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ARL-FLIGHT-MECH-TM-450

AR-006-623

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Flight Mechanics Technical Memorandum 450

INSTRUMENTATION FOR AIRWAKE MEASUREMENTS ON THE FLIGHT DECK OF A FFG-7

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Approved for public release

NOVEMBER 1991

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SUMMARY

This paper describes the instrumentation and techniques used to successfully gather airwake data on the flight deck of HMAS Darwin in the Tasman Sea during September 1989

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CONTENTS

1 INTRODUCTION

The Royal Australian Navy (RAN) operates helicopters aboard many classes of ships, including the Sikorsky S-70B-2 Seahawk helicopter on the FFG class and possibly the new ANZAC class of frigate. In support of the RAN aviation activities the Aeronautical Research Laboratory (ARL) is pursuing the development of a computer simulation model of helicopter operations from a ship.

As part of the RAN sponsored helicopter/ship model validation task (Task 89/073) sea trials were conducted aboard HMAS Darwin, an extended deck FFG-7 class of ship, to obtain airwake data in the proximity of the flight deck. The data, after processing, will be used, together with results obtained from wind tunnel tests based on a 1/64th scale ship model, to form a suitable airwake model in a helicopter/ship simulation computer code.

This airwake trial was the first of it's kind undertaken by the Aeronautical Research Laboratory (ARL). The results provide a basis for preliminary studies into an area of helicopter/ship interaction that has been given little attention.

Much of the instrumentation described in this paper has had extensive use in other wide-ranging applications such as a Clear Air Turbulence (CAT) investigation, First of Class Flight Trials (FOCFT) and dynamic undercarriage measurements on a Sikorsky S-70B-2 Seahawk helicopter. Motion-related trials have involved a road vehicle and various types of ships. The equipment was reconfigured to that considered applicable for the airwake application.

2 GENERAL DESCRIPTION OF TRIAL REQUIREMENTS

The airwake trial (Ref. 1) enabled the following data to be recorded at sample rates of between 5 and 20 samples/second/channel:

- ship angular rates, attitudes (roll and pitch) and axial accelerations
- ship speed and heading
- relative wind speed and direction from ship's anemometer
- flight deck reference windspeed and direction
- wind vector components at three levels above the flight deck, at grid positions premarked on the flight deck
- air temperature at the three levels for each of the deck grid positions

In addition, the following information was recorded by video camera:

- flow visualisation using orange smoke
- sea conditions viewed from the ship's bridge and time synchronized to the ship motion data

3 INSTRUMENTATION SYSTEM OVERVIEW

A motion platform (Section 5.1) containing a number of transducers was used to measure many of the quantities associated with ship motion. These included triaxially mounted accelerometers to measure longitudinal, lateral and vertical accelerations, triaxially mounted rate gyroscopes to measure the rates of roll, pitch and yaw, and two attitude sensors to measure roll and pitch attitudes.

The raw airwake data was obtained relative to a ship-fixed frame of reference. The ship motion data are needed to adapt the airwake data to other frames of reference, such as an approaching helicopter.

Ship speed and heading information were recorded from synchro signals obtained by connecting to terminal strips of the repeater indicators located in the Helicopter Control Station (HCS).

Reference wind speed and direction were derived from three sources:

(1) The ship's anemometers - which are fixtures on the main mast on top of 02 deck. Connections to the wind speed and direction signals were made at the terminal strip of the synchro repeater indicator also located in the HCS.

(2) A Young aero-vane anemometer - fitted to the top of a four metre high mast positioned in "free air" at the stern of the ship (Section 6.2.1). The ARL-supplied aero-vane anemometer was of similar type to the ship anemometer.

(3) Two cup anemometers and directional vanes - mounted on masts that overhung each side of the ship at the stern (Section 6.2.2).

In order to adequately characterise the flight deck airwake, recordings of the wind's orthogonal components uvw were obtained using nine anemometers arranged as three arrays. The three anemometers of each array were aligned parallel with the ship's principal axis and the arrays were spaced at 3.2 metre height intervals on a ten metre high moveable mast (Fig 1) above marked grid positions on the flight deck.

A semiconductor type temperature sensor was attached to the mast at each of the three anemometer levels to allow the ship's exhaust efflux temperature to be measured when present in the stream.

4 PORTABLE COMPUTER BASED DATA ACQUISITION SYSTEM

An AT Compaq Portable III Computer fitted with an analogue-to-digital card and a synchro-to-digital card formed the basis of the recording system. The in-house written control program enabled the desired channels to be selected and sampled at predetermined rates. The program also provided the operator with quick-look graphical displays of channel data. For calibration use the signal voltages were displayed in scaled engineering units.

The ARL developed data recording system is referred to as the Versatile Airborne Data Acquisition and Replay (VADAR) system. The specification for VADAR is included in Appendix 1 and is described in Ref 2.

A data gathering run is initiated from either the computer keyboard or a remote switch, mounted on a small box at the end of a wander cable. Data are gathered at preprogrammed rates from preselected channels (Appendix 2) and written into sequential addresses in extended Random Access Memory (RAM). When the run is terminated the acquired data automatically transfers from the volatile RAM to the computer hard disk with a unique file name based on time and date. At an opportune time the data file(s) are manually transferred to floppy disks for subsequent processing (Refs 3 & 4).

5 SHIP MOTION MEASUREMENT

5.1 Motion Platform Position

The motion platform used with VADAR contains a total of eight transducers which are arranged to measure roll and pitch attitude, the three axial accelerations and the three angular rates of roll, pitch and yaw.

The platform was fitted to the "checking and filling blade stowage frame" in the starboard hangar, and was aligned such that the sensitive axis of the longitudinal accelerometer was parallel with the hangar wall. The platform was levelled to be parallel with the horizontal plane while the ship was docked. The ship's trim and list angles were obtained from instruments on the bridge.

Specification for the platform is given in Appendix 3.

5.2 Motion Platform Sign Convention

The eight motion sensing transducers were aligned in a common housing to produce output signal voltages with polarities corresponding to the following convention.

Attitude sensors:	Positive for bow up pitch and starboard roll.
Accelerometers:	Positive for forward surges, starboard sways and downward heaves.
Rate gyroscopes:	Positive for bow up pitch, starboard roll and bow yaw to starboard.

Because the platform was installed for this trial at a location in the starboard hangar, which is aft of the ship's centre of gravity, a bow up pitch would produce positive signal polarities for the pitch attitude, pitch rate and vertical acceleration. If the platform had been installed forward of the centre of gravity the vertical acceleration signal would be of negative polarity.

At the time of the trial the only attitude transducers available for use with the motion platform were fluid damped pendulum types, intended for static applications, with the attitude signal being derived from the angular rotation at the pendulum bearing. Unfortunately, the dynamic attitude data obtained was of limited use because the pendulums effectively duplicated the accelerometers. A serviceable vertical displacement gyro has since become available to provide attitude data.

6 REFERENCE WIND MEASUREMENT

6.1 Ship's Anemometer

The ship's two anemometers are multibladed propeller types that swivel in azimuth to point into the relative wind. They are mounted about 40 metres above the ship's flight deck at each end of a lateral cross arm that forms part of a tower.

