7.5 FAA TEST METHODS FOR RUNWAY VISUAL RANGE VISIBILITY AND AMBIENT LIGHT SENSORS

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1. INTRODUCTION

The United States (US) Federal Aviation Administration (FAA) has developed a new specification (FAA, 2003a) for RVR systems that details specific visibility sensor (VS) and ambient light sensor (ALS) performance requirements for the purpose of procuring a new PC-Based RVR system. The previous FAA RVR procurement for the New Generation RVR (NGRVR) System experienced a six-year delay from contract award in 1988 to first commissioning in 1994; this time was required to address the technical issues involved in changing from transmissometer technology to forward scattermeter technology (Burnham et al., 1997; Burnham and Pawlak, 2000). Since the initial procurement of the NGRVR system, forward scattermeter technology has become well established and shown to be capable of meeting the FAA's requirements. Nevertheless, to minimize the risk of significant delays in implementing the new PC-Based procurement, any VS or ALS to be provided must be field tested before contract award as part of the FAA's evaluation process. A formal Operational Capabilities Test (OCT) Plan (FAA, 2003b) has been defined to evaluate three VS units and two ALS units. The intent of the OCT is to significantly reduce the risk that extensive post-contract development might be required to meet the sensor requirements. This paper describes the essential features of the OCT methodology.

The OCT focuses on a subset of requirements considered essential to VS and ALS performance. The test period is selected to include the possibility of severe winter weather that presents the most challenging conditions for sensor performance while also ensuring a high probability of experiencing a number of significant fog events. An OCT was conducted this past winter (2003-2004) at the Otis Weather Test Facility (WTF) on Cape Cod, MA. The test methods are described and sample test results presented to illustrate the data-gathering and analytical procedures employed. The test results utilize data from the current FAA New Generation RVR (NG-RVR) sensors as opposed to any of the candidate sensors used during the actual OCT, since the latter are necessarily proprietary and outside the public domain.

The tests are divided into three categories:

1. Tests based on naturally occurring events during the six-month test period;
2. Tests based on artificially applying contaminants to the sensor windows; and
3. Tests conducted during installation and at 90-day maintenance intervals.

In general, operationally the sensors must meet strict limits on sensor systematic errors, typically less than 10% for the VS extinction coefficient and 20% for the ALS background luminance. These limits are tempered by the need to have the RVR products available, even under severe conditions where the strict accuracy limits cannot be met. Under such conditions, sensors should continue to report their measurements so long as the resulting RVR value is lower than actual (i.e., VS extinction coefficient measurements or ALS background luminance higher than actual).

2. REFERENCE SENSORS

2.1 *Reference Transmissometers*

Two standard US transmissometers with crossing baselines of 90 and 150 m define the center of the WTF visibility test area. The two transmissometers are termed T300 and T500, respectively, according to their approximate baselines in feet. These transmissometers have the following characteristics:

1. The projector uses an incandescent lamp and the receiver a silicon photodiode.
2. A short-wave pass filter at the receiver end (0.63-micron half response) assures that only visible light is used. Otherwise, the transmissometer response would be dominated by infrared light.
3. The output consists of short pulses with a frequency proportional to the transmittance; 4,000 pulses per minute corresponds to 100-percent transmissisivity.
4. The transmissometer pulses are counted from Second 8 of one minute to Second 8 of the next minute to give a one-min average of the transmittance and hence the extinction coefficient.
5. Every hour the lamp is turned off to measure the background light that is assumed to remain constant for the next hour. The lamp is turned off at Second 8 of Minute 2 of the hour. After waiting 15 s for the light to become fully extinguished, the background signal is counted for 60 s after which time the light is turned on again. The lamp has about 45 s to reach steady state before the next 60-s count begins. In practice, care must be taken to ensure steady state operation of the lamps.

The average extinction coefficient for T300 and T500 (termed TAVE) is used as the reference extinction

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coefficient for the minute, provided comparisons of measurements from T300 and T500 meet the homogeneity test discussed in the next section.

2.1.1 Homogeneity Test

In order to utilize the transmissometers as reference visibility sensors for evaluating the performance of forward scatter sensors, it is necessary to ensure homogeneity of visibility in the vicinity of the test sensors that are located near the center lines of the transmissometers to ensure good comparisons. To this end, T300 and T500 are compared to see if their measurements agree to within 10-percent. This homogeneity test employs 10-min of data to reduce the possibility of random agreements between the two transmissometers. For the ten samples, all but one must be within the 10-percent limits or none will be included in the analysis. Any individual points not meeting the homogeneity test are also excluded from the analysis.

