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ROYAL AEROSPACE ESTABLISHMENT

Technical Memorandum

June 1990

RAE Bedford's Experience of Using Direct Voice Input (DVI) in the Cockpit

by

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Procurement Executive, Ministry of Defence
Bedford

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RAE BEDFORD'S EXPERIENCE OF USING DIRECT VOICE INPUT (DVI) IN THE COCKPIT

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N. Cooke

SUMMARY

This Technical Memorandum presents the RAE Bedford's past and present work on the use of Direct Voice Input (DVI) in the cockpit.

The content of this Technical Memorandum was presented during the Military Applications session of the Voice Systems Worldwide Conference, London, May 1990.

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1 INTRODUCTION

This Memorandum describes research on the use of automatic speech recognition in the cockpit of an aircraft. Such applications are commonly referred to as Direct Voice Input or simply DVI. The research used a BAC 1-11 aircraft and was concerned with the civil flight deck. The Memorandum aims to draw out the lessons learned and refer them to military operations. Trials currently underway using a Tornado GR1 are also described. This military programme is planned to build directly on the experience gained using the BAC 1-11.

2 BACKGROUND

In late 1981, the RAE embarked upon a flight research programme to investigate the potential benefits of using DVI on the civil flight deck. The trials aircraft was the BAC 1-11 shown in Fig 1. The role of this aircraft was to provide a flying laboratory for civil avionics research. Various trials were conducted at the time, covering such research as improved navigation techniques, the use of electronic cockpit displays, enhanced Flight Management Systems (FMS) and research on non-linear energy based control laws[1]. The advent of such new technology has had a significant effect on the pilot's role. The days of flying with hands permanently on the control column have become a thing of the past. The pilot has become much more of a systems manager. Hands are now increasingly required for button selection on a variety of onboard data entry keyboards. The majority of these keyboards are far from ideal due to the constraints of available space in suitable locations and the complexity of the task for which they are required. As a result, control functions can take excessive time due to a combination of keying errors and protracted procedures. Such operations generally require the full visual attention of the pilot. Keeping a good look out is affected as a result, as is the ability to monitor other cockpit display surfaces.

Many avenues could have been explored in improving the cockpit management procedures, such as better designed and positioned keyboards, or the use of joysticks, rollerballs and touch sensitive screens. All of these would have required significant cockpit re-design; DVI would have little impact on the cockpit real estate, although some of the systems implications would be profound. The location of the Automatic Speech Recogniser (ASR) is unimportant. The microphone requirements are similar to those of communications. The main additional requirements are a switch to engage DVI and a display to present the output of the recogniser.

DVI, untried before in a cockpit environment, appeared to offer three main advantages, namely convenience, speed and freedom. It is obviously more convenient and faster for humans to communicate by speaking to each other, this method of communication allowing the hands or eyes freedom to conduct other tasks at the same time. The problems of DVI were likely to be recognition performance and restrictions on vocabulary imposed by the equipment. The purpose of the flight trials onboard the BAC 1-11 was to test whether the advantages could be realised in flight conditions, whether the advantages outweighed the disadvantages, what recognition performance was required for operational use and to establish guidelines for system integration.

3 THE BAC 1-11 TRIAL

The prime requirement for this trial to commence was an ASR. In late 1981 no suitable UK device existed and an American Threshold T-500 isolated word recogniser was used to gain experience.

Initially, the main interest was to characterise recognition performance in the airborne environment. At that time, no performance figures for recognition during flight existed. Nor, indeed, did any standard test. Thus, a test procedure had to be devised. It is worth remembering that recognition results obtained from any ASR will depend on various parameters. The size of the active vocabulary, how similar words sound in the vocabulary, the level of background noise which could affect the input signal or change the way the speaker talks are examples[2]. Recognition performance will also depend on the user, DVI being ideal for consistent speakers but less so for others.

The initial test vocabulary consisted of the ICAO phonetic alphabet, alpha to zulu and the digits one to twenty-six. This test vocabulary was intended to consist of words which would be easily understood by humans over a radio link as well as words that could be confused, such as five and nine. Prior to the test commencing, each user trained the recogniser following the procedure laid down by the manufacturer. This involved saying each word ten times. An average utterance from these ten samples was then calculated by the recogniser. The duration of this training session was found by all users to be too long. There was a danger that the later samples would be unrepresentative due to boredom, resulting in poor templates. In conclusion, training or enrolment sessions must be fairly short; reading a short passage of speech or saying one sample of each word would be preferable.

During the test, conducted in the quiet of the laboratory and then in the BAC 1-11 during flight, the user would say each allowable word in isolation, following the order of Alpha, Bravo, Charlie etc. This was repeated twenty times, giving 1040 utterances for a test. Percentage errors were then calculated and a confusion matrix was produced to illustrate the pattern of the errors.

Many results could be presented for the various speakers undertaking these tests. For convenience, a brief summary is given in Table 1, indicating that the performance obtained during flight was unacceptable and much worse than in the laboratory. The main difference between laboratory and flight tests was that the background noise level was much greater in flight; typical noise levels in the aircraft are given in Table 2. Although the Threshold T-500 provided a useful benchmark for other recognisers, its performance was inadequate for use in the cockpit. This preliminary trial also showed that isolated word recognition was completely unsuitable for inputting strings of data such as radio frequencies and latitudes and longitudes. The aircrew found isolated recognition to be slow, unnatural, irritating and distracting.

