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BOOM PROBE POSITION ERROR CORRECTIONS FOR
SEA KING MK. 50 FLIGHT TESTS

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SUMMARY

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Position error has been determined for a nose-boom mounted pitot-static probe installed on a Sea King Mk. 50 helicopter. The error is sensibly constant in the speed range 35 - 110 knots and is unchanged in climb and descent. Corrections to be applied to indicated nose boom values are 7.5 knots in velocity, and up to 80 ft.* in altitude.

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NOTATION

ASI  Aircraft airspeed indicator reading, knots
\( \rho \)  standard density at which ASI is calibrated
Cp  pressure coefficient
h  total head
p  static pressure
q  dynamic pressure
\( \Delta p \)  difference between boom and corrected towed static
\( \Delta q \)  difference between corrected towed dynamic and boom dynamic pressure
V  velocity or airspeed, knots

Suffixes

\( a \)  free stream undisturbed values
b  boom probe values
t  towed probe values
DOPP  Longitudinal doppler values
ASI  refers to ASI
1. INTRODUCTION

A series of trials, using a Sea King Mk. 50 helicopter, has been conducted with the aim of obtaining reliable flight test data relating to the aircraft's behaviour over a wide range of flight conditions. This information, including both steady state and dynamic response data, will form the basis of a data bank for validating the A.R.L. mathematical model of this aircraft.

Unfortunately, because of the siting of the aircraft's pitot static probes the static pressure in their vicinity does not register the desired free stream value. Pressure error corrections (P.E.C.) have therefore to be applied to the Air Speed Indicator (A.S.I.) and altimeter readings. The P.E.C. values given in the Operating Data Manual (O.D.M.) vary greatly depending on airspeed and flow direction. For the present work more accurate data are required and therefore an instrumented nose boom was installed so that both airspeed and flow direction could be measured in a region less disturbed by the aircraft flow field and rotor downwash.

This note describes the calibration of the boom-mounted pitot static probe against a reference trailing probe whose performance is known from wind tunnel calibration. A wide range of flight conditions, covering climb, descent and level flight was used from which the probe P.E.C. could be determined. Two corrections have to be applied to flight test data:

(a) to airspeed as deduced from the boom probe dynamic pressure,

(b) to altitude as deduced from the boom static pressure (absolute).

Flow direction is derived from angles of attack and sideslip registered by a pair of vanes mounted aft of the boom probe. More details of these sensors are available in Ref. 2.

2. DESCRIPTION OF TESTS

2.1 Probe Details

2.1.1 Boom mounted probe

Dimensions of the boom and its associated sensors are given in Fig. 1 while Fig. 2 is a photograph of the installation on the aircraft. The boom length chosen was sufficient to render the sensors clear of direct downwash effects for forward airspeeds greater than 30 knots. The method of attachment to the aircraft, using a pin-jointed mounting together with wire bracing, allowed a comparatively small boom diameter to be used while keeping the boom's natural frequency above the blade frequency of 17 Hz.
Bearing in mind the wide range of sideslip/attack angles expected in the trials a hemispherical nose geometry was chosen for the probe. Relevant dimensions are shown in Fig. 3 and further details are available in Ref. 2.

2.1.2 Towed reference probe

This probe is trailed from the aircraft to which it is attached by a steel wire cable 150 ft in length. P.V.C. pressure leads are taped to the cable and transmit the static and total pressures to transducers housed in the aircraft. The probe design is the result of further development, by A.R.D.U.*, of a U.S. design to improve the probe's flying qualities. Details are presented in Fig. 4 and a photograph of the probe undergoing wind tunnel calibration is shown in Fig. 5.

2.1.3 Probe calibration in wind tunnel

Results of calibrations of each probe in the A.R.L. Low Speed Wind Tunnel are taken from Ref. 2 and shown in Figs. 6, 7. As can be seen, the towed probe static holes have a positive pressure coefficient corresponding to a velocity error of about 1%. Because of this probe's self-aligning properties the effect of flow incidence was examined for a limited range only.

In Fig. 7 the boom probe's dependence on flow angle is shown for incidences up to 30°. Values are in coefficient form referenced to data at zero incidence and vary in a similar manner to that shown in Ref. 3 for the same probe design. The absolute pressure coefficient was not determined because in practice the probe always operates in the region of upstream influence of the aircraft. The P.E.C. determined here combines both effects.

