Doc 9328
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Manual of Runway Visual Range Observing and Reporting Practices

Approved by the Secretary General
and published under his authority

Third Edition — 2005

International Civil Aviation Organization

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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by
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2	25/11/13	ICAO
3	31/03/18	ICAO
4	04/12/18	ICAO

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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, 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. Further amendments to Annex 3 including the introduction of a provision to use the maximum light intensity for the assessment of RVR resulted in the publication of the third edition of the manual in 2005.

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 Annex 3, Chapter 4, 4.6.3, and Appendix 3, 4.3.

Note.— 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)*.

Chapter 2

DEFINITION, PURPOSE AND OPERATIONAL USE OF RVR

2.1 RVR is defined in Annex 3, Chapter 1, as:

"The range over which the pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line."

2.2 This definition was developed by the Eighth Air Navigation Conference (Montreal, 1974). The definition implies that RVR is not an "observation" or a "measurement" of a meteorological parameter such as surface wind direction and speed, temperature and pressure; it is an assessment, based on calculations that take into account various elements, including atmospheric factors such as extinction coefficient of the atmosphere, physical/biological factors such as visual threshold of illumination, and operational factors such as runway light intensity. Therefore, the assessment of RVR presents many more complexities than the mere observation of meteorological parameters and, for this reason, there exists a need for detailed information and guidance on the subject.

2.3 The main purpose of RVR is to provide pilots, air traffic services (ATS) units and other aeronautical users with information on runway visibility conditions during periods of low visibility, whether due to fog, the most frequent cause of low visibility in many places, or due to other causes such as rain, snow or sandstorms. In particular, RVR is required to assess whether conditions are above or below the specified operating minima for take-off and landing. It is to be noted that for this purpose RVR values supersede the reported visibility and that in the case of precision approaches it is normally not permissible to start an approach if the applicable RVR value(s) is below the required minimum.

2.4 The commonly acceptable aerodrome operating minima for different runway categories (defined in Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations*) are specified in the *Manual of All-Weather Operations* (Doc 9365) (also see 6.5.4). The range of RVR assessments (i.e. from 50 to 2 000 m) is designed to cover most aerodrome operating minima. Therefore, RVR requires a high reporting resolution as indicated in 11.4.

2.5 Operationally, RVR is sometimes taken to have a broader meaning than as defined in 2.1, in that it is used by many pilots as an indication of the visual guidance that may be expected during the final approach, flare, touchdown and roll-out. In this way, RVR may be assumed by the pilot to provide an indication of the overall visual range conditions. However, as RVR applies only for the visual range on the runway, the conditions during approach may be significantly different. Until the pilot is actually on the runway, the view from the cockpit down to the ground represents rather a slant visual range (SVR) and as such may be affected by fog densities varying with height. Whilst SVR would be the ideal representation of the visual range, there is currently no requirement for SVR owing to the inherent difficulties in its measurement or assessment and the fact that research into its assessment has been negligible in recent years. Furthermore, it is now widely accepted that the use of RVR has ensured the safe conduct of low-visibility operations over the last few decades.

2.6 The fact that RVR depends upon both meteorological and operational parameters complicates the assignment of responsibility for RVR assessments. Some States assign the responsibility for RVR assessments to the meteorological office while others assign this responsibility to the ATS provider.

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]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 2 700 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 travelling the length of a unit distance in the atmosphere.

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

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

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 the photometric luminosity function of the International Commission on Illumination (CIE) (metre (m) or kilometre (km)).

Note 1.— The relationship between meteorological optical range and extinction coefficient (at the contrast threshold of $\varepsilon = 0.05$) *using Koschmieder's law is: MOR =* $-ln(0.05)/\sigma \approx 3/\sigma$. MOR = *visibility under certain conditions (see below).*

Note 2.— Using the assumptions in 3.2, the definition can be also stated as follows: the length of the path in the atmosphere required to reduce the luminous flux in a collimated beam to 0.05 of its original value.

Runway visual range (RVR)*. The range over which the pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line (metre, m).

Scatter meter. An instrument for estimating extinction coefficient by measuring the flux scattered from a light beam by particles present in the atmosphere.

Slant visual range (SVR). The visual range of a specified object or light along a line of sight which differs significantly from the horizontal; for example, the visual range of ground objects or lights as seen from an aircraft on the approach (metre, m).

Transmissivity (or transmission coefficient) (T). The fraction of luminous flux which remains in a beam after traversing an optical path of a unit distance in the atmosphere (dimensionless).

Transmittance (t_b). Transmissivity within an optical path of a given length *b* in the atmosphere (dimensionless).

Transmissometer. An instrument that takes a direct measurement of the transmittance between two points in space, i.e. over a specified path length or baseline.

Visibility (V)*. Visibility for aeronautical purposes is the greater of:

a) the greatest distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognized when observed against a bright background;

b) the greatest distance at which lights in the vicinity of 1 000 candelas can be seen and identified against an unlit background.

Note.— The two distances have different values in air of a given extinction coefficient, and the latter b) varies with the background illumination. The former a) is represented by the meteorological optical range (MOR).

Visual range. The maximum distance, usually horizontally, at which a given light source or object is just visible under particular conditions of background luminance.

Visual threshold of illumination (E_T). The smallest illuminance required by the eye to make a small light source visible (lux, lx).

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.

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

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).

4.2.2 The small-particle lithometeors (haze, smoke and volcanic ash) can remain suspended more or less indefinitely in the atmosphere. Only under abnormal conditions, such as dense smoke from large fires, will these phenomena reduce the visibility below 1 500 m.

4.2.3 The large-particle lithometeors (sand and dust) require substantial wind speeds to remain suspended in the atmosphere, which only occur in association with the following phenomena:

a) *sandstorm*

A strong and turbulent wind carrying sand through the air, the diameter of most of the particles ranging from 0.08 to 1 mm. In contrast to duststorms, sand particles are mostly confined to the lowest 2 m, and rarely rise more than 15 m above the ground. Sandstorms are best developed in desert regions where there is loose sand, often in sand dunes, without much mixture of dust. They are due to strong winds caused or enhanced by surface heating and tend to form during the day and die out at night.

The forward portion of a sandstorm may have the appearance of a wide and high wall. Walls of sand often accompany a cumulonimbus that may be hidden by the sand particles; they may also occur without any clouds along the forward edge of an advancing cold air mass.

b) *duststorm*

Particles of dust are energetically lifted by a strong and turbulent wind over an extensive area. These conditions often occur in periods of drought over areas of normally arable land, thus providing the very fine particles of dust that distinguish them from the more common sandstorm of desert regions.

A duststorm usually arrives suddenly in the form of an advancing wall of dust which may be kilometres long and is commonly well over 3 000 m in height. Ahead of a duststorm there may be some dust whirls (either detached or merging with the main mass) and, ahead of the wall of dust, the air is very hot and the wind is light. Walls of dust often accompany a cumulonimbus which may be hidden by the dust particles; they may also occur without any clouds along the forward edge of an advancing cold air mass.

c) *dust/sand whirls*
(dust devils)

A rapidly rotating column of air usually over a dry and dusty or sandy ground carrying dust and other light material picked up from the ground. Dust or sand whirls are of a few metres in diameter. Normally in the vertical they extend no higher than 60 to 90 m (200 to 300 ft) (dust devils). Well-developed dust/sand whirls in very hot desert regions may reach 600 m (2 000 ft).

4.3 HYDROMETEORS: MIST AND FOG

4.3.1 Mist is an atmospheric obscuration produced by suspended microscopic water droplets or wet hygroscopic particles, generally producing a thin greyish veil over the landscape. The particles contained in mist have diameters mainly of the order of a few tens of micrometres.

4.3.2 Mist is reported when the visibility is at least 1 000 m but not more than 5 000 m with relative humidity greater than 90 per cent.

4.3.3 Fog is an atmospheric obscuration in the lowest layers of the atmosphere which is caused by a concentrated suspension of water droplets or ice crystals, the air being at about 100 per cent humidity. In cold conditions, the suspension may be ice crystals and the resulting fog is called *ice fog*.

4.3.4 Fog is generally classified according to the physical process that produces the saturation or near saturation of the air. *Radiation fog* forms as a result of radiative cooling, usually on cloudless nights in light wind conditions. *Advection fog* forms as warm, moist air from the sea or land cools as it passes over a colder surface. *Sea fog* is an advection fog that forms as warm air from the land moves out over cooler water. *Evaporation fog (steam fog)* is produced within a colder and stable air mass by rapid evaporation from an underlying warmer water surface. *Upslope fog* forms as air cools when it is blown up a slope causing *mountain obscuration*. Clouds form by the same processes, and when stratus clouds descend to the ground they are considered to be fog.

4.3.5 Fog is reported when the visibility is less than 1 000 m.

4.3.6 During the life of a fog its characteristics and the visual conditions within it change (see also 11.5.2). For purposes of description it can be said that most fogs have three phases:

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.

h) *small hail and/or snow pellets*

Translucent ice particles with a diameter of up to 5 mm that, when falling on hard ground, bounce with an audible sound. Small hail consists of snow pellets totally or partially encased in a layer of ice and is an intermediate stage between snow pellets and hailstones.

4.4.3 Showers are associated with convective clouds. They are characterized by their abrupt beginning and end and by the generally rapid and great variations in the intensity of the precipitation. Drops and solid particles falling in a shower are generally larger than those falling in non-showery precipitation.

4.4.4 In connection with snow, the characteristics of "low drifting" and "blowing" are used. Low drifting snow means that snow is raised from the surface by the wind to a height less than 2 m (6 ft) above the ground (the assumed eye level of an observer). Blowing snow indicates that snow particles are raised from the surface by the wind to a height of 2 m or more above the ground.

4.5 IMPACT OF WEATHER PHENOMENA ON VISIBILITY

4.5.1 Liquid precipitation (rain, drizzle) alone rarely reduces visibility into the RVR range. However, conditions of liquid precipitation can produce operationally significant values of RVR when the precipitation is accompanied by fog, which is frequently the case with drizzle, or when the precipitation is particularly heavy. In addition, steam fog generated from cooler, moist air moving over a hot, wet runway may also reduce the visibility into the RVR range.

4.5.2 Solid precipitation (various forms of snow) is more efficient than water droplets in scattering light and, therefore, will frequently reduce the visibility into RVR values that are of operational significance. In particular, under conditions of high winds, blowing snow can produce conditions that lead to very low values of RVR. Furthermore, dense and widespread drifting snow may totally or partially prevent the pilot from seeing the runway lights although the reported visibility may be high. Similar phenomena may occur with drifting sand.

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 (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 assessments 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).

5.1.4 Following Amendment 72 to Annex 3, the use of instrumented RVR systems is now mandatory for Categories II and III operations and is recommended for Category I instrument approach and landing operations. (Annex 3, Appendix 3, 4.3.2.1 and 4.3.2.2 refer.)

5.2 ASSESSMENTS REQUIRED

5.2.1 The assessment and reporting of RVR is covered by Annex 3, Chapter 4, 4.6.3, and Appendix 3, 4.3.

5.2.2 According to Annex 3, Chapter 4, 4.6.3.1, RVR must be assessed on all runways intended for Categories II and III instrument approach and landing operations.

5.2.3 Additionally, Annex 3, Chapter 4, 4.6.3.2, states that RVR should be assessed on all runways intended for use during periods of reduced visibility, including:

a) precision approach runways intended for Category I instrument approach and landing operations; 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".

5.2.4 Where RVR assessments are required, according to Annex 3, Chapter 4, 4.6.3.3, they should be made and reported throughout periods when either the visibility or the RVR is observed to be less than 1 500 m.

5.2.5 RVR can be reported for values ranging from 50 m to 2 000 m (Annex 3, Appendix 3, 4.3.6.2 refers). It should be noted that values in the range 1 500 m to 2 000 m would only be reported in situations where the visibility is less than 1 500 m.

5.3 LOCATIONS FOR ASSESSMENTS — GENERAL

5.3.1 RVR systems should be set up to provide assessments that are representative of a pilot's viewing position to the extent possible without infringing on the obstacle provisions of Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations*; and, in case of human observers, without risk to the observers. These provisions require that objects which, because of their functions, are permitted within the strip[1] in order to meet air navigation requirements, should be frangible and sited in such a manner as to reduce collision hazards to a minimum (Annex 14, Volume I, 9.9).

1. The "strip" of a precision approach runway or an instrument approach runway should extend to a distance of at least 150 m on each side of the centre line of the runway and its extended centre line throughout the length of the strip (Annex 14, Volume I, 3.4.3 and 3.4.4).

5.3.2 Since the RVR cannot be measured directly on the runway, the error caused by the difference in conditions at the runway and at the location where the RVR is assessed can have an operational impact. The RVR systems are usually installed up to 120 m from the runway centre line on a grass or sand surface, which can sometimes be covered with snow in winter. In contrast, the runway is made of concrete or asphalt, which may warm more rapidly than the surrounding grass, snow or sand surfaces. The resulting temperature difference between the runway and surrounding area will affect the distribution of fog and may result in a greater RVR along the runway than that assessed by the instruments. This effect may be enhanced by aircraft movements on the runway. At least in the short term, aircraft movements on the runway tend to cause the dissipation of fog due to the hot exhaust gases and turbulence generated. However, the exhaust gases contain condensation nuclei and water vapour which may lead to the thickening of fog in a longer term. In cold climates, during surface inversions, only one flight operation may be enough to cause fog formation because of the turbulence generated. This type of fog often disappears shortly after its formation. If the fog is caused by advection, the wind direction and obstacles may lead to a non-homogeneous distribution fog. If the fog is not homogeneous, the measuring volume of the instrument used may influence the representativeness of the assessed RVR. This is best illustrated by the example of patchy fog where the instrument may be completely covered by a fog patch while at the same time the visibility on the runway is relatively good, or vice versa.

5.3.3 In cold climates, snow removal should be taken into account in siting RVR sensors near taxiways; snow removal equipment may throw snow onto the sensors and damage them or affect their performance.

5.4 HEIGHT ABOVE RUNWAY

5.4.1 An eye level of 5 m above the runway was originally suggested as being representative of a pilot’s viewing position above the runway. Since the runway lights are near ground level, this implied an average height of about 2.5 m for the light path to a pilot’s eyes. It is therefore recommended that RVR should be assessed at a height of approximately 2.5 m (7.5 ft) (Annex 3, Appendix 3, 4.3.1.1, refers).

5.4.2 For the human observer system, the observer’s eye height should, ideally, be 5 m, the same as that of the representative viewing position of the average pilot. In practice, the observer often stands on the ground. At some aerodromes, it is impossible to see and identify all the required lights from such a low level because of humps and dips in the runways or snow banks alongside the runways. In these cases, assessments should be made from an elevated platform or the top of a vehicle. Also, raised positions are sometimes necessary in order to obtain a better view of the lights on the far side of the runway where these are used for RVR assessments.

5.4.3 In practice, the pilot’s eye height can vary significantly from the 5-m value assumed in paragraph 5.4.1. Figure 5-1 illustrates this variation for commercial aircraft registered in the United States; similar variations would be expected for aircraft in other States. The figure presents the cumulative percentage of windscreen heights. Each point represents the contribution of a particular aircraft type. The height distribution is dominated by the large percentage of narrow-body commercial jet transport aircraft that appear as three large vertical steps in the cumulative percentage at heights between 3 and 4 m. The large horizontal step at the top of the figure is the contribution of the Boeing-747 which has the highest cockpit window. The median height (corresponding to 50 per cent of aircraft) is about 3.6 m. The height of 5 m assumed in 5.4.1 is at the 89th percentile. Although the pilot’s eye height can be almost a factor of two higher, or a factor of three lower, than the 5-m value, it would be impractical to vary the measurement height from one airport to the next based on the typical pilot eye height at the airport.

5.4.4 Despite these differences in eye height of aircraft on the runway, the light intensities directed towards the pilot from runway edge and centre line lights conforming to ICAO specifications do not vary to a significant extent. Hence RVR is not very sensitive to the changes in eye height presented by various aircraft, as far as runway light intensity is concerned. (See Section 6.5.)

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, Chapter 4, 4.6.3.4, calls for RVR assessments 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. The site for observations to be representative of the mid-point and stop-end of the runway should be located at a distance of 1 000 to 1 500 m along the runway from the threshold and at a distance of about 300 m from the other end of the runway. The exact position of these sites and, if necessary, additional sites should be decided after considering aeronautical, meteorological and climatological factors such as long runways, location of navigation aids, adjacent structures or the location of swamps and other fog-prone areas.

5.5.3 Existing installations follow these provisions closely. All have one observation site adjacent to the touchdown zone — usually 300 m from the threshold — and many instrumented RVR systems have supplementary observation sites. One of these is usually near the stop-end, which becomes the touchdown zone when the runway is used in the opposite direction.

5.5.4 All-weather operations require the provision of RVR, and the level of detail to be provided depends on the category of aerodrome operations. The detailed requirements for all-weather operations are given in regional air navigation plans as follows:

non-precision approach and Category I operations

— one site providing information representative of the touchdown zone;

Category II operations

— as for Category I, plus a second site representative of the mid-point of the runway;

Category III operations

— as for Category II, but normally with a third position representative of the stop-end of the runway, unless assessments at two sites are adequate for the operations planned.

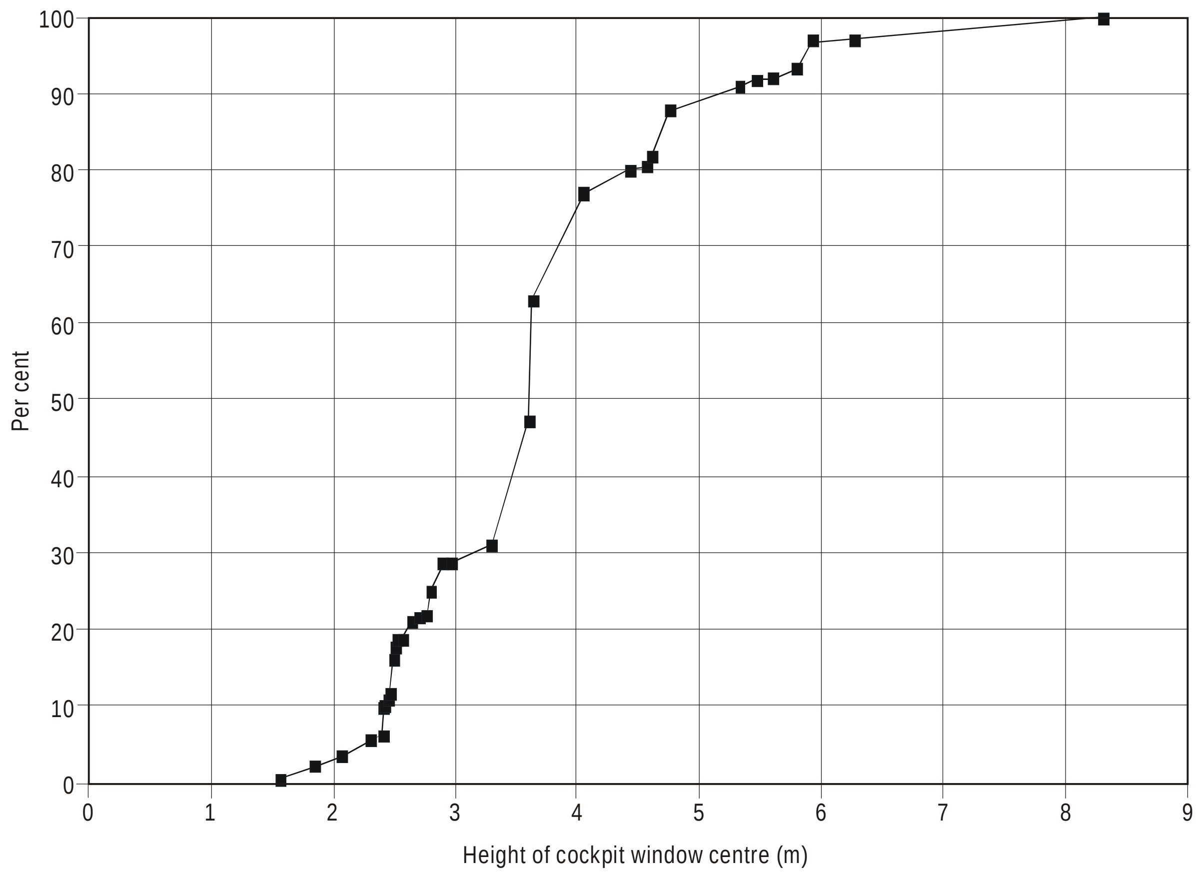

Figure 5-1. Cumulative distribution of cockpit window heights for U.S. commercial aircraft (1994)

5.5.5 Because visibility can vary considerably along a runway, particularly when fog is forming, useful information can be obtained from multiple instruments even if only Category I operations are being undertaken.

