ARL-AERO-TECH-MEMO-332

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AR-002-298

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Aerodynamics Technical Memorandum 332

SEA KING FLIGHT TESTS
PITOT-STATIC PROBE AND DIRECTIONAL VANE INSTRUMENTATION

D.T. HOURIGAN and M.J. WILLIAMS

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JULY 1981

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SUMMARY

A short description is given of the pitot-static pressure probe and vanes mounted on a nose boom for Sea King flight tests. Also described is a probe which was trailed below the aircraft to determine the position error of the boom probe. Results of wind tunnel calibrations of these probes are given.

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DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1.	DOCUMENT NUMBERS	2.	SECURITY CLASSIFICATION
a.	AR Number: AR-002-298	a.	Complete document: UNCLASSIFIED
b.	Document Series and Number: AERODYNAMICS TECHNICAL MEMORANDUM 332	b.	Title in isolation: UNCLASSIFIED
c.	Report Number: ARL-AERO-TECH-MEMO-332	c.	Summary in isolation UNCLASSIFIED

3. TITLE:

SEA KING FLIGHT TESTS
PITOT-STATIC PROBE AND DIRECTIONAL VANE INSTRUMENTATION

4.	PERSONAL AUTHORS: D.T. HOURIGAN and M.J. WILLIAMS	5.	DOCUMENT DATE: JULY, 1981
		6.	TYPE OF REPORT AND PERIOD COVERED:
7.	CORPORATE AUTHOR(S): Aeronautical Research Laboratories	8.	REFERENCE NUMBERS
		a.	Task: NAV-74/4
9.	COST CODE: 51 2070	b.	Sponsoring Agency: NAVY
10.	IMPRINT: Aeronautical Research Laboratories, Melbourne	11.	COMPUTER PROGRAM(S) (Title(s) 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: Pitot-static probes, Flight instruments, Helicopters, Wind vanes	15.	COSATI CODES: 0104

16. ABSTRACT:

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NOTATION

H		total head or pitot pressure
p		static pressure
q		dynamic pressure = H-p
ΔH	}	probe pressure errors
Δp	}	excess over free stream values
Δq	}	

1. INTRODUCTION

During August 1979 flight trials of a Sea King Mk. 50 helicopter of the RAN were undertaken at HMAS Albatross, Nowra, NSW. Extensive data were recorded and form the basis of a data bank which will enable the validation of predictions made by the ARL mathematical model of this aircraft to be tested.

Among the many parameters monitored were those pertaining to the aircraft motion relative to the air mass, in particular, velocity and flow direction angles. It was considered necessary to install on the nose, a boom extension on which was mounted a pitot static probe and a pair of vanes to measure fuselage angles of sideslip and attack. The forward location of these sensors ensures that the rotor wake only impinges directly at relatively low airspeeds. Additionally, it was expected that the pressure error correction of the boom pitot static system would be far less dependent on rate of climb or descent than the system installed in the aircraft.

Calibration of the boom pressure probe, as installed, was made against a towed probe of known performance. The latter probe trailed well below the aircraft (approx. 45m (150 ft)) and measured both pitot and static pressures. This method was considered safer than the "Douglas" trailing cone which trails directly behind the aircraft and measures static pressure only.

Details of the design and performance of each probe and of the vanes are now given.

2. DESCRIPTION

2.1 Boom

Fig. 1 shows relevant dimensions of the boom and associated probe and vanes. A photograph of the installation on the aircraft is shown in Fig. 2. A relatively simple method of attachment was devised by AMAFTU*; the tube has a pin jointed attachment at the aircraft nose and is directionally located by 3 steel wire cables tensioned back to anchor points on the fuselage. This system allows easy dismantling and setting up, and permits the use of a comparatively small tube diameter while still keeping the boom natural frequency above the blade frequency ($\approx$ 17 hz).

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* Aircraft Maintenance and Flight Trials Unit, HMAS Albatross

The boom length was chosen on the basis that the probe and vanes would be free of rotor downwash effects at airspeeds greater than 30 knots. Estimates of the rotor wake sweepback angle were based on Iroquois flight measurements, these being the only data available.

2.2 Boom-mounted pitot static probe

Bearing in mind the large range of sideslip and incidence angles expected in the trials program, a hemispherically-nosed probe design was chosen. According to Ower (Ref. 1) this geometry exhibits a variation in measured kinetic pressure of not greater than 5% for flow angles up to 30° off-axis. Static holes are located 6 body diameters ($X/_D = 6$) aft of the nose in accordance with recommendations of Ref. 1; likewise a value of $d/D = 0.3$ was chosen where d and D are the pitot hole and body diameters respectively.

As can be seen from the sketch (Fig. 3) a conical transition piece is needed to match the pitot-static tube to the boom dimensions. The up-stream effect of this enlargement in diameter should be to offset the negative static coefficient which would occur at $X/_D = 6$ on a very long, constant diameter static tube.

In practice, the probe operates in the region of upstream influence of the aircraft and the position error has to be determined by calibration. It was therefore not considered necessary to determine the coefficient of the probe in isolation, in the wind tunnel; instead a series of tests were performed to determine its sensitivity to angle of attack for angles up to 30°, at 3 typical airspeeds. (see Acknowledgement). Some results of these tests are shown in Fig. 4 where the static and pitot pressure coefficients are non-dimensionalized with respect to the values at $\alpha = 0^{\circ}$.

Also shown is the variation of kinetic pressure which is in agreement with the original design data of Ref. 1. Only data for one airspeed are shown for clarity as no significant effect of airspeed could be discerned. The apparent increase in pitot pressure at 5° probably arises from tunnel flow non-uniformity since the probe nose was translated across the tunnel as the angle of attack varied.

