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VISUALLY COUPLED EO SYSTEM DEVELOPED FOR THE RAE SEA KING XV371

by

I. Mansfeld

Royal Aircraft Establishment,
Farnborough, Hants, England

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Ian Mansfeld

of Helicopter Section, Flight Systems Department,
Royal Aircraft Establishment, Farnborough, Hants

ABSTRACT

This paper describes the development of a visually coupled system (VCS) and its assessment as a piloting and navigational aid for low level night operations. The overall aim is to define the requirements for each component of a VCS.

The trials have been carried out using a Sea King helicopter as the trials vehicle, fitted with a rapid acting two degree of freedom platform capable of matching the head motion rates of the pilot. The sensor used on this platform is an Isocon low light TV camera, though an infra-red sensor has been fitted for the next stage of trials. Two types of head position tracker have been used, one electromagnetic in principle and the other utilising infra-red light. Flight symbology has been superimposed onto the sensor image and presented to the pilot on a monocular helmet mounted display comprising a miniature CRT and optics.

The results of the trials and their implications on the system components are described. The current trials equipment and plans for the next stage of investigations are discussed.

1 INTRODUCTION

For future battlefield helicopters there is an increasing need to achieve a 24 hour operational capability. Trials at RAE Farnborough have thus investigated various forms of passive night vision systems for low-level piloting. The Sea King helicopter is a unique trials vehicle for these systems, and has carried a comprehensive range of fixed sensors, both visual and infra-red sensing. These trials have now progressed to a stage where a two degree of freedom camera platform is fitted, capable of matching the head motion rates of the pilot. By expanding the system to include various forms of head motion tracking and image display devices, the visually coupled system has been created. By conducting trials with this system, it will be possible to decide how, if at all, future helicopters may benefit from such a system, and what form the sensors and displays should take.

1.1 Trials objectives

The VCS is to be assessed as a piloting and navigation aid for low level night operations in helicopters. This is preliminary to future programmes in which VCS may be used for target acquisition and subsequent weapon release.

2 SYSTEM DESCRIPTION

2.1 General

Figure 1 shows the VCS in block diagram form.

The equipment is installed on Mk 1 Sea King XV371 at Farnborough (Figure 2). A moveable ball assembly on the aircraft nose carries a low light television (LLTV) camera, and allows it to be steered in azimuth and elevation. The steering signals are provided by a system that tracks the motion of the pilot's helmet, and thus his line of sight. The TV picture is then presented to the pilot's right eye via a helmet mounted display (HMD). The TV image has flight information in the form of symbology superimposed upon it. Figure 3 shows the pan and tilt ball assembly.

2.2 Camera

This is a LLTV with a square Isocon tube and a forty degree field of view. The fitment of a surface silvered neutral density filter allows it to be used as a daylight camera. A control unit mounted inside the aircraft allows variation of the aperture, and operation under automatic gain control (AGC) or in manual control.

2.3 Pan and tilt ball

The movable ball is capable of ±100 degrees in azimuth and +20 to -90 (full down) in elevation. The drive in both axes is through reduction gearboxes from electric motors. Each axis has independent feedback loops for rate and position, each one passing through a shaping network. In azimuth, an inner gimbal is provided which allows faster settling after a disturbance by using fine and coarse feedbacks to the servomotors. The outer casing of the ball is glass-fibre, and a vertical slot allows for the elevation freedom of the camera. The camera looks out through a series of five optically flat glass panels.

2.4 Symbol generator

This item takes as input the camera video and synchronisation signals, and a series of signals from the aircraft flight instrumentation systems. The information superimposed onto the video signal is listed below. Figure 4 illustrates the symbology set, mixed onto a LLTV picture. The set comprises:

- Aircraft heading and heading to steer bug
- Altitude (barometric or from radio altimeter)
- Airspeed or groundspeed (from Doppler)
- Rate of climb (derived from altitude)
- Aircraft pitch angle
- Aircraft roll angle
- Hover cross (using TANS drift data)

The format and locations of the symbology are fixed, although symbols may be individually deleted from the display.

2.5 Symbol switcher

The switching unit uses analogue comparators to check on head position in azimuth and elevation. If the position is outside a preset envelope, then certain, selectable, symbology is removed from the display. A built in hysteresis loop prevents its re-appearance until the line of sight is within an inner envelope.