5.6 DISTANCE FROM THE RUNWAY

5.6.1 The point from which RVR assessment is made should be such as to present a minimum of hazard to aircraft and instruments and to observers who should never be exposed to the risk of being hit by aircraft taking off or landing. On the other hand, in order that the observations may be closely representative of conditions over the runway, observation sites should be near the runway. This point is recognized in Annex 3, Appendix 3, 4.3.1.2, which indicates that RVR assessments should be carried out at a lateral distance from the runway centre line of not more than 120 m.

5.6.2 Regulatory provisions concerning the construction and siting of equipment and installations are included in Annex 14, Volume I, 9.9, and additional relevant guidance material appears in the *Airport Services Manual*, Part 6 — *Control of Obstacles* (Doc 9137). Figure 5-2 indicates the closest positions to the runway at which various meteorological instruments may be located without infringing the transitional surfaces.

5.6.3 With regard to the safety of observers, it should be noted that Annex 14 obstacle limitation specifications relating to the runway strip and associated transitional surfaces effectively prevent the location and use of vehicles or other non-frangible RVR assessment structures (whether fixed or mobile) within the runway strip at any time when the air traffic control (ATC) has cleared aircraft to land or take off (see also 10.2.1).

5.7 ACCURACY OF THE ASSESSMENTS

5.7.1 The accuracy should be compatible with the requirements to report RVR in given increments. The current recommendations for reporting increments are stated in Annex 3, Appendix 3, 4.3.6.1. These are discussed in detail in Section 11.4 of this manual.

5.7.2 As early as 1974, when the subject of accuracies was discussed by the Eighth Air Navigation Conference, it was noted that observations made without the aid of instruments were less accurate than those made with instruments. The gap between the accuracies of these two types of assessments of RVR has continued to widen, and only RVR values determined by instruments are likely to approach the accuracies as indicated under "Operationally desirable accuracies"[2] in Annex 3, Attachment A.

5.8 RUNWAY LIGHTS TO BE USED

5.8.1 When landing in poor visibility conditions (Category I and Category II), the pilot generally needs to see a number of approach and runway lights or markings at and below the decision height. A similar requirement exists for monitoring purposes at heights below 30 m (100 ft) in 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:

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

b) the 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.

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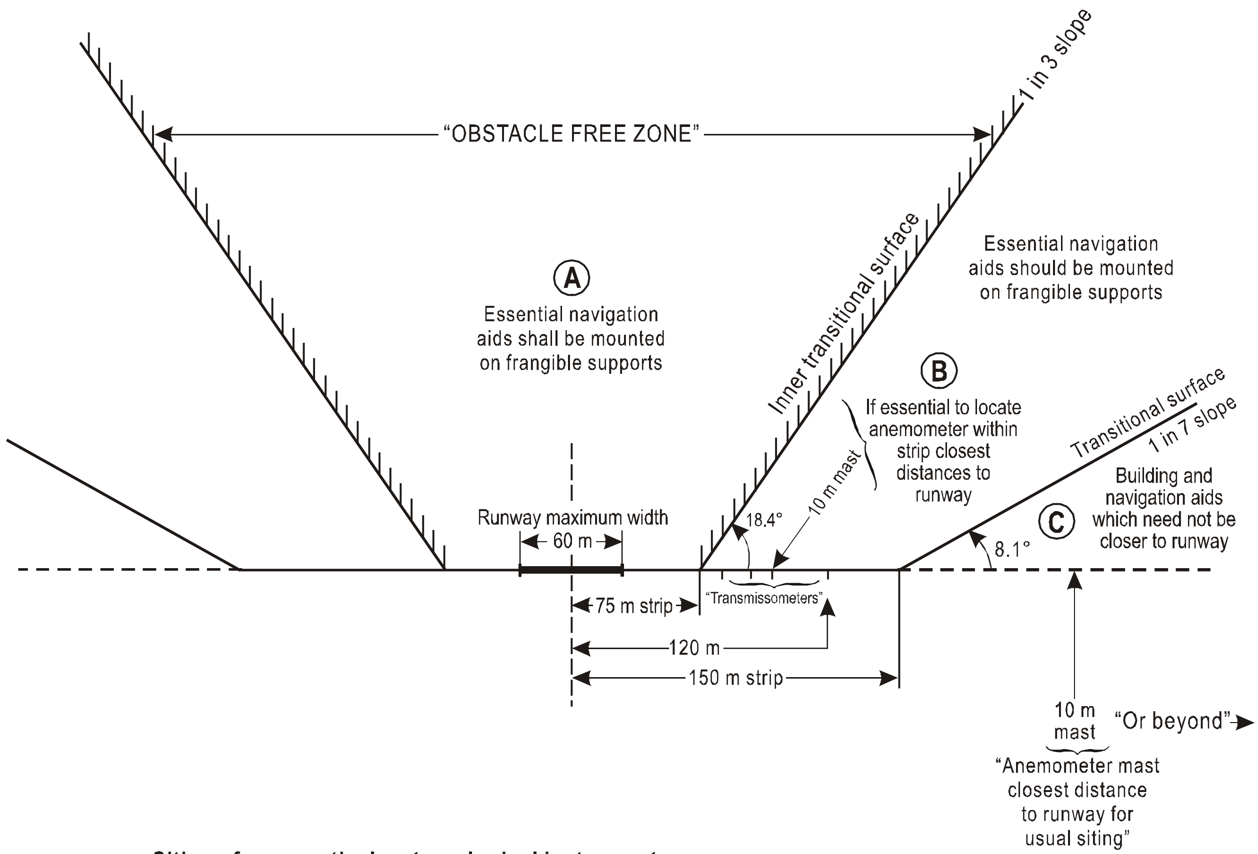
2. The operationally desirable accuracy is not intended as an operational requirement; it is to be understood as a goal that has been expressed by the operators.



Siting of aeronautical meteorological instrument sensors

Ⓐ "OBSTACLE FREE ZONE" — Generally speaking no MET sensors should infringe this region unless exceptional local circumstances so dictate. In the latter case sensor supports must be frangible, lighted and if possible sensor should be "shielded" by an existing obstacle.

Ⓑ 1) Transmissometer sited between 66 m and 120 m from runway centre line 2) Ceilometer may be sited in this region if not located near middle marker 3) If essential to locate within strip, anemometer height 10 m minimum distance from centre line = 90 m.

Ⓒ Usual location of anemometer masts minimum distance from runway centre line for 6 m mast is = 192 m and for a 10 m mast = 220 m, assuming surface wind observations made in this region are representative of conditions over runway.

(Cross section of typical precision approach runway reference number 3 or 4)

Note.— Slope angles not drawn to scale.

Figure 5-2. Obstacle limitation surfaces

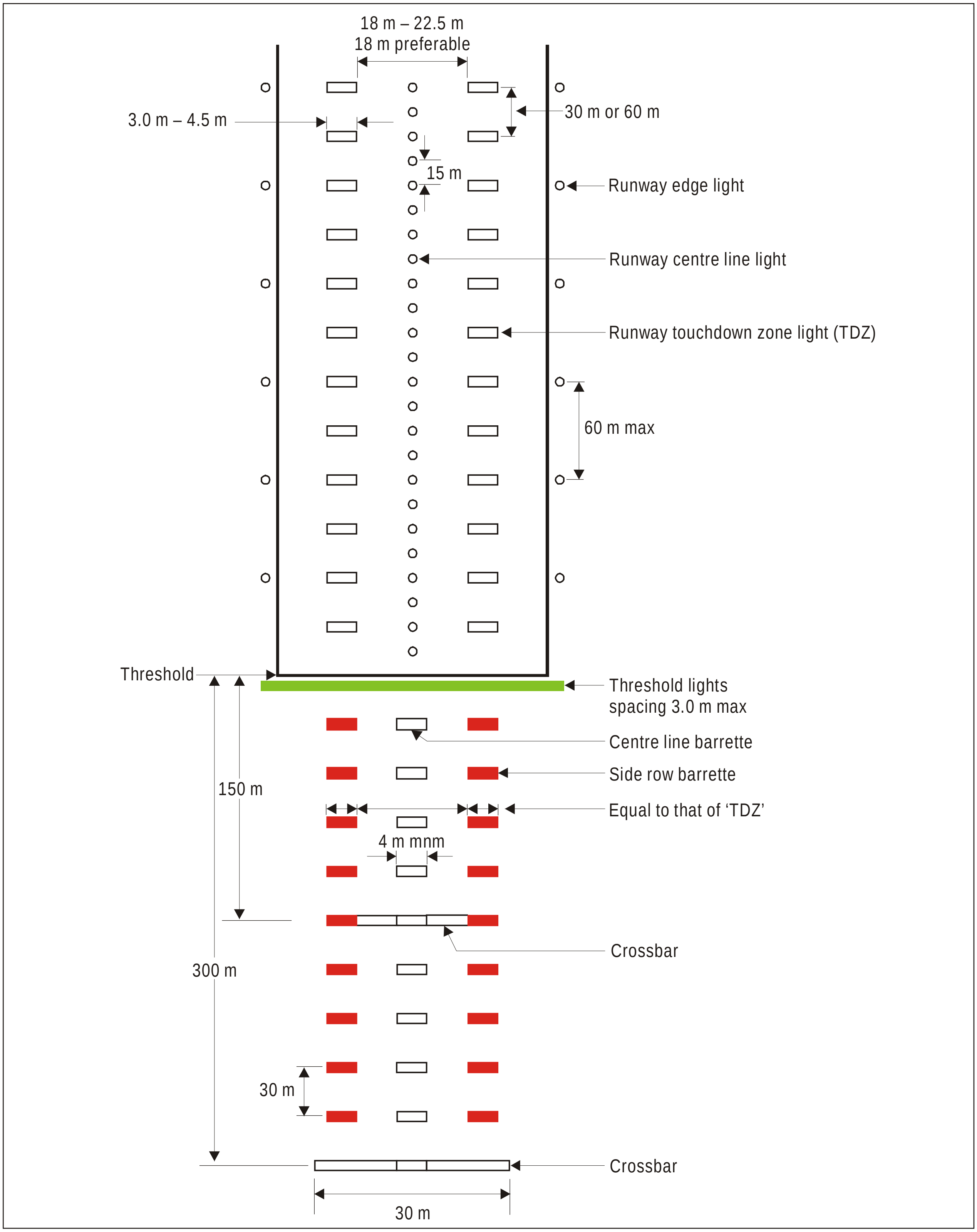
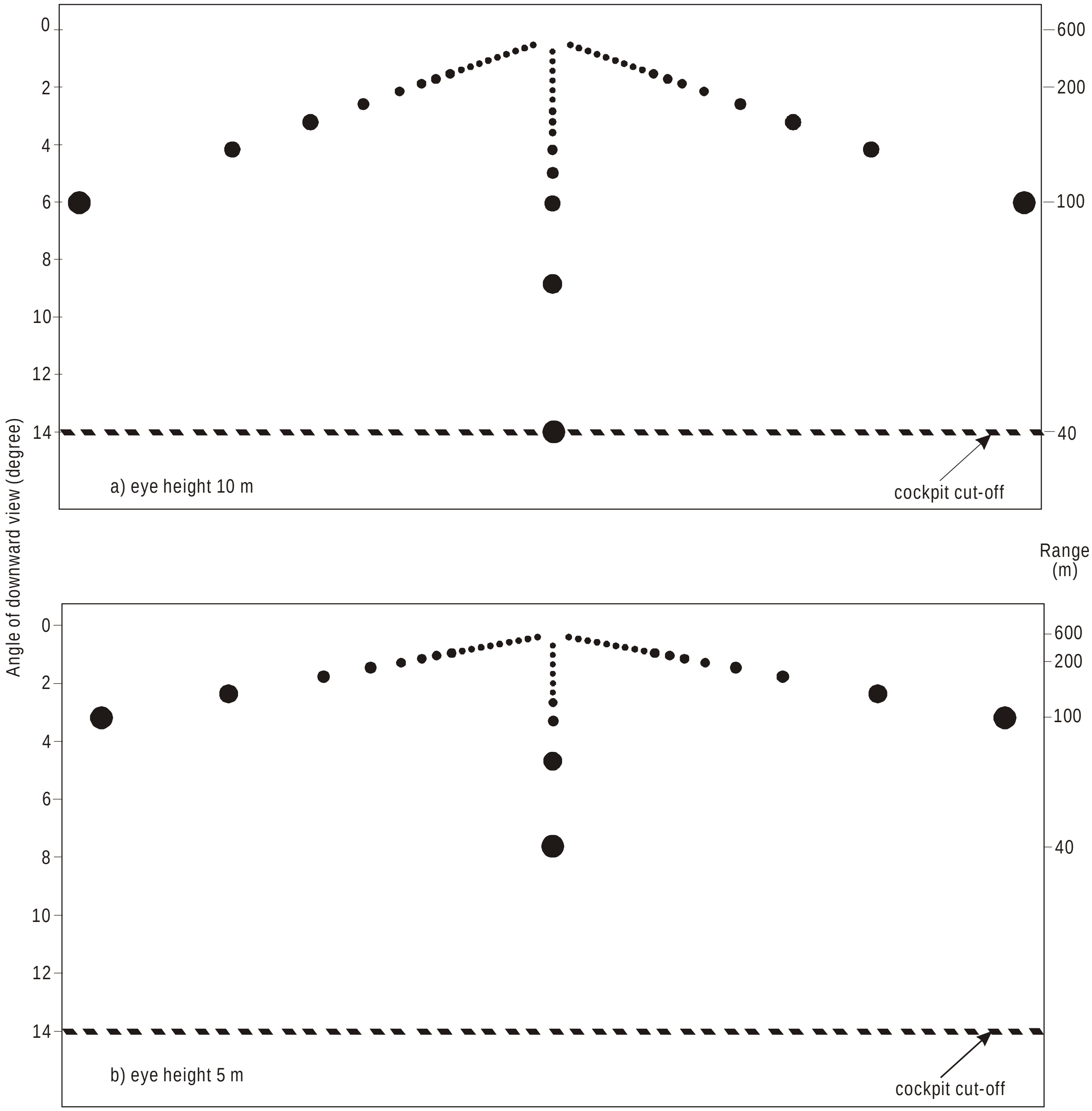


Figure 5-3. Inner 300 m approach and runway lighting for precision approach runways Categories II and III



Notes.— Edge lights : 60 m spacing
Centre line lights : 30 m spacing
Pilot eye height : 10 m and 5 m
Runway width : 60 m
Viewing distance for diagram : 30 cm

Figure 5-4. Edge and centre line lights as seen by a pilot during landing and/or take-off runs

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. Assessment of RVR by calculation should be made separately for each available runway in accordance with Annex 3, Appendix 3, 4.3.5.

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 Annex 3, Attachment A, 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, Appendix 3, 4.3.6.1;

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 (σ), meteorological optical range (MOR), transmittance (t_b) and transmissivity (T). All these parameters can be related to each other by the following equations:

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

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

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

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

In the following sections of this manual, the appropriate parameters will be selected to best represent the needs of the discussion concerned. In particular, Chapter 7, which addresses transmissometers, will utilize transmittance or transmissivity while Chapter 8, which covers forward-scatter meters, will utilize extinction coefficient. The analysis of RVR errors in Section 6.7 will use extinction coefficients that can pertain equally to transmissometers and forward-scatter meters. Since MOR is more closely related to visibility than is extinction coefficient, it will be used to compare the results of Allard’s and Koschmieder’s laws in Sections 6.4 and 6.7.

6.2.2 The atmospheric extinction coefficient (σ) or, alternatively, the atmospheric transmittance (t) are the most important factors in determining RVR from Koschmieder’s (Section 6.3) or Allard’s (Section 6.4) law. The extinction coefficient represents the attenuation of light by aerosols from two effects:

a) the scattering of light; and

b) the absorption of light.

Scattering is the dominant effect of fog and snow, which are the most prevalent weather phenomena causing reduced visibility and leading to RVR below 1 500 m. Absorption plays a larger role for haze, dust and smoke. The extinction due to both the scattering and absorption of light is measured by a transmissometer (see Chapter 7 and Appendix A). Only the extinction due to the scattering of light is estimated by a forward-scatter meter (see Chapter 8). Paragraph 8.1.1 outlines the resulting limitations of forward-scatter meter measurements.

6.3 RVR BASED ON MARKERS OR OTHER BLACK OR DARK OBJECTS

It is accepted that objects such as markers, small trees, huts, etc., can be seen by the pilot from the cockpit and identified in the assessment of visibility if the luminance contrast (*C)* with the sky or fog background is above 0.05. The maximum visual range of such black or dark objects of limited size can be calculated for this luminance contrast if the atmospheric transmittance (*t*) or extinction coefficient (σ) is known (see Appendix B, Equation 13). This calculated range, derived from Koschmieder's law, based on a luminance contrast of 0.05 is referred to as the meteorological optical range (MOR) (see Equation (2)). However, when the MOR by day exceeds the RVR based on lights, it is usually quoted as the RVR. The assumptions leading to Equation (2) may not strictly apply to actual objects and markings. Instrumented RVR values may therefore have errors that would not occur for direct human observations. Since runway lights are typically more visible than objects under conditions where RVR limits runway use, this source of error can normally be ignored.

6.4 RVR BASED ON LIGHTS

6.4.1 The following factors, which are discussed below, are taken into account in the calculation of RVR for lights:

a) the intensity of the runway edge and runway centre line lights (*I*);

b) the optical clarity of the atmosphere, expressed in terms of transmissivity (*T*) or extinction coefficient (σ); and

c) the visual threshold of illumination (E_T) of the eye that is required for a point source or small light to be visible. This is related to the measured or assumed luminance of the background against which the light is viewed.

6.4.2 The RVR based on lights is related to the factors listed in 6.4.1 by Allard's law:

$$E_T = Ie^{-\sigma R}|R^2 = IT^R|R^2 \qquad (5)$$

where *R* = visual range of light.

The derivation and the various formulations of Allard's law are included in Appendix A.

6.4.3 Allard's law in graphical form is illustrated in Figure 6-1, which plots the ratio RVR/MOR versus MOR for *I* = 10 000 cd and five values of E_T. For each value of E_T, the RVR/MOR ratio decreases almost linearly with log(MOR) for RVR/MOR > 1. These curves can be used to estimate the RVR value derived from Allard's law. For example, consider the middle curve in Figure 6-1 for $E_T = 10^{-4}$ (a daytime condition). For MOR = 1 000 m, the RVR value is about 1.3 times the MOR value. The exact value given by Table 6-1 is 1 340 m. The middle curve would also apply when *I* and E_T are both reduced by the same factor, e.g. *I* = 100 cd and $E_T = 10^{-6}$ (a night-time condition) or *I* = 1 000 cd and $E_T = 10^{-5}$ (an intermediate condition).

