EARTH OBSERVING LABORATORY

Memorandum:

23 August 2015

TO: DEEPWAVE Applanix File
FROM: Al Cooper
SUBJECT: First look at Applanix measurements

1 Source of data

Dick Friesen, working with Kelly Schick, produced an ASCII file containing the 10-Hz Applanix measurements for DEEPWAVE flight 15 (the flight with calibration maneuvers). The measurements were associated with a time in seconds after midnight. This file was read into R, a POSIX-format time was produced from the time variable, the measurements were renamed according to names saved in the file 'NewNames' (to variables like PITCH_APPX), and the measurements were linearly interpolated to a 25-Hz sequence. That result was then smoothed slightly using Savitzky-Golay polynomials (3rd order, spanning 7 points). The resulting file was truncated to match the times in the high-rate production file (/scr/raf/Prod_Data/DEEPWAVE/HRT/DEEPWAVErf15hPC.nc). That production file also included processing to produce a corrected measurement of PITCH, PITCHC, based on detection of the Schuler oscillation. The resulting file, produced only with a subset of the variables in the original file to save space, was then saved as the netCDF file /scr/raf/cooperw/DEEPWAVErf15hPC_APPX.nc, so that file is available for continued study. The following listing shows some of the required R code; for a more complete listing, see the source file ApplanixMemo.Rnw at the location specified in the "Reproducibility" section at the end of this memo.

```
ApplanixRF15 <- read.table ("~/RStudio/DEEPWAVE/ApplanixRF15.txt",
                            header=TRUE, quote="\"", stringsAsFactors=FALSE)
## convert times to a POSIX-format time, for merging with standard netCDF:
## (note 2014-07-03 is the flight date)
ApplanixRF15$Time <- as.POSIXct (ApplanixRF15$time_.UTC_seconds_of_day.,
                                 origin="2014-07-03", tz="GMT")
NewNames <- names (ApplanixRF15)
## reassign names as specified in file NewNames:
source ('NewNames')
NewNames <- c(NewNames, "Time")
names (ApplanixRF15) <- NewNames
```

The new netCDF file has the following new variables: time_seconds_APPX, LAT_APPX, LON_APPX, ALT_APPX, UI_APPX, VI_APPX, VSPD_APPX, ROLL_APPX, PITCH_APPX, HDG_APPX, WANDER_APPX, THDG_APPX, BACCX_APPX, BACCY_APPX, BACCZ_APPX, BROTX_APPX, BROTY_APPX, BROTZ_APPX, DPITCH, DROLL, DTHDG. The variables with names beginning with BACC are components of the body accelerations; those beginning with BROT are components of the body rotation, and those beginning with D are difference variables between the denoted variable and the corresponding Applanix-provided variable; i.e., DPITCHC is the difference between PITCHC and PITCH_APPX. This is particularly useful in the case of THDG because the variable is calculated with correction for wrap-around cases that otherwise would produce differences near 360 or -360°.

2 Comparison between Applanix and Honeywell measurements

It is evident from turns that there are small angle differences in how the two IRUs are installed, so to avoid that problem the measurements will initially be restricted to those for which |ROLL| < 5. Figure 1 shows the measurements from the two systems, and shows important consistency between them because the measurements are almost indistinguishable at this plot scale. Figure 2 shows the differences directly. For pitch, the differences are mostly small relative to the expected uncertainty in the Honeywell measurement, expected to be 0.05°, but there is a mean offset of around 0.08° and a few regions near the end of the flight of more systematic variations. In roll, the deviations are a little larger and there is a similar but opposite-sign offset; this is still reasonable in comparison to the expected uncertainty, except for the offset. In heading, the variations are apparently more systematic and of larger magnitude, approaching the expected uncertainty.