2.3 Towed pitot static probe used for calibration

Relevant dimension of the towed probe are shown in the sketch (Fig. 5) and photographs of the probe in the wind tunnel and in flight are shown in Figs. 6 and 7 respectively. The probe was made to a design developed by A.R.D.U.* which followed from modifying a U.S. designed probe to give stable flight when towed from an Iroquois helicopter.

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* Aircraft Research and Development Unit R.A.A.F. Salisbury, South Australia.

Results of calibration in the ARL Low Speed Wind Tunnel are plotted in Fig. 8 and show the pressure coefficients of the static and pitot holes as a function of wind speed. The coefficient of the pitot hole should rightly be zero; the small negative values measured are attributable to experimental error. The static holes have a positive error coefficient, presumably arising from the upstream influence of the conical stabilizer. The reason for the velocity-dependence of the coefficient is not known but could arise from Reynolds number effects on the flow in the region of the body-stabiliser junction. Naturally the derived dynamic pressure reflects this variation with velocity. The error in dynamic pressure is -2% at the lower speeds and corresponds to a velocity error of -1%.

The effect of the flow angle of attack on the towed probe was also studied over a more limited range of angles than for the boom probe, in view of the self-aligning properties of the former. Results are shown in Fig. 9 for the highest speed of 118 knots (= 200 ft/s). Both the boom and towed probe (Figs. 4,9) exhibit the same general trends in respect of pitot and static pressure readings with flow angle. The nett result is that the dynamic pressure error of the towed probe is negative and increases in magnitude with angle. In contrast, the boom probe dynamic pressure error is positive in the same range of flow angle.

2.4 Vanes

The vanes are required to perform satisfactorily in the airspeed range 30 to 110 knots; below 30 knots the rotor downwash influence is felt. Also, the vane natural frequency should be not less than 12 Hz at the highest speed, this being compatible with the low pass cut-off of the filters in the data acquisition system. Although the literature on wind vanes is quite extensive, ranging from meteorological applications to those for high speed aircraft, there is little information on vanes specifically for helicopters. For the present installation only small potentiometers were available for use as shaft angle transducers. Since appreciable friction occurs in the wiper of the potentiometer and an extra pivot shaft bearing was necessary to relieve the potentiometer bearings, it was required that the aerodynamic moment of a deflected vane should be relatively large even at the lowest speed.

An intensive study of the dynamic behaviour of angle-of-attack vanes is described by Karam (Refs. 3,4). As the effects of both unsteady aerodynamics and dry friction are included, the analysis is somewhat lengthy. A corresponding experimental program was carried out on a commonly-used low aspect ratio (= 1/2) vane geometry with the pivot axis located at the leading edge. Results confirmed the predicted linear dependence of vane natural frequency with airspeed, while the frequencies were predicted within +20% of the experimental value. On the other hand, the measured damping coefficients were 2 to 3 times greater than predicted although they remained sensibly constant, as predicted, until the dominance of dry friction effects at the lowest speeds.

A vane of similar geometry (Fig. 10(a)) was tested in a small ARL wind tunnel to assess its performance at low airspeeds.

Fig. 11(a) shows the vane response after being deflected 10° and released. The slow approach to equilibrium is characteristic of the dominance of dry friction effects over the aerodynamic restoring moments at small angles of attack. With this vane geometry, both the proximity of the centre of pressure to the pivot axis and the lower lift coefficients of low aspect ratio geometries tend to limit the available restoring moment. On the other hand, the vane of Fig. 10(b) has an aspect ratio of 2:1 and, at the same time, the leading edge is offset one chord length aft of the pivot axis. These changes are estimated to produce a 6-fold increase in restoring force, although a small (≈ 10%) reduction in natural frequency results from the increase in the vane inertia moment. Test results (Fig. 11(b)) show the rapid approach to equilibrium condition and confirm the relative reduction in friction effects. However, the transient is more highly damped than would be expected from aerodynamic cause, thus indicating that dry friction effects are still in evidence.

Vanes of this latter type were considered adequate for the flight test program following checks of the complete boom, probe and vane installation in the ARL Low Speed Tunnel at the highest expected speed. Although no dynamic response tests were done at this speed, the natural frequency estimated from the tests of Fig. 11 of 5 - 6 Hz suggests that, assuming proportionality with airspeed, the response at 110 kn will more than adequately meet the 12 Hz requirement.

During flight tests, no mechanical trouble was experienced with the pair of plain balsa vanes used throughout the August 79 trials and the preceding January 79 tests. Calibration of the angular sensitivity of each vane channel was performed in situ prior to flight. For this purpose a jig was used to set the vane at a series of angles with respect to the boom. This jig is shown in Fig. 12.

Typical data from Sea King flight tests are shown in Fig. 13. Commencing at trimmed flight conditions at 80 knots, a rapid fore-aft input is made to the cyclic stick (PITCH STK) after a time of about 2 sec. The subsequent variation of the pitch and sideslip vane angles, together with the aircraft attitude in pitch (PITCH ATT) is clearly shown. Unsteadiness in the vane outputs probably reflects the turbulent state of the ambient air but a contribution from vibration has not been ruled out.

ACKNOWLEDGEMENT

Thanks are due to Mr. K. O'Dwyer and the A.R.L. Low Speed Wind Tunnel staff for calibrating the two pressure probes.