Note that the homogeneity test also eliminates data when one of the two transmissometers is subject to significant error (e.g., snow hitting the projector or receiver lens). It does not, however, eliminate data when both transmissometers suffer similar conditions such as nearly equal window contamination losses; such errors are corrected only when high visibility conditions return and the transmissometers can be recalibrated (see Sect. 2.1.2).

When the fog density produces an extinction coefficient of 60 km^{-1} or more, the T500 transmittance becomes too low to be read and the homogeneity test is automatically failed. Such dense fog occurs rarely at the WTF.

2.1.2 Transmissometer Calibration

The WTF transmissometers are not calibrated by the conventional manual method of (a) checking their alignment and (b) setting their transmission near 100% based on the estimated visibility on a clear day. Instead, periodic alignment checks are made with automatic calibration carried out using a high-visibility forward scattermeter (HVFS) not under test (HSS Model VR-301B). Once an hour, whenever a five-min average HVFS reading is below 0.1 km^{-1}, the corresponding measurements from T300 and T500 are used to determine an offset correction for subsequent transmissometer measurements. An assumed high visibility slope between the transmissometer and the HVFS readings is used to reference the offset to zero extinction coefficient. This calibration process is applied: (a) in real-time to provide continuously corrected reference values; and (b) offline to calibrate a block of transmissometer data independently of whether the real-time calibration was properly functioning.

2.2 *Weather Conditions*

Standard sensors for wind speed and direction, temperature and relative humidity monitor the weather conditions during the OCT. An HSS present weather sensor (Model PW-402B) is used to classify precipitation by detecting individual precipitation particles.

2.3 *Ambient Light*

The absolute response of an ALS is not considered during OCT, since this assessment is better dealt with in a standards laboratory than in the field. The emphasis of the OCT is on relative response of two sensors and effects due to contamination.

3. INSTALLATION/OPERATION

3.1 *Physical*

3.1.1 Visibility Sensor (VS)

The VS units under test are installed near the crossing point of the two reference transmissometers. To avoid effects due to vertical variations in fog density, the VS units are mounted to have their scatter volumes at the same 10-ft height above the ground as the transmissometer beams. To assess any wind effects on VS response, the three VS units are installed at different azimuth orientations. The first is installed according to the vendor's recommendation (typically with the receiver pointing north to avoid solar influences). The other two are rotated by 60^{o} to the east and west of north. Because the OCT is in the winter half of the year, the VS receivers will never point into the sun.

3.1.2 Ambient Light Sensor (ALS)

The height of the ALS sensors is unimportant for the OCT. However, both units are aimed at the same part of the northern sky so that their readings can be intercompared for the tests.

3.2 *Data Acquisition*

The WTF data acquisition system is based on an industrial PC running DOS and supporting 32 serial ports for acquiring and archiving data. The data collection program individually processes every character received and hence can accommodate most message formats. The 32 channels are checked every 0.2 s for completed messages, which are then stored with the time stamp second the message was received appended to the end of the message. Messages are saved in 1-min data blocks containing all the messages received during the minute. The 1-min blocks are saved in daily files and in a single-min file containing the data from the latest minute. In addition to recording sensor messages, the data collection program operates the transmissometers and processes their measurements in real time.

3.3 *Data Monitoring*

Sensor messages are checked for validity at two levels:

1. The messages in the single-min file are checked once every working day.
2. Processed data from the daily files are plotted on 24-h plots to check all messages for validity.

When missing messages or error flags are noted, a sensor/data acquisition maintenance procedure is initiated.

3.4 *Data Processing*

3.4.1 Performance Files

A processing program converts the messages in the daily files into measurement parameters that are identified by a four-character name (e.g., TAVE) and saved in binary performance files that can save up to 122 parameters. Because the performance files can only accommodate values from -100 to +100, provision for scaling parameters prior to saving is included. Bad or missing measurements are flagged with a value of -99.

A sensor's messages are first screened for message validity (checksums or other message characteristics) and measurement validity (from self-check information). Then, the VS and ALS measurements are processed to obtain valid 60-s averages synchronized, as close as possible, with the 60-s averages from the reference transmissometers. Some sensors provide running 60-s averages that need simply be picked to be closest in time to the transmissometer averages, i.e., at second 8 of each minute. Others might require calculating a 60-s average from raw measurements with shorter averaging times. If a sensor provides other parameters (e.g., window contamination measurements) in addition to extinction coefficient or background luminance, these are also saved.