This is shown more clearly in Figs. 3, where histograms of the differences in angles are plotted (again restricted to the absolute value of the roll less than 5°). For pitch, the standard deviation of the differences is only 0.012°, well below the expected uncertainty from instrument specifications but consistent with comparisons between identical IRUs onboard the aircraft (as discussed in the document on Wind Uncertainty). The mean offset is likely a difference in installed orientation on the aircraft. For roll, the standard deviation is twice as large and the distribution is not symmetrical but shows a peak near 0.07° difference and outliers (vs a Gaussian distribution) toward positive values or toward Honeywell values being larger than those from the Applanix. Errors in roll do not have serious influence on errors in wind measurement, so this plot indicates that roll measurements are also quite consistent between the units and within expected error limits. However, the panel in Fig. 3 for heading shows that the standard deviation in heading is larger and there are some measurements well outside the tolerance expected from instrument specifications. The specifications for the Applanix IRU indicate much smaller uncertainty limits for that instrument than for the Honeywell IRU, so a plausible interpretation is that these differences arise mostly from errors in the Honeywell measurement of heading. The heading offset is quite small, 0.02°, so the IRUs appear to be aligned consistently with the longitudinal axis of the aircraft.

It is interesting that a similar comparison to 'PITCHC', the pitch after correction for the detected Schuler oscillation, shows only a slightly smaller standard deviation. (This is shown as the red histogram in the top panel of Fig. 3.) There should be some improvement if the algorithm works properly, but this small improvement may indicate that the remaining errors don't arise from the Schuler oscillation but rather from other inaccuracies in the measurements. Indeed, flight 15 was one where the pitch corrections applied by the pitch-correction algorithm were especially small.

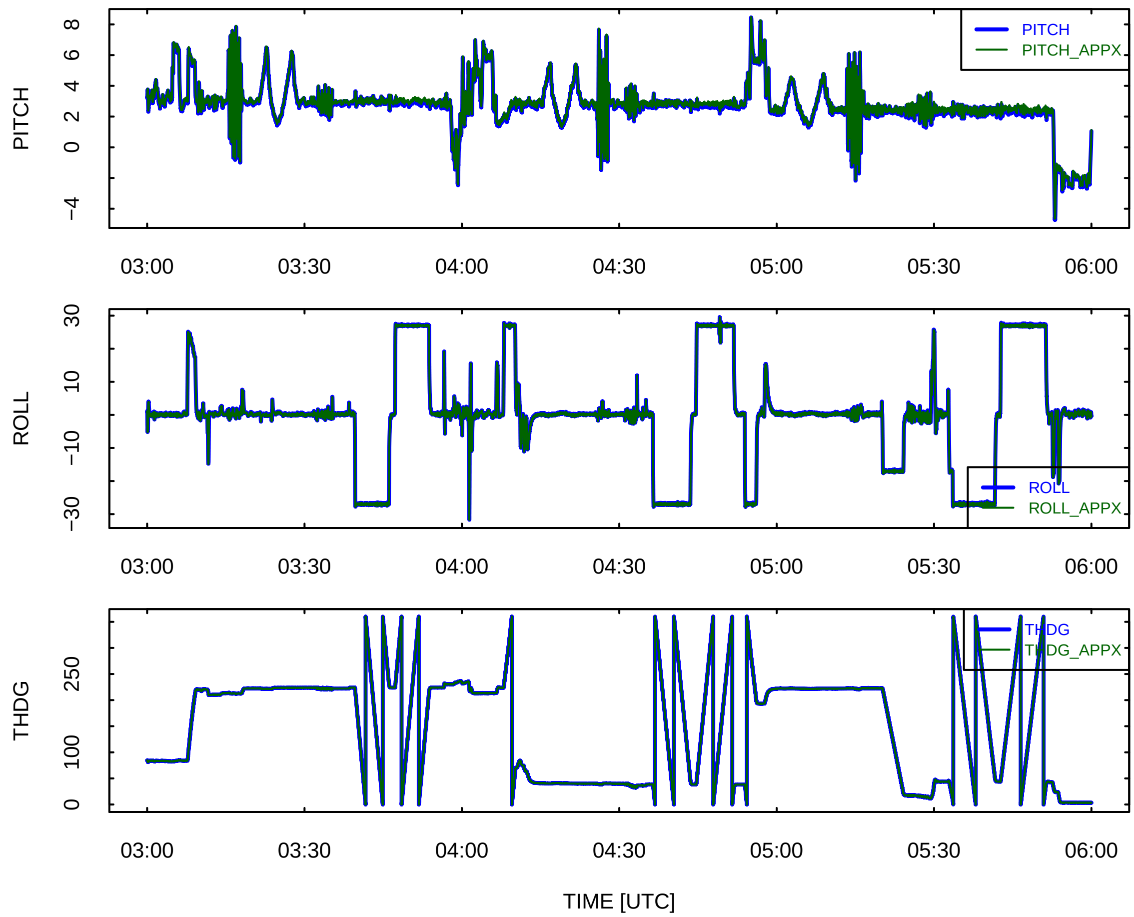

Figure 1: Plots of attitude angles measured by the Honeywell IRU and the Applanix IRU, for DEEPWAVE flight 15 on 3 July 2014

