Doc 9328-AN/908

# MANUAL OF RUNWAY VISUAL RANGE OBSERVING AND REPORTING PRACTICES

SECOND EDITION — 2000

*Approved by the Secretary General and published under his authority*

INTERNATIONAL CIVIL AVIATION ORGANIZATION

# MANUAL OF RUNWAY VISUAL RANGE OBSERVING AND REPORTING PRACTICES

(Doc 9328-AN/908)

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# Table of Contents

# Chapter 1

# INTRODUCTION

1.1 This manual was first issued as a circular in 1973 (Circular 113, *Runway Visual Range Observing and Reporting Practices)*. It was based on information provided by a number of States on their runway visual range (RVR) assessment practices. Owing to numerous subsequent changes to the provisions governing RVR contained in Annex 3 — *Meteorological Service for International Air Navigation* and to changes in RVR assessment practices by States, it became necessary to produce a revised edition of the material in the circular. In 1981, in view of the expected wider operational use of the document, it was issued as a manual and contained updated information on assessment practices, which had been made available by a number of States, together with information on technical developments and research.

1.2 As a result of subsequent amendments to Annex 3 provisions related to RVR assessment over the past two decades, it became clear by 1995 that the manual needed to be revised. In particular, detailed guidance concerning forward-scatter meters was considered necessary following comparisons between transmissometers and forward-scatter meters conducted by a number of States which had indicated that forward-scatter meters were capable of producing comparable output to transmissometers.

1.3 The purpose of this manual is to assist States in setting up efficient RVR systems, or, where such systems already exist, in updating and standardizing them. This is particularly important in view of the different assessment practices being used. It is hoped that the manual will also stimulate further research and development in the field of RVR assessment.

1.4 In conclusion, it should be stressed that nothing in the manual should be taken as contradicting or conflicting with the RVR provisions contained in Section 4.7 of Annex 3.

*Note 1.— RVR is the approved ICAO abbreviation for runway visual range and is normally used in this manual instead of the full name. See the* Procedures for Air Navigation Services — ICAO Abbreviations and Codes *(PANS-ABC, Doc 8400).*

*Note 2.— The RVR Study Group, consisting of experts from seven States and three international organizations, assisted the Secretariat in preparing the second edition of this manual.*

# Chapter 3

# EXPLANATION OF TERMS

3.1 These explanations are generally based on established scientific definitions, some of which have been simplified to assist non-specialist readers. Approved ICAO definitions are marked with an asterisk (*) and published WMO definitions[1] with a double asterisk (**). The units, where appropriate, are indicated in brackets.

3.2 In considering the definitions below, the following assumptions are made:

a) extinction coefficient, meteorological optical range, transmissivity and transmittance can all be defined in terms of luminous flux and are interchangeable for quantifying the clarity (i.e. transparency) of the atmosphere (see 6.2.1);

b) for all definitions, luminous flux is defined by the International Commission on Illumination (CIE) response of human vision; and

c) whether stated or not, quantities related to luminous flux are referenced to an incandescent light source with a colour temperature of 2700 K.

***Allard's law***. An equation relating illuminance (*E*) produced by a point source of light of intensity (*I*) on a plane normal to the line of sight, at distance (*x*) from the source, in an atmosphere having a transmissivity (*T*).

*Note. — Applicable to the visual range of lights — see Appendix A.*

***Contrast threshold (ε)*****. The minimum value of the luminance contrast that the human eye can detect, i.e. the value which allows an object to be distinguished from its background (dimensionless).

*Note.— The contrast threshold varies with the individual.*

***Extinction coefficient** (σ )***. The proportion of luminous flux lost by a collimated beam, emitted by an incandescent source at a colour temperature of 2 700 K, while travelling the length of a unit distance in the atmosphere (per metre, $m^{-1}$).

*Note 1.— The coefficient is a measure of the attenuation due to both absorption and scattering.*

*Note 2.— Using the assumptions in 3.2, the definition can be also stated as follows: the proportion of luminous flux lost by a collimated beam while traveling the length of a unit distance in the atmosphere.*

***Illuminance***** (*E*). The luminous flux per unit area (lux, lx).

***Koschmieder's law***. A relationship between the apparent luminance contrast ($C_x$) of an object, seen against the horizon sky by a distant observer, and its inherent luminance contrast ($C_0$), i.e. the luminance contrast that the object would have against the horizon when seen from very short range.

*Note. —Applicable to the visual range of objects by day — see Appendix B.*

***Luminance (photometric brightness) (L)***. The luminous intensity of any surface in a given direction per unit of projected area (candela per square metre, $cd/m^2$).

***Luminance contrast (C)***. The ratio of the difference between the luminance of an object and its background to the luminance of the background (dimensionless).

***Luminous flux (Φ)*****. The quantity derived from radiant flux by evaluating the radiation according to its action upon the International Commission on Illumination (CIE) standard photometric observer (lumen, lm).

*Note.— The radiant flux represents the power in a light beam while the luminous flux represents the magnitude of the response of the human eye to the light beam.*

***Luminous intensity (I)*****. The luminous flux per unit solid angle (candela, cd).

***Meteorological optical range (MOR)*****. The length of the path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp, at a colour temperature of 2 700 K, to 0.05 of its original value, the luminous flux being evaluated by means of

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1. *Guide to Meteorological Instruments and Methods of Observation*, Chapter 9 (WMO-No.8)

# Chapter 4

# WEATHER PHENOMENA REDUCING VISIBILITY

## 4.1 INTRODUCTION

4.1.1 Visibility is always restricted to some extent by the effect of light being scattered and absorbed by atmospheric particles (e.g. microscopic salt crystals, dust and soot particles, water droplets), whether suspended in or falling through the atmosphere. Even in the absence of particles, molecular scattering (Rayleigh scattering) limits the visibility. Hence, infinite visibility never occurs in the atmosphere, although it is often possible to see over long distances. This chapter reviews the weather phenomena that can reduce visibility, with particular emphasis on those that can reduce the visibility into the RVR range, i.e. below 1 500 m. Table 4-1 lists the most common of those weather phenomena and some of their characteristics. The MOR ranges indicated are typical values based on experience. The issue of absorption is relevant to scatter meters only while the wavelength dependence is applicable for any instrument with optical response not centred around 0.55 μm (i.e. maximum response for human vision).

4.1.2 Mist and fog are, in many parts of the world, the primary causes for visibility restrictions of operational significance. Heavy precipitation may also cause low visibilities restricting aircraft operations. Snow is one of the most common factors reducing visibility in cold climates. Sand and dust (including dust- and sandstorms) can result in sharply reduced visibilities in arid and desert areas.

## 4.2 LITHOMETEORS: HAZE, SAND, DUST, SMOKE AND VOLCANIC ASH

4.2.1 The reduced visual range due to dust or other microscopic (dry) particles in the atmosphere is called haze. In haze, blue light is scattered more than red light such that dark objects are seen as if viewed through a veil of pale blue. Visibility is not necessarily constant in any direction because variations due to smoke and other impurities from residential and industrial areas often occur. Haze and other lithometeors are reported only when the visibility is 5 000 m or less (except for low drifting sand and volcanic ash which are always reported for operational reasons).

**Table 4-1. Common weather phenomena reducing visibility**

| *Weather phenomenon* | *Typical MOR values (m)* | *Absorbing* | *Wavelength dependent* |
|---|---|---|---|
| Sandstorm | | Yes | Possible |
| Duststorm | | Yes | Possible |
| Smoke | | Possible | Possible |
| Haze | 1 000 - 5 000 | Possible | Yes |
| Mist | 1 000 - 5 000 | No | No |
| Fog | 30 - 1 000 | No | No |
| Drizzle | > 1 000 | No | No |
| Rain | > 1 000 | No | No |
| Snow | > 300 | No | No |
| Blowing snow | > 50 | No | No |

a) *fog onset phase*

This is the time from the first signs of fog until it has become continuous over a relatively large area. In the case of advection fog blown onto and across the aerodrome, this phase may last only a few minutes. At the other extreme, radiation fog may take up to several hours to complete this phase, but it can also form very quickly. Radiation fog may first appear as very shallow but dense patches of ground fog. Later, large isolated patches may form and drift slowly along in very light wind. At night, the existence of such patches is not evident until one of them encounters an instrument and results in a low value of RVR. Alternatively, shallow ground fog may form, covering part or the whole of the aerodrome. As a result, during the fog onset period, especially in radiation fog, large local spatial and temporal variations in visibility may exist and the RVR reported from individual instruments may not be representative of the whole runway.

b) *main fog phase*

This applies to any type of fog which has formed as a continuous blanket over a relatively large area including part or all of the aerodrome, until it starts to decay or disperse. Such fog can be spatially uniform, with relatively small and slow changes in visibility. However, in other instances, changes in visibility of up to about 50 per cent can occur within the main body of the fog. Generally, the visibility conditions are fairly well represented by observations and instrumented measurements. Since changes are gradual, trends can be easily discerned.

c) *decay phase*

This covers the decay or dispersal period of the fog. Large changes in visibility within the fog can occur, but the variations can also remain small. Instrumented measurements are normally fairly representative except when radiation fog starts to lift off the ground to become low stratus.

## 4.4 PRECIPITATION

4.4.1 Precipitation is a hydrometeor consisting of water particles, liquid or solid, that fall from the atmosphere and reach the ground. Precipitation includes *drizzle, rain, snow, snow grains, ice crystals (diamond dust), ice pellets, hail, small hail and/or snow pellets.*

4.4.2 Precipitation can be characterized by its droplet size and physical state as follows:

a) *drizzle*

Fairly uniform precipitation composed exclusively of fine drops of water with diameters from 0.2 to 0.5 mm. The drops appear to float to the ground and are very close to each other. Drizzle usually falls from low stratus and stratocumulus clouds.

b) *rain*

Precipitation in the form of liquid water drops, varying in size from 0.5 to a maximum of 6 mm in diameter (generally, drops above 6-mm diameter will break up). Rain may be either continuous or occur as showers.

c) *snow*

Solid precipitation in the form of ice crystals. The crystals are usually branched to form six-pointed stars and interlocked to form snowflakes. Snow may be either continuous or occur as showers.

d) *snow grains*

Precipitation of very small white and opaque grains of ice similar to snow pellets but which are fairly flat or elongated and do not readily rebound or burst when falling on hard ground. Their diameter is generally less than 1 mm.

e) *ice crystals* (diamond dust)

Precipitation of unbranched ice crystals in the form of needles, columns or plates, often so tiny they seem suspended in the air. They fall from a clear sky.

f) *ice pellets*

Precipitation of transparent or translucent ice particles of small size (less than 5 mm diameter).

g) *hail*

Precipitation of ice particles (hailstones) with a diameter generally between 5 and 50 mm, hard and partly transparent, that fall separately or frozen together into irregular lumps. Hail falls from cumulonimbus clouds and occurs as showers.

# Chapter 5

# OBSERVING PRACTICES

## 5.1 SUMMARY OF OBSERVING TECHNIQUES

5.1.1 Two main observing techniques currently in use are described below. In this context, *observing* implies instrumented measurements or visual observations of physical parameters (e.g. transmittance, extinction coefficient, numbers of runway edge lights visible, etc.) on which an *assessment* of RVR can be based.

a) *Instrumented technique*

In the determination of RVR by instrumented means it is common practice to use a transmissometer (see Chapter 7) to measure the transmittance of the atmosphere or a forward-scatter meter[1] (see Chapter 8) to measure the atmospheric extinction coefficient. RVR is then calculated taking into account the measured quantity (i.e. transmittance or extinction coefficient), the characteristics of the lights and the expected detection sensitivity of the pilot's eye under the prevailing conditions of background luminance (see Chapter 6). There are other instrumented techniques, but at present only those based on transmissometers and forward-scatter meters are recommended for use in assessing RVR.

b) *Human observer technique*

An observer counts the number of runway lights or markers visible from an observing position near the runway. This number is converted to runway visual range, making due allowance for the differences in light intensity, background, etc., from the different viewing positions of the observer and the pilot. Sometimes, where it is difficult to count runway lights, observations are made on a special row of runway or other lights set up near the runway. (Reporting by human observer is considered in Chapter 10.)

5.1.2 In order to meet requirements for the rapid updating of information on changes in RVR, the trend has been towards automatic systems capable of giving digital read-outs of RVR, sometimes supplemented by printed or magnetic records.

5.1.3 Human observations are not practicable nor recommended for precision approach runways and, in particular, not for those with Categories II and III operations for the following reasons:

a) accuracy and consistency are poorer than those of instrumented RVR systems (5.7.2 refers);

b) multiple locations along the runway must be monitored simultaneously (5.5.4 refers);

c) updating frequency and averaging period as required cannot be adhered to (Section 11.5 refers); and

d) fluctuations of RVR, including tendencies, cannot be indicated (Section 11.6 refers).

## 5.2 OBSERVATIONS REQUIRED

5.2.1 The observing and reporting of RVR is covered by Section 4.7 of Annex 3 — *Meteorological Service for International Air Navigation.*

5.2.2 According to Annex 3, 4.7.3, RVR observations should be made on all runways intended for use during periods of reduced visibility and in particular on:

a) precision approach runways; and

b) runways used for take-off and having high-intensity edge lights and/or centre line lights.

*Note.— Precision approach runways are defined in Annex 14, Volume I, Chapter 1, under "Instrument runway".*

5.2.3 Where RVR observations are required, according to Annex 3, 4.7.5, they should be made and reported throughout any period when either the horizontal visibility or the RVR is observed to be less than 1 500 m.

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1. A reference to forward-scatter meters is proposed to be included in Amendment 72 to Annex 3.

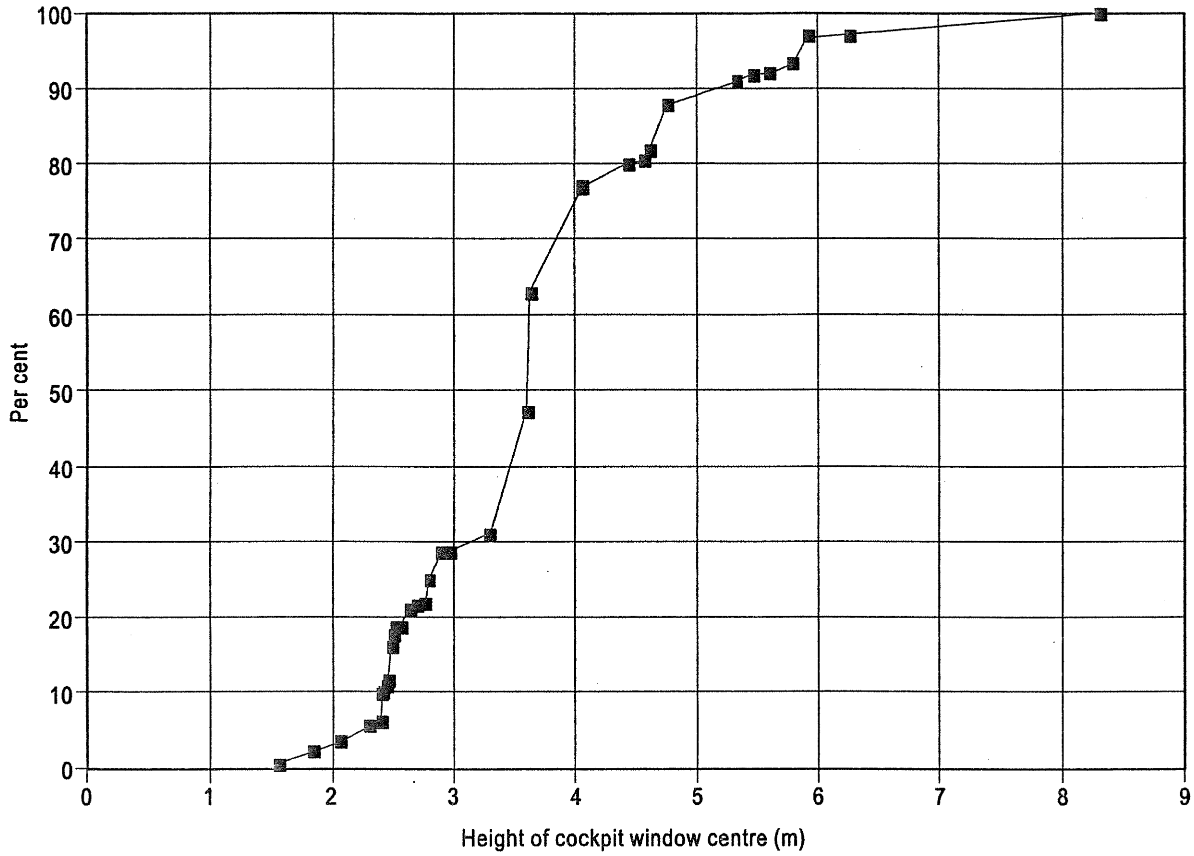


**Figure 5-1. Cumulative distribution of cockpit window heights for U.S. commercial aircraft (1994)**

5.4.5 However, if the reduction in visibility varies with distance from the ground, the effective RVR value *can* depend upon eye height. Consideration should also be given to the possible influence of vegetation, snow banks, etc., in that they may:

a) reduce fog density near the ground and thereby enhance the variation in RVR with eye height; and

b) shield the instrument and prevent a representative measurement.