A wide variety of processing programs, including strip-chart, scatter-plot and box-plot display programs, have been written to analyze data stored in performance file format.

3.4.2 Combined Files

For generating box plots (Sect. 4.2.1), performance files are usually combined for many days and then processed to compare sensor measurements with transmissometer data. An option for explicitly removing bad transmissometer data is also available.

4. NATURAL EVENTS

4.1 *Calibration Checks*

Initially, calibration of the sensors is made using data from the first fog and snow events. A minimum of 500 and 100 valid VS measurements (homogeneous with TAVE extinction coefficient > 3.0 km^{-1}) are required for fog and snow, respectively.

Since the FAA has adopted the WTF transmissometers as the reference standard for US RVR systems, the calibration provided with the VS units is disregarded. Results from the first fog event are used to correct the provided VS calibration to the FAA standard. A box plot is then used to derive the median ratio of test unit extinction coefficient to TAVE extinction coefficient for all three VS units. The middle value of the three ratios is selected as the best estimate of the median response of the VS production run under the premise that one of the three test sensors might have an abnormal calibration. This middle value is adopted as the calibration correction for the test units and then applied to all measurements and subsequent analyses. To meet the 7% unit-to-unit consistency requirement, the ratio for the other two sensors must be within 7% of the middle ratio.

During the first snow event, the median Test Unit/TAVE extinction coefficient ratio is calculated for each test unit. To meet the requirement of equal fog and snow response, the fog and snow ratios to TAVE must agree to within 10% for at least one test unit.

Note that restricting these calibration tests to the early part of the OCT period minimizes the influence of window contamination on the test results.

4.2 *Full Test Analysis*

4.2.1 Box Plot

The VS random accuracy test is based on fog and snow box plots as shown in Figs. 1 and 2. Note that fog is defined as visibility events that occur when there is an absence of any precipitation as deduced from the reference present weather sensor.

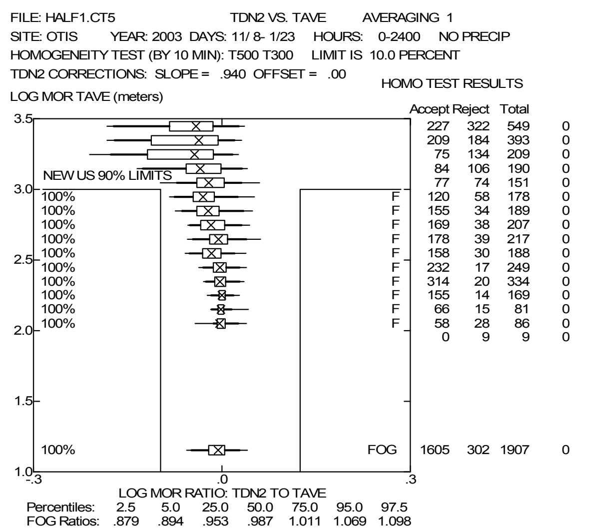

Fig. 1. Fog Box Plot for NGRVR Visibility Sensor.

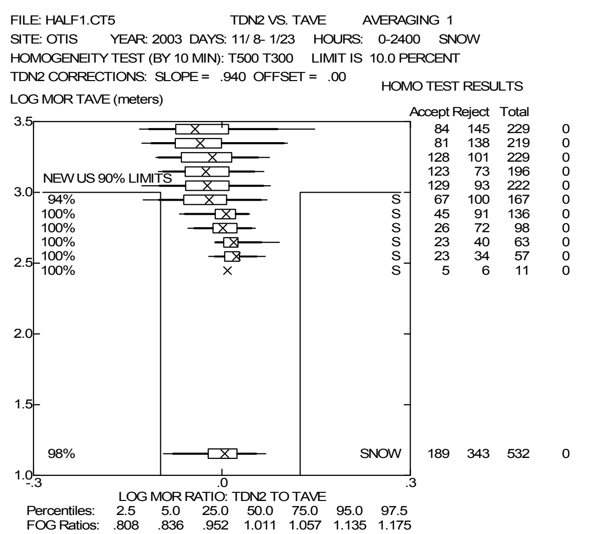

Fig. 2. Snow Box Plot for NGRVR Visibility Sensor.

