AD-A096 329 AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA) F/G 1/3
R.A.N. SEA KING CABIN ENVIRONMENT SURVEY. PART 2. MEASUREMENT O--ETC(U)
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UNCLASSIFIED ARL/MECH-ENG-NOTE-377 NL

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LEVEL II

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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

MECHANICAL ENGINEERING NOTE 377

R.A.N. SEA KING CABIN ENVIRONMENT SURVEY

Part 2.

MEASUREMENT OF TEMPERATURE AND HUMIDITY

by

B. REBBECHI and D. H. EDWARDS

Approved for Public Release.

COPY No 9

NOVEMBER 1979

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AR-001-777

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SUMMARY

Measurements of temperature and humidity have been made in a Royal Australian Navy Sea King over a period of four months. These measurements were carried out as part of a survey of the cabin environment which had been reported to be sufficiently adverse to cause impairment of crew efficiency, even when operating in moderate ambient temperatures. This survey has shown that the cabin temperature may be up to 12°C above the outside air temperature; this temperature differential, however, tends to decrease with increasing outside air temperature. Cabin wet bulb globe temperatures reached 32·3°C in an outside air temperature of 29°C. A WBGT level of 28°C is generally accepted as the level above which crew performance decreases; this level was reached at an outside air temperature of only 19°C.

It is shown that operation of the Sea King to the extreme limits of outside environment such as the humid extremes of the Australian environment, or the United States MIL-STD-210B design environment (naval operations) would be quite impracticable, as it would be physiologically very hazardous to crew members.

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Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

- A

DOCUMENT CONTROL DATA SHEET

Security classification of this page: Unclassified

1. Document Numbers
   (a) AR Number:
   AR-001-777
   (b) Document Series and Number:
   Mechanical Engineering Note 377
   (c) Report Number:
   ARL-Mech-Eng-Note-377

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

3. Title: RAN SEA KING CABIN ENVIRONMENT SURVEY
   PART 2—Measurement of Temperature and Humidity

4. Personal Author(s):
   Rebbechi, B.
   Edwards, D. H.

5. Document Date:
   November, 1979

6. Type of Report and Period Covered:

7. Corporate Author:
   Aeronautical Research Laboratories

8. Reference Numbers
   (a) Task:
   NAV 77/18
   (b) Sponsoring Agency:
   Department of Defence (Navy Office)

9. Cost Code:
   43 4310

10. Imprint:
    Aeronautical Research Laboratories,
    Melbourne

11. Computer Program(s)
    (Titles and language(s)):

12. Release Limitations (of the document):
    Approved for public release

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

13. Announcement Limitations (of the information on this page):
    No limitations

14. Descriptors:
    Helicopters
    Aircraft cabins
    Human factors engineering
    Performance
    Environments
    Temperature
    Humidity
    Efficiency

15. Cosati Codes:
    0505
    0103

16. ABSTRACT

Measurements of temperature and humidity have been made in a Royal Australian Navy Sea King over a period of four months. These measurements were carried out as part of a survey of the cabin environment which had been reported to be sufficiently adverse to cause impairment of crew efficiency, even when operating in moderate ambient temperatures. This survey has shown that the cabin temperature may be up to 12°C above the outside air temperature; this temperature differential, however, tends to decrease with increasing outside air temperature. Cabin wet bulb globe temperatures reached 32·3°C in an outside air temperature of 29°C. A WBGT level of 28°C is generally accepted as the level above which crew performance decreases; this level was reached at an outside air temperature of only 19°C.

It is shown that operation of the Sea King to the extreme limits of outside environment such as the humid extremes of the Australian environment, or the United States MIL-STD-210B design environment (naval operations) would be quite impracticable, as it would be physiologically very hazardous to crew members.

CONTENTS

1. INTRODUCTION

The Sea King helicopters operated by the Royal Australian Navy have a cabin environment in which high levels of noise, vibration and temperature are experienced.

Following a meeting between RAN and ARL personnel (Department of Defence 1976),* ARL accepted the task of evaluating the cabin environment with respect to noise and vibration (separately reported by Pavia and Edwards 1977), and temperature and humidity.

Equipment was installed by ARL to enable the recording of cabin temperatures over an extended period, when several RAN Sea Kings were travelling to the United Kingdom on HMAS *Melbourne*. A wide range of climatic conditions could then be expected.

This report does not explore the reasons for the high cabin temperatures; however, an analysis of the source of heat inputs and suggestions for partial alleviation of the problem are given by Rebbechi (1977). A subsequent analysis of the heat balance for the cabin, and flight trials performance of an electrically powered vapour cycle cooling unit are reported by Rebbechi (1979).

The instrumentation used for the temperature survey and the results obtained are described in this note, together with an estimate of the effect on crew efficiency of operating the aircraft in environmental extremes.