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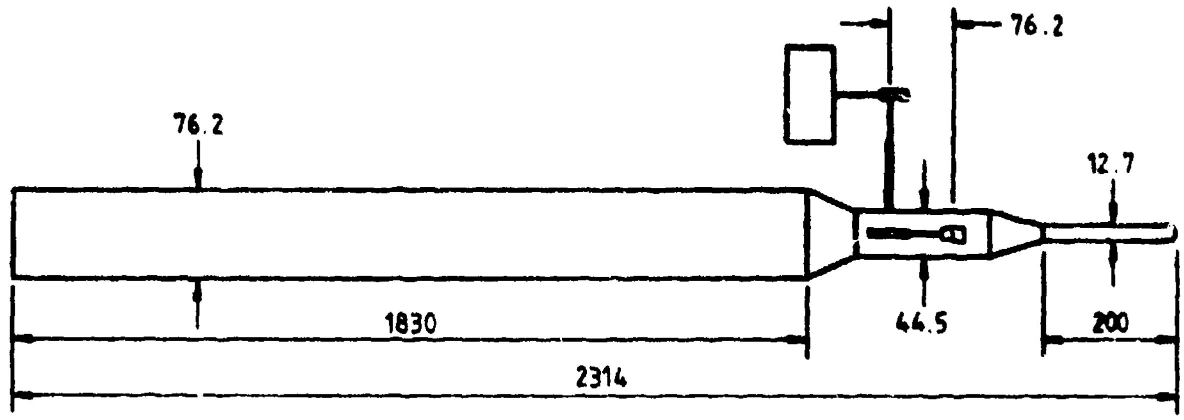
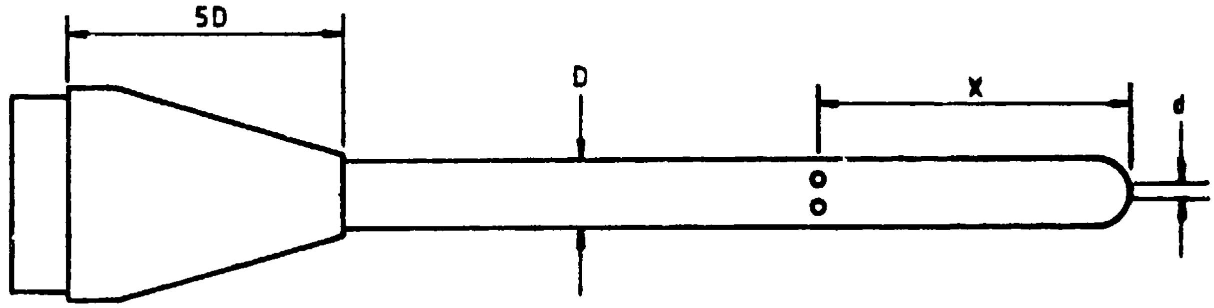


Dimensions in mm .

FIG. 1 BOOM PITOT STATIC PROBE AND DIRECTIONAL VANES

FIG. 2 BOOM INSTALLED ON R.A.N. SEAKING AIRCRAFT



$$\frac{d}{D} = 0.3$$

$$\frac{X}{D} = 6.0$$

FIG. 3 GEOMETRY PITOT STATIC PROBE WITH CONICAL TRANSITION PIECE

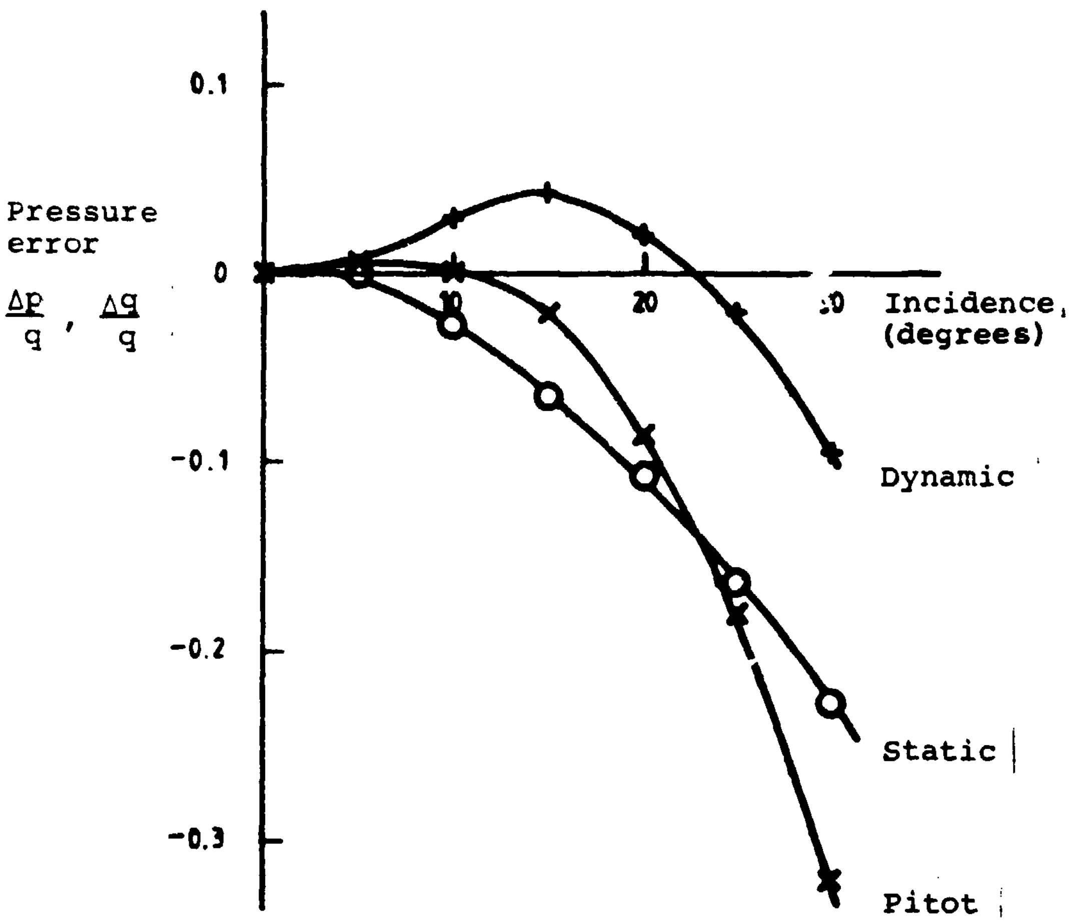


FIG. 4 BOOM PROBE PRESSURE ERROR VARIATION WITH ANGLE OF INCIDENCE (V=100 Knots)

