2 August 2019

TO: OTREC processing and QA
FROM: Al Cooper
SUBJECT: AKRD and WIC for OTREC

The Problem With AKRD/WIC

The characteristics of the radome have clearly changed prior to OTREC, perhaps because of modifications to the pressure ports to remove rough edges and features that might affect the flow. The mean vertical wind (WIC) in OTRECtf01.nc and OTREC-TESTtf01.nc was below -2 m/s for both flights. In both bases, the offset was apparent between AKRD and AOAREF, the fit variable calculated on the assumption that the vertical wind is zero. The problem is illustrated by Fig. 1, which shows AKRD, the expected angle-of-attack for zero vertical wind (AOAREF), and the vertical wind for test flight #1. There is a significant offset between mean values of AKRD and AOAREF (about 0.87°), which is not normal and is reflected in the large offset in the vertical wind. This indicates that a new representation of AKRD needs to be found for the new radome.

Perhaps this is in opportunity to explore a new approach to finding AKRD. This note outlines some ideas that seem worth exploring for OTREC.

A Revised Approach

The standard approaches to determining new sensitivity coefficients for angle-of-attack can be repeated once appropriate flight conditions, esp. speed runs, are included in the OTREC test flights. However, some new steps seem worth exploring:

1. First, obtain the best estimate of the pitch angle using either the Ranadu::CorrectPitch() function or the Kalman filter. Usually the change will not be significant, but that should be checked so that the optimal values of pitch can be used in the following analysis. Pitch is a very important measurement for this study because the difference between pitch and angle of attack determines the magnitude of the vertical component of the relative wind, as the next equation shows.

2. The complementary representation in terms of slowly varying and rapidly varying components should be used because it separates the sensitivity to fluctuations from the need to represent the slowly varying components, as discussed in previous memos. The equations used are:

$$\alpha_f = \left(\frac{\{\mathrm{ADIFR}\}}{\{\mathrm{QCF}\}}\right)_f (c_1 + c_2 M) \tag{1}$$

