Airspeed Calibration

Summary

The UH–60A airspeed was measured using two independent systems: a boom system, specially mounted to the test aircraft and the installed ship's system. Measurements of dynamic pressure, static pressure, temperature, and rotor speed were used to derive the aircraft's airspeed, in both dimensional and non-dimensional form. The data reduction equations used are based on those developed at the US Army Aviation Engineering Flight Activity, Edwards Air Force Base, California; now the US Army Aviation Technical Test Center, Ft. Rucker, Alabama. Calibrated airspeed and the static position error for the boom system were determined from in-flight calibration tests using a T-34 aircraft as a reference.

Airspeed Measurement

The UH–60A velocity measurements are based on the dynamic pressure measured on the aircraft test boom and the ship's system, item codes V001 and V002 respectively. This measured dynamic pressure is the difference between the measured total or stagnation pressure and the measured static pressure and, for the UH–60A, is expressed in in-Hg.

$$q = P_t - P_s \tag{1}$$

An IF statement is used in the parameter calculations to catch any case where V001 or V002 is less than zero and, in this case, the dynamic pressure is arbitrarily set to 0.00001 in-Hg.

The calculation of airspeed in TRENDS is based on aircraft measurements using the data reduction equations from Blaha (1977), an internal publication of the US Army Aviation Engineering Flight Activity, Edwards Air Force Base, California; now the US Army Aviation Technical Test Center, Ft. Rucker, Alabama (Charles Cassil, pers. comm.). The indicated and calibrated airspeeds were obtained as functions of the measured dynamic pressure. The indicated airspeeds, VICB for the boom and, VICS for the ship's system, are calculated as

$$\mathrm{VICB} = \left\{ \left[\left(\frac{\mathrm{V001}}{\mathrm{PASTD}} + 1 \right)^{\frac{2}{7}} - 1 \right] 5\,\mathrm{ASTD}^2 \right\}^{\frac{1}{2}} \tag{2}$$

$$\text{VICS} = \left\{\left[\left(\frac{\text{V002}}{\text{PASTD}} + 1\right)^{\frac{2}{7}} - 1\right] 5\,\text{ASTD}^2\right\}^{\frac{1}{2}} \tag{3}$$

where PASTD = 29.92125 in-Hg and ASTD = 661.4786 knots.

The determination of calibrated airspeed as a function of indicated airspeed depends upon which system is used. For the test boom, the calibrated airspeed, VCALB, is based on calibration data obtained on Flights 82 and 83. In the Derived Parameter calculation there is a section signed by Chris Jennsion and Brent Wellman, dated 10/19/93. This calibration does not use the calculated value of VICB, however, but instead is determined directly from V001 in counts, before its conversion to engineering units (in-Hg).

$$\text{DISCRIM} = 11.7994593(\text{V001CNTS}) - 420.731139 \tag{4}$$

If DISCRIM is less than 0, then VCALB is set to 0. Otherwise

$$\text{VCALB} = 3.4440642 + \sqrt{\text{DISCRIM}} \tag{5}$$

The ship's calibrated airspeed is based on VICS

$$\text{VCALS} = \text{VICS} + 11.69756 - 0.1514664(\text{VICS}) + 0.0003801299(\text{VICS})^2 \tag{6}$$

The calibrated airspeeds for the boom and ship's systems are compared in Fig. 1 for level flight data obtained from Flights 84 to 110. Generally, above 30 to 35 knots, good agreement is observed between the two systems. The airspeed difference between the two systems is shown in Fig. 2 as a function of the boom system calibrated airspeed. Above 35 knots, the deviation between the two systems varies between about –1 knots and +2 knots.

The calculation of true airspeed requires air density, which is determined from measurements of temperature and pressure. To calculate the ambient pressure from measured static pressure requires corrections for static pressure position error. This is estimated based on the difference between the indicated and calibrated airspeeds

$$\begin{aligned}\text{DPPB} = {} & 1.4\,\text{PASTD}\left(\frac{\text{VICB}}{\text{ASTD}}\right)\left[1 + 2\left(\frac{\text{VICB}}{\text{ASTD}}\right)^2\right]^{2.5}\left(\frac{\text{VCALB} - \text{VICB}}{\text{ASTD}}\right) \\ & + 0.7\,\text{PASTD}\left[1 + 2\left(\frac{\text{VICB}}{\text{ASTD}}\right)^2\right]^{1.5}\left[1 + 1.2\left(\frac{\text{VICB}}{\text{ASTD}}\right)^2\right]\left(\frac{\text{VCALB} - \text{VICB}}{\text{ASTD}}\right)^2\end{aligned} \tag{7}$$