3 Timing of the measurements

All indications are that the measurements are perfectly aligned in time. Various tests were applied, shifting to see if the correlation between signals were improved and also, in a very sensitive test, comparing the phase and coherence of the signals. For pitch, the signals remain coherent at >0.75 for all frequencies up to the Nyquist frequency of 12.5 Hz. If the signals were delayed even by one sample (0.04 or 0.1 s), the expected phase shift at 1 Hz would be 14–36°, and this would increase for higher frequencies, so the absence of phase shift at all frequencies is a sensitive indicator that there is no timing difference between the signals.

Figure 4 shows a shorter example of the time correspondence between PITCH and PITCH_APPX, to illustrate that there is no apparent time shift.

There is, however, one significant difference: The Applanix measurements of pitch have much lower variance at high frequency in comparison to the Honeywell measurements. This is shown in

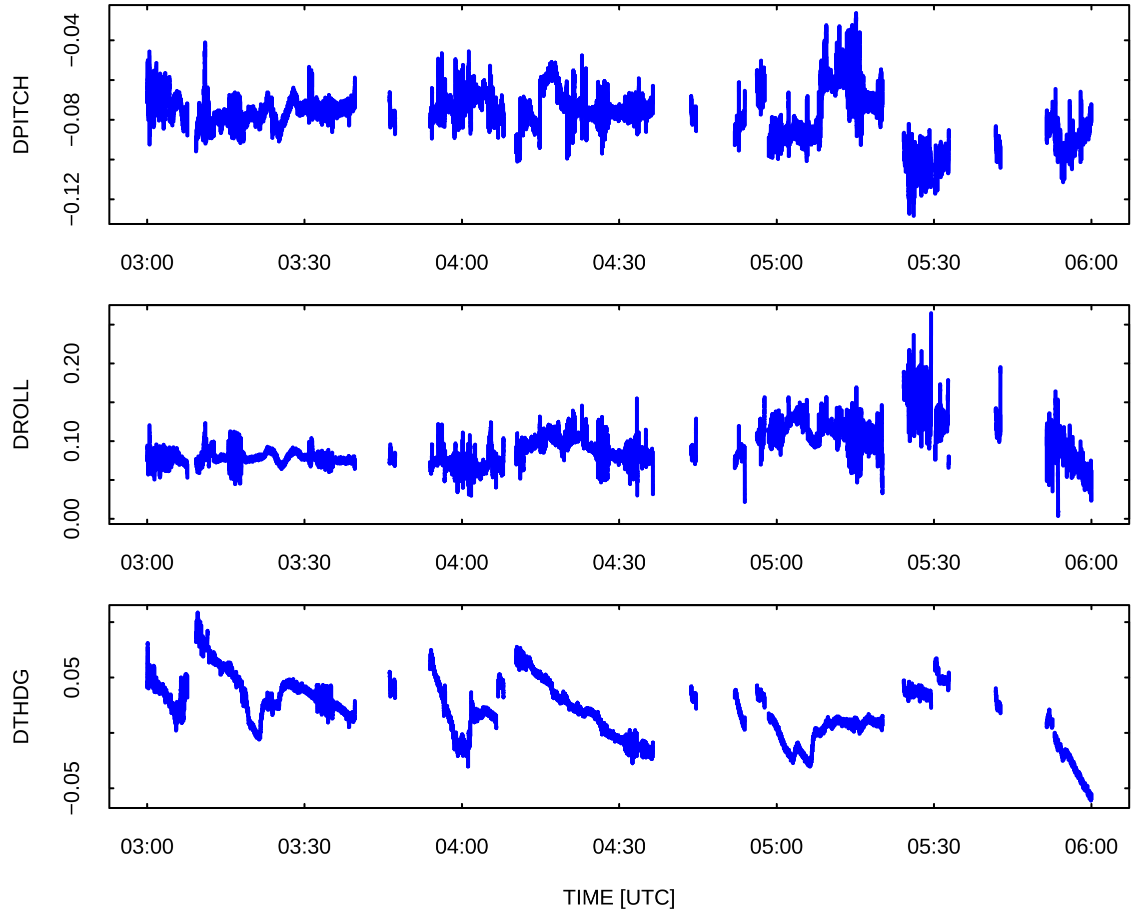

Figure 2: Plots of the differences between the attitude angles measured by the Honeywell vs. Applanix IRUs, for the same measurements shown in the preceding figure. Gaps indicate regions excluded because the magnitude of the roll exceeded five degrees.