The "into the wind" anemometer is selected from the bridge to provide wind data to the ship. Synchro signals from repeaters (Section 8) located in the HCS represent the wind speed and direction from the chosen anemometer and were converted into a digital form for recording by the ARL VADAR system.

6.2 Reference Anemometers

6.2.1 Aero-vane anemometer

At the stern of the ship a vertical mast four metres high was secured to a deck rail fitting about 0.6 metre to starboard of the ship's centre line. Attached to the top of this mast was the Young four bladed propeller aero-vane anemometer (Fig.1). The specification for the anemometer is given in Appendix 4.

6.2.2 Cup anemometers

On both the starboard and port sides near the stern of the ship a two metre long mast was bolted to brackets which normally held a guard rail post at the step between the flight deck and the deck extension.

Each mast was inclined at 45 degrees to the deck outwards and upwards (Fig. 1). A cup anemometer and directional vane were mounted to the top end of each mast and overhung each side of the ship. Both anemometer outputs were recorded, but during data analysis the upstream cup anemometer was selected for the reference wind off the sea. By comparison, the Young aero-vane provided a reference wind above the flight deck.

7 WIND MEASUREMENT ON THE FLIGHT DECK

7.1 Anemometer Arrays

Modifications had been made to the anemometers so that each revolution of the propeller generated twelve pulses of fifteen volt amplitude. The pulse trains are transmitted differentially, through multicore shielded cable, to frequency to voltage converters. The output from the converters provide the VADAR with analogue voltage signals proportional to wind speed.

Wind direction for each of the anemometers is recorded as a separate digital bit using the convention that rotation of the propellers in a counter-clockwise direction (when viewed front on) is recorded as a low logic state while propeller rotation in a clockwise direction is recorded as a high logic state. The arrays were orientated on the mast such that wind components from fore to aft, starboard to port and downwards, towards the deck, produced flow into the anemometer propellers to rotate the respective propellers counter-clockwise and set the direction bits to logic low states.

The horizontal anemometers of each array were positioned 3.2, 6.4 and 9.6 metres respectively above the flight deck with the lower two arrays aligned vertically above each other. The lower two arrays were mounted on support arms 0.5 metre long that kept the anemometer propellers clear of flow disturbances produced by the small (36 mm) diameter mast. The upper array was mounted at the top of the mast and was not subject to possible disturbance from the mast.

7.2 Moveable Mast

7.2.1 General

There was concern that standing waves of significant voltage might be induced on to the mast from four vertical transmission aerials attached to 02 deck immediately above the hangar. Also, the ship's radar was capable of pulsing several megawatts and there was potential for the high field radiation to be a health hazard to the trial team and likely to damage the VADAR circuits or at least corrupt the acquired data. Hence a ship's RADHAZ clearance was requested during the periods that the mast was positioned on the flight deck.

Another operational requirement was that the mast could be removed and the flight deck totally cleared at short notice should there be an unexpected need for helicopter operations. The mast was also required to be portable for transport and for ease of carrying aboard via the ship's gangway. Unassembled, the longest mast component was about 3.3 metres.

An inexpensive 9.6 metre high mast was constructed using three sections of a Hills telescopic antenna mast (Fig. 1). The mast was bolted to a triangular shaped steel base plate with three 1.5 metre long horizontal legs attached. The mast was held upright by securing and tensioning guy wires that extended from the top of each mast section to the outer ends of the base legs. A configuration of three braces and a strut (Section 7.2.2) prevented the base deflecting under the compression load at the foot of the mast caused by tensioning the nine guy wires (Appendix 5).

Each leg was fitted with a castor and a levelling jack so that the mast could be manoeuvred and set vertical at each required grid point on the sloping flight deck. At each point the jacks were lowered a predetermined distance to set the mast vertical and transfer the mass of the mast from the castors to the jack pads. A table of screw turn adjustments for each jack was prepared, while the ship was berthed, and attached to the corresponding leg to simplify repeatable levelling at the various grid points. Data from the motion platform (Section 5) were available during subsequent processing to correct for changes in ship roll and pitch angles.

Three webbing straps, with ratchet type tensioners, were provided to enable the mast to be secured at the desired grid positions using existing tie-down points recessed into the deck. During the trials, the team found that the mast was stable in relative winds to 30 knots and slight seas and the straps were not required. Estimates of the aerodynamic drag acting on the mast are given in Appendix 5.

A hinged footmount allowed the mast to be folded down so that the mast structure could be wheeled, fully assembled, for off-deck stowage in the port side hangar. The mast, when in the lowered position, lay opposite one leg and between the other two legs and rested on two temporary support frames that kept the anemometers clear of the deck. The top end of the mast was then about one metre above the deck and the mast sloped downwards towards the base, which was typically 0.1 metre above the deck.

7.2.2 Mast assembly

To assemble the mast required that the three legs be attached with U bolts to the under side of the base plate. Then, after the vertical strut was firmly clamped to the base plate, the three braces could be clamped between the strut and each of the legs thus completing the base structure and making it rigid. The braces and strut also provided convenient hand holds to facilitate the moving and positioning of the mast on the flight deck.

The hinged footmount of the mast was attached to the base plate and the telescopic sections of the mast were extended horizontally and secured. Two support arms were then fitted to the mast to provide the necessary mast clearance for the anemometer propellers, and the two lower level anemometer arrays attached to the support arms. The third array was fitted to the top of the mast.

A box containing two inclinometers was fitted to the mast at about mid height to sense lateral and longitudinal slant of the mast when erected. In practice the mast was maintained vertical (referenced to the berthed horizontal calibration plane - see Sections 5.1 and 7.2.1) using the levelling jacks. The inclinometer signals then duplicated the motion platform lateral and longitudinal accelerometer signals.

Electrical cables were then installed and taped to the mast. With the system powered, a functional check was possible by rotating each propeller while the corresponding channel was monitored using the VADAR quick-look facilities. Following a successful functional check the wire guys and erection rope were attached and the mast was ready to raise.

7.2.3 Mast erection

The mast could be raised or lowered in about three minutes by two persons. The preferred technique to raise the mast, from the near horizontal position, required one person to lift the top end of the mast and walk towards the base end, eventually lifting the mast to an overhead position, thus achieving a steep mast angle.

The second person prevented the base from moving and simultaneously pulled on a rope which was attached to the mast, about three metres below the top. Two sets of guy wires were always left attached to two legs, as shown in Appendix 5, thus preventing the mast from pivoting beyond the vertical when being raised. With the mast held vertical, the guy wires were then attached to the legs and tensioned.

The ease and success of raising the mast required that all the guy wires and the rope be kept free of the propellers. This involved careful thought in three dimensional geometry to optimise the clearances. Important considerations were:

- angular relationship of the base legs with respect to the anemometer arrays
- angular relationship of the base legs with respect to the hinged foot mount
- locations of attachment points for the guy wires and rope
- placement positions of the braces and strut

8 SHIP'S INSTRUMENTS

Four repeater instruments in the HCS, each driven by three wire synchro type signals, were tapped into to measure their displayed parameters. These signals provided ship's speed and true heading and ship's relative wind speed and direction (Fig. 2). An analysis of the displayed winds is given in Appendix 6.