2.6 Head tracker

The head position tracker is used to measure, relative to an adjustable datum, the pilot's head position and hence to determine his line of sight. The adjustable datum is used to initially align the system, such that the sensor line of sight is boresighted to the pilot's line of sight.

2.6.1 Infra-red sensing tracker

This system was originally intended for fixed wing use. Two transmitters containing an IR light source and a mechanical interrupter provide scanning beams of narrowband IR that are time referenced together. Pairs of detectors mounted on the sides of the helmet then sense the arrival times of the beams and of the reference pulses and a computer is then used to calculate the line of sight in three dimensions. Head roll inputs are cancelled out of the system such that it then provides drive signals in elevation and azimuth only.

2.6.2 Electromagnetic sensing tracker

This uses a spatial synchro technique where a cockpit roof mounted radiator unit envelopes the helmet location with three consecutive bursts of electromagnetic radiation from three mutually orthogonal coils. Pick up coils on the helmet mounted detector then feed signals back into the controlling computer which then applies a fixed compensation for effects due to cockpit metalwork and systems before outputting azimuth and elevation drive signals. Again head roll is negated, but it is available for roll compensation of the HMD image if required.

3 WORK CARRIED OUT TO JUNE 1983

These results and observations are based on the complete system during installation and operation over 16 sorties, four of which have been at night. Of the total, 13 have used the infra-red sensing head tracker and three the electromagnetic. The same low light TV sensor and miniature CRT display were used throughout.

3.1 Camera

The system was designed for use with a UK Thermal Imaging Common Module (TICM) sensor, but lack of such a sensor and the problems and cost of installing a Germanium window in the ball has constrained trials to the use of a LLTV. By day, using an ND6 filter, the picture is acceptable for shakedown use, but is lacking in contrast and detail. Operation at night has highlighted several problems that interfere with the VCS trials:

(i) Whilst manoeuvring on the ground, the TV tube is very prone to collecting burn marks from airfield and ground crew vehicle lights. The camera is thus kept under observer control until airborne.

(ii) The AGC is very susceptible to any bright light source in the field of view. Since it is difficult to find trials areas completely free of cultural activity, the effect is an immediate loss of detail, particularly in the foreground, whenever any vehicle or street lights are in view. This is a prime factor in determining safety heights for trials routes. The camera control unit has recently been relocated such that the trials' observers can set it into manual mode, which alleviates the problem slightly.

(iii) Pilot comments have suggested that there is an image lag in the Isocon and image intensifier combination, manifesting itself in a waiting time between looking at an object and being able to look at the image of that object, (this being dominant over the servo system settling time.)

3.2 Pan and tilt ball

During the winter months, a considerable amount of condensation on the lens and glass panels obscured the camera picture, particularly below horizon level. Removal of the ball assembly showed several areas where ingress of water could occur and then accumulate before spilling into the base of the ball. These areas were sealed with silicon rubber, as was a new mounting plate gasket made up by the trials' team. Further to this, two drainage holes were introduced at the lower rear of the ball to prevent accumulation. No further condensation problems have been encountered.

The first flight on which the ball was slaved to the head tracker in normal (non VCS) daytime flight resulted in a failure of the azimuth drive. This was subsequently traced to the shear of a mills pin on the azimuth gearbox intermediate shaft. A mills pin is also present on the output of the servo motor, and is more accessible, so the sheared pin was replaced by a taper pin. Any future problem will thus require only removal of the motor, with no interference with the settings of the position transducer and motion limit switches.

3.4 Head tracker

3.4.1 Infra-red sensing

This system has been the prime method of head tracking to date.

(i) Installation

The airframe components are generally satisfactory, though the seat 'wings' used by RAE to hold the scanning units needed more rigidity. The vibration of these did not seem to be transmitted to the image however, since it was in excess of the ball response. The sensor units were designed for use with USAF helmets and their transfer onto MK3C resulted in a clumsy appearance that was acceptable for trials use only.