2. INSTRUMENTATION

Temperatures at 10 locations in the aircraft (Figs. 1 and 2) were sensed by type K (NiCr/NiAl) thermocouples. A Fluke digital thermometer Model 2100A-10, mounted in the sonar operator's instrument rack was used to measure and display the thermocouple outputs by operator selection of the desired channel.

Because of the wide tolerance of line voltage and frequency permitted for power supply to the temperature indicator (180–256 V at 50–440 Hz), this equipment was satisfactorily operated from the aircraft alternating current supply of 200 V, line to line, at 400 Hz.

3. RESULTS

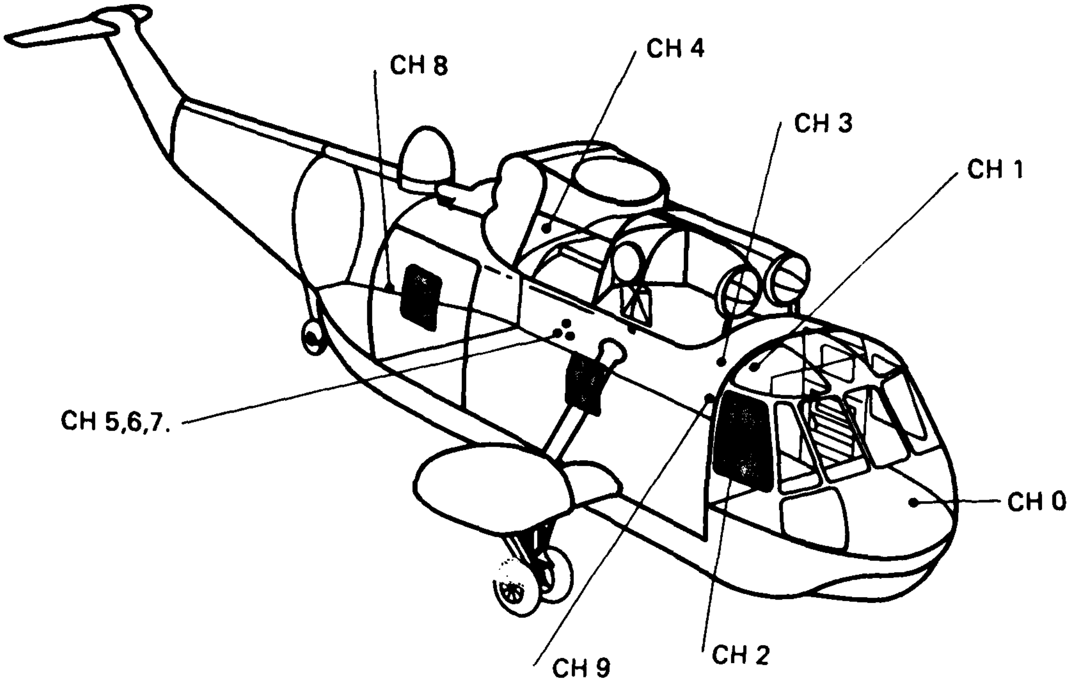
The complete results of the temperature survey are contained in Appendix 1. Data were available from March–June 1977, and were recorded in flight by the Sea King sonar operator. For nearly all of the flights the cabin ventilation air fan was on; where this was not the case the records are annotated accordingly. For the months of March, April and May information is not available as to whether the sonar equipment was on, or the front vent windows open. However, it can be assumed that the front vent windows were always open whenever the cabin became uncomfortably warm. Also the sonar could be assumed to be on for most of the flights, as the aircraft was at this time being used in its primary anti-submarine-warfare training role.

4. DISCUSSION OF RESULTS

4.1 Cabin Environment

The Wet Bulb Globe Temperature (WBGT) index is used here as a measure of the level of heat stress experienced by the crew. The index, which is defined in Appendix 2, has become widely used as a predictor of heat stress. An index level of 28°C is currently regarded as the upper limit for effective aircrew performance (Aircraft Research and Development Unit 1968; Nunneley

* References are listed at the end of this report.