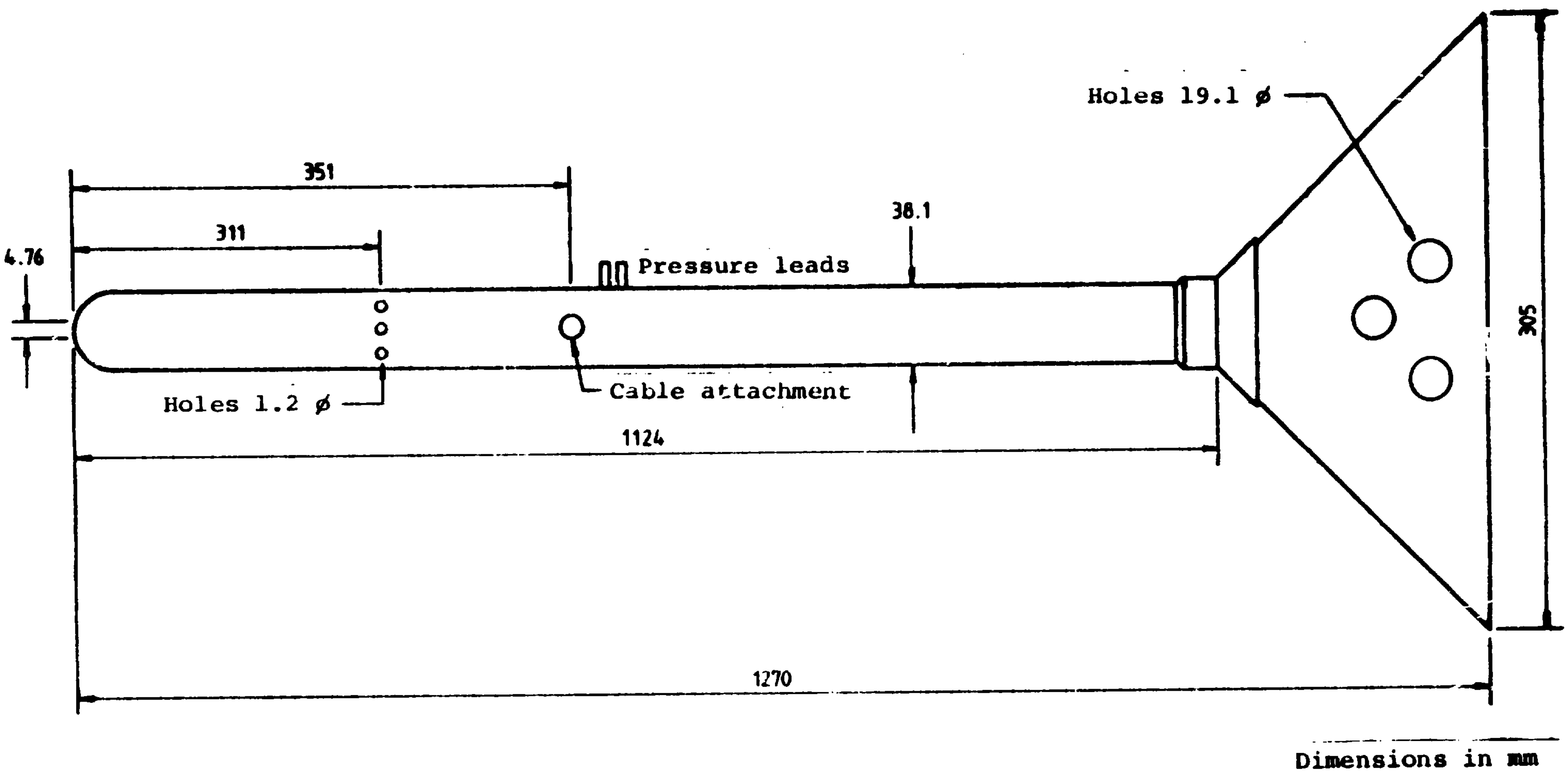


FIG. 5 GEOMETRY OF TRAILING PITOT STATIC PROBE

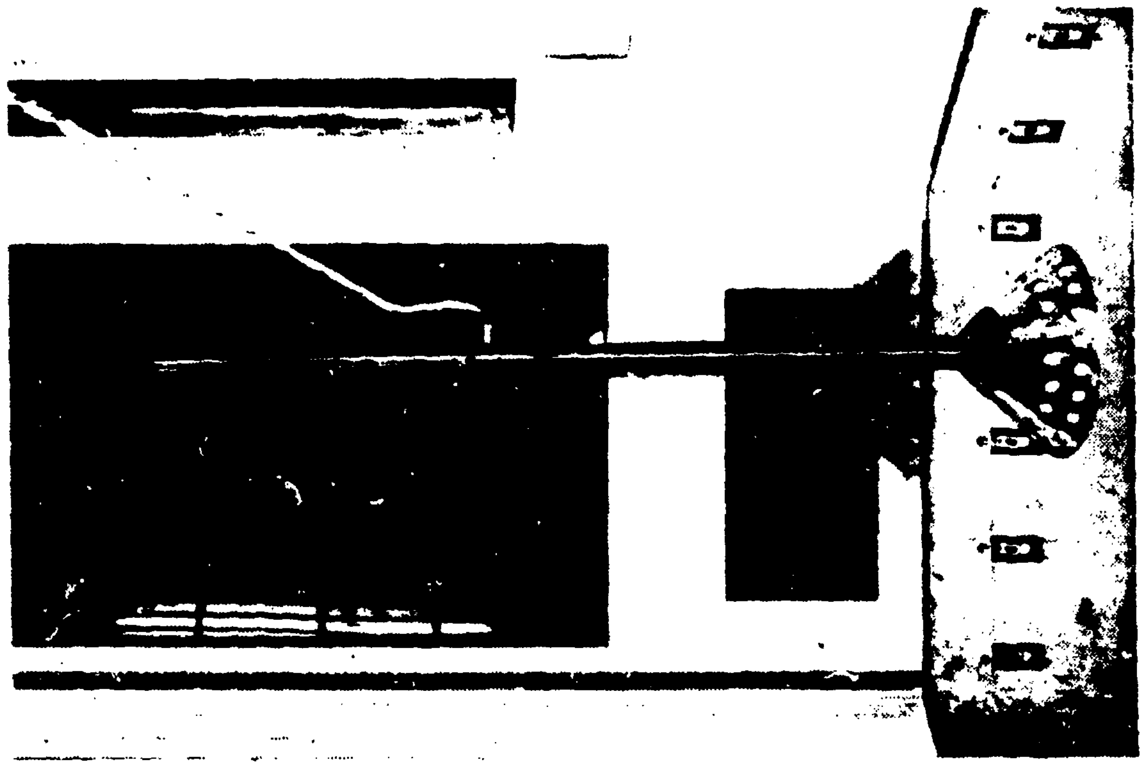


FIG. 6 TRAILING PITOT STATIC IN WIND TUNNEL

FIG. 7 TRAILING PITOT STATIC SUSPENDED FROM AIRCRAFT DURING R.A.N. SEAKING TRIAL