Before integration with the avionics could take place, the ASR required background noise compensation, and a connected word capability. The Marconi SR 128 was developed to meet these requirements and is illustrated in Fig 2. Although the SR 128 required the user to update the background noise mask manually, the very fact that some form of compensation had been implemented was a move in the right direction. Additionally, a larger vocabulary of 240 words or phrases was provided and the training routine only required one sample per utterance. A programmable syntax enabled the vocabulary to be structured such that only relevant words were considered in the recognition processing; this not only maximised the recognition performance, it also reduced the time taken for recognition. The SR 128 was delivered to RAE in early 1982.

The same tests as previously described were conducted. A summary of these are shown in Table 3. The results were very encouraging, certainly adequate to attempt some system integration. The programme of system integration was defined in three phases:

Phase 1 - Integrate DVI with the onboard electronic displays.

Phase 2 - If the pilot opinion was favourable towards DVI, integrate it with a Radio and navigation Management System (RMS).

Phase 3 - Control the route change procedures and other flight conditions, such as speed and height, by DVI through the FMS.

4 BAC 1-11 TRIAL PHASE 1

The port side of the BAC 1-11 cockpit had been converted to electronic colour displays, as shown in Fig 3. Each display could show not only the primary information but also a simple electronic map representing the aircraft position in plan or elevation along its pre-programmed route. Prior to using DVI, the pilot's control of this map was restricted to switches on the coaming and centre pedestal. The map was generated by a programme residing in a General Purpose digital Computer (GPC). Although the task of changing formats or selecting information was not causing any significant workload, this initial phase could answer the question, "Do you like using DVI?" Also, the act of coupling the SR 128 to the GPC enabled some of the basic issues of integrating DVI into the cockpit to be addressed.

On recognition of a word or phrase, the SR 128 would output the code for the word or phrase chosen, the text of that word or phrase and the score of the match with the corresponding training template. Two methods of integration were therefore considered:

(1) Modify the programme in the GPC to take account of the serial data sent by the ASR or

(2) introduce some downstream processing between the ASR and the GPC. This inhouse microprocessor based system would emulate the discrete signals which defined the configuration of the electronic map, normally sent to the GPC directly. The programme within the GPC could therefore remain unchanged.

As further integration with other avionics was considered, method (2) was chosen because it offered greater flexibility. The general layout of the DVI system onboard the BAC 1-11 is shown in Fig 4. This working system was demonstrated at the SBAC Air Show during September 1982.

The vocabulary required for control of the Electronic Map was 36 words, well within the 240 word capability of the SR 128. A few of these words and the resulting actions are indicated below:

"NORTH-UP" - selects map to North-up orientation.

"NAVAIDS" - displays the navaids in the coverage of the selected map scale.

"THREE-HUNDRED" - selects the 300 nautical mile scale.

"LOOK-AHEAD" - looks ahead to the end of the pre-programmed flight plan.

"STEP-BACK" - steps back progressively from the destination airfield until "STOP" is said.

Isolated commands were generally used in this phase and the effect of connected speech recognition was not explored. However, a number of important lessons were learnt from this initial use of DVI. These have been listed below.

(1) Some form of recognition feedback is required by the user. Originally the only feedback available to the pilot was the state of the electronic display. If a command was given and the display did not change, the pilot had no idea if the problem was speech recognition or in the downstream processing. So that he could resolve this, a small LCD display showing the ASR output was placed in front of the pilot on the coaming. This feedback could be even more essential for flight critical tasks, such as weapons management in the military aircraft. Audio feedback was considered, but in response to pilot opinion, was never installed. It was felt that there was already a surfeit of audio activity on the flight deck without adding to the problem. This situation differs from the military cockpit where there is a need for head-out/hands busy operation. This need, coupled to radio silence or minimised radio communication, makes audio feedback a potentially valuable option. One merit of a visual display over audio feedback is that the message remains available over a period of time and the pilot can decide when to read it.

(2) The use of a press and hold switch was found to be best for engaging the speech recogniser since the pilots were already familiar with this concept. The use of keywords, to alert the ASR that a DVI command was about to be given, was disliked. The use of a keyword takes longer than using a switch and requires the pilot to remember to use a further keyword to disengage the system.

(3) Commands should be concise but, within this constraint, should correspond as closely as possible to the natural language of the cockpit. For example, it is undesirable to issue the following instruction via the ASR:

"WOULD YOU MIND TUNING VHF RADIO THREE TO ONE THREE OH POINT SEVEN".
Much better would be:
"BOX THREE ONE THREE ZERO DECIMAL SEVEN ENTER".

Occasionally, words that are in normal aircrew usage might cause recognition problems, such as "FIX" and "SIX" which are mutually confusable. The use of syntax can sometimes resolve such confusions. For example, the word "FIX" might not be required at the same branch in the syntax as the digits. As a last resort, a word might require changing. For example, change the word "FIX" to "PLOT". The use of familiar vocabulary will reduce the memory load on the pilot.

