilot wore a special fixture over his finger, which he dipped in ink and then marked his display relative to any instantaneously designated spot. The error was simply measured off with a ruler. In this way, the human factors data was collected uncontaminated by the vagaries of specific equipments.

More recently, we have used an actual touch sensing display on a vibration rig with two axis vibration and much higher levels of vibration, as illustrated in Figs 3 and 4. An early look at the results shows an effect of increased vibration level, here 0.3 g rms, corresponding to a rather rough ride, but they are still being analysed. So far, they are still looked upon as an encouraging view of the use of a touch sensing system in a cockpit. Most certainly, at the highest vibration level, pressing an individual key in a keyboard would also have been very difficult.

With the early success of the vibration work, and while still acknowledging the uncertainty of the effect of much lower frequency vibration and steady g, it seemed to us worthwhile to consider what one could do with a touch sensing display in a cockpit. To this extent we have sponsored work at BAe at Warton to incorporate such a device in a cockpit to evaluate its role in a typical low level military mission. Formats have been drawn up to explore simple keyboarding, system switching, data entry into the navigation communication and IFF systems, and the interaction with pictorial displays. Fig 5 illustrates the data input panel for navigation update where the use with touch sensing is self evident. Of course, as some of the mode systems are pressed, they change to other legends related to the navigation function. Pictorial displays are very powerful descriptors of system state and function, and in Fig 6 is illustrated the use of a pictorial display with a fuel system: pressing any particular valve (twice for safety) causes that valve to change state, to open or close depending on its previous state. This work is in progress at present and only preliminary evaluations have been undertaken in the course of format development. However, even with these early formats very favourable initial comments have been received from the pilots. It should also be added that engineers have expressed considerable interest in touch sensing displays from the point of view of improved packaging of displays and keyboards in the congested prime area of the cockpit.

III. Helmet Sight

Instead of pointing at an item of interest, a pilot can simply look at it, more especially if it is outside the cockpit, and this leads to the concept of a helmet sight. In fact, helmet sights as we now know them have been around for some years. They simply measure the angular coordinates of the pilot's helmet relative to the cockpit. This is not necessarily where his eyes are looking, and the pilot has to move his head rather than simply move his eyes. With his head movement he overlays a reticle which is projected in front of his eyes on the item of interest, and the sensing elements on the helmet then determine the angles of the helmet relative to the cockpit. The sensing elements and the reticle are harmonised, and movements of the pilot's head within the helmet do not affect the accuracy of the system, they simply determine whether he can see the reticle or not.

We have used both helmet sights, and also helmet displays with CRTs on the helmet, extensively in research, and illustrated in Figs 7 and 8 are some old equipment which we borrowed from the US many years ago and which is still doing stalwart service in our research. Newer designs look better, are lighter and offer certain improvements, but no improvements which markedly affect our human factors research. It is important to realise that the simple reticles of the traditional helmet sight, Fig 7, bear little relationship to the bulk or electrical power of CRTs on the helmet, Fig 8. These CRT displays have applications, and problems, all of their own, and they are not the subject of the present paper: they are merely introduced to emphasise the difference between them and the helmet sight.

All the position sensing designs now available, and there are a number on the market, are characterised by offering at least hemispherical coverage and some nearly spherical coverage. The system accuracies are very dependent on the installation and their particular use, but in general one can think of the order $\frac{1}{2}^{\circ}$ CEP over the forward hemisphere.

Over and above this basic aiming accuracy of the helmet sight, the pilot has a problem in keeping his head still while aiming, especially in turbulent flight conditions. Some of this head motion can be filtered, but as the main amplitude of this head angular motion is at fairly low frequency itself, less than 4 Hz, really effective filters cannot be introduced without introducing long time delays into the output. Tests on the vibration rig at RAE, aided by BAe (Filton), gave the relationships between head movements and g level in the laboratory, and later in flight, found in Fig 9a&b. The graphs show the very large head movements which are obtained at the higher vibration levels, but it must be pointed out that those levels constituted a very rough ride and are not met in modern military aircraft, certainly not while at the same time trying to achieve any head aiming tasks. The relationship between the flight data and the laboratory data is interesting in that the anomalous behaviour of aiming under flight conditions C2 relates to angular movements of the aircraft used, a motion which could not be incorporated in the laboratory vibration environment. In flight, the helmet sights were used to point a narrow field of view sensor, such as might be used for air to sea search and rescue. The filters used resulted in sensor movements being about half the head movements, and in fact some pointing angles measured for the sensors used in the flight trials are illustrated in Fig 10 and show the order of aiming accuracy which was achieved. The circles in the figure represent the CEP of the sensor pointing errors measured during a single aiming sequence of about 10 seconds during flight. The larger circles represent the rougher rides in the aircraft.