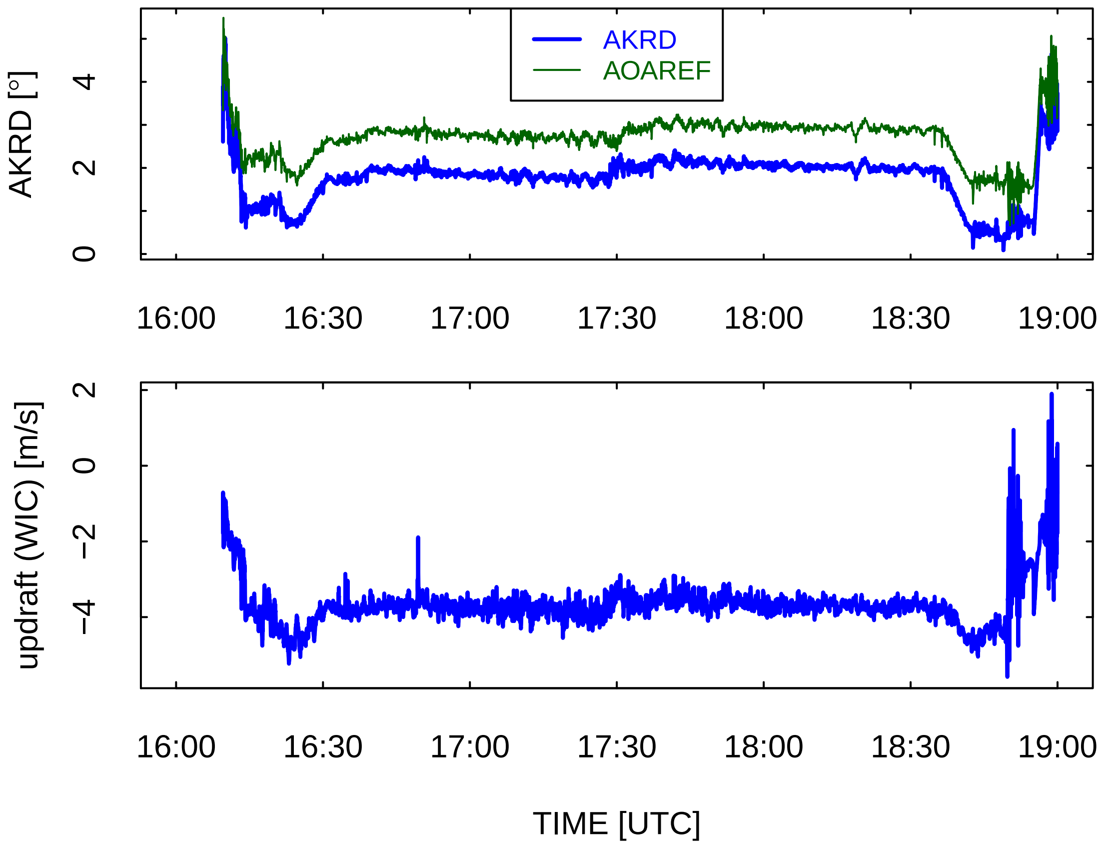

Figure 1: (top) Angle-of-attack (AKRD, blue line) and the reference variable AOAREF (green line) for OTREC tf01. The flight included a ground stop and several approaches / landings, so the time range is restricted to only part of the flight.

$$\alpha_s = d_0 + d_1 \left(\frac{\{\mathrm{ADIFR}\}}{\{\mathrm{QCF}\}} \right)_s + d_2 \{\mathrm{QCF}\}_s \tag{2}$$

where the f and s subscripts represent the high-pass and low-pass components after filtering. More complicated representations were tested in both cases, but these appear to provide adequate fits without additional terms. The c_2 term representing Mach-number dependence does not appear to be necessary, but the expectation that there will be some dependence on M justified its tentative inclusion. However, the fits below show no significant difference with $c_2 = 0$, and an analysis of variance made its inclusion appear questionable, so it has been dropped from the calculations presented here.

3. The simplified formula for the vertical wind w is:

$$w = V(\alpha - \phi) + w_p \tag{3}$$

where V is the airspeed, α the angle of attack, ϕ the pitch angle, and w_p the rate-of-climb of the aircraft. The conventional approach has been to assume that the vertical wind is zero, for example during a speed run, and then fit to $\alpha^* = \phi - w_p/V$. There will be errors in this representation whenever the vertical wind is not zero, because the correct representation of α is $\alpha = \phi + (w - w_p)/V$, but it has been assumed that averaging over flight periods should give average vertical wind near zero. An improved approach to finding an empirical representation of α in terms of other measurements $\{m_i\}$ like ADIFR might be as follows:

   (a) High-pass filter as in the complementary-filter representation, where it is reasonable to expect $w_f = 0$ so this can be used to find $\alpha(\{m_i\})_f$ in the conventional way. The problem then is to find the slowly varying component $\alpha_s = \alpha - \alpha_f$.

   (b) Find a first estimate of the slow component in the usual way, assuming w is zero.

   (c) Use the fit to calculate w.

   (d) Repeat using the expanded representation, with low-pass-filtered components, for which no change is expected but the fit RMS should decrease significantly:

$$\alpha_s^* = (\phi + (w - w_p)/V)_s \tag{4}$$

   (e) Iterate? This should not be necessary but might be useful once. Eq. (4) is not satisfied exactly in the procedure used because w is calculated without simplification, including roll and pitch angles as well as rotational corrections, but the agreement should be very good and is worth checking.

4. The components affecting the vertical wind, AKRD, PITCH, and GGVSPD, potentially have relative offsets in time, so results should be optimized by introducing appropriate time shifts. (Checks indicate that no significant effect arises from shifts of ± 200 hPa or so.)

5. The angle-of-attack tends to decrease systematically during a flight as the aircraft becomes lighter and less lift is required. In the slowly varying component, it may be useful to include a time factor, although that dependence should be represented via changes in ADIFR unless

the airflow changes as the weight of the aircraft changes. Exploration of this dependence, however, revealed a significant dependence, so a new fit variable (called TIA here, "Time In Air") was introduced.

The OTREC test flights have maneuvers and are suitable to use for this study. This can be extended later to include other data including that from research flights.

```
## lm(formula = AOAREFS ~ QRS + QCFS + TIA, data = DF)
## [1] "Coefficients:"
##                  Estimate   Std. Error    t value      Pr(>|t|)
## (Intercept)  4.929377e+00 4.892371e-03 1007.56405  0.00000e+00
## QRS          1.131900e+01 1.273835e-01   88.85760  0.00000e+00
## QCFS        -8.964647e-03 1.252038e-04  -71.60044  0.00000e+00
## TIA         -6.866185e-06 2.831663e-07  -24.24789 1.35478e-127
## [1] "Residual standard deviation: 0.108, dof=16061"
## [1] "R-squared 0.959"
```

Results

One iteration was used to find the coefficients needed to represent angle-of-attack. First, (4) was used with WIC as in the original processing used for w. (That processing was consistent with the standard coefficients given in "ProcessingAlgorithms.pdf".) The coefficients found from fits to that representation of angle-of-attack were used to calculate a new angle of attack and new value of the vertical wind, and then that value of vertical wind was used in (4) to revise the reference value and the processs was repeated.

