4-Beam LAMS in ARISTO-2015/2016

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OVERVIEW

The topics addressed here:

Data_Quality:
: overconstrained processing, parallel algorithms

Sensitivity_Coefficients:
: independent determination, value for future projects

Pressure Corrections:
: change apparent from original; also, extension to near sea level

LAMS-based Temperature:
: sometimes good, sometimes not, esp. in dense cloud. 3-beam solution is often preferable.

Transient Effects:
: study incomplete

BACKGROUND INFORMATION

ARISTO: Used four beams:

1. Downward, 35° below the longitudinal axis
2. Forward, along the longitudinal axis
3. Upward and outboard, 120° around the longitudinal axis and 35° from the longitudinal axis.
4. Upward and inboard, -120° around the longitudinal axis and 35° from the longitudinal axis.

Data processing:

1. Determine line-of-sight wind speed along each beam
2. Use geometry to determine cartesian components of the relative wind vector and, for four beams, "goodness of fit"
3. Combine with Earth-relative motion as provided by the SDN500 IRU to get Earth-relative wind.
4. Using relative-wind components, find angles of attack and sideslip.

ANGLES OF ATTACK AND SIDESLIP

- From LAMS, find relative-wind components {u,v,w}.
- Find angle of attack and sideslip from these components: $\alpha_{LAMS} = \arctan \frac{w}{u}, \quad \beta_{LAMS} = \arctan \frac{v}{u}$
- LAMS is not aligned along the fuselage center-line, so α_{LAMS} is offset from α. Fitting to α_{LAMS} should give an offset in the first coefficient but the same second coefficient. E.g., fit for the coefficients in

$$\alpha_{LAMS} = c_0 + c_1 \frac{\mathrm{ADIFR}}{\mathrm{QCF}}$$

and then correct c_0 based on match to a conventional fit. Similar correction needed for the sideslip coefficients.

TWO PROBLEMS

Bias in LAMS during low-level flight

- Ground return sometimes affected the downward-pointing beam
- Results could not cover low-level flight well.

Inconsistency among flights

- The fits determined from individual speed runs in ARISTO-2015 do not produce consistent coefficients, and a fit to all data from ARISTO-2016 flight 6 produced still different coefficients.
- Each individual result appears consistent with the measurements on which it is based.
- ARISTO-2016 flight 6 may be the best because it spanned a larger range of conditions, with many speed variations and changes in angle-of-attack, so that will be presented here.

FITTING FOR ANGLE OF ATTACK

Conventional fit: reference is
$\alpha_{ref} = \phi - \frac{V_z}{TAS}\frac{180^\circ}{\pi}$ where ϕ is pitch, V_z is rate-of-climb.
LAMS fit: reference is
$\alpha_{ref} = \arctan\frac{u_z}{|u|}$ where u_z is the vertical relative-wind component.

in both cases, fit this equation using uncorrected pressures:

$$\alpha_{ref} = c_0 + \frac{q_m}{p_m}(c_1 + c_2 M(p_m, q_m))$$

Result, 2016 flight 6:

Data Source	c_0 [°]	c_1 [°]	c_2	std. deviation[a]
This LAMS fit	4.812	10.667	4.986	0.169°
Conventional fit	4.883	13.164	−0.798	0.231/0.180°
-> (2 coefficient)	4.920	13.021	0	0.228°
"standard" fit	5.776	15.031	0	0.277°/0.204°

[a] σ : first value is wrt AOAREF; 2nd wrt LAMS

LAMS-BASED COEFFICIENTS

Advantages:

1. No assumption that the vertical wind is or averages to zero.
2. Scatter in fitted values vs reference is consistently smaller than in conventional calibration.
3. No special flight maneuvers required, as long as there is an appropriate range in angle-of-attack.
4. Good confirmation of the validity of the standard approach via an independent measurement (α and WIC).
5. Useful to include a LAMS-based calibration, at least during set-up, for projects where accurate vertical wind is important.

Disadvantage:

Must still correct for the difference in angle-of-attack, LAMS vs radome, but the correction is straightforward.