In addition to the head angle sensors, a helmet sight usually constitutes a simple reticle, a cross or a circle simply for aiming the helmet. This has also included some small amount of information in the form of discrete cueing lights. This simple concept is readily extended by replacing the cueing lights with alpha numeric symbols, generated by LEDs, but there is a strong limit to this in that each symbol of a 7-segment font requires 7 leads, and, despite possible reductions on this in specific layouts, there is a marked limit to the number of leads which can go up a connection to the pilot's helmet. An upper limit to the display of information would be the helmet mounted CRT display referred to earlier, but they are still too heavy and awkward to use in military aircraft with ejection seats, and I personally can hardly see them being accepted in the average civil airliner. An interesting intermediate stage is that of the LED matrix display: this allows more information to be displayed than a simple reticle but not as much as a CRT display. It is simply an array of LEDs which can display any symbology which can be defined as a collection of dots. This display is driven by digital addressing with small decoding and drive circuitry actually on the helmet, so that the number of leads to the helmet is minimised. We have used such a device in research, with 32 × 32 LED elements and hybrid circuitry on the helmet. It is expected that the drive circuitry can be miniaturised with LSI electronics to make, with the LED array, a very compact optical unit to be mounted over the brow of the pilot. Fig 11 illustrates the type of information which can be portrayed, and Fig 12 illustrates an installation based on hybrid electronic circuits on an RAF helmet, as is being used in our present research. Such a unit allows information to be available to the pilot wherever he may be looking. Hence, we now have a complete combination of an aiming system that can tell the aircraft where the pilot is aiming his head, and display essential information to him without his having to look back into the cockpit. Such a system has been evaluated in simulators with favourable comment from the pilots. The work has now been extended to take the display into flight, and we look forward to the subsequent conclusions.

IV. Direct Voice Input

The helmet sight with the added LED matrix display allows the pilot to communicate directly to the aircraft and also to receive from the aircraft a certain amount of information no matter where he is looking. However, both his hands may be full. It would be very convenient to keep looking at the outside world, not to have to change his hand positions, but simply to instruct the aircraft systems to change or to input data simply by talking to them. The aircraft could be instructed verbally to change destination to a set of new coordinates recently radioed to the pilot, and so on. This is Direct Voice Input (DVI) using Automatic Speech Recognition (ASR). DVI has long been the goal for a wide variety of commercial applications; however, in the airborne role progress has been much more cautious for a number of reasons, not least the point I will return to later of establishing a clear role for it.

In an airborne environment, more particularly a military environment, the additional factors affecting DVI performance are: electronic noise on the intercom, the effect of the oxygen mask and the closeness of the microphone to the mouth affecting speech, changes in voice with high g manoeuvres and pressure breathing or any other form of stress. Because of the early state of airborne application no equipment exists yet which could be flown in high manoeuvre military aircraft. However, the potential limitations of DVI have been explored by recording test tapes from pilots in a variety of aircraft situations, from low altitude high speed flight to low levels of manoeuvre (4-5 g) from flight in Hunter and Phantom aircraft. These tapes are being replayed through equipment on the ground, and the experiences suggest that while breath noise and oxygen masks are limiting factors, it is likely that these limits can be overcome. The change of voice with increase in g and the effect of pressure breathing on the human voice are rather fundamental to the present state of the art, and will take substantially longer to overcome. In this research, two speech recognition equipments are being used for research, as illustrated in Fig 13. The first, the upper equipment, requires that words be enunciated discretely, a requirement not wholly alien to our pilots, and the second, the lower equipment, allows for connected speech.

DVI works on sampling voice patterns at something like 20 millisecond intervals. Fig 14 illustrates the output of a microphone at the enunciation of the numeral 'one'. Such an output is Fourier analysed to give a distribution of frequencies and amplitude, as illustrated for the same numeral in Fig 15. The energy in the sample can be normalised to take account of the loudness of the speech, but as yet the frequencies are not normalised. Words are recognised by pattern matching the distributions of energy obtained across the frequencies and across the 20 millisecond sampling rate. It is immediately obvious that each operator has to calibrate himself to ensure that his pattern of energy in the frequency space defines precisely the words that he had in mind. Thus, calibration is essential as people do speak and pronounce words in different ways. It is also obvious that changes to voice due to the oxygen mask, or stress, high g or pressure breathing will result in this calibration in a non-stressed situation being inapplicable. Research continues on the more basic aspects of speech recognition to try to make the recognition algorithms less operator voice dependent, but in practice our main interest at present is to try and establish if the technique really has a role to play in a cockpit.