CHANNEL	PARAMETER	LOCATION
0	Air temperature	Co-pilots feet area
1	Black globe temperature	Cockpit
2	Air temperature	Rear of pilot's seat, at chest height
3	Air temperature	Forward cabin
4	Skin temperature	Roof of aft cabin
5	Dry bulb temperature	Between sonar/navigator crew
6	Black globe temperature	Between sonar/navigator crew
7	Wet bulb temperature	Between sonar/navigator crew
8	Air temperature	Aft compartment
9	Outside air temperature	Cabin fresh air intake grill

FIG. 1: LOCATION OF TEMPERATURE SENSORS

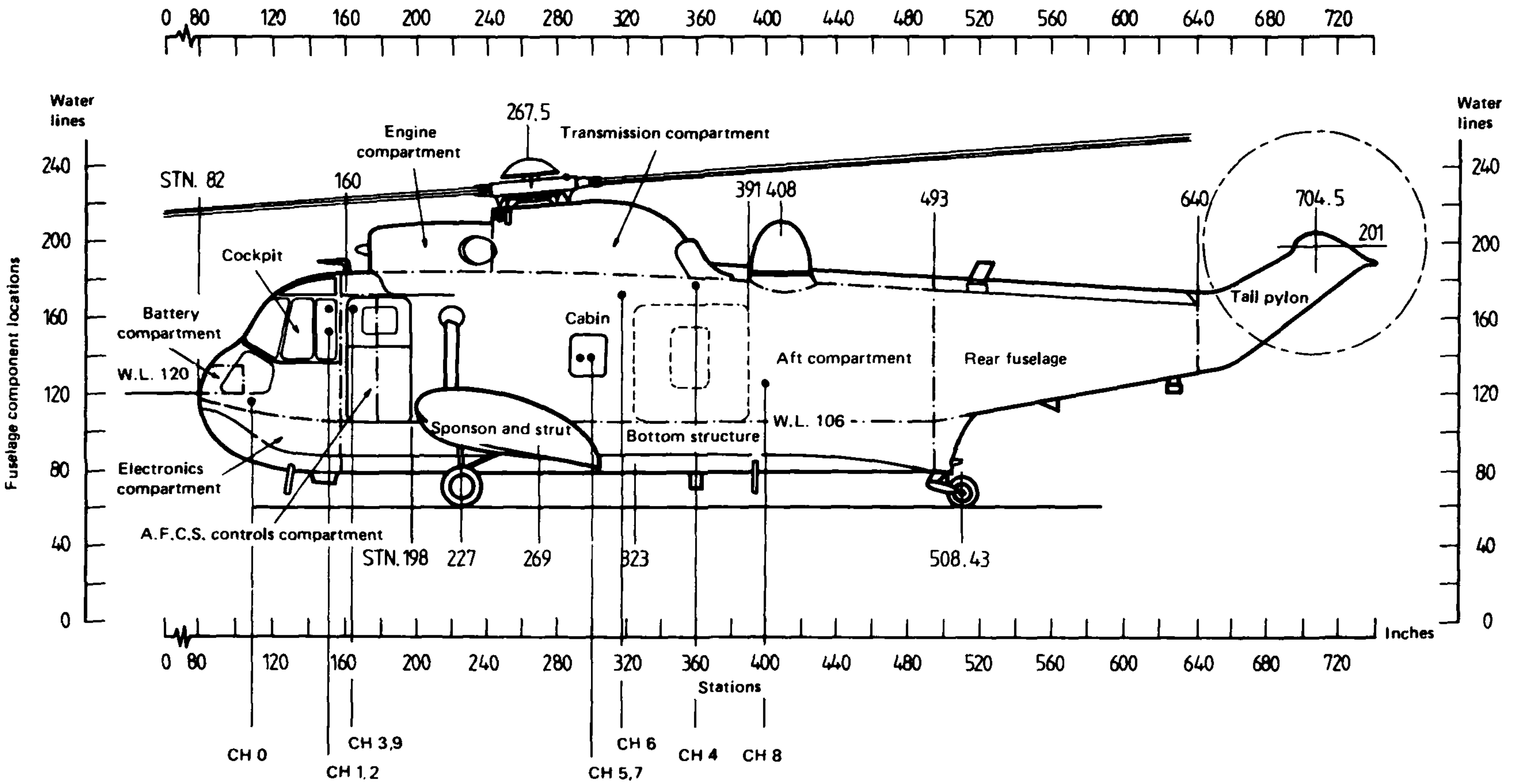


FIG. 2: LOCATION OF TEMPERATURE SENSORS AT VARIOUS AIRCRAFT STATIONS

et al. 1978). During flight trials carried out by the RAAF Institute of Aviation Medicine (1976), a WBGT level of 35°C was sufficient to induce a situation of near collapse in a subject after one hour.

The WBGT temperatures for the flight during which the highest cabin temperatures were recorded are given in Table 1. From this it can be seen that although the ambient climatic conditions were not severe, with an outside air temperature 28–29°C, the WBGT levels of 30–32·6°C are excessive from the viewpoint of crew efficiency.