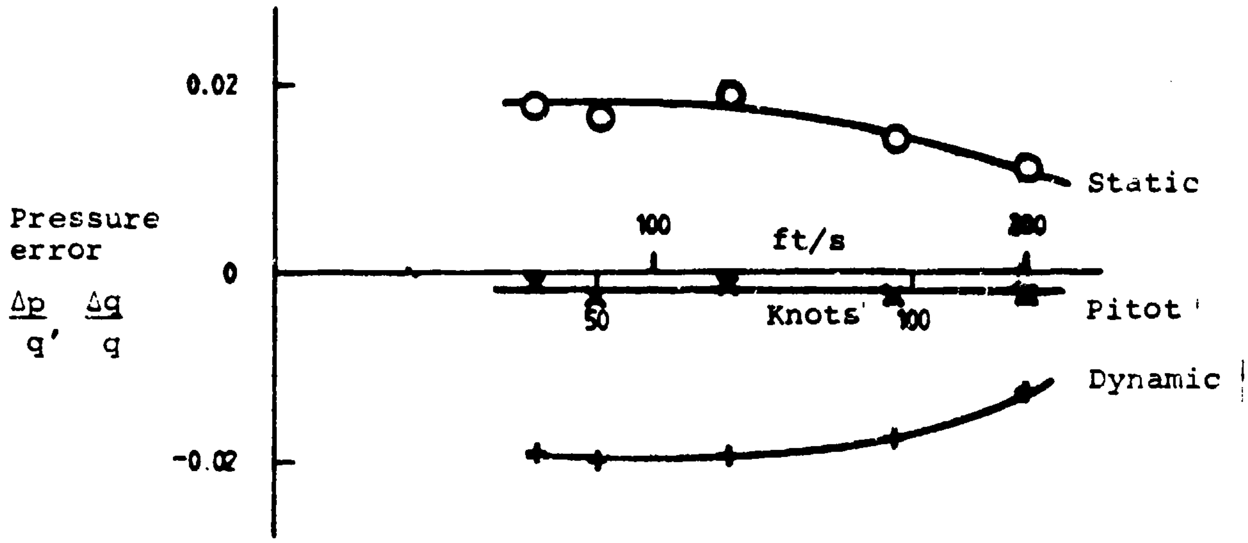


FIG. 8 TOWED PROBE - EFFECT OF AIRSPEED ON ERRORS

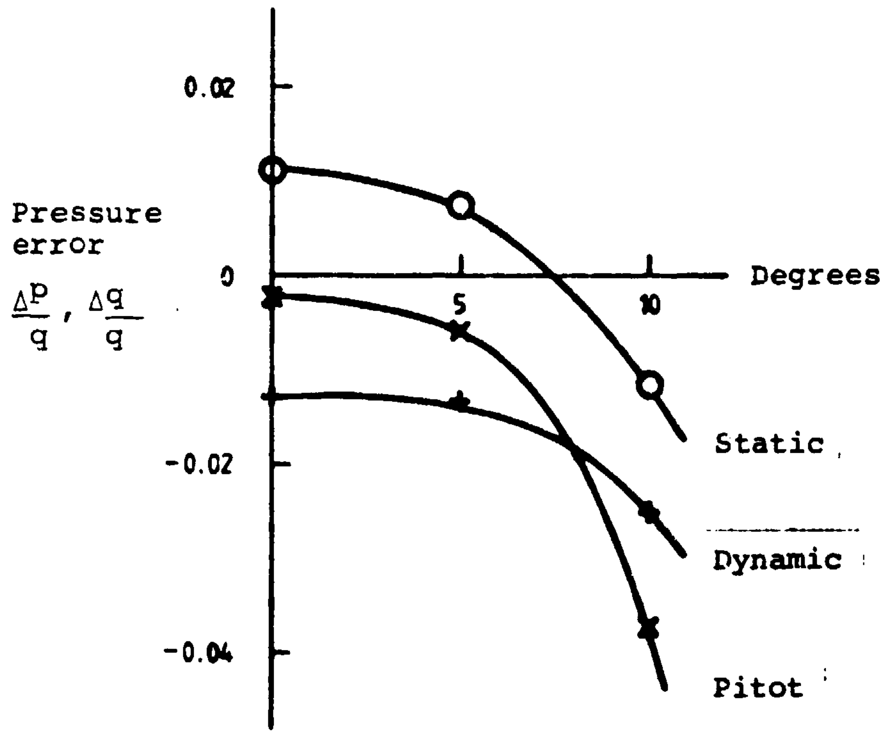


FIG. 9 TOWED PROBE - EFFECT OF FLOW ANGLE ON ERRORS 118 knots
(200 ft/s)