A plug-in synchro-to-digital converter card changed the synchro signals into a computer compatible form. The repeaters operated with 115 volt references and 90 volt outputs but three of the signals were from a 60 hertz source and the fourth originated from a 400 hertz source (Appendix 3). Because the card required a common line for the low reference voltages a bank of four transformers was used to provide isolation between the inputs. A quick release connector was inserted in the cable between the HCS and the isolation transformers in case the ARL equipment was required to be disconnected from the ship's wiring. The connector also enabled the synchro voltages, which were present continuously, to be quickly and safely removed from the VADAR.

9 FLIGHT DECK AIRWAKE VISUALISATION

A visualisation record of the airwake was made for selected wind velocity conditions using orange smoke flares. The coloured smoke was video recorded from two positions simultaneously.

One video camera was located on the upper deck between the hangar doors and viewed downwards towards the stern, while the second camera was located upwind and to one side of the flight deck. This provided both a side and a down view of the smoke pattern as the smoke flare was carried above head height and moved systematically around the flight deck (Fig. 3).

10 POWER REQUIREMENTS

VADAR is designed to be powered from a range of electrical supplies. Aboard the ship the readily available 115 volts at 60 hertz was used. Other frequencies and voltages for distribution to VADAR circuits are provided by a power pack, solid state inverter and DC-DC converters.

The VADAR system may be powered from one of the following sources:

- 240 volts at 50 hertz
- 115 volts at 60 hertz
- 115 volts at 400 hertz
- 28 volts DC (Total nominal load current of 12 amperes).

11 PRE SEA TRIAL ASSESSMENT

11.1 General

Several months prior to the sea trial, arrangements were made for the equipment to be assessed at the Australian Army Engineering Development Establishment, (Vehicle) Proving Ground at Monegeetta. The purpose was to:

- check the integrity of the mast hardware
- evaluate the instrumentation
- produce controlled conditions of motion to check transducer responses
- acquire data under controlled motion conditions to evaluate correction techniques to anemometer data
- provide an opportunity for the trials team to gain experience in the installation and operation of the equipment

11.2 Vehicle Based Trial

The ten metre high mast, fitted with three levels of anemometer arrays, and the motion platform were attached to the tray of an army UNIMOG truck (Fig. 4a). The computer portion of VADAR was fitted into the cabin of the truck. A motor generator was slung in a rope style gimbal across the tray to avoid petrol spilling from the filler cap when the vehicle was positioned on steep inclines (Section 11.3).

The ARL owned Young anemometer was mounted on top of a five metre high mast staked to the ground, at a location upwind of the zone where the vehicle was operating, to provide reference wind speed and direction.

The majority of the area chosen for the land-based trial was in open terrain and generally the few isolated trees and wide creek gullies could be avoided. The vehicle was driven only on smooth and sealed surfaces during data gathering runs. There were no overhead obstructions and the area was clear of traffic.

11.3 Vehicle Motion

A low profile ramp for evaluating vehicle entry and exit on landing craft had an angle of 25.5 degrees and was used to simulate roll and pitch motion to the on-board anemometers, mast and motion platform. By selective positioning of the vehicle at the upper and lower extremes of the ramp a range of angles between 25.5 degrees was obtained (Fig. 4b). Several runs were made crossing the ramp and included stop/start and creep.

Roll and pitch motion simulation was achieved by duplicating runs with the mast and motion platform rotated through 90 degrees with respect to the longitudinal axis of the vehicle.

Yaw simulation was obtained by steering the vehicle on a predetermined turning radius, marked by traffic cones, at a predetermined speed.

A 3.6 kilometre first class road circuit contained sufficient corners and undulations to enable a range of acceleration components to be produced in yaw, roll, pitch and heave. The mast hardware was tested at speeds of up to 95 kilometres per hour without any noticeable problems but this did not check the stability of the mast against tipping or sliding, as the mast was securely strapped to the vehicle.

For comparison and if practicable, it was intended to record relative wind speeds to 50 knots on the rolling and pitching flight deck at sea.

12 SEA WAVE CREST VIDEO RECORD

A video recording of the wave crests forward of the ship was made with a camera mounted in an adjustable cradle clamped to a ledge above a port side window in the ship's bridge. The camera was synchronised to VADAR so that the ship motion, resulting from the passing of particular waves could be identified and analysed.

The camera was aligned to provide a field of view of the sea state ahead, and to the sides, of the ship with the bow visible in the bottom of the field of view.

Unfortunately the sea state during the trial was calm, making identification of wave crests very difficult and only a few degrees change in ship attitude was recorded.

13 MEASUREMENT TECHNIQUE

Tape marks were placed on the flight deck at the thirteen positions assigned for the airwake measurements (Figs 5 and 6). These markings simplified the procedure for mast setting and alignment. Data gathering runs, with the mast at each position in turn, were timed for up to ninety seconds duration, which was longer than the period likely to be encountered by any passing ocean wave.

A complete set of data at any relative wind velocity required about 45 minutes, allowing two minutes for the team of four to position the mast at each grid position and readjust the leg heights.

The motion platform was powered up and allowed to stabilise for about 30 minutes prior to the commencement of any data run.

14 CALIBRATION

All the anemometer channels were calibrated in the ARL low speed wind tunnel where recordings were made over the range of likely wind velocities. On board pre and post installation calibrations were made on the attitude and acceleration channels. The rate gyros were checked on a rate table at ARL before and after the trial.

15 CONCLUSION

An instrumentation system was successfully developed and used aboard a FFG class of ship to measure and record ship motion and airwake data over the flight deck. The system and measuring procedure worked satisfactorily in relative wind velocities up to 35 knots with slight ship motion. A simple graphical presentation of the relative winds achieved is depicted in Fig. 7. Airwake measurements over the flight decks of several different types of ships have been performed overseas (e.g. Ref. 5) but detailed information is limited.

Data obtained during the sea trial provides an invaluable data base with application towards the validation of key aspects of the simulation model and the subsequent improvement in the level of confidence for simulated predictions of operational situations.

The moveable mast structure was produced simply, quickly and at low cost. The anemometers were originally used in a land-based ARL program to measure clear air turbulence. They were refurbished for use on this sea trial. VADAR was specifically developed as a general purpose portable (versatile) data acquisition system and was easily configured to acquire the airwake data.

Possible improvements to the mast structure would be to:

(1) increase the diameter of the castor wheels from 90 mm to 150 mm to reduce the problem of the wheels catching on deck obstructions such as the RAST groove and the numerous cavity type tie-down points. An anticipated disadvantage of the larger diameter wheels is that greater restraint will be required in controlling the mast position, especially in rough seas and high winds.

(2) replace the original levelling jacks, located beneath each leg, with caravan type levelling jacks attached at the ends of each leg. Apart from being easier to operate, the replacement jacks would have a larger contact area with the deck and offer greater sliding resistance. Also, relocation of the jacking points would give a larger footprint for the base and thereby increase the safety margin against the mast tipping over in hostile weather.

(3) provide a height scale at each jack to more easily and quickly facilitate the levelling at the grid points.

Because this was the first trial of its type in Australia and together with the complexity of the overall task it was very gratifying to achieve a successful outcome.