In terms of applying the techniques to a cockpit, the first question which usually arises is the size of vocabulary which DVI can handle. This has, surprisingly perhaps, not caused us a great deal of concern in that we envisage DVI as operating within a tightly structured, branching, command and data input system. In such a system, at any given level in any branching structure the number of words which have to be differentiated by DVI will be limited much more by the pilot's ability to remember and handle the number of alternatives at each level. We do not know this limit, and it will certainly interact with the display used for visual feedback, but one can guess of the order of no more than seven alternatives as being usable at any particular level. To differentiate between these seven is easily catered for by DVI unless one chooses words that are confusable. Consequently, the scale of the overall structure is limited primarily by memory size, processing time and the pilot's comprehension. Two exceptions to this limit of 7 are the numerals 0 to 9, and any data input requiring alphabetical input from A to Z. The former is a common requirement, and has been used in most testing as being a severe test of DVI recognition in that one cannot avoid 10 alternatives and much similarity occurs in the enunciations of certain numbers. The 27 possibilities from A to Z have not been tackled in any of our research programmes to date, and in terms of our research systems applications are avoided until further research has established the limitations. Using the phonetic alphabet will certainly help to differentiate these letters.

In the search for a role for DVI a useful initial experiment has been conducted at RAE to compare the concept of DVI numerical data input with keyboard entry when the pilot also has a primary flying task. In fact, the experiment was fairly rudimentary with the flying task being simulated on CRT displays as a flight director following task and without any cockpit motions. On the DVI side, in order to explore the human factors of the task unconfused with the imperfections of DVI, no actual DVI equipment was used. The voice records from the subject were analysed by the experimenters for accuracy and time responses. In the event the results were quite illuminating. Fig 16 shows the results from the experiments for the number of mistakes of data entry with DVI and the flying quality, (as an angular deviation of the display from director symbol while data entry was in progress). It is seen that DVI resulted in many fewer input errors than the keyboard, and also is much quicker. On the flying side, the flying quality was much better with DVI, undoubtedly a reflection of the fact that the DVI input was much quicker.

This experiment has led us to consider it worthwhile to continue the evaluation of Direct Voice Input in the cockpit, and plans are being laid to incorporate DVI into the cockpit task earlier presented in the evaluation of touch sensing displays. The moding and data input in that cockpit parallels exactly potential inputs from a touch sensing display, into any of the main systems of navigation communications, etc, *eg* as in Figs 5 and 6. The evaluation will still not include any elements of stress, but the degree of completeness of the cockpit and flying task will result in an important next stage in this work. Meanwhile, plans are also being laid at RAE to explore facets of DVI in a cockpit in more controlled experimental circumstances in a longer term programme.

V. Conclusion

In conclusion to this paper, I would simply like to recap on the way in which touch sensing displays, helmet sights, and Direct Voice Input offer exciting new prospects for a pilot to interact with his aircraft systems. While improvements in hand controllers and keyboards, research in which we are also interested, may offer improvements in cockpits, there is nothing like simply pointing at something to designate it, looking at it with a helmet sight if it is outside the cockpit, and telling the aircraft directly what is wanted. Only continuing research, coupled with overall systems requirements, will determine which, if not all, of them will find their way into future aircraft.

Acknowledgments

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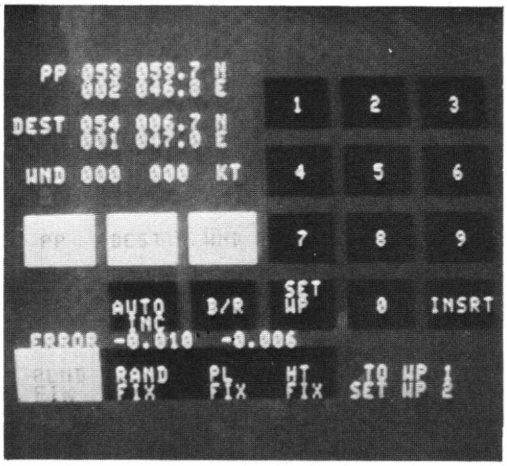