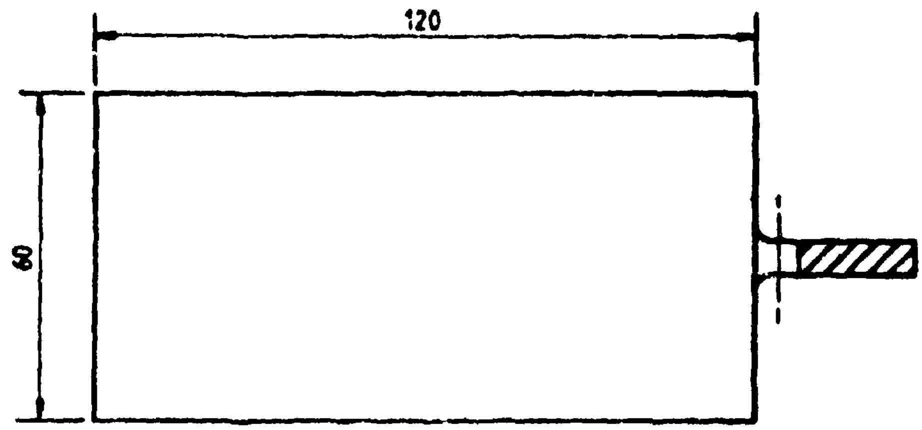


FIG. 10(a) VANE ASPECT RATIO = ½

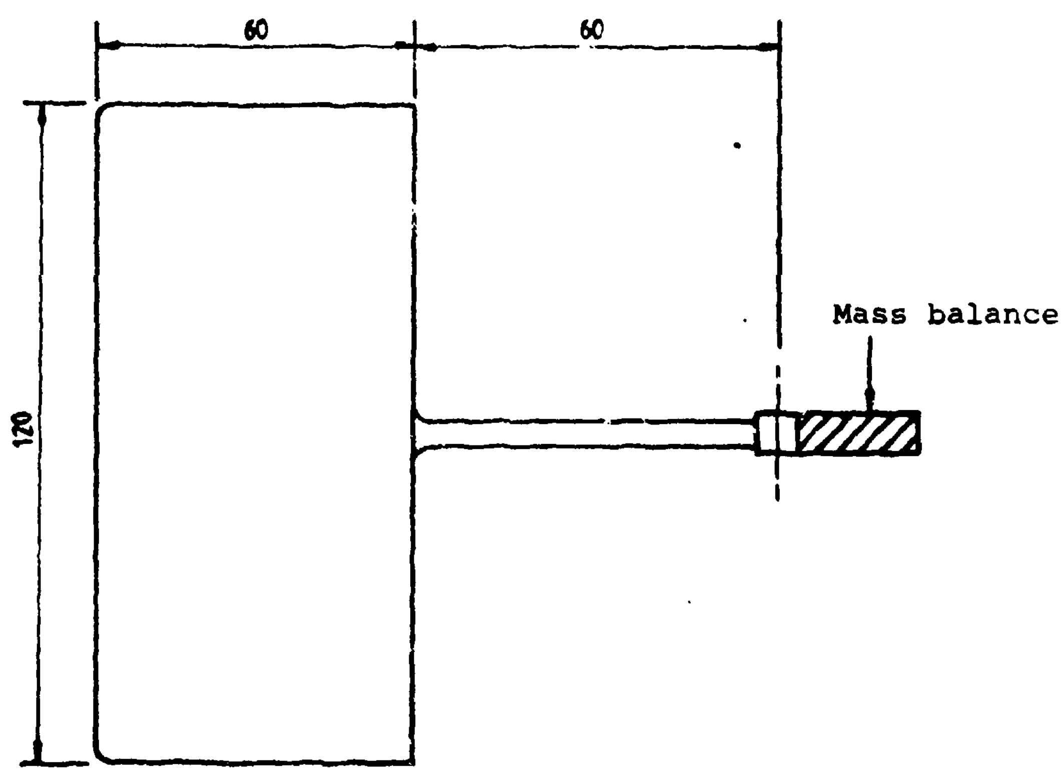