6.4.4 The runway light intensity is normally selected to give RVR > MOR for RVR < 1 000 m. At the lowest MOR plotted in Figure 6-1 (10 m), the RVR can be as much as five times greater than MOR (*I* = 10 000 cd and $E_T = 10^{-6}$ at night). For RVR > MOR, the RVR/MOR ratio varies regularly, with increments of 0.5 to 0.7, as *I* or E_T is varied by a factor of ten. Note that the reported RVR will be equal to MOR in the daytime when RVR obtained from Allard's law would be below MOR.

6.4.5 The relative importance of the three factors in the computation of RVR should be appreciated. For this purpose, Table 6-1 has been prepared. It must be understood that the visual threshold of

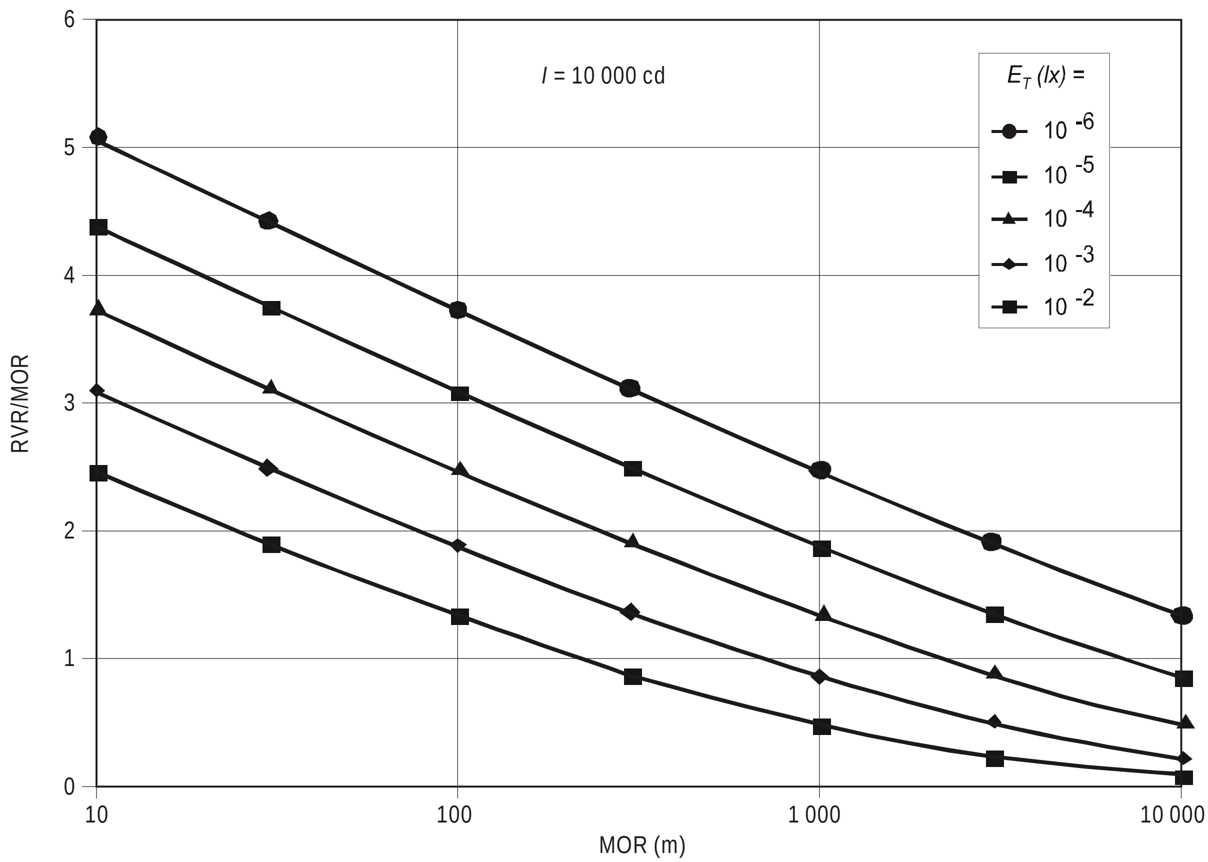


Figure 6-1. RVR/MOR ratio from Allard's law

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

illumination (E_T) can be exchanged for luminous intensity (I). For example, if E_T decreases by one order of magnitude (i.e. factor of ten), e.g. from 10^{-4} to 10^{-5} lx, then the visual range will be the same according to Allard's law, if the luminous intensity (I) is also decreased by one order. Changes in light intensity or the visual threshold of illumination have a relatively small impact on RVR. For the case $\sigma = 0.001$ m^{-1} (i.e. MOR = 3 000 m), a one-order reduction in intensity, or the same reduction in the visual threshold of illumination, produces a 44 per cent decrease in RVR from 2 654 to 1 497 m.

6.5 LIGHT AND LIGHT INTENSITY

6.5.1 As outlined in 6.4 above, the calculation of RVR for lights is based on Allard's law, according to which the distance to the furthest light just visible depends, in addition to other factors to be discussed in the next two sections, on the light intensity *I* directed by that light towards the viewer.

6.5.2 The intensity of a high-intensity runway edge light may vary from a peak value of 15 000 cd in the centre, to as low as 5 000 cd on the periphery of the main beam[1]. The intensity of a runway centre line light may vary in a similar fashion, although the values are lower. The recommended performances of runway edge and runway centre line lights are given in Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations* and in the *Aerodrome Design Manual*, Part 4 — *Visual Aids* (Doc 9157). The specified characteristics represent the minimum beam dimensions and intensities at maximum nominal rating. In practice, manufactured lights are designed to exceed the recommended minimum intensities by a considerable margin. However, this margin is offset to some extent by manufacture and installation tolerances and underrunning of the lamps. In RVR calculations, use should not be made of the nominal light intensity that refers to a typical new light; it is necessary, instead, to decrease such values owing to contamination and aging; decreases of 20 per cent for runway edge lights and 50 per cent for runway centre line lights were suggested by the Fifth Meeting of the Visual Aids Panel (1970). It should be noted that runway centre line lights may be covered partly by snow or sand in adverse weather conditions. Also, during heavy snow or sandstorm, the drifting snow and sand may reduce the light intensity, and the values used in computing RVR may be significantly greater than those observed by the pilot.

6.5.3 Pilots see each runway edge and centre line light at different horizontal and vertical angles, depending on their distance from each light and from the centre line of the runway. They will therefore receive from each runway edge and centre line light a different light intensity, in accordance with that portion of the beam of the light which is in their line of sight. From the known characteristics of the lights, and taking into account the effect of elevation setting angle and, in the case of edge lights, the toe-in angle, the beam intensity directed towards the pilot can be determined. The toe-in angles of edge lights are 4.5 and 3.5 degrees for 60 and 45 m-wide runways, respectively. Normally, the elevation angle of centre and edge lights is 3.5 degrees. For the purpose of illustration, isocandela diagrams[2] for runway edge and centre line lights are given in Figures 6-2 and 6-3, respectively, in which the locations of the pilot's eyes within the beams at various ranges and for eye heights of 5 and 10 m are indicated. The light intensity along the eye-height lines is replotted as a function of range in Figures 6-4 through 6-6:

a) Figure 6-4 gives the variation in runway edge light intensity directed towards the pilot with range when the pilot is on the runway centre line. Two curves are plotted for eye heights of 5 and 10 m;

1. These figures are based on intensities recommended by ICAO. The guidance material in this section does not apply where lights of very different intensities are used.
2. These diagrams result from interpretations of the isocandela diagrams specified in Appendix 2 to Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations*. Manufactured lights may have a significantly different performance.

b) Figure 6-5 shows the runway centre line light intensity for the pilot located on the runway centre line; and

c) Figure 6-6 shows the runway centre line light intensity for the pilot displaced 5 m from the runway centre line.

The difference in intensity between eye heights of 5 and 10 m is not significant.

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:

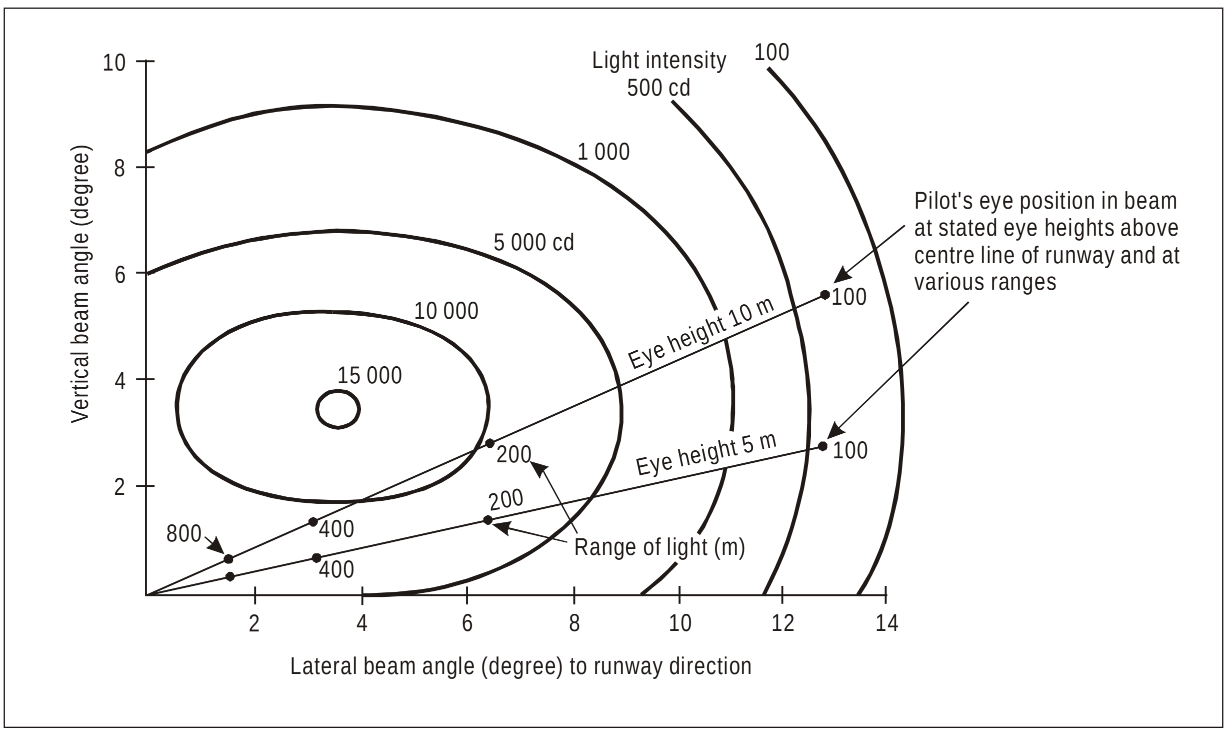


Figure 6-2. Isocandela contours for runway edge light (new light at maximum intensity setting) showing the position of pilot's eyes in the beam at various ranges and heights above centre line of runway

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.

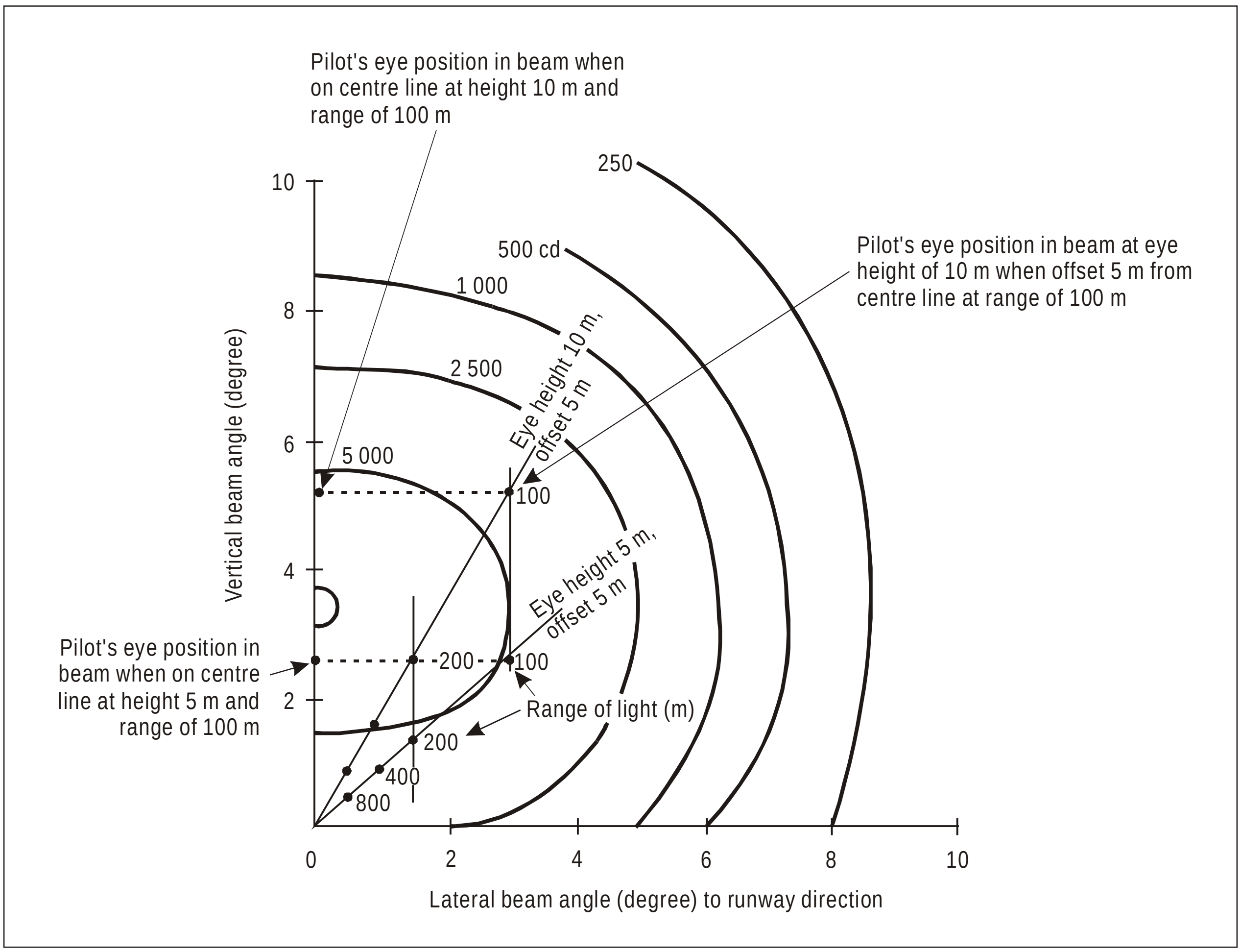


Figure 6-3. Isocandela contours for a runway centre line light (new light at maximum intensity setting) with 30 m longitudinal spacing showing the position of pilot's eyes in the beam at various eye heights and distances

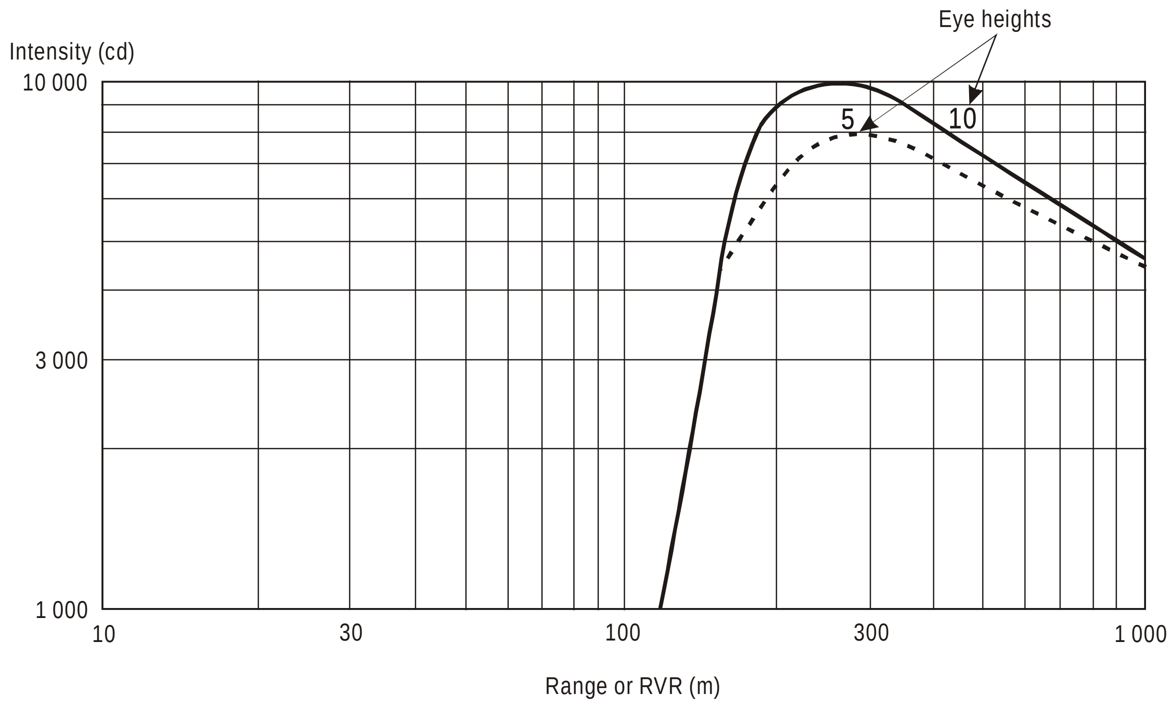


Figure 6-4. Runway edge light intensity viewed by pilot on centre line (for new light at maximum intensity setting)

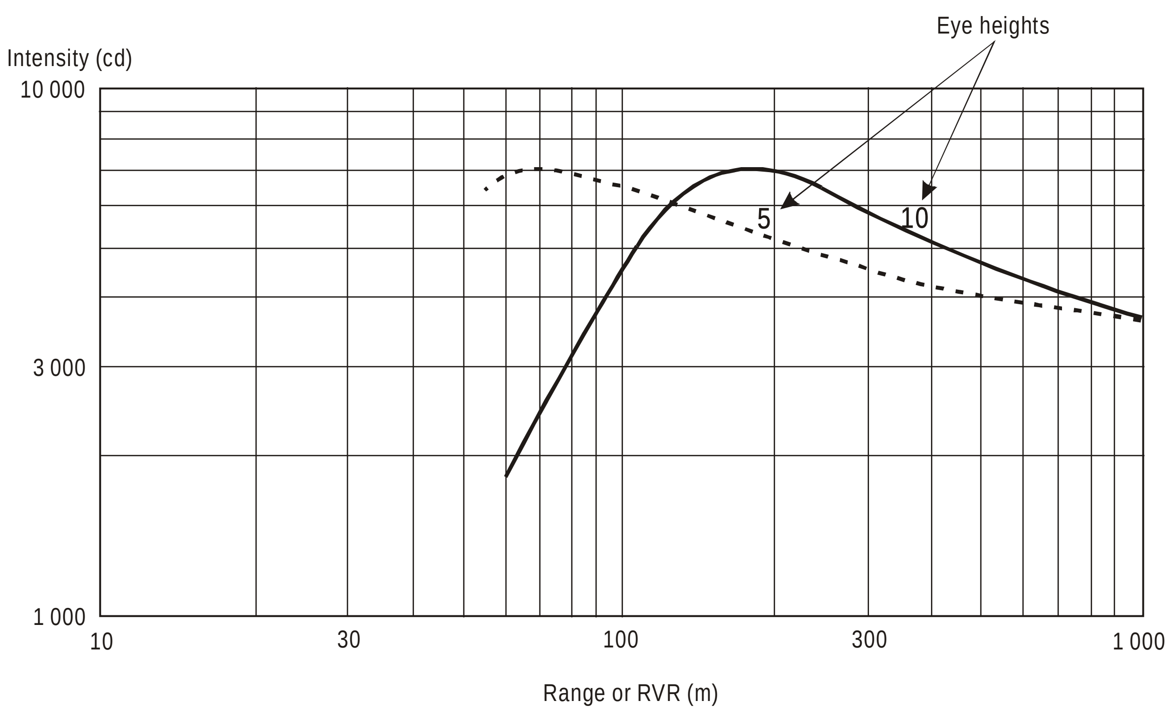


Figure 6-5. Runway centre line light intensity viewed by pilot on centre line (for new light at maximum intensity setting)