Fig 5 Nav display for touch sensing evaluation

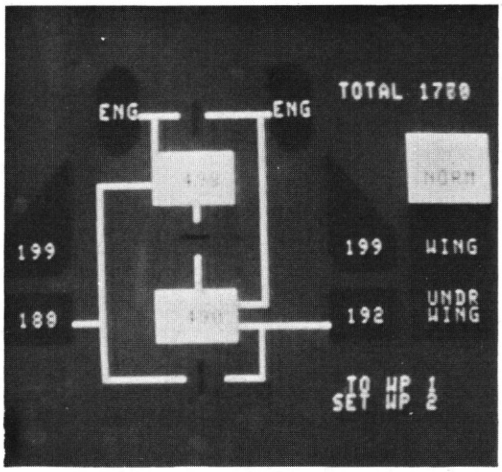


Fig 6 Pictorial display (fuel) for touch sensing evaluation

Fig 7 Early helmet sight

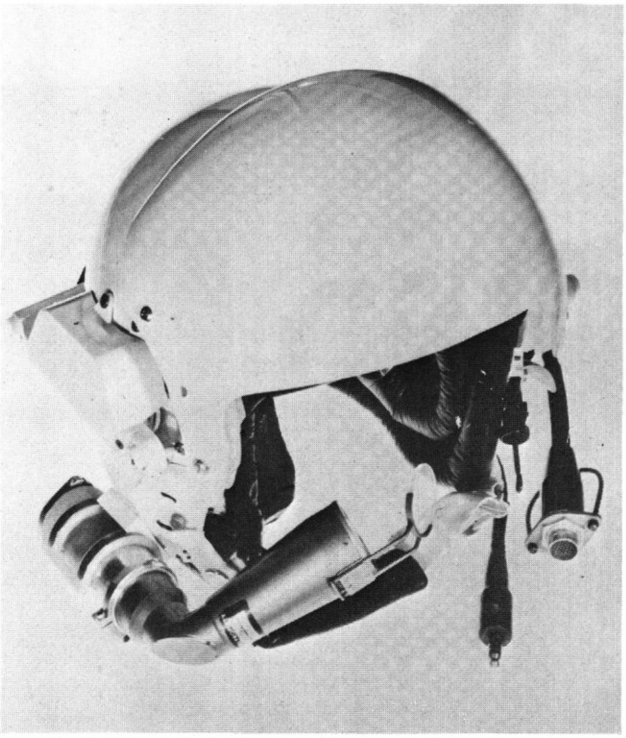