TABLE 1

Sea King Temperatures

Date: 21 May 1977

Ground conditions at take-off: Dry bulb temperature, 29°C
Wind speed, 5 kn

Time:		1415	1515	1600
Flight phase: Cloud cover:		Forward 3/8	Hover 3/8	Forward 3/8
Temperatures (°C)	Recording channel			
Outside air	9	27·7	28·3	29·2
Co-pilot, feet area	0	34·8	34·4	34·4
Cockpit black globe	1	39·7	40·9	35·7
Rear of pilot's seat, at chest height	2	33·1	33·5	33·6
Forward cabin ceiling	3	32·6	39·2	44·1
Aft cabin skin	4	44·6	38·8	43·2
Sonar–nav. crew	5	32·3	35·6	35·6
Sonar–nav. black globe	6	32·8	36·6	35·4
Sonar–nav. wet bulb	7	28·8	30·6	30·4
Aft compartment	8	34·5	35·1	35·9
Cabin relative humidity (%)		76·0	65·0	65·0
Cockpit relative humidity (%)		72·0	70·0	70·0
WBGT (pilot) (°C)		31·6	32·6	31·4
WBGT (sonar–nav. crew) (°C)		30·0	32·3	31·9
Crew comment		Very hot and uncomfortable		

In Table 2 a comparison is given between WBGT levels and ouside air temperatures for two flights in which the cabin WBGT was approximately the recognised limit for effective crew performance of 28°C. It can be seen that the outside air temperature did not exceed 20·3°C; the cloud cover was described as haze (the extent of which, however, is not known).

TABLE 2

Sea King Temperatures

Date: 6 June 1977
Ground conditions at take-off: Dry bulb temperature, 23°C
Relative humidity, 74%
Wind speed, 10 kn
Cloud cover: Haze throughout flight

	Flight 1					Flight 2		
Time	1115	1200	1210	1215	1420	1425	1455	1515
Flight phase	On deck	Fwd.	Hov.	Hov.	Fwd.	Hov.	Hov.	Fwd.
Outside air temp. (°C)	20·3	20·3	18·9	18·9	19·3	19·6	18·8	19·0
WBGT (°C)	22·7	26·7	28·3	28·7	27·4	27·3	26·6	28·7

Tables 1 and 2 thus emphasize that only very moderate ambient temperatures result in effective cabin temperatures at which a deterioration in crew performance can be expected.

If the Sea King crew were to be required to operate in a more severe environment than encountered during this survey, then it is apparent that a physiologically hazardous state would be attained by the crew in any prolonged missions. It would be quite impracticable, for example, for the crew to operate in the humid extremes of the Australian environment, where typically the temperature can be 32°C and the absolute humidity 0·024, as a pilot WBGT of 32·6°C would then result (assuming a cockpit black globe temperature of 12·6°C above ambient, as in Table 1).

An even greater hazard would result from operation in the more severe design climatic environment of MIL-STD-210B for Naval Air Operations, where the prescribed temperature is 48°C, and the humidity ratio is 0·030 kg moisture/kg dry air. The resulting WBGT for the sonar operator/navigator crew area would then be 40·7°C.

In Figure 3 the rise in cabin dry bulb temperature (sonar/navigator crew position) above ambient temperature is plotted *vs.* ambient temperature for all of the records in Appendix 1. This figure shows a wide spread of results with the only discernible trend being an apparent decrease in temperature differential with rising outside air temperature.

The cockpit temperatures (recording channel 2—rear of pilot's seat), despite the transmission of solar radiation through the transparencies, are at times *lower* than the cabin temperatures (channel 5), as can be seen in Table 1; this is due to the ventilation of the front cockpit area by the open vent windows. Very little ventilation of the rear cabin appears to take place even with these windows open.

The forward cabin temperatures (channel 3) appear to be quite high. However, this is a very localised temperature rise, brought about by the close proximity of electrical equipment, and is not representative of bulk air temperatures in this region.

4.2 Aft Compartment Temperatures

The aft compartment is separated from the crew area by a thin insulated curtain. As can be seen from Table 1, the temperature of air in this compartment is nearly equal to the cabin temperature.

The description printed on the curtain—THERMAL BARRIER—tends to give a misleading impression of temperature levels to be expected here. The partitioning of the tail compartment is useful in that it prevents a forward flow of air from this region, which is undesirable if, as is likely at least in forward flight, the air contains engine exhaust gas.