In general, vegetation and snow banks in the vicinity of runways and RVR sensors should be kept well below the lowest pilot eye height and the height of the instrumented measurement.

## 5.5 POSITION ALONG THE RUNWAY

5.5.1 Since visibility is often not uniform (e.g. patchy fog), the ideal would be for the observations to cover the entire length of the runway. This is, however, impracticable as such coverage would require the installation of an excessive number of instruments. It is, therefore, usual to make the observations near the touchdown zone and at selected additional sites to provide satisfactory indications of conditions in the parts of the runway of primary interest, normally the mid-point and stop-end. This may, of course, sometimes lead to contradictory results particularly in the case of patchy fog where, for example, one instrument near the touchdown zone could give an RVR of 2 000 m, while a second instrument near the mid-point of the runway, some 1 500 m from the touchdown-zone instrument, could indicate an RVR of 500 m.

5.5.2 Annex 3, 4.7.2, calls for RVR observations to be representative of the touchdown zone and of the mid-point and stop-end of the runway. The site for observations to be representative of the touchdown zone should be located about 300 m along the runway from the threshold, while the site for observations to be representative of the stop-end should be located at a distance of about 300 m from the other end of the runway. The site for observations to be representative of the mid-point of the runway should be located at a distance of between 1 000 and 1 500 m along

Category III operations (see the *Aerodrome Design Manual*, Part 4 — *Visual Aids* (Doc 9157)). Finally, when landed (and with nose wheel lowered), the pilot sees the runway lights or markings from the cockpit height. A typical approach and runway lighting configuration at the inner 300 m for Categories II and III is presented in Figure 5-3.

5.8.2 It is highly desirable that the RVR assessments be based on the lights from which pilots derive their main guidance. Where there are both edge lights and centre line lights, it is normal to use edge lights when RVR assessment is above 550 m; with lower visual range, however, practices vary from State to State. The tendency is to use centre line lights for the lowest RVR values because of the:

a) inferior directional guidance provided by edge lights at short range; and

b) fact that edge lights become dimmer than centre line lights when viewed off axis.

The increasing importance of the guidance provided by the centre line lights as visibility decreases is readily seen if Figure 5-4 is obscured progressively from the top by a sheet of paper having its bottom edge parallel to the longer edges of the diagram. Some States use closer edge light spacing (30 m) than shown in Figure 5-4 and hence may have better guidance from edge lights at low RVR values. (See 6.5 for more detailed information.)

5.8.3 It should be noted that this transition from edge lights to centre line lights as RVR decreases is normally not relevant for human observers. Human observers are generally appropriate only for Category I runways which may not have centre line lights.

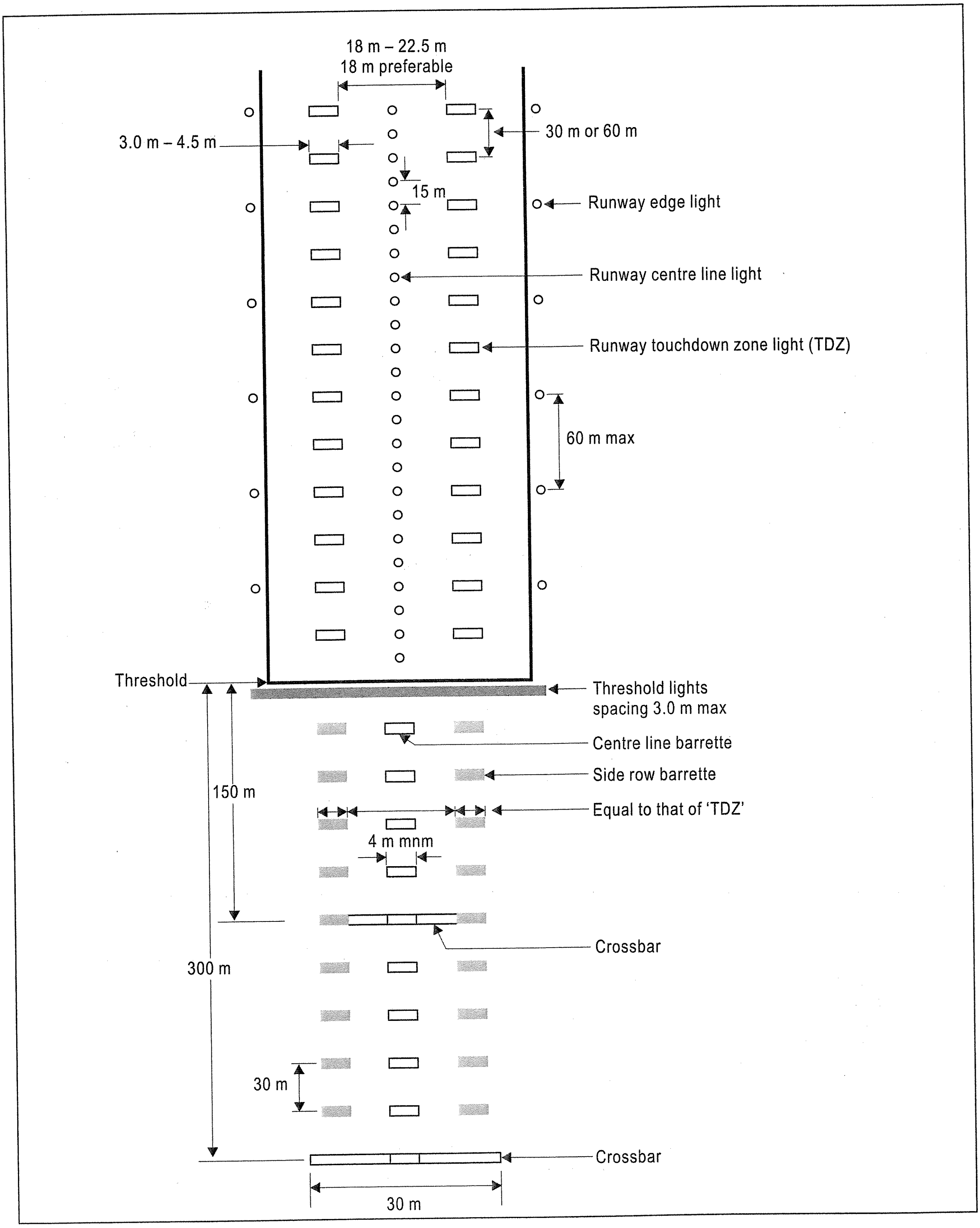


**Figure 5-3. Inner 300 m approach and runway lighting for precision approach runways Categories II and III**

# Chapter 6

# THE ASSESSMENT OF RUNWAY VISUAL RANGE

## 6.1 GENERAL

6.1.1 RVR, as defined in 2.1, is the range over which a pilot can see runway lights or runway surface markings. Assessment of RVR is by calculation, based on Koschmieder's law (in the case of objects or markings) or Allard's law (in the case of lights), taking into account the prevailing atmospheric conditions.

6.1.2 The theoretical aspects of the visual range of objects and runway markings are discussed in Appendix B and summarized in Section 6.3. The theoretical background of the visual range of lights together with the basic relationships between the variables on which RVR depends are considered in Appendix A and summarized in Section 6.4. The following sections present the practical calculation processes involved in the assessment of RVR based on objects and lights.

6.1.3 In assessing RVR no account is taken of the effect on the pilot's vision of such factors as:

a) the transmittance of the windscreen of the aircraft (this aspect is discussed in Appendix C);

b) rain on the windscreen;

c) the level of cockpit lighting;

d) the illumination to which the pilot has been exposed prior to take-off or landing such as apron floodlighting, very bright fog and flying over bright approach lights;

e) physical and psychological conditions, e.g. tiredness or stress;

f) directionality of background luminance (may be reduced by the use of multiple background luminance sensors); and

g) increase in background luminance from backscatter of aircraft landing lights (especially significant in snow).

6.1.4 Ideally, the reported RVR value should accurately represent what the pilot will experience on landing or take-off. This requirement is implied in the statement of desirable and attainable RVR accuracies specified in Attachment B to Annex 3, which indicates that both negative and positive RVR errors are equal. However, due to a desire to prevent non-conservative RVR values (i.e. those higher than actual), RVR systems are intentionally biased in a conservative direction. This results in an inherent under-reporting of RVR. Ways in which States bias their respective systems are listed below:

a) most round down the estimated value to the nearest lower step in the reporting scale, as recommended by Annex 3, 4.7.10;

b) all derate the runway light intensity to account for possible aging and contamination of lamps (see Section 6.4); and

c) at least one State applies a lag in the reported RVR value, dropping the reported value as soon as a lower value is indicated, but requiring an increase of 1.5 increments before increasing the reported value.

Care must be taken in applying multiple biases. If the RVR values are biased too far below the actual values, runway use may be unnecessarily curtailed under conditions where normal operations can be carried out without problem.

## 6.2 OPTICAL CLARITY OF THE ATMOSPHERE

6.2.1 In accordance with the definitions in Chapter 3, the optical clarity of the atmosphere can be expressed by means of various parameters: extinction coefficient ($\sigma$), meteorological optical range (MOR), transmittance ($t_b$) and transmissivity ($T$). All these parameters can be related to each other by the following equations:

$$\sigma = -\ln(t_b)/b = -\ln T \qquad (1)$$

$$\text{MOR} \approx 3/\sigma \qquad (2)$$

$$t_b = e^{-\sigma b} = T^b \qquad (3)$$

$$T = e^{-\sigma} \qquad (4)$$

**Table 6-1. Allard's law calculation of RVR for normal day on left and normal night on right, with the visual thresholds of illumination ($E_T$) of $10^{-4}$ and $10^{-6}$ lx, respectively**

| MOR (m) | 10 000 | 3 000 | 1 000 | 300 | 100 | 30 |
|---|---|---|---|---|---|---|
| σ ($m^{-1}$) | 0.0003 | 0.001 | 0.003 | 0.01 | 0.03 | 0.1 |
| *I* (cd) | | | *RVR (m) — day/night* | | | |
| 10 000 | 4 839/13 400 | 2 653/5 722 | 1 340/2 468 | 572/935 | 247/373 | 93/133 |
| 1 000 | 2 255/8 646 | 1 496/4 090 | 865/1 881 | 409/749 | 188/309 | 75/113 |
| 100 | 877/4 839 | 703/2 653 | 484/1 340 | 265/572 | 135/247 | 56/93 |
| 10 | 302/2 255 | 276/1 469 | 225/865 | 150/409 | 86/188 | 41/75 |

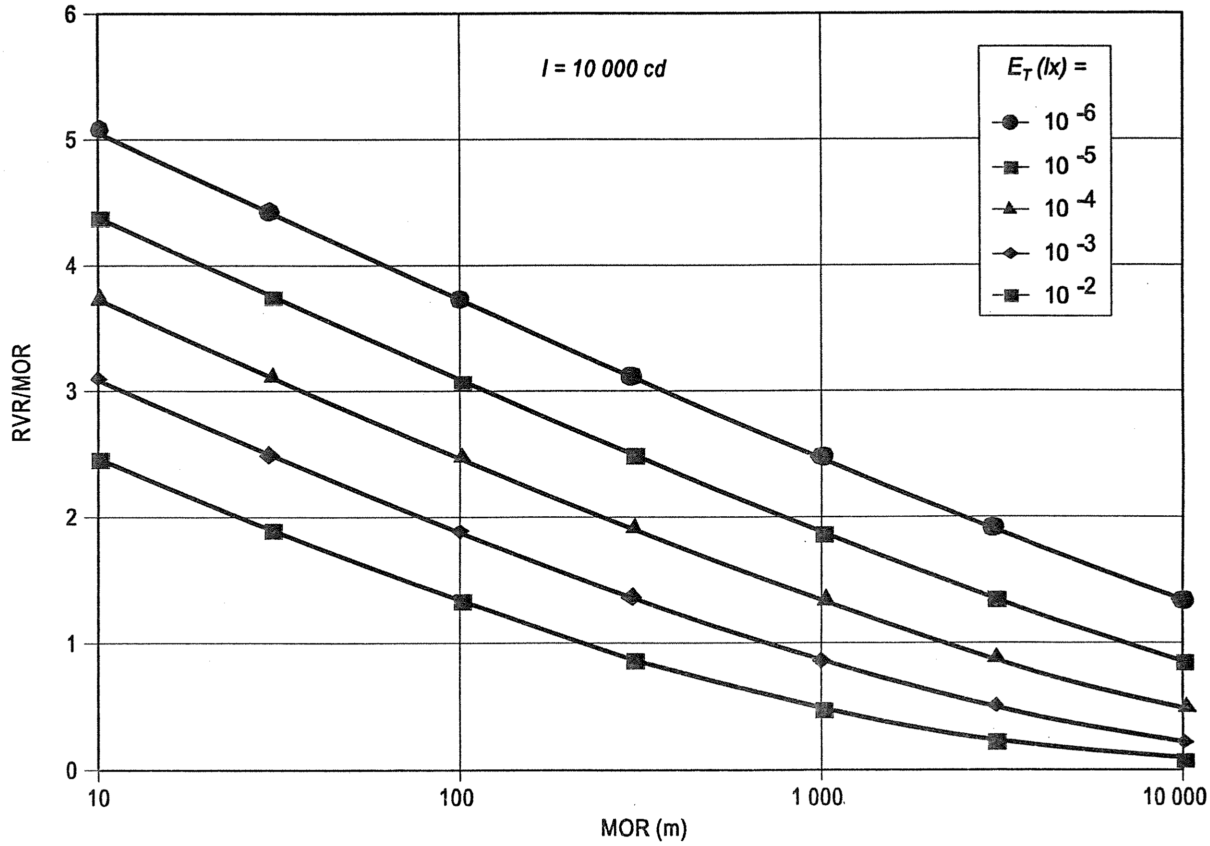


**Figure 6-1. RVR/MOR ratio from Allard's law**

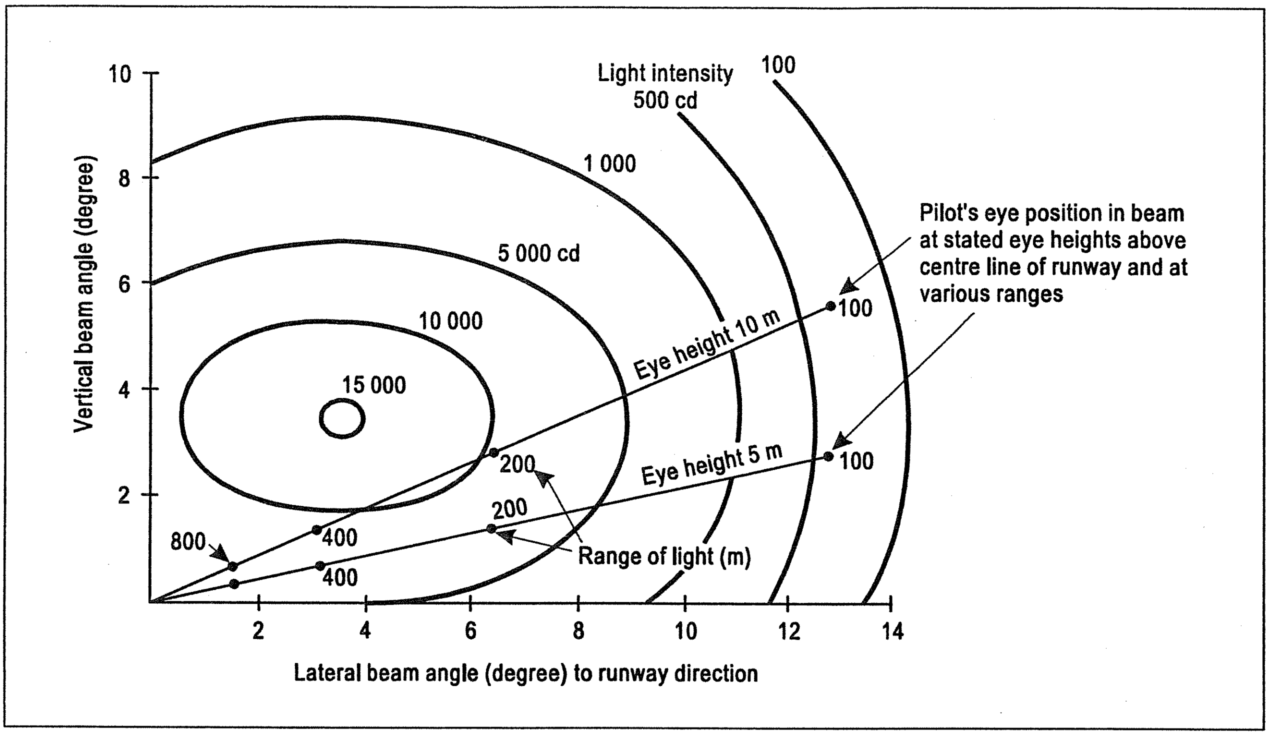


**Figure 6-2. Isocandela contours for runway edge light (new light at maximum intensity setting) showing the position of pilot's eyes in the beam at various ranges and heights above centre line of runway**