CALIBRATION OF PRESSURES

The "Processing Algorithms" correction:

$$\frac{\Delta p}{p} = a_0 + a_1 \frac{\alpha}{a_r} + a_2 M \qquad (1)$$

(Determined from IDEAS-4 (2011) data)

Problems:

1. Some weaknesses have been apparent in subsequent projects:
   (a) poor performance in reverse-heading maneuvers
   (b) inconsistency in comparison to avionics pressure PS_A
2. Data in IDEAS-4 did not extend to near sea level:
   (a) Danger of extrapolation beyond range of validity
   (b) Esp. poor performance in low level flight (WINTER, e.g.)

THE GENERAL APPROACH

Ensure data quality:

1. Use beam-speed determination that meets a strict signal-to-noise test.
2. Use only 4-beam measurements where the chisquare for overconstrained fit for TAS meets a strict test.
3. Restrict data to exclude significant turns and very low airspeed (<60 m/s).
4. Use recalculated angle-of-attack as determined from LAMS-based calibration.

Use appropriate data: ARISTO-2016 flight 6

- An excellent data set, with mostly good LAMS performance
    - includes flight to near sea level
    - includes frequent variations in airspeed
    - includes fluctuations in angle-of-attack also to constrain the fit

THE FIT PROCEDURE

1. Find the reference value for q_LAMS for the fit:
   (a) LAMS measures airspeed
   (b) use that to deduce q_{LAMS} required to give that airspeed.
      - Depends on ATX and PSXC, but not very sensitively.
2. Fit $q_{LAMS} = \sum c_j F_j$
3. Start with a very complex fit:
   (a) 63 F_j terms based on q_m/p_m, α, M, squares of these factors, and products of these factors and their squares.
      - (explored other possibilities also)
   (b) Consider the result a target for a simplified fit: standard deviation in the fit residual was about 0.20 hPa.
   (c) Then simplify the fit (using analyses of variance) to obtain a simpler fit with similar standard deviation.

NEW RESULT

Compromise, simplicity vs. small standard deviation: 0.24 hPa

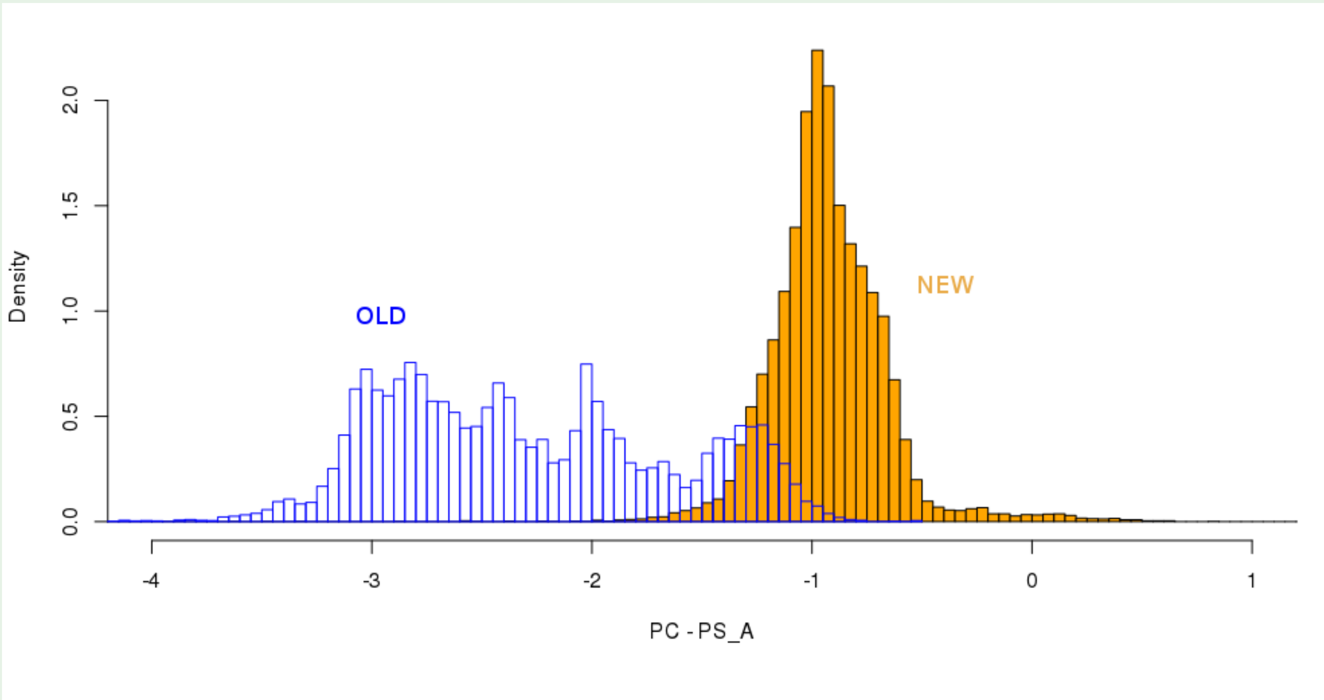
$$\frac{\Delta q}{p_m} = b_0 + b_1 \frac{q_m}{p_m} + b_2 \frac{\alpha}{a_r} + b_3 M + b_4 \frac{q_m}{p_m} \left(\frac{\alpha}{a_r} \right)^2 \qquad (2)$$