4.3 Rear Fuselage Skin Temperature

The skin temperature was measured by attaching a thermocouple to the inside of the skin, in the location shown in Figures 1 and 2. From Appendix 1, the highest recorded temperature

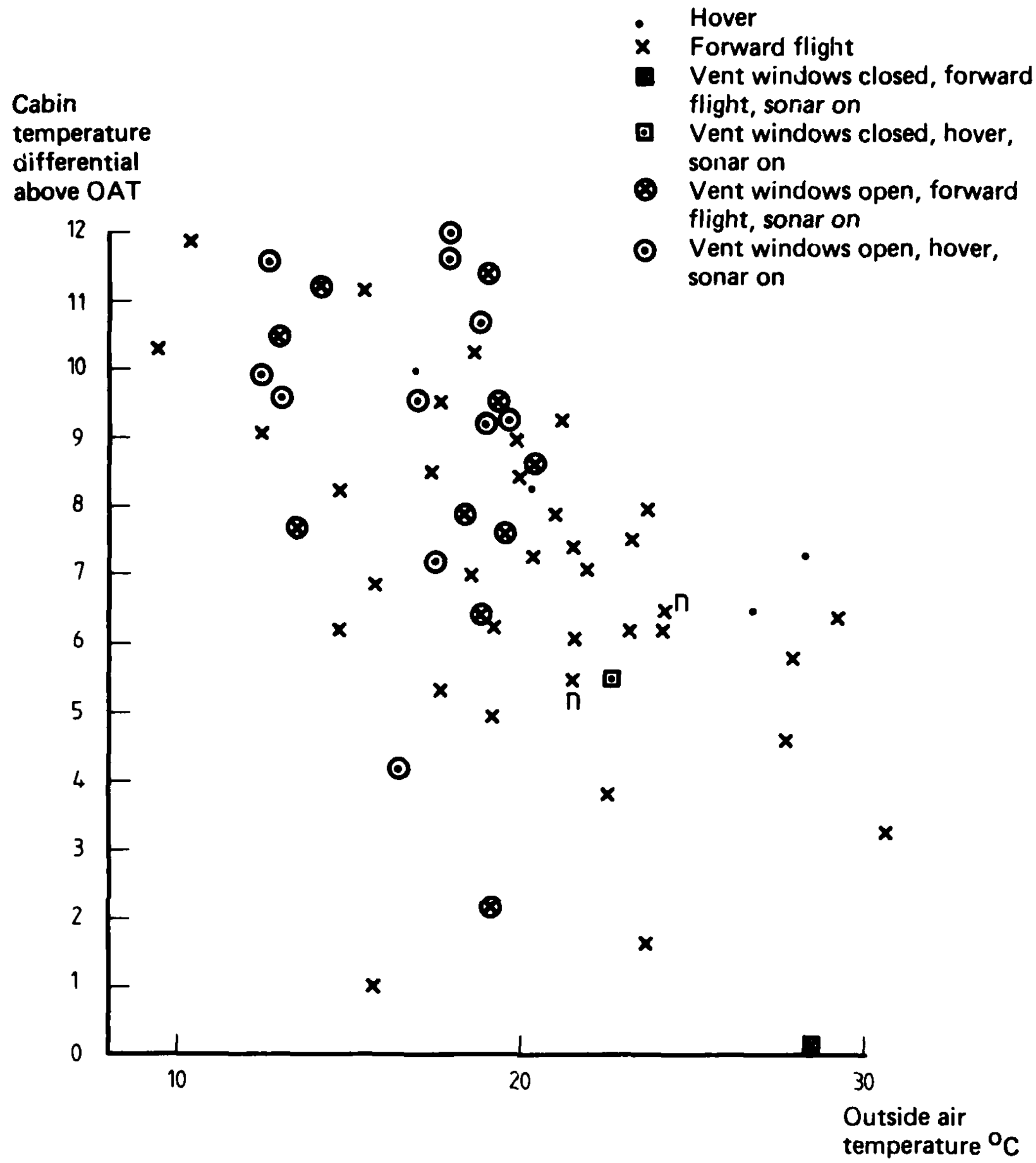


FIG. 3: CABIN TEMPERATURE RISE ABOVE OUTSIDE AMBIENT TEMPERATURE

on 24 May 1977 was 50·2°C, in an ambient of 30·6°C. A slightly greater *differential* of 23°C was recorded on 18 April 1977. The temperature rise appears to depend upon the flight phase, and, as can be seen from Table 1 (and also Appendix 1), is higher in forward flight than in the hover.

The dependence on flight configuration probably arises from the aft location of the measurement point; in forward flight a greater concentration of exhaust gas would impinge on this region, than in the hover.

4.4 Comparison with other Military Helicopters

4.4.1 Comparison with Royal Navy Sea King Cabin Temperatures

Lovesey *et al.* (1976) conducted a brief survey of the RN Sea King cabin environment, in outside ambient temperatures of up to 17°C. The largest cabin temperature differential was 6°C above ambient. Cloud cover varied from 4/8 to 7/8. The conclusions reached from this survey were that the environment was judged to be acceptable—neither unpleasantly hot nor unpleasantly cold. This conclusion concurs with the findings here, that outside air temperatures of up to 19°C would not produce excessive WBGT levels in Australian Sea Kings.