6.5.4 With regard to the lights and the light intensities that are actually used by States, practices vary considerably. Some States use only the intensities given by edge lights because their experience and requirements do not extend into Category II and particularly into Category III. Ideally, RVR assessment should be based on the light intensity directed at the pilot by the furthest visible runway edge or centre line light. However, the light selection should also consider the differing quality of the directional guidance provided by the edge and centre line lights (see Section 5.8). Furthermore, the guidance related to the commonly acceptable precision approach minima provided in the *Manual of All-Weather Operations* (Doc 9365) should be taken into account. This guidance indicates that commonly acceptable Category I landing minima for RVR vary from 550 to 1 200 m depending on the lighting system available, while for Categories II, IIIA and IIIB, the corresponding minima for RVR are 350, 300 and 100 m, respectively. Runway edge lights are required for all precision approach runways while a requirement for runway centre line lights is stated only for Categories II and III precision approach runways. The following selection of light intensities is therefore recommended:

a) For RVR values up to 200 m, the assessment should be based on the intensities of the centre line lights.

b) For RVR values between about 200 and 550 m, i.e. the transition zone where the guidance for the pilot changes from the centre line lights to edge lights, the assessment should be based on light intensities that can be computed by means of a linear transition from the intensity corresponding to RVR = 200 m (point A in Figure 6-7) to the intensity corresponding to RVR = 550 m (point B in Figure 6-7). Alternatively, for the transition zone it is possible to use a linear relation between RVR and MOR. This method is illustrated in Table 6-2.

c) For RVR values above 550 m, the assessment should be based on the intensities of the edge lights.

d) The light intensity used for this purpose should be the intensity directed at the pilot's position 5 m above the centre line of the runway by the furthest visible runway edge or centre line light.

vision at the red end of the spectrum and also to the tolerances on the runway lamps. Guidance on light intensity settings is given in the *Aerodrome Design Manual*, Part 4 — *Visual Aids* (Doc 9157).

6.5.7 For a runway where the lights are switched on, Annex 3, 4.7.8, requires that computation of RVR should be based on the light intensity actually in use on that runway. For a runway with the lights switched off (or at the lowest setting pending resumption of operations), the computation of RVR should be based on the optimum light intensity that would be appropriate for operational use in the prevailing conditions. This cannot be done in a straightforward manner by fully automated systems if the intensity settings transmitted to the computer are linked with the air traffic control panel or a light current monitor. In addition, if the airfield lighting is not in operation at the required intensity setting, the background luminance monitor may give a value that is different from that with lights switched on. However, a value of RVR can be computed separately from Allard's law using the transmittance or extinction coefficient reading and assumed values of the other variables. The above provisions apply also to RVR values included in reports in the METAR/SPECI code forms; that is, they should be based on the same light intensity settings as those appropriate for use during take-off and landing at the time the report is made; however, any temporary changes in the light intensity settings should be discarded in these reports.

6.5.8 Light intensity setting procedures are selected by individual States. It should be noted, however, that although an automated RVR system may indicate the highest visibility value for maximum light intensity settings, pilots may not experience a corresponding increase when light settings are increased to maximum. This condition can result when scattered light from runway illumination raises the background luminance and thus diminishes the benefit of the increased intensity of the runway lights. Higher light settings may also result in "dazzling" of the pilot, i.e. the glare that can be produced by the highest light settings may actually hamper the pilot's vision.

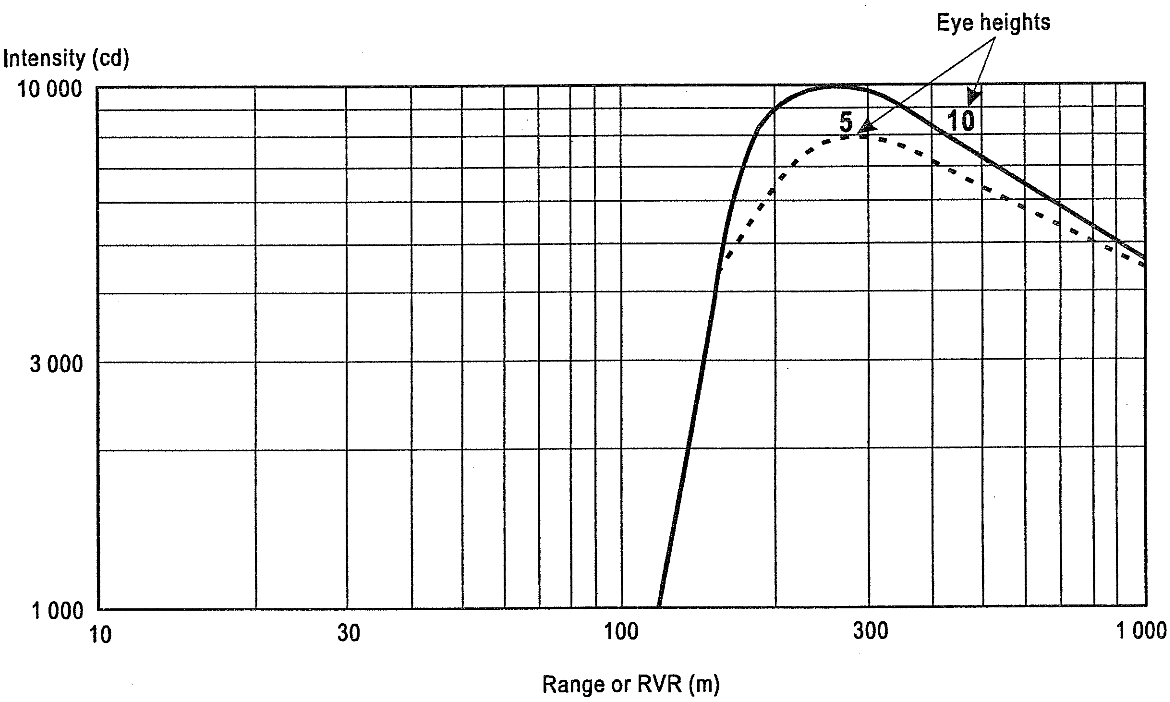


**Figure 6-4. Runway edge light intensity viewed by pilot on centre line (for new light at maximum intensity setting)**

**Table 6-2. The use of the intensities of runway edge and centre line lights in the RVR assessment where both edge and centre line lights are available**

| | |
|---|---|
| 1. edge lights | ▶ Calculate RVR using the intensity of runway edge lights (greater than those of the centre line lights). If you obtain RVR > 550 m, then that is the final RVR value and no further action is needed; if RVR ≤ 550 m, go to 2). |
| 2. centre line lights | ▶ Calculate RVR using the intensity of runway centre line lights. If you obtain RVR < 200 m, then that is the final RVR value and no further action is needed; if RVR ≥200 m (it is also ≤ 550 m as it is computed with lower intensity), go to 3) |
| 3. transition zone | *Note.— RVR is a function of: a) background luminance (L), b) luminous intensity (I) and c) optical clarity of the atmosphere. This optical clarity of the atmosphere may be represented by transmissivity (T), the extinction coefficient (σ) or visual range by day (MOR). Choose MOR, which is the most natural choice, as it has the most linear relationship with RVR in the transition zone.*<br><br>▶ Calculate $MOR_{550}$ corresponding to RVR = 550 m using the actual background luminance and the intensity of edge lights (Point B in Figure 6-7);<br><br>▶ Calculate $MOR_{200}$ corresponding to RVR = 200 m using the actual background luminance and the intensity of centre line lights (Point A in Figure 6-7);<br><br>▶ Let $MOR_t$ be the measured MOR (which may be directly computed from the sensor output). Note that $MOR_t < MOR_{550}$ and $MOR_t > MOR_{200}$;<br><br>▶ Compute α such as $MOR_t = \alpha \bullet MOR_{550} + (1 - \alpha) \bullet MOR_{200}$.<br>Then the final value of $RVR = \alpha \bullet 550 + (1 - \alpha) \bullet 200$. |

**Table 6-3. The use of the intensity of runway edge lights where no centre line lights are available**

| | |
|---|---|
| RVR > 550 m | ▶ Use the intensity of runway edge lights. |
| 200 m ≤ RVR ≤ 550 m | *Note.— the full intensity of runway edge lights cannot be used (if that were done, the RVR value would be greater than the corresponding RVR value for a runway equipped with centre line lights).*<br><br>▶ Assume that the effective intensity of runway edge lights corresponding to RVR = 200 m is reduced to a fraction (e.g. by a factor of two from the intensity of Point C to the intensity of Point D in Figure 6-7);<br><br>▶ Calculate $MOR_{200}$ corresponding to RVR = 200 m with the actual background luminance and the reduced intensity of edge lights;<br><br>▶ Apply the same process as for the transition between edge lights and centre line lights in Table 6-2. |
| RVR < 200 m | ▶ Report RVR as less than 200 m. |

**Table 6-4. Illumination threshold steps**

| *Condition* | *Illumination threshold (lx)* | *Background luminance (cd/m²)* |
|---|---|---|
| Night | 8 x $10^{-7}$ | ≤ 50 |
| Intermediate | $10^{-5}$ | 51 - 999 |
| Normal day | $10^{-4}$ | 1 000-12 000 |
| Bright day (sunlit fog) | $10^{-3}$ | > 12 000 |

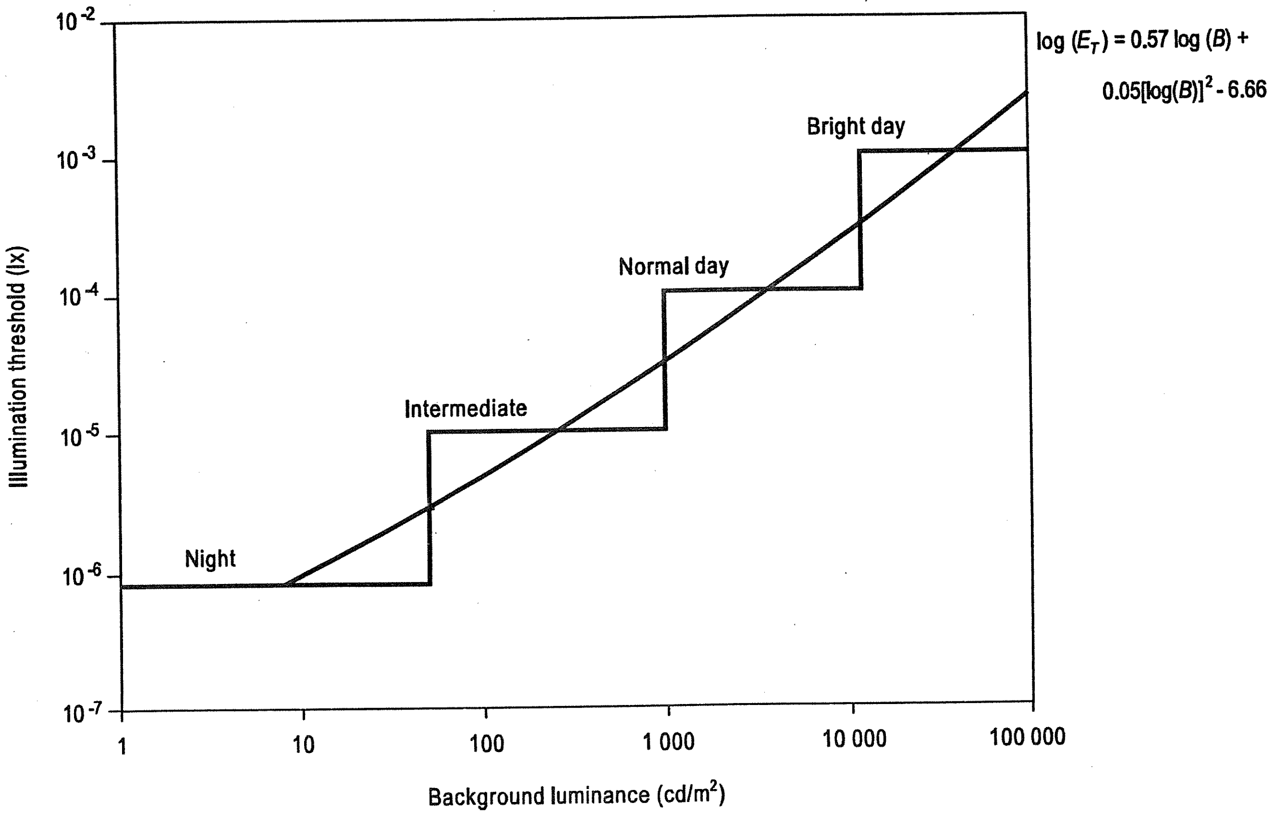


**Figure 6-8. Relationship between the illumination threshold $E_T$ (lx) and background luminance $B$ (cd/m$^2$)**

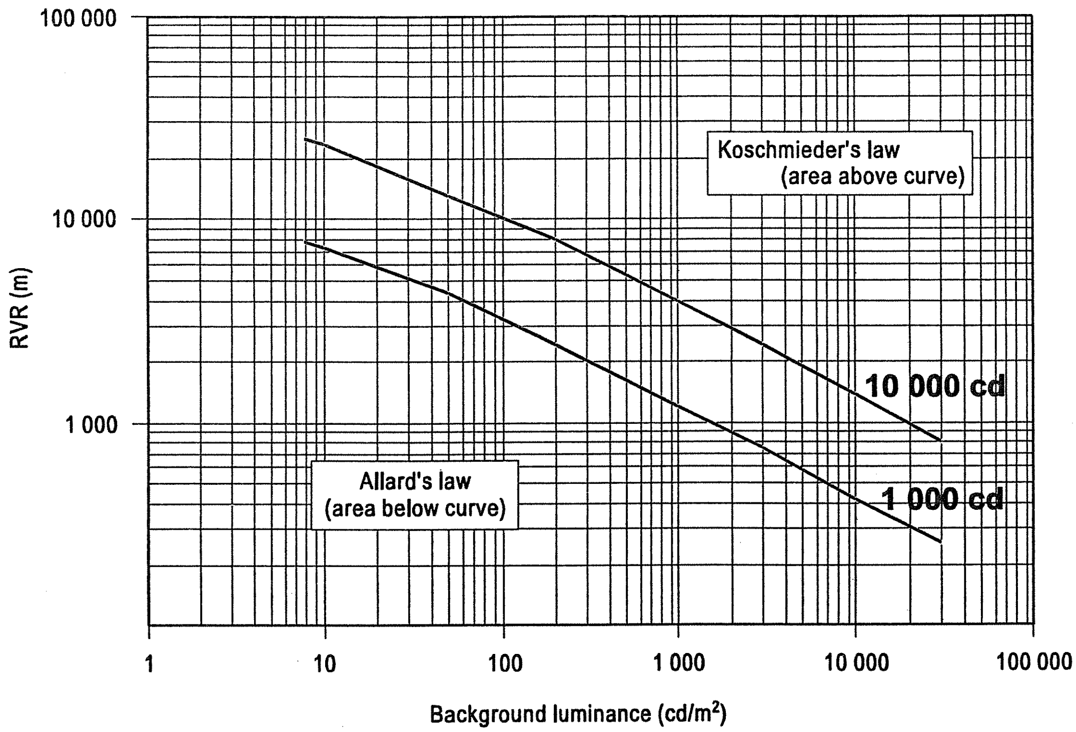


**Figure 6-9. Breakpoint between Koschmieder's law and Allard's law for light intensities of 1 000 and 10 000 cd**

6.7.3 The reported RVR value is intended to represent how far a pilot can see down a runway. Errors in these values are generated by a number of factors, such as:

For both Koschmieder's and Allard's laws:

a) variations in the pilot's eyesight;

b) variations in aircraft cockpits;

c) spatial variations in the weather phenomenon between the pilot's view and the location where the extinction coefficient is measured;

d) measurement errors in the sensor measuring the extinction coefficient ($\sigma$) or transmissivity ($T$);

For Koschmieder's Law:

e) non-ideal visibility targets;

For Allard's Law:

f) angular and temporal variations in light intensity;

g) differences between the actual and assumed runway light intensity ($I$);

h) differences in background luminance between the pilot's view and the direction where the background luminance is measured;

i) errors in measuring background luminance ($B$); and

j) errors in relating illumination threshold to background luminance.