ACKNOWLEDGMENTS

The work was initiated by R.A.Feik and Dr N.E.Gilbert, with the deck grid and desired wind condition parameters being provided by Dr N.Matheson who also devised a wind tunnel program to complement the full scale trial.

Development, calibration and evaluation of the instrumentation was a team effort by J.F.Harvey, I.M.Kerton, O.F.Holland, Ms A.J.Leslie and S.B.Walter. Subsequent processing of the acquired data and comparison against wind tunnel data and computer model simulations is being done by A.M.Arney and L.P.Erm.

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APPENDIX 1

GENERAL SPECIFICATION FOR VADAR

VADAR was developed by the Instrumentation and Trials Group, ARL, Melbourne.

ANALOGUE SIGNAL INPUTS

No of channels	programmable 1 to 32
Data size	12 bits
Max. input signal range	± 5 volts
Sampling rate	programmable 1 to 100 samples/sec
Low pass filter range	selectable 1 to 17 hertz
Analogue gain	programmable 1, 10, 100 or 500 selectable 0.26, 0.7, 1.4, 2.2, 2.9, 3.6, 4.4, 5.1

SYNCHRO INPUTS

Synchro channels	up to 6 channels (synchro voltage 11.6 or 90 at ref voltages 26 or 115)

DIGITAL SIGNAL INPUTS

Digital lines	8 bits (or 12 bits with multiplexing)

DIGITAL SIGNAL OUTPUTS

Digital lines	8 bits

ANALOGUE SIGNAL OUTPUT

Digital to analogue	2 channels
Signal output range	0 to 10 or ± 5 volts

NOTES

Data are automatically transferred, with a unique file name, from temporary RAM storage to the hard disk at the completion of each run.

RAM capacity 2 Mbytes, expandable to 6 Mbytes.

Quick look graph and table displays are incorporated.

The system is configurable for specific applications and includes a limited capacity to acquire 1553 bus data.

Programmable refers to keyboard changes.
Selectable refers to onboard jumper link changes.

RECENT VADAR APPLICATIONS

Deflection of helicopter oleos and tyres during landings and crane releases.

Ground clearance of a helicopter during shipboard and tarmac landings.

Ship motion and helicopter flight dynamics.

Airwake measurements on the flight deck of a FFG-7.

FOCFT of a helicopter on a FFG-7.

APPENDIX 2

CHANNEL IDENTIFICATION FOR MOTION AND AIRWAKE TRIALS ON HMAS DARWIN

23/7/1991

CHAN No	QUANTIY TO BE MEASURED	SAMPLE RATE (Hz)	FILTER (Hz)	TRANSDUCER TYPE	TRANSDUCER SIGNAL	SENSITIVITY (TRANSDUCER)	RANGE (VOLTS)	CHANNEL GAIN	SIGNAL SENSITIVITY	SIGNAL RANGE (EST)	REMARKS
N/A	TIME CLOCK	50	-	P/C INTERNAL	R T C	10mSec	Logic levels	-	0.01sec		P/C INTERNAL
N/A	EVENT MARKER	20	-	DIGITAL	KEY-STROKE		Logic levels	-			Remote hand terminal
N/A	START/STOP		-	DIGITAL	KEY-STROKE		Logic levels	-			
1	SHIP SPEED	5	1	SYNCHRO 115V/60Hz	2 BYTES/READING (DIGITAL)				Sens /Bit (10 bits FS) 0.1K	0-40 Knots	Tap into HMAS Darwin wiring at helicopter control station (HCS)
2	SHIP HEADING	5	1	SYNCHRO 115V/400Hz	2 BYTES/READING				0.1 Degrees	0-360 Degrees	
3	SHIP WIND SPEED	5	1	SYNCHRO 115V/60Hz	2 BYTES/READING				0.1K	0-100 Knots	
4	SHIP WIND DIRECTION	5	1	SYNCHRO 115V/60Hz	2 BYTES/READING				0.1 Degrees	0-360 Degrees	
5	ATTITUDE PITCH	5	1	ROTARY DIFFERENTIAL VOLTAGE TRANSDUCER	DC	125mV/deg	+-5V/+-40deg	x2	4deg/Volt	+-20 Degrees	Non linear beyond +-40deg Ship attitude should be less +-20deg
6	ATTITUDE ROLL	5	1	R D V T	DC	125mV/deg	+-5V/+-40deg	x2	4deg/Volt	+-20 Degrees	
7	ANGULAR RATE - PITCH	5	1	RATE GYRO	DEMODULATED 400Hz	87.26mV/deg/sec	+-5V/57.3deg/sec				Signal are differentiated during processing and MUST NOT BE NOISY
8	ANGULAR RATE - ROLL	5	1	RATE GYRO	DEMODULATED 400Hz	87.26mV/deg/sec	+-5V/57.3deg/sec				
9	ANGULAR RATE - YAW	5	1	RATE GYRO	DEMODULATED 400Hz	250mV/deg/sec	+-5V/20deg/sec				
10	ACCELERATION - VERTICAL	5	1	SERVO ACCELEROMETER	DC	500mV/g	+-5V/+-10g	x5	0.4g/Volt	+-2g	Ship accelerations range should be less than +-2g
11	ACCELERATION - LATERAL	5	1	SERVO ACCELEROMETER	DC	500mV/g	+-5V/+-10g	x5	0.4g/Volt	+-2g	
12	ACCELERATION-LONGITUDINAL	5	1	SERVO ACCELEROMETER	DC	1V/g	+-5V/+-5g	x2	0.5g/Volt	+-2.5g	
16	PORT REF WIND SPEED	20	5	OPTO	PULSES/REVOLUTION	18 pulses/rev	+-5V	x2	6m/sec/Volt	30m/sec	3 cup anemometers (OPTO pulses with 18 pulses/rev) or 4 blade propeller (alternator with 3 cycles/rev)
17	PORT REF WIND DIR	20	5	POT (10K)	DC	29.4mV/deg	+-5V/+-170deg	x1	36deg/Volt	+-180 Degrees	
18	STARBOARD REF WIND SPEED	20	5	OPTO	PULSES/REVOLUTION	18 pulses/rev					
19	STARBOARD REF WIND DIR	20	5	POT (10K)	DC	29.4mV/deg					
20	UPPER LEVEL ON MOVABLE MAST: WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					(Max. 12 Pulses/Rev 31m/sec = 1.2kHz) "Youngs" 4 blade propeller 180mm diameter, 300mm pitch. Axial flow at zero deg. ccw rotation of propeller
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
21	WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
22	WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
13	TEMPERATURE	5	1	SEMICONDUCTOR	DC						
23	MIDDLE LEVEL ON MOVABLE MAST: WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					as above
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
24	WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
25	WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
14	TEMPERATURE	5	1	SEMICONDUCTOR	DC						
26	LOWER LEVEL ON MOVABLE MAST: WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					as above
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
27	WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
28	WIND SPEED	20	5	OPTO PULSES	PULSES/REVOLUTION	12 pulses/rev					
*	PROP DIRECTION	20	-	1 BIT	TWO STATE	C W =1 A C W =0	+15V - 0V				
15	TEMPERATURE	5	1	SEMICONDUCTOR	DC						
29	MAST SLANT-LATERAL	5	1	SERVO ACCELEROMETER	DC	+-5V/+-1g	+-5V/+-90 Deg				Top of mast angle
30	MAST SLANT-LONGITUDINAL	5	1	SERVO ACCELEROMETER	DC	+-5V/+-0.5g	+-5V/+-30 Deg				Top of mast angle
	REF WIND SPEED	20	5	ALTERNATOR	SINUSOIDAL	3 cycles/Rev					"Youngs" @ 5Vp-p @15 Knots
	REF WIND DIRECTION	20	5	POTENTIOMETER	DC	352deg/10V	0-10V	x1	36deg/V	0-352	