$$\begin{aligned}\text{DPPS} = {} & 1.4\,\text{PASTD}\left(\frac{\text{VICS}}{\text{ASTD}}\right)\left[1 + 2\left(\frac{\text{VICS}}{\text{ASTD}}\right)^2\right]^{2.5}\left(\frac{\text{VCALS} - \text{VICS}}{\text{ASTD}}\right) \\ & + 0.7\,\text{PASTD}\left[1 + 2\left(\frac{\text{VICS}}{\text{ASTD}}\right)^2\right]^{1.5}\left[1 + 1.2\left(\frac{\text{VICS}}{\text{ASTD}}\right)^2\right]\left(\frac{\text{VCALS} - \text{VICS}}{\text{ASTD}}\right)^2\end{aligned} \tag{8}$$

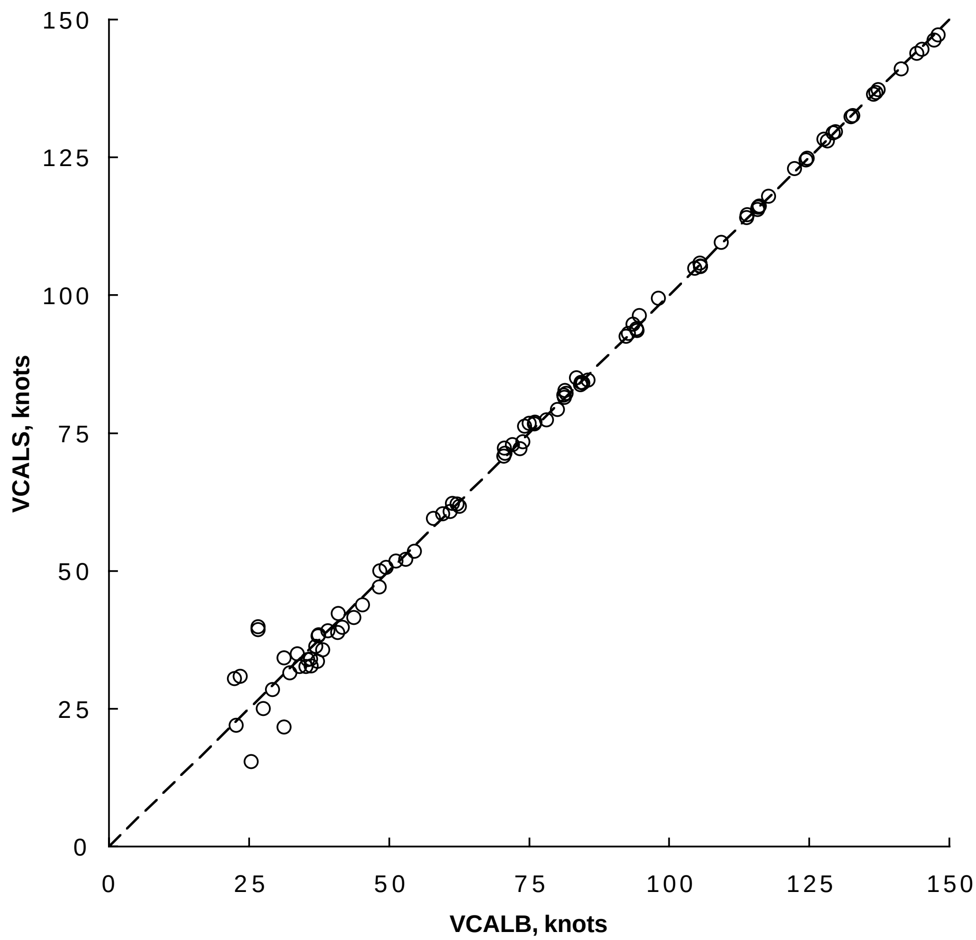

Figure 1. Ship's system calibrated airspeed as a function of the boom system calibrated airspeed; Flight 84 to 110 level flight data.