Fig. 5, which shows that the variance spectra are essentially identical at frequencies below about 2 Hz but differ significantly above that frequency, with an apparent peak in the spectrum for PITCH at about 7 Hz that does not appear in PITCH_APPX and is likely not real. In comparison to the spectrum for AKRD, this is insignificant and so has no important effect on the vertical wind.

4 Tentative conclusions

The Applanix data are available continuously for this full flight, and the measurements have no obvious problems. In comparison to the Honeywell measurements of attitude angles, the two systems are apparently offset slightly, but only by less than 0.1° in the worst case (roll). The standard deviations are consistent with expected measurement uncertainties, with pitch appearing

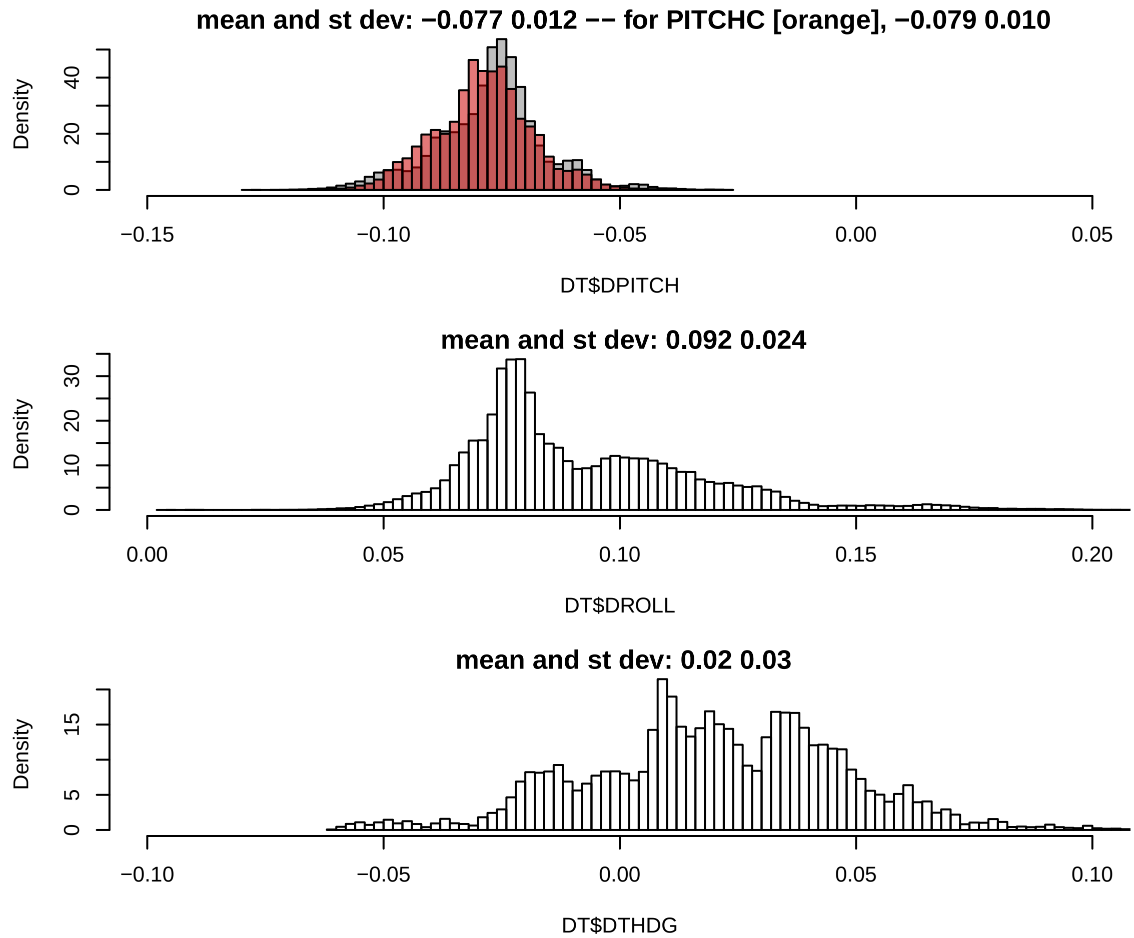

Figure 3: Histograms of the differences between angles measured by the Honeywell and Applanix IRUs, for DEEPWAVE flight 15.