(ii) Motion box

The system was initially developed for use in fixed wing aircraft, and it was found that the motion box was too small for helicopter use, both laterally and vertically. Laterally this was accentuated by the wider spacing of the sensors needed to mount them on a MK3C helmet. The main lateral effect is that in looking in excess of 60-70 degrees left or right, the helicopter pilot has freedom to move the upper torso from the waist. This extra sideways translation of the head was often sufficient to exceed the motion box limits. When deliberately moving from the neck pivot only, no problems were encountered, but this is an artificial and unrealistic constraint on a helicopter pilot.

Vertically, two of our pilots when in their normal seating positions were outside the motion box, one above and one below. (The motion box is referenced to the seat rather than the cockpit.)

Fore and aft, the RAE installation of the scanners caused the motion box to be slightly forward of the most desirable postion, so that the subject pilots had to ensure that they sat in a slightly forward position. Although unrealistic, no problems in this position were encountered.

(iii) Alignment

As installed, the system uses RH and LH sensors with a cross-over algorithm in the computing. Thus at the cross-over points, both sensors must be in alignment if a discontinuity is to be avoided. In practice, this required adjustment to within 6 minutes of arc. Without complex optical alignment, this could only be done by adjusting sensor positions on the helmet, and this contributed to the lateral width of the helmet installation.

(iv) Operation

After a short period of operation, it was established that the boresighting bias was unuseable. The fitting of MK3C helmets is such that angular pitch variations of 20 degrees between pilots is not uncommon, and this is outside the head tracker bias limits. Thus compensation has to be carried out by the rear seat observer adjusting offset inputs to the ball. Of a more serious nature was the behaviour of the system when the motion box is exceeded. The system is intended to lock its outputs at the last value in this case, but this never occurred. In flight, the main tendency was to demand a maximum rate up and right motion until the camera was looking into the rotor disc. This was very disorientating for the subject pilot, and became a major factor in undermining pilot confidence in the system. The effect was such that after a few of these uncommanded movements, the pilot constrained himself to move his head as little as possible, and then only very slowly. The problem has never been satisfactorily resolved.

This last problem, together with increasing unreliability of the computer has dictated the replacement of the head tracker before any further trials.

3.4.2 Electromagnetic sensing

This system has only just been installed, and only three shake-down flights with it have been made.

(i) Installation

The installation has been straightforward, the cockpit mounted transmitter having been installed for several months following the lengthy cockpit mapping procedure to allow compensations to be introduced on the computer. One connection onto a transmitter coil was found to be broken, presumably under vibration, and the detail finish of this interface is not to the same standard as the remainder of the equipment. The helmet sensor has been attached using Velcro, and has proved satisfactory thus far.

(ii) Operation

The motion box appears satisfactory, but only just. A movement to look 90 degrees down can exceed the forward box limits. The computer outputs are frozen in a satisfactory manner in such a case. Even in the limited operation of the system it has been noted that pilot confidence in the head tracker is being regained, and that once it is found that the motion box is very difficult to exceed, and that spurious ball movements are not demanded, the pilot begins to relax and allow normal head motion to occur.

3.5 Trials helmet (Figure 5)

Certain modifications have been required to the MK3C helmet for these trials.

For the infra-red head tracking system, a pair of can-mounted sensor units and cables had to be fitted. The sensors were mounted onto flat adaptor plates, which were then located at three points to the helmet. Spring loaded adjustors were initially tried, but later replaced with a pair of locking nuts to ensure a fixed position setting. This allowed the required azimuth overlap and elevation matching to be achieved.

As described above, the spatial synchro sensor is currently attached with Velcro and this will be retained, for ease of use, until proved unacceptable.

The HMD is fitted using a simple nylon 'C' clamp on the RH side of the helmet. A special adapter block was manufactured to conform to the helmet contours at this point, and to provide the correct clamp orientation.

Binocular rivalry provided some difficulties at night, leading to a feeling of detachment from the image. To help overcome this, a specially cut visor was fitted to mask the left eye whilst allowing the

HMD access to the right eye. A heavy cloth cover was then manufactured to clip onto this visor. This has proved good enough to allow a limited amount of daylight VCS flying to be done, at least for shakedown and familiarisation purposes.