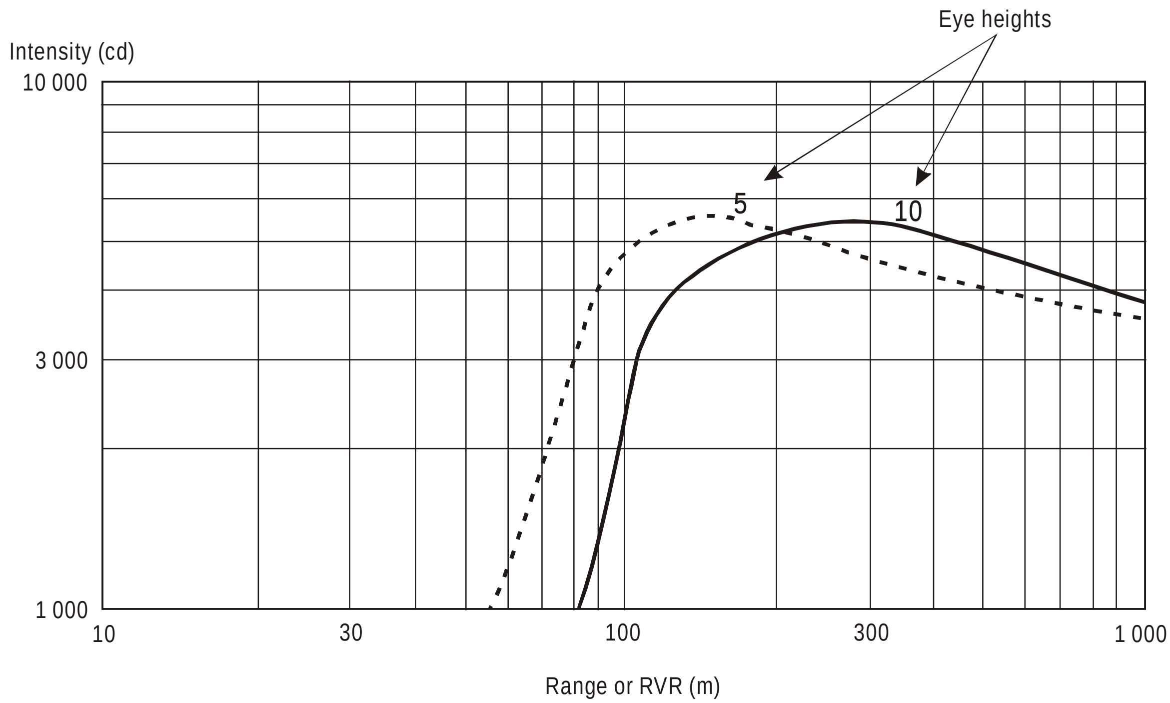


Figure 6-6. Runway centre line light intensity: from 5 m off centre line (for new light at maximum intensity setting)

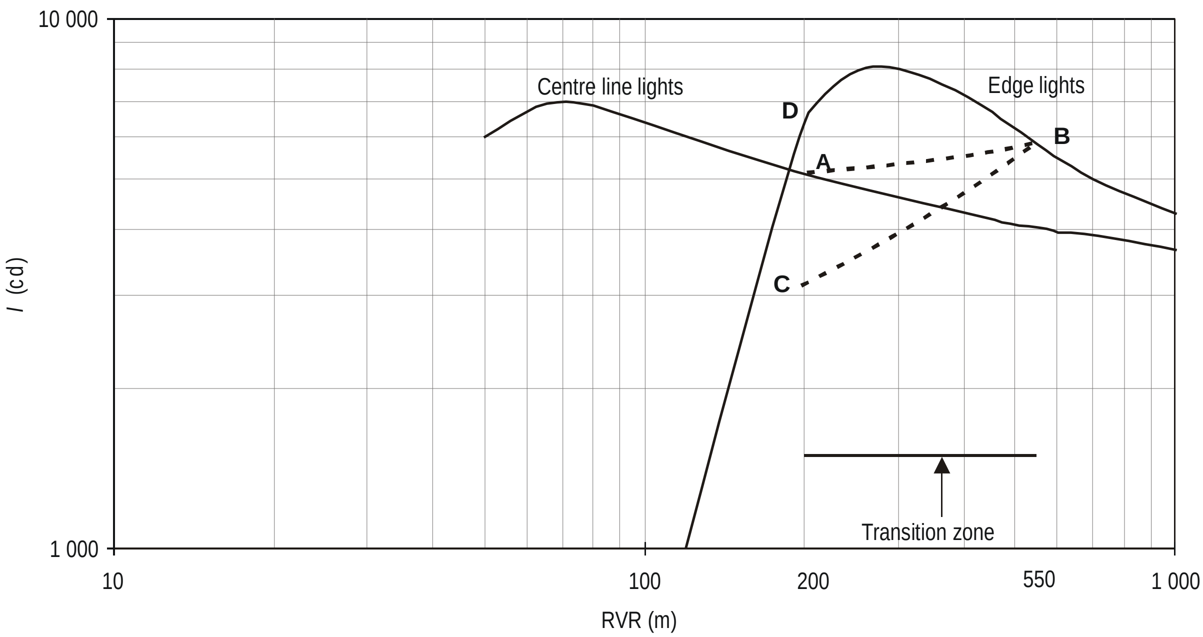


Figure 6-7. Figures 6-4 and 6-5 combined for 5-m eye height

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. For precision approach runways using matched intensities of runway centre line and edge lights, the need for interpolation is significantly reduced. Note that if runway centre line lights do not exist or are turned off or down, the same algorithm should still be used to account for the decreasing utility and intensity of runway edge lights at low RVR.

Note.— Additional guidance for the case in which runway centre line lights are not available is provided in Table 6-3.

6.5.5 In calculating RVR in accordance with 6.5.4 above, polar isocandela diagrams must be constructed for the runway centre line and edge lights as described in 6.5.3 above; the intensity derived from the diagrams is used in the calculation of RVR. Figure 6-7 illustrates this process by comparing the light intensity directed towards the pilot at an eye height of 5 m by the edge and centre line lights.

Note.— In the past, in order to simplify RVR assessment, some States, instead of using the directed light intensity values, calculated an average light intensity value for all lights on the runway. However, the Visual Aids Panel (VAP), at its eleventh meeting (1987), agreed that the average intensity concept to define light intensity distribution was imprecise and should be replaced by appropriate isocandela diagrams (see Figures 6-2 and 6-3) which have since been included in Annex 14.

6.5.6 Generally, RVR is determined for three intensity settings corresponding to the intensity set by the control tower (although additional settings may be available). Typically these settings are 100 per cent, 30 per cent and 10 per cent. Whatever intensities are used, it is undesirable for RVR to be computed for an intensity of 3 per cent or less of the maximum setting (Annex 3, Appendix 3, 4.3.5 refers). This is due to the variations in human 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, Appendix 3, 4.3.5 a) and b), require that in local routine reports and local special reports computation of RVR should be based on:

a) the light intensity actually in use on the runway if a light intensity of more than 3 per cent of the maximum light intensity is available; and

b) the optimum light intensity that would be appropriate for operational use in the prevailing conditions if a light intensity of 3 per cent or less of the maximum light intensity is available.

In accordance with Annex 3, Appendix 3, 4.3.5 c), for a runway with the lights switched off (or at the lowest setting pending resumption of operations), the computation of RVR in local routine reports and local special reports 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 do not apply to RVR values included in METAR and SPECI where the value reported should be based on the maximum light intensity available on the runway.

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.

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.* 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); 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); Let MOR_t be the measured MOR (which may be directly computed from the sensor output). Note that $MOR_t < MOR_{550}$ and $MOR_t > MOR_{200}$; Compute α such as $MOR_t = \alpha \times MOR_{550} + (1 - \alpha) \times MOR_{200}$. Then the final value of $RVR = \alpha \times 550 + (1 - \alpha) \times 200$.

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).* 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); Calculate MOR_{200} corresponding to RVR = 200 m with the actual background luminance and the reduced intensity of edge lights; 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.

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.

6.6 VISUAL THRESHOLD OF ILLUMINATION (E_T)

6.6.1 In order for a light to be seen, it has to illuminate the eye to a level above the illumination threshold for detection (E_T) — see Appendix A. The threshold is not constant but is affected by a number of factors, the chief of which is the background luminance, i.e. the brightness of the background against which the light is seen.

6.6.2 With a view to achieving some degree of comparability between RVR values from different aerodromes, the illumination thresholds shown in Table 6-4 were proposed as guidance material by the All Weather Operations Panel at its Fourth Meeting (1971).

6.6.3 The four illumination thresholds are nearly equally spaced on a logarithmic scale and are convenient for use in the computation of RVR.

6.6.4 The above-mentioned relationship between illumination threshold and background luminance is illustrated in Figure 6-8. The scale of background luminance from left to right goes from the darkest night to the brightest day fog. The illumination threshold varies by more than three orders of magnitude, that is to say, over 1 000 times between darkness and bright day fog.

6.6.5 Some States use the stepped values of illumination threshold as given Table 6-4 and illustrated in Figure 6-8. The number of steps may depend on geographical location (i.e. length of twilight). Switching from one threshold value to another is sometimes done automatically in conjunction with monitoring of background luminance by a sensor.

6.6.6 In view of the large changes in E_T between each of the four steps in Figure 6-8, the opinion is held in several States that background luminance should be monitored and E_T obtained from a continuous relationship such as the curve in Figure 6-8. The smooth curve in this figure can be approximated by the equation (E_T in lux (lx)):

$$\log (E_T) = 0.57 \log (B) + 0.05[\log(B)]^2 - 6.66 \qquad (6)$$

Using this equation, values of the illumination threshold of E_T below $8 \cdot 10^{-7}$ lx should be taken as $8 \cdot 10^{-7}$ lx to take into account the fact that the cockpit is never completely dark. Equation (6) has been derived from the step values in Table 6-4 by finding a curve that intersects the steps in the middle. Paragraph 6.7.9 presents the errors generated by using the stepped relationship. The opinion has also been expressed that while the slope of the curve may be well founded, its vertical location in Figure 6-8 may not be the optimum for a number of reasons. For example, it may be satisfactory with regard to an observer on the ground, but higher thresholds may be applicable to pilots because of the effect of viewing through a windscreen (see Appendix C). Further research into illumination threshold questions appears to be desirable (see Appendix G).

6.6.7 Doubts have been expressed whether the recommended values of the illumination threshold are always representative. For example, the background luminance at night increases as fog becomes denser due to the forward scatter of light from runway approach and lighting systems. To counteract this effect, some States reduce the intensity setting of the lights at night in low visibility. This has the connected advantage of reducing background luminance without any marked effect on RVR. Even so, experience has shown that at the lower end of Category III at night, when the lights are at the 100 per cent setting, the background luminance conditions might perhaps be better represented by a threshold of 10^{-5} lx than by the recommended value of approximately 10^{-6} lx which is intended to apply to good visibility conditions at night and low or moderate light intensities.

Table 6-4. Illumination threshold steps

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

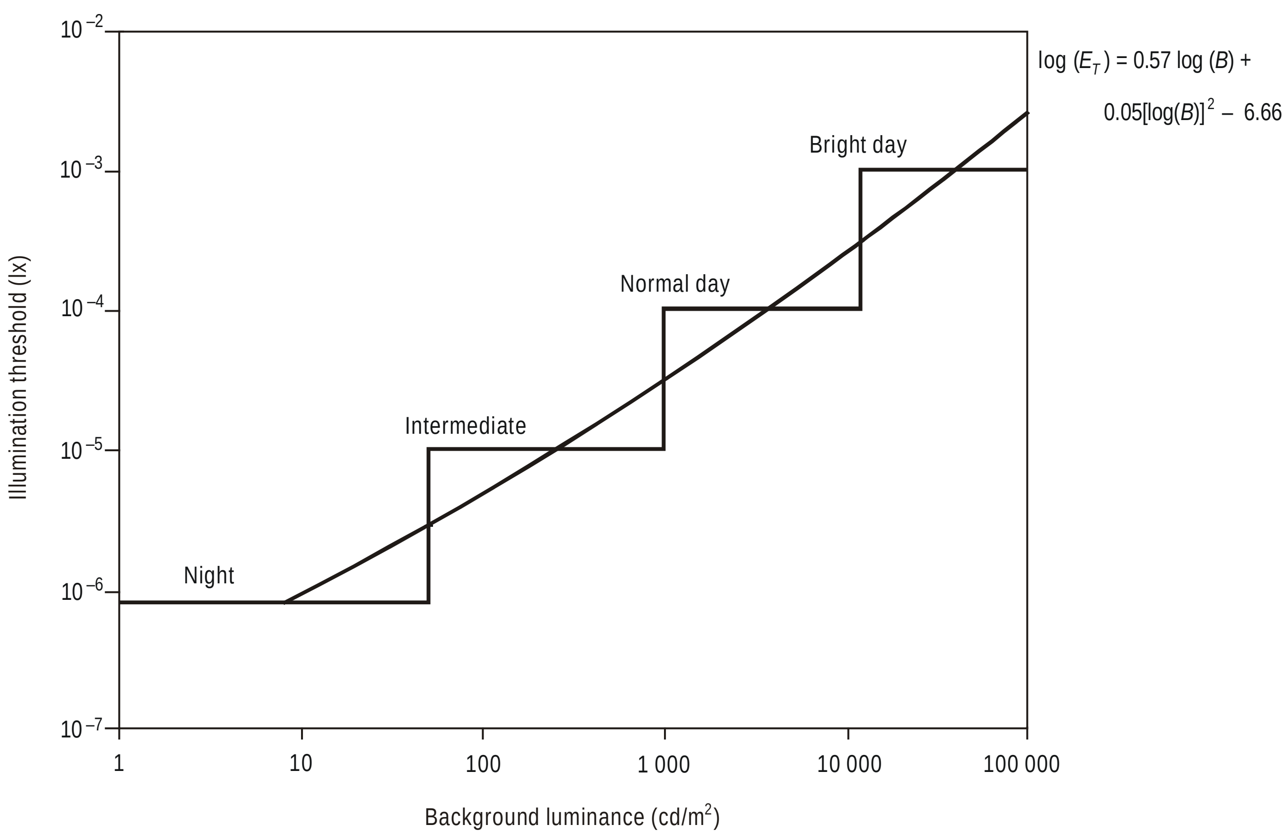


Figure 6-8. Relationship between the illumination threshold E_T (lx) and background luminance B (cd/m²)

6.7 ACCURACY OF RVR ASSESSMENT

6.7.1 In an automatic RVR system, the RVR is typically calculated (see 9.1.4) using both Koschmieder's law (Appendix B) and Allard's law (Appendix A); the reported RVR value is taken as the greater of the two values. Figure 6-9 shows which law gives the greater RVR value as a function of RVR and background luminance (using Equation 6 for E_T). The two curves show the boundaries between the two laws for two runway light intensities (1 000 and 10 000 cd). For a given light intensity curve, if the RVR value and background luminance point lies above the curve, the RVR was determined by Koschmieder's law (RVR = MOR). If the point lies below the curve, the RVR was determined by Allard's Law (RVR > MOR). For example, consider a background luminance value of 1 000 cd/m^2. For a runway light intensity of 1 000 cd, Allard's law will apply for RVR < 1 100 m and Koschmieder's law for RVR > 1 100 m. If the runway light intensity is increased to 10 000 cd, the break point between the two laws increases to RVR = 4 000 m. Since the operational RVR limits are 800 m (Category I) or below, Allard's law will apply to airport operations except under the very brightest background luminance conditions for the typical maximum runway edge light intensity of 10 000 cd. Koschmieder's law may become important for the operational RVR limits when the runway lights are not at maximum intensity.

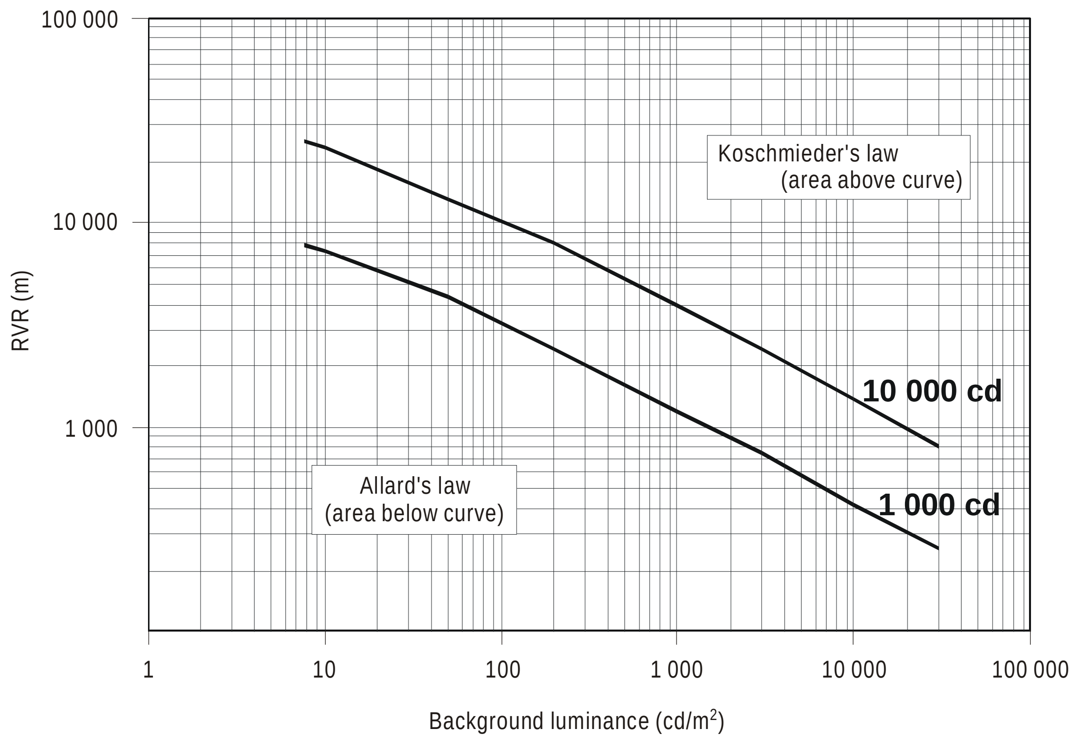


Figure 6-9. Breakpoint between Koschmieder's law and Allard's law for light intensities of 1 000 and 10 000 cd

6.7.2 RVR is calculated from the three measured parameters σ, *I* and *B* that are listed in Table 6-5. Both Allard's and Koschmieder's laws are affected by errors in the value of σ. Only Allard's law is affected by errors in *I* and *B*. For a given percentage measurement error, the RVR value is much more sensitive to errors in σ than to errors in *I* and *B*. Consequently, the performance of the instrument measuring the extinction coefficient σ has received more attention than the runway light intensity determination and the performance of the background luminance meter. Furthermore, the attainable accuracy values included in Annex 3, Attachment A (see 6.7.4) should be better for visibility than for RVR since the errors in *I* and *B* affect only RVR, not visibility. Although a given error in *I* and *B* has less impact than an error in *σ*, the variations in *I* and *B* may become large enough to have an influence on RVR accuracy comparable to the variation in σ. The analysis of RVR accuracy will be presented in two stages, as indicated in Table 6-5. First, the accuracy of the parameter measurement will be addressed. Second, the impact of parameter errors on RVR as calculated using Koschmieder's or Allard's law will be presented. Table 6-5 lists the paragraphs containing these presentations. Note that, since Allard's law is usually operative when RVR is low enough to limit airport operations and RVR accuracy depends on the independent errors of three parameters for Allard's law, no simple relationship can be defined to relate the overall RVR accuracy to sensor accuracy or to define sensor accuracy requirements in terms of RVR accuracy requirements.