the best (about 0.01° standard deviation) and heading the worst (about 0.03° standard deviation). Figure 2 (bottom) shows that the difference in heading tends to drift, as might be expected if the Kalman filter incorporated in the Applanix is correcting for errors that otherwise grow in the uncorrected measurement from the Honeywell IRU. It is hard to test the quality of the heading measurement except via circle maneuvers, which have already been applied to adjust the offset in THDG. However, the standard deviation and distribution shown in the bottom plot of Fig. 3 suggest that there is significant error in THDG that can be improved through use of THDG_APPX.

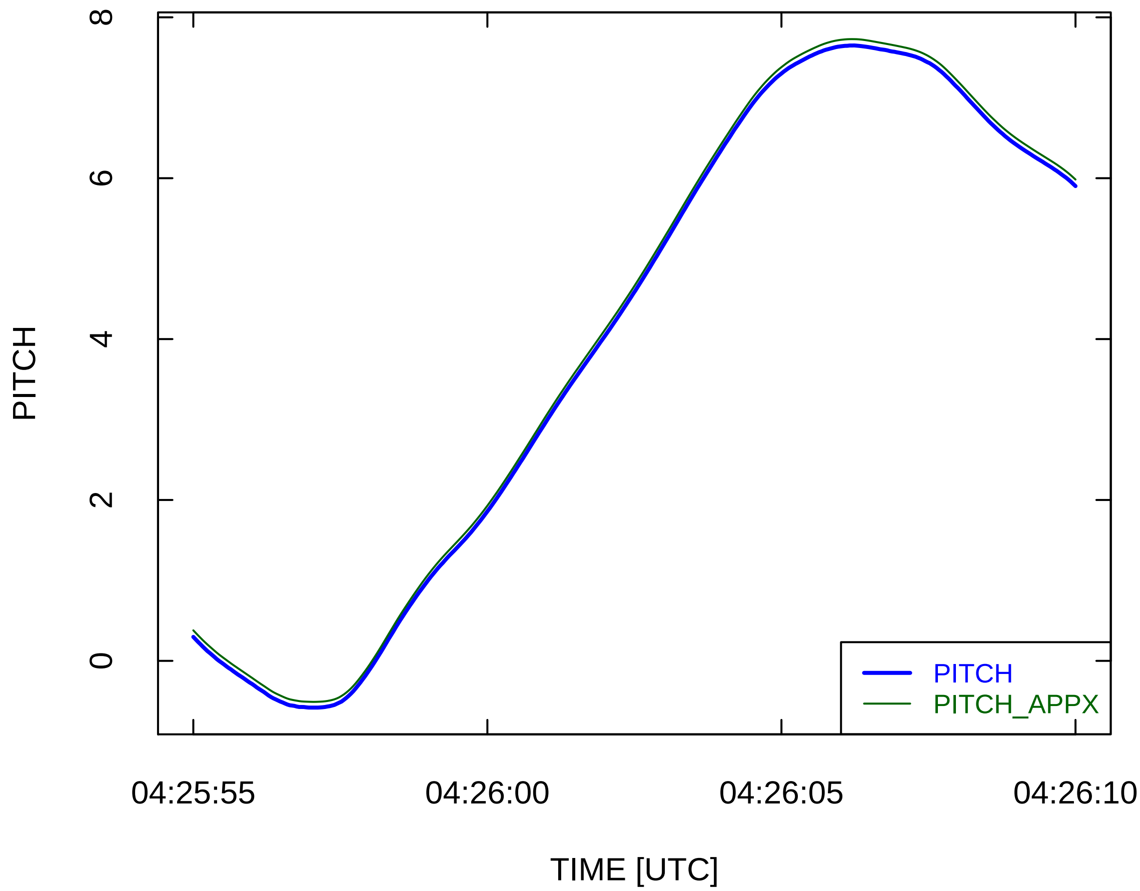

Figure 4: Example of the time correspondence between PITCH and PITCH_APPX for a sequence of measurements including a pitch maneuver, from DEEPWAVE flight 15 on 3 July 2014.

