Determining the Angle of Attack[1]

The first-order expression for the vertical wind w is

$$w = V\sin(\alpha - \phi) + w_p \tag{1}$$

where V is the true airspeed, α the angle of attack, ϕ the pitch, and w_p the vertical motion or rate-of-climb of the aircraft. The solution for the angle-of-attack is

$$\alpha = \phi + \arcsin\frac{w - w_p}{V} \tag{2}$$

If it is reasonable to assume that w is zero, or that it averages to zero, then

$$\alpha = \phi - \arcsin\frac{w_p}{V} \tag{3}$$

can be used to determine the angle-of-attack from the measurements of pitch, rate-of-climb, and true airspeed. Even in the presence of waves, fitting to this as functions of the radome measurements and other flight characteristics should average any real effects of vertical wind as long as the vertical wind over the flight segments used averages to zero.

NOMADSS

The simplest result is

$$\alpha = a_0 + a_1\frac{ADIFR}{QCF}\ . \tag{4}$$

QCF was selected because, in preference to QCR, it is less often affected by ice or frozen water that sometimes affects the radome. QCFC is a more awkward choice because it requires application of a correction that itself depends on angle-of-attack.

The coefficients can be determined by fitting data obtained almost anywere, provided the vertical wind is negligible or averages to being negligible. The NOMADSS flight data were used with these restrictions:

1. TASX > 80.
2. $-4 <$ WIC < 4

[1] for reference: Programs used were AKRDC130.ipynb and AOAC130.py. This memo generated by AKRDC130.lyx.

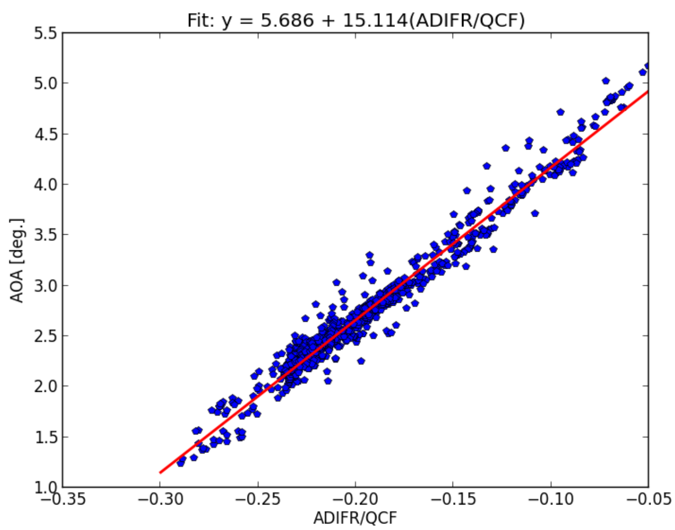
3. $-4 < \mathrm{VSPD} < 4$

There are 19 flights in NOMADSS, and fits to them are quite consistent, with results tabulated in the following table. These were actually calculated using QCXC instead of QCF, but the consistency is the point of the table and the results only change slightly if QCF is used instead.

Flight	a_0	a_1
1	5.818	15.24
2	6.028	16.00
3	5.661	14.27
4	5.670	14.53
5	5.699	14.37
6	5.761	15.06
7	—	—
8	5.719	14.58
9	5.704	14.62
10	5.769	15.13
11	5.727	14.79
12	5.775	15.00
13	5.745	14.76
14	—	—
15	5.656	14.37
16	5.772	14.83
17	5.535	13.85*
18	5.688	14.54
19	5.730	14.52

(Two flights were omitted because of data problems, and flight 17 is shown with an asterisk because the scatter in the relationship was unusually high for this case, perhaps from extended flight in the turbulent boundary layer.

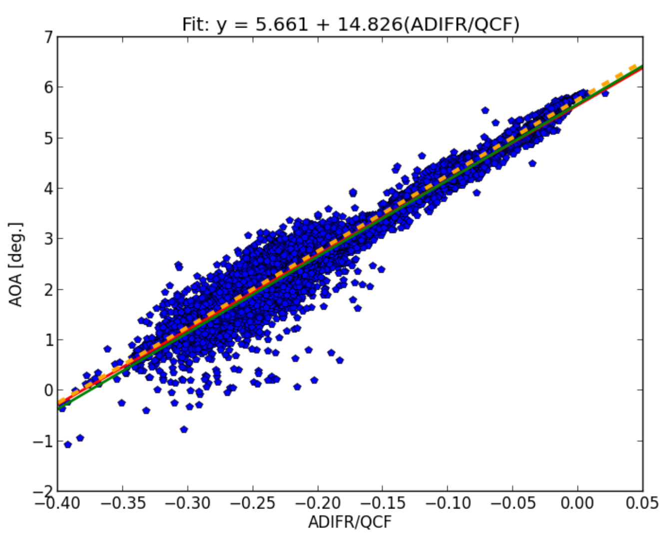
There were two sets of maneuvers flown on flight 18, spanning the period from 2325 – 2350 UTC. These provide a result with low scatter, as shown in the following figure:



The respective coefficients $\{a_0, a_1\}$ with standard uncertainties are $\{5.686\pm0.014, 15.114\pm0.069\}$, but the uncertainties are highly correlated so estimating the uncertainty in angle-of-attack involves the full error matrix:

$$\begin{pmatrix} 0.00020 & 0.00094 \\ 0.00094 & 0.0048 \end{pmatrix}$$

Two other flights with relatively high correlation between α as given by (3) and ADIFR/QCXC were flights 12 and 16. Combining the measurements from these two flights and from the period of calibration maneuvers from flight 18 led to the following correlation:

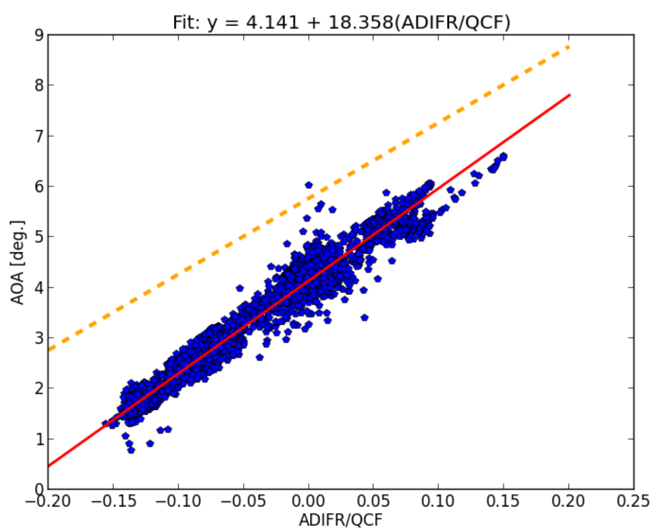


with respective coefficients $\{a_0, a_1\}$ equal to $\{5.661 \pm 0.004, 14.826 \pm 0.016\}$ displayed as the thin red line. The green line is the calibration from the maneuvers alone, as in the preceding figure, and the orange dashed line is the standard in nimbus code as of early 2014, equivalent to$\{5.773, 15.031\}$ but often used with QCXC which introduces a small change vs QCF. The deviation in predicted α if the vertical wind differs from zero by 1 m/s is about 0.44 deg., so much of the scatter in this figure may arise from real fluctuations in the vertical wind.

Because the conditions for the maneuvers were much more quiescent, it appears that it might be preferable to use the first fit from the flight period with maneuvers rather than this composite one from three flights, although the difference is insignificant. However, both are so close to the standard sensitivity coefficients in use that it does not seem justified to make any change. It may be best to await an opportunity to repeat this calibration with 3D-LAMS data before considering any change.

IDEAS-4

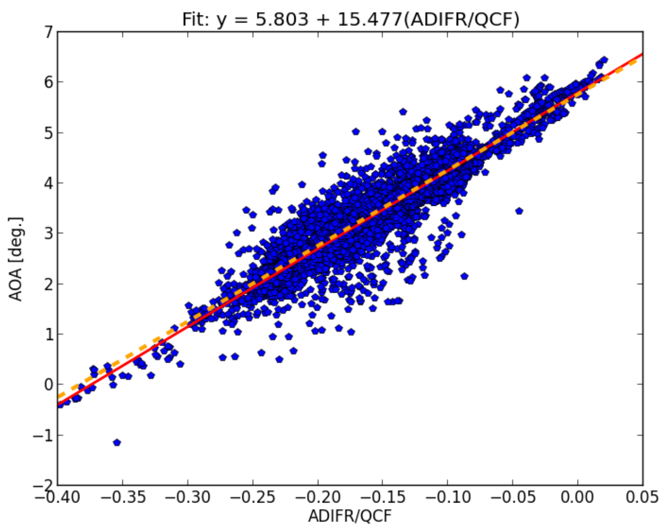
Repeating the same analysis for the IDEAS-4 project on the C-130 (Sept-Oct 2013) produces rather different results. For example, for flight 9 on 17 Oct 2013, the result is shown below:



The red line is the linear fit, and the orange line is the standard C-130 processing. These are clearly quite different. The problem this introduces is that the PCORS based on LAMS for the C-130 were determined as functions of ADIFR/QCR as measured in IDEAS-4. If the radome response was different in IDEAS-4 vs NOMADSS, an error would be introduced when those PCORS are used for NOMADSS. Earlier, I recommended a fix for this, but that needs to be revisited before the PCOR processing is extended to any other past projects.

ICE-T

The C-130 project preceding IDEAS-4 was ICE-T, so it is worth checking the radome sensitivity for that project. The following plot shows a plot similar to those above for flight 6. The dashed orange line is again the standard for C-130 processing, and that line represents the measurements well for this flight and is quite close to the red line representing the liniear fit to the data.



Conclusions:

1. The sensitivity coefficients determined here for ICE-T and NOMADSS are consistent with standard processing. No change is necessary.
2. In IDEAS-4 for the C-130, the radome for some reason exhibited different sensitivity and needs to be processed with different calibration coefficients. It is not evident why this was the case, because there was apparently no change prior to or after this project.
3. The C-130 PCORs determined from LAMS, as described in earlier memos and in the ProcessingAlgorithms.pdf document, need review to see if the formulation in terms of angle of attack should be modified in response to these radome calibrations.
4. The radome was apparently refurbished after NOMADSS, so the calibration will need to be checked prior to or during FRAPPE.