The static pressure position error is then used to correct both the static pressure measurements

$$PAB = H001 - DPPB \tag{9}$$

$$PAS = H002 - DPPS \tag{10}$$

and the dynamic pressure measurements

$$QCB = V001 + DPPB \tag{11}$$

$$QCS = V002 + DPPS \tag{12}$$

The static pressure in psi is also computed, but only for the boom system

$$H3DP = 0.49131(PAB) \tag{13}$$

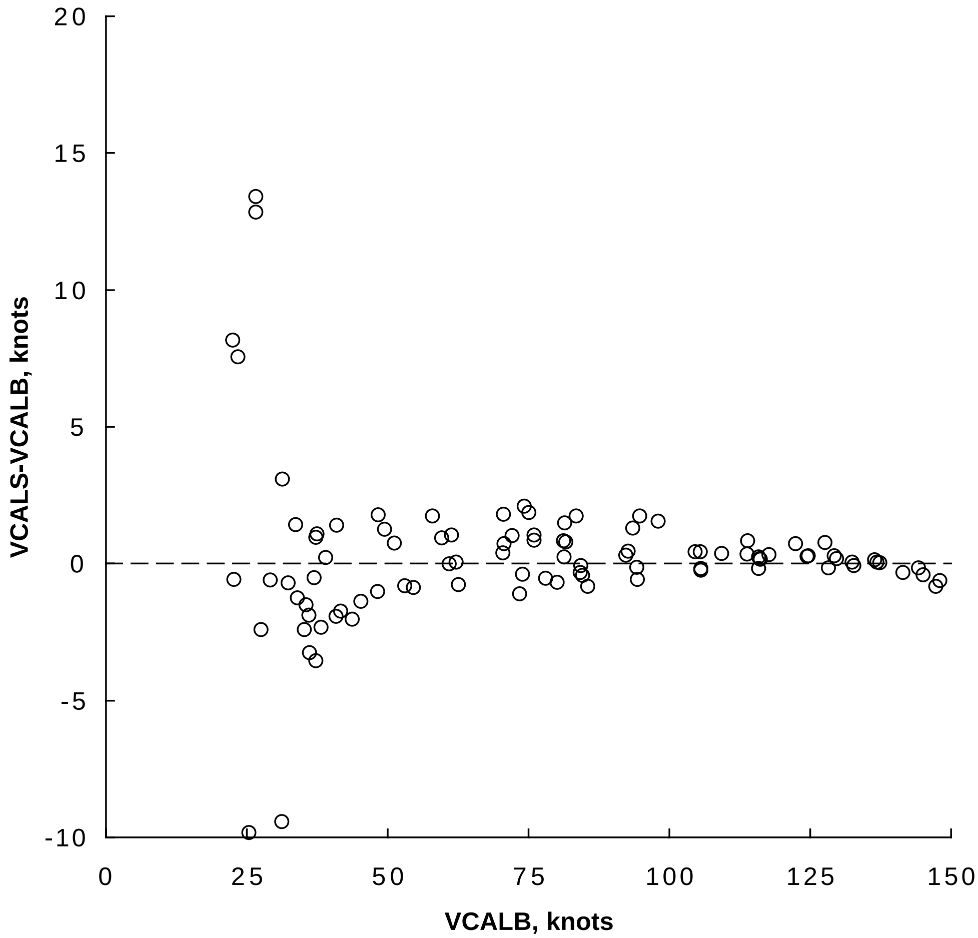

Figure 2. Difference in calibrated airspeed between the ship's and boom systems as a function of the boom calibrated airspeed; Flight 84 to 110 level flight data.

The air temperature is based on the OAT measurement, item code T100, corrected for dynamic heating

$$\mathrm{TAK} = \frac{\mathrm{T100} + 273.15}{\left[1 + \frac{\mathrm{TK}}{7}\mathrm{RHOSTD}\frac{(1.6878099\,\mathrm{VCALB})^2}{70.726323\,\mathrm{PAB}}\right]} \tag{14}$$

where TK, the probe recovery factor, is one and RHOSTD is 0.00237689 lb-sec^2/ft^4. The temperature ratio, THETA, then is

$$\mathrm{THETA} = \frac{\mathrm{TAK}}{288.15} \tag{15}$$

Pressure ratios are calculated for both the boom and ship's system

$$\text{DELTAB} = \frac{\text{PAB}}{\text{PASTD}} \tag{16}$$

$$\text{DELTAS} = \frac{\text{PAS}}{\text{PASTD}} \tag{17}$$

and similarly, the density ratios are also calculated for both systems

$$\text{SIGMAB} = \frac{\text{DELTAB}}{\text{THETA}} \tag{18}$$

$$\text{SIGMAS} = \frac{\text{DELTAS}}{\text{THETA}} \tag{19}$$

Density is computed based on the boom system

$$\text{RHO} = \text{SIGMAB(RHOSTD)} \tag{20}$$

and this value is used in computations for Mach number and weight and power coefficients.