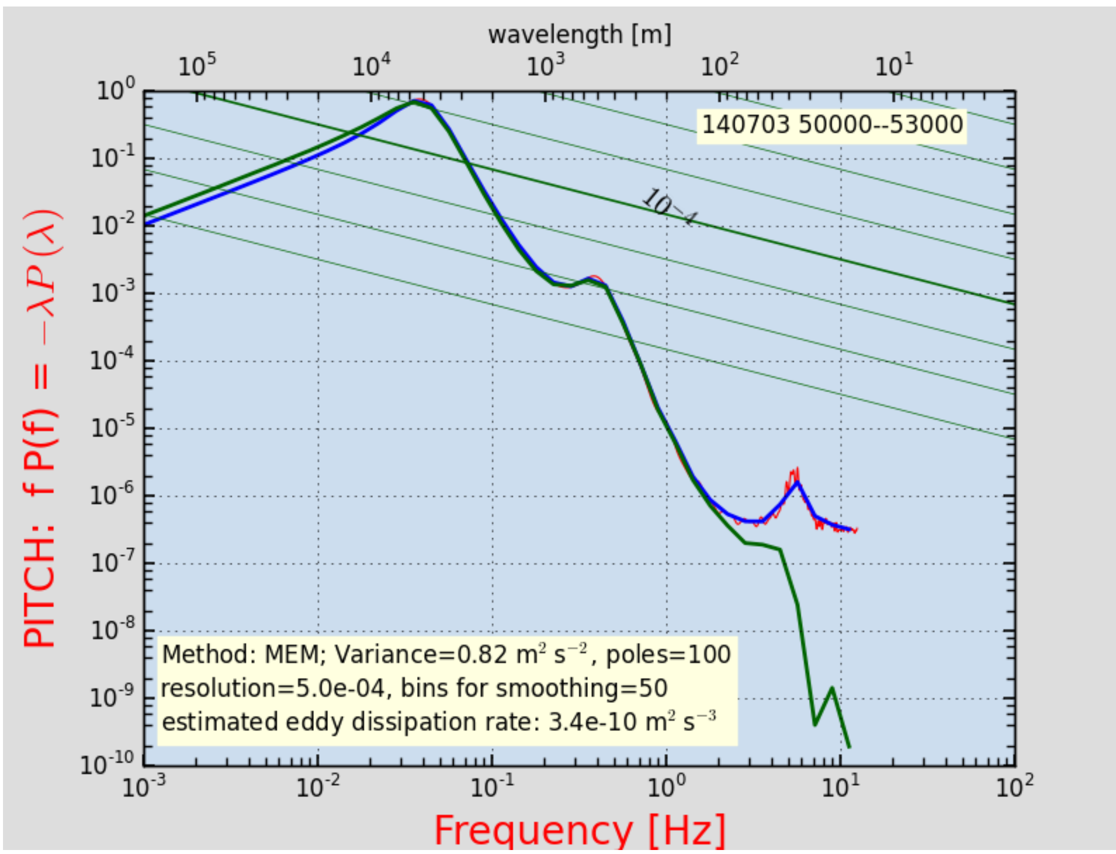

Figure 5: Variance spectra for the measurements PITCH (from the Honeywell IRU) and PITCH_APPX (from the Applanix IRU).

– End of Memo –

Reproducibility:

PROJECT:	ApplanixMemo
ARCHIVE PACKAGE:	ApplanixMemo.zip
CONTAINS:	attachment list below
PROGRAM:	ApplanixMemo.Rnw
ORIGINAL DATA:	/scr/raf/Prod_Data/DEEPWAVE/HRT/DEEPWAVErf15hPC.nc
	/scr/raf/Raw_Data/DEEPWAVE/Applanix/POS_to_ASCII_output/RF15ASCII.txt
MERGED DATA:	/scr/raf/cooperw/DEEPWAVErf15hPC_APPX.nc
GIT:	git@github.com:WilliamCooper/ApplanixMemo.git

Attachments: ApplanixMemo.Rnw
ApplanixMemo.pdf
SessionInfo