10.4 FEDERAL AVIATION ADMINISTRATION REQUIREMENTS FOR RUNWAY VISUAL RANGE (RVR) VISIBILITY AND AMBIENT LIGHT SENSORS

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1.INTRODUCTION

The International Civil Aviation Organization (ICAO) provides guidance (ICAO, 2000; 2001) for the selection of sensors for use in Runway Visual Range (RVR) systems but does not define specific requirements for qualifying sensors. The United States (US) Federal Aviation Administration (FAA) has developed a new specification (FAA, 2003) for RVR systems that details specific visibility sensor (VS) and ambient light sensor (ALS) performance requirements for use in procuring a new PC-Based RVR system. This paper outlines the basic rationale behind this performance specification and discusses its key components.

1.1 *RVR Product*

RVR is defined by ICAO as the range over which the pilot of an aircraft on the center line of a runway can see the runway surface markings of the lights delineating the runway or identifying its center line. Two different laws govern the visibility of lights and objects, Koschmieder's Law for objects and Allard's Law for lights. Operationally, the law giving the greater RVR value is used to provide the RVR product.

1.1.1 Koschmieder's Law

Koschmieder's Law (Koschmieder, 1924) is applicable to RVR during daytime conditions. It estimates the visibility of black objects and is defined by

$$C_t = e^{-\sigma R} \qquad (1)$$

where

R = RVR (m);
σ = atmospheric extinction coefficient (m^{-1}); and
C_t = contrast threshold, which is taken as 0.05.

Koschmieder's Law is not used at night, which is defined by a background luminance value less than 6.85 cd-m^{-2}.

1.1.2 Allard's Law

Allard's Law (Allard, 1876) estimates the visibility of lights and is defined by

$$E_t = (I/R^2)e^{-\sigma R} \qquad (2)$$

where

E_t = visual threshold (lx);
R = RVR (m);
σ = atmospheric extinction coefficient (m^{-1}); and
I = runway light intensity (candelas).

The visual threshold E_t(lx) is approximated by

$$\log E_t = -5.7 + 0.64 \log B \qquad (3)$$

where

B = background luminance (cd-m^{-2}).

A lower threshold on E_t is set at 6.8×10^{-6} lx, which corresponds to the night limit for background luminance.

1.1.3 Reporting Increments

US RVR systems report in English units and use the following reporting increments: 100-ft increments from 0 ft through 800 ft; 200-ft increments from 800 through 3,000 ft; and, 500-ft increments from 3,000 through 6,500 ft.

The actual RVR value is rounded off to the nearest reporting increment; for example, RVR values from 751 feet to 899 feet would be reported as 800 feet. The limiting values 6,500 feet and 100 feet indicate RVR > 6,249 feet and RVR < 150 feet, respectively.

1.2 *RVR Use*

An RVR system is used to assess the conditions needed to conduct a precision instrument approach. Each approach category has specific requirements for number and locations for VS measurements along with the minimum permitted RVR value at each location that authorizes a pilot to attempt the approach. Note that the pilot must acquire visual contact with the ground (usually the approach lights) before they reach the decision height specified for the approach category.

1.3 *RVR Sensors*

Three different sensors are required to provide the information for the RVR product calculation.

1.3.1 Visibility Sensor (VS)

The VS measures the atmospheric extinction coefficient (σ) that is needed for both laws.

1.3.2 Ambient Light Sensor (ALS)

The ALS measures the background luminance that is used directly in Allard's Law and used to assess the applicability of Koschmieder's Law.

1.3.3 Runway Light Intensity Monitor (RLIM)

The RLIM measures the current flowing in the runway lighting circuits to assess the light level setting (0, 1, 2, 3, 4 or 5). The light intensity (I) is then assigned to the appropriate intensity for the particular runway lights

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(edge or centerline). Measuring the actual current protects against reporting light-based RVR values when the lights are not operating.

1.4 *Timing*

The RVR product must respond quickly to changes in RVR conditions. This implies:

1. The RVR product is based on running 60-s averages of σ and B and the instantaneous runway light intensity.
2. The product must be updated every 15-s or more frequently.
3. Any sensor time constants must be short enough that no more than 10% of the measurements included in a 60-s average come from the previous minute.