The recognition results for two of the pilots using DVI to control the electronic map are shown in Table 4. The overall feeling was that DVI provided a useful additional method of controlling a system. All pilots were in favour of extending the use of DVI to the RMS.

5 BAC 1-11 TRIAL PHASE 2

During the early part of 1983, an experimental RMS was installed into the cockpit of the BAC 1-11. The two principal aims of this device were (a) to reduce the space required by the conventional controllers and (b) to ease the tuning of radio and navigation aids. The interface between the pilot and the radio/navaid fit was the Integrated Control and Display Unit (ICDU) shown in Fig 5. By use of the CRT and its associated keyboard, the user could control the state of 10 transmitter/receivers, as well as selecting the various check-lists during the flight.

The unit saves space in the already crowded cockpit but all pilots commented that the ICDU was more difficult to use than the dedicated controllers. The pilot now had to remember the correct button sequence to select the required page, before data entry commenced. DVI was used to replace long sequence by explicit instructions.

At the rear of the ICDU there was a remote keyboard port available. By a process of 'pin-shorting', each key push could be emulated. (At a later date, a serial interface was added to the ICDU allowing the ASR to interface with the ICDU directly). The downstream processing between the ASR and the ICDU was programmed to emulate these 'pin-shorts' when a word was received from the ASR. The pilot now simply asked for the correct page and this was found directly. A typical command would be "BOX 3 130 DECIMAL 7 ENTER"; regardless of the current page, VHF radio 3 range was selected directly. The frequency line was automatically chosen, and the frequency of 130.7 MHz was inserted. If recognition was correct, the pilot would then activate this frequency by saying "ENTER".

Various points arise from this example; the pilots used the word "BOX" instead of Radio, the former being an example of conventional usage on the flight deck. The pilots preferred to say the digits as in normal conversation, FIVE not FIFE. The word "ENTER" acted as the executive word, indicating that the frequency string was complete and a retune was required. Another method of carrying out this could have been to use the state of the DVI activation switch; on release of the switch, it could be assumed that the command was complete and tuning was required. Generally, this assumption would be correct but a degree of caution is always required. Pilots commented that having to say "ENTER" was acceptable and gave them the confidence of being in control.

The integration of DVI with the ICDU was seen to be highly beneficial; the system was not only a 'space saver' but also easier to use. The number of button selections that could be saved by using DVI is demonstrated by the following example: "ILS PAIR 108 DECIMAL 3 ENTER". The tuning of both Instrument Landing System (ILS) receivers can take a minimum of 16 button selections, even with the simple keyboard of the ICDU. By saying "PAIR", both receivers are tuned simultaneously.

These are examples of the many features available and a full description can be found in Ref 3. One feature that is worth describing here is the tuning of radios and navaids by name. DVI affords a method which would be impracticable to achieve by any other means. "BOX 2 BEDFORD TOWER", "VOR DAVENTRY" and "SQUAWK RADIO FAILURE" serve as examples of typical commands that were used in the Phase 2 programme.

The size of vocabulary required to control the electronic colour displays and the RMS had increased to 106 words. The recognition performance with all of these words active was found to be unacceptable, so a syntax was programmed to reduce the size of the active vocabularies. (Note: - The vocabulary used for the electronic colour display in Phase 1 did not use syntax). A number of points arose from the use of syntax and are itemised below:

(1) Segmenting the vocabulary into the respective areas, in this case display and RMS, improves recognition significantly.

(2) Pilots did not like saying the keywords, display or comms before the main part of the command commenced. If keywords are to be used, they must be part of the normal command.

(3) The syntax must be as transparent as possible to the user. If the user has to remember the exact way of saying the command, just to follow some unnatural syntax, the convenience of DVI can soon disappear.

(4) The user should be able to exit from the syntax at any point by using a special word. This is vital if an incorrect syntax branch is entered. In the case of the BAC 1-11 the word used was "RESTART".

(5) Syntax can greatly aid connected digit recognition, especially when frequency entry is considered. If "BOX 3" is said, this indicates that a VHF frequency will follow; the first digit will therefore be ONE, and the second digit will be ONE, TWO or THREE.

The general feeling of all pilots using DVI to control the RMS was favourable. It was becoming more apparent that some pilots obtained better recognition than others. The range of word error rates covered 1% to 4%. The pilot who obtained 4% considered his performance to be unacceptable. However, he believed that DVI was a technique that should be pursued, since DVI would offer benefits to other users. (It was later shown that an ASR with some form of Automatic Gain Control (AGC) on the speech input reduced this particular pilot's error rate dramatically).

The choice of error correction strategies is a function of recognition performance and the application. Methods investigated as part of the Phase 2 programme were as follows:

(1) Say a special word to indicate that an ASR or user error had taken place; in the case of the BAC 1-11 the word "CANCEL" was used. After this repeat the complete digit string.

(2) Say a special word or phrase to indicate where the error had occurred in the string. This might be the phrase "BACK 3" which would have a similar action as pressing, 3 times, a left cursor control key on a conventional VDU. The digit was then corrected when it was highlighted.