The result of fitting using (1) was c_1 =19.9438, but for whole-project averages like this the slope often is too small because low-angle-of-attack fluctuations dominate and bias the results. Isolated speed runs and pitch maneuvers provide a check; when this is done for OTREC the result is 19.9398, not significantly different, but that result was then used in the iteration. For comparison, the result obtained for DEEPWAVE was 21.481, and this was supported by subsequent LAMS measurements.

For the low-pass component, the coefficients from the fit to (2) after iteration were $\{d\}$ = {4.8542, 8.9817, -0.011126, -7.53×10^{-6}}, and the residual standard deviation for the combined fit (slow + fast components) was 0.018°. This is small, reduced significantly from the original-fit values, which confirms consistency between the iterated results for angle-of-attack and updraft. These coefficients were then used to calculate the revised angle of attack (AKY) and revised vertical wind (WIY). For OTREC, the resulting mean values of the vertical wind, restricted to measurements where TASX > 105 and abs(ROLL) < 2 and with intervals flagged earlier excluded, are shown in the following list. Mean values are very good for all flights, but the standard deviations indicate

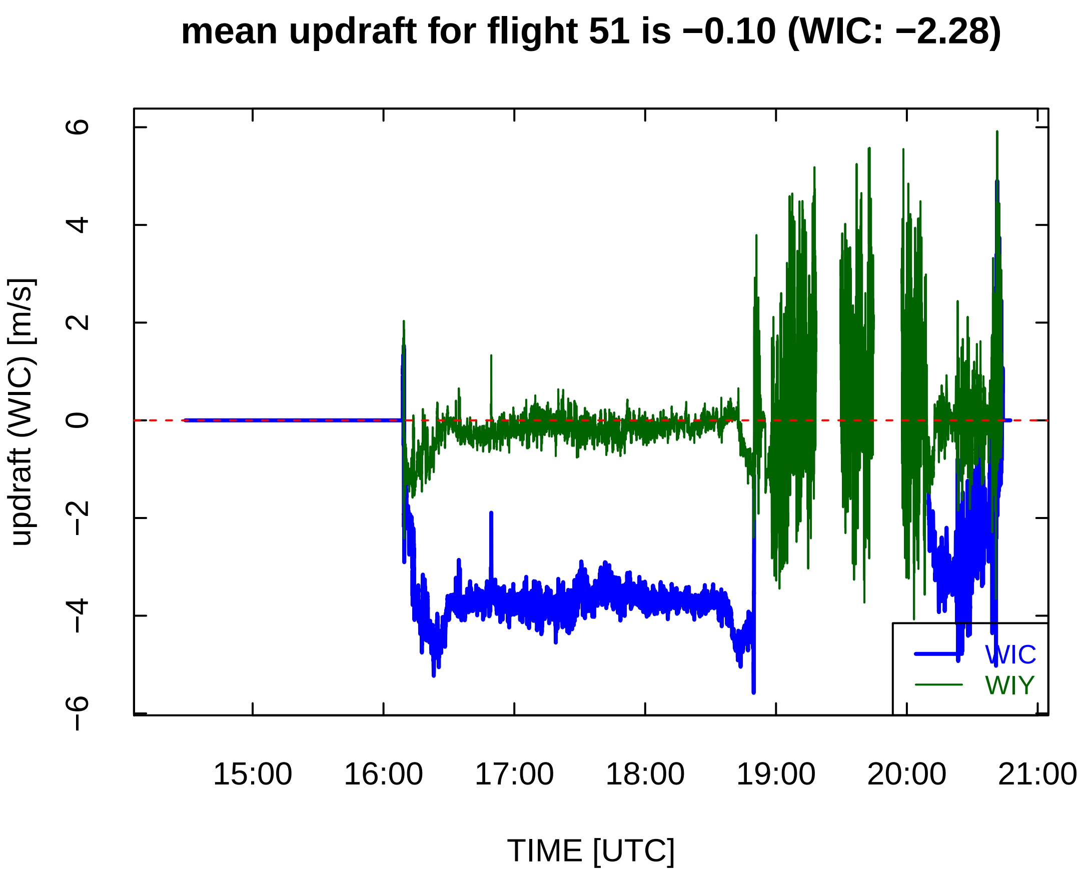

Figure 2: Old and new value for the vertical wind. Gaps in WIC indicate where values have been excluded from the fits but not from average-WIY.