Equivalent airspeeds are calculated for both the boom and the ship's system

$$\text{VEB} = \frac{1}{1.6878099}\left\{\text{ABS}\left[\left(\frac{7\,\text{PAB}\,70.726323}{\text{RHOSTD}}\right)\left(\frac{\text{QCB}}{\text{PAB}}+1\right)^{\frac{2}{7}}\right]\right\}^{\frac{1}{2}} \tag{21}$$

$$\text{VES} = \frac{1}{1.6878099}\left\{\text{ABS}\left[\left(\frac{7\,\text{PAS}\,70.726323}{\text{RHOSTD}}\right)\left(\frac{\text{QCS}}{\text{PAS}}+1\right)^{\frac{2}{7}}\right]\right\}^{\frac{1}{2}} \tag{22}$$

and these are in turn used to compute the true airspeeds

$$\text{VTB} = \frac{\text{VEB}}{\sqrt{\text{SIGMAB}}} \tag{23}$$

$$\text{VTS} = \frac{\text{VES}}{\sqrt{\text{SIGMAS}}} \tag{23}$$

Normally, the true airspeed for final calculations, VT, is set to VTB.

Figure 3 compares the true airspeeds for the ship's system and boom system for Flights 84 to 110. The difference between the two measurements is shown in Fig. 4. As was observed previously for the calibrated airspeeds, the two systems show good agreement above about 35 or 40 knots, with the maximum difference varying from –1 knot to +2 knots.

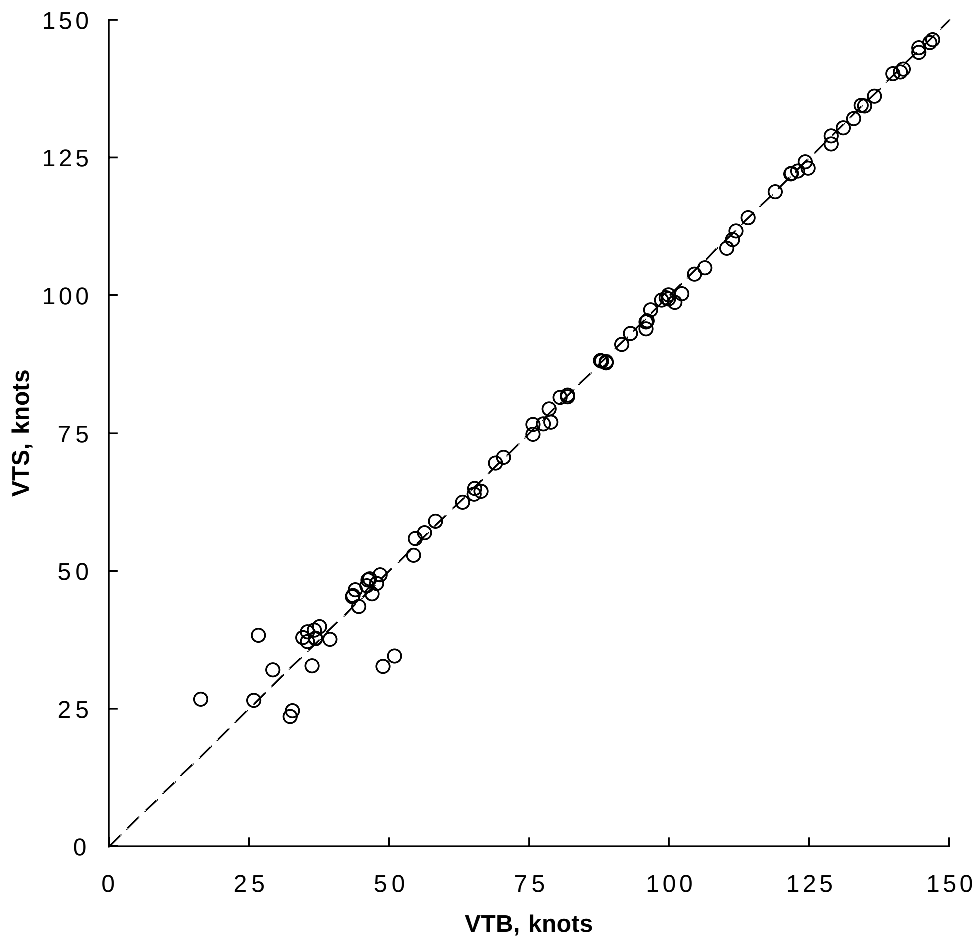

Figure 3. Ship's system true airspeed as a function of the boom system true airspeed; Flight 84 to 110 level flight data.