(3) Use a combination of method (1) and (2).

Each method has advantages depending on the digit string length and where the error has occurred. However, the pilots were unanimous in their preference for method (1). They felt that repeating whole digit strings was most typical of human behaviour. A telephone number incorrectly heard comes to mind. This may not be the case in military applications where longer strings and poorer recognition may dictate the need for a segmented approach.

6 BAC 1-11 TRIAL PHASE 3

The final phase of the BAC 1-11 trial was to be the most convincing use of DVI. The number of button selections required for route changing through the onboard FMS had always been a source of pilot criticism. DVI could be seen to assist in this problem along with such devices as a joystick and a rollerball. An example of the comparison between button selection and the use of DVI is given in Fig 6. In this example, the pilot has been given a route instruction by ATC to fly direct from the present aircraft position to a waypoint, identified as COR. In this instance, COR is not part of the database of known waypoints held in the FMS memory. The sequence of button selections is self explanatory. A point worth noting is the number of button selections required for the waypoint identifier alone; a case where multi-function keys can save space but can also result in a large number of button selections being required. For this application DVI was found to be twice as fast and to be less frustrating for the pilot to use.

Whilst the voice command was being given, feedback was presented in three forms. Along with the normal recognition feedback display mounted on the coaming, the pilots received feedback from the FMS Control and Display Unit (CDU) and the electronic map. The electronic map showed the route change requested, known as the secondary route, in a different colour as the command was being given. If the pilot described the latitude or longitude incorrectly, the secondary route could indicate gross errors pictorally. This error would not be as obvious if purely represented by a digit string on the FMS CDU. Once the route change request had been completed, the pilot would then say "EXECUTE"; the secondary route then became the primary route followed by the aircraft. The change of direction of the aircraft could be regarded as a fourth form of feedback.

The combination of DVI with a joystick or rollerball was ideal for other route change procedures. The insertion of a number of new waypoints, which were held in the FMS memory, could be carried out by using two techniques. These are indicated by two typical voice instructions:

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(1) "WAYPOINT ALPHA BRAVO CHARLIE INSERT DELTA ECHO FOXTROT INSERT GOLF HOTEL INDIA EXECUTE" or

(2) "WAYPOINT ALPHA BRAVO CHARLIE INSERT JOYSTICK".

In the first example, the pilot sequentially says the identifiers of the new waypoints to be inserted. In the second example, DVI is used to indicate where the insertion should take place and instruct a joystick entry procedure to commence. These new waypoints are chosen by moving a cross cursor or the electronic map over the displayed waypoints required, using the joystick. The insertion is completed by pressing a button positioned on the joystick. An alternative to the joystick was a rollerball mounted on the pilot's right arm-rest. The combination of voice and tactile control was liked by all pilots who flew it in the BAC 1-11.

Along with the various other route change facilities such as inserting holding patterns or removing part of the pre-programmed route, the pilots could insert cruise levels, headings, speed and power settings by DVI. A vocabulary size of 235 words was required for electronic display, RMS and FMS control. Word recognition error rate for the pilots ranged from $<$ 1% to 6% when using a structured syntax which was suggested by users and which they considered natural. The maximum number of words active at a branch in this syntax was 47, the ICAO phonetic alphabet and the digits accounting for 36 of these words. Although DVI was still regarded as a very useful interfacing technique, a few problems had become apparent.

With the SR 128 as the ASR, recognition response times for some commands had become excessive. The response time from the end of the DVI command is not only a function of the algorithm and technology used, but also a function of the number of words active at the syntax branches and the number of words in the command. The single command "TIME" is matched against 27 other words in the syntax and has a response time of 0.5 sec. The command "GO DIRECT DELTA TANGO YANKEE" is matched against 74 other words in total and the response time is 2.6 sec as a consequence. (In both of these examples, 0.4 sec of 'silence', required before the recognition process begins, has been included). The next generation of ASR would need to have quicker response times, ideally 0.25 sec. The current generation of recognisers, replacing the SR 128, has little problem meeting this.

The other area causing concern was not connected with ASR performance. Despite the words and syntax being chosen by the pilots, for larger vocabularies there had become a tendency for them to forget the details of commands to be given. This human deficiency was noticed mainly during flight demonstrations or during periods of high workload. On one occasion a pilot asked the author over the aircraft intercom, "What do I have to say to Go Direct to Whiskey India Tango?" The author replied, "Why don't you say, Go Direct Whiskey India Tango?" Even the pilot's question had not reminded him of what was required. In the short term, this problem can be addressed to some extent by automatic prompting. A longer term solution would be to use recognisers with more intelligence that could interpret what the pilot meant. There is no problem for small vocabularies which the pilot can remember. Also, very large vocabularies, which the pilot is unlikely to exceed, will probably present few problems. The real difficulty resides with intermediate size vocabularies such as that used in the Phase 3 trials.

Although I have shown that using DVI in the cockpit is feasible, certainly in the relative quiet of the civil cockpit, I have indicated where improvements are required. Some of these improvements would be essential for DVI to be viable in the military cockpit.