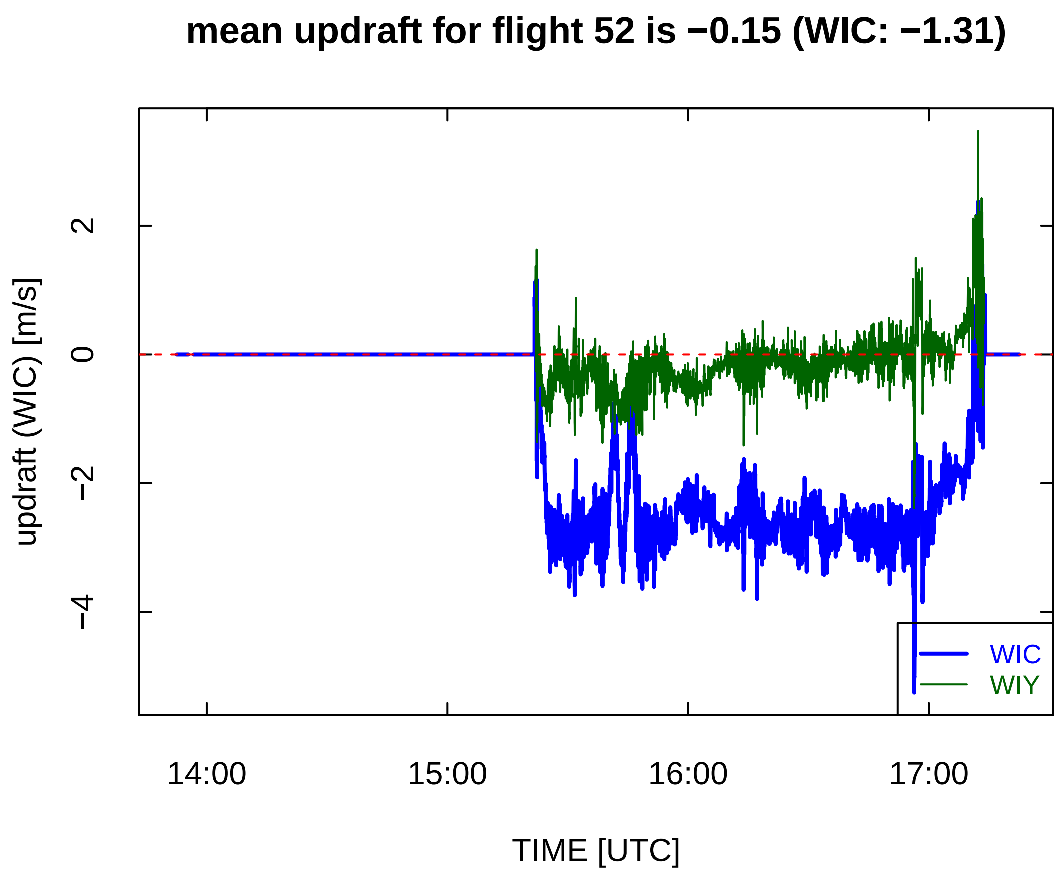

Figure 3: Old and new value for the vertical wind. Gaps in WIC indicate where values have been excluded from the fits but not from average-WIY.