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 (σ) 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*);

Table 6-5. Parameters affecting RVR calculation.
Numbers refer to paragraphs where the material is presented

Parameter	*Measurement accuracy*	*Koschmieder's law*	*Allard's law*
Extinction coefficient (σ)	6.7.4	6.7.5	6.7.6
Runway light intensity (*I*)	6.7.7		6.7.8
Background luminance (*B*)	6.7.9		6.7.10

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:

a) The attainable accuracies for visibility and RVR in Attachment B of Annex 3 were provided by the World Meteorological Organization. They are understood to reflect attainable accuracies in extinction coefficient (σ) measurements (see 6.7.2), or alternatively in MOR (see Equation 2 for the relationship between σ and MOR).

b) The attainable accuracies for transmissometers are discussed in Section 7.4.

c) The attainable accuracies for forward-scatter meters are discussed in Section 8.4.

6.7.5 Errors in the measured extinction coefficient are the only instrumental error affecting Koschmieder's law (Appendix B). For moderate errors, the fractional error in RVR is the same as the fractional error in extinction coefficient.

6.7.6 Errors in the measured extinction coefficient have a more complex effect on Allard's law. The fractional error in RVR is smaller than the fractional error in extinction coefficient. Figure 6-10 shows the ratio of the magnitude of the RVR fractional error to the fractional error in the extinction coefficient as a function of background luminance and RVR for 10 000 cd runway light intensity. The ratio of RVR error to extinction coefficient error decreases with increasing background luminance to a minimum value of 0.6 (see Appendix F), where the lights become less visible than black objects and Koschmieder's law applies rather than Allard's law. In Figures 6-11 and 6-12, for light intensities of 10 000 and 1 000 cd, respectively, the relationship between fractional RVR error and fractional extinction coefficient error is expanded and plotted against MOR rather than against background luminance. The range of plots in Figures 6-11 and 6-12 is for background luminance from 7 to 30 000 cd/m^2. The ratio of RVR error reaches a lower limit of 0.6 at the transition from Allard's law to Koschmieder's law where RVR = MOR. For I = 10 000 cd, this limit is reached only for RVR = 1 000 m. For I = 1 000 cd, the limit is reached for both 300 and 1 000 m.

6.7.7 Light intensity varies with viewing angle as discussed in Section 6.5. Within the normal viewing angles, the intensity variation for new lamps is slightly less than a factor of two from the nominal intensities of the edge (10 000 cd) and centre line lights (5 000 cd). Lamp aging and external window contamination or degradation can result in additional reductions in light intensity. Since the centre line lights are imbedded in the runway pavement, they are particularly susceptible to contamination losses. The combination of angular variations and aging and contamination losses may readily lead to total light intensity losses as large as a factor of four. Most States (see Section 6.5) make some allowances for these various sources of light reduction and choose to calculate Allard's law with a lower limit light intensity (see 6.5.2) that will give a conservative RVR value (i.e. lower than expected for new, clean lights). Current practice for light replacement and cleaning may not include a systematic programme of ensuring that runway light intensities are kept above the lower intensity limit used for the RVR calculation.

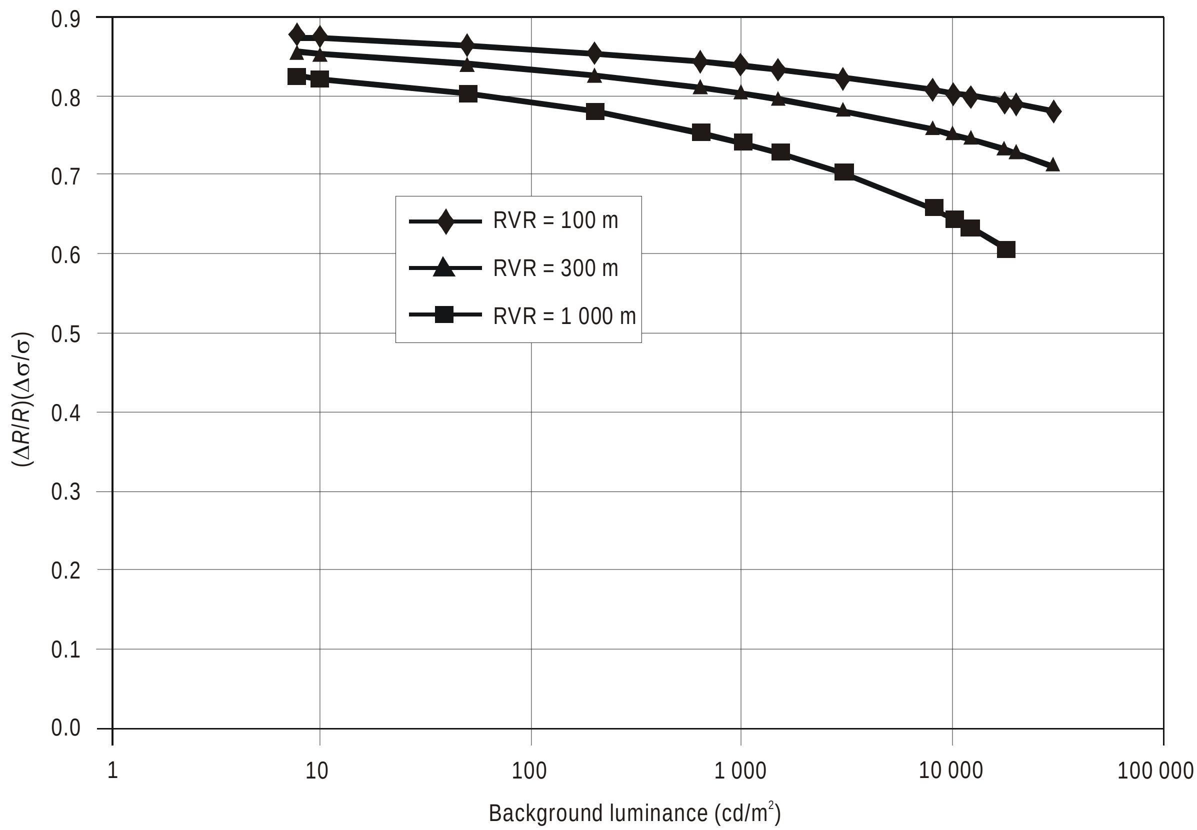


Figure 6-10. Ratio of fractional RVR error (Δ*R/R*) to fractional extinction coefficient error (Δσ/σ) for Allard's law for runway light intensity of 10 000 cd

6.7.8 The effect of errors in light intensity on RVR depends upon how rapidly the light intensity decays with distance in Allard's law (Appendix A). Intensity variations have a larger effect for the slow decay of beam spreading (inversely with range squared) and a smaller effect for rapid decay via exponential attenuation. For example, in clear air ($\sigma = 0$) if I is reduced by a factor of four, Allard's law (Equation 5) gives a reduction in R by a factor of two, which is large. On the other hand, for daytime $E_T = 10^{-4}$, $\sigma = 92\ \text{km}^{-1}$, and $I = 10\ 000$ cd, R is 100.1 m. If I is reduced by a factor of four to 2 500 cd, R is 87.8 m, a 12.2 per cent reduction, which is relatively small. Figures 6-13 and 6-14 are similar to Figures 6-11 and 6-12 and show the effects of small fractional errors in intensity on the fractional error in RVR. The ratios increase with MOR and reach the upper limit of 0.2 at the transition from Allard's law to Koschmeider's law (Appendix F). Note that, since light intensity and illumination threshold enter inversely in Allard's law, the ratio of RVR errors to illumination threshold errors have the same absolute values as shown in Figures 6-13 and 6-14. Light intensity errors large enough to have a significant effect on RVR are too big for the differential analysis of Figures 6-12 and 6-13. Consequently, Figures 6-15 and 6-16 are provided to illustrate how intensity reduction factors of four and two reduce RVR for assumed light intensities of 10 000 and 1 000 cd, respectively. Equation 6 is used to determine the value of E_T from the background luminance (B). The RVR errors are plotted for three representative values of RVR: 100, 300 and 1 000 m. When the runway light intensity is smaller than assumed in the RVR calculations, the reported RVR value is larger than the actual RVR value. The figures illustrate 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 two. In some cases, however, the increased background luminance reaches the region (see Figure 6-9) where the RVR is determined by Koschmieder's law; in this case, the reduction in RVR with change in light intensity drops to zero since Koschmieder's law has nothing to do with runway lights.

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).

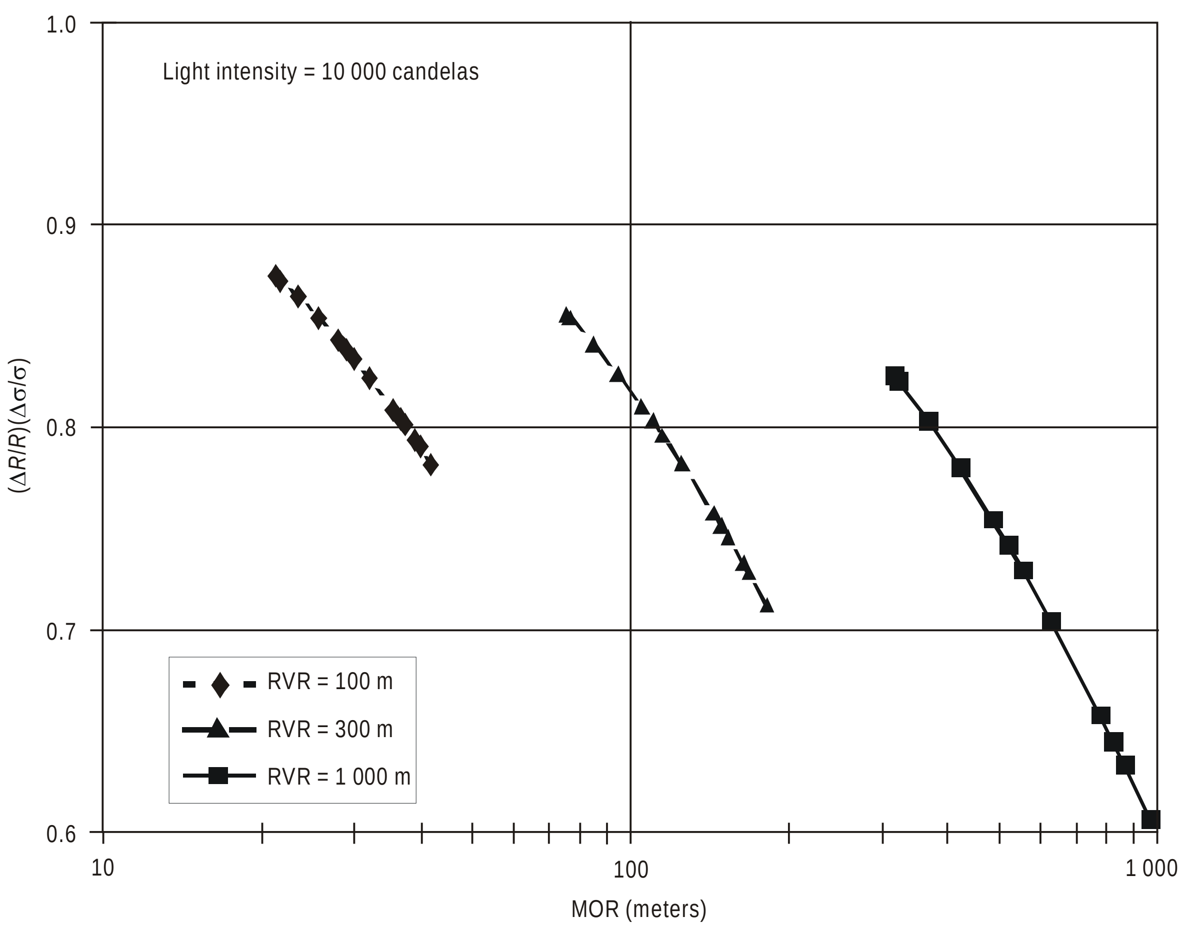


Figure 6-11. Ratio of fractional RVR error (Δ*R/R*) to fractional extinction coefficient error (Δσ/σ) for light intensity of 10 000 cd

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.

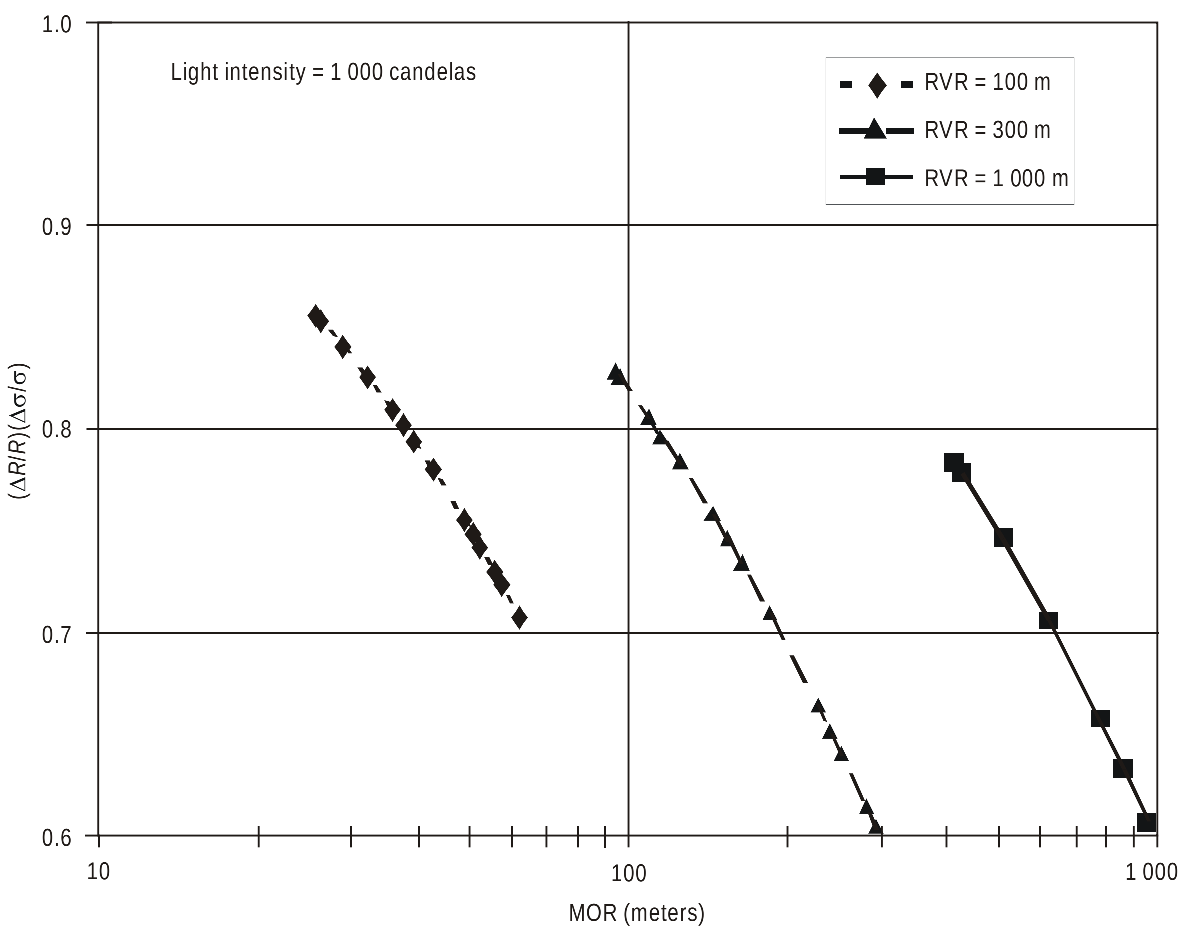


Figure 6-12. Ratio of fractional RVR error ($\Delta R/R$) to fractional extinction coefficient error ($\Delta\sigma/\sigma$) for light intensity of 1 000 cd

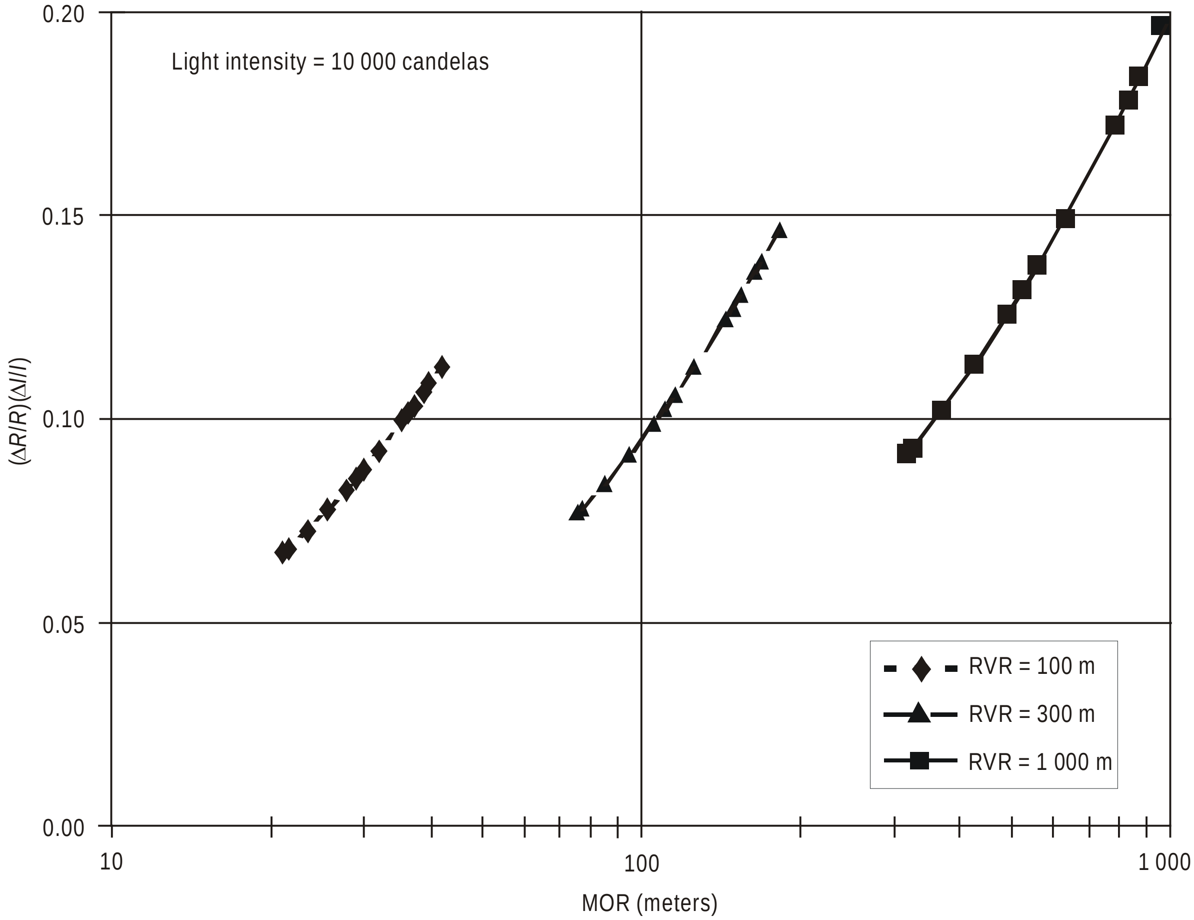


Figure 6-13. Ratio of fractional RVR error (Δ*R/R*) to fractional light intensity error (Δ*I/I*) for light intensity of 10 000 cd

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

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.