2. BACKGROUND

2.1 *History*

Forward scattermeters were originally developed by the US Air Force (Muench et al., 1974). By the mid-1980's, forward scattermeter technology had advanced to the point where the FAA decided to specify a forward scattermeter as the visibility sensor (VS) for the New Generation RVR (NGRVR) system. This decision was prompted by two considerations related to use of the prior US transmissometer system (Tasker Model 500):

1. Its sensitivity to window contamination required extensive window cleaning; and
2. It required two baselines (40 and 250 feet) to cover the full RVR dynamic range. The short baseline was found to have large forward-scatter errors and was difficult to align.

A forward scattermeter has much less sensitivity to window contamination and can cover the entire RVR range with a single instrument. Additionally, transmissometers can be recalibrated on any clear day, while scattermeters must derive their basic calibration from comparisons to reference transmissometers. Fortunately, a scattering device that simulates scattering from fog of a particular density can be used as a reliable secondary standard to transfer the calibration from transmissometer-calibrated scattermeter units to scattermeters for deployment and operation of scattermeters at airports.

Previous FAA qualification testing (Burnham et al., 1997; 2000) and extensive experience with the NGRVR system provided the basis for the development of the PC-Based RVR System.

2.2 *Accuracy Targets*

Because RVR is derived from the values of three independent parameters (σ, B and I), its overall accuracy must be translated into accuracy requirements for each of the measurement of these parameters. The calculated RVR is most sensitive to σ errors and much less sensitive to B and I errors. Consequently, the tolerances and verification requirements are much more stringent for the VS.

2.2.1 Visibility Sensors

The FAA VS accuracy requirement is based on actual test results and inherently includes consideration of the errors associated with the reference transmissometers. The accuracy targets are set at 10% for systematic errors that can bias RVR values and 15% (standard deviation) for random errors. The random errors are tested at the 90% confidence level.

2.2.2 Ambient Light Sensors

The ALS measures the luminance of the northern sky with a 6-degree field of view aimed 6 degrees above the horizon. This orientation avoids viewing the sun in the northern hemisphere below the Arctic Circle and attempts to give a reasonably representative value for all landing directions. Since RVR is relatively insensitive to background luminance, this orientation requirement suffices over attempting to measure background luminance along the pilot's view. The FAA ALS accuracy requirements are intended to fall well within the state of the art. Thus, the systematic error limits are relaxed to 20%, and no random error limit is set.

2.2.3 Tradeoffs

Because RVR measurements are intended to assure that RVR values are at or above the minimum value for a particular precision instrument landing operation, positive and negative RVR errors are not equally significant. Reporting an RVR value greater than actual can reduce safety because approaches will be attempted that might (a) have lower chance for success or (b) challenge the pilot's capability of remaining on the runway. Reporting an RVR value less than actual will not affect operations unless the error reduces the RVR below the minimum value for the category of operation, in which case the approach will not be allowed (ICAO, 2000, Sect. 5.5.4). On the other hand, not reporting RVR at all because the reported value would be below the actual value by more than the normal tolerance will normally require shutting down the runway unless some other source of RVR estimate is available. The specification therefore relaxes the accuracy requirements under short-term severe conditions (such as excessive window contamination) as long as the reported RVR would be lower than actual (i.e., σ or B greater than actual). Note that, significant uncorrected window contamination or blockage yields the opposite effect, namely, producing values of σ or B less than actual, which is unacceptable and thus must be detectable to avoid overestimating RVR.

3. VS REQUIREMENTS

3.1 *General Considerations*

To give valid measurements, the VS scattering volume must be representative of the free atmosphere. Consequently, the scattering volume must not experience significant shadowing by sensor heads or mounts and must not be significantly heated by sensor heat sources.

3.2 *VS Operating Range*

To cover the RVR range of 100 to 6,500 ft, the VS must measure extinction coefficients from 1.0 to 300 km^{-1} with a resolution of 0.01 km^{-1} or 1%, whichever is greater. The VS should spend at least 75% of the time measuring the extinction coefficient, and, at the highest extinction coefficient values, the measurements must be corrected for beam attenuation inside the sensor.