4.4.2 Comparison with CH-47 (Chinook) Cabin Temperatures

Laing *et al.* (1975) carried out a survey of temperatures in 20 different locations in the CH-47 helicopter: the average temperature rise in the cockpit was 6·5°C (forward flight) and 5·1°C (hover), in full solar radiation. These temperatures are similar to those found for the RAN Sea King (see Fig. 3).

5. CONCLUSIONS

Considerable variability was evident in the temperatures recorded during the survey. However, the results demonstrate that:

(*a*) a deterioration in crew performance will occur in quite moderate external climatic conditions, thus limiting the operational effectiveness of the aircraft;

(*b*) operation of the Sea King in the humid extremes of the Australian environment would be physiologically very hazardous to the crew members;

(*c*) operation of the Sea King in the more severe climatic design environment of the United States MIL-STD-210B, Naval Environment (Operations) would be quite impracticable.

6. ACKNOWLEDGMENTS

Thanks are due to aircrew members of 817 Squadron for their recording of temperature data, and to the co-operation of RAN personnel at Nowra during installation of the recording equipment.

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APPENDIX 1

Sea King Temperatures

(*a*) March 1977

Date	Ground condition at take-off			Time	Cloud cover	Flight phase	Temperature (°C)										Crew comment
	T (°C)	R.H. (%)	V (kn)				0	1	2	3	4	5	6	7	8	9	
15	29	65	10	1100	4/8	Fwd.	32·8	36·1	33·1	30·6	44·4	30·3	30·9	24·3	32·3	27·2	Hot
16	20	62	20	1100	3/8	Hov.	26·1	34·9	26·9	31·6	32·8	26·9	26·6	20·9	25·7	16·9	
				1200	2/8	Fwd.	26·2	35·7	32·2	37·1	40·2	27·1	26·9	21·3	24·3	17·6	
17	25	37	20	1500	Nil	Hov.	30·1	38·2	28·2	35·4	33·2	28·8	28·9	22·8	28·5	19·7	Warm
				1600	Nil	Fwd.	29·2	34·2	31·5	30·4	36·2	29·3	28·9	23·0	27·4	23·1	
17	17	32	10	1900	2/8	Hov.	27·4	26·3	28·7	32·7	29·1	28·6	28·4	22·6	26·9	20·3	Warm
				2000	2/8	Fwd.	27·6	27·3	29·5	36·2	39·0	28·5	27·8	22·7	27·0	20·0	
				2100	2/8	Hov.	27·8	27·3	29·8	31·1	30·6	28·9	28·7	23·3	27·1	19·9	Hot
				2200	2/8	Fwd.	27·2	26·9	27·6	36·6	30·6	28·9	28·5	23·2	23·6	21·0	Hot and sticky
22	22	94	10	2005	Nil	Fwd.	27·5	26·4	29·5	37·0	33·3	27·1	27·5	22·9	26·9	21·6	Warm
23	25	54	10	1300	3/8	Fwd.	30·9	36·5	29·4	30·3	31·7	29·0	29·9	24·7	29·0	21·6	Very uncomfortable
				1400	3/8	Fwd.	31·6	39·7	32·0	42·4	42·2	30·4	31·4	25·1	29·6	24·1	
25	25	48	15	1600	Nil	Fwd.	31·4	35·3	31·6	43·2	42·2	31·7	32·6	25·7	32·0	23·7	Hot and uncomfortable
29	10	75	15	1440	7/8	Fwd.	21·7	25·1	28·5	24·0	25·7	22·2	23·4	20·7	18·3	10·3	Comfortable
				1540	8/8	Fwd.	19·9	20·3	27·2	21·7	25·9	19·9	20·6	18·0	15·6	9·6	
				1615	8/8	Fwd.	21·8	20·7	27·9	22·8	33·5	21·4	22·1	19·7	19·3	12·3	
30	25	30	8	1400	5/8	Fwd.	28·9	37·7	28·4	39·5	36·6	27·1	27·5	25·2	26·0	18·0	Comfortable
30	25	30	10	2000	Nil	Fwd.	28·9	31·5	30·5	42·2	39·2	30·6	30·3	28·9	28·9	24·1	Hot and uncomfortable