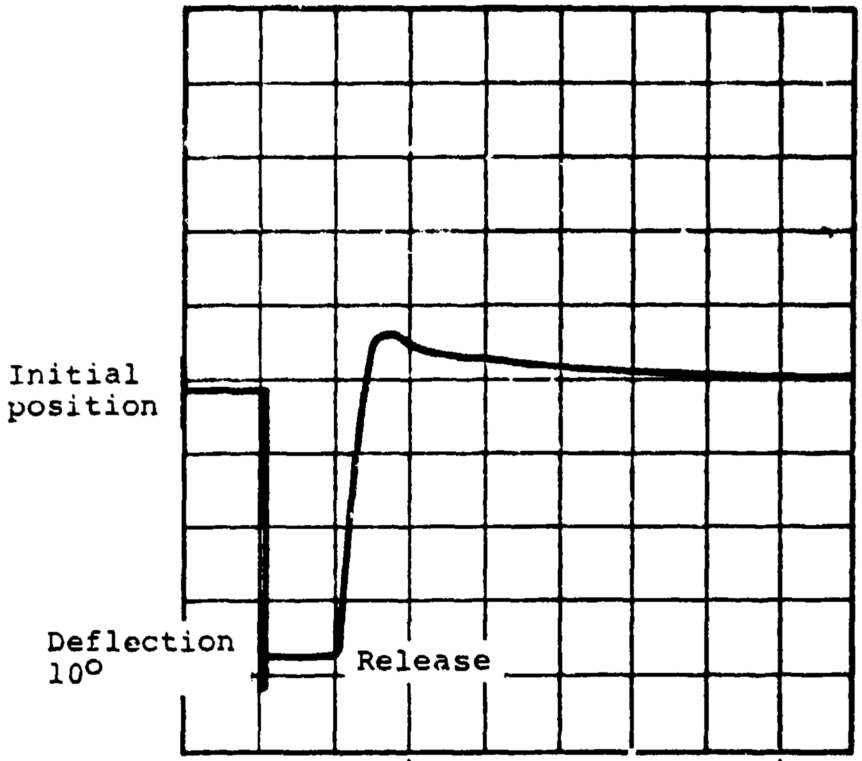
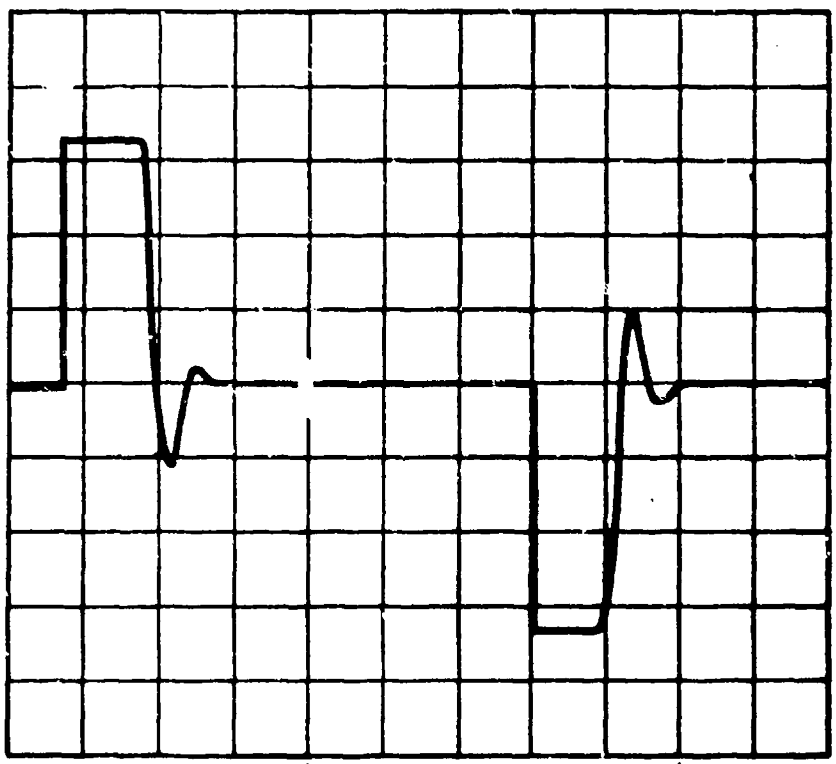


