ARL-SYS-NOTE-64 AR-001-725

AUSTRALIA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

SYSTEMS NOTE 64

WESSEX HELICOPTER COCKPIT ERGONOMICS

by

K. C. HENDY and B. A. J. CLARK

Australian Defence Department only. Other requests for this document must be referred to Chief Superintendent, Aeronautical Research Laboratories.

COPY No 37

FEBRUARY 1979

AR-001-725

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORIES

SYSTEMS NOTE 64

WESSEX HELICOPTER COCKPIT ERGONOMICS

by

K. C. HENDY and B. A. J. CLARK

SUMMARY

It has been proposed that Wessex helicopters of the RAN should have their service life extended by the fitment of twin engines and other mechanical modifications. This Note describes the present ergonomic state of the Wessex and indicates that by current knowledge, major aspects of the man-machine interface are inefficient and unsafe. Suggestions are made for improvements to the cockpit layout, instrument panels, crew and cabin seating and the crew environment.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories,
Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

DOCUMENT CONTROL DATA SHEET

Security classification of this page: Unclassified

1. Document Numbers
   (a) AR Number:
   AR–001–725
   (b) Document Series and Number:
   Systems Note 64
   (c) Report Number:
   ARL–Sys–Note–64

2. Security Classification
   (a) Complete document:
   Unclassified
   (b) Title in isolation:
   Unclassified
   (c) Summary in isolation:
   Unclassified

3. Title: WESSEX HELICOPTER COCKPIT ERGONOMICS

4. Personal Author(s):
   K. C. Hendy
   B. A. J. Clark

5. Document Date:
   April, 1979

6. Type of Report and Period Covered:

7. Corporate Author(s):
   Aeronautical Research Laboratories

8. Reference Numbers
   (a) Task:
   NAV 78/136 Navy 1083
   (b) Sponsoring Agency:
   Navy Office

9. Cost Code:
   73 2285

10. Imprint
    Aeronautical Research Laboratories,
    Melbourne

11. Computer Program(s)
    Nil

12. Release Limitations (of the document)
    Australian Defence Department only. Other requests for this document must be referred to Chief Superintendent, Aeronautical Research Laboratories

12-0. Overseas:	N.O.		P.R.		A	4	B	1	C	1	D	1	E	1

13. Announcement Limitations (of the information on this page):
    Normal limitation

14. Descriptors:
    Cockpits
    Pilot performance
    Flight instruments
    Aviation safety
    Human factors engineering

15. Cosati Codes:
    1312
    0505
    0103
    0509

16. *ABSTRACT*

It has been proposed that Wessex helicopters of the RAN should have their service life extended by the fitment of twin engines and other mechanical modifications. This Note describes the present ergonomic state of the Wessex and indicates that by current knowledge, major aspects of the man-machine interface are inefficient and unsafe. Suggestions are made for improvements to the cockpit layout, instrument panels, crew and cabin seating and the crew environment.

CONTENTS

Page No.

1. INTRODUCTION

For some time, the matter of replacing the RAN Wessex helicopters has been under discussion within the Department. These helicopters were introduced into RAN service in 1962. Instead of buying a modern replacement, there is some possibility that modernising the present aircraft might enable the Navy to fulfil the relevant operational tasks until say 1995, when new aircraft would be required. Questions which arise are:

(i) Can the present Wessex be modernised well enough to meet operational requirements until a replacement is eventually bought?

(ii) If so, is the modernisation an economically acceptable way of delaying the purchase of new helicopters?

Hawker de Havilland Pty. Ltd. contracted with the Commonwealth in April 1978 to undertake a "Design Definition Study for Wessex Helicopter Modernisation for Royal Australian Navy". The principal modernisation requirements given in the contract are, inter alia, replacement of the present single engine by two engines of the type fitted to the RAN Sea King Mk 50 helicopter, replacement of much of the avionics and instruments, and alteration of the interior to allow carriage of a squad of armed soldiers. Not much attention is paid in the contract to human factors considerations. The modernised aircraft is required to comply with parts of the UK specification AvP 970. Presumably that specification was used in development of the existing aircraft model.

The authors inspected Wessex helicopters in company with Aircraft Maintenance and Flight Trials Unit (AMAFTU) personnel in a hanger at RANAS Nowra on the night of 15 June 1978 and the following morning, specifically for the purpose of providing information to Navy about the necessary and desirable changes that should be considered in any plan to make the Wessex ergonomically fit for fifteen years of further service. This Note describes the results of that inspection, together with suggestions for modifications where appropriate.

2. COCKPIT LAYOUT

2.1 Cockpit Position

The cockpit in the Wessex is situated above and aft of the engine which is in the nose of the aircraft. This places several constraints on the cockpit layout. For instance, vision upwards, which is relatively unimportant, is good, but downwards vision which is often crucial is hindered. The transmission shaft between the engine and main rotor gearbox passes through the cockpit and thereby constrains the size and positioning of centre consoles and the collective control. The cockpit floor is at head height for someone standing in the cabin and it is not possible to move between the cabin and cockpit in flight. However it is possible for articles such as maps or navigation equipment to fall into the cabin from the cockpit through the large apertures in the cockpit floor under the crew seats, and if the cabin is unoccupied these objects would be irretrievable for the remainder of the flight.

The cockpit position is therefore a major fault in the Wessex and it is noteworthy that this fault has been avoided in virtually all helicopters of more recent origin by positioning the engines above or behind the cockpit and cabin areas.

2.2 Controls

The flight controls are conventional. No adjustment is provided for the position of the collective or cyclic controls. The anti-torque pedals are adjustable in the fore-and-aft direction only. The crew chairs have a 70 mm range of adjustment in a direction parallel to the backrest frame. Thus the position of the collective and cyclic controls relative to the seat reference point of the crew seat is virtually without fore-and-aft adjustment. The seat height can be set to optimise vertical position of the pilot with respect to design eye position, cyclic, collective or pedals. In general, the best position for any one of these will not be the best position for the others.

Wessex pilots suggested that a provision of a vertical adjustment for the cyclic handgrip would allow the right forearm to be rested on the thigh in cruise flight regardless of seat height adjustment. They also suggested that the collective control should be altered so as to operate in a fore-and-aft direction rather than the existing rotation in the vertical fore-and-aft plane about a pivot which is to left of, aft and below the seat reference point.

The first of these suggestions has some merit. However, it does not go far enough. What is really needed are sufficient adjustments between the ~~chair~~ seat and all controls so that all pilots with body dimensions within some specified range can adjust all of the controls to a comfortable position. The penalties for bad controls placement are effectively non-existent for designers and possibly severe for operators in terms of a flight safety hazard, discomfort, and temporary and chronic back pain.