Of all these errors, only d), g) and i) pertain directly to the performance of an automated RVR system. In general, the design goal for an RVR system is to ensure that the measurement errors are smaller than the other sources of error. Note that some of the other error sources can also be controlled. For example, variations in runway light intensity could be reduced by setting close tolerances on lamp current and by careful maintenance of runway lights. Directional differences in background luminance can be avoided by using multiple background luminance sensors.

6.7.4 The accuracy of extinction coefficient measurements is considered in the following locations:

b) The RVR error for a factor of four reduction in light intensity is about twice that for a factor of two reduction.

c) The fractional RVR error is somewhat larger for higher values of RVR.

d) The RVR errors are only slightly higher for 1 000 cd lights than for 10 000 cd lights. However, since the Koschmieder region is reached more quickly with increasing *B* for 1 000 than for 10 000 cd lights, the maximum errors are similar for both light intensities (less than 13 per cent for a factor of two loss in intensity and 23 per cent for a factor of four loss in intensity).

6.7.9 Background luminance errors from instrumented measurements are generally much less than a factor of two, with two possible exceptions:

a) When the windows of the background luminance meter are clogged with snow, errors of more than a factor of four are possible.

b) When a small number of illumination threshold steps are used for specified ranges of background luminance values in lieu of the continuous curve (see Table 6-4 and the stepped relationship in Figure 6-8), the illumination threshold values agree with the continuous curve in the middle of each background luminance range but will disagree by a factor of about three at the edge of each range. Table 6-6 presents a detailed analysis of these errors on either side of the steps in illumination threshold. In the worst case, the RVR error can be greater than 20 per cent; because of these errors, caution should be exercised when using the stepped relationship (paragraph 6.6.6).

The directional variation in background luminance is normally not a factor under reduced visibility conditions. However, large variations can occur for a thin fog layer with no upper level clouds and the sun at a low elevation angle.

6.7.10 The RVR errors generated by errors in background luminance are similar to those produced by errors in light intensity (see 6.7.8). For the same fractional error, background luminance errors are slightly smaller because the log-log slopes of the illumination threshold versus background luminance curves are less than one (see Figure 6-8). Figures 6-17 and 6-18 show how background luminance reductions by factors of four and two increase RVR for light intensities of 10 000 and 1 000 cd, respectively. Reductions in measured background luminance (*B*) below the true value result in reporting an RVR value greater than the actual value. A reduction in measured *B* could result, for example, from snow clogging of the window of the background luminance meter. The figures show the following effects:

a) In all cases, the RVR error increases as the background luminance (*B*) increases; the amount of increase is about a factor of three. This variation is larger than observed for runway light intensity errors because the log-log slope in Figure 6-8 increases for larger values of *B*. In some cases, however, the highest background luminance values are in the region (see Figure 6-9) where the RVR is determined by Koschmieder's law; in this case, the reduction in background luminance has no effect on the RVR value.

**Table 6-6. Maximum RVR percentage errors from using stepped relationship between illumination threshold and background luminance**

| *Log true illumination threshold* | *Log stepped illumination threshold* | *Extinction coefficient (1/km)* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *2* | *4* | *8* | *16* | *32* | *64* | *128* |
| –3.50 | –3.00 | 0 | –18 | –17 | –15 | –13 | –12 | –11 |
| | –4.00 | 16 | 21 | 18 | 15 | 14 | 12 | 11 |
| –4.50 | –4.00 | –18 | –16 | –14 | –12 | –11 | –10 | –9 |
| | –5.00 | 19 | 16 | 14 | 13 | 11 | 10 | 9 |
| –5.55 | –5.00 | –15 | –14 | –12 | –11 | –10 | –9 | –8 |
| | –6.10 | 16 | 14 | 13 | 11 | 10 | 9 | 9 |

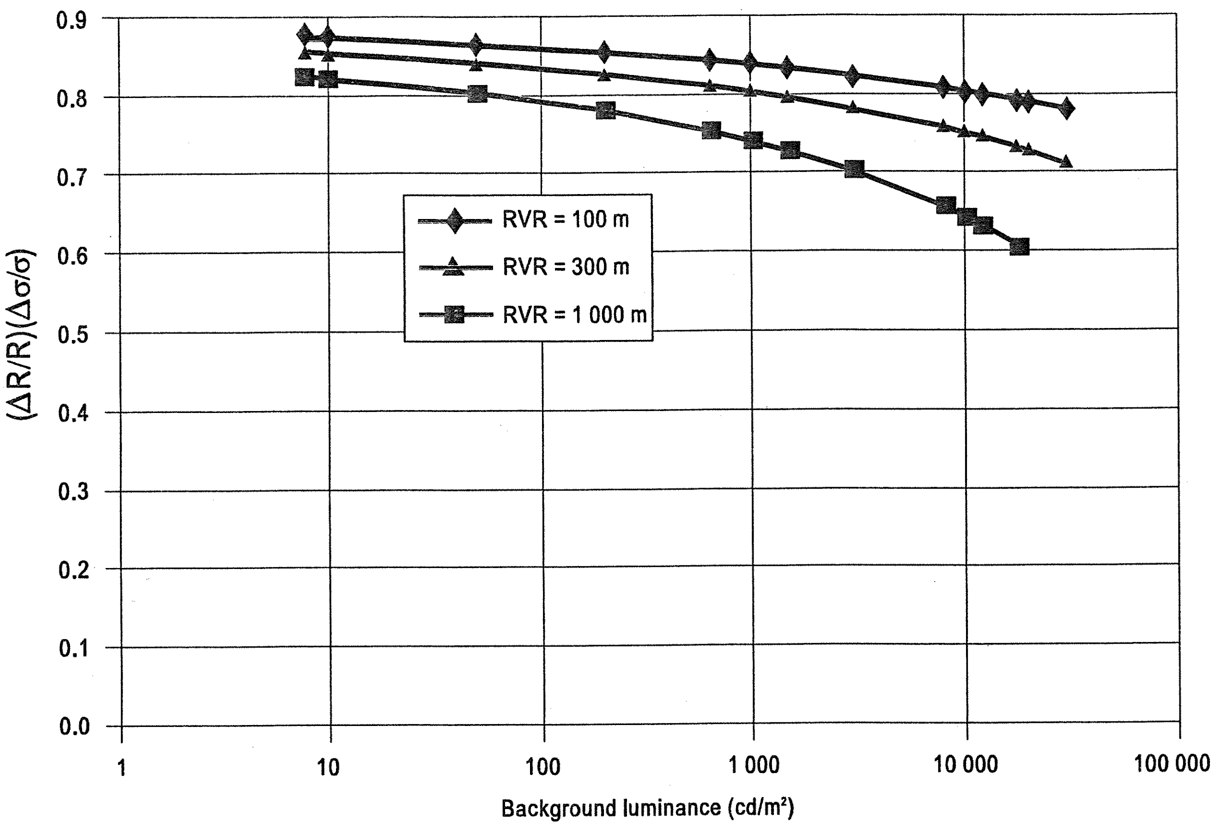


**Figure 6-10. Ratio of fractional RVR errors (ΔR/R) to fractional extinction coefficient errors (Δσ/σ) for Allard's law for runway light intensity of 10 000 cd**

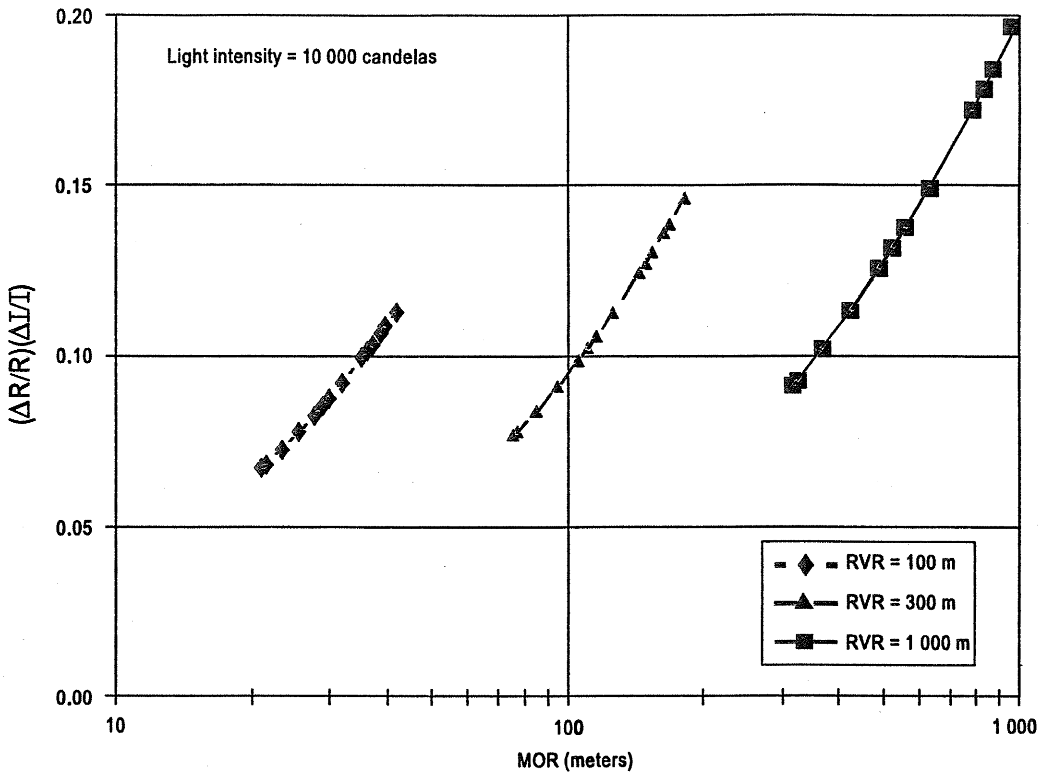


**Figure 6-13. Ratio of fractional RVR error (ΔR/R) to fractional extinction coefficient error (ΔI/I) for light intensity of 10 000 cd**

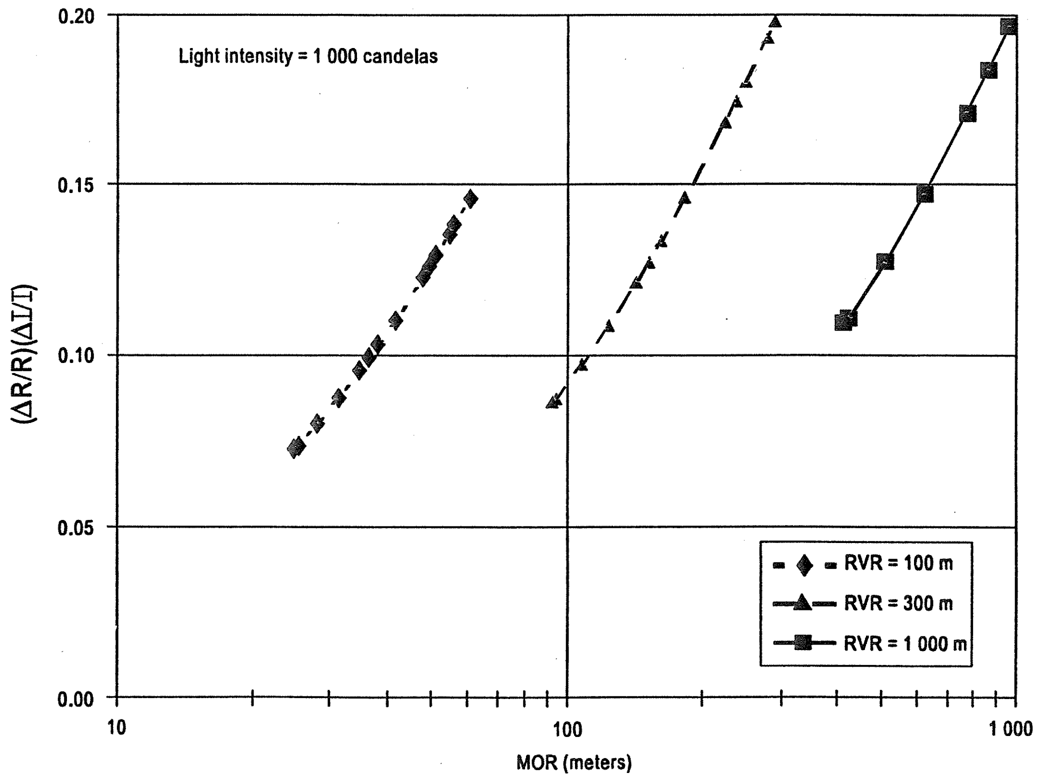


**Figure 6-14. Ratio of fractional RVR error (ΔR/R) to fractional light intensity error (ΔI/I) for light intensity of 1 000 cd**

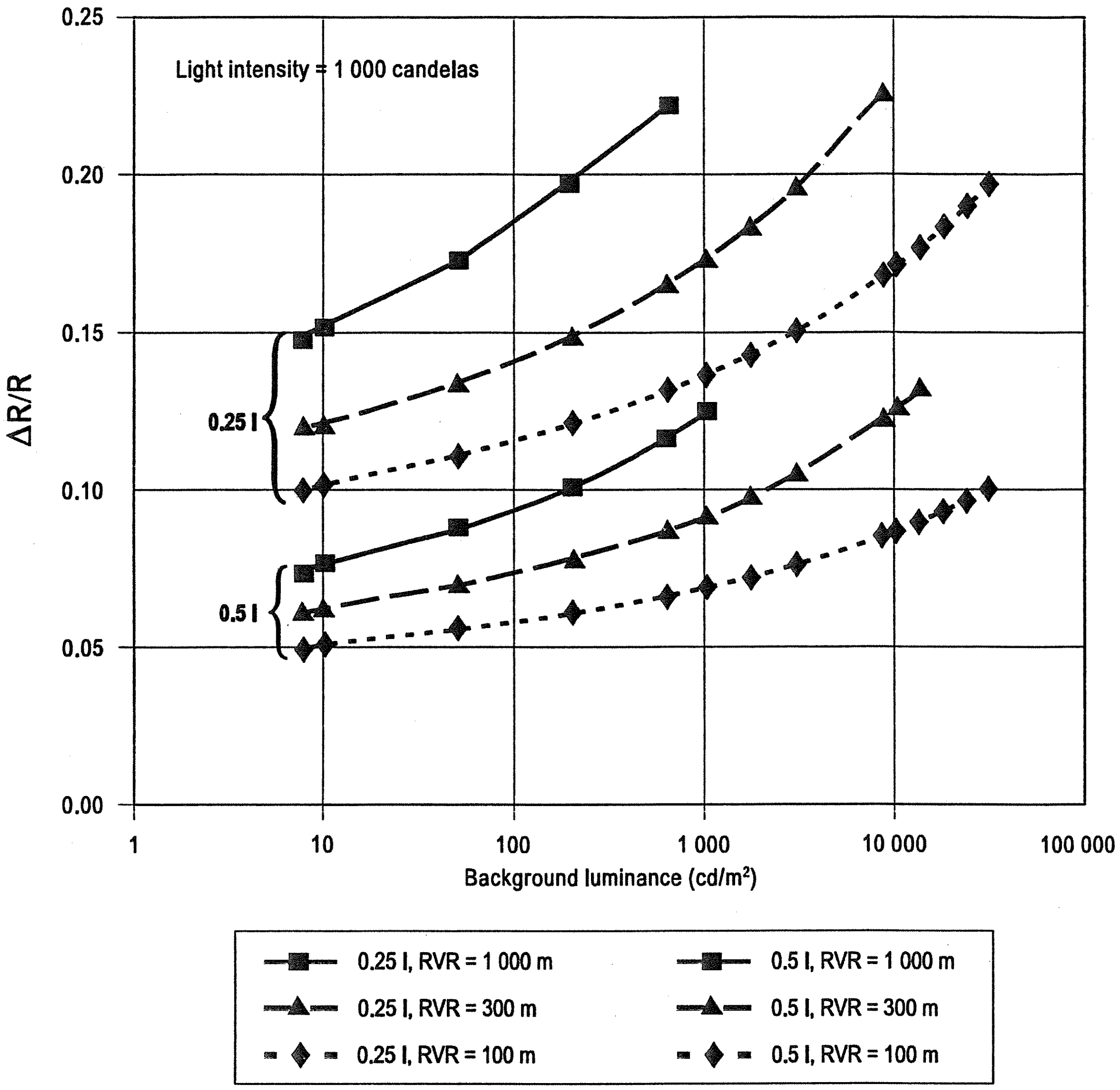


**Figure 6-16. Fractional reduction in RVR (ΔR/R) for reductions in runway light intensity by factors of four (0.25 *I*) and two (0.5 *I*) from assumed intensity of 1 000 cd**