* - Allocation (8 bit each) on Digital input pm

APPENDIX 3

PARAMETER	TRANSDUCER TYPE	RANGE	SENSITIVITY
Long. Accln	Schaevitz LSBC-10	± 10 g	0.5V/g
Lat. Accln	" "	± 10 g	0.5V/g
Vert. Accln	" "	± 10 g	0.5V/g
Pitch Rate	General Design 7735A	57.3°/s	7.3mv/deg/sec
Roll Rate	" " "	"	"
Yaw Rate	Smiths 422-RGS/2	20°/s	250mv/deg/sec
Pitch Attitude	Schaevitz R30DC	± 40°	125mv/deg
Roll Attitude	" "	± 40°	"

MOTION PLATFORM TRANSDUCERS

CHANNEL		FREQ (Hz)	OUTPUT VOLTAGE
Ship Speed	0-40 knots	60	90
Ship Heading	0-360 degrees	400	90
Wind Direction	0-360 degrees	60	90
Wind Speed	0-100 knots	60	90

SHIP SYNCHRO CHANNELS

APPENDIX 4

TYPE:	Young Model 05102 Wind Monitor
WIND SPEED OUTPUT:	AC Voltage 3 cycles/revolution
AZIMUTH OUTPUT:	DC Voltage from potentiometer Mechanical range 0 to 360 degrees Electrical range 0 to 355 degrees
PROPELLER:	Four bladed Type 08234 180mm diameter x 300mm pitch

REFERENCE ANEMOMETER DETAILS

APPENDIX 5

MAST CONSIDERATIONS

LOADING ON MAST BASE

Each leg of the mast base is 1.5 metres long with 280 mm of the leg length secured beneath a reinforced 10 mm thick mild steel base plate.

Assuming that the three guy wires from the end of each leg attach at 3.2, 6.4 and 9.0 metre levels as shown in Fig. 8 then typically:

The upper guy wire is angled 80 degrees at the end of the leg

" mid " " " " 75 " " " " " "

" lower " " " " 55 " " " " " "

The vertical downward force component on the mast becomes almost the combined tension in the cables.

The total tension in the guy wires, combined with the mass of the mast, produces a downward force at the centre of the base plate which was sufficient the produce significant deflection of the base plate. This deflection reduced the clearance distance between the deck and the underneath surface of the base plate giving potential for the base plate to scrape on the uneven deck during wheeling operations. Also, the mast structure exhibited a lightly damped vertical resonance.

The base was strengthened by securing the lower end of a vertical strut to the base plate, close to and parallel with the raised mast, and clamping the upper end of the strut to the rigid apex formed by three braces. The opposite ends of the three braces were clamped to separate legs close to the attachment point of the wheels. This prevented the base and legs from deflecting as the guy wires were tensioned.

With this configuration the downward load acting at the foot of the mast was carried by the vertical strut in tension and distributed by the braces directly to the wheels. This provided an extremely rigid structure that had the added advantage of increasing the mass of the base and lowering the centre of gravity for the mast.

MASS ALLOCATION

The legs, braces and strut were short lengths (typically 1.5 metres) of 50 mm diameter steel galvanised scaffolding pipes. Scaffolding clamps were used to secure the tubes. This approach provided an economical, easily transportable and versatile hardware system that could, in an emergency, be considered expendable.

The triangular shaped base plate of 10 mm thick mild steel had 500 mm by 14 mm steel bars welded to the under side of the plate along each of the three edges.

The galvanised steel mast was in three telescoped sections and was readily available commercially as an antenna mast.

The total mass of the structure was approximately 150 kilograms with the main components contributing to the total as follows.

APPENDIX 5 (cont)

ITEM	MASS (kg)
Base plate, mast and nine anemometers	56
Three legs, three braces and strut (7.5 kg each)	52.5
Three wheels (1 kg each), three jacks (4.5 kg each) and six clamps (1.5 kg each)	25.5
Bracing cables and fittings	14

AERODYNAMIC DRAG ON MAST

From Reference 6 an estimate of the aerodynamic drag on the mast was obtained by:

Drag force = 0.5 * Rho * Velocity^2 * Area * Cd

where:

Rho is air density and has the value 1.226 kg/m^3 at Mean Sea Level Standard Atmosphere ISA conditions

Cd is the Drag coefficient (Assumed 1.0 for cylinder and 1.2 for guy wires)

Velocity of the air (assumed 30 knots or 15.4 m/s)

Area is the effective side on section area of the structure and calculated values are:

ITEM		AREA (m^2)
Mast:	10 metres by 36 mm	0.36
Guy wires:	60 metres by 3 mm	0.18 (total)
Anemometer array:		0.04 (each)
Propeller:	180 mm diam	0.02 (each)

The "into wind" anemometer propeller was considered as a spinning disc, and exhibited a cross section area (0.025 m^2) equivalent to a disk the diameter of the propeller.

Each anemometer array contributed an estimated drag force of about 10 newtons contributed by:

APPENDIX 5 (cont)

Vertical anemometer and stand:	4.9 newtons
One side anemometer:	1.4 newtons
One propeller (into the wind):	3.6 newtons

From above, a 30 knot wind is estimated to produce a total mast side force of about 110 newtons and a turning moment on the mast of approximately 550 newton-metres.

UPRIGHT MAST RESTRAINING MOMENT

The inbuilt stability that resists the wind forces acting on the mast is provided by the mass of the mast assembly revolving about the overturning moment arm formed by the jacks at the ends of two of the base legs.

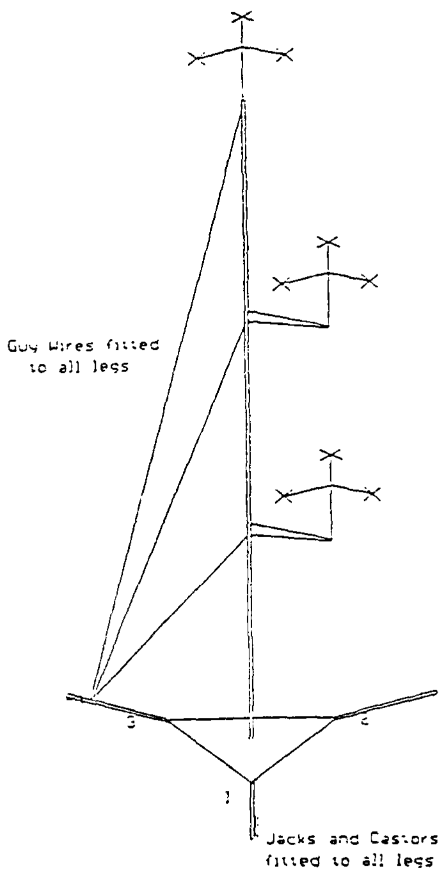
The estimated restraining moments of the main components are:

ITEM	MASS (kg)	ARM (m)	MOMENT (N.m)
Two legs	7.5 (each)	0.3	44.1
Two braces	7.5 (each)	0.42	61.7
Base plate, strut and clamps	39	0.84	321.4
Nine anemometers and mast	30	0.84	247.0
One brace	7.5	1.2	88.2
One leg	7.5	1.8	132.3
TOTAL			894.7

The restraining moment of the unsecured mast when standing on the level flight deck was estimated to be approximately 900 newton-metres. At 40 knots the drag force increases by a factor of about 1.8 over the drag at 30 knots and the turning moment increases to almost 1000 newton-metres.