Fitzgerald and Crotty (Ref. 1) surveyed the incidence of backache in RAF aircrew and groundcrew. They stated:

> "To control a helicopter the right arm must be outstretched to the cyclic control while the left arm hangs more or less vertically with the hand on the collective lever. When these arm attitudes are maintained for more than a few minutes the tendency is for the upper trunk to rotate to the left while the left shoulder drops and the spine bends towards the left. This form of scoliosis stresses sensitive, normally non-load bearing joint membranes, and discomfort or pain may result on the left hand side of the spinal column at about the level of the junction of the lower thoracic and upper lumbar vertebrae. In addition, several of the helicopter pilot respondents described a second area of discomfort located to the right of the spine at the level of the base of the shoulder blade; this, very likely, is due to prolonged stretching of the latissimus dorsi muscle when the right arm is maintained in the outstretched position."

Sliosberg (Ref. 2) found that of 128 helicopter pilots selected by an unstated procedure and examined medically, 87% complained of cervical, thoracic, or lumbar spinal pain. He suggested that the cyclic control should be positioned so that the right forearm can be rested on the right thigh. The collective control should have a length and travel which does not require the pilot to lean to the left. A movable elbow rest which would support the left elbow, or a surface on which the left elbow could slide ought also be considered.

The second of the suggestions by Wessex pilots, about changing the collective to fore-and-aft motion, raises complex issues. It is a basic tenet of ergonomics that control movements and results ought to correspond. Thus pushing a throttle forward in a fixed wing aircraft increases the tendency to go forward, and upwards as a secondary effect, and pushing the control column to one side lowers the wing on that side. In a helicopter, pulling the collective lever up increases the upwards motion, with increased forwards motion as a secondary effect. The usual arrangement of collective actually results in a slight backwards movement of the lever as it rotates upwards; nevertheless, it has become an almost universal arrangement partly because it is easier to pull towards the shoulder than, for example, to lift a control up while keeping it at arm's length. This has particular importance if the control requires much effort to move it in the event of failure of servo-assistance. The usual method also seems to be simpler mechanically than the alternatives.

The suggestion for fore-and-aft collective movement apparently stems from some design innovation being tried in the USA. However for the Wessex this arrangement does not seem to offer any real advantage over the conventional method and it does appear to have some disadvantages:

(i) the effect of collective control is mostly upwards so that a fore-and-aft control movement seems less compatible than an upwards, slightly rearwards movement;

(ii) the maximum forces available to operate the controls may be less in the case of the fore-and-aft arrangement; and

(iii) possible confusion in sense of operation arising in pilots who have previously flown helicopters in which the collective lever pivot is low enough to give a substantial rearwards movement when the lever is raised to increase collective pitch. Such pilots (and they may form the majority) would move a fore-and-aft collective to the rear to go up, whereas the usual convention can be interpreted as requiring upwards effect to result from a forward movement of the control.

The introduction of a fore-and-aft collective appears to be too important to be decided without controlled experiments on a representative number of pilots. If indeed the question has to be settled before the proposal can be given an adequate investigation, the conventional style of collective must be retained. In this event, fore-and-aft and vertical adjustment of the handgrip must be provided, however. The ranges of adjustment would need to exceed the ranges of crew seat adjustment (see Section 4.2) by appropriate distances obtained from the 1977 anthropometric survey of Australian Defence Force personnel (Ref. 3).

2.3 Consoles

Little can be said about the consoles insofar as the available space and position is largely determined by the aircraft structure and the size and shape of individual pieces of equipment mounted in the consoles. However all controls, switches and displays in the consoles, both central and overhead, should be within easy reach or sight, as the case may be, for the full anthropometric range of aircrew. Furthermore, all components of the aircrew-consoles interface should comply with standard ergonomic practice (e.g. shape coding of knobs) and no item should be located aft of the pilot or require unusual head attitudes to see or operate because of the risk of spatial disorientation. These points cannot readily be detailed in a document of this sort: practical examination in a cockpit mockup and/or the actual cockpit is necessary.

One further point seems worth consideration: at present the overload protection for electrical circuits in the Wessex is a large bank of fusible links in the nose of the aircraft. These are inaccessible in flight. The value of having circuit breakers instead of fuses and of having these readily accessible in flight has been demonstrated so often in practice that it is a practically universal arrangement in modern aircraft. If the Wessex life-of-type (LOT) is to be extended for 15 years, it would seem mandatory for circuit breakers to be installed for in-flight accessibility. Perhaps space for them could be arranged in one or other of the consoles.

2.4 Stowage

A recent RAAF report highlighted the inadequacy of stowage space and facilities in RAAF aircraft for maps, navigation equipment, rations and essential personal items (Ref. 4). At a glance, the Wessex can be seen to have the same problems. The quantity of essential aeronautical information required to be carried has increased steadily since the Wessex was introduced in RAN service, and there is little reason to doubt that the trend will continue. Sufficient stowage facilities therefore have to be provided not just for the quantity and size of items currently carried but for those estimated to be required approaching the LOT.

One current stowage space consists of a small box situated above and behind the pilot's head. Because of the risk of items falling out or being dropped and because of the risk of disorientation, this stowage area is unacceptable for use in flight by pilots and thus constitutes a flight safety hazard in the present Wessex fleet.

The actual disposition of stowage facilities in the refurbished Wessex is again a matter best decided by examination of the possibilities in a cockpit mockup and actual cockpits. Anthropometric constraints need to be considered. If the open area under the crew seats between the cockpit floor and bulkead is to remain, then some device (e.g. a removable wire grille) should be provided to prevent the unintended passage of articles through this area.

2.5 Secondary Safety

With the possible exception of full harness crew restraint systems, the secondary safety features of most aircraft seem to be inferior to current automotive practice. In the Wessex several features were readily identified as posing potential hazards in the event of a crash, viz.:

(i) the gap under the crew seats mentioned in Section 2.4 appears likely to increase the risk of injury to the occupant if a crew seat breaks loose;

(ii) the absence of crash padding on the hard metal edge at the bottom of the instrument panel; and

(iii) the antitorque pedals and associated hydraulics and adjusting mechanism may cause foot or leg injury, or trap the lower limbs, in the event of a crash with a substantial G_x deceleration.

Other aspects of the proposed Wessex modernisation affecting secondary safety appear worth consideration, viz.:

(a) structural integrity of the cabin area in the event of an accident;
(b) crew protection in the event of a major mechanical failure of an engine;
(c) smoke/fume contamination of the cockpit from the engine compartment both in normal operating and failure modes; and
(d) cabin isolation from the engine compartment during an engine fire.