(*b*) April 1977

Date	Ground condition at take-off			Time	Cloud cover	Flight phase	Temperature (°C)										Crew comment
	T (°C)	R.H. (%)	V (kn)				0*	1	2	3	4	5	6	7	8	9	
18	21		5	1005	Nil	Fwd.	22·6	28·6	21·6	27·6	31·3	22·9	24·2	20·8	24·5	17·6	Hot and uncomfortable
				1025	Nil		22·8	26·3	22·4	30·7	32·8	24·1	25·1	22·9	26·9	19·1	
				1045	Nil		23·8	28·2	24·8	26·4	30·0	25·5	26·3	24·5	28·2	19·2	
				1200	Nil		27·7	33·2	28·9	32·2	31·4	27·6	28·8	26·5	29·2	20·3	
18	22·6		10	1230	Nil		25·1	33·1	29·0	33·2	34·9	22·6	22·3	22·6	21·8	15·7	Hot and uncomfortable
				1300	Nil		27·0	36·9	31·1	37·1	40·3	25·8	26·2	24·6	25·0	17·3	
18	27		5	1510	Nil	Fwd.	32·2	41·8	29·7	40·9	36·0	30·4	30·9	29·3	29·8	21·1	Hot and uncomfortable
				1625	Nil		32·2	32·2	30·3	36·1	34·0	29·1	29·6	29·0	28·9	22·0	
19	21		5	0830	7/8	Fwd.	16·9	18·9	16·1	16·3	19·7	16·0	15·0	16·7	16·7	14·7	Hot and uncomfortable
				0930	6/8		25·1	29·9	21·0	28·0	35·2	25·6	23·6	26·0	26·0	18·6	
				1030	5/8		26·9	29·6	28·0	34·2	25·1	28·9	27·6	25·1	25·4	18·6	
				1130	5/8		26·0	34·4	25·2	33·9	36·2	25·0	25·3	22·3	22·3	18·5	
28	28		5	1530	1/8	Fwd.	29·5	34·3	28·2	26·2	25·5	25·3	25·8	24·1	25·8	23·6	Warm
				1630	1/8	Fwd.	28·6	32·5	29·9	40·4	35·4	27·6	29·9	27·2	27·4	21·5	

* Channel 0 Co-pilot's rudder pedal area.

1 Cockpit globe.

2 Pilot's rear seat, mid-height.

3 Forward cabin air temperature.

4 Aft cabin skin temperature.

5 Sonar-navigator crew air temperature

6 Sonar-navigator crew black globe temperature.

7 Sonar-navigator crew wet bulb temperature.

8 Aft fuselage air temperature.

9 Outside air temperature.

(*c*) May 1977

Date	Ground condition at take-off			Time	Cloud cover	Flight phase	Temperature (°C)										Crew comment
	T (°C)	R.H. (%)	V (kn)				0	1	2	3	4	5	6	7	8	9	
4	15		10	0820	7/8	Fwd.	15·0	16·1	15·8	16·6	17·7	16·7	17·4	15·7	17·3	15·7	
				0920	7/8	Fwd.	18·4	22·1	25·4	21·3	29·3	20·8	22·5	20·1	21·0	14·6	
9	23		5	0930	Nil	Fwd.	25·8	27·6	26·3	27·9	27·5	26·5	27·5	22·8	28·9	22·6	Uncomfortable
				1030	Nil	Fwd.	28·2	28·2	28·9	39·5	32·7	30·8	31·4	25·9	29·3	23·3	
17	31		15	0820	3/8	Deck	29·9	31·4	30·3	30·6	33·0	30·3	31·4	27·7	34·2	29·0	Uncomfortable
				0850	3/8	Hov.	32·9	36·0	35·0	35·0	37·4	33·3	35·3	29·8	33·8	26·8	
				0910	3/8	Fwd.	33·2	39·4	35·5	44·5	44·4	33·7	35·6	30·2	34·4	27·9	
				1000	3/8	Deck	34·1	40·5	34·7	37·2	42·7	34·3	35·0	29·2	34·3	30·9	
21	29		5	1415	3/8	Fwd.	34·8	39·7	33·1	32·6	44·6	32·3	32·8	28·8	34·5	27·7	Very hot and uncomfortable
				1515	3/8	Hov.	34·4	40·9	33·5	39·2	38·8	35·6	36·6	30·6	35·1	28·3	
				1600	3/8	Fwd.	34·5	35·7	33·6	44·1	43·2	35·6	35·4	35·4	35·9	29·2	
24	33		10	1100	3/8	Fwd.	33·4	40·9	33·9	42·4	50·2	33·9	33·8	29·8	36·7	30·6	Very hot and uncomfortable

(*d*) June 1977

For all of these flights the sonar is on, the front vent windows open and the cabin air fan on, unless otherwise noted.