Fig 8 Early helmet mounted CRT display

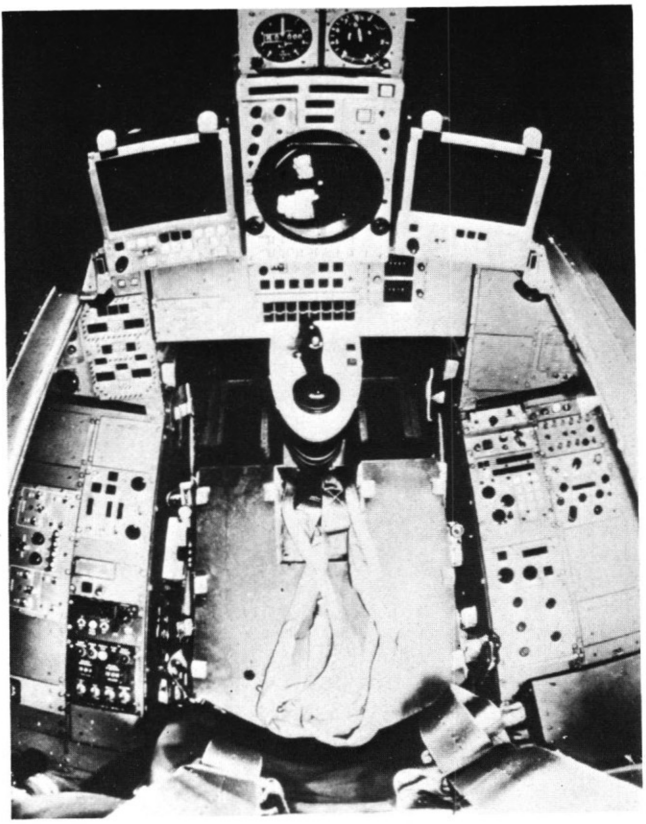


Fig 1 Mock-up of Tornado rear seat showing TV displays

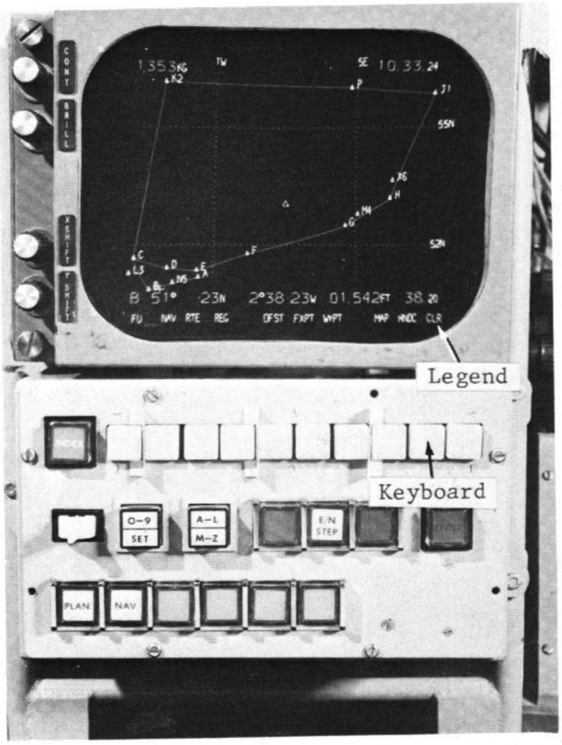