3. INSTRUMENT PANELS

3.1 Layout

The present Wessex instrument panels reflect no credit on the designers. Instruments are laid out in a capricious fashion by present standards, and granted that standard layouts were in their early days when the panels were first produced, the logic of placement is barely evident. Warning lights, too, are in disarray, as they are in no less than six different locations. One could wonder whether Wessex pilots have a permanently induced nystagmus! Certainly, warning systems should follow the guidelines given by Munns (Ref. 5).

Two proposed panel layouts have been seen by the authors. The first, proposed by AMAFTU, makes use of colour-coded strip instruments with redundant digital counter displays for functions such as engine speeds and temperatures. The second, by the contractors, uses conventional dial instruments like those in the Sea King. Both are basically good layouts, and preferences for features of one or the other need to be considered together with factors such as cost, availability, engineering practicability and commonality (with Sea King) of the alternatives. The contract stipulates Sea King commonality although some case could be made for commonality with the new helicopter for FFG ships, an announcement of the type apparently being imminent.

Whichever layout or combination of layouts is finally chosen, it needs to pass close scrutiny in simulated flights in a cockpit mockup. Other requirements, apart from compliance with relevant DEF (AUST) or ASCC standards (where these are unexceptionable) should include a bias towards single pilot operation (e.g. some instruments tilted to face the pilot).

3.2 Lighting

The instrument lighting should be all-white as the laboratory advantages of red lighting are not of much account in quasi-operational situations by comparison with the disadvantages in loss of colour coding of instruments and difficulties of map reading (Ref. 6). Red should be present only as a connotation of danger. The actual colour of the light obtained from incandescent lamps at rated power is white with a correlated colour temperature of about 3200 K. If dimming is achieved by reducing the power (whether by voltage, current or pulse-width control), the emitted light becomes reddish. Even with lamps at the lowest operationally useful light output, at which the correlated colour temperature may be as low as 1000 K, there is still enough energy in the green and blue parts of the spectrum to allow useful colour rendition of items such as colour coded sectors on instruments and coloured markings and legends on maps. This appears to combine some of the advantages of both the all-red and all-white systems without introducing any serious disadvantages. It is questionable whether any real advantage is to be gained by specifying the interposition of colour-temperature-raising bluish filters (such as 'Arctic White') as the power dissipated by each lamp has to be markedly increased to make up for the large absorption of light at the red end of the spectrum by these filters.

AMAFTU has suggested the replacement of 'eyebrow' and pillar lighting by integral lighting wherever practicable. Integral lighting is superior in the evenness of illumination produced on the instrument face but it does, at least in some cases, require much greater maintenance effort and it also seems to be much more troublesome in terms of unwanted reflections in the cockpit transparencies. It appears that each instrument should be examined with these points in mind before any decision is made about its installation or method of illumination.

Daytime floodlighting should be available so that the luminance of the instrument panel can be increased when necessary to reduce the luminance difference between the external field and the instrument. Small luminance differences keep the out-to-in visual transition time close to the minimum practicable and thereby enhance operational effectiveness and safety. Particular care is necessary with such floodlighting to ensure that only the instrument panels are lit, i.e. unwanted illumination of scatterers on the transparencies has to be avoided or perception of small low-contrast external objects may be degraded. A light-baffle system recently developed at ARL may be useful in this connection.

Lighting of legends on instrument panels and consoles can be achieved by external illumination of opaque lettering or by use of internally lit so-called plastic plate legends. AvP970 in fact specifies the latter. Unfortunately, one of the most useful potential advantages of plastic plate legends is seldom realised in practice, viz. the possibility of controlling the directional distribution of the emitted light so as to minimise the problem of illuminated legends causing undesirable reflections in the cockpit transparencies. Careful consideration of the lighting and form of each legend may result in useful improvements in this respect without compromising the requirement for visibility of the legends to be maintained in the event of failure of individual lamp bulbs.

It is stressed that it should be possible for the pilot to set all the brightness controls for the cockpit lighting to the desired levels quickly in flight and furthermore, that at any level chosen, all instruments should have the desired brightness relative to their neighbours. This is rarely the case in production aircraft in the writers' experience, presumably because of the mixture of instruments from different manufacturers with their different lighting systems, and presumably also because of within-tolerance variations between nominally identical aircraft. A methodology for balancing instrument lighting was developed in ARL–ARDU collaboration during the evaluation of Nomad for the Army and this method would appear applicable in the case of the Wessex. It may be that each aircraft would need to be examined individually. The ergonomics aspects of the method are described in Reference 7.

3.3 Cover Glasses

Perceptible reflections of the cockpit interior by day, and of illuminated parts of the interior by night (including parts of the lighting system) are present in the instrument cover glasses of nearly all aircraft, and the Wessex is certainly no exception. The effects of these reflections on crew performance range from serious to insignificant. The more important effects do not usually seem to be apparent or known to crew members. Pilots tend to 'get used to' such reflections and are often not even conscious of their presence; in other words they 'look through' or otherwise ignore the reflections, an act which is made easier by the difference in accommodative and convergence stimuli presented by the reflection on one hand and the instrument display on the other. Nevertheless, the reflections have an insidious effect on instrument perception, principally by reduction of contrast and by overlay of distracting, irrelevant detail. As the reflections affect both operational effectiveness and flight safety, and the magnitude of the reflections can be reduced to about one quarter by the application of inexpensive commercially available anti-reflection coatings, there should be no compromise: all instrument cover glasses must be anti-reflection coated.

4. SEATING

4.1 Comfort and Crashworthiness

If a pilot's seat is uncomfortable enough to cause pain after an hour or two of use it can be regarded as a flight safety hazard because of the possibility of distraction from the flying task. Discomfort may also result in a reduction of the pilot's motivation to fly and navigate precisely and thereby reduce operational effectiveness. Many aircraft crew seats are more-or-less uncomfortable and the Wessex seats are certainly in that category. Uncomfortable cabin seats may also impair the operational effectiveness of the occupants and again the seating arrangements currently in the Wessex are notably poor. The problem is worse in helicopters than fixed wing aircraft because the levels of vibration are generally much greater. Seat arrangements which could otherwise be quite satisfactory may actually enhance vibration, i.e. the occupant may have a vibration amplitude several times greater than the amplitude of the floor at the seat attachment points. As the frequencies present in helicopters envelop the range of frequencies at which components of the human body resonate, the problem is serious in practice. Strenuous efforts are justifiable in ensuring that all seats in the Wessex are adequately comfortable both statically (on the ground) and dynamically (in flight).