7 TORNADO DVI TRIAL AT RAE BEDFORD

At the time of writing this Memorandum, a trial based on board a trainer version of a Tornado GR1 has commenced at RAE Bedford. This trial will take DVI into a more testing environment than that encountered in the BAC 1-11. Factors such as increased cockpit noise, high 'g' and vibration, breath noise along with impulse noises produced by the oxygen mask exhaust valve, must be considered. Added to this list of system difficulties, must be those associated with the missions conducted in this type of aircraft, often resulting in frequent high stress states in the crew. The potential benefits offered by DVI are primarily system control when the pilot's hands and eyes are busy with tasks outside and within the cockpit. There are also military benefits in being able to short circuit long keying sequences and being able to reduce the need for keyboard functions to occupy prime space within the cockpit. Although DVI seems to be a necessity in this very high workload situation, it must work well to be effective. The trials at RAE will attempt to show that this can be achieved with current technology.

Trials so far have concentrated on assessing the recognition performance under several flight conditions with the next generation commercial recognition system manufactured by Marconi. This ASR is called Macrospeak. Macrospeak offers many of the improvements that were required as a result of the BAC 1-11 trial. Some of these improvements are faster response time, larger vocabulary, adaptive background noise compensation, automatic gain control on the input signal and a more flexible syntax structure. Even with all these added features, the recognition algorithm remains similar to that of the SR 128. As a result, flight tests in the Tornado using no syntax have produced unacceptable recognition performance for some crew members. This is true for not all but a few of the commands used.

As a consequence, the next trial will use a flightworthy advanced recogniser called the ASR 1000. A history of the development of this ASR was recently reported in the periodical Speech Technology[5]. The recognition performance of the ASR 1000 will be assessed during flight, commencing August 1990. It is expected that the new algorithm based on Hidden Markov Modelling (HMM) will result in acceptable performance for the vast majority of crew members under a wide range of conditions. If this proves to be the case, the prospects for the operational use of DVI in military aircraft will be promising.

One potential application for the military use of DVI has been identified by both RAE and service pilots. This is the interface between the rear crew member of the Tornado and the aircraft's main computer. The problems to be overcome include the need for too many button pushes and the attendant keying errors. The keying procedures also often take longer than the time available. These are all issues that have been addressed by the BAC 1-11 programme, permitting the Tornado trials to benefit extensively from the earlier activity.

SUMMARY OF RECOGNITION RESULTS.

= THRESHOLD T500 =

Conditions	Sample size	% Error rate
Laboratory	11,460	9
Flight	3,120	37

(Test vocabulary – Alphanumerics)

TABLE 1

COCKPIT SOUND PRESSURE LEVELS.

RAE/BAC 1-11 –

On ground (equipment on)	---	72 dbA
During flight	130 K IAS	73 dbA
	210 K IAS	78 dbA
	300K IAS	85 dbA

TABLE 2

SUMMARY OF RECOGNITION RESULTS.

= MSRS SR128 =

Conditions	Microphone used	% Error rate.
Laboratory	Shure SM 10 boom	0·6
	Airlite 62 boom	0·9
	Amplivox throat	0·7
	Oxygen mask V2	1·3
Flight (250K IAS)	Shure SM 10 boom	0·6
	Airlite 62 boom	2·1

(Test vocabulary – Alphanumerics)

TABLE 3

SUMMARY OF RECOGNITION RESULTS.

=MSRS SR 128 – Displays Operation in Flight.=

Microphone used	Pilot A		Pilot B	
	% error rate	sample	% error rate	sample
Airlite 62 boom	1·76	1251	1·96	1073
Oxygen mask	0·78	128	2·88	417
Throat mic.	3·77	265	3·31	242