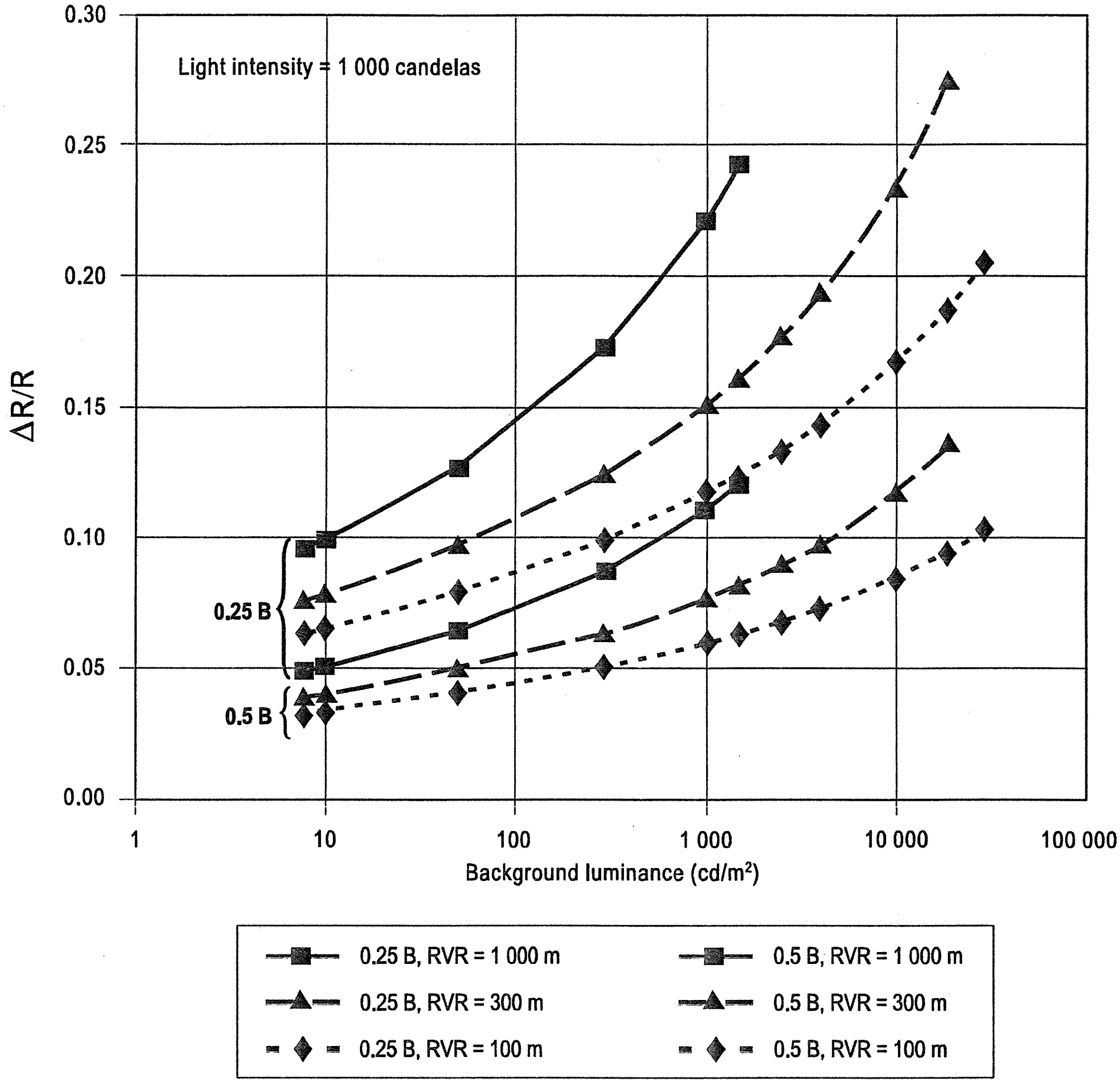


**Figure 6-18. Fractional increase in RVR (ΔR/R) for reductions in measured background luminance by factors of four (0.25 *B*) and two (0.5 *B*) from runway light intensity of 1 000 cd**

consequently, the working length (baseline) of the light beam is twice the distance between the emerging beam and the unit housing the reflector. This is known as a "reflecting", "folded-baseline" or "single-ended" transmissometer. The reflected beam is separated in the transmitter/receiver from the transmitted beam (e.g. by means of a beam splitter as shown schematically in Figure 7-1 b)). Some transmissometer systems allow dual baseline operation, i.e. they are equipped with one transmitter and two receiver units.

7.1.3 When considering the choice of a transmissometer for an RVR system, it is first necessary to decide the range of RVR to be assessed as this determines the optimum baseline lengths of the transmissometer. For example, consider the full RVR range from 50 to 1 500 m. The extreme MOR measurements occur for viewing lights (Allard's law) at night for RVR = 50 m and for viewing objects (Koschmieder's law) in the daytime at RVR = 1 500 m. If one assumes a runway light intensity of 10 000 cd and a night $E_T$ value of $10^{-6}$ lx, then, according to Allard's law, RVR = 50 m will occur for MOR = 9.87 m. According to Koschmieder's law, RVR is equal to MOR. Consequently, a full RVR range transmissometer must measure MOR from 9.87 m to 1 500 m. The factors that must be considered regarding baseline lengths are described below:

a) The transmissometer has a non-linear relationship between transmittance and RVR. The shorter the length of the baseline, the higher the accuracy required in transmittance measurement for any required accuracy in RVR. For very short baselines, only the top few percentages of the transmittance range are used in assessing RVR and, as a consequence, the requirements for linearity and accuracy become very stringent.

b) As the length of the transmissometer baseline is increased, the lowest value of RVR that can be assessed increases. In general, transmissometers cannot be used for the assessment of RVR values less than the transmissometer baseline length, since the transmittance falls to a very low value as the RVR approaches the length of the baseline.

c) For any given range of RVR values, the dynamic range over which the transmissometer must operate increases as the baseline length is increased. Increased dynamic range can be achieved by increasing transmitter light intensity and/or receiver sensitivity or by using dual baseline systems.

7.1.4 Transmissometer noise threshold has an important influence on choice of baseline length. All transmissometers generate electrical noise and this limits the minimum transmittance that can be measured. This noise is primarily generated by electrical components and caused by stray light within the transmissometer. Some existing systems try to overcome this by measuring the noise output and subtracting it in the computation of RVR. Since noise level is not constant, this practice can cause errors unless frequent noise calibration is conducted. The minimum transmittance can be related to maximum baseline length, and this is considered in Appendix D.

7.1.5 Since covering the entire RVR range (MOR from 10 to 1 500 m) requires high resolution and stability, many States use two instruments or a dual baseline instrument to cover RVR from 50 to 1 500 m. The requirements for a single, full RVR-range transmissometer can be expressed by the required resolution of the A/D converter used to measure the transmitted light signal. High resolution is required at the high RVR end to resolve small changes in transmittance and at the low RVR end to detect the small fraction of the light received relative to that received for 100 per cent transmittance. Figure 7-2 shows how these two requirements depend upon the selected transmissometer baseline, assuming that an RVR accuracy of 10 per cent corresponds to one bit resolution. The optimum baseline is about 17 metres and the A/D converter must have at least 8 bits of resolution. A practical instrument would have higher resolution (e.g. 10 bits or better) so that A/D converter resolution is not the dominant error source for most systems in operational use.

7.1.6 A transmissometer has only a few inherent sources of error:

a) Since the RVR value is intended to estimate human vision, errors may result when the instrument wavelength response is different from that of human vision. Significant errors would occur only for weather phenomena having significant variation in MOR with wavelength (e.g. haze, see Table 4-1).

b) The instrument determines the transmissivity by assuming that the receiver signal represents the initial light intensity minus the light absorbed or scattered out of the beam. This assumption is not valid when light is also scattered into the receiver by forward scattering from the weather phenomena. This source of error can be reduced to insignificance if the transmitter beam and the receiver field of view are made sufficiently narrow (see 7.2.3).

## 7.2 INSTRUMENT CHARACTERISTICS

7.2.1 Numerous types of transmissometers are available commercially. Various light sources are used, including tungsten filament lamp, xenon pulse discharge tube, modulated tungsten halogen lamp, and amplitude modulated light emitting diode (LED).

7.2.2 In some transmissometers, there is little light spillage and the beam may be low intensity; in others, a high intensity beam may be used which is also wide and, as a consequence, may be visible externally. In this case, the baseline may have to be angled away from the direction of the runway so that the light is not troublesome to pilots.

7.2.3 To avoid forward-scatter errors, the transmitter and receiver should have narrow beams coaxially aligned. The use of narrow beam angles and the resulting need for fine optical alignment makes it necessary for the units to be mechanically rigid and mounted on firm foundations, since small changes in alignment can cause large changes in receiver output. Changes due to misalignment can be wrongly interpreted as being variations in the atmospheric conditions. Sometimes, the receiver field of view is made just large enough to see the complete transmitter. In some cases, the beam width and alignment requirements make it impractical to achieve dual baseline capabilities (one long, the other short) using a single transmitter with two separate receivers. First, the transmitter cannot be pointed at both receivers simultaneously. Second, although the transmitter diameter may be narrow enough to eliminate forward-scatter errors for the long baseline, the receiver for the short baseline will have to operate with a much wider field of view to see the entire transmitter and will therefore collect more forward-scattered light. However, these problems can be overcome if two separate beams are produced by the transmitter.

7.2.4 A factor that must be taken into consideration when working with transmissometers is the contamination of optical surfaces. This effect may be minimized by hoods and by blown air. However, it is important to ensure that hoods and air flow systems do not interfere with the measurement path (see 7.1.6 c)). In systems where the contamination rate can be accurately determined, compensation for contamination could be applied .

7.2.5 The high overall accuracy required of transmissometers demands a light source of constant intensity or monitoring the light intensity and correcting the measurement for any intensity variations. In addition, the transmissometer, as a system, should have means of calibration and should provide automatic adjustments for long- and short-term drifts.

7.2.6 The advantages and disadvantages of the transmissometer are summarized here. Some advantages are:

a) The instrument is self-calibrating. On a clear day, the calibration can be validated independently for every instrument.

b) Absorption effects are correctly measured.

c) The accuracy of the measurement does not depend upon the weather phenomena reducing the visibility.

Some disadvantages are:

a) To preserve alignment, the instrument must be firmly attached to the ground. Making the instrument frangible can be a challenge, particularly if the measurement height is well above the ground. Preserving alignment in locations with unstable ground (e.g. tundra, frost heaves) can be difficult.

b) Covering the complete RVR range from 50 to 1 500 m with a single instrument is technically difficult.

c) Transmissometer measurements are particularly sensitive to errors caused by window contamination, especially in the upper range of transmissivity.

d) A transmissometer should not be recalibrated under low visibility conditions.

## 7.3 TRANSMISSOMETER CALIBRATION

7.3.1 The transmissometer has a range of transmittance from 0 to 1, the 0 (zero) value corresponding to zero visibility and the full-scale 1 (unity) value corresponding to infinite visibility. There are various ways of establishing these end points, and while a comprehensive description is outside the scope of this manual, the following gives a brief outline of the main methods used. The linearity of the transmissometers may be initially established by means of calibration against reference filters.

7.3.2 Basically, the zero point is determined by obscuring the light input to the receiver. The full-scale calibration is carried out by direct comparison with the distance at which specified objects and lights of known intensity can be seen by an observer. Calibration should be carried out only in high visibility conditions, preferably at visibilities greater than 10 km and in no case lower than 5 km. The observation should be as close as possible to MOR, as it

RVR. This is explained in Section 6.7 and Appendix E. By way of illustration, the variation of the fractional error $\Delta V/V$ with $V$ is shown in Figure 7-4 a) and the corresponding variation of $\Delta R/R$ with RVR is given in Figure 7-4 b). The curves illustrate the features mentioned in 7.4.2 and 7.4.3, in particular, the effect signal offset error has in limiting the minimum working range of the transmissometer.

7.4.6 Transmissometer errors and the minimum resolution of transmittance due to the noise threshold (as explained in 7.1.4) are important factors in the choice and maintenance of a transmissometer system. It is essential that this topic be fully assessed and taken into account in the selection, setting up, calibration and maintenance of the intended system.

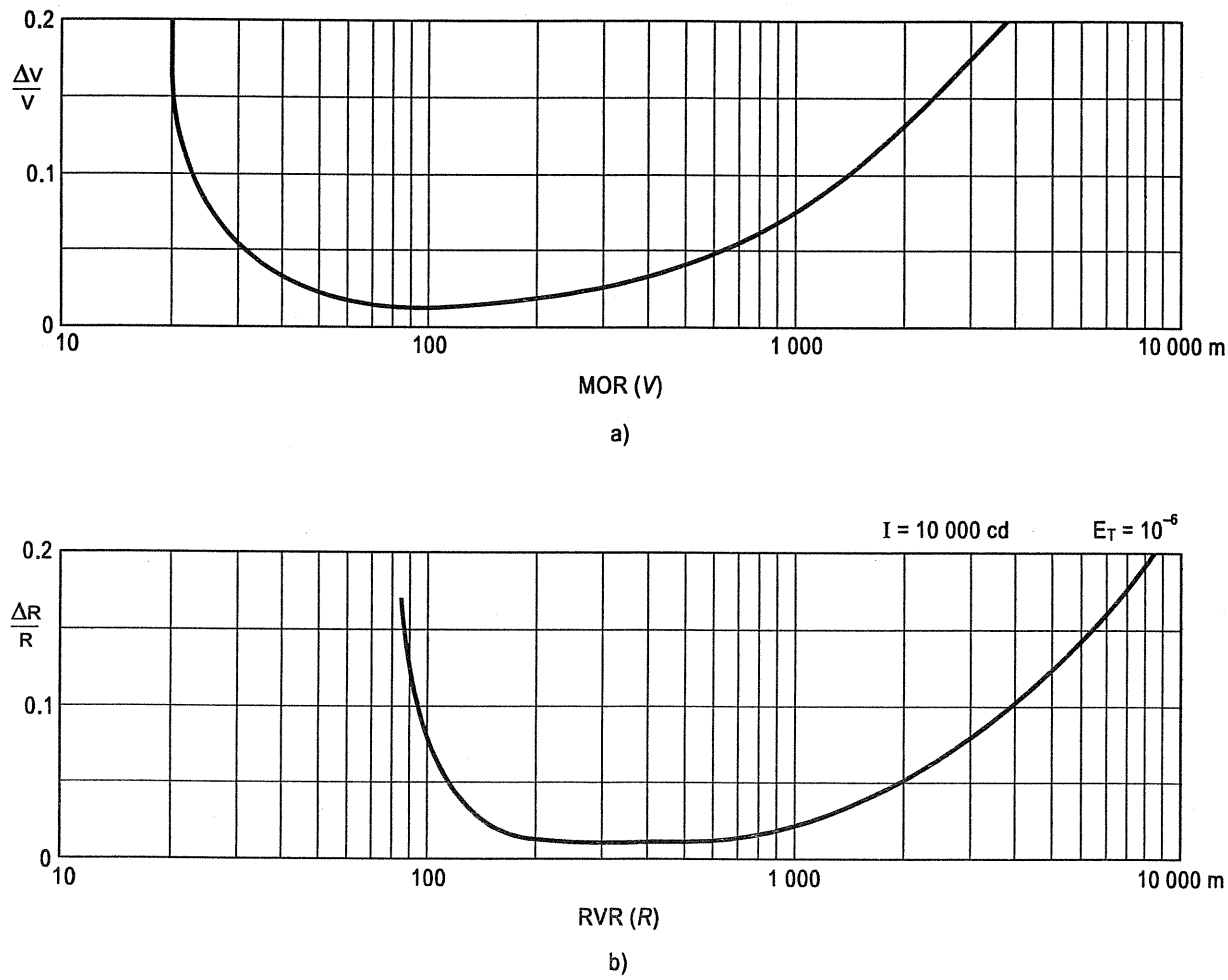


**Figure 7-4. Typical errors in computed MOR and RVR due to the effect of the calibration errors illustrated in Figure 7-3**

b) *Snow.* Snow has a much more slowly varying scatter function than fog; light scatters more uniformly at all angles. At an angle of approximately 40 degrees, fog and snow have the same ratio of scattering to extinction coefficient; therefore, this angle is useful for a forward-scatter meter that cannot determine the phenomenon reducing the visibility. In contrast, back-scatter instruments have an abnormally high response to snow.

c) *Rain.* Rain has an even narrower forward-scatter peak than fog. The peak is so narrow that it may not significantly affect human vision and may not be detected by a transmissometer. Consequently, a forward-scatter meter may underestimate the RVR by rain up to a factor of two relative to a transmissometer. Since rain that is not mixed with fog is rarely heavy enough to reduce the RVR substantially, this issue has not received much attention in the design of forward-scatter meters. If a forward-scatter meter can identify rain as the only phenomenon reducing the visibility, it can correct for the corresponding RVR underestimate. Such a correction could, however, lead to reported RVR higher than actual if any fog that is mixed with the rain is not detected and accounted for.

d) *Small aerosol particles* (haze or smoke). The scatter function for particles with diameter less than the wavelength of light varies significantly with wavelength, but varies much less with angle than that for larger particles. The difference results in greater scattering relative to the extinction coefficient at the angles used for forward-scatter meters. Some of this difference may be compensated for by the absorption that may be produced by such phenomena. Thus, the proportionality between scattered light and extinction coefficient will be different from that of fog and will depend upon the wavelength selected for the measurement. The wavelength and scatter function effects result in approximately equal haze and fog forward-scatter meter calibrations for human vision (centred in the green) if red light is used for the instrument.

e) *Absorbing particles* (smoke, sand and dust). Since a forward-scatter meter cannot measure absorption, the forward-scatter meter measurement may overestimate the RVR for absorbing particles. If the particles can be identified and the forward-scatter meter response has been quantified for the phenomena, then the RVR value can be corrected.