2.2 Pressure Measurement and Pre-flight Checks

The arrangement of pressure transducers and associated pressure lines is shown schematically in Fig. 8. All transducers were by Setra Systems Inc. and were excited by 24v unregulated d.c. Output was 5v d.c. at the nominal pressure range. Details are as follows:

(a) Boom pitot-static (differential) Type 236, nominal range 1.4 kPa but linearity is maintained up to 3.4 kPa
(b) Boom static (absolute) Type 236, nominal range 85 - 110 kPa
(c) Towed pitot-static (differential) Type 236, nominal range 3.4 kPa
(d) Boom/towed static (differential) Type 237, nominal range 1.4 kPa

* Aircraft Research and Development Unit. Royal Australian Air Force.
Referring to Fig. 8 again it can be seen that the static pressure differential transducer registers the pressure difference that would exist if the towed probe was flying at the aircraft altitude, because the same hydrostatic gradient exists inside and outside the pressure leads. On the other hand, a small difference occurs in the free stream dynamic pressure at the two probe altitudes because of the density gradient. For the present work this amounts to at most 0.4%, and is allowed for in data reduction.

In situ pre-flight checks of the transducers were carried out by surrounding the relevant probe pressure holes with a scaled sleeve which could be pumped to pressure levels needed to simulate expected ASI and altimeter readings in flight.

2.3 Flight Details

Calibration flights with the towed probe attached were carried out during the course of Flights 1 and 5 of the test schedule. Data presented here were obtained towards the end of Flight 1 and at the start of Flight 5. The two sets of data thus correspond to different trimmed pitch angles because of differing fuel loads. The calibrations in climb/descent conditions were made during Flight 1 only. The level flight calibrations of Flight 5 were made over a set course and at a fixed height during successive flights past cameras set up on Point Perpendicular, Jervis Bay. The purpose of flying this course was to enable the shape of the towed probe cable to be determined from photographs taken at a series of flight speeds.

2.4 Data Handling

Data were recorded on the A.R.L. flight data package described in Ref. 4 and later transcribed on to the ARL-PDP-10 computer system. Final processing was carried out using the routines given in Ref. 5.

Relations linking the various measured and reduced parameters are given in Appendix A.

3. RESULTS AND DISCUSSION

3.1 Position Error Correction to Airspeed

3.1.1 Level flight

Table 1 presents a listing of all flight data corrected where necessary as in Appendix A. Typical results are shown in Fig. 9 where the boom probe dynamic pressure is plotted against trailing probe dynamic pressure data for Flight 1. Points to be noted are, firstly, rotor downwash effects on the boom probe prevent the curve passing through the origin, and also, the points undulate about a straight line. With this behaviour a simple pressure coefficient can not be used to relate the two sets of dynamic pressure measurements.
As shown in Fig. 8, separate transducers measured each dynamic pressure. In addition, the static pressure differential of the probes was separately measured thus providing redundancy in the measurements. Assuming steady flight conditions, and after correction for density variation with altitude, the total head should be the same for each probe and therefore the difference between the two dynamic pressures should agree with the directly-measured static differential. As shown in Fig. 10a, b, for both flights this agreement is not realised and a consistent discrepancy exists between the direct measurement of $\Delta p$ and that value derived from the two dynamic pressure measurements, $\Delta q$. Naturally, because of the less direct method of obtaining $\Delta q$ one would expect a higher degree of scatter than for the $\Delta p$ values, and this does occur. However, the overall discrepancy is greater than would be expected in view of the degree of repeatability found in pre-flight transducer checks.

Several possibilities exist as to the source of this disagreement. Obviously, any of the three transducers involved may be reading a spurious pressure or giving a spurious reading of a true pressure. Factors producing the former could be leakage, gas evolution in the tubing and unexpectedly large flow angles at the probes. No evidence of leakage has been detected during pre-flight calibration, and the boom mounted vanes confirm that flow angles are well within the design range of the probe. The towed probe, as far as could be seen, "flew" in a stable aligned fashion. Consideration of these factors suggests that the presence of one or more spurious transducer outputs is a more probable cause of the discrepancy. Some change in transducer calibration is implied and whilst good repeatability was obtained during pre-flight routines, no information is available to indicate how they are affected by the vibrational environment in flight.