The calculation of advance ratio, AMU, requires both the true airspeed and the rotational speed. The rotational speed is

$$\text{OMEGAR} = \text{RPMUSED}(2\pi/60)\,\text{RADIUS} \tag{24}$$

where RPMUSED is based on VR05, rather than VR04, and RADIUS is 26.833333 feet. The advance ratio, then , is

$$\text{AMU} = \frac{1.6878099\,\text{VT}}{\text{OMEGAR}} \tag{25}$$

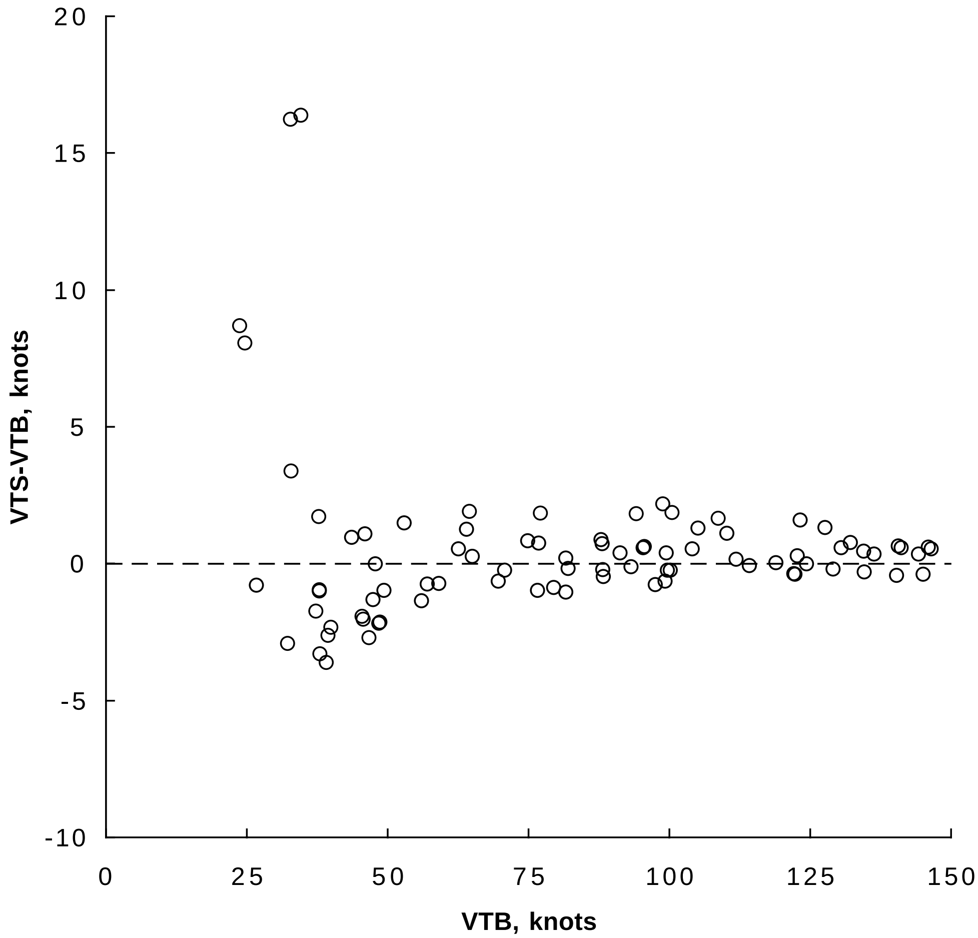

Figure 4. Difference in true airspeed between the ship's and boom systems as a function of the boom true airspeed; Flight 84 to 110 level flight data.

Conclusions

The UH–60A test aircraft flown at NASA Ames Research Center during the Airloads Program during 1993 and 1994 had two independent airspeed systems: a test boom installed on the aircraft for this test program and the normal ship's system. The equations used for the calculation of vehicle airspeed during the UH–60A airloads program were, for the most part, those used for flight data reduction by the US Army Aviation Technical Test Center at Ft. Rucker, Alabama and these equations have been reviewed in this Occasional Note. Airspeed calibration data from Flights 82 and 83 were used to derive a relationship between the boom dynamic pressure (in counts) and calibrated airspeed (in knots). In addition, these calibration data were used to estimate the static pressure position error for the test boom. The ship's system current calibration was not modified. Comparisons of calibrated and true airspeeds for the boom and ship's system show good agreement above 35 or 40 knots. Generally, the differences are within the range of –1 knot to +2 knots.

References

John Blaha, "Calculation of Atmospheric Parameters," USAAEFA Technical Note 77–66, 1977.

William G. Bousman
US Army Aeroflightdynamics Directorate (AMCOM)
Ames Research Center
Moffett Field, CA 94035-1000
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