Human tolerance to deceleration when seated and securely restrained by a standard aircraft shoulder harness is at least $\pm 25\,G_x$, $+25\,G_z$, $-7{\cdot}5\,G_z$ and $\pm 15\,G_y$ (Ref. 8). Unfortunately these tolerances have been ignored by or not known to the majority of aircraft seat designers in the past with the result that most aircraft crew and cabin seats fail structurally at loads specified in design guides to be as small as 2G in some instances. The result is that seats tend to break loose in otherwise survivable crashes or hard landings and because of the much greater potential for injury in the absence of body restraint, literally thousands were unnecessarily killed or severely injured in helicopter crashes in the US Army alone in the 3 years from 1967 to 1969 (Ref. 9). Since these findings became apparent, much effort has gone into the testing and production of crashworthy crew and troop seating in the USA and also the UK (e.g. Ref. 10). As AvP970 specifies design loads which are only about half of those given in Reference 8, AvP970 is clearly an inappropriate guide in this matter. If the Wessex seats were designed to comply with AvP970 they may require replacement or modification.

4.2 Crew Seats

The present Wessex crew seats are totally unsatisfactory in terms of comfort on the basis of accounts from operators and the judgements of the writers. The seat cushion has a domed shape, the opposite of what is needed and the backrest gives inadequate support. When the survival pack is used in place of the backrest cushion, shoulder support is inadequate. The backrest-seat angle is large, although this may not be a disadvantage. It appears that the seat cushion slope might usefully be increased by five or ten degrees. To quote again from Reference 1:

> "Loss of lumbar lordosis can occur in helicopter seats and can give rise to low back pain, but, apparently it is extension rather than flexion of the spine which causes the most severe form of lower back discomfort in these pilots. This form of spinal deformation is most likely to occur either when the aircraft is flying forwards at high speed or when an underslung load is being carried. Both of these flying conditions induce a nose-down attitude in the aircraft which gives the pilot the feeling that he is falling out of his seat; when he attempts to combat this tilted position by tightening his shoulder harness he may well make matters worse by increasing the degree of spinal extension. A large number of helicopter pilots felt that a further five or even ten degrees of rearward tilt should be built into the back of helicopter crewseats. The seat in the Wessex MK2 was frequently mentioned in this context . . ."

What is needed for the Wessex is a completely new crew seat, with fore-and-aft adjustment, height adjustment, backrest rake angle or whole seat tilt adjustment, adjustable arm supports, contoured seat and backrest cushions and a properly shaped survival pack. Woolled sheepskin upholstery is most desirable for the cushions and pack (Ref. 11). The vibration damping characteristics of the seat assembly could be improved substantially by using elastomeric rubber isolators (Ref. 12). The vibration limits specified in AvP970 are inapplicable in the light of more recent work (Ref. 13). If it is not practicable at this stage to incorporate energy absorption devices for crash protection, at least the seat and its supporting structure should remain intact (i.e. no hazardous breaks or deformation) at the 25G levels mentioned above. Anthropometric data for the seat design can be taken from the 'Humanscale' guide (Ref. 14), modified where necessary to incorporate data from the 1977 anthropometric survey (Ref. 3).

4.3 Cabin Seats

The seats proposed for the Wessex cabin are apparently of the tube front rail and stretched canvas type. The comfort and crashworthiness of this type could be suspect. Although comfort may not be as important to a passenger as is the case for pilots, it is not unimportant and there can be no justification for proposing a cabin seat which is uncomfortable simply because the designer had insufficient knowledge. Small mass and ease of stowage are important considerations for the Wessex cabin seats but they should not override crashworthiness considerations. For instance, aft-facing seats are the most preferred type, followed by forward-facing seats. Side-facing seats should be avoided (Ref. 9).

5. VISION

5.1 External Vision

Vision is the most important of the senses used in flying. Clear, unobstructed vision is desirable but the mechanical and physical requirements of aircraft structures always lead to an adverse affect. For instance, canopy frames occlude part of the external visual field and transparencies always reduce the apparent contrast of external objects by overlaying a veiling glare originating in surface imperfections, dirt and dust, inherent scatter, reflections and fluorescence.

Some of these factors may be beyond control, but others are not. In the Wessex, the external fields of view are, by inspection, limited to such an extent that the fields could be regarded as inadequate for military purposes. A discussion of the desirable extent of the field of view in military strike aircraft in Reference 15 provides some support for this statement. Because of the curious placement of the engine in the Wessex, low forward vision is obstructed badly, and 'chin' windows or equivalent, a feature of practically all other modern helicopters, are not available. Vision in the low forward direction is of demonstrable major importance in helicopters (e.g. Ref. 16). Landing in autorotation, a necessary manoeuvre in the case of helicopters with power or transmission failure, requires considerable skill on the pilot's part in correct timing and extent of the pre-touchdown nose-up flare, and the lack of adequate low forward vision in the Wessex causes added difficulty which some pilots try to circumvent by executing the manoeuvre with their heads out the cockpit side windows. Misjudged landings in autorotation are a major source of damage to helicopters. One further point in connection with the poor low forward vision in the Wessex: Sliosberg (Ref. 2) stated that if the external field was hindered by the control panel, the pilot had to lean forward to see, thus accentuating the poor seated posture responsible for backache in helicopter pilots. The situation in the Wessex is poor to begin with, and is made worse by the relatively high top of the instrument panel and by instruments actually mounted on top of the coaming. A fully adjustable crew seat would allow some improvement.

In two of the three Wessex helicopters inspected, much of the external and internal surfaces of all the cockpit transparencies were covered with a layer of oil. In some areas the deposit was continuous but mostly it consisted of minute droplets as if deposited from an oil mist. In both cases the effect on external vision by day was marked: objects that had near-threshold contrast when seen through clean parts of the windshield just disappeared when viewed through the oil-contaminated parts. This is a flight safety hazard especially as the effects are insidious. The source of the oil was not ascertained but it was thought to be mostly due to seepage from the main gearbox. Other possible sources were leaks in the hydraulic system and oil used on the structure of the aircraft as an attempted corrosion control measure.

5.2 Internal Vision

The oil layer was also present on instrument cover glasses (in fact, on every surface in the cockpit). Instrument indications could still be seen, but legibility was definitely degraded. This would matter little in ordinary flight but in an overload situation (e.g. any in-flight emergency) it could be crucial. Oil would have a detrimental effect on the performance and possibly on the durability of anti-reflection coatings on instrument cover glasses. Oil mist deposited in flight on pilot's visors would add to the adverse effects already described, especially in sunlit or moonlit conditions.