3.6 Helmet mounted display

Very few problems have been encountered with the display. The nylon 'C' clip which retains it to the helmet is particularly good, in that it allows rapid and easy one handed fitting and removal, as well as simple adjustment by the pilot of the display unit position. Against this, the picture focus and rotation adjustment are combined, and such that a second person is needed in the setting up task. Consequently these two parameters tend not to be altered to suit individual pilots.

Regarding the display image itself, the main comment is that the final reflecting mirror and picture lens are slightly too small, in that the corners of the CRT picture are clipped. The CRT picture can be reduced via the horizontal and vertical deflection amplifiers, but the image is then not one to one with the real world. Without extensive investigation, it is considered that at maximum a 10% variation could be tolerated. With the symbology set in use, this leads to occasional loss of the airspeed and altitude characters. The eye-mirror-tube alignment is thus critical, and easily upset, as for instance in turning the head through large angles.

The loss of display edges at large head angles has demonstrated that, totally independently of any cable drag, a well fitted MK3C helmet will move on the head. This movement is the outer shell tending to remain fixed, whilst the head is still turning by a twisting of the inner strap suspension system. With a larger image display area, the problem would probably not appear - for example, there are no comments on this from the use of standard NVG equipment on aircrew helmets.

The weight of the display has been satisfactory, even on sorties of 2½ hours duration.

3.7 Waveform generator

The waveform generator forms the core of the system, and has fortunately proved reliable throughout, even following extensive internal modifications.

The fixed format is its main limitation. Some parts of the display can be in one of two locations, or information may be deleted altogether. Only the hover cross has been deleted successfully in use, and then only because the resolution of the rest of the VCS system is not sufficient to permit investigation of approach and landing tasks.

Pilot comments have suggested that a rotary analogue (*ie* dial and pointer) speed and height display would be better than the existing three digit display, and a thermometer style percentage power indicator is required. A slip indicator is also desirable, and could replace the rate of turn indication at present shown. The moving 'tape' format of the heading display is acceptable. The VSI scale is useful, but the existing one has a disconcerting software problem. The VSI trend is calculated from height information, and if the rate of climb exceeds the scale maximum an off-the-screen rate of descent is indicated. This is certainly unacceptable for low level flight.

Modification of the waveform generator has allowed the symbology, wholly or partly, to be deleted as the pilot's head is turned. This avoids any problems that may be caused by retaining the full symbology set as the head turns, such as possible confusion of pitch/roll information. To prevent any possible disorientation, the pilot's symbology is then preset to disappear at a certain azimuth angle. The incorporation of a variable hysteresis loop eliminates any disconcerting flicker effects, and ensures that the head must be in a smaller envelope before pitch symbology is regained.

A second benefit is the generation of an artificial 'straight ahead' reference. When using the VCS, the pilot has no visual clues, such as window struts, coaming or instruments to inform him that he is looking straight ahead. The inclusion of the inner symbology envelope allows him to regain a straight ahead position when required.

In practice, the settings of the symbology on and off envelopes has not proved at all critical, and pilots are content for a switch off to occur between 40 and 70 degrees. Some have commented that the switch off is not really necessary.

3.8 Trials method and data handling

During a short pre trial brief, it is ensured that the pilot is familiar with the HMD itself, and the control panel locations. In the trials done to date, once it is ensured that the pilot is aware of the parameters that can be adjusted (HMD alignment for symbology switching for example) then the pilot is left to adjust the system to suit his own preferences. The progress of each sortie is geared to pilot confidence in the system, the general brief being one of low level flight around a known route. Pilot comments during the flight are noted by the observers for later discussion. Cockpit voice recording has been tried, but this requires far too long to analyse, sorting comments from radio and internal talk on intercom.

On completion of the sortie, a short debrief is held, assisted by the use of a specially developed debrief form, Figure 6. This requires the pilot to answer a series of questions on all aspects of the system flown, and also to give the system an overall rating. To do this, a rating scale is provided, Figure 7. The scale has been based around the Cooper-Harper scale which is widely used in referring to an aircraft's handling characteristics. The scale has thus been revised so as to be applicable to a flight aid or system instead. This has been very useful and is under consideration by Experimental Flying Squadron to assist in future systems assessment.

4 CURRENT STATUS AND FUTURE WORK

Following the trials carried out with the equipment described a programme to improve the trials equipment has been carried out.