8.1.4 Because the forward-scatter meter signal depends upon the particle density and type and the instrument geometry in a complex manner, forward-scatter meter calibration is determined empirically by comparing the sensor output to the measurement of a reference transmissometer under appropriate weather conditions.

## 8.2 INSTRUMENT CHARACTERISTICS

8.2.1 A typical forward-scatter meter consists of a transmitter and a receiver spaced by about one metre (see Figure 8-1). A variety of forward-scatter meter designs have been tested over the past few decades. Current designs have resolved many of the problems experienced with early models.

8.2.2 The early designs used chopped incandescent light sources with a modulation frequency of about 300 Hz, while current designs use flash lamps or electrically modulated infrared emitting diodes. The short light pulse or higher modulation frequency of these units has virtually eliminated the sunlight effects that were observed in early designs. The new light sources have also reduced maintenance requirements. Note that the use of infrared light for the measurement gives valid results for fog and snow, but will give incorrect measurements for smaller aerosol particles with sizes comparable to the wavelength (e.g. haze).

8.2.3 Early designs suffered from window contamination (e.g. snow clogging the instrument windows). These problems have been largely solved in the most recent designs (see Figure 8-2) which use a look-down scattering geometry.

8.2.4 The advantages and disadvantages of the forward-scatter meter are summarized here. More details will be presented in subsequent paragraphs.

Some advantages are:

a) Because of its small size and light weight, a forward-scatter meter can be mounted on a single frangible pole. It is not affected by unstable ground conditions.

b) A forward-scatter meter can readily cover the full RVR range with a single instrument.

c) A forward-scatter meter is relatively insensitive to window contamination and normally does not require frequent cleaning. Moreover, look-down scattering geometry reduces the chances of window contamination or precipitation hitting the windows.

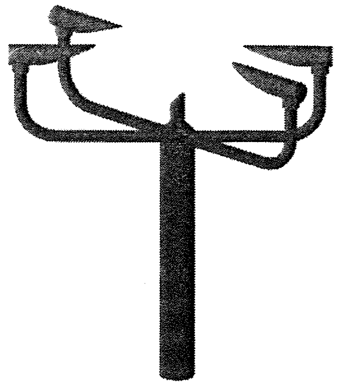

**Figure 8-3. Four-head forward-scatter meter**

b) Measuring the amount of light scattered internally from the windows to estimate the window loss. This method works well for dry contamination but may have problems with spurious signals from water droplets produced by blowing rain or snow. It can also detect snow clogging as a large, unvarying window signal. The use of look-down scattering geometry dramatically reduces the occurrence of contamination as well as water droplets.

Note that the reported RVR values will be higher than actual if window losses are not completely compensated. Snow clogging represents the worst case and must be avoided or detected to assure that misleading RVR values are not reported.

8.2.7 Whereas each transmissometer can be calibrated by itself (see 7.3), the calibration of a forward-scatter meter is more complicated. Two issues are involved:

a) The response of a forward-scatter meter depends upon many variables, such as the transmitter intensity, the receiver sensitivity, the transmitter and receiver beam sizes and overlap, and the mean scattering angle. Calibrating each of these factors separately would be very difficult. Instead, the scattering from dense fog is simulated by using a scatter meter calibration unit (SCU), the design of which is specific to each forward-scatter meter design. An SCU typically consists of a diffuse scattering plate (see Figure 8-4) accompanied by some method for attenuating the large signal scattered from the plate down to the dynamic range of the receiver. The SCU may consist of two separate units (e.g. scattering plate and attenuator), or for convenience, all components may be combined into a single unit. The calibration of a forward-scatter meter can be reset to a standardized value by measuring an SCU and setting the gain to give the nominal response of the SCU.

b) The scattered signal measured by a forward-scatter meter cannot be directly related to the extinction coefficient. The forward-scatter meter signal must ultimately be compared to direct extinction coefficient measurements made by a transmissometer. Such a comparison can be used to determine the fog equivalent extinction coefficient value of an SCU.

Because the calibration process is critical to the validation of each forward-scatter meter design, it will be discussed in more detail in Section 8.3.

8.2.8 If the forward-scatter meter is to give a good representation of atmospheric extinction coefficient, the atmosphere in its scatter volume must be similar to that of the free atmosphere. Two effects must be avoided:

a) The forward-scatter meter heads and mounting arms must not block the wind from carrying the particles reducing visibility freely into the scatter volume (possibly significant for both fog and snow). This problem can be minimized if the heads and supports are small and located far away from the scatter volume. Wind blockage effects can be reduced to a few per cent.

manufacturing tolerances translate into calibration differences. For an SCU based on a scattering plate, two effects are particularly important: a) how the transmitter and receiver beams overlap at the SCU location (see Figures 8-5 and 8-6); and b) the average scattering angle of the sensor. The first effect reduces the plate scattering much more than the volume scattering. The second effect is important because the scattering from fog varies much more rapidly with angle than the scattering from the calibrator plate. In light of the influence of scattering geometry on calibration, it is important that: a) the units used to determine the fog calibration against the reference transmissometer be from the middle of the calibration distribution of the forward-scatter meter production run; and b) manufacturing tolerances be as tight as practical to reduce the distribution range.

8.3.3 Because of aging effects on the instruments or SCUs, the calibration of a forward-scatter meter could drift systematically over the lifetime of the RVR system. The SCU calibration should be periodically traced to a reference transmissometer.

## 8.4 FORWARD-SCATTER METER ERRORS

8.4.1 Comparisons between forward-scatter meters and transmissometers in homogeneous fog show a typical spread in the ratio of one-minute average extinction coefficient measurements of about ± 5 per cent or less between the 25th and 75th per cent limits of the ratio distribution. This spread may indicate the calibration variation for different types of fog. Somewhat larger ratio spreads between the 25th and 75th per cent limits (±10 per cent or less) are observed in snow. Smaller ratio spreads in both fog and snow are observed with sensors with larger scattering volumes. The greater spread in snow may reflect both different types of snow and the effect of averaging over a small number of snow flakes passing through the scatter volume in a minute. For the results obtained in the United States, see D. C. Burnham, E. A. Spitzer, T. C. Carty, and D. B. Lucas, "United States Experience using forward-scatter meters for runway visual range," Report No. DOT/FAA/AND–97/1, US Department of Transportation, Federal Aviation Administration, March 1997.

8.4.2 Forward-scatter meters may show systematic variations in calibration for different weather phenomena reducing visibility. To date such variations have been measured for fog, rain, snow and haze. A suitable scattering angle of approximately 40 degrees will give equal median fog and snow calibrations. The forward-scatter meters on the market at present may have differences between snow and fog calibration of as much as ±30 per cent.

8.4.3 Computer simulations in the United States suggest that, with close production tolerances and good scattering geometry design, the unit-to-unit variations in the median fog calibration of a forward-scatter meter can be controlled to ±7 per cent. Not all forward-scatter meters achieve such close tolerances. In light of this potential source of error, forward-scatter meter field tests must include multiple units of each model (see 9.4.6 to 9.4.8).

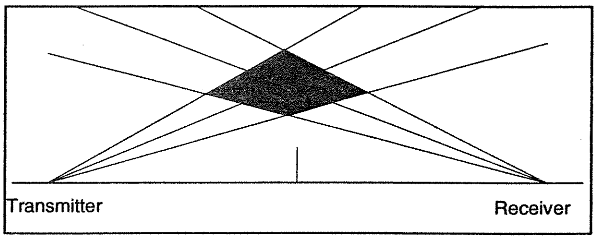


**Figure 8-5. Volume scattering with alignment error**

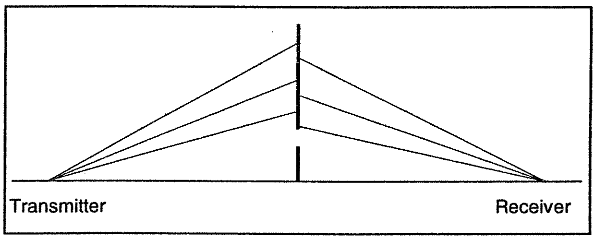


**Figure 8-6. Scatter meter calibration unit (SCU) scattering with alignment error**

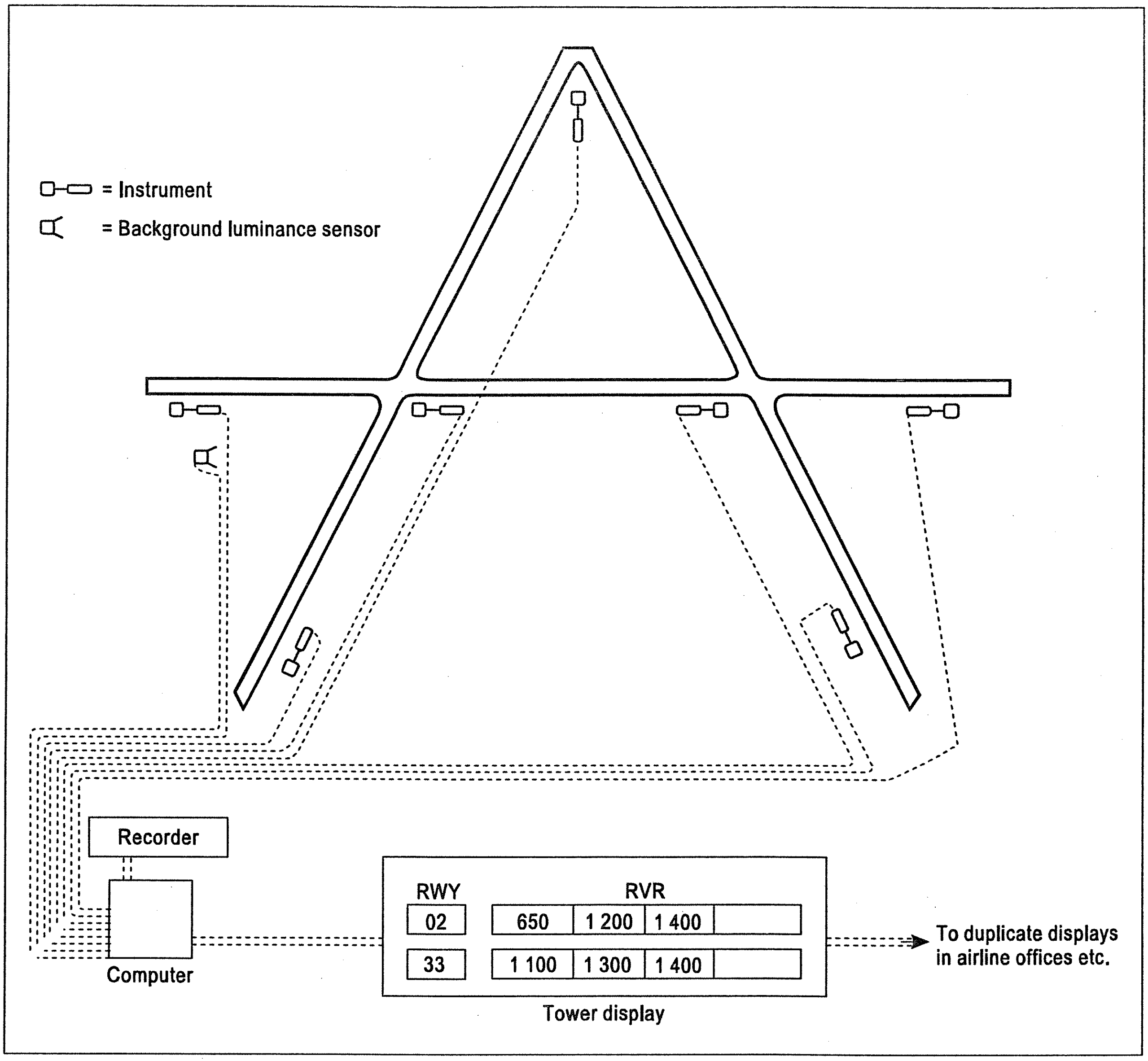


**Figure 9-1. Diagram of an automated runway visual range system**

reported RVR on the actual runway light setting in accordance with 4.7.8 of Annex 3. In some States, the tower control panel setting is used to define the light intensity for calculating RVR. However, it may be preferable to sense the actual runway light output or current.

### 9.1.7 Calculation of RVR

9.1.7.1 The calculation of RVR in automated systems is usually carried out by means of a computer, into which are fed the currently applicable values of the three variables $T$ (or $\sigma$), $B$ and $I$. The computer calculates RVR by Allard's and Koschmieder's laws; whichever value is the greater is taken to be the reported RVR. Computed values of RVR should be rounded down to the nearest lower step in the reporting scale.

9.1.7.2 Several States have installed, in the meteorological station or elsewhere, a recorder which displays RVR and MOR values. For this purpose it is advantageous to use logarithmic scales. Several States archive the data on a given period of time (e.g. one month).

9.2.2.4 The calibration of a transmissometer should be checked during high visibility periods (e.g. visibility above 10 km) which are free of local disturbances such as strong updraughts or heavy rains. During calibration, the visibility should stay stable. The uniform conditions needed for a valid calibration can be verified by looking for a relatively constant transmittance reading or, if other calibrated instruments are available, looking for consistent readings at different locations.

9.2.3 Forward-scatter meters are less sensitive to optic contamination. A periodic check of the calibration must be done, in accordance with the manufacturer's recommendations. As for a transmissometer, it is necessary to clear any cobweb filament from the optical field. The calibration may be carried out under a large range of meteorological conditions, excluding blowing precipitation and high winds. Maintenance and operations personnel should be aware of the possibility of clogging during periods of blowing snow as this condition could result in an overestimation of RVR. Depending on the sensor design, frequent cleaning or clearing of the sensor lenses may be required under these conditions.

## 9.3 INTEGRITY AND RELIABILITY OF INSTRUMENTED RVR SYSTEMS

The Third Meeting of the All Weather Operations Panel formulated Recommendation 3/10 inviting States to take steps to ensure that instrumented RVR systems have the same integrity and reliability as other ground facilities for all-weather operations. The reliability is the ability of the system to perform a required function under stated conditions for a stated period of time. It is a characteristic of the system expressed by the probability that it performs a required function under stated conditions for a stated period of time. The integrity is the status of a system not to be influenced by a deterioration of its constitutive parts. It is therefore the capacity of the system to indicate RVR values with the "nominal" accuracy.

## 9.4 METHOD OF EVALUATION OF THE PERFORMANCE OF AN INSTRUMENT

### 9.4.1 Introduction

The operationally desirable accuracy expressed by users for RVR is indicated in Attachment B to Annex 3. The final accuracy of an RVR value is difficult to evaluate, as RVR is a complex combination of several parameters. Therefore, the performance of an instrument is difficult to express in terms of RVR. The output of an instrument may be a transmittance ($t_b$) or an extinction coefficient ($\sigma$) which can be expressed in meteorological optical range (MOR) (see Section 6.2). In both cases the common parameter is MOR, hence it is easier to express the performance of an instrument in terms of MOR.