Fig 2 Conventional display with MFK

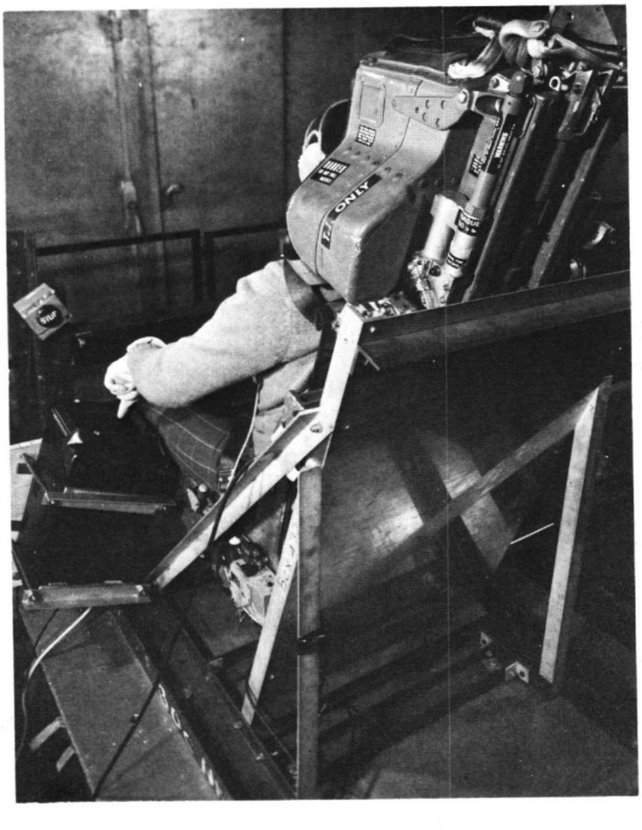


Fig 3 Touch sensing display in a vibration rig

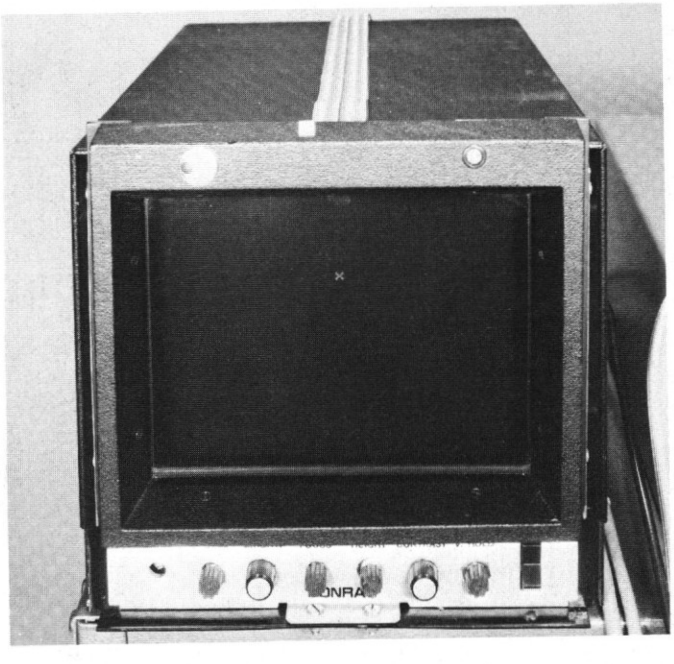
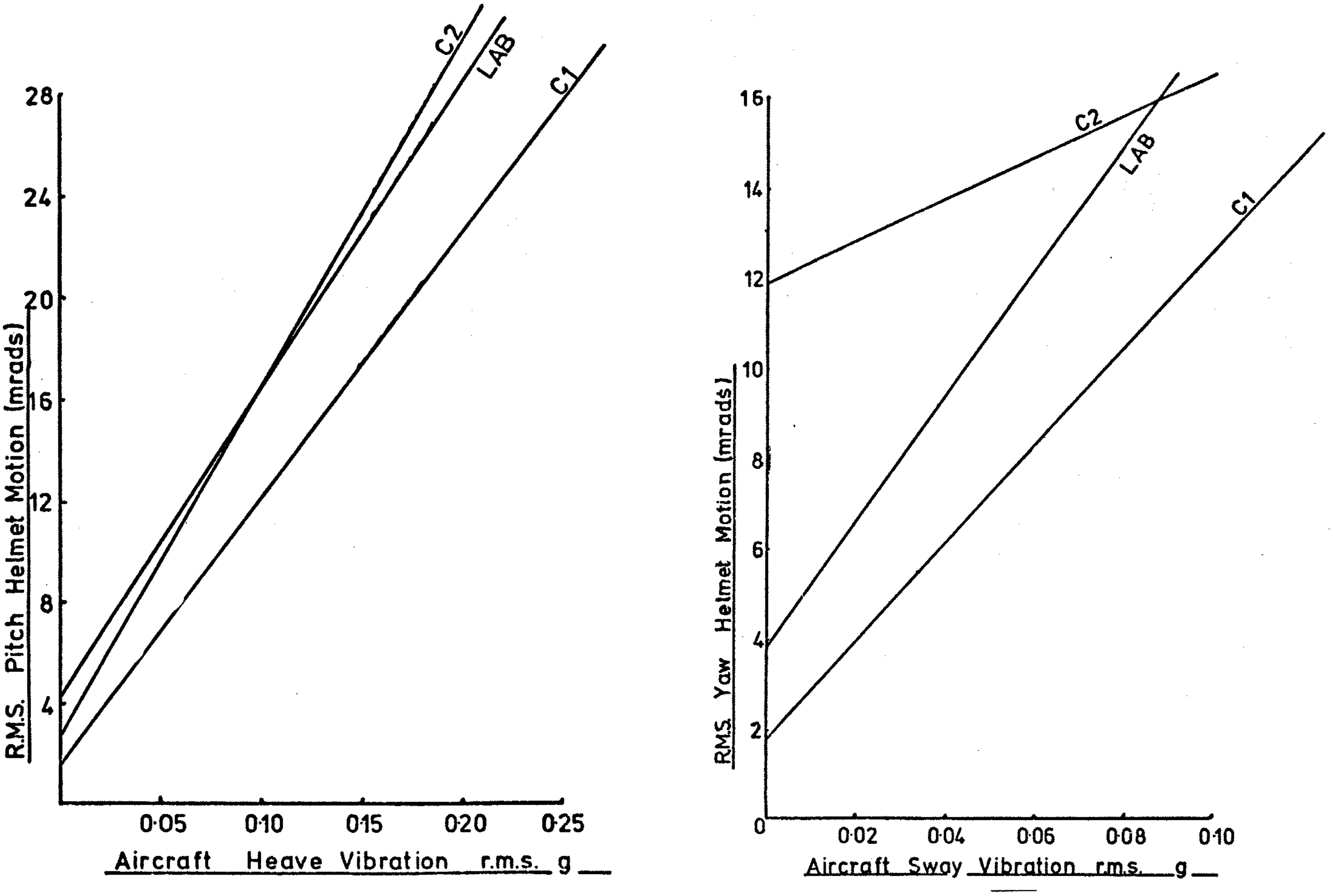