4.1 Sensor

It was felt that the image quality, particularly in areas of cultural activity, from the low light TV camera was the weakest link in the system. A scanning thermal imager with integral cooling system has now been installed on the platform for the next phase of trials. The cost of a germanium window has been avoided by use of a curved film of polypropylene with a wire reinforcement.

4.2 Head tracker

The electromagnetic system is now installed, and will be used for all future work. It may prove necessary to reprogramme it to enlarge the motion box.

4.3 Helmet mounted display

An alternative HMD is now available utilising large eye relief optics and the ability to roll-compensate the image. This system is monochrome and monocular as before. Work has also been carried out on an alternative HMD using components from this one married to a modified NVG mount. This allows a wider range of adjustments for the wearer, as well as the ability to investigate a combined VCS and NVG display to the pilot. Other systems are under investigation for presenting images to the aircrew on a helmet mounted system, but these will not be available for some considerable time.

4.4 Symbology

The symbology set used was found to be restrictive, and several alternative symbology sets have been defined using a programmable raster display generator. Although the PRDG is intended for a different aircraft, timescales may permit its installation into the VCS for a limited trial.

4.5 Data recording

A compact digital data recording system has been designed and developed within helicopter section, and has been successfully used during our Puma flight trials. A similar installation is available for the VCS, to be used to back up data from the debrief form. Typically, the pilot will perform a preset task whilst using VCS, and the amount of head movement together with aircraft height, speed and heading can be recorded. By increasing the tasking and workload until one or all of the flight parameters begins to deteriorate, a measure of the VCS qualities can be made. Similarly, the effects of changes in symbology and helmet mounted display can be assessed.

4.6 Pilot tasking

As the quality and integrity of the system is improved, it is intended to introduce more varied and demanding tasks to supplement the basic route flying task. For example, take off, point to point tactical navigation, searching for concealed targets, transition, hover, cross wind hover, approach and landing.

5 CONCLUSIONS

The work done so far has demonstrated the capabilities and limitations of the various components of the visually coupled system. With the upgraded equipment now available, it is possible to pursue further the assessment of VCS as a piloting and navigational aid. Although the system is more complex than night vision goggles, the speed of response is similar, and there is a greater flexibility in the information that is presented to the pilot. Flight symbology and warning information can be supplied, and it is possible to foresee the presentation of multi-waveband information with automatic target cueing.

The trials have demonstrated the feasibility of the visually coupled system and development work is now needed to enhance the basic concept.