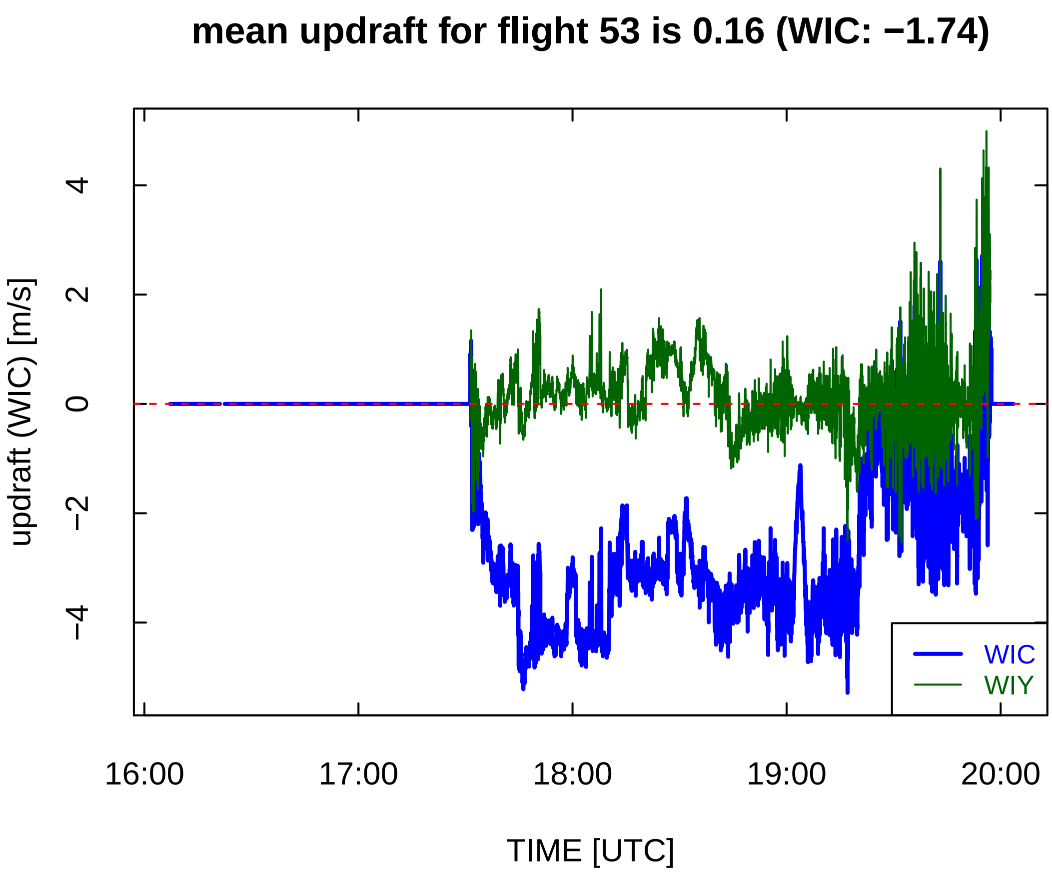

Figure 4: Old and new value for the vertical wind. Gaps in WIC indicate where values have been excluded from the fits but not from average-WIY.

that the changes are significant and that the result is an improved representation of the vertical-wind measurements.

The time-in-air dependence is larger than that found for SOCRATES, and it is worrisome that the test flights were not maximum-duration flights so this term might need revision once research and/or ferry flights are available.

```
## [1] "mean WIY for flight 51 is -0.14; WIC was -3.60"
## [1] "mean WIY for flight 52 is -0.15; WIC was -2.64"
## [1] "mean WIY for flight 53 is 0.19; WIC was -2.99"
```

Bad measurements (e.g., where ADIFR and/or QCF are affected by blockage or other problems) can affect the results, but using this procedure such problems should be identifiable by considering if the measured WIY differs from that expected from AOAREF outside prescribed limits. A section is included in the code, but it was inhibited when the document was produced although it was checked to ensure that there were no obvious outliers that might bias the fit.

Summary: Processing Recommendations

Use the complementary-filter representation of AKRD as developed previously. If feasible, the best representation of the measurements uses an added variable called "TIA" here ("Time In Air") and is the number of seconds after the first WOW_A == 0 measurement. The equations are:

$$\alpha_f = \left(\frac{\{\mathrm{ADIFR}\}}{\{\mathrm{QCF}\}}\right)_f c_1 \tag{5}$$

$$\alpha_s = d_0 + d_1\left(\frac{\{\mathrm{ADIFR}\}}{\{\mathrm{QCF}\}}\right)_s + d_2\{\mathrm{QCF}\}_s + d_3\{\mathrm{TIA}\} \tag{6}$$

with coefficients c_1 =19.9398 and $\{d\}$ = {4.8542, 8.9817, -0.011126, -7.53×10^{-6}}. An alternate representation, if TIA is not feasible or convenient to include, is $\{d\}$ = {4.8515, 10.7259, -0.009377, 0}, the best fit without TIA.

– End of Memo –

Reproducibility:

PROJECT:	AKRDforOTREC
ARCHIVE PACKAGE:	AKRDforOTREC.zip
CONTAINS:	attachment list below
PROGRAM:	AKRDforOTREC.Rnw
ORIGINAL DATA:	/scr/raf_data/OTREC/tf01–tf03.nc on 31 Jul 2019
WORKFLOW:	WorkflowAKRDforOTREC.pdf
GIT:	https://github.com/WilliamCooper/Reprocessing/AKRDforOTREC

Attachments:
AKRDforOTREC.Rnw
AKRDforOTREC.pdf
WorkflowAKRDforOTREC.pdf
AKRDforOTREC.Rdata
SessionInfo