Fig 4 Touch accuracy task in the vibration rig



a

b

Fig 9 Head movements under vibration

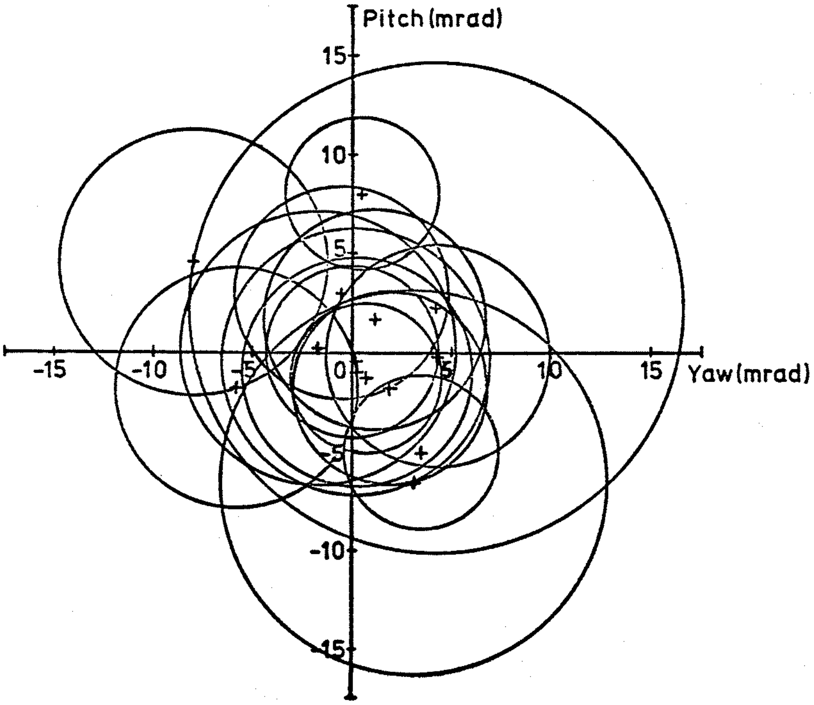
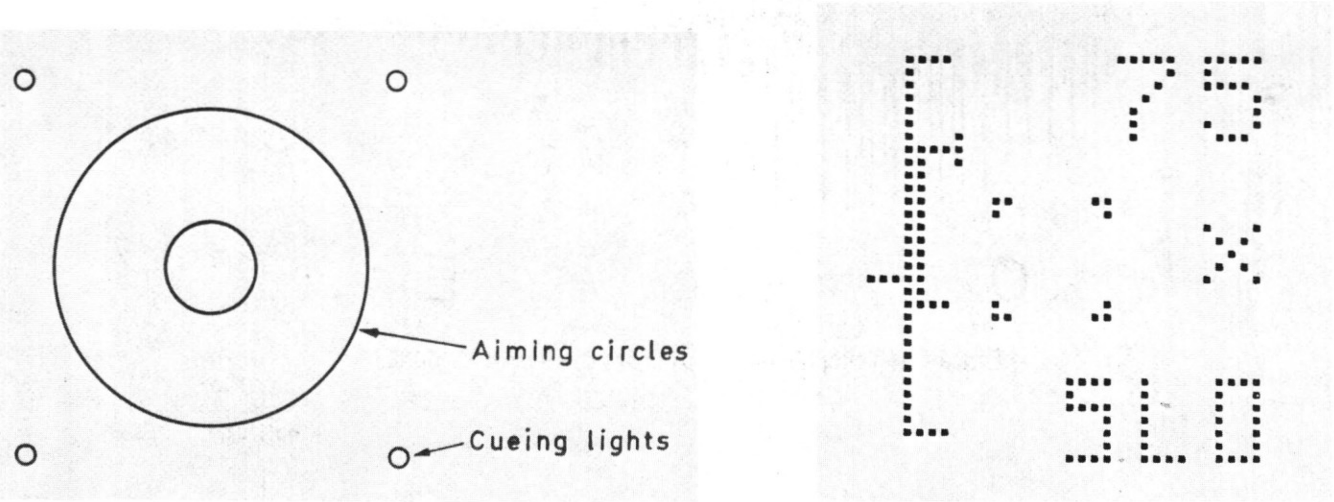