The box plot header specifies the name of the file being evaluated, the sensors being compared, the averaging period (min), the test site, the test period, the homogeneity test, any corrections and the precipitation conditions (e.g., no precipitation in Fig. 1).

The x-axis is the log to the base ten of the ratio of meteorological optical range (MOR) from the test sensor (TDN2) to the reference sensor (TAVE). MOR is the same as RVR that is calculated for daytime conditions from Koschmieder's Law for viewing black objects. TAVE is the average extinction coefficient from the two crossed WTF transmissometers that have met the homogeneity criterion. The ratio scale runs from 0.5 (log 0.5 = -0.3) to 2.0 (log 2.0 = 0.3).

The y-axis is the log of MOR (m) from the reference transmissometers (TAVE). Each decade of MOR is broken up into 10 MOR bins for which the distribution of the MOR ratio is plotted.

The distributions labeled with "F" or "S" to the right are combined into the artificial bin labeled "FOG" or "SNOW" at the bottom. The FOG and SNOW bins include all the data (extinction coefficient > 3 km^{-1}) to which the VS accuracy analysis applies. The two vertical lines show the ±25% allowed extinction coefficient errors; that is, 90% of the ratios must lie between these two lines. The percentage lying between the lines listed at the left and the value for the "FOG" bin defines whether the sensor meets the test requirements. In Fig. 1 the test sensor fog performance is ideal (100% of the ratios reside within the two lines). Fig. 2 shows excellent snow performance (98% of the ratios are within the two lines).

The ratio distribution is indicated as follows: X = median or 50th percentile; box (from which the plot is named) = 25th to 75th percentile; thick line = 5th to 95th percentile; and thin line = 2.5th to 97.5th percentile. The ratios for the percentiles of the "FOG" or SNOW" bins are listed at the bottom.

The first three columns to the right show the bin-by-bin-results of the homogeneity test. The final two columns to the right show the number of points lying outside the plot limits to the left and right, respectively. Within the MOR test range (i.e., the FOG bin), only 0.2% of the ratios can lie outside these limits.

4.2.2 Angle Box Plot

The requirement that the VS scatter volume be representative of the free atmosphere is tested using an angle box plot such as shown in Figs. 3 and 4 for fog and snow, respectively. Ideally, the physical arrangement of the sensor components should not interfere with the performance of the sensor under all weather conditions. Since winds affect the transport of atmospheric particles into the scattering volume, any interference with this transport can potentially alter the representativeness of the volume and thus the measurement of extinction coefficient.

The primary difference between the angle box plot and the box plots in Figs. 1 and 2 is the change in y-axis from MOR to wind direction. Two restrictions are placed on the points included in the plot:

1. The extinction coefficient must be greater than 3.0 km^{-1}; and
2. The wind speed must be greater than 5 knots so that the wind direction is well defined.

The data points satisfying the second test are combined in the WIND bin near the top, while the points not meeting this condition are combined in the CALM bin at the top. The ratios for these two bins and five percentiles are listed at the bottom.

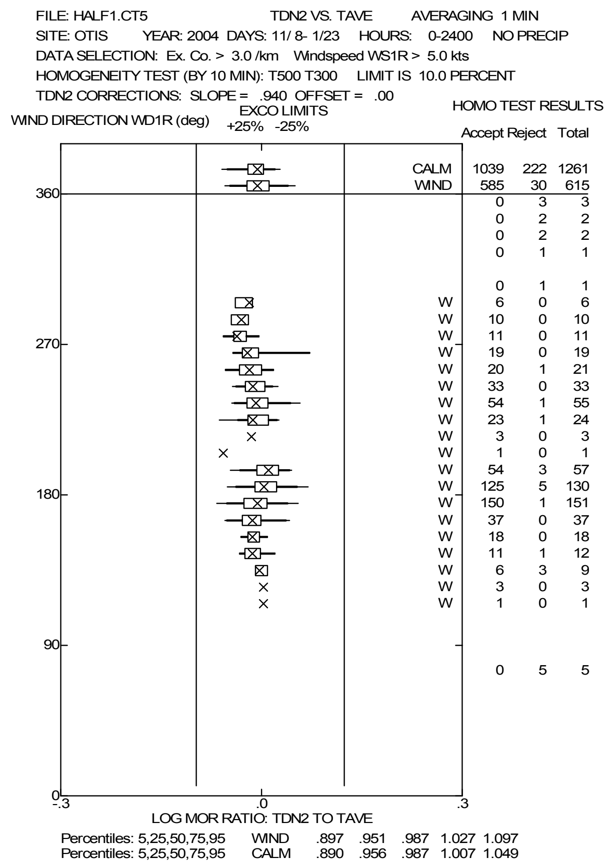

Fig. 3. Fog Angle Box Plot for NGRVR VS.