In the light of the foregoing discussion, the following rationale has been adopted for computation of the P.E.C. Firstly, because values of $\Delta p$ are directly determined and exhibit a smoother variation than $\Delta q$ with airspeed, they are accepted as the true boom static pressure excess over free stream. Secondly, the boom dynamic pressure values are accepted because, as will be shown later, the P.E.C.'s derived therefrom produce better agreement with O.D.M. values than the P.E.C. derived from the towed probe dynamic pressure. The discrepancy, in terms of velocity, is nevertheless, only about 3 knots as is shown in Fig. 11 where, for the case of Flight 5, the values of towed probe velocity, $V_t$, are compared with those of $V_m$ derived from the measured values of boom dynamic pressure corrected for position error. The relativity shown between $V_t$ and $V_m$ naturally reflects that between $\Delta q$ and $\Delta p$ previously shown in Fig. 10a, b. Also shown on Fig. 11 are measured longitudinal Doppler velocities which may be validly included because the calibrations of Flight 5 were made on repeated flights in the same direction over a set course into a steady wind. The substantially linear variation with $V_b$ adds
further support to the rationale adopted. On the other hand, the ASI values are extremely non-linear and it follows that P.E.C.'s of that instrument will vary similarly. Values of the P.E.C.'s for the measured boom velocity, \( V_b \), and also for the ASI are shown in Figs. 12a, b for Flights 1 and 5 respectively. The boom correction is sensibly independent of airspeed and has a value of 7.5 ± 1 knots for both flights. The ASI correction, \( V_m - \text{ASI} \), varies considerably with speed and, in the case of Flight 5, has a mean value of 3 knots, the same value as given in the O.D.M. for level flight. For Flight 1 the correction is generally 2 knots higher, probably reflecting the different pitch altitude in trimmed flight associated with a different fuel load distribution. The variation of pitch attitude with speed is shown in Fig. 13 for the two cases.

Referring back to Figs. 12a, b and the (P.E.C.)ASI graphs, additional curves are drawn which would have applied if the towed probe velocities, \( V_t \), were accepted as being the correct airspeed. In such a case the P.E.C. values are increased on average by 3 knots and when compared with the O.D.M. values appear less credible.

3.1.2 Climb and descent

Unfortunately, when data for the climb and descent cases are considered, pressure stabilisation effects in the long trailing probe leads markedly affect the value of \( \Delta p \) and thus preclude the usual calculation of \( V_m \). However, because the tow leads to the towed dynamic pressure transducer are similar, no error occurs in this pressure. Therefore in presenting data for the boom performance in climb and descent, the trailing probe velocity, \( V_t \), must be used. Because of the self-aligning properties of the towed probe no error should occur, other than the error of ± 3 knots estimated in the previous section. Fig. 14 shows values of \( V_t - V_b \) obtained for four torque settings in climb and descent during Flight 1 together with the level flight values. Generally, the climb/descent values are spread about the level flight data in random fashion, virtually independent of speed and the wide range of flow angles incident at the boom probe at the various torque settings. Angles of attack obtained from vane data are shown in Fig. 15 together with aircraft pitch attitude and the deduced climb/descent angle for 3 indicated airspeeds.

It is concluded that the P.E.C. previously determined in level flight is applicable to all other flight conditions within the range of these calibrations. The benefit of using the boom probe can also be gauged when comparison is made with the P.E.C's to be applied to the ASI system. Fig. 16 shows data from the present tests together with recommended ASI corrections derived from the O.D.M. The manual specifies only 'climb' and 'autorotation' not the actual rates of these manoeuvres.
3.2 Position Error Correction to Altitude

Altitudes derived from static pressure measurements need to be corrected for the boom static-pressure position error. The correction is a function of speed, as shown by the relationship for pressure error

\[ \Delta p = \Delta \rho - \rho_\infty = C_{D_b} \times q_\infty. \]

Thus provided \( C_{D_b} \) is known, the calculated pressure error can be expressed in terms of an altitude change.

A more workable relationship, with the altitude error given as a function of the airspeed error is given by Coulthard (Ref. 6), namely

\[ \Delta H = 0.09 \times (P.E.C.) \times V \]

Thus, for P.E.C. \( \approx 7.5 \) knots then a maximum altitude correction of 80 ft must be applied at the highest speed of 110 knots.

4. CONCLUSIONS

1. Position error has been determined for a nose-boom mounted pitot-static probe installed on a Sea King Mk 50 helicopter. The reference probe was a towed, cone-stabilised, pitot-static probe which trailed below the aircraft.

2. The position error correction to be applied to the indicated nose boom velocity is sensibly constant in the speed range 35 to 110 knots, including both climb and descent in the torque range 10% to 100%. It has a value of 7.5 \( \pm \) 1 knot.

3. The correction was derived by directly measuring the static pressure difference between the boom and towed probes. An alternative measure of the correction derived from dynamic pressure differed by about 3 knots. Erratic behaviour of a dynamic pressure transducer is suspected.

4. Corrections to altitude arising from position error vary linearly with airspeed and amount to 80 ft at 110 knots.
1. **Corrections to Measured Data**

Data presented in Table 1 have been corrected where necessary using expressions set out below.

(a) Boom probe dynamic pressure, $q_b = H - p_b$

In nearby free stream $q_\infty = H - p_\infty$

whence free stream dynamic pressure $q_\infty$ may be deduced, namely

$$q_\infty = q_b + (p_b - p_\infty) = q_p + \Delta p$$

(b) Differential static pressure, $p_b - p_t$

We have $\Delta p = p_b - p_\infty = (p_b - p_t) + (p_t - p_\infty)$

where $p_t - p_\infty$ is derived from the known pressure coefficient*, $C_p$, of the towed probe according to the relation

$$p_t = p_\infty + C_p \times q_\infty$$

Then

$$\Delta p = (p_b - p_t) + C_p \times q_\infty$$

(c) Towed probe differential pressure, $q_t$

Using the known coefficient*, $C_p$, and the expression below,

we have $q_t = q_{tm} \times (1 - C_p)$ where $q_{tm}$ is the measured value of dynamic pressure.