Fig 10 Sensor aiming errors with HMS



(a) Simple HMS aiming display

(b) LED matrix display

Fig 11 Helmet sight reticles and displays

Fig 12 Experimental LED matrix reticle on RAF helmet

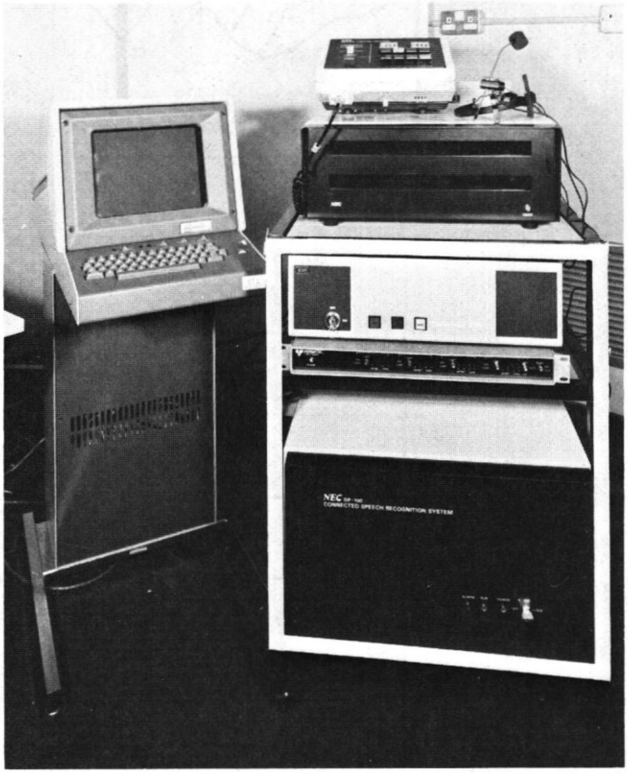


Fig 13 DVI equipment used in RAE research

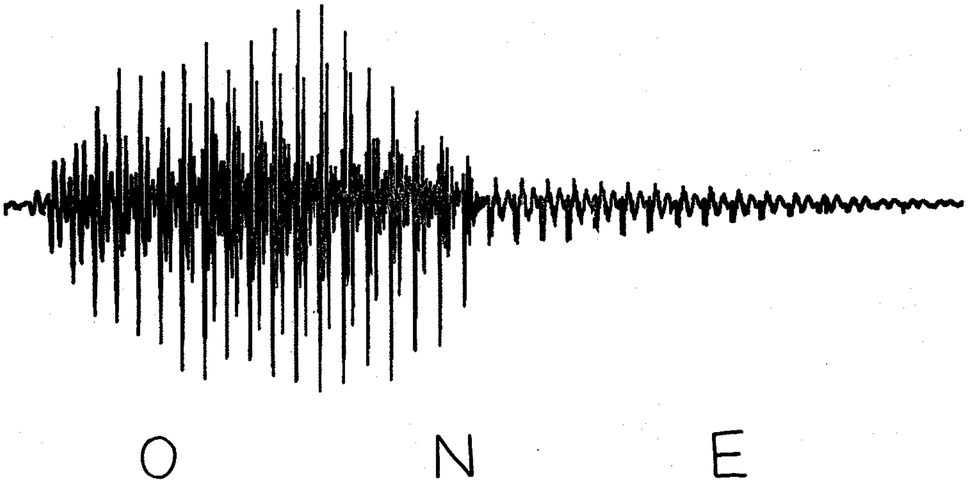


Fig 14 Microphone output for the numeral 'ONE'

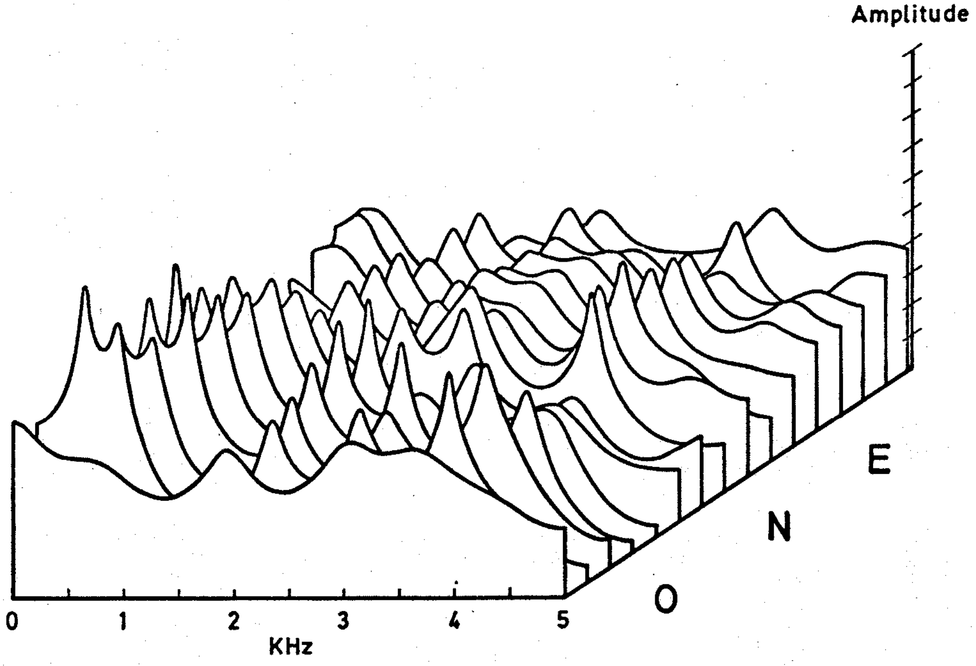


Fig 15 Frequency analysis of the record in Fig 14

Data entry				Flying errors†		
MFK		DVI		MFK	DVI	Flying only
Errors	Time*	Errors	Time*	Mean rms error		
23.9%	3.19 (0.62)	3.9%	1.86 (0.34)	80.34	66.89	61.6

* Time - seconds (sd)

† Flying errors - arbitrary units

Fig 16 Data from DVI/keyboard comparison