The data in Figs. 3 and 4 show little variation of the MOR ratio with wind direction and hence give no signs of significant shadowing of the scatter volume by sensor mounts or heads. The snow data shown in Fig. 4, however, are limited in wind directions. A more complete assessment would require either additional data under different wind conditions with the same sensors or, alternatively, placement of additional sensors mounted with different orientations.

The acceptance criteria for angle box plots requires that, for bins with 100 or more points, less than 10% of the points can transgress the right error limit (reported RVR would be roughly 25% greater than actual) and, for bins with 20-99 valid points, less than 20% of the points can transgress the right error limit.

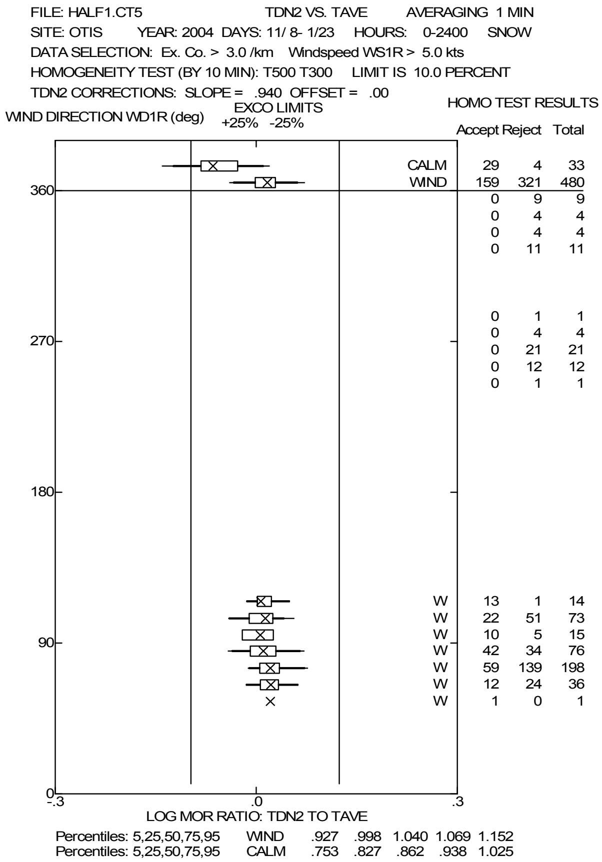

Fig. 4. Snow Angle Box for NGRVR VS.

4.3 *Natural Snow Events*

Snow events occurring during the test period are identified and examined in detail to assess sensor performance. If window contamination measurements are made by the VS or ALS, they are inspected to check for signs of window clogging (e.g., steady, large window contamination values); sensor measurements should be invalidated if significant clogging is observed. When the reference transmissometers are operating correctly the ratios of the test sensor measurements to the transmissometer measurements are plotted as a time series to determine times when the performance of the test VS sensors might be degraded. When the reference transmissometers are not giving valid measurements, it is still possible to assess the consistency of the test VS sensors by plotting ratios of their measurements. Because of the different VS pointing directions, such comparisons can also detect anomalies that are related to the direction that the snow is blowing onto the sensors. The same comparison for ALS sensors (with no reference sensor) is not as useful because both ALS units are pointing in the same direction in order to measure the same point in the sky. Thus, both units are exposed to the same blowing snow conditions

VS and ALS sensor measurements must be valid during most snowstorms. Consequently, during the limited time and moderate conditions experienced during OCT, no invalid measurements (i.e., hard alarms) are expected from acceptable sensors. Time series plots are useful for assessing the occurrence of such events. Note that this test requirement applies whether the window contamination is caused by snow or the slow buildup of window contamination.

4.4 *Other Parameters*

4.4.1 ALS Range

ALS measurements during the OCT period at the WTF are expected to remain within the upper measurement limit of 10,000 ft-Lamberts. ALS measurements over the entire test period are examined to assure that no clipping is observed at a level lower than the upper measurement limit.

4.4.2 VS Offsets

The HVSM used to calibrate the reference transmissometers is also used to identify clear days for checking the test VS offset requirement that applies to high visibility conditions. That is, corresponding measured extinction coefficients or offset values (corrected for the HVFS measurements) must be within the range of ± 0.3 km^{-1}.