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

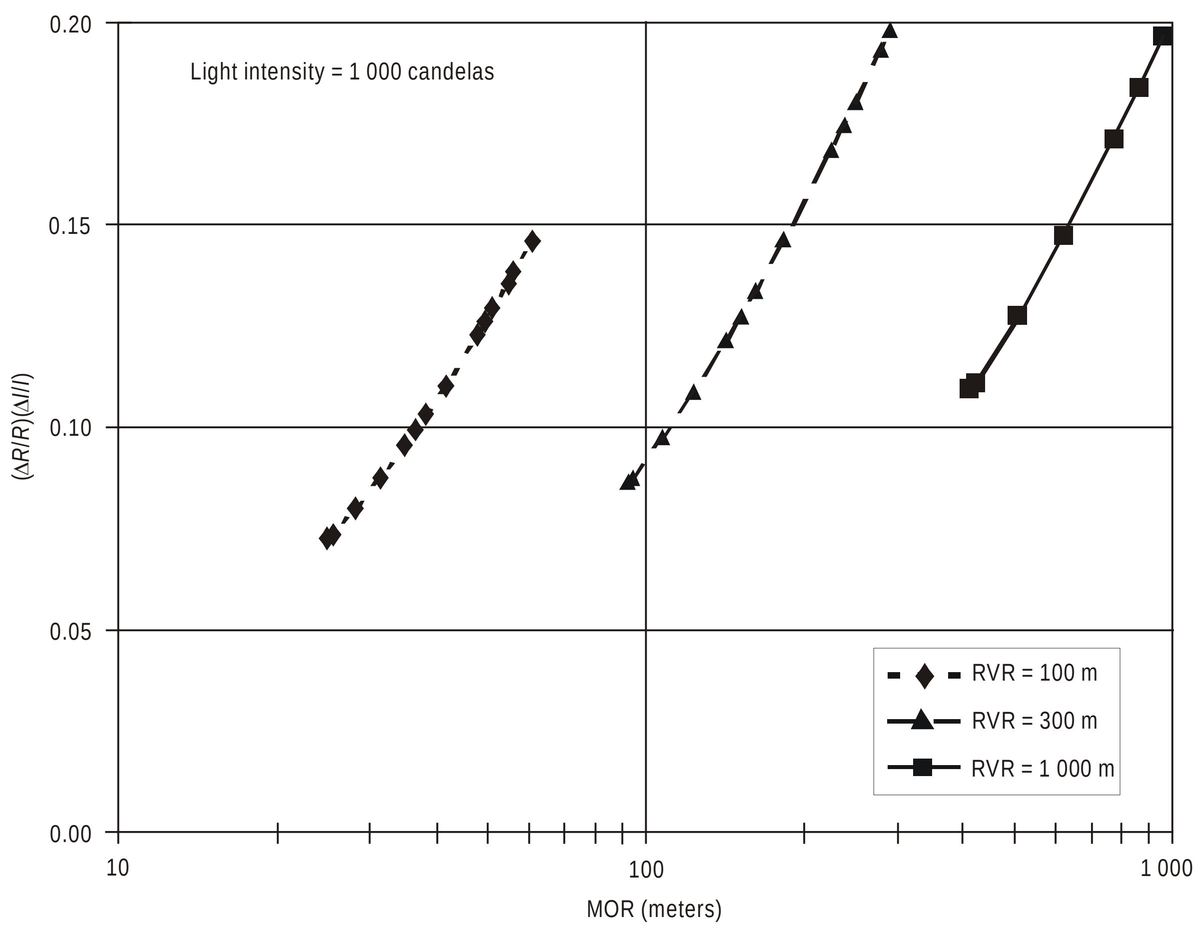


Figure 6-14. Ratio of fractional RVR error ($\Delta R/R$) to fractional light intensity error ($\Delta I/I$) for light intensity of 1 000 cd

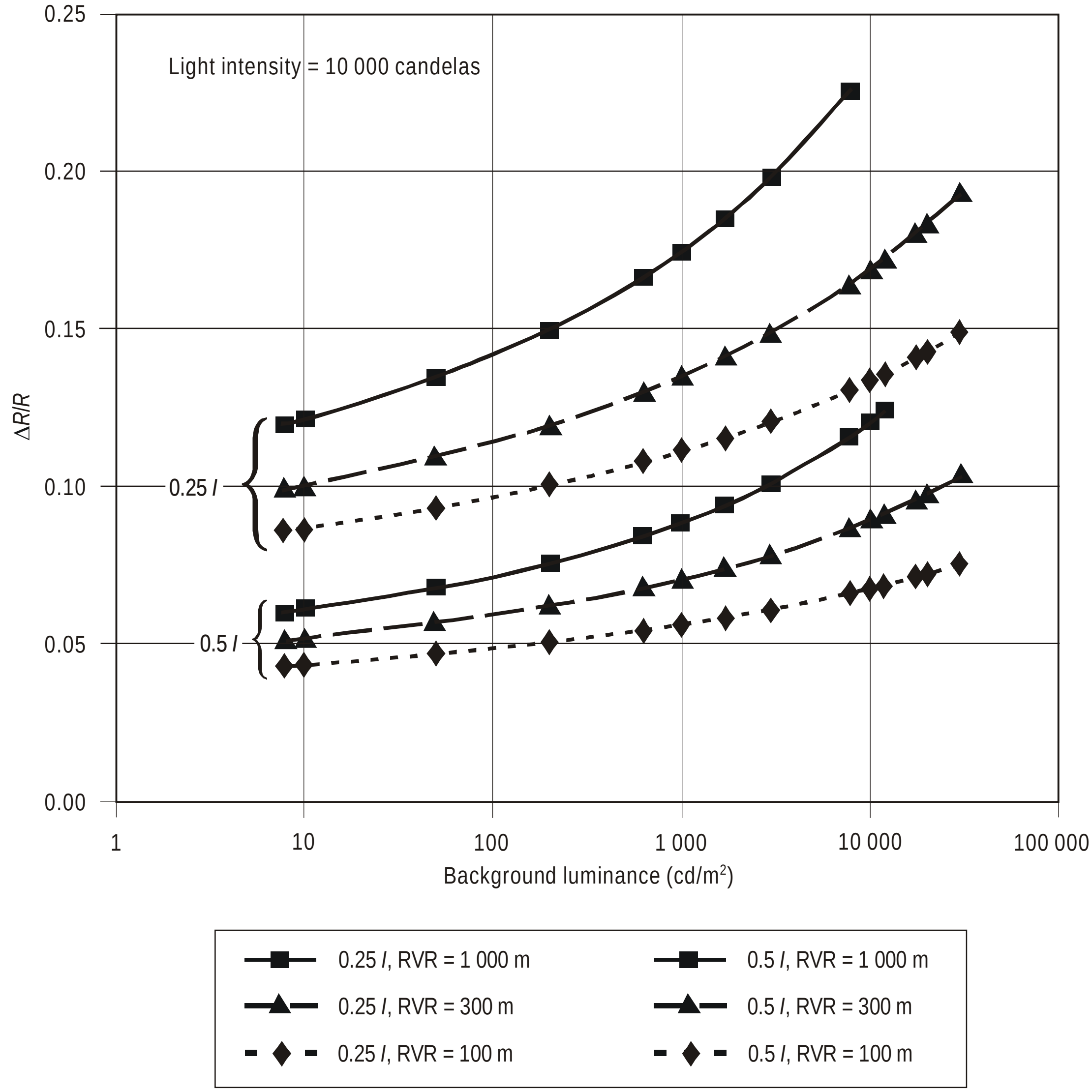


Figure 6-15. Fractional reduction in RVR (Δ*R/R*) for reductions in runway light intensity by factors of four (0.25 *I)* and two (0.5 *I*) from assumed intensity of 10 000 cd

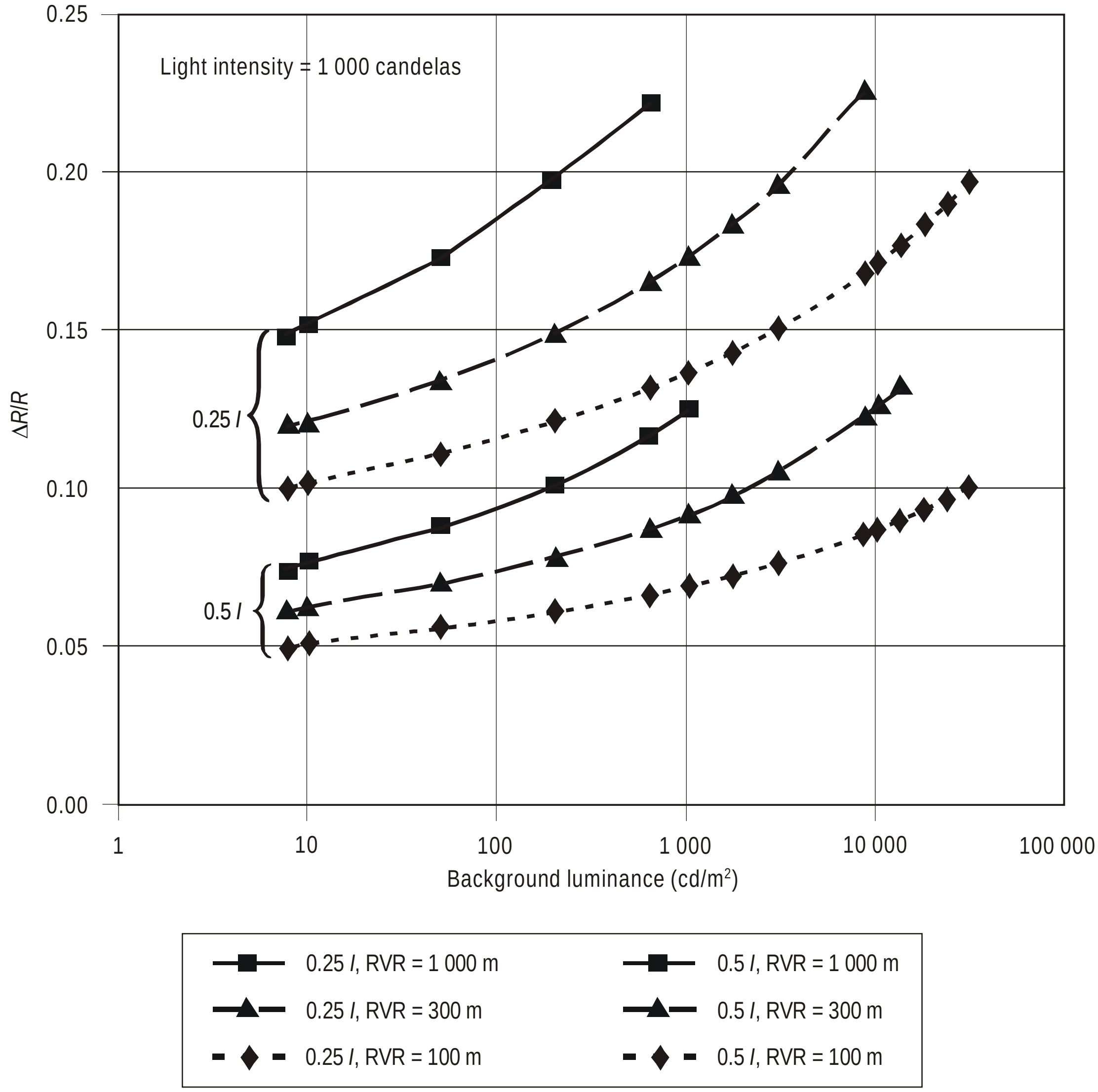


Figure 6-16. Fractional reduction in RVR (Δ*R/R*) for reductions in runway light intensity by factors of four (0.25 *I*) and two (0.5 *I*) from assumed intensity of 1 000 cd

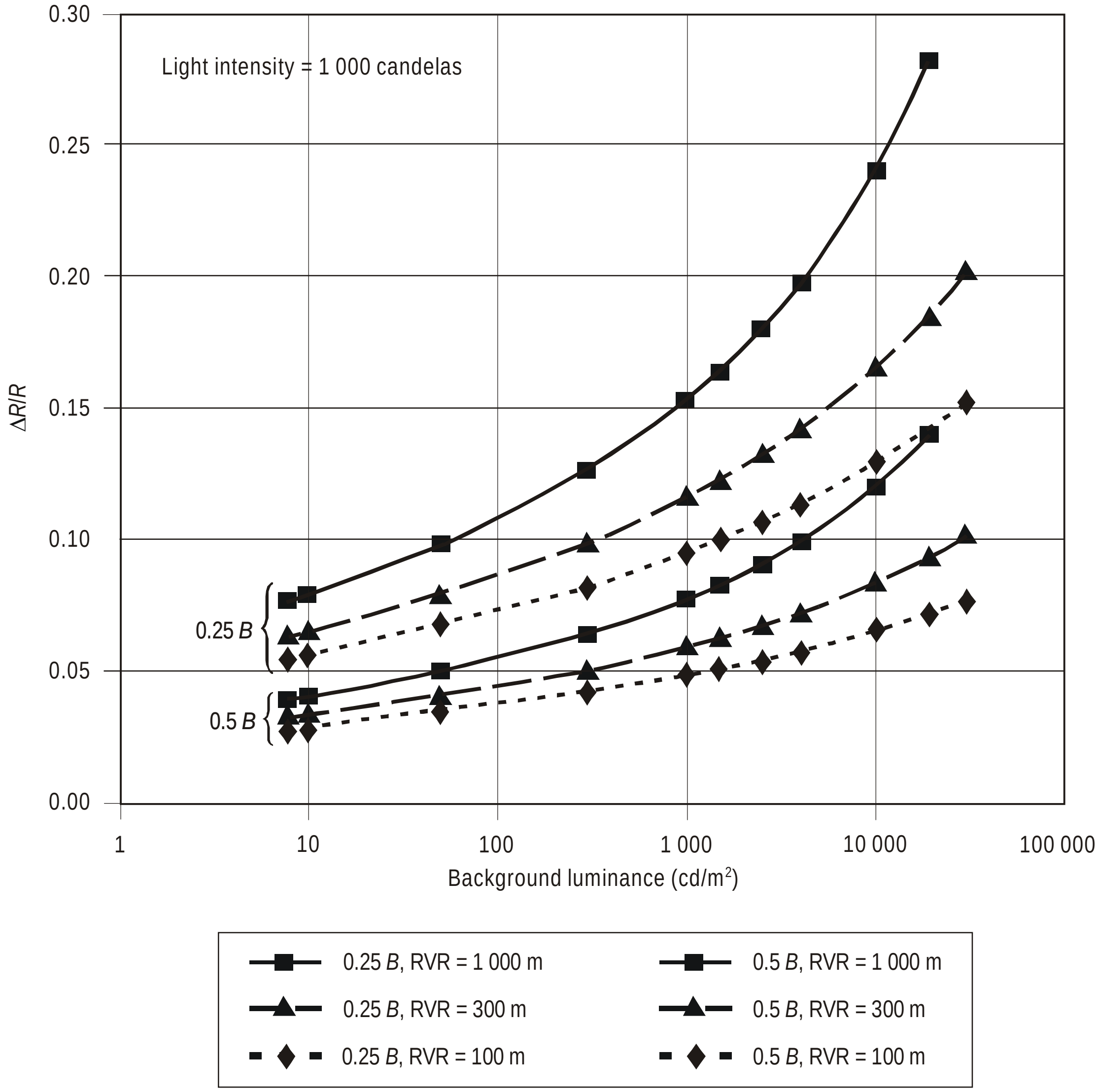


Figure 6-17. Fractional increase in RVR ($\Delta R/R$) for reductions in measured background luminance by factors of four (0.25 *B*) and two (0.5 *B*) from runway light intensity of 10 000 cd

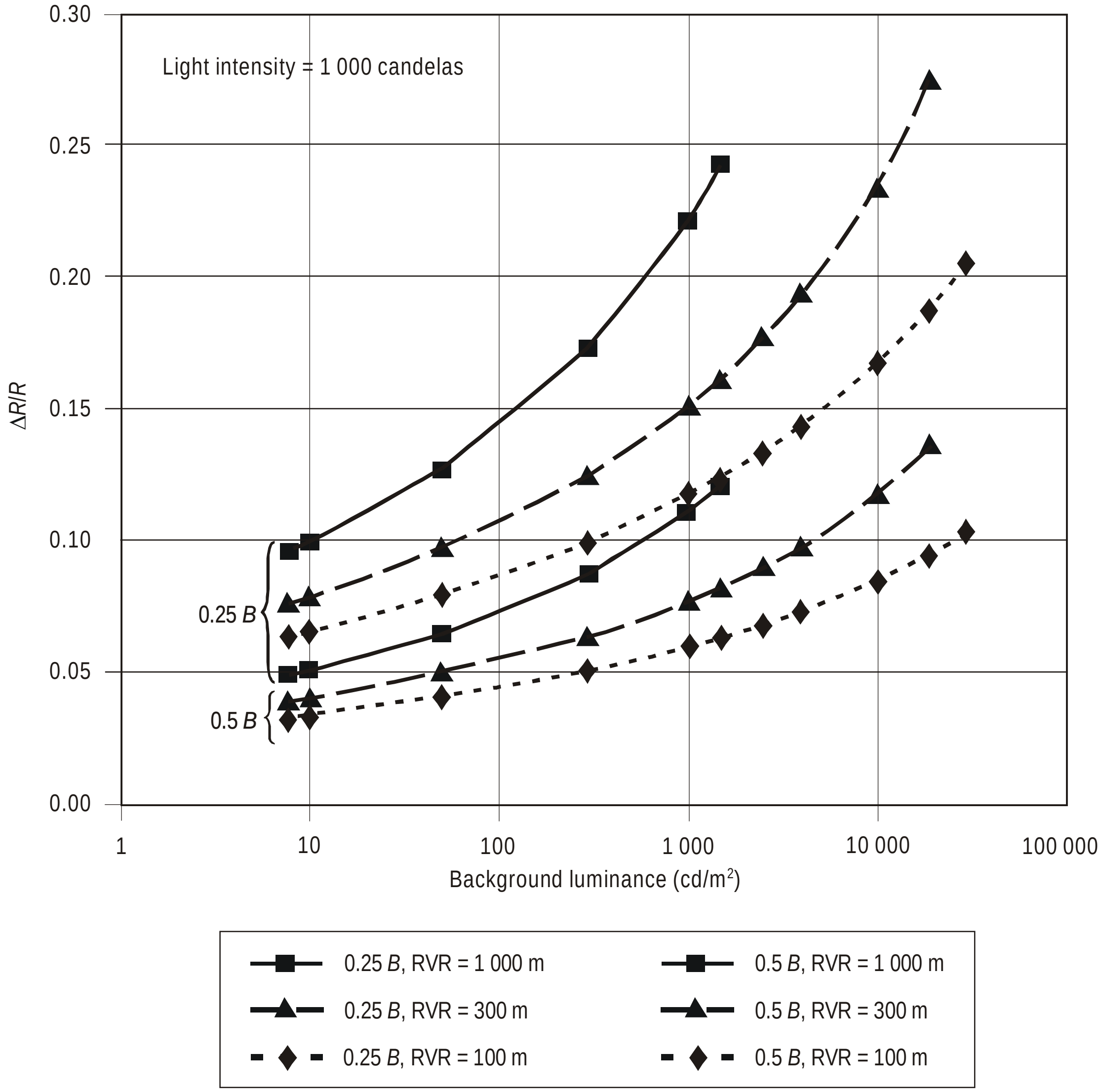


Figure 6-18. Fractional increase in RVR (Δ*R/R*) for reductions in measured background luminance by factors of four (0.25 *B*) and two (0.5 *B*) from runway light intensity of 1 000 cd

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 cd lights than for 10 000 cd lights, the maximum errors are similar for both light intensities (less than 14 per cent for a factor of two loss in background luminance and 28 per cent for a factor of four loss in background luminance).

6.7.11 Table 6-7 summarizes the effect of changes in the three RVR parameters, i.e. σ, *I* and *B* on RVR. The parameter changes needed to reduce RVR by 10 per cent are listed for two values of background luminance *B* and three values of RVR. RVR is much more sensitive to changes in σ than to changes in the other two parameters. Changes in RVR are more sensitive to *I* and *B* changes in the daytime than at night. It may be noted that Table 6-7 is for illustration purposes only and that, due to the non-linearity, the changes that would increase RVR by 10 per cent would not be proportional to those shown.