### 9.4.2 Expression of performance

Expressing the performance of an instrument in terms of accuracy with a single number (for example ± 10 per cent) does not provide much information about the real performance of the instrument. The question may be posed whether the 10 per cent is a standard deviation of error, a mean error, a maximum median error, a repeatability error or a root mean square (rms) error. The numerous past comparisons of instruments (and the test method described here) have all used the same type of data analysis, based on box plots for different classes (ranges) of MOR. These boxes depict the distribution of the ratio between the MOR measured by the instrument and that used as the reference: median, 25 per cent and 75 per cent limits (50 per cent interval), 5 per cent and 95 per cent limits (90 per cent interval) and sometimes more. Therefore, the performance of an instrument is better represented by the distribution ratio (e.g. median value) and the intervals containing a given percentage (e.g. 50, 90 and 99 per cent) of the measurements.

### 9.4.3 Reference(s)

Because of the measurement principle used by a transmissometer, it can be used as a reference instrument during field tests. However, a transmissometer is subject to additional attenuation from window contamination. Therefore, a transmissometer must be well maintained and its data must be carefully checked before being used as a reference. These data can be cross-checked with data values of known forward-scatter meters. At high MORs, large differences between values obtained from transmissometers and forward-scatter meters may be an indicator of window contamination of the transmissometer(s). A "known" forward-scatter meter is an instrument the characteristics of which have been checked during past comparisons and have no bias. When a set of such forward-scatter meters are regularly checked against transmissometers, they can be used as part of the reference data. Therefore, an "ideal" reference is a set of instruments of at least two transmissometers (ideally using two different baselines) and two forward-scatter meters exhibiting median values with a bias less than 5 per cent, when compared to the transmissometers. With such a set of instruments, the possible to use the time variability of the MOR to detect non-homogeneous periods. During such periods the MOR measured by a given instrument is usually changing quickly. Therefore, the stability of the MOR on a short period of time is an indicator of its spatial (at the scale of the test field) homogeneity. For each data point, a homogeneity indicator can be constructed by calculating the mean and standard deviation of MOR values over the period starting five minutes earlier and lasting until five minutes later. The ratio of the standard deviation with the mean value is the indicator. If this ratio is greater than 0.1, the conditions may be suspected as "non homogeneous" for the given minute. For low values of MOR, the use of the 0.1 threshold usually excludes between 10 to 20 per cent of data over a period of several months.

### 9.4.9 Test report

A field test report should describe the following features:

— the reference set of instruments used;

— the location of instruments;

— the test period;

— the meteorological conditions during the test;

— the method used to determine the present weather conditions;

— the application of the method to filter out the "non-homogeneous" periods; and

— the results, to be expressed as box plots, of MOR ratio to the reference, for different ranges of MOR and different meteorological and diurnal conditions (no precipitation, snow, rain, day, night).

Considering such a report, the performance of an instrument is the synthesis of the median values and 90 per cent intervals for the different MOR ranges and meteorological conditions. Figure 9-3 shows examples of box plots diagrams.

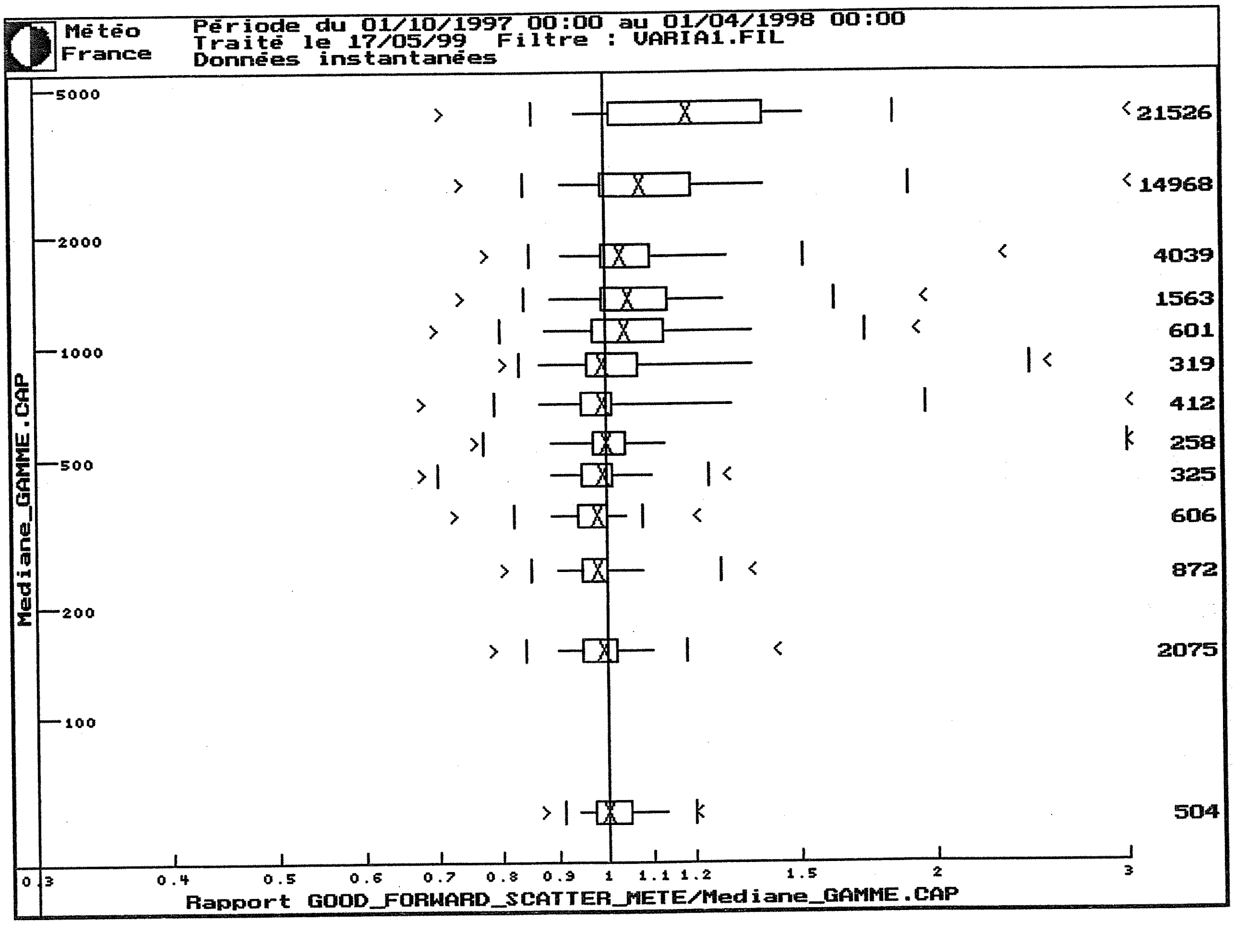


**Figure 9-3 b). Example of a box plot diagram for a forward-scatter meter with good performance for a six-month period (1 October 1997 to 1 April 1998)**

# Chapter 10

# HUMAN OBSERVER SYSTEMS

## 10.1 INTRODUCTION

Before the introduction of instrumented RVR systems, the method of assessing RVR was based on visual observations using lights or special markers, performed by a human observer. In some States it is still the only system available; while in others, it is retained as a standby system for use in case of failure of the instrumented system. Due to its inherent weaknesses (5.3.1 refers), the human observer method should be used only under the following circumstances:

a) at aerodromes with low frequency of occurrence of fog, or any other weather phenomena reducing RVR below 1 500 m (not recommended for Categories II and III);

b) for non-precision approach runways; and

c) as a back-up in case of failure of the instrumented system (not recommended for Categories II and III).

## 10.2 VISUAL OBSERVATIONS USING LIGHTS

10.2.1 In the visual observations method using lights, the RVR should ideally be assessed at a height of 5 m above the centre line of the runway and the observer should count runway lights from the runway threshold or from the touchdown zone. If it were possible to assess RVR this way, the observing position would correspond best to what the pilot sees. However, during flight operations, the observer, with the observation vehicle, must be removed from the runway and its immediate area so that the obstacle provisions of Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations* are fulfilled. Because it is also necessary for continuous RVR information to be available to the pilot during flight operations, it is clear that human RVR observations cannot be made from the runway itself. Instead, an observing position is chosen so that continuous RVR assessment can be carried out from a safe location. Moreover, RVR observing structures are made as frangible as possible consistent with their purpose. In all applications of human observer RVR systems, the observers should meet a specified vision standard and be subject to periodic vision checks.

*Note.— Where specific local conditions, such as sloping terrain or occurrence of snow banks, make it impracticable to assess RVR from a location outside the runway, it may be assessed from the runway itself. Under these circumstances, it is necessary that arrangements are in force to ensure that all mobile objects are removed from the runway during its use for landing and take-off.*

10.2.2 Normally, the runway edge lights on the side of the runway opposite the observing position are counted; centre line lights, being flush fittings, are not sufficiently visible therefrom. (Furthermore, runways with centre line lights tend to be equipped with instrumented RVR systems.) Using the far side lights provides a better assessment of conditions along the runway than would be achieved by using the same side lights. In a basic human observer system, the straight line distance from the observing position to each light is measured and this becomes the reported RVR, but this method has considerable inaccuracy, albeit on the conservative (safe) side, if the light intensity is not uniform over all angles of azimuth (see 10.3). The edge lights are usually 60 m apart, except at taxiway intersections, where the distance is different (e.g. 120 m). The RVR assessed visually is the distance in the runway direction between the observer and the furthest visible edge light. A simple conversion table is often compiled relating the number of observed lights to RVR to be reported. An example of a conversion table is given in Table 10-1.

10.2.3 Counting runway edge lights that are visible on either the near or far side of the runway is a difficult task because the edge lights may become confused with other white lights on the aerodrome; also, the observer's perception of the spacing between lights becomes progressively less as range increases making it difficult to accurately count the number of lights. Therefore, some States use separate lights — identical to the runway lights in use and varied in intensity in the same way — for assessing RVR. Because the observer and the light rows used are beyond the obstacle limits, RVR observations can be made during flight operations provided that these lights do not give false indication of the runway position to pilots (see Annex 14, 5.3.1.2). Some systems include the possibility of switching separate lights on and off to assist the observer. The use of separate light rows requires special calibration procedures (see 10.3), which may be difficult to perform. These kind of lights also need periodic cleaning like the runway lights.

which a given runway edge light can be seen. Each light is viewed through the Gold meter from the RVR observation point at the observer's normal eye height and then from the runway centre line abeam the RVR observation point at the height of 5 m. At both locations the filter is adjusted so that the light is just extinguished. By application of a formula to the readings of the Gold meter when the light is just extinguished at the two points, a table converting the number of lights visible from the RVR observation point to the RVR to be reported can be compiled. To remove most sources of error, two sets of the readings are taken on a clear night by each of two calibration personnel, using separate Gold meters on each of two successive nights, and all eight pairs of readings are averaged. The calibration personnel should meet the same vision criteria as the RVR observers.

## 10.4 VISUAL OBSERVATIONS USING SPECIAL MARKERS ALONG THE RUNWAY EDGE

10.4.1 If a runway is used at night, it should be equipped with runway edge lights, in accordance with Annex 14, Volume I, 5.3.9.1. These edge lights can also be used to assess RVR as described in 10.2 above. Furthermore, at night, any surface markers would not be visible enough for assessing RVR. However, for visual observations in daylight, a row of special markers placed near the runway would be useful for assessing RVR.

10.4.2 The visual markers may be placed in rows near the observing point, taking into account the obstacle clearance provisions for runways. Furthermore, the markers should be such that the pilots would not confuse them with the edge markers of the runway (Annex 14, Volume I, 5.5 refers). The markers are usually in the form of triangular prisms on their sides or vertical rectangular boards, and they are painted so that they present the appearance of two surfaces, 1 to 1.5 $m^2$, side by side, one black (or red) and one white. They are set up at distances of 4 to 10 m from the runway edge, most often on the opposite side from an observer, and are usually spaced at regular intervals up to 100 m apart. This results in a slightly irregular series of steps in the observing scale because the line of sight from an observer to the markers is not parallel to the runway. This difficulty can be overcome by using a variable spacing of markers designed to give uniform steps in the observing scale.

## 10.5 ERRORS WITH HUMAN OBSERVER SYSTEMS

Ideally, the RVR reported should correspond to the conditions on the runway experienced by the pilot when landing or taking off. However, errors in the visual observations occur due to a number of factors:

a) *Differences in the exposure to lights.* Significant differences may occur in the background luminance and extraneous lights to which an observer and a pilot are exposed. This can be important where observations are not made at the runway centre line (e.g. using a separate row of lights in a direction different from that of the runway in use).

b) *Variations in vision among observers.* Pilots must check their eyesight periodically and have generally high demands on their vision, but this does not necessarily apply to personnel making RVR observations. A group of observers may have a different distant visual acuity, significant variations in the visual threshold of illumination in different background luminance conditions or other degraded vision characteristics.

c) *Exposure of an observer to high levels of illumination.* If this happens just before making visual observations using lights, as would be the case when an observer leaves a lighted area to make night observations, it would degrade the observer's ability to see the lights, and the RVR values would be underestimated, which could result in the unnecessary deviations of aircraft to alternative aerodromes. This difficulty can be overcome by allowing several minutes for adjustment to illumination conditions outside the station.

d) *Beaming of the runway edge lights.* The runway edge lights are so directed that the beam intensities have a high value at the runway centre line while the intensity falls off rapidly towards the edges. Because runway lights are not observed at the centre line, the intensities directed towards the observer are lower. If the calibration of visual observations as described in 10.3 is not undertaken carefully, errors in reported RVR values will occur.

**Table 11-1. Detailed structure of RVR information included in local meteorological reports[1]**

| Detailed content | Template | Examples |
|---|---|---|
| Name of the element | RVR | RVR RWY 10 BLW 50M; |
| Runway [2] | RWY nnn | RVR RWY 14 ABV 1500M; |
| Runway section [3] | TDZ | RVR RWY 32 400M; |
| RVR | [ABV *or* BLW] nnnnM | RVR RWY 16 TDZ 600M MID 500M END 400M; |
| Runway section [3] | MID | RVR RWY 26 500M RWY 20 800M; |
| RVR | [ABV *or* BLW] nnnnM | RVR RWY 20 500M; |
| Runway section [3] | END | RVR RWY 12 ABV 1200M; |
| RVR | [ABV *or* BLW] nnnnM | RVR RWY 10 BLW 150M |

*Notes. —*

1. *To be included if visibility or RVR < 1 500 m;*
2. *To be included if more than one runway in use;*
3. *To be included if RVR is observed from more than one location along the runway.*

**Table 11-2. Detailed structure of RVR information included in METAR/SPECI messages[1]**

| Detailed content | Template | Examples |
|---|---|---|
| Name of the element | R | R10 M0050;<br>R14L P1500; |
| Runway | nn[n] | R32 0400;<br>R16L 0650 R16C 0500 R16R 0450; |
| RVR | [P *or* M] nnnn | R26 0550N R20 0800D;<br>R20 0700V1200; |
| RVR variations [2] | Vnnnn | R09 0375V0600U;<br>R12 1100U; |
| RVR past tendency [3] | U, D *or* N | R12 P1200;<br>R10 M0150 |

*Notes. —*

1. *RVR to be included if visibility or RVR < 1500 m for up to a maximum of four runways.*
2. *To be included if the one-minute RVR values during the ten-minute period immediately preceding the observation vary from the mean value by more than 50 m or more than 20 per cent, whichever is greater. The one-minute mean minimum and the one-minute mean maximum values are reported (instead of the ten-minute mean value).*
3. *To be included if the ten-minute period preceding the observation has shown a distinct tendency such that the mean RVR during the first five minutes varies by 100 m or more from the mean during the second five minutes of the period.*

11.5.2 RVR sometimes fluctuates rapidly by several hundred metres in less than a minute. Fog studies have shown that such large changes can occur when the front of a bank of fog passes across an airport. However, large and rapid excursions in indicated RVR may occur during periods of shallow fog. These are generally caused by slight variations in the height of the fog top, which, while alternately covering or exposing the measurement path or volume, have little genuine operational significance. Large changes can also result from isolated fog patches encountering an instrument as they drift in light winds. Thus, as already stressed in Chapter 4, large fluctuations in RVR are difficult to interpret, particularly when radiation fog is forming, and the computed values do not necessarily represent the actual RVR. However, rapid changes in visual range create difficulties for ATS units when passing information to aircraft; some smoothing of observations, by averaging over a period of time, is therefore desirable.

11.5.3 In local meteorological reports, an averaging period of one minute should be used. In some cases, simple averaging is carried out every minute by the RVR computer; in others, the most recent one-minute running mean value of RVR is displayed in real time. In reports in the METAR/SPECI code forms, the RVR reported should be the mean value during the ten-minute period immediately preceding the observation. If a marked discontinuity in RVR values occurs during the ten-minute period, only those values occurring after the discontinuity should be used to obtain the mean values.