AvP970 specifies "The instrument and panel lighting shall be arranged to avoid reflections from the windscreen, other transparent panels or objects in the crew station". Insofar as this is possible by panel layout, directional lighting and shields, such reflections ought to be avoided by these means. The geometry of the cockpit transparencies themselves is of fundamental importance also, and by inspection the Wessex transparencies are arranged almost in the optimum way to maximise the number of internal reflections produced. Serious consideration should therefore be given to rearrangement of the whole cockpit structure and its transparencies in order to meet the requirements of AvP970 which are presumably based on the recognition that internal reflections in the transparencies can degrade flight safety and operational effectiveness.

6. ENVIRONMENT

Designers have long recognised the need to control the environment in which machines operate, for to exceed the design limits of a machine usually results in a predictable failure of some component with a demonstrable degradation in system performance. However, this same concern is often not present when considering the environment in which man, the human 'system component' is expected to operate. Certainly man is flexible and adaptable to a wide variety of work situations, but this is seldom a cost-free process (Refs 17, 18 and 19). The pilot of a helicopter is required to perform a demanding task (Ref. 20), often with little margin for error, whilst subjected to harsh environmental factors of temperature, noise and vibration.

6.1 Temperature

The deep body temperature of a sedentary or lightly exercising human subject is maintained within a narrow range (approximately $\pm 0{\cdot}5$°C) during a 24 hour period despite quite large changes in the environmental conditions. This is achieved by a complex internal thermoregulatory system. In addition to the control of the energy transfer at the body's surface by vasomotor and several gland functions, the shiver reflex can generate internal heat energy in low temperature environments.

Of particular importance to Australian operations is the behaviour of the thermoregulatory system in elevated temperature environments, as the margin between normal and injurious body temperatures is relatively small at this end of the scale (Ref. 21). The body combats an increased thermal energy load (this could be generated internally as in heavy work or exercise) by vasodilatation, allowing a greater blood volume in the surface tissues, and increased secretary activity of the sweat glands. Substantial fluid loss coupled with extensive vasodilatation may result in hypotension and subsequent 'heat exhaustion' (fainting, nausea etc.). In this state the skin may be damp and cool, with internal temperatures within limits, but the diminished blood supply to the head (as a result of lowered blood pressure) may result in a temporary loss of consciousness. This effect is likely to be aggravated in positive G manoeuvres. A second, more serious condition results from the failure of the sweating mechanism. This condition is characterised by a hot dry skin and rising body temperature, often accompanied by delirium and unconsciousness. If this temperature rise is unchecked, 'heat stroke' results, leading to brain damage or even death.

Certainly in these extreme cases the performance decrement is total at the point at which consciousness is lost. Of more practical interest is the extent to which less extreme thermal stresses degrade performance. Grether (Ref. 22) reviewed the literature relevant to performance in elevated environmental temperatures for various types of tasks, viz. time estimation, reaction time, vigilance and monitoring, tracking, cognitive and other skilled tasks. The summary of findings from his report is consistent with an arousal theory of behaviour with thermal load acting as a stressor. The most significant conclusion to be drawn is that generally, cognitive and complex skilled tasks are adversely affected by environmental conditions of 29°C effective temperature (ET)(i) and greater. This level appears to coincide with the thermal load at which the thermoregulatory system loses authority over deep body temperature allowing an increase in the heat energy stored by the body core.

The ET measurement does not include the effect of radiant energy and for this reason, inter alia, the Wet Bulb Globe Temperature(ii) (WBGT) is considered to be a more satisfactory metric in aviation heat stress studies (Ref. 24).

A suggested limit for the maximum acceptable steady state cockpit WBGT can be established in a number of independent ways. Firstly, the 29°C ET established by Grether (op. cit.) as the critical crossover point for performance versus environmental demand can be converted to an equivalent WBGT using a number of assumptions. The ET value was converted to equivalent dry and wet bulb temperature using assumed relative humidities (RH) of 50% and 80% and

---

(i) Effective Temperature: an empirical unit combining the effects of dry bulb temperature, wet bulb temperature and air movement (Ref. 23).

(ii) Wet Bulb Globe Temperature: an empirical relationship relating dry bulb (*Tdb*) and wet bulb (*Twb*) temperatures together with the temperature of a black globe (*Tbg*), e.g.:

$$\mathrm{WBGT} = 0{\cdot}7\,Twb + 0{\cdot}2\,Tbg + 0{\cdot}1\,Tdb.$$

putting $Tbg = Tdb$ (i.e. assuming no additional radiant heat load in this instance). For the two levels of RH quoted, WBGT was calculated to be 28°C and 29°C respectively.

Secondly, the results of some studies involving radiant heat loads were examined (Refs 25, 26, 27), against the criterion for zero core heat storage established in Grether's review (op. cit.). For the 'sweating' copper manikin used in one study (Ref. 26) heat debt was small (<29 W) for a WBGT of 27°C. The 1978 study of Nunneley et al. (Ref. 27) showed increased rectal temperatures of approximately 0·5°C to 0·6°C (tending to a steady state) in WBGTs of 29°C and 31°C respectively. Increases in rectal temperatures of these amounts suggest the environmental conditions were just above the 'knee' in Lind's data (as quoted by Grether, op. cit.) and hence the maximum WBGT for general maintenance of performance should be just below these values. A somewhat different conclusion might be drawn from the earlier study of Nunneley and Myhre (Ref. 25). Despite a WBGT of 36°C, rectal temperature remained constant in these conditions. Nunneley and Myhre suggest that this may have been an artifactual outcome of the experimental situation in which almost dry air at 24°C was discharged at a rate of approximately 5·4 Ls^{-1} in the vicinity of the subject's legs, hence depressing rectal temperature. Thus rectal temperature may have been a biased estimate of mean core temperature, not reflecting net energy storage even if this did occur. Two aspects of the experimental results support this view: firstly, falling rectal temperature during the time course of heat exposure and secondly, accompanying increases in sweat and heart rates.

The third method used to derive a maximum WBGT specification was to use the results of a study that draws together much of the previous work on the effects of thermal environment on human performance (Ref. 28). The results of this review are summarised in two figures (one for mental reaction time, the other for combined tracking, vigilance and complex tasks) giving WBGT for various exposure times at different levels of probability that a statistically significant performance decrement will result from the imposed conditions. An important conclusion is that the effects of thermal stress on tracking, vigilance and complex tasks are only very weakly time dependent. For a 0·5 probability that a performance decrement will result from the imposed conditions, the WBGT is 28°C to 29°C. It follows from the relationship for mental reaction time performance, that a decrement can be expected (0·5 probability) for this class of tasks after a 125 to 150 minute exposure to these temperatures.