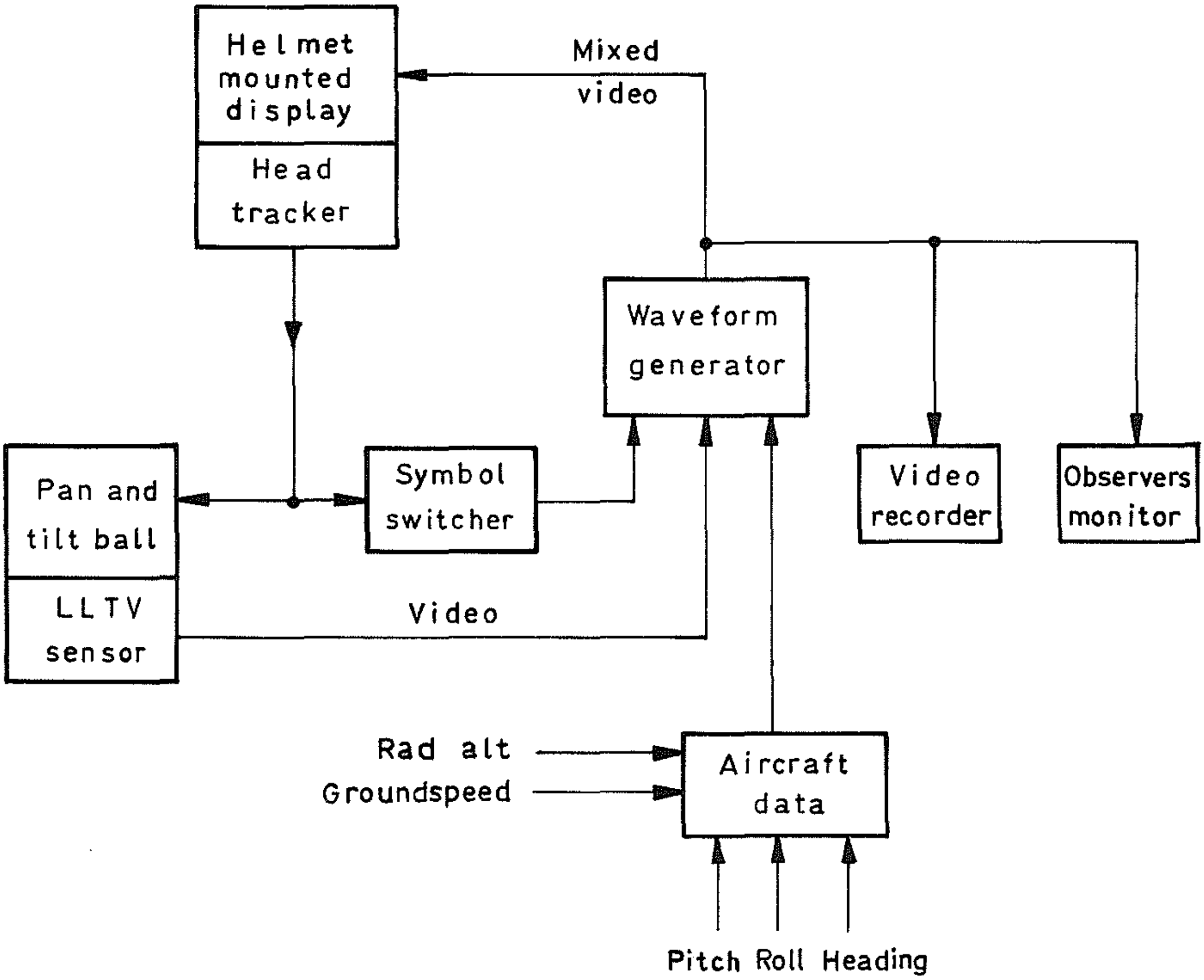

Fig 1 Visually coupled system - block diagram

Fig 2   Sea King XV371

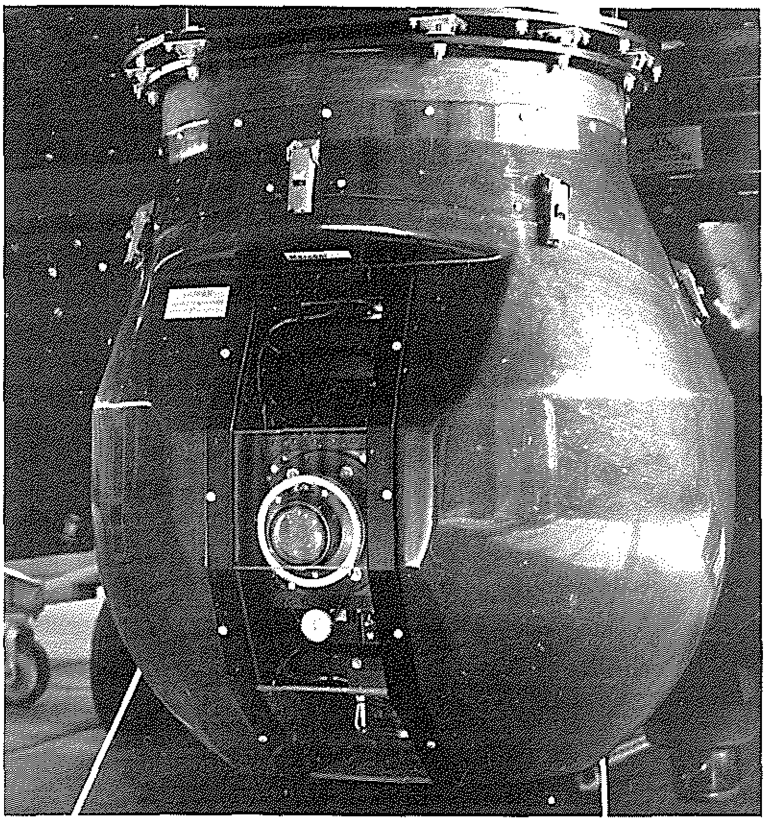

Fig 3   Pan and tilt ball

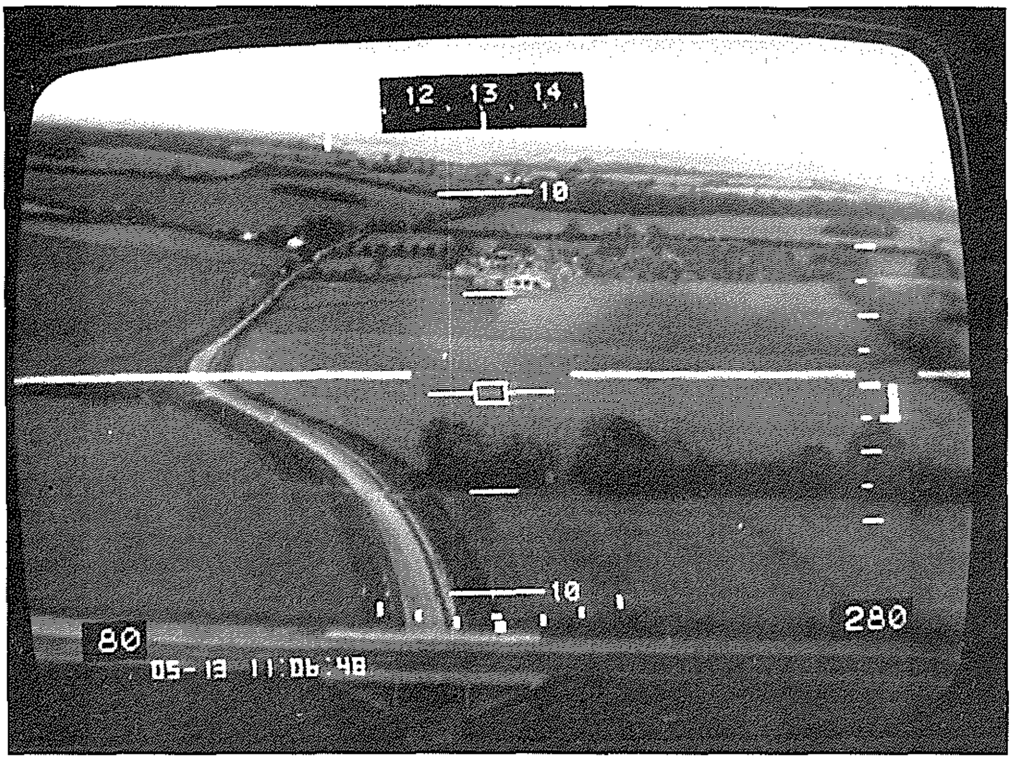

Fig 4 Symbology set

Fig 5 Trials helmet and HMD

AIRCREW DEBRIEF FORM FOR THE VCS

NAME:
DATE:

1 GENERAL

1.1 Using the rating scale provided, what is your assessment of the suitability of the VCS for?:

The route flying task
The target seeking task
Approach and landing
General flying

2 VISUALLY COUPLED SYSTEM

2.1 Was the physical size, shape and weight of the helmet mounted equipment?

Tolerable
Tolerable for trial
Intolerable

2.3 Was image vibration?

Not noticeable
Noticeable but tolerable
Intolerable

2.4 Did using the VCS require you to alter your normal seating attitude?

No
Yes but with no difficulty
Yes and unacceptably

2.5 Was the field of view?

Adequate
Too small
Too large

2.6 Were the motion rates of the camera in pitch and yaw?

Satisfactory
Too slow
Too fast

2.7 Which phase of flight was most difficult using the VCS and why?

Take off	Navigation
Hover	Approach
Route task	Landing
Target task	Taxiing

3 SYMBOLOGY

3.1 Which symbology could be omitted from the display?

Hover cross	Pitch bars	Airspeed
Horizon bar	Turn indicator	R.o.C.
Aircraft symbol	Altitude	Heading
Heading bug		

Fig 6 Debrief form

3.2 What extra symbology do you think?

is necessary
is desirable

3.3 Which symbology, if any, must be retained irrespective of head position?

Hover cross	Pitch bars	Airspeed
Horizon bar	Turn indicator	R.o.C.
Aircraft symbol	Altitude	Heading
Heading bug		

3.4 Can you suggest any better methods of presenting the symbology, or better locations for it within the image?

4 COMMENTS

Please write any other comments you have on the VCS or trial in this space.