Table 6-7. Changes (in per cent) in parameters that reduce RVR by 10 per cent for *I* = 10 000 cd

Parameter	Night, *B* = 8 cd/m^2			Day, *B* = 10 000 cd/m^2		
	RVR (m)					
	100	300	1 000	100	300	1 000
σ	11	12	12	13	13	16
I	–80	–74	–69	–64	–54	–44
B	881	637	429	185	129	79

Chapter 7

TRANSMISSOMETERS

7.1 OPERATING PRINCIPLE

7.1.1 The transmissometer takes a direct measurement of the atmospheric transmittance between two points in space. Alternatively, it can be said that it makes an assessment of the mean extinction coefficient including both scattering and absorption contributions to the measurement and provides a reliable method of assessing the extinction irrespective of the type of atmospheric condition that produces reduced visibility; for example, fog, rain, snow, dust, etc.

7.1.2 The two forms of transmissometer that are most commonly employed are illustrated diagrammatically in Figure 7-1. Both consist essentially of a transmitter that directs a beam of light at a photo detector in a receiver unit. In one arrangement, sometimes referred to as a "double ended" transmissometer (Figure 7-1 a) refers) , the light is beamed directly to the receiver. The distance the light travels from the transmitter to the receiver is commonly referred to as the "baseline". In the second type, the transmitter and receiver are combined in one unit, the transmitted beam being returned by a retro-reflector; 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 2 000 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 = 2 000 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 2 000 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.

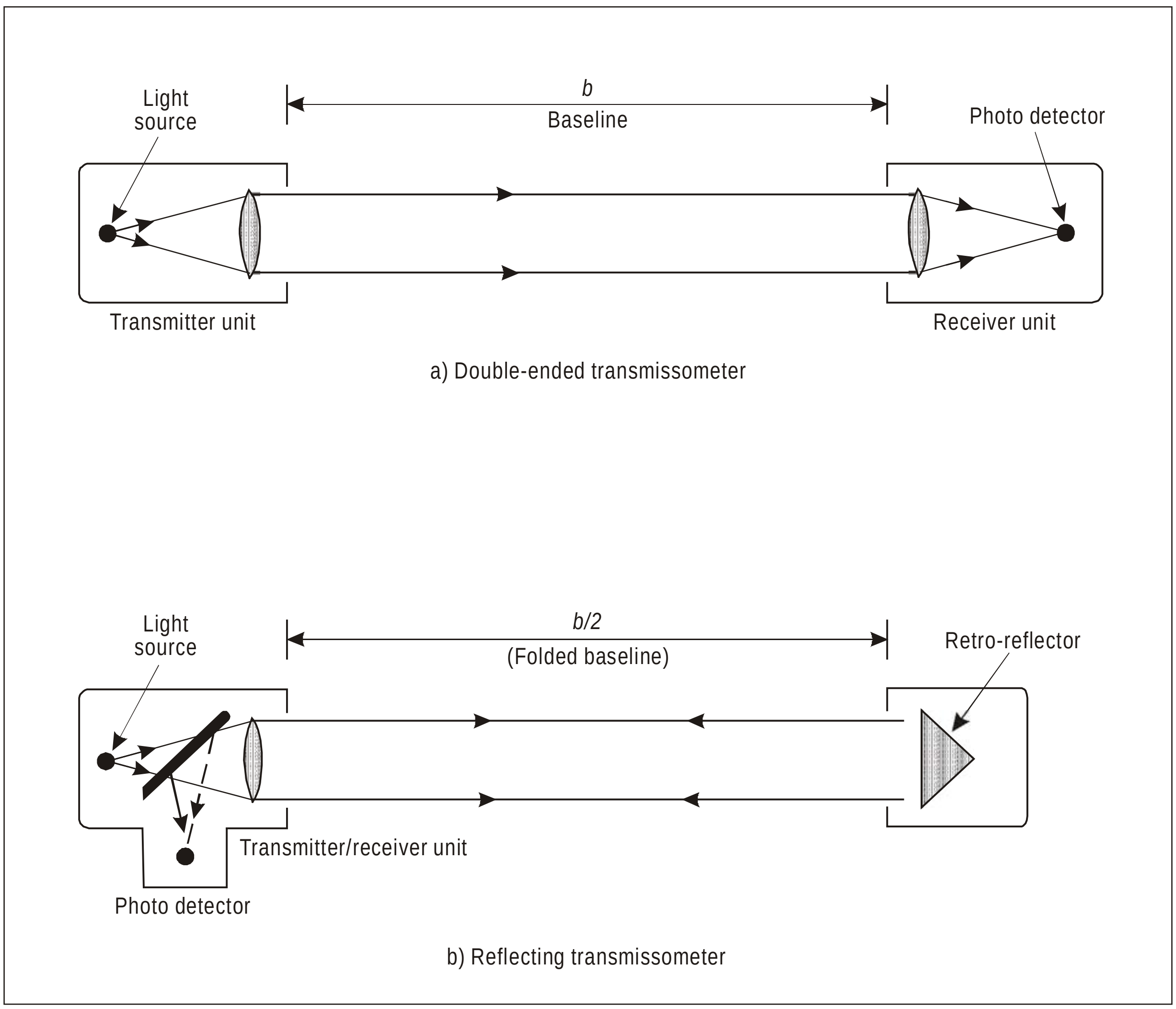


Figure 7-1. Schematic diagrams of two forms of transmissometer

7.1.5 Since covering the entire RVR range (MOR from 10 to 2 000 m) requires high resolution and stability, many States use two instruments or a dual baseline instrument to cover RVR from 50 to 2 000 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).

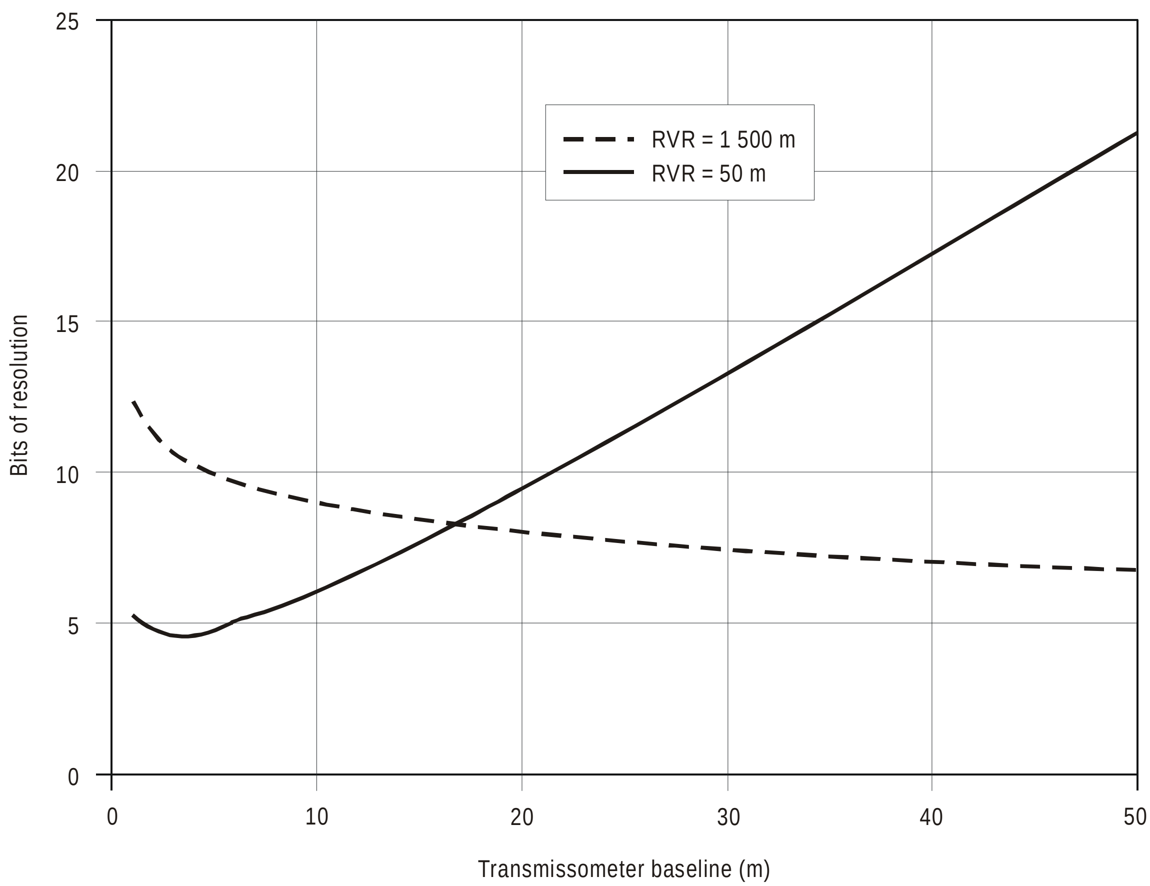


Figure 7-2. A/D converter resolution to cover the full RVR range

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).

c) For short baselines, the exact length of the baseline may be uncertain enough to introduce measurement errors. The transmissometer optics are normally enclosed by hoods to prevent window contamination. Typically, the baseline is defined as the distance from hood tip to hood tip and it is assumed that the weather phenomena do not penetrate into the hoods. This assumption may not be valid under all weather conditions, as fog, mist, etc., may penetrate into the hood structure. On the other hand, many instruments use blowers to protect their optics from contamination and to prevent weather from entering the hoods. Unfortunately, under light wind conditions, such blowers may clear some of the path in front of the hood and make the actual baseline shorter than the nominal baseline.

7.1.7 The collection of forward-scattered light by the transmissometer receiver leads to a measurement error that is conveniently expressed as a fractional error in extinction coefficient (lower than the true extinction coefficient). The fractional error increases with the radius of the scattering particles but can be considered independent of the baseline. For particles much larger than the wavelength of light, the error is roughly proportional to the particle radius and to the angular width of the receiver. For a particle of 10 μm (i.e. the largest particle radius typically in fogs) and 0.55-μm wavelength (peak in response of human vision), the error will be less than five per cent if the receiver half angle is less than 0.001 radians.

7.1.8 Background light will add to the source light arriving at the receiver, and to avoid errors due to this, it is normal to either modulate the transmissometer light source or to otherwise eliminate the unwanted background light. Despite these precautions, the linearity of the photo detector can still be affected by very high ambient illuminations such as direct or specularly reflected sunlight which will cause errors in measurement. To prevent direct sunlight from reaching the receiving photo detector, it is common practice for the transmissometer to be tilted downwards so that the centre line of the measurement beam is depressed by 0.5 degrees with respect to the horizontal.

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 airflow 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 2 000 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 is MOR which is usually used for conversion to obtain transmittance. In case lights have been used for the assessment, the conversion to MOR must be made. If other well-calibrated instruments are available on site, they may be used to obtain the reference MOR value. The MOR so determined can be converted to obtain transmittance, and the calibration is adjusted accordingly. Because atmospheric path losses can be inhomogeneous, there may be poor correspondence between the losses over the transmitted light pass and the reference MOR value. Therefore, care should be taken when using this calibration technique.

7.4 CALIBRATION ERRORS

7.4.1 Three types of errors in transmissometer calibration are:

a) error in the zero-signal offset;

b) scaling error; and

c) signal drift.

These are illustrated in Figure 7-3 and described below. Typical values are given in Appendix E.

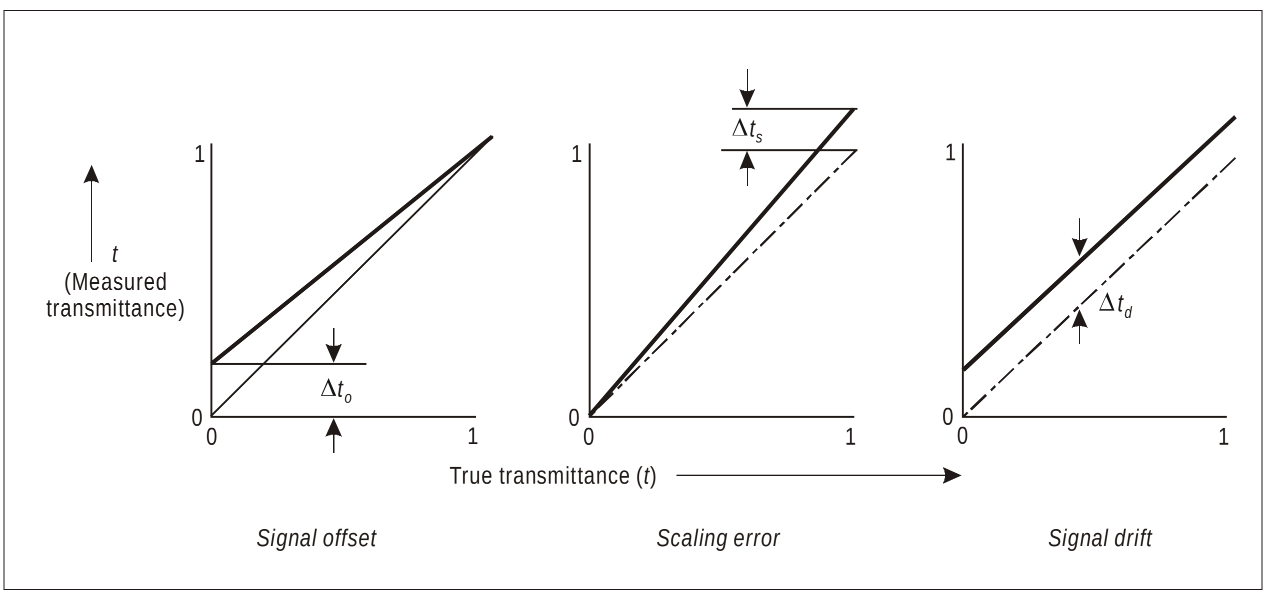


Figure 7-3. Three calibration errors

7.4.2 The signal offset (Δt_0) comes about when the zero point on the scale of transmittance is incorrect. This gives rise to increasing errors in RVR towards the low end of the working range of the transmissometer. This is illustrated by the left-hand parts of the *R* and *V* curves in Figure 7-4, showing the characteristics of an extremely rapid increase in the error.

7.4.3 The scaling error (Δt_s) is due to the top point of the calibration being incorrect. This causes the error in RVR to increase with range as illustrated by the right-hand parts of the curves in Figure 7-4. It is called a scaling error since it appears to be an error in the slope of the calibration curve.

7.4.4 The signal drift error is caused by the whole calibration moving by an amount Δt_d. The magnitude of the error is usually much less than that of signal offset and scaling errors.

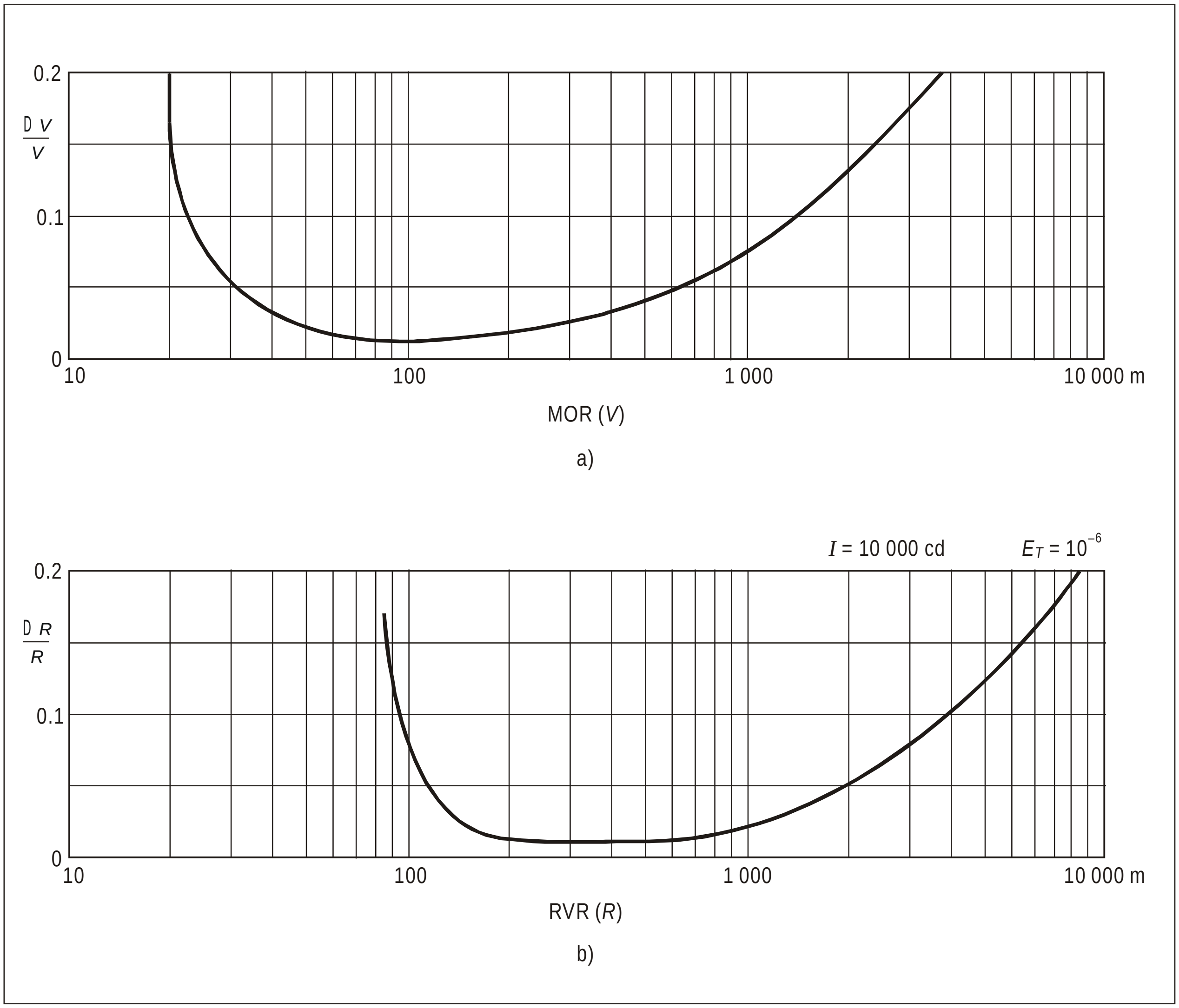


Figure 7-4. Typical errors in computed MOR and RVR due to the effect of the calibration errors illustrated in Figure 7-3

7.4.5 These errors give rise to fractional errors of $\Delta\sigma/\sigma$ in the extinction coefficient and an identical error $\Delta V/V$ in MOR (also in Figure 7-4); likewise, a fractional error $\Delta R/R$ in 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.

Chapter 8

FORWARD-SCATTER METERS

8.1 OPERATING PRINCIPLE

8.1.1 A transmissometer (Chapter 7) measures the fraction of light (transmittance) that has not been absorbed or scattered out of a light beam after it has travelled a certain distance through the atmosphere. The study of human vision has shown that the transmittance — or the extinction coefficient which is easily computed from transmittance — is the correct parameter to characterize the degradation of vision by precipitation or aerosols. In contrast to the transmissometer, a forward-scatter meter measures a small portion of light scattered out of a light beam (see Figure 8-1) into a relatively narrow band of scattering angles. The forward-scatter meter measurement is then used to estimate the extinction coefficient; the scattered signal is assumed to be proportional to the extinction coefficient. The validity of the estimate depends upon the physical properties of the scattering particles as follows:

a) *Particle density.* Since both the forward-scatter meter signal and the extinction coefficient are proportional to the particle density, variations in particle density cannot affect the validity of the forward-scatter meter measurement.

b) *Particle scatter function* (i.e. the angular distribution of scattered light). The response of a forward-scatter meter depends upon fraction of light scattered into the range of angles detected. Since particles of different types have different scatter functions, the ratio of scattered signal to extinction coefficient (i.e. the forward-scatter meter calibration factor) can depend upon the type of scattering particles. One way of addressing this problem is to select a scattering angle where scatter function is as closely proportional as possible to the extinction coefficient for the weather phenomena that reduce visibility into the RVR range. Another approach is to identify the weather phenomena and apply a different calibration to different weather types.

c) *Particle absorption.* It can be a problem, since a forward-scatter meter cannot detect absorption. However, if the amount of absorption is proportional to the amount of scattering, the effect of absorption simply changes the proportionality between scattered signal and total extinction coefficient.