These estimates seem reasonable as during the sea trial the mast was found to be stable at up to 30 knots. Exposed to a relative wind strength of 35 knots with higher speed gusts the trial team considered that the safe maximum working limit for the unsecured mast had been reached.

APPENDIX 5 (cont)



MAST DIAGRAM AND RAISING PROCEDURE

NOTES:

In the lowered mast position the anemometer support arms pointed upwards to ensure that the propellers were clear of the ground.

The mast was raised by pulling on a rope towards leg number 1.

During raising and lowering of the mast the guy wires remained attached to number 2 and 3 legs.

Prior to use the mast and base were rotated to orientate leg number 3 to point aft and for each anemometer array to point forward, starboard and upwards as shown in Fig. 1.

APPENDIX 6

RELATIVE WIND FROM SYNCHRO REPEATER VALUES IN HCS

Readings from the indicators shown in Figure 2 are:

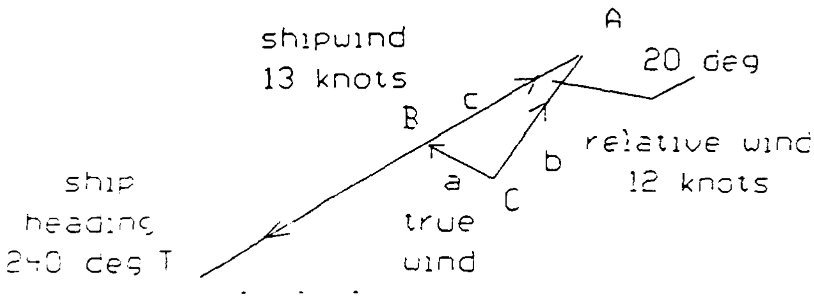
Relative wind: 12 knots at 20 degrees off the port bow

Ship's speed: 13 knots at ship heading 240 degrees true

From the following vector diagram

RELATIVE WIND VECTOR = TRUE WIND VECTOR + SHIP WIND VECTOR

Also SHIP WIND VECTOR is opposite sense of SHIP HEADING VECTOR



Applying the cosine rule: $a^2 = b^2 + c^2 - (2 * b * c * \cos(A))$

TRUE WIND SPEED = $\sqrt{[12^2 + 13^2 - (2*12*13*\cos(20))]}$

gives TRUE WIND SPEED of 4.45 knots.

Applying the sine rule: $a/\sin(A) = b/\sin(B)$

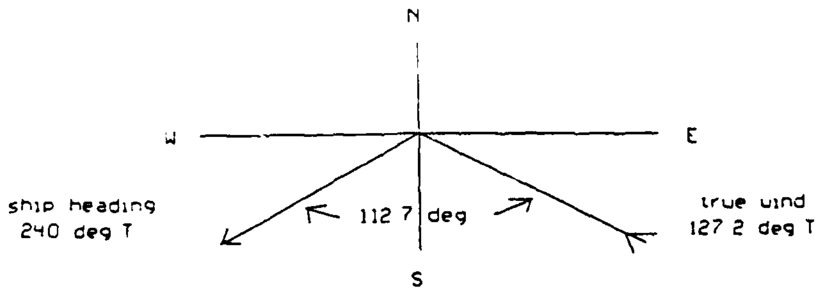
WIND DIRECTION RELATIVE TO SHIP = asin[12 * sin(20) / 4.45]

gives WIND DIRECTION (relative to ship) of 67.3 degrees off port stern. (or 112.7 degrees off port bow).

TRUE WIND DIRECTION = SHIP HEADING - 112.7

gives TRUE WIND DIRECTION of 240 - 112.7 = 127.3 degrees true.

Hence the TRUE WIND VELOCITY is 127.3 degrees at 4.45 knots (generally expressed as 5 knots at 130 degrees).