Although it is not clear how many of the data used by Ramsey and Morrissey (Ref. 28) include a radiant energy component in their thermal load, there appears to be a consistent trend in the studies previously cited. This trend is to establish 28°C to 29°C WBGT as the critical value at which performance on complex tasks is expected to degrade and at which there is a net thermal energy gain characterised by increasing core temperature.

It is recommended that the Wessex modernisation provide facilities to maintain thermally imposed stresses within the limits discussed in this Section. Depending on the environmental extremes in which the aircraft is expected to operate and the thermal properties of the airframe and equipment (heat from the engine, hydraulic and electrical systems etc.), provision of these facilities may require one or more of:

(i) an adequate supply of air at ambient temperature, directionally controllable (i.e. at the head and face particularly) and available during all ground and air operations (including the hover and ground running situation);

(ii) cabin conditioning, i.e. a supply of air at other than ambient temperature and/or humidity; and

(iii) personal conditioning, e.g. liquid conditioned garments, air ventilated helmets etc.

In the case of (i) and (ii), cabin environment should be controlled to a maximum WBGT of 28°C to 29°C. For personal conditioning, cooling sufficient to prevent heat energy storage over the range of environmental conditions would be required.

6.2 Noise

Although noise and vibration usually occur together, these two stressors will be considered separately in so far as they exhibit specific effects on human performance. There are two aspects of noisy environments that must be considered, viz.:

(i) potential for noise-induced hearing loss; and

(ii) effects on speech intelligibility.

6.2.1 Damage risk criteria

A questionnaire was administered to RN aircrew, as part of a study of environmental variables of Sea King helicopters (Ref. 29), in which respondents were asked to judge the relative noise levels of a number of RN service helicopters (Hiller, Wessex, Whirlwind and Sea King). Of the 69 respondents, 77% judged the Wessex to be the worst of this group. Of particular significance to the current Wessex refurbishment is the fact that the measured noise levels at the crews' ears (i.e. under a MK3 flying helmet), in the case of the Sea King, already exceed limits that may cause permanent hearing damage (e.g. the limits set by NAS-NRC CHABA Working Group 46, Ref. 30). These figures do not include communication system sound pressure levels and therefore they are likely to be conservative estimates of the potential for auditory damage. In view of the perceived 'noisiness' of the RN Wessex it appears likely that the envisaged configuration for the RAN modernised Wessex will pose a similar threat to hearing.

6.2.2 Speech intelligibility

Speech communication is an integral part of most aircraft operations. The most valid measure of how well a communications system is functioning is the degree to which information is correctly perceived at the receiving end of the system. In aviation this is usually a three-way process, with information being transmitted from air to ground, ground to air and from one crewmember to another. Noise fields in aircraft cabins may disrupt voice communications by masking at the crewmember's ear or by adding to voice information at the crewmember's microphone.

Maslin (Ref. 31) recently reported a method for specifying maximum permissible noise levels in aircraft cabins. The method attempts to provide for satisfactory communications as well as protection against hearing loss. This technique can be modified to include other noise-induced effects (effects of other tasks, temporary threshold shift, noise-induced fatigue, interference with short term memory etc.). The advantage claimed for this method (Ref. 31) over other approaches (e.g. Ref. 32) is that it can be used to assess situations in which the noise spectrum exceeds defined limits at some frequencies but is less at other frequencies. The spectral limits developed in Reference 31 would need modification before being applied to the Wessex modernisation project. The additional factors that should be included in the computation include:

(i) noise entering the communication system through the crewmember's microphone;
(ii) the upwards spread of auditory masking due, particularly, to the major discrete components of the noise spectrum;
(iii) reduction in speech intelligibility due to task sharing (Ref. 33);
(iv) loss of helmet attenuating properties due to poor fit or wear (Refs 29, 34); and
(v) possible reduction in intelligibility at the high sound pressure levels (105 dB re 20 μPa overall level, in $\frac{1}{3}$ octave bands from 315 Hz to 3·15 kHz) used by Maslin (Refs 35, 36).

6.3 Vibration

Vibration may affect task performance either directly (e.g. reduced legibility of vibrating displays (Ref. 37), interaction with arm-hand coordination in tracking tasks (Ref. 38)), or indirectly through a reduced feeling of well being (Ref. 39) or predisposition to certain pathological conditions (Ref. 2). Griffin (Ref. 13) recommended limits for whole body vibration, specifically for the helicopter environment. His document includes a proposed amendment for incorporation into AvP970 dealing with the three critical aspects of vibration exposure, viz.:

(i) whole body vibration (linear and angular);
(ii) legibility of vibrating displays; and
(iii) vibration of peripheral parts of the body.

These recommendations are summarised in Appendix I.

For the Wessex modernisation program, vibration spectral density function may be largely determined by the proposed engine/airframe configuration. However, the crew chair transfer function provides a means for limiting the vibration-induced accelerations applied to the crewman. As mentioned previously, experimental elastomeric isolators have been used in laboratory studies of the Lynx helicopter crew seat ~~chair~~ (Section 4.2) to provide attenuation at the dominant main rotor blade passing frequency (Ref. 12).

7. CONCLUSIONS

The proposed refurbishment of existing RAN Wessex helicopters presents a number of problems related to the man-machine interface. These problems have largely arisen because many of the interface aspects thought good enough for the crew over two decades ago when this aircraft was being designed are now known to be deleterious to human performance and survival. Thus, while it is no doubt feasible to re-engine and otherwise recondition the Wessex so that it will continue to function as a mechanism for another decade or two, the performance of the Wessex *system* which depends on the performance of the human component may be inadequate for the outlay involved in extending the Wessex LOT. This Note has identified the interface aspects of the Wessex thought to have the most adverse effects on human performance, and in many of these cases, attempts have been made to suggest solutions or improvements.

In summary, the Wessex cockpit is badly located and this restricts external vision and hampers crew mobility. The crew and cabin seats are uncomfortable and probably unsafe in survivable crashes. The crew seats lack adequate modes and ranges of adjustment and are not in anthropometrically determined harmony with the controls. The controls also require provision for positional adjustment. Instruments and switches are badly located, the fuses cannot be reached in flight and cockpit stowage space for flight and navigation handbooks, documents and equipment is inadequate. Cockpit lighting is sub-standard. Reflections in, and oil contamination of instrument glasses and the cockpit transparencies handicap the crew in routine tasks and may cause a crucial loss of performance in emergencies. Cockpit temperatures in hot weather are thought to rise so high that operational effectiveness and flight safety are badly degraded, and some system of crew cooling is necessary. Cockpit and cabin noise is also a serious problem and substantial improvements to the aircraft communications system and personal equipment such as helmets may be necessary to maintain or improve speech intelligibility without hastening the onset of hearing loss in crewmembers. Vibration in the Wessex is reported to be severe and substantial improvements to the crew seats appear necessary to reduce the adverse effects of vibration on human performance (e.g. vision and health). The long-term effects of helicopter vibration and ergonomically poor controls placement on the human body have begun to be recognized comparatively recently and, together with the trend for increasing personal damages litigation, provide a powerful incentive for helicopter-operating organisations to eschew out-moded concepts of minimal consideration for occupational health.