This is the *error*, the negative of the correction needed. $\Delta p = -\Delta q$.

Important consequences:

1. Mean error is 2.47±0.49 hPa for QCF but 6.12±0.78 hPa for QCFR.
2. Old parameterization gives 1.34 hPa, a significant difference. Something has changed.
3. Comparison to PS_A also suggests a change has occurred:
   (a) Original parameterization and data: PSC=PS_A−1.08 hPa.
   (b) New parameterization, new data: PSC=PS_A−0.93 hPa.
   (c) Old parameterization with new data: PSC=PS_A−2.29 hPa, a significant change
   (d) Similar comparisons can indicate at what time the needed PCor function changed (sometime 2011–2016).

COMPARISON TO PS_A



LAMS-BASED MEASUREMENT OF TEMPERATURE

Quick summary:

1. LAMS-based measurements of temperature are reasonably consistent out of cloud.
2. In cloud, results are variable:
   (a) Sometimes, esp. in weak cloud, results are consistent, perhaps showing weaknesses in ATX.
   (b) In moderately dense cloud, beam-1 is strongly affected and the 4-beam solution is compromised. However, a 3-beam solution (excluding the forward beam) often looks reasonable, perhaps because the angled windows shed water better.
   (c) In very dense cloud, all beams are affected and the LAMS-based measurement is not reliable.

CONCLUSIONS

1. LAMS provides the best calibration of the radome.
2. 4-beam LAMS provides a significant advantage because consistency among the four line-of-sight airspeeds tests the validity of the deduced airspeed.
3. A significant change in static defect has occurred since the time of IDEAS-4.
4. A new parameterization corrects C-130 pressure and airspeed to low tolerance (est. <0.3 hPa and 0.2 m/s).
5. The LAMS-based measurement of temperature works best with three off-axis beams, and is often successful except in very dense clouds.

FUTURE CONSIDERATIONS

Data processing:

- This presentation is based on the results in ARISTO-LAMS.Rnw, which generates a text file with much more detail. That file is available at this URL.
- To process the data to line-of-sight airspeeds, two methods are available:
  - Scott Spuler can produce a netCDF file with the appropriate line-of-sight airspeeds added to the file. He uses a principle-component-analysis approach, which is the most sensitive available. However, sometimes it produces a claimed solution that is erroneous. Four-beam analysis can help identify when these results should not be trusted.
  - A Python program named LAMS-ARISTO.py will also produce a netCDF file with line-of-sight airspeeds. See ARISTO-LAMS.pdf for instructions and to find where this routine resides on the EOL file system.
- In addition, the processing in ARISTO-LAMS.Rnw is needed to get LAMS-based wind, angle-of-attack, sideslip, and airspeed.