3.3 *VS Accuracy*

3.3.1 Transmissometer Comparisons

RVR values are most significant for operational values below 3,000 ft, as indicated by the 200-ft reporting increments in Sect. 1.1.3. The VS accuracy tests are applied only to extinction coefficients greater than 3.0 km^{-1}, which corresponds to a Koschmieder daytime RVR of ~3,000 ft.

Comparisons with reference transmissometers are done during homogeneous conditions in order to ensure representativeness of the measurements among sensor types. The 10% homogeneity requirement can be satisfied by either examining the time variability of a single reference transmissometer or by comparing two crossed transmissometers. When using a single transmissometer, the Taylor hypothesis (Taylor, 1937) is invoked, that is, time-stationarity of the measurements within certain tolerances is equated to spatial stationarity between the transmissometer and nearby sensors being calibrated. When two transmissometers are used, the average of their readings is taken as the reference extinction coefficient, provided the two transmissometers satisfy a homogeneity requirement. The two-transmissometer approach also reduces the possibility that systematic error might affect the transmissometer measurements.

The VS random error limit of 15% standard deviation is evaluated at the 90% confidence level. In other words, for 90% of the valid measurements with $\sigma > 3.0$ km^{-1}, the extinction coefficient ratio of test to reference must lie between 0.75 and 1.25. In addition, the number of outliers is limited by the requirement that less than 0.2% of the ratios are less than 0.5 or greater than 2.0. The random error limit must be satisfied for both fog and snow.

3.3.2 Offsets

Electronic offsets can arise when portions of the VS transmitter signal leaks into the VS receiver electronics and produces unwanted responses. Such offsets are detected with the sensor heads blocked and must be less than $\pm$0.2 km^{-1}.

Optical offsets can occur when VS transmitted light reaches the receiver after inadvertent scatter off nearby surfaces. These offsets can be determined on a clear day. Total offsets, including both optical and electronic, must be less than $\pm$0.3 km^{-1}.

These offset requirements are intended to be applied on a long-term basis. Transient optical offsets are also possible and can affect other accuracy requirements, especially those involving snow. Snow sticking on sensor hoods or melting and forming icicles can generate optical offsets. Such occurrences are to be avoided.

3.3.3 Calibration Consistency

A 10% calibration consistency requirement is distributed between variations introduced by different calibration devices (3%) and variations associated with manufacturing tolerances of the VS units (7%).

Calibrator-to-Calibrator

The calibration of each VS must vary by less than $\pm$3% for different calibration devices. This is to ensure that operational performance throughout the National Airspace System has a common standard.

Unit-to-Unit

The fog response of various VS units must vary by less than $\pm$7% when calibrated by the same calibration device. This consistency must be maintained over the entire VS production run.

The scattering properties of the calibration device can be significantly different from those of fog, since volume scattering of fog and snow is very different from plane scattering from a flat plate-type calibration device. Consequently, the unit-to-unit variability in the scattermeter fog response depends upon two considerations:

1. The sensitivity of the ratio between fog scattering and calibration device scattering on the exact scattering geometry, and
2. The unit-to-unit consistency of the scattering geometry.

The first consideration can be mitigated by careful design. The second can be mitigated by tight manufacturing tolerances.

3.3.4 Fog-Snow

The most important obstructions to vision for RVR are fog and snow. The median VS response to fog and snow relative to transmissometer measurements must agree to within $\pm$10%. The specification does not directly address other obstructions to vision such as dust or smoke that can reduce visibility within the RVR range.

The angular distribution of light scattering from fog and snow is quite different. Fog scattering is strongly peaked in the forward direction while scatter from snow is more uniform in all directions. Thus, at some scattering angle the two obstructions to vision will have the same amount of scattering (relative to the extinction coefficient that is equal to the sum of the absorption coefficient and the scattering coefficient integrated over all scattering angles). For the NGRVR forward scattermeter equal response is given by a nominal, beam-center scattering angle of 42^{o} (Burnham et al., 1997). Note that the correct angle for equal fog and snow response will depend upon the beam width of the scattering volume. Because the fog scattering is greater for smaller scattering angles, the intensity-weighted, mean scattering angle in fog will be less than the beam-center scattering angle.