REFERENCES

1. Fitzgerald, J. G. and Crotty, Jane. The incidence of backache among aircrew and groundcrew in the Royal Air Force. FPRC/1313, Flying Personnel Research Committee, UK Ministry of Defence, February 1972.

2. Sliosberg, R. Backache in helicopter pilots. Analysis, etiology, treatment and prevention. Library Translation 1857, Royal Aircraft Establishment, Farnborough UK, May 1975.

3. Hendy, K. C. 1977 Australian tri-service anthropometric survey. Systems Report No. 15, Aeronautical Research Laboratories, Melbourne, August 1979.

4. Mather, P. J. Stowage of flight documents—single place aircraft. Report No. TI555, Aircraft Research and Development Unit, RAAF Edinburgh, March 1978.

5. Munns, M. Ways to alarm pilots. *Aerospace Medicine*, 42 (7), 732–734, 1971.

6. Johnson, N. A. and Poston, A. M. A comparison of red and white cockpit lighting under quasi-operational conditions. Report No. HEL-TM-6-76, Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, USA, January, 1976.

7. Clark, B. A. J. Cockpit vision assessment. In Vol. 2 of Nomad cockpit assessment, Report No. TS1638, Aircraft Research and Development Unit, RAAF Edinburgh, September, 1978.

8. Reader, D. C. Helicopter crew seat design. Report No. 365, RAF Institute of Aviation Medicine, Aircrew Equipment Group, Farnborough, UK, 1975.

9. Singley, G. T. III, Desjardins, S. and Reilly, M. J. Crashworthy Army helicopter crew and troop seating systems. Proceedings of Eleventh Annual Symposium, Survival and Flight Equipment Association, Phoenix, Arizona, USA, 1973.

10. Jamieson, J. and Reader, D. C. An assessment of the production Lynx crew seat and harness under dynamic conditions. Report No. 408, RAF Institute of Aviation Medicine, Aircrew Equipment Group, Farnborough, UK, 1976.

11. Garrow, C. and Wooller, J. The use of sheepskin covers on vehicle seats. *Ergonomics*, 13 (2), 255–263, 1970.

12. Jessop, D. A. C., Grimster, W. F. and Holliday, C. D. Aircrew seat design study—interim report. Research Paper 568, Westland Helicopters Ltd., Yeovil UK, March 1978.

13. Griffin, M. J. The evaluation of human exposure to helicopter vibration. *Aeronautical Journal*, 81 (No. 795), 110–123, 1977.

14. Diffrient, N., Tilley, A. R. and Bardagjy, Joan. *Humanscale* 1/2/3. MIT Press, Cambridge, Massachusets, USA, 1974.

15. Green, G. N. External vision from the military cockpit. Technical Report 76045, Royal Aircraft Establishment, Farnborough, UK, 1976.

16. Frezell, T. L., Hofmann, M. A. and Snow, A. C. Aviator visual performance in the UH-1. Study II. Report 75–11, US Army Aeromedical Research Laboratory, Ft. Rucker, Alabama, USA, 1975.

17. Grether, W. F., Harris, C. S., Mohr, G. C., Nixon, C. W., Ohlbaum, M., Sommer, H. C., Thaler, V. H. and Veghte, J. H. Effects of combined heat, noise and vibrational stress on

human performance and physiological functions. *Aerospace Medicine*, 42 (10), 1092–1097, 1971.

18. Iampietro, P. F., Melton, C. E., Higgins, E. A., Vaughan, J. A., Hoffman, S. M., Funkhauser, G. E. and Saldivar, J. T. High temperature and performance in a flight task simulator. *Aerospace Medicine*, 43 (11), 1215–1218, 1972.

19. Stave, A. M. The effects of cockpit environment on long term pilot performance. *Human Factors*, 19 (5), 503–514, 1977.

20. Billings, C. E., Bason, R. and Gerke, R. J. Physiological cost of piloting rotary wing aircraft. *Aerospace Medicine*, 41 (3), 256–258, 1970.

21. Hardy, J. D. and Bard, P. Body temperature regulation. In N. Mountcastle (Editor), *Medical Physiology*: *Volume II*. Thirteenth edition. C. V. Mosby Co, St Louis, USA, 1974.

22. Grether, W. F. Human performance at elevated environmental temperatures. *Aerospace Medicine*, 44 (7), 747–755, 1973.

23. Poulton, E. C. *Environment and Human Efficiency*. Charles C. Thomas, Illinois, USA, 1970.

24. Harrison, M. H., Higenbottam, C. and Rigby, R. A. Relationship between ambient, cockpit, and pilot temperatures during routine air operations. *Aviation, Space and Environmental Medicine*, 49 (1), 5–13, 1978.

25. Nunneley, S. A. and Myhre, L. G. Physiological effects of solar heat load in a fighter cockpit. *Aviation, Space and Environmental Medicine*, 47 (9), 969–973, 1976.

26. Breckinridge, J. R. and Levell, C. A. Heat stress in cockpit of the AH-1G Hueycobra helicopter. *Aviation, Space and Environmental Medicine*, 41 (6), 621–626, 1970.

27. Nunneley, S. A., Dowd, P. J., Myhre, L. G. and Stribley, R. F. Physiological and psychological effects of heat stress simulating cockpit conditions. *Aviation, Space and Environmental Medicine*, 49 (6), 763–767, 1978.

28. Ramsey, J. D. and Morrissey, S. J. Isodecrement curves for task performance in hot environments. *Applied Ergonomics*, 9 (2), 66–72, 1978.

29. Lovesey, E. J., Gray, R., Rood, G. M., Howells, H., Grimster, W. F., Holliday, C. D. and Jessop, D. A. Vibration and other measurements in RN Sea King helicopters. Technical Memorandum FS72, Royal Aircraft Establishment, Farnborough, UK, 1976.

30. Kryter, K. D., Ward, W. D., Miller, J. D. and Eldredge, D. H. Hazardous exposure to intermittent and steady state noise. *Journal of the Acoustical Society of America*, 39 (3), 451–464, 1966.

31. Maslin, K. R. Specifying permissible noise levels in aircraft. Technical Memorandum FS150, Royal Aircraft Establishment, Farnborough, UK, December, 1977.