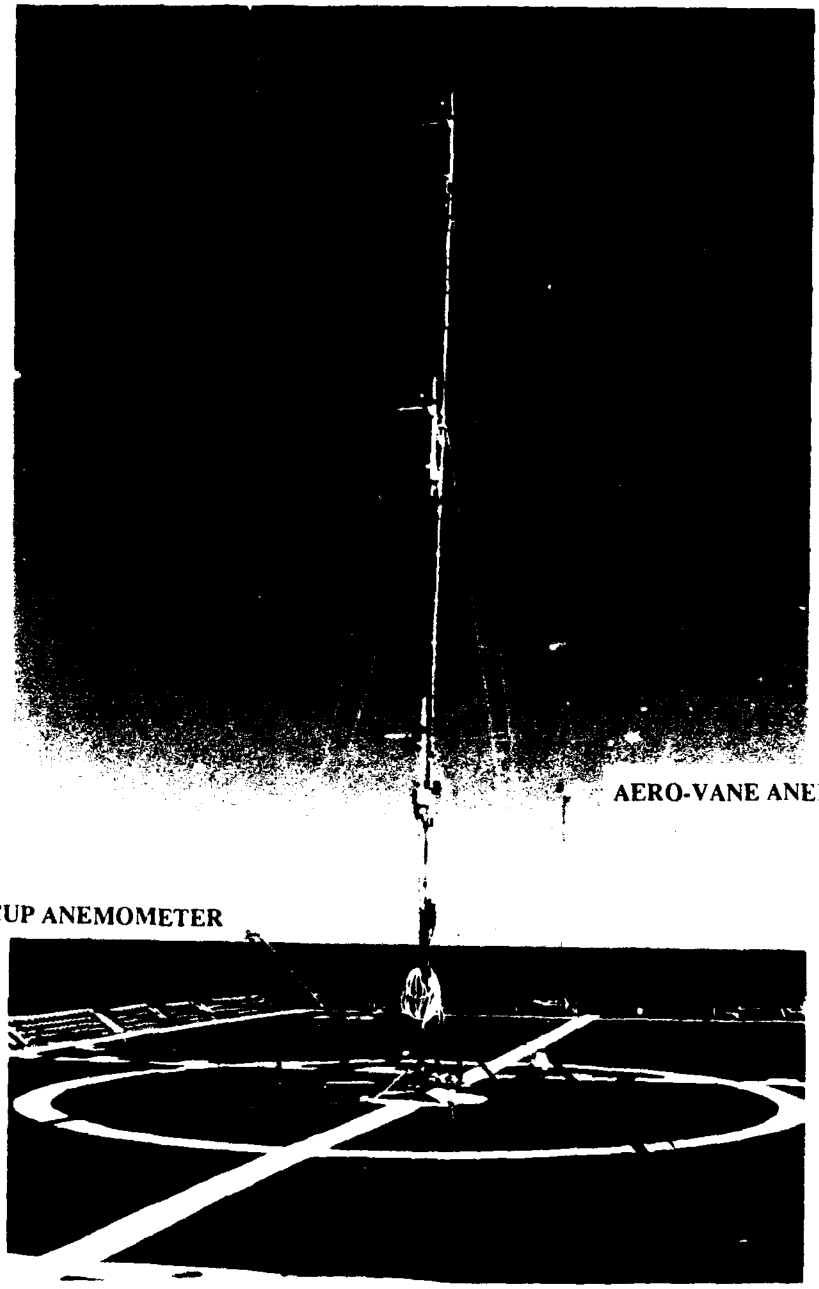
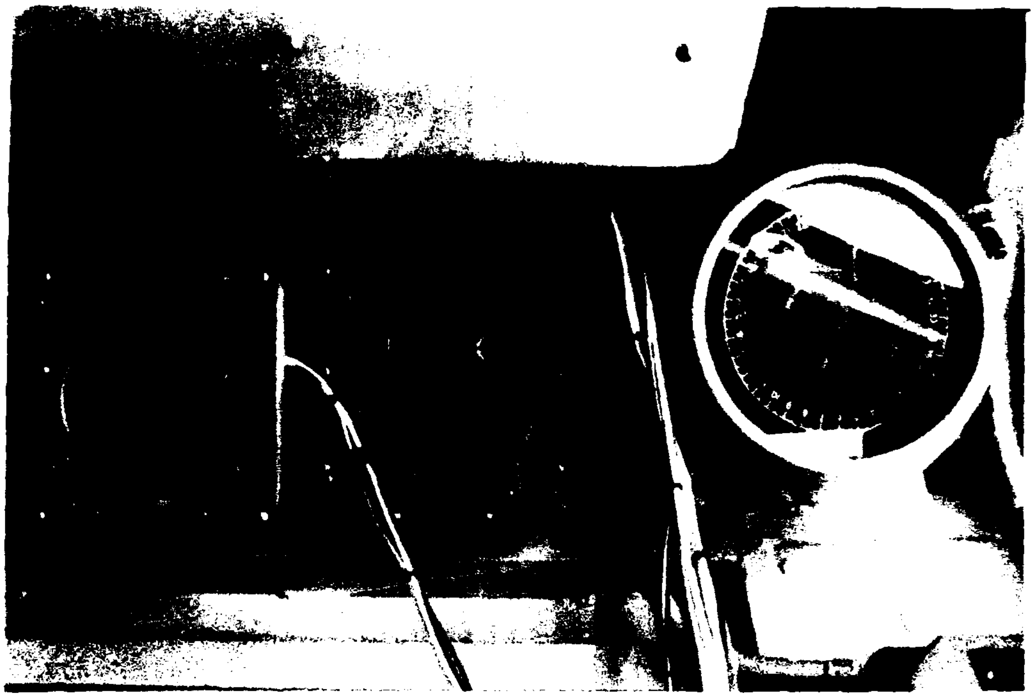


FIG 1 MAST ON THE FLIGHT DECK



DISPLAYS (left to right):

SHIP SPEED AS 13 KNOTS

WIND SPEED AS 12 KNOTS

RELATIVE WIND DIRECTION AS 20 DEGREES OFF BOW TO PORT

(ABSOLUTE WIND DIRECTION 220 DEGREES)