3.4 *VS Calibration*

The specification requires that calibration of the VS be traceable to visibility measurements obtained from transmissometers. This ensures that the sensors can meet the performance standards and that the calibration device produces results that are comparable with actual visibility conditions to within the prescribed accuracy.

3.4.1 Audit Trail

A well-defined procedure must be used to derive the extinction coefficient value on each calibration device from VS comparisons with reference transmissometers.

3.4.2 Computer Guidance

Use of the calibration device during field calibration must be guided by the VS processor and must include validation steps that will prevent operator error. Further, all electromagnetic interference requirements must be met during calibration to assure a valid calibration.

3.5 *Geometry Check*

Because the scattering geometry of a forward scattermeter can be changed accidentally after leaving the factory, a geometry check device must be provided to quickly verify the scattering geometry of fielded forward scattermeters. This device must be sensitive to geometry errors that can lead to fog response outside the ±7% error limits in Sect. 3.3.3.

4. ALS REQUIREMENTS

4.1 *ALS Range*

The ALS must measure background luminance from 0.5 to 10,000 fL with a resolution of 0.5 fL or 5% of the measurement, whichever is greater. The ALS should spend at least 75% of the time measuring the background luminance.

4.2 *ALS Accuracy*

The accuracy of the ALS measurement at or above 2 fL shall be ± 20%.

5. WINDOW REQUIREMENTS

Similar window requirements apply for both the VS and ALS.

5.1 *Snow Clogging*

One critical VS or ALS failure mode is when a window becomes clogged with snow. Under this condition, the resulting RVR value can be much greater than actual. Whenever clogging occurs, the condition must be detected and the data invalidated. However, the VS and ALS must operate satisfactorily during most snowstorms. The RVR system must not be the initial reason for closing a runway or airport because of snow.

A look-down scattering geometry (Burnham et al., 1997) can facilitate keeping VS windows clear of snow, if suitable hoods and heaters are provided. The ALS must view the northern sky and hence cannot benefit from a look-down geometry. Hoods and heaters are also employed to reduce the possibility of clogging in the ALS.

5.2 *90-Day Drift*

The expected minimum periodic maintenance cycle for cleaning and/or recalibration of VS and ALS windows is 90 days. Thus, the VS fog response can drift no more than 10% in 90 days, and the ALS fog response can drift no more than 20% in 90 days.

5.3 *Window Contamination Correction*

Successful VS and ALS designs usually use window contamination measurements to detect snow clogging and compensate for the buildup of dirt. The development of the NGRVR (Burnham et al., 1997) revealed that water droplets and dirt on sensor windows have different scattering and attenuation properties and must be accounted for by a window contamination correction algorithm.

6. GENERAL SYSTEM REQUIREMENTS

6.1 *Power*

Sensors must operate on standard AC commercial power. They must also restart automatically when power is restored after a power failure.

Battery backup is required for four hours of uninterruptible operation after a power outage. Heaters need not operate from battery backup.

6.2 *Self Checks*

Sensors must be designed with built-in self-check capabilities. The first use for this capability is to verify proper sensor operation. Hard alarms are issued when a checked parameter is outside permitted tolerances and the sensor's data are flagged invalid. When a checked parameter is approaching the hard alarm limit, a soft alarm is issued to alert maintenance personnel for possible action.

6.3 *Maintenance*

The FAA requires a minimum of 90 days between required periodic maintenance. Otherwise, system self-check information, including performance of VS and ALS components, must determine if corrective, unscheduled maintenance is required. The sensors should monitor themselves and, if necessary, alarms should be reported and data invalidated. Guidance must be provided on defective operation and whether any least replaceable unit(s) (LRU) must be replaced.

6.4 *Environmental*

Standard FAA requirements must be met for outdoor operation and electromagnetic compatibility.

7. ACKNOWLEDGEMENTS

This work was supported by the Federal Aviation Administration Office of Navigation Services.

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