TABLE 4

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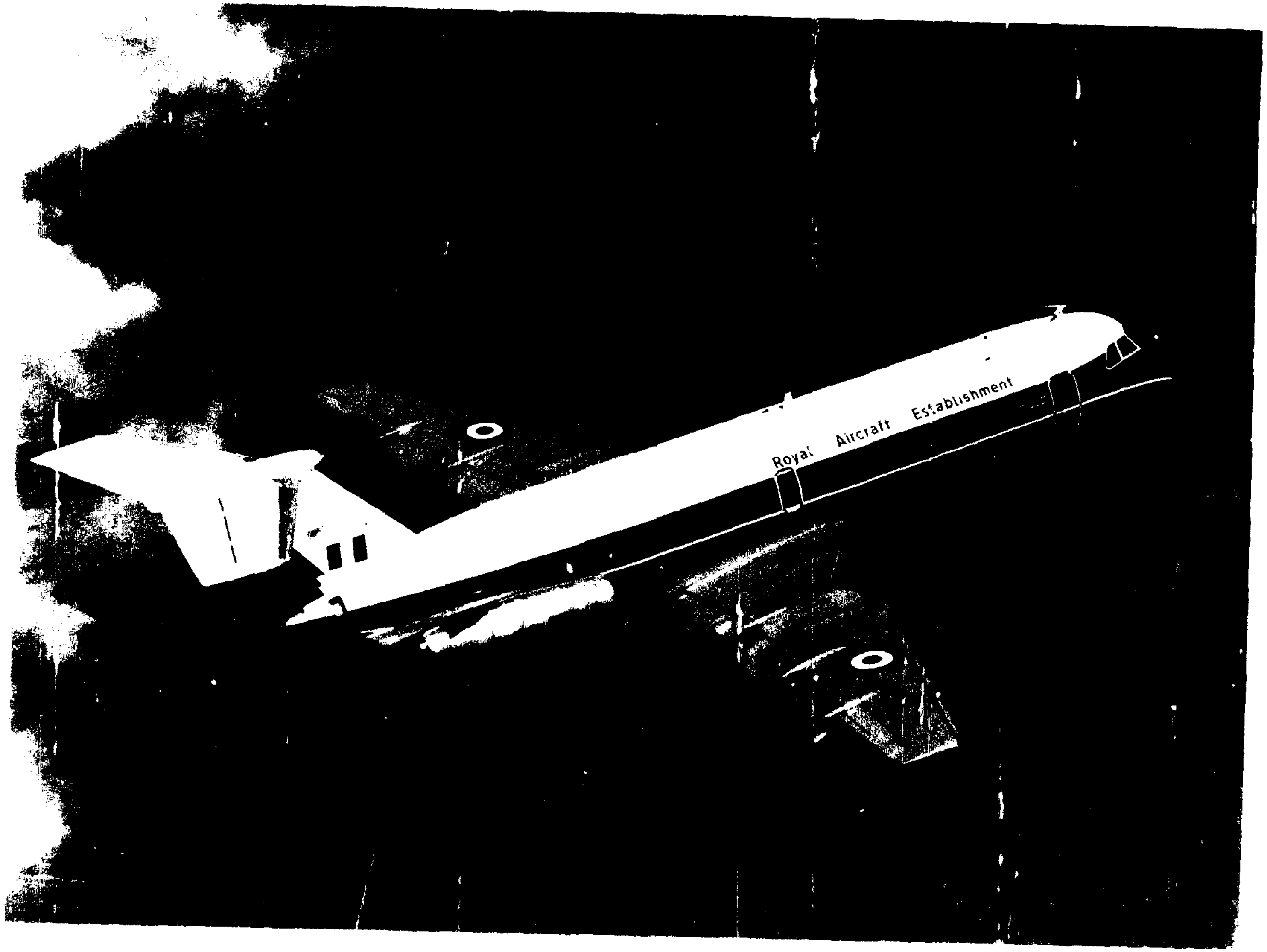
Royal Aircraft Establishment