Date	Ground condition at take-off			Time	Cloud cover	Flight phase	Temperature (°C)										Crew comments
	T (°C)	R.H. (%)	V (kn)				0	1	2	3	4	5	6	7	8	9	
3	22	76	10	0800	Nil	Deck	21·3	23·7	21·8	22·0	22·6	21·2	19·7	22·5	20·0	21·2	*Cabin fan off, vents closed*
				0900	Nil	Hov.	26·1	31·8	31·6	32·9	27·1	28·1	31·7	24·6	26·6	22:6	
				0925	Nil	Fwd.	26·9	36·5	27·6	39·0	34·7	28·7	32·1	24·9	26·8	28·5	
4	20	65	15	1410	2/8	Deck	22·7	23·8	21·2	20·4	22·6	19·9	20·7	17·3	22·9	21·9	Hot and uncomfortable
				1445	3/8	Hov.	25·7	32·9	26·1	24·3	32·5	24·9	26·1	21·0	26·4	17·7	
				1520	3/8	Fwd.	26·4	35·7	25·6	32·7	36·3	26·3	27·7	22·2	26·8	18·4	
				1550	3/8	Hov.	26·6	33·9	24·7	25·6	32·8	26·6	27·6	22·7	27·6	17·0	
5*	20	67	5	0445	5/8	Fwd.	25·0	26·6	32·8	25·8	24·7	25·3	20·8	23·4	23·6	18·9	Hot and uncomfortable
				0530	5/8	Fwd.	24·3	25·4	24·6	35·4	32·9	25·3	26·6	21·6	21·6	14·1	
6	23	77	3	0900	6/8	Deck	22·6	25·1	21·3	22·0	27·3	21·8	21·3	19·7	21·9	19·0	Hot—comfortable
				1000	5/8	Fwd.	26·3	34·9	25·0	35·1	35·6	27·2	27·4	23·4	27·6	19·6	
				1020	5/8	Hov.	26·5	30·9	26·3	33·6	29·0	28·2	29·6	24·4	26·8	19·0	
6	23		10	1115	Haze	Deck	28·9	34·0	27·2	25·7	35·6	24·4	24·0	22·1	27·5	20·3	Hot—comfortable
				1200	Haze	Fwd.	28·6	36·5	28·5	40·2	42·1	28·9	31·2	25·1	26·6	20·3	
				1210	Haze	Hov.	28·7	38·2	28·8	36·5	31·9	30·5	33·6	26·4	27·3	18·9	
				1215	Haze	Hov.	30·4	44·3	32·4	39·0	29·6	30·9	34·5	26·8	27·1	18·9	
6	22	74	15	1350	Haze	Fwd.	28·2	38·3	26·6	30·3	33·2	28·9	28·9	26·7	26·7	19·3	Hot and uncomfortable
				1425	Haze	Hov.	28·2	36·9	28·3	33·5	35·3	28·9	29·0	26·6	26:6	19·6	
				1455	Haze	Hov.	28·3	35·9	37·1	34·0	31·9	29·5	30·0	25·2	27·1	18·8	
				1515	Haze	Fwd.	28·9	36·0	27·5	38·8	41·7	30·4	25·0	27·9	27·8	19·0	
11	14		5	0710	1/8	Fwd.	15·0	17·3	17·5	24·3	22·9	17·2	17·8	13·7	18·8	16·4	
				0810	Nil	Hov.	20·2	21·0	22·6	22·2	15·4	22·3	23·0	18·7	19·2	12·4	
11	14	57	5	0920	1/8	Fwd.	21·3	24·3	21·0	30·9	29·7	21·1	22·6	16·9	22·0	13·4	Hot—comfortable
				1015	1/8	Hov.	20·4	24·7	21·0	31·1	26·8	22·7	26·2	19·1	19·9	13·1	
				1120	1/8	Hov.	21·4	25·3	20·8	22·2	19·0	24·2	25·6	20·4	19·7	12·6	
				1150	1/8	Fwd.	22·5	27·4	23·4	32·9	27·2	23·4	26·5	20·0	20·5	12·9	
12	12	66	2	0900	4/8	Deck	15·0	17·2	13·7	13·0	19·7	13·0	13·3	17·1	15·0	12·3	Cabin air off
				1030	4/8	Hov.	17·2	21·3	15·9	24·0	20·3	20·7	22·9	17·7	18·3	16·5	
				1130	4/8	Fwd.	17·6	23·5	17·7	30·1	24·3	21·3	23·9	18·6	17·6	19·1	
27	50	80	10	1030	7/8	Fwd.	18·6	23·6	18·9	21·0	24·4	18·8	22·5	16·4	20·0	15·7	Sonar off, comfortable

* This date was originally recorded as 4 June 1977, however this was most likely in error, so it is amended to 5 June 1977.

APPENDIX 2

Wet Bulb Globe Temperature

The Wet Bulb Globe Temperature (WBGT) takes account of incident thermal radiation, ambient temperature and humidity. It is defined (Kerslake 1972) as

$$\mathrm{WBGT} = 0{\cdot}7T'_{wb}+0{\cdot}2T_g+0{\cdot}1T_a,$$

where T'_{wb} = naturally convected temperature of a wet bulb exposed to radiation from surroundings (°C),

T_g = temperature of a 150 mm black globe (°C),

T_a = dry bulb temperature (°C).

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