Fig 6 (concluded)

Adequacy of piloting system for task

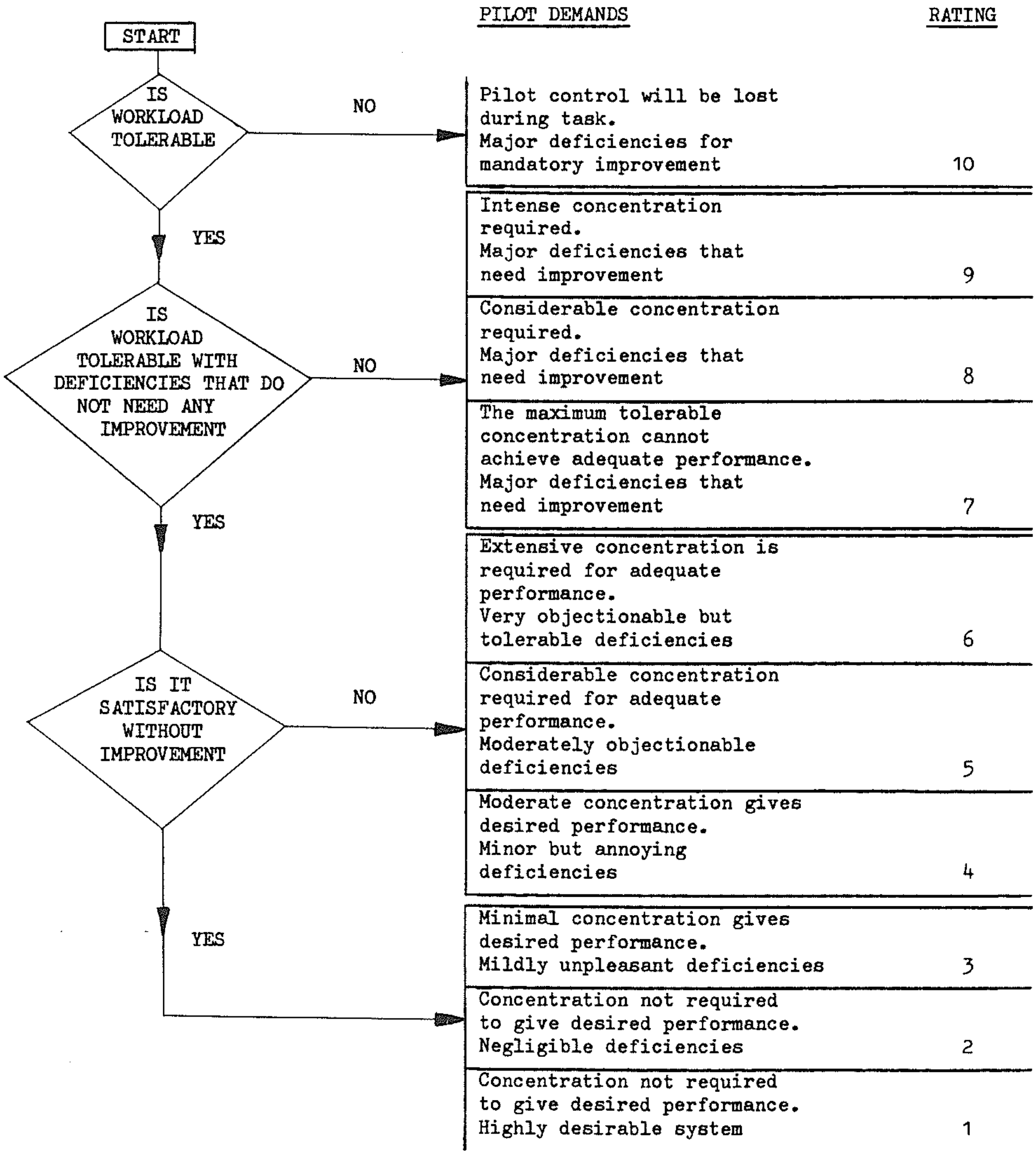

Fig 7 System rating scale