FIG. 10(b) VANE ASPECT RATIO = 2



1 second

(a) Plain balsa vane
A.R. = ½
Type A (see Fig. 10a)



1 second

(b) Plain balsa vane
A.R. = 2
Type B (see Fig. 10b)

FIG. 11 WIND TUNNEL TESTS OF VANE RESPONSE TO RELEASE FROM 10° INITIAL DEFLECTION AT 24 Knots, (40 ft/s)

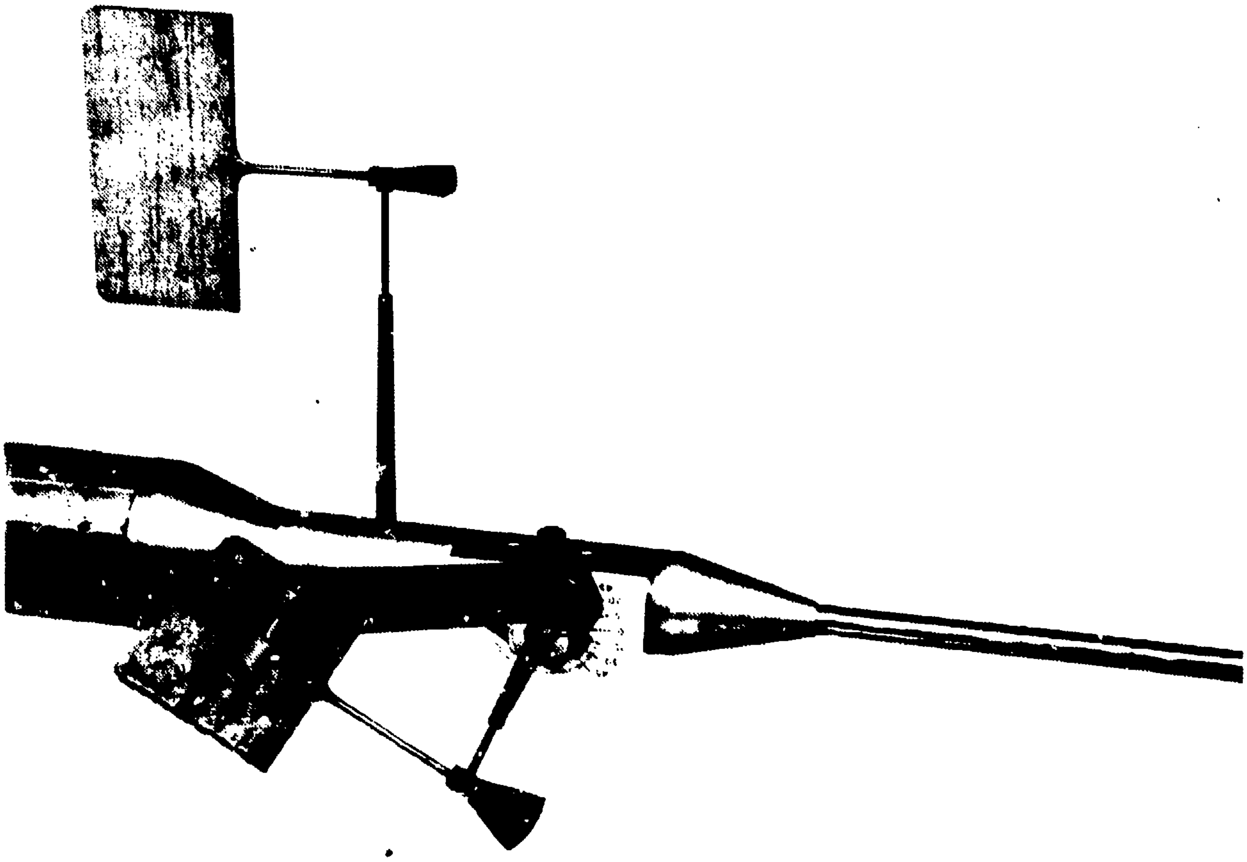


FIG. 12 VANE CALIBRATION JIG

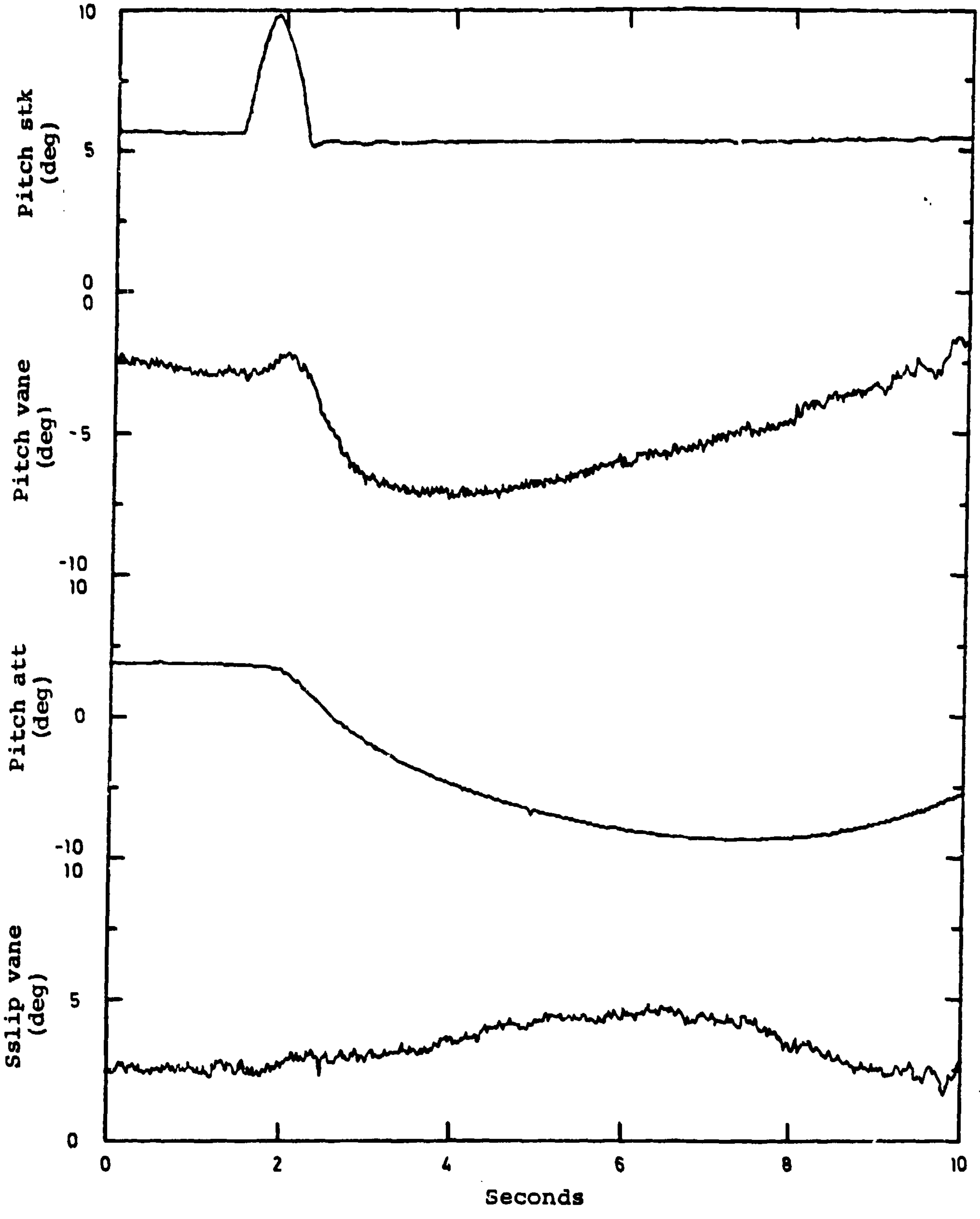


FIG. 13 TYPICAL OUTPUT FROM SEA KING FLIGHT TEST (80 KIAS) RESPONSE OF VANES AND AIRCRAFT PITCH TO FORE/AFT PULSE TO CYCLIC STICK

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