32. Attwood, H. C. On the specification of maximum noise levels in aircraft. Technical Report 72089, Royal Aircraft Establishment, Farnborough, UK, June, 1972.

33. Johnston, M. E. The effect of a tracking task on speech intelligibility in noise. Technical Report 75014, Royal Aircraft Establishment, Farnborough, UK, March, 1975.

34. Greene, J. W. Technique for optimal fitting of flight helmets. *Aerospace Medicine*, 42 (12), 1338–1340, 1971.

35. Kryter, K. D. Effects of ear protective devices on the intelligibility of speech in noise. *Journal of the Acoustical Society of America*, 18, 413–417, 1946.

36. Pollack, I. and Pickett, J. M. Masking of speech by noise at high sound levels. *Journal of the Acoustical Society of America*, 30, 127–130, 1958.

37. Meddick, R. D. L. and Griffin, M. J. The effect of two axis vibration on the legibility of reading material. *Ergonomics*, 19 (1), 21–33, 1976.

38. Shoenberger, R. W. Human performance as a function of direction and frequency of whole body vibration. AMRL-TR-70-7, Aerospace Medical Research Laboratories, Wright Patterson Air Force Base, Ohio, USA, October, 1970.

39. Guignard, J. C. and King, P. F. *Aeronautical Aspects of Vibration and Noise*. AGARDograph No. 151, North Atlantic Treaty Organisation, Advisory Group for Aerospace Research and Development, November, 1972.

APPENDIX I: PROPOSED VIBRATION ACCELERATION LIMITS

(Summary of Griffin's proposals, Reference 13)

1. LIMITS FOR LINEAR MOTION

Definition: the vibration acceleration level (a_n) will be evaluated separately in the three translational axes x, y and z from the expression

$$a_n = [\int_1^{80}\{G_n(f).\,|H_n(f)|^2.\,S_n{}^2(f)\}\,df\,]^{\frac{1}{2}}$$

where:

$G_n(f)$ = acceleration power spectral density function in the n axis,

$H_n(f)$ = frequency response function of the chair in the n axis, and

$S_n(f)$ = assumed frequency function of human response to acceleration in the n axis.

For normal flight conditions the limits for a_n (determined over periods of 10 s or greater) are

$n =$	x	y	z	
(a_n) max =	0·3	0·3	0·4	ms^{-2} rms.

2. LIMITS FOR ANGULAR MOTION

Definition: the angular vibration acceleration level (r_a) will be evaluated as follows:

$$r_a = [\int_1^{80}\{h.d^{-1}\,A_a(f).|H_a(f)|^2.\,S_a{}^2(f)\}\,df\,]^{\frac{1}{2}}$$

where:

d = distance separating a pair of seat attachment points A and B,

h = average vertical distance from the seat attachment points A and B to the highest points on the seat normally in contact with the body,

$A_a(f)$ = power spectral density function of the instantaneous difference in vibration acceleration in the z-axis at the two points A and B,

$H_a(f)$ = frequency response function of the seat in the rotational axis centered about a horizontal line which bisects the line AB at right angles (may be estimated from $H_x(f)$ and $H_y(f)$), and

$S_a(f)$ = assumed frequency response function of human response to acceleration in the x and y axis.

Under normal flight conditions the limit for r_a (determined over periods of 10 s or greater) is 0·3 ms^{-2} rms for measurements made at any pair of points A and B to which the seat is secured.

3. LEGIBILITY OF INSTRUMENTS

The combined displacement for all frequencies greater than or equal to 3 Hz should not exceed ±0·25 mm. [The present writers suggest that this should apply at any part of any instrument dial.]

4. VIBRATION OF PERIPHERAL PARTS OF THE BODY

It is recommended that:

(a) no part of the head shall normally be in contact with any structure having, in any axis, a vibration level greater than $0 \cdot 4$ ms^{-2} rms in the frequency range 3 to 80 Hz, and

(b) the hands and feet shall not be required to operate or rest upon any device or structure having, in any axis, a vibration level greater than $1 \cdot 5$ ms^{-2} rms in the frequency range 3 to 80 Hz.

DISTRIBUTION

	Copy No.
AUSTRALIA	
Department of Defence	
Central Office	
Chief Defence Scientist	1
Deputy Chief Defence Scientist	2
Superintendent, Science and Technology Programs	3
Australian Defence Scientific and Technical Representative (UK)	4
Counsellor Defence Science (USA)	5
Defence Library	6
Assistant Secretary, D.I.S.B.	7–15
Joint Intelligence Organization	16
Aeronautical Research Laboratories	
Chief Superintendent	17
Library	18
Superintendent, Systems Division	19
Divisional File, Systems Division	20
Principal Officer, Cybernetics	21
Authors: K. C. Hendy	22
B. A. J. Clark	23
Materials Research Laboratories	
Library	24
Defence Research Centre, Salisbury	
Library	25
Central Studies Establishment	
Information Centre	26
Engineering Development Establishment	
Library	27
RAN Research Laboratory	
Library	28
Defence Regional Office	
Library	29
Navy Office	
Naval Scientific Adviser	30
O.C. Naval Air Station, NOWRA	31–32
AMAFTU	33
Director of Naval Aviation Policy	34
Deputy Director, Naval Aviation Policy	35–38
Deputy General, Naval Operational Requirements	39
Director of Naval Aircraft Engineering	40
Director of Nursing Services	41
Director of Psychology—Navy	42
O.C., HMAS Melbourne	43
Director General, Naval Operations and Plans	44

Air Force Office	
Air Force Scientific Adviser	45
Aircraft Research and Development Unit	46
Engineering (CAFTS) Library	47
D. Air Eng.-AF	48
HQ Support Command (SENGSO)	49
Director of Psychology—Air Force	50
C.O., Institute of Aviation Medicine	51
Army Office	
Army Scientific Adviser	52
Royal Military College Library	53
Department of Productivity	
Government Aircraft Factories	
Manager/Library	54
Department of Transport	
Secretary/Library	55
Airworthiness Group, Mr K. O'Brien	56
Director of Aviation Medicine, Dr. J. Lane	57
CANADA	
DCIEM, Head, Behavioural Sciences Division	58
CAARC Coordinator, Human Engineering	59
INDIA	
CAARC Coordinator, Human Engineering	60
NEW ZEALAND	
Air Department, RNZAF Aero Documents Section	61
CAARC Coordinator, Human Engineering	62
O.C., DEMU	63
UNITED KINGDOM	
CAARC Coordinator, Human Engineering	64
Royal Aircraft Establishment Farnborough, Library	65
Royal Aircraft Establishment Bedford, Library	66
RAF Institute of Aviation Medicine, Farnborough	67
Spares	68–78