Fig 2 MSRS 128 automatic speech recogniser

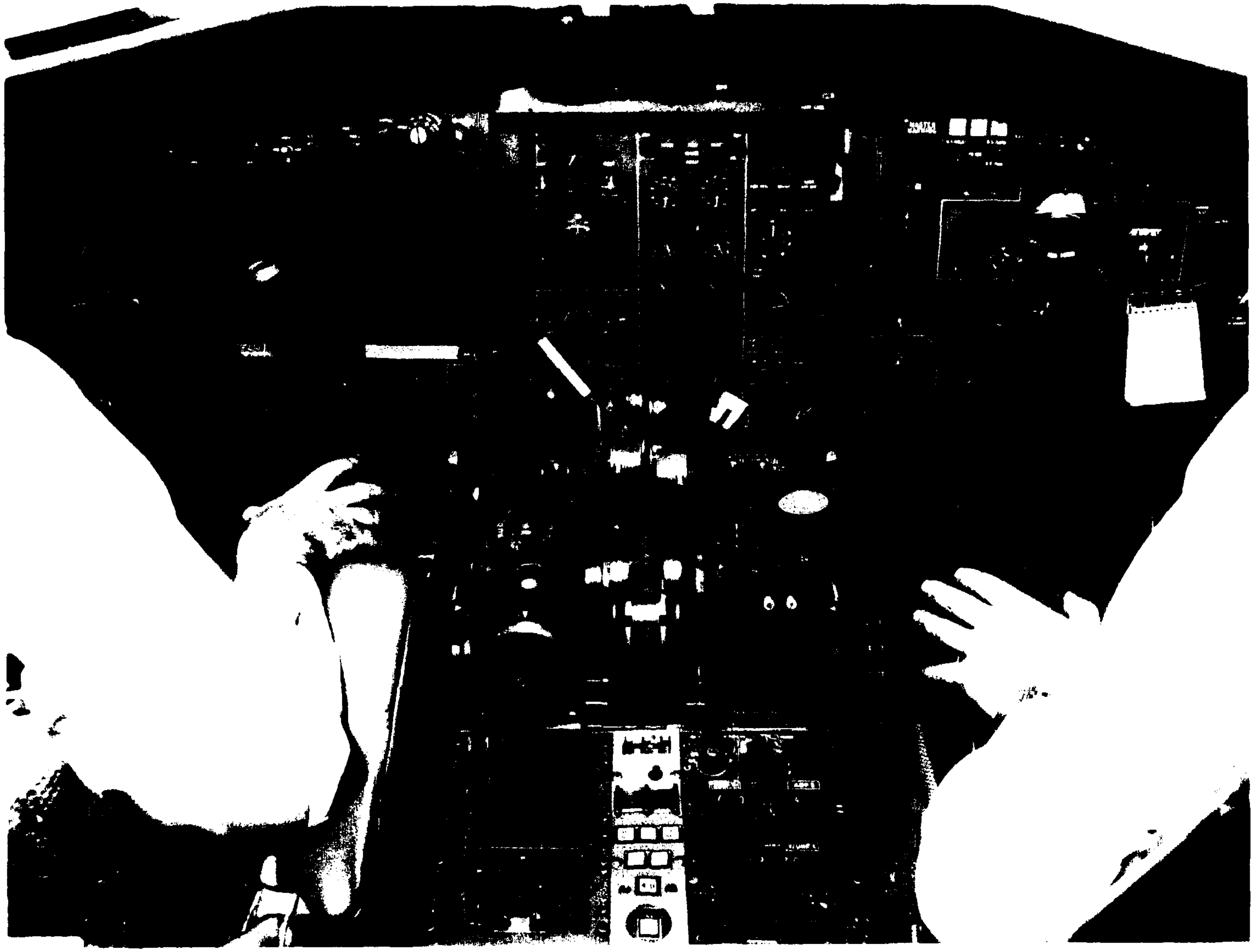

Fig 3 BAC 1-11 cockpit showing electronic displays

Fig 4

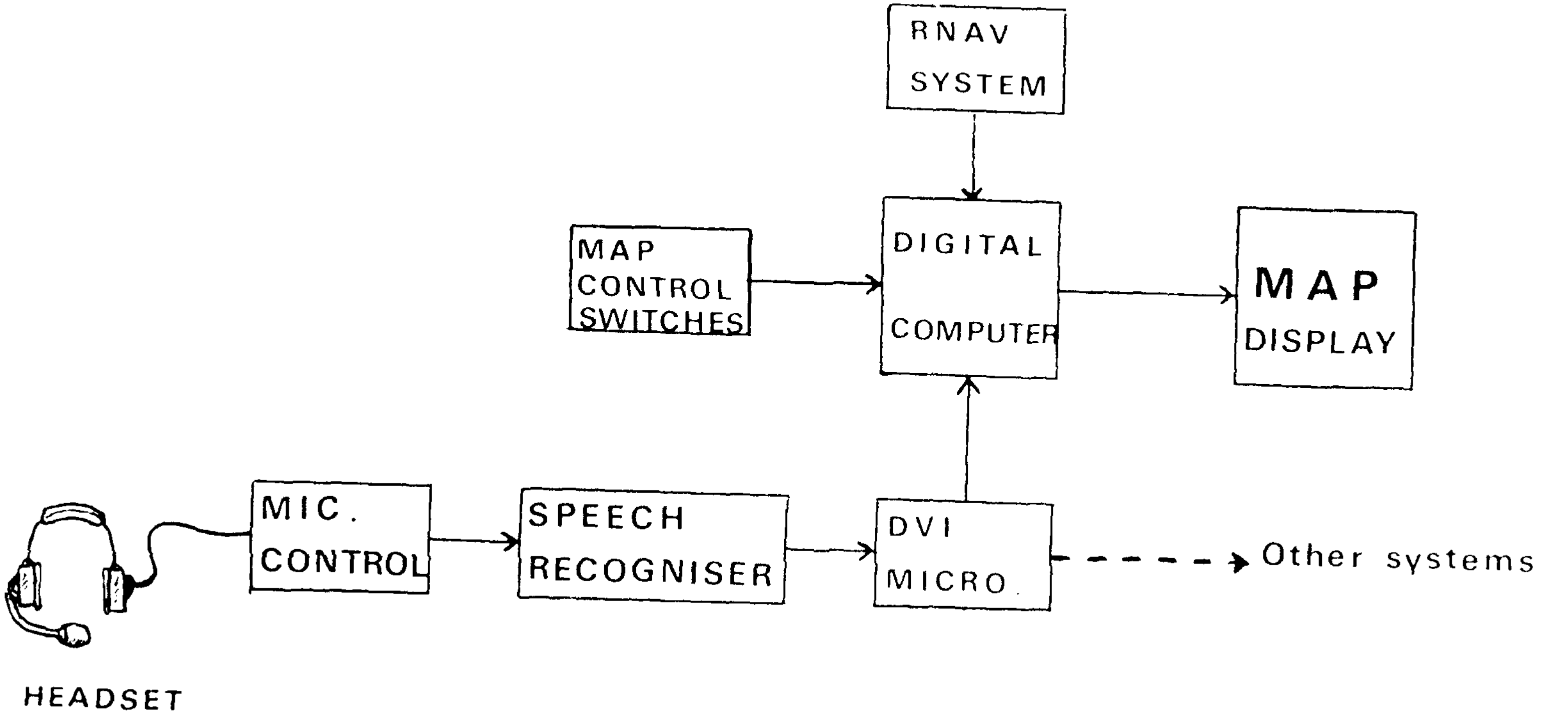

Fig 4 Voice control [illegible]