5. ARTIFICIAL EVENTS

Artificial events assess the impact of window contamination or blockage on sensor measurement accuracy. Single VS and ALS units are tested. This assessment requires a reference signal for comparison. For the VS, the calibration device or other stable scattering device is installed in the scatter volume. For the ALS, the other ALS is used as the reference and the test is conducted when the ALS signals are stable (i.e., cloudless northern sky).

5.1 *Window Contamination*

The sensor windows are contaminated with four substances: water droplets, salt spray, white dirt and black dirt that are intended to duplicate the range of natural contaminants. The sensor passes the test for a contaminant, if all errors are less than the systematic error limits (10% for VS and 20% for ALS) or if 90% of the errors beyond the systematic error limits give measurements greater than actual.

The contaminant levels are increased gradually. Continuous spraying is required for water droplets. Salt spray is applied intermittently to give the water time to evaporate and leave a residue resulting in increasing amounts of window loss. The two types of dirt are also applied intermittently. The contamination test is terminated when the sensor reaches hard alarm or no further increase in contamination level is likely. For the VS, both transmitter and receiver windows are tested. Each contamination test is repeated to check for consistency.

5.2 *Blowing Snow*

The blowing snow test is intended to represent real blowing snow in so far as possible; it is very difficult, however, to quantify the amount of snow hitting the sensor. Initial testing uses snow blowing horizontally onto the sensor head. Because it is not practical to blow snow on the VS windows with a scattering device installed, the first VS test blows snow horizontally onto the sensor to see if any buildup of snow is noted on the window or inside the sensor hood. If a significant buildup is noted, then a scattering device is installed and snow is blown directly onto the window (avoiding the scattering device) with increasing intensity until the window clogs. A VS or ALS clog should generate a hard alarm to disable the sensor output. The errors under non-clogging conditions are analyzed in the same way as for other contaminants (Sect. 5.1)

The snow-clogging test must be done when the temperature is below freezing. Artificial snow from a snow machine is used if natural snow is not available. The snow-blowing machine is based on a leaf blower that allows snow to be introduced into the airflow through a screened opening to the air conduit. Manual adjustment of the snow intake enables the snow rate to be increased gradually to assess the sensor response to different snow intensities.

5.3 *Analysis methods*

These tests are analyzed by extracting the relevant parameters with time tags from the performance files for the test day and saving them in comma separated variable (csv) format. The csv file is then imported into a spreadsheet program for analysis. The window-contamination measurements are compared to the clean-window values to assess the error introduced by the different contaminations. The VS readings are analyzed directly. The ALS analysis examines the ratio of the readings from the two units.

6. INSTALLATION/MAINTENANCE

6.1 *Installation*

A number of requirements are tested during installation:

1. Operation on commercial 115 VAC power.
2. Automatic restart after loss and return of power.
3. VS is a forward scattermeter.
4. VS calibration procedure is guided by VS processor and includes final validation step.
5. VS calibration device represents fog with a specified extinction coefficient.
6. VS geometry check device shows all three VS units to have valid geometry.
7. After calibration of all three VS units with the same calibration device, the measurement of each calibration device in each VS unit (five minutes for each combination) will verify less than 3% variation in VS calibration with different calibration devices.

6.2 *90-Day Maintenance*

After 90 days of operation the sensor calibration drift and VS electronic zero offset are measured. For the VS, the calibration device is installed and measured for five minutes. The windows are cleaned and the calibration device is measured for another five minutes. The windows are blocked and the VS measurements recorded for another five minutes. The sensor is recalibrated and the calibration device is measured for a final five minutes. Window cleaning and recalibration must not change the response to the calibration device by more than 10%. The VS reading with heads blocked must be zero to within $\pm 0.2\ km^{-1}$.

The ALS sensor drift test uses each ALS unit as the reference for the other and is done on a day with no clouds in the northern sky to assure stable ALS readings. First the ratio of the two ALS readings is measured for five minutes. Then one ALS is cleaned and the ratio measured for another five minutes. Finally the second ALS is cleaned and the ratio measured for a final five minutes.

6.3 *Analysis Method*

These tests are analyzed by the spreadsheet method described in Sect. 5.3. The five-minute measurement periods are identified by the time log of the test sequence and averaged. Any inconsistent points at the beginning or end of the five-minute period are discarded.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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