SHIP HEADING AS 240 DEGREES

FIG 2 SYNCHRO REPEATERS IN HCS

FIG 3 (a) VISUALISATION OF THE AIR FLOW NEAR GRID POINT 12

FIG 3 (b) VISUALISATION OF THE AIR FLOW NEAR GRID POINT 7

FIG 4 (a) MAST EVALUATION AT MAXIMUM SLOPE

FIG 4 (b) MAST EVALUATION USING AN ARMY UNIMOG

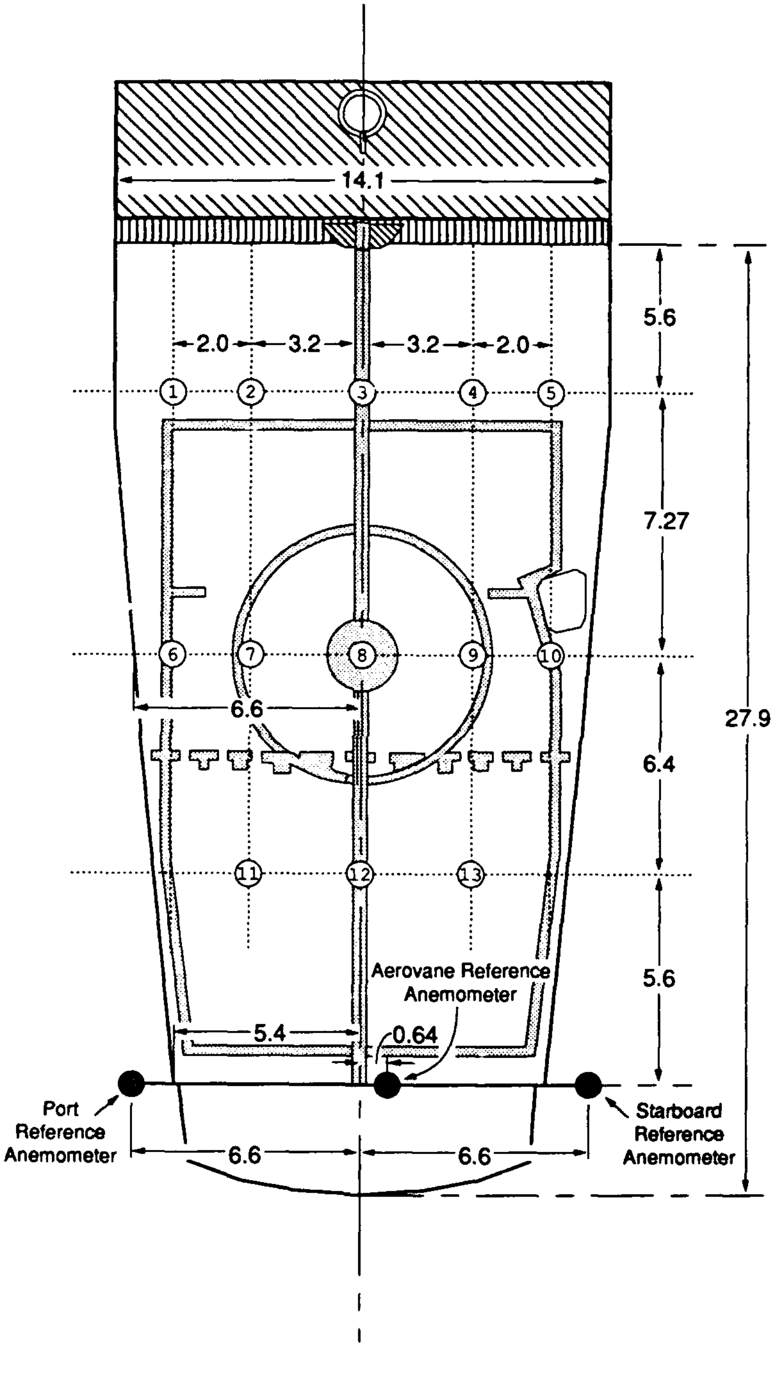


FIG 5 GRID PATTERN FOR MAST POSITIONS ON THE FLIGHT DECK

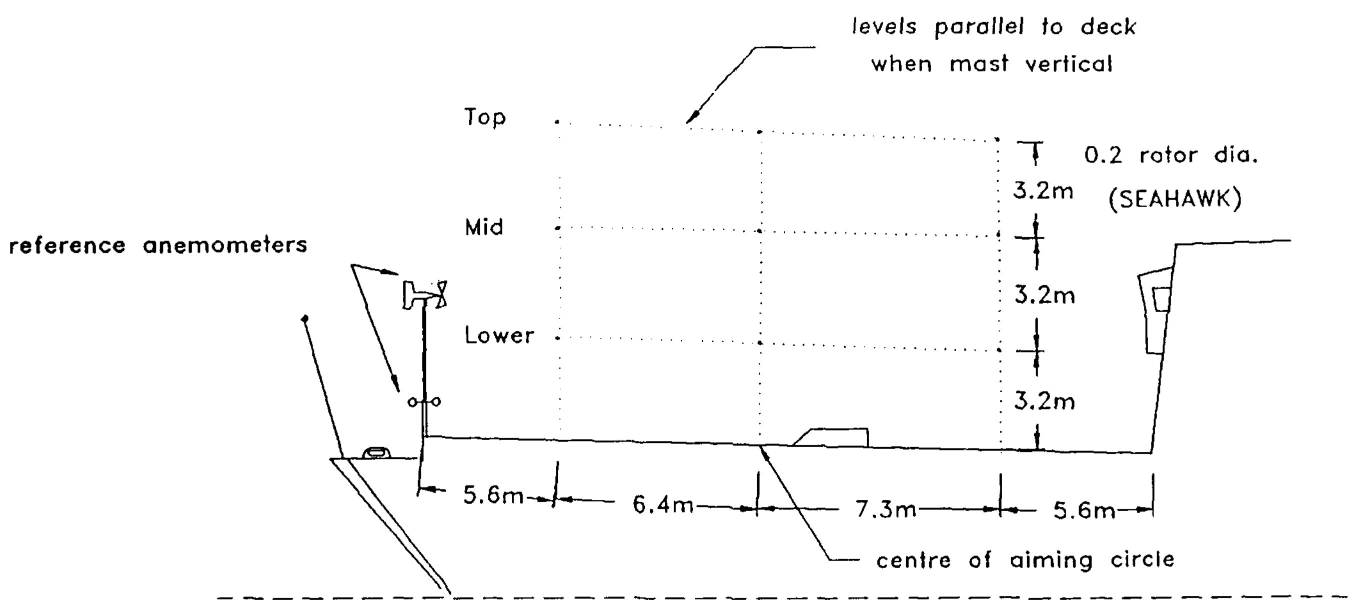
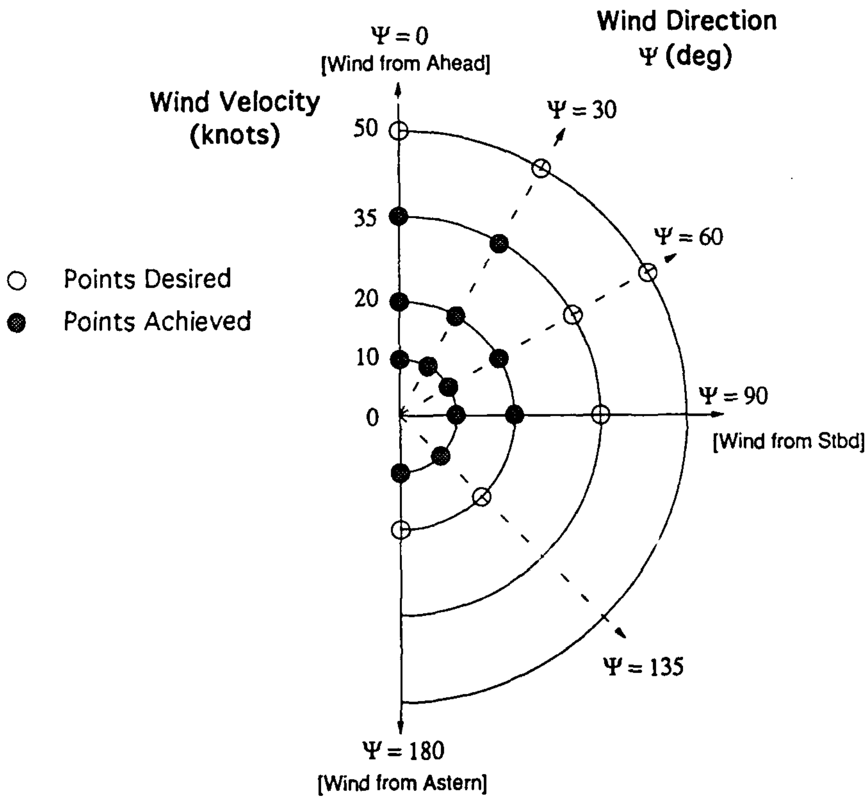


FIG 6 MAST ANEMOMETER LEVELS ABOVE FLIGHT DECK



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PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

1a. AR NUMBER	1b. ESTABLISHMENT NUMBER	2. DOCUMENT DATE	3. TASK NUMBER
AR-006-623	ARL-FLIGHT-MECH-TM-450	NOVEMBER 1991	NAV 89/073

4. TITLE
INSTRUMENTATION FOR AIRWAKE MEASUREMENTS ON THE FLIGHT DECK OF A FFG-7

5. SECURITY CLASSIFICATION (PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF. (C) RESTRICTED (R), UNCLASSIFIED (U)).

DOCUMENT	TITLE	ABSTRACT
U	U	U

6. NO. PAGES
30

7. NO. REFS.
6

8. AUTHOR(S)
D.T. HOURIGAN
C.W. SUTTON
F.J. BIRD

9. DOWNGRADING/DELIMITING INSTRUCTIONS
Not applicable

10. CORPORATE AUTHOR AND ADDRESS
AERONAUTICAL RESEARCH LABORATORY
506 LORIMER STREET
FISHERMENS BEND VIC 3207

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14. DESCRIPTORS
Air flow
Flight decks
Oliver Hazard Perry class frigates
FFG-7 frigates
HMAS Darwin
Tasman sea

15. DISCAT SUBJECT CATEGORIES
1310
2004
0104

16. ABSTRACT

This paper describes the instrumentation and techniques used to successfully gather airwake data on the flight deck of HMAS Darwin in the Tasman Sea during September 1989.

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16. ABSTRACT (CONT).

17. IMPRINT

AERONAUTICAL RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER	19. COST CODE	20. TYPE OF REPORT AND PERIOD COVERED
Flight Mechanics Technical Memorandum 450	57 5561	

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF.(S)

23. ADDITIONAL INFORMATION (AS REQUIRED)