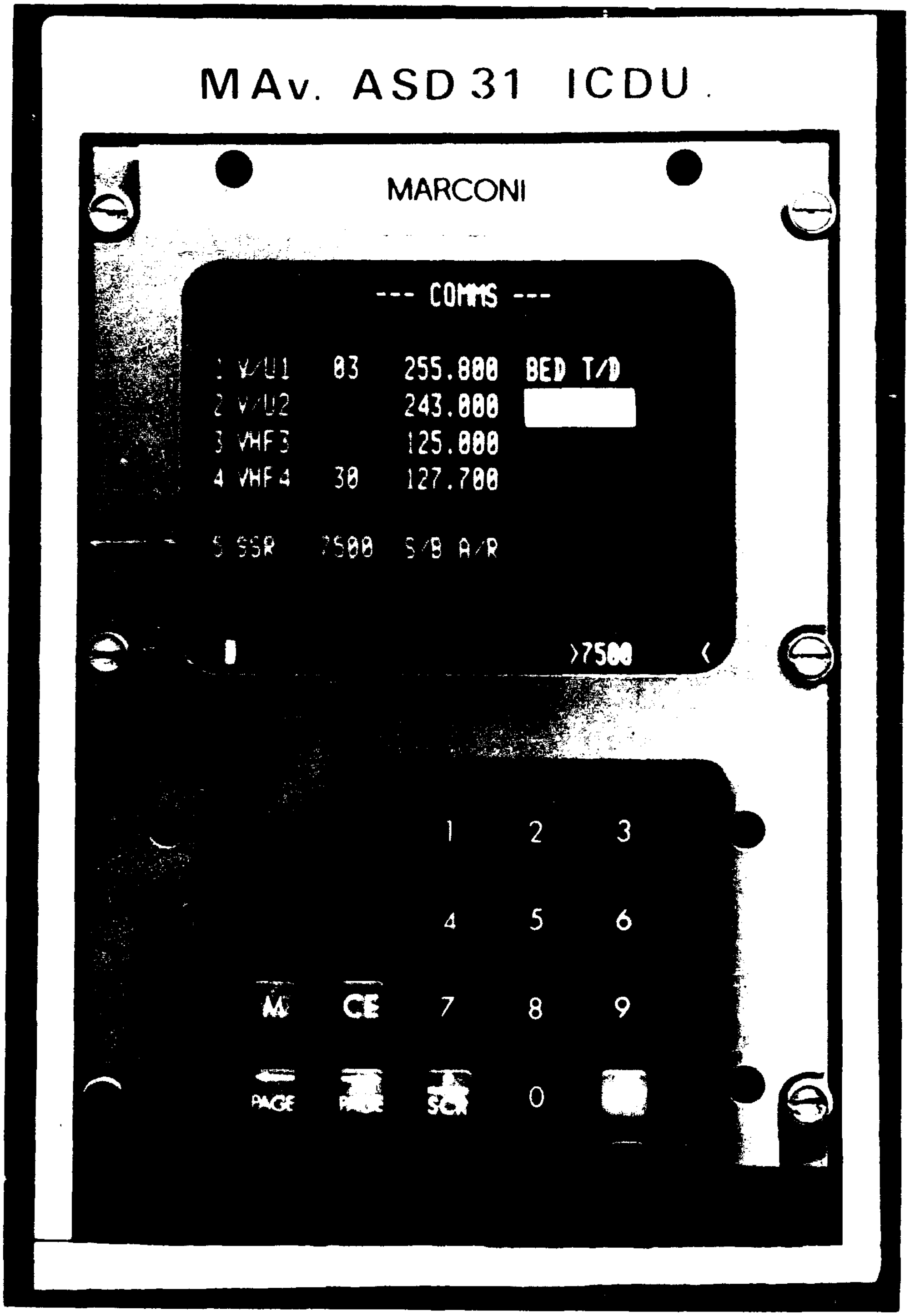

Fig 5 Radio management system control unit

Fig 6

FMS KEYBOARD.	D.V.I.
1- Select Route Change page.	Press DVI activation switch.
2- Select Insert Wpt. option.	Say 'Go Direct Charlie Oscar
3- Select After A/C posn. ident.	Romeo Enter.'
4- Key in 'COR' code.	
[1 ABC] = 4 pushes	
[5 MNO] = 4	
[6 PQR] = 4	
5- Select Insert button.	
?? Position of 'COR' required ??	
6- Select Latitude index.	Say 'North 40 37 decimal 8'
7- Key in N 40 37 8	
8- Select Insert button.	
9- Key in E 27 50 9	Say 'East 27 50 decimal 9
10- Select Insert button.	Enter.'
11- " Execute button.	
12- " Route Change page.	
13- " Go Direct option.	
14- " From A/C posn. ident.	
15- " 'COR' = To Waypoint.	
16- " Execute button.	Say 'Execute'
TOTAL No. = 37 button pushes.	

Fig 6 Actions required - 'COR' not in FMS database

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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Direct Voice Input (DVI). Man machine interface.

17. Abstract

This Technical Memorandum presents the RAE Bedford's past and present work on the use of Direct Voice Input (DVI) in the cockpit.