*Note. — A marked discontinuity is considered to have occurred when there is an abrupt and sustained change in RVR, lasting at least two minutes, which reaches or passes through the RVR criteria for the issuance of reports in the SPECI code form (i.e. 150, 350, 600 or 800 m).*

11.5.4 Annex 3, 4.7.7, specifies that instrumented measurements should be updated as necessary to permit the provision of current, representative values of RVR. This provision implies that successive average values should be available at least every 60 seconds to permit prompt reporting of changes of one or more steps in the reporting scale. The periods between updating times of RVR data are mainly between one (i.e. a typical sampling rate) and 60 seconds (i.e. maximum permitted by Annex 3 provisions).

## 11.6 INDICATION OF VARIATIONS OF RVR IN REPORTS IN THE METAR/SPECI CODE FORM

*Note.— The variations of RVR cannot be indicated by the human observer system.*

11.6.1 Additional information concerning the variations of RVR is included in reports in the METAR/SPECI code forms. All these variations refer to the ten-minute period immediately preceding the observation. The inclusion of this information requires that the instrumented RVR system calculates and stores the RVR values as follows:

a) ten-minute period immediately preceding the observation;

b) two five-minute periods preceding the observation; and

c) ten one-minute periods preceding the observation.

11.6.2 If the RVR values (during the ten-minute period) have shown a distinct tendency, i.e. the mean during the first five minutes varies by 100 m or more from the mean during the second five minutes of the period, this should be indicated by the abbreviation "U" for an upward tendency, and the abbreviation "D" for a downward tendency. If there is no distinct tendency during the ten-minute period, this should be indicated by using the abbreviation "N" (for examples, see Table 11-2). When indications of tendencies are not available, none of the three abbreviations should be used.

11.6.3 If any one-minute RVR values (during the ten-minute period preceding the observation) vary from the mean value by more than 50 m or more than 20 per cent of the mean value, whichever is greater, the one-minute mean minimum and the one-minute mean maximum values should be reported instead of the ten-minute mean value (for examples, see Table 11-2).

11.6.4 If a marked discontinuity in RVR values occurs during the ten-minute period, only those values occurring after the discontinuity should be used to obtain the variations. (For the definition of a marked discontinuity, see Note under 11.5.3).

# Chapter 13

# SLANT VISUAL RANGE (SVR)

## 13.1 NEED FOR SVR

13.1.1 During the approach, until the pilot is actually on the runway, the view from the cockpit down to the ground represents a slant visual range (SVR) which may differ from the RVR observed from an aircraft on the runway. That will be the case under the following conditions:

a) In a mature fog, SVR is typically less than RVR because studies have shown that the density of deep fog usually increases with height, even though it may appear to be uniform along the ground. In those cases, it is not uncommon from a height of 30 m in deep fog for SVR to be less than half RVR, when the MOR is between 300 and 600 m. In this case, a pilot's ability to see the approach lights at the decision height will be overestimated by RVR and would be better estimated by SVR.

b) In a shallow fog, SVR may be significantly smaller than the RVR. The extreme case is a shallow fog (by definition < 2 m) with a top below the height at which instruments assess the RVR. Such fog may affect a pilot's ability to see the runway once the aircraft has landed but cannot be detected by the RVR system. An SVR system may detect such a shallow fog and provide some pre-warning.

c) In thin fog layers extending above the height of the RVR sensor, the RVR system will give better operational guidance than the SVR system. The pilot's assessment on approach and the SVR system may both suggest a greater visibility than will be experienced on landing.

13.1.2 SVR information would be particularly relevant to aircraft that do not have an automatic landing capability. It could be of value for the pilot who has to make a manual landing to know the visual conditions that would be encountered during the final part of the descent and during the flare manoeuvre. The main advantage of an SVR system would likely be its potential to improve the regularity of landings in all visibility conditions, without a reduction in the landing success rate.

13.1.3 A need for SVR information was expressed by a number of ICAO Meetings during the 1960's and 1970's. At the Fifth Air Navigation Conference (Montreal, 1967), it was agreed that, in the lower limits of Category I and in Categories II and III meteorological conditions, there was a requirement to provide pilots with SVR information prior to commencement of final approach, thereby enabling them to assess whether they could expect to establish the necessary reference to a ground segment of visual aids, and whether this reference could be maintained for the completion of the approach and the touchdown on the runway. This requirement was confirmed by the Ninth Air Navigation Conference (Montreal, 1976) and is still reflected in the *Procedures for Air Navigation Services — Rules of the Air and Air Traffic Services* (PANS-RAC, Doc 4444), Part IV, Section 15. However, it could be argued that many years of safe landings using RVR have proven that the requirement for SVR may no longer be justified.

13.1.4 A number of States have carried out studies on SVR during the past 20 years but only in two States, i.e. Germany and the Russian Federation, have these studies resulted in the development of prototype and/or pre-operational SVR observing systems. The results of the operational trials conducted by Germany and the Russian Federation are briefly addressed below.

## 13.2 PROGRESS REPORT ON THE SVR SYSTEM BEING DEVELOPED IN GERMANY

13.2.1 The SVR instrument is based on light detection and ranging (LIDAR) technology, detecting back-scattered light. Two series of tests and operational trials have been completed in Germany. The MOR measurements from the SVR equipment have been compared with those obtained from transmissometers sensing the same portion of the atmosphere. To achieve this, the transmissometer was inclined while the reflector was mounted on a mast. The results of comparative measurements were considered "satisfactory" to "good", except for the critical MORs between 50 and 2 000 m, where reservations were expressed. A third series of tests was undertaken in 1994. In these trials, the SVR equipment was used as if it were a transmissometer, i.e. the instrument was orientated

# Appendix A

# ALLARD'S LAW

*Note.— This appendix provides the detailed equations to support Section 6.4, which deals with RVR based on lights.*

1. The luminous flux of a beam of light is attenuated as it passes through the atmosphere. The fraction of the flux that remains after the light beam has travelled a distance ($b$) is known as the transmittance ($t_b$), the suffix denoting the distance ($b$).

2. Transmittance ($t_b$) can be otherwise expressed as transmittance per unit distance. The resulting fraction of received to transmitted flux is known as the transmissivity ($T$) of the atmosphere and is related to transmittance by the equation:

$$t_b = T^b, \text{ or} \tag{1}$$

$$T = \sqrt[b]{t_b} \tag{2}$$

3. The atmospheric transmittance ($t_b$) is usually measured by means of a transmissometer which transmits and receives a light beam over a specified distance ($b$). Hence transmissivity can be determined using Equation 2.

4. As an alternative to transmissivity ($T$), the attenuating property of the atmosphere can be expressed in terms of extinction coefficient ($\sigma$). The relationship between them is as follows:

$$\sigma = -\ln T \tag{3}$$

where ln denotes the natural logarithm,

$$\text{thus} \quad T = e^{-\sigma} \tag{4}$$

$$\text{hence} \quad T^b = e^{-\sigma b} = t_b \tag{5}$$

where $e$ is the base of the natural logarithm..

5. A source of light of luminous intensity ($I$) produces an illuminance ($E$) on a plane normal to the light rays at a given distance ($x$) from the source, when transmitted through an atmosphere having a transmissivity ($T$) or extinction coefficient ($\sigma$). These variables are related by the following equation:

$$E = \frac{IT^X}{x^2} = \frac{Ie^{-\sigma X}}{x^2} \tag{6}$$

6. It is this illuminance at an observer's eye that determines whether the light will be seen. For the light to be seen, the illuminance ($E$) has to exceed the visual threshold of illumination ($E_T$). The distance where $E_T$ is equal to $E$ is the visual range of the light ($R$). Then with $x$ = R:

$$E_T = \frac{IT^R}{R^2} = \frac{Ie^{-\sigma R}}{R^2} \tag{7}$$

Using the transmittance ($t_b$) measured by a transmissometer over a baseline ($b$) instead of transmissivity ($T$) from Equation 2, Equation 7 becomes:

$$E_T = \frac{It_b^{R/b}}{R^2} \tag{8}$$

7. The relationship given by Equations 7 and 8 is generally known as Allard's law.

# Appendix C

# TRANSMITTANCE OF THE WINDSCREEN

*Note.— The following is the result of individual research; it is included in this manual for information and to stimulate further work on the subject.*

1. The loss in transmittance owing to the aircraft windscreen is usually neglected in applying laboratory and field illumination threshold data to the aircraft pilot, but it can be significant.

2. When the line of sight passes through a single sheet of uncoloured glass at perpendicular incidence, the loss is nominal, about 9 per cent, corresponding to a transmittance of 0.91. Most of this loss is caused by reflection at the two air-to-glass surfaces.

3. The windscreen of a transport aircraft usually has four air-to-glass surfaces, and two or more glass-to-plastic surfaces; moreover, the line of sight is not perpendicular to the windscreen and the windscreen may have an electrically conducting film to provide heat for de-icing.

4. It is estimated that the angle of incidence of the windscreen to the line of sight for typical aircraft may be in the range of 45 to 70 degrees. The effect of this angle of incidence upon the transmittance of windscreens is illustrated in Table C-1, which gives the transmittance of a set of two sheets of clear glass as a function of angle of incidence.

5. Based upon the transmittances listed in Table C-1 and an estimate of the effects of the other factors noted above, an illumination threshold obtained without the interposition of a windscreen needs to be multiplied by a factor of the order of 1.5 to 2.5 in order to obtain an illumination threshold applicable to a pilot in the cockpit of an aircraft. It should be noted that no consideration is given to the transmittance of the windscreen in the development of the illumination threshold criteria considered in this manual and shown in Figure 6-8.

**Table C-1**

| *Angle of incidence of windscreen to line of sight (degrees)* | *Transmittance of windscreen* |
|---|---|
| 45 | 0.82 |
| 50 | 0.80 |
| 55 | 0.77 |
| 60 | 0.73 |
| 65 | 0.65 |
| 70 | 0.54 |
| 75 | 0.38 |

The transmittances listed above do not include losses within the glazing material or loss due to tinting or conducting films.

# Appendix E

# CALCULATIONS OF THE EFFECT ON RVR OF TRANSMISSOMETER CALIBRATION ERRORS

*Note.— The following provides the analytical basis for Section 7.4 on transmissometer errors.*

1. Typical values of the calibration errors described in Chapter 7, 7.4, for current designs of transmissometer, are as follows:

a) Signal offset $\Delta t_0$ to < 0.001 good; < 0.005 fair

b) Scaling error $\Delta t_s$ < 0.005 very good; < 0.01 good

c) Signal drift $\Delta t_d$ < 0.0001 good; < 0.0005 fair

2. As shown in Figure 7-3, the magnitude of the errors, with the exception of signal drift, varies with transmittance, but the ratio $\Delta t/t$ is constant. Although the errors are shown as being positive, each of them can be positive or negative.

3. For any value of transmittance the total fractional error $\Delta t/t$ can be determined. This can be expressed in terms of $\Delta\sigma/\sigma = \Delta V/V$ ($V$ = MOR) by means of the following equation:

$$\frac{\Delta\sigma}{\sigma} = \frac{\Delta V}{V} = \frac{1}{\log_e t} \cdot \frac{\Delta t}{t} \qquad (15)$$

For negative errors of Δt, Equation (15) can be written:

$$\frac{\Delta\sigma}{\sigma} = \frac{\Delta V}{V} = \frac{\log_e\left[1 + \frac{\Delta t}{t}\right]}{\log_e t} \qquad (15a)$$

4. It can be shown that the fractional errors $\Delta\sigma/\sigma$ and $\Delta V/V$ are related to RVR (denoted by R) by the following equation:

$$\frac{\Delta R}{R} = \frac{\Delta V}{V}\left[\frac{1}{1 + \frac{2V}{3R}}\right] \qquad (16)$$

hence the variation of $\Delta V/V$ with $V$ and $\Delta R/R$ with RVR can be determined.

**Table 1. Dependence of relative RVR error to relative parameter error on the ratio RVR/MOR.**

| RVR/MOR | $(\Delta R/R)/(\Delta I_v/I_v)$ | $(\Delta R/R)/(\Delta V/V)$ |
|---|---|---|
| 1 | 0.2 | 0.6 |
| 2 | 0.125 | 0.75 |
| 3 | 0.091 | 0.818 |
| 4 | 0.071 | 0.857 |
| 5 | 0.059 | 0.882 |

**Table 2. Dependence of $(\Delta R/R)/(\Delta I_v/I_v)$ on RVR and MOR.**

| | MOR | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| RVR | 10 | 20 | 50 | 100 | 200 | 500 | 1000 | 2000 |
| 100 | 0.031 | 0.059 | 0.125 | 0.200 | | | | |
| 200 | 0.016 | 0.031 | 0.071 | 0.125 | 0.200 | | | |
| 500 | 0.007 | 0.013 | 0.031 | 0.059 | 0.105 | 0.200 | | |
| 1000 | 0.003 | 0.007 | 0.016 | 0.031 | 0.059 | 0.125 | 0.200 | |
| 2000 | 0.002 | 0.003 | 0.008 | 0.016 | 0.031 | 0.071 | 0.125 | 0.200 |

**Table 3. Dependence of $(\Delta R/R)/(\Delta V/V)$ on RVR and MOR.**

| | MOR | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| RVR | 10 | 20 | 50 | 100 | 200 | 500 | 1000 | 2000 |
| 100 | 0.938 | 0.882 | 0.750 | 0.600 | | | | |
| 200 | 0.968 | 0.938 | 0.857 | 0.750 | 0.600 | | | |
| 500 | 0.987 | 0.974 | 0.938 | 0.882 | 0.789 | 0.600 | | |
| 1000 | 0.993 | 0.987 | 0.968 | 0.938 | 0.882 | 0.750 | 0.600 | |
| 2000 | 0.997 | 0.993 | 0.984 | 0.968 | 0.938 | 0.857 | 0.750 | 0.600 |

# Appendix H

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*Airport Services Manual*, Part 6 — *Control of Obstacles* (Doc 9137)

*Third Meeting of the All Weather Operations Panel (1967)*, Volume 2 (Doc 8685, permanently out of print)

*Fourth Meeting of the All Weather Operations Panel (1971)* (permanently out of print)

*Fifth Air Navigation Conference (1967)* (Doc 3720, permanently out of print)

*Fifth Meeting of the Visual Aids Panel (1970)* (Doc 8862, permanently out of print)

*Eleventh Meeting of the Visual Aids Panel (1987*, permanently out of print*)*

*Eighth Air Navigation Conference (1974)* (Doc 9101, permanently out of print)

*Manual of All-Weather Operations* (Doc 9365)

*Ninth Air Navigation Conference (1976)* (Doc 9168, permanently out of print)

**WORLD METEOROLOGICAL ORGANIZATION (WMO)**

*Guide to Meteorological Instruments and Methods of Observation*, 6th Edition, (WMO-No. 8)

**OTHER**

D.C. Burnham, E.A. Spitzer, T.C. Carty, and D.B. Lucas "United States Experience using forward-scatter meters for runway visual range" Report No. DOT/FAA/AND–97/1, US Department of Transportation, Federal Aviation Administration, March 1997.

# ICAO TECHNICAL PUBLICATIONS

*The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the* Aeronautical Chart Catalogue *or the* Meteorological Tables for International Air Navigation.

**International Standards and Recommended Practices** are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications contained in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

**Procedures for Air Navigation Services** (PANS) are approved by the Council for worldwide application. They contain, for the most part, operating procedures regarded as not yet having attained a sufficient degree of maturity for adoption as International Standards and Recommended Practices, as well as material of a more permanent character which is considered too detailed for incorporation in an Annex, or is susceptible to frequent amendment, for which the processes of the Convention would be too cumbersome.

**Regional Supplementary Procedures** (SUPPS) have a status similar to that of PANS in that they are approved by the Council, but only for application in the respective regions. They are prepared in consolidated form, since certain of the procedures apply to overlapping regions or are common to two or more regions.

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*The following publications are prepared by authority of the Secretary General in accordance with the principles and policies approved by the Council.*

**Technical Manuals** provide guidance and information in amplification of the International Standards, Recommended Practices and PANS, the implementation of which they are designed to facilitate.

**Air Navigation Plans** detail requirements for facilities and services for international air navigation in the respective ICAO Air Navigation Regions. They are prepared on the authority of the Secretary General on the basis of recommendations of regional air navigation meetings and of the Council action thereon. The plans are amended periodically to reflect changes in requirements and in the status of implementation of the recommended facilities and services.

**ICAO Circulars** make available specialized information of interest to Contracting States. This includes studies on technical subjects.

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