A further correction $\rho_t/\rho_\infty$ allows for the difference in air density between the altitudes at which the two probes are moving is shown in Fig. A1.

Thus

$$q_t = q_{tm} \times (1 - C_p)/\rho_t/\rho_\infty$$

As discussed in the main text the value of $q_t$ should agree with $q_\infty$. Unfortunately a discrepancy exists which is thought to originate in the towed probe transducer.

2. **Calculation of Velocity**

Velocity, $V$ (knots) is derived from the relevant dynamic pressure, $q$ (Pascal), by the relation

$$V = 2.484\sqrt{q}$$

---

* Obtained from wind tunnel calibrations.
FIG. A1  PROBE DISTANCE BELOW AIRCRAFT \((\Delta h = h_\infty - h_t)\) AND DENSITY RATIO VS AIRSPEED
REFERENCES


5. Gilbert, N.E. and Fleming, J.A. Computer programs used for Reducing Data from Aerodynamics Division Flight Data Acquisition System - to be published.

### Table 1

**Flight 1**

<table>
<thead>
<tr>
<th>A.S.I.</th>
<th>$q_0$ (kn)</th>
<th>$\Delta q_0$ (kn)</th>
<th>$q_0$ (kn)</th>
<th>$\Delta q_0$ (kn)</th>
<th>$q_0$ (kn)</th>
<th>$\Delta q_0$ (kn)</th>
<th>$v_b$ (kn)</th>
<th>$v_e$ (kn)</th>
<th>$V_{-V}$ (kn)</th>
<th>$V_{+V}$ (kn)</th>
<th>$V_{-ASI}$ (kn)</th>
<th>$V_{+ASI}$ (kn)</th>
<th>Torque (lbf)</th>
</tr>
</thead>
</table>

**Flight 2**

<table>
<thead>
<tr>
<th>A.S.I.</th>
<th>$q_0$ (kn)</th>
<th>$\Delta q_0$ (kn)</th>
<th>$q_0$ (kn)</th>
<th>$\Delta q_0$ (kn)</th>
<th>$q_0$ (kn)</th>
<th>$\Delta q_0$ (kn)</th>
<th>$v_b$ (kn)</th>
<th>$v_e$ (kn)</th>
<th>$V_{-V}$ (kn)</th>
<th>$V_{+V}$ (kn)</th>
<th>$V_{-ASI}$ (kn)</th>
<th>$V_{+ASI}$ (kn)</th>
<th>Long. (mi)</th>
<th>Conquer (kn)</th>
</tr>
</thead>
</table>

(V_L, 7.5) true level flight data
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 GEOMETRY OF TRAILING PITOT STATIC PROBE
FIG. 5 TRAILING PROBE TESTING IN A.R.L. 9X7 WIND TUNNEL
FIG. 6 TOWED PROBE-EFFECT OF AIR SPEED
FIG. 7 BOOM PROBE PRESSURE ERROR VARIATION WITH ANGLE OF INCIDENCE (V=100 Knots)
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FIG. 9 COMPARISON OF BOOM AND TOWED PROBE DYNAMIC Pressures
FIG. 10 STATIC PRESSURE DIFFERENCE COMPARED WITH DIFFERENCE IN DYNAMIC PRESSURES
FIG. 11  COMPARISON OF VELOCITY AS GIVEN BY TRAILING PROBE, ESTIMATED FREE STREAM, A.S.I. AND DOPPLER
FIG. 12 PRESSURE ERROR CORRECTIONS TO INDICATED BOOM VELOCITY, $V_b$, AND A.S.I. READING
FIG. 13 PITCH ATTITUDE VARIATION WITH SPEED.
Flight 1

Torque

- 100% Climb
- 80% Climb
- 30% Descent
- 10% Descent
- Level flight

FIG. 14 EFFECT OF CLIMB/DESCENT RATES ON BOOM PROBE PRESSURE ERROR CORRECTION
FIG. 15 VARIATION OF ANGLE OF INCIDENCE, PITCH ATTITUDE AND CLIMB ANGLE WITH TORQUE SETTING
Flight 1.

O.D.M. values

- 100% torque
- 80
- 30
- 10

- - - Level flight

FIG. 16 A.S.I. CALIBRATION COMPARED WITH OPERATING DATA MANUAL (O.D.M.)
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