8.1.2 At many airports, fog and snow are the most common weather phenomena reducing visibility into the RVR-reporting range. Under these weather conditions, little absorption and little variation in extinction coefficient with wavelength are normally experienced. Heavy rain, smoke, sand and dust are other weather phenomena that can substantially reduce visibility; some of these are associated with significant absorption. An accurate forward-scatter meter assessment of RVR in the presence of these phenomena may require identification of the phenomenon and application of a different calibration from that used with fog and snow.

8.1.3 The following list describes the scattering properties of different weather phenomena causing reduced visibility:

a) *Fog.* Fog has a relatively narrow scattering peak in the forward direction, very little scatter at 90 degrees, more scatter at 180 degrees and small maxima at the rainbow angles. The amount of scattering in the range 30 to 50 degrees is roughly independent of the drop-size distribution and, therefore, forward-scatter meters operating at an angle in this range have provided the most consistent performance. On the contrary, back-scatter instruments (180 degrees scattering) have a variable fog response.

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.

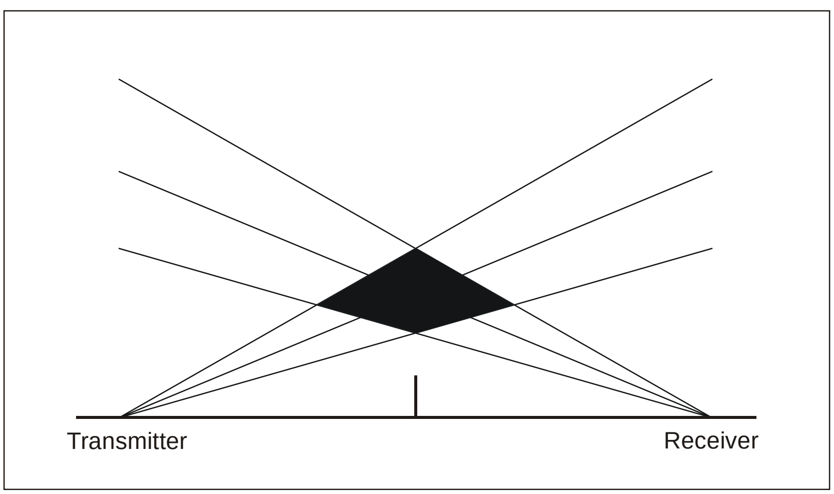


Figure 8-1. Forward-scatter meter principle

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.

d) A forward-scatter meter can be repaired, recalibrated and restored to service under most weather conditions, including low visibility (with the exception of blowing precipitation or high winds).

Some disadvantages are:

a) A forward-scatter meter is not self-calibrating. A process must be established to trace the calibration of each individual forward-scatter meter to a reference transmissometer.

b) The relationship of a measurement by a forward-scatter meter to the extinction coefficient can depend on the nature of the phenomenon reducing the visibility, particularly if absorption is important. This variation may be corrected if the sensor can accurately identify the phenomenon reducing the visibility. However, such corrections may be inaccurate for mixed phenomena (e.g. rain and fog, rain and snow).

c) Strict manufacturing tolerances on scattering geometry must be maintained to prevent unit-to-unit calibration variations.

d) Undetected obstructions of the sensor windows (e.g. snow clogging) can result in reporting RVR values higher than actual. Look-down scattering geometry (see Figure 8-2) significantly reduces the chances of snow clogging.

8.2.5 Forward-scatter meters have a linear relationship between optical signal and extinction coefficient; the signal output is proportional to the extinction coefficient. This feature has two implications:

a) A single forward-scatter meter can easily cover the full RVR reporting range.

b) Window losses from contamination produce proportional errors in the measurements of a forward-scatter meter.

8.2.6 The proximity of the sensor heads to the scatter volume makes it impractical to use blowers to protect the windows from contamination; the blower may clear the fog from the scatter volume. Consequently, methods have been developed to correct for window losses to permit long periods between window cleaning (e.g. three months). Two approaches have been taken:

a) *Using two transmitters and two receivers and horizontal scattering geometry (see Figure 8-3).* Each receiver looks directly at one transmitter and detects the scattered signal from the other. The transmitters are activated alternately. The resulting signals can determine the extinction coefficient independent of any window losses. Snow clogging is readily detected; if only one window is clogged, the extinction coefficient can still be determined, although window loss errors can no longer be corrected.

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

Figure 8-2. Look-down forward-scatter meter

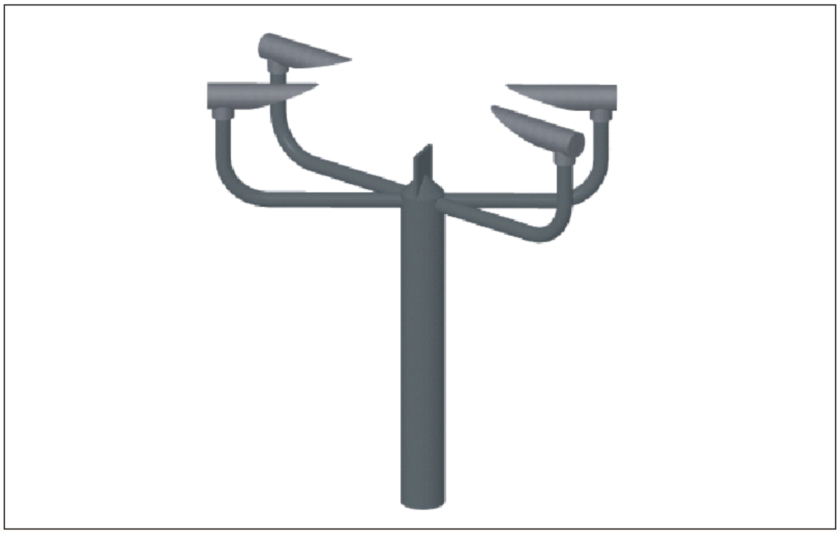


Figure 8-3. Four-head forward-scatter meter

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.

b) Heat from the sensor heads or electronics must be kept away from the scatter volume. The look-down geometry is less susceptible to this problem than other scattering geometries since the heads are located above the scatter volume.

8.2.9 Since the forward-scatter meter averages over a very small volume of space, the question has been raised as to whether a forward-scatter meter will represent the RVR over the runway as well as a transmissometer which integrates over the length of its baseline *b* (m). If there is a wind blowing fog past the forward-scatter meter, then the spatial average difference between the two measurements can become much less than the nominal difference between the small scatter volume and the long baseline. For a wind of speed *v* (m/s), the one-minute time average of the forward-scatter meter measurement will effectively average over a distance 60 X *v* (m).

8.2.10 Field studies in the United States have shown that forward-scatter meters and transmissometers have comparable capabilities of estimating the extinction coefficient 150 m away from the instrument.

8.3 FORWARD-SCATTER METER CALIBRATION

8.3.1 The field calibration of a particular forward-scatter meter is straightforward:

a) the windows are cleaned;

b) the beams are blocked and the zero extinction coefficient reading is determined; and

c) an SCU (see 8.2.7) is installed into the sensor and measured. The sensor gain is adjusted to give a reading equal to the designated equivalent “fog extinction coefficient” of the calibrator, which is marked on the SCU.

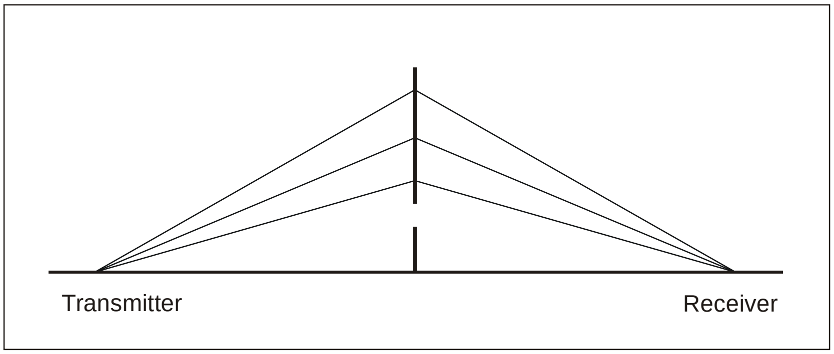


Figure 8-4. Forward-scatter meter with a scatter meter calibration unit (SCU)

Although the procedure is simple, the validity of the calibration depends upon the correctness of the calibrator's "fog extinction coefficient" and the proper performance of the calibration procedure. There is no way to independently verify the calibration in the field. In installations with multiple extinction coefficient sensors, consistency between measurements at different locations may give some calibration validation under homogeneous conditions.

8.3.2 The "audit trail" for the forward-scatter meter calibration must trace the calibration back to a transmissometer fog measurement. The calibration process is unique for each forward-scatter meter design. Several steps are involved:

a) A number of forward-scatter meter units are operated in fog near one or more transmissometers. Since the calibration may vary somewhat from one fog event to the next (event-to-event variations of as much as ±7 per cent have been observed), the calibration must be averaged over many fog events. Calibration variations from one group of events to another are typically less than ±3 per cent. The variance of the fog calibration process is reduced by restricting the forward-scatter meter-transmissometer comparison to conditions when the fog is reasonably homogeneous (e.g. variations up to 10 per cent). Homogeneity can be tested by comparing the readings of two perpendicular transmissometers or by looking at the time variation of a single transmissometer.

b) After the forward-scatter meter calibration against the transmissometers is complete, the calibration of each forward-scatter meter unit is known to a few per cent. An SCU can then be calibrated by installing it into each calibrated unit and averaging the extinction coefficient readings.

c) For convenience, an additional step may be added to the calibration audit trail. A master SCU measured in transmissometer calibrated units can be used to calibrate other forward-scatter meter units at the factory, which are then used to measure new SCUs.

In practice, the interchangeability of SCUs can be maintained to a few per cent. The biggest source of error in the calibration audit trail is the use of SCU scattering to represent the volume scattering from fog. The calibration process assumes a fixed ratio of SCU to fog volume scattering; this ratio depends upon the consistency of the scattering geometry from one unit to the next. Field tests have often shown significant differences (e.g. 15 per cent) between forward-scatter meters that have been calibrated with the same SCU. Computer simulations have shown how 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).

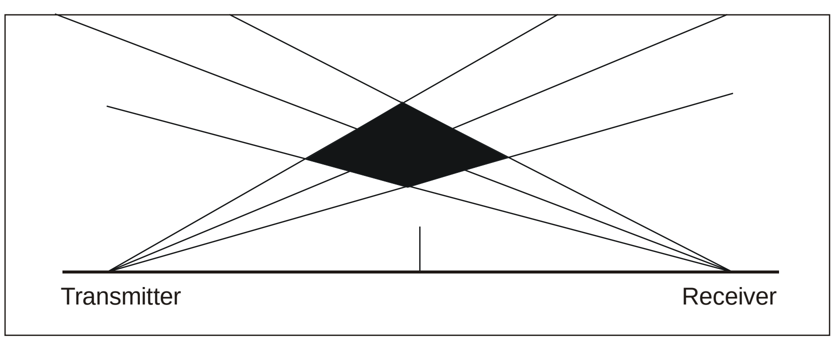


Figure 8-5. Volume scattering with alignment error

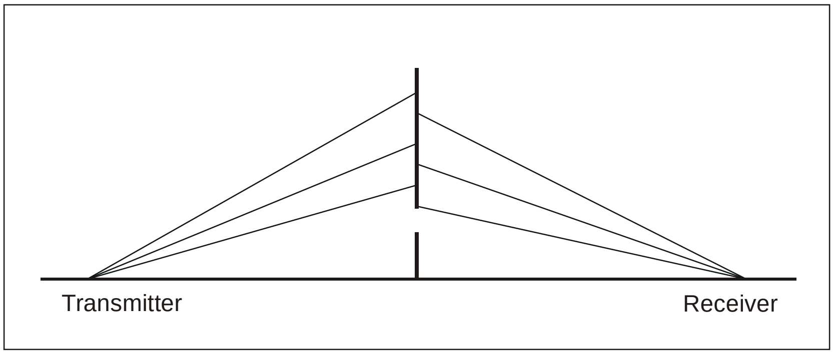


Figure 8-6. Scatter meter calibration unit (SCU) scattering with alignment error

Chapter 9

INSTRUMENTED RVR SYSTEMS

9.1 COMPONENTS OF INSTRUMENTED RVR SYSTEMS

9.1.1 Instrumented RVR systems can vary in complexity from simple systems using one instrument to comprehensive fully automated systems employing two, three or four instruments per runway.

9.1.2 In the simplest systems installed in the past, a human operator read the information (i.e. transmittance t_b) transmitted by the instrument and calculated the corresponding RVR using tables depending on the actual light intensities and eye threshold values. This process is of limited value because of the time needed to make and update RVR assessments, and should therefore be avoided. Modern technology now allows a digital computation of RVR, based on measurement of transmittance and luminance, as well as on the known intensity values of runway lights. The computer or automatic system used may be specific to RVR assessments or may be part of an integrated meteorological observing system of the airport.

9.1.3 Figure 9-1 shows a diagram of a fully automated RVR system for three runways with a digital display providing information for two runways in use simultaneously. The horizontal runway in this illustration has four instruments and the converging runways have three instruments, two being common with the other runway. At some large airports with parallel runways, each has three or possibly four instruments. When three instruments are used, it is recommended that they are located alongside the touchdown zone and the corresponding position at the stop end, the third being sited at the mid-point of the runway (see 5.5).

9.1.4 A typical automated system is further illustrated in Figure 9-2 which shows the various components of the RVR system: instrument (a transmissometer shown in Figure 9-2), background luminance sensor (see below), recorder, RVR computer (dedicated or part of the integrated observing system) and means of providing inputs of light intensities. The computed values of RVR are displayed digitally at various stations as required, including indicators in the appropriate air traffic services units. These displays may be separate or may be used for the complete set of meteorological parameters of the aerodrome.

Note. — The instruments measuring the extinction coefficient (σ) and/or transmissivity (T) are addressed in detail in Chapters 7 and 8 and are not dealt with in this chapter.

9.1.5 Background luminance (*B*) sensor

A background luminance sensor is a basic component of an RVR system. Ideally, this sensor should measure the brightness of the background against which the pilot would view the runway lights. However, difficulties arise for two main reasons:

a) *runway lights* must not shine directly into the sensor and influence the measurement; and

b) *direct sunlight* into the sensor must be avoided.

Although the direct effect of runway lights must be avoided, some States wish to detect the indirect effect of runway lights in increasing the background luminance against which the runway lights must be viewed. In this case, the background luminance sensor must be carefully positioned to avoid the direct runway light but be sensitive to scattered runway light. Other States locate the background luminance sensor where no runway light can be detected. For example, the United Kingdom monitors the north sky at an angle of elevation of 22.5 degrees. In practice, the avoidance of direct sunlight means that RVR observed by a pilot against a lit background (e.g. against the sun at low elevation angles) is less than the RVR reported by the instrumented system.

Note.— A single background luminance sensor may be used on aerodromes, even if equipped with several instruments. However, to enhance the representativeness of measurements and system reliability (i.e. eliminating single points of failure), the use of two or more sensors may be preferable. For example, Germany uses a separate background luminance sensor at the end of each runway.

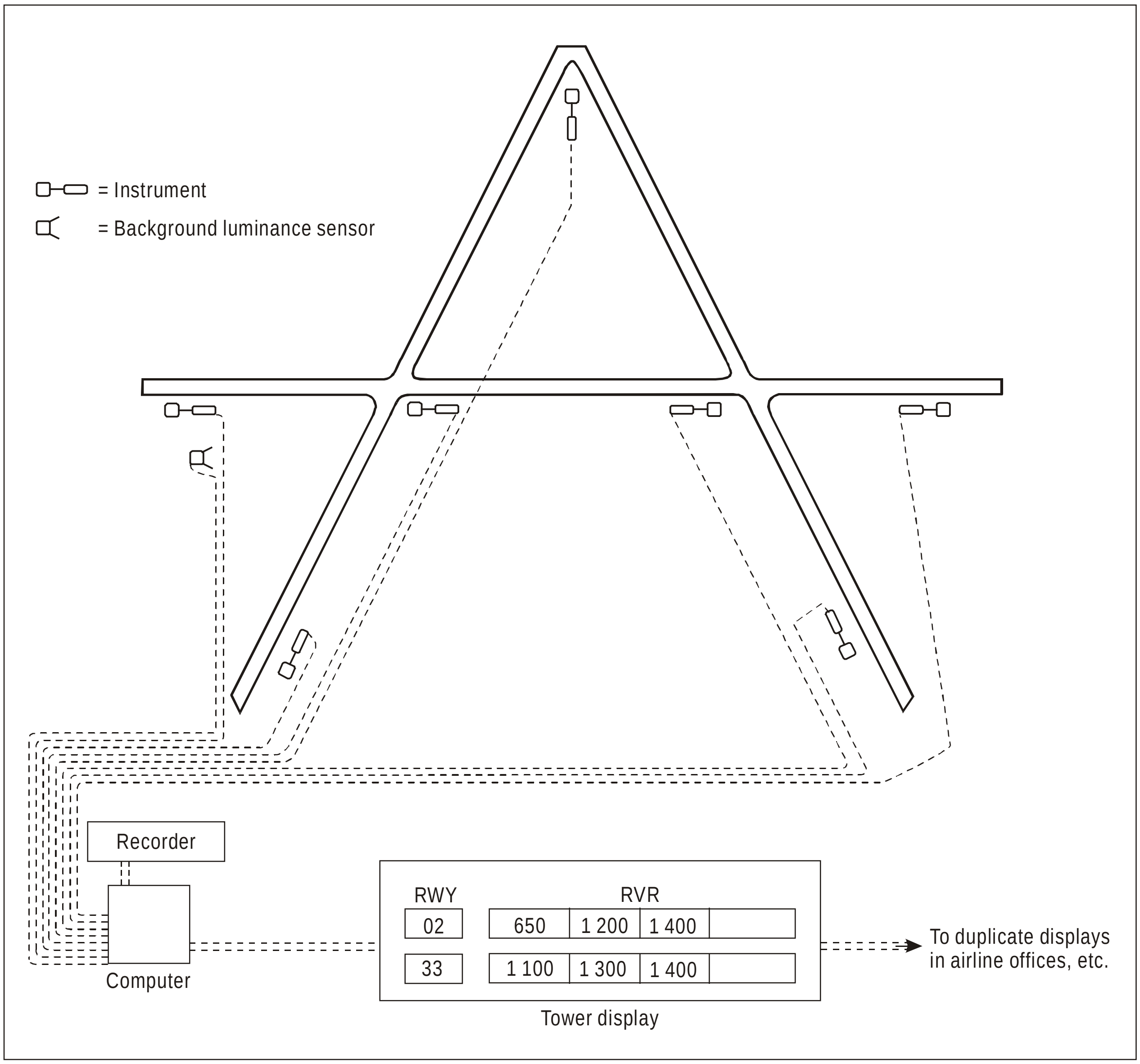


Figure 9-1. Diagram of an automated runway visual range system

9.1.6 Runway light intensity (*I*) monitor

A runway light intensity monitor, which may be part of an instrumented RVR system, provides information on runway light setting. Although States report RVR included in METAR and SPECI based on an assumed runway light intensity setting (i.e. the maximum light intensity), most base the reported RVR included in local routine reports and local special reports on the actual runway light setting in accordance with Annex 3, Appendix 3, 4.3.5. 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 σ), *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 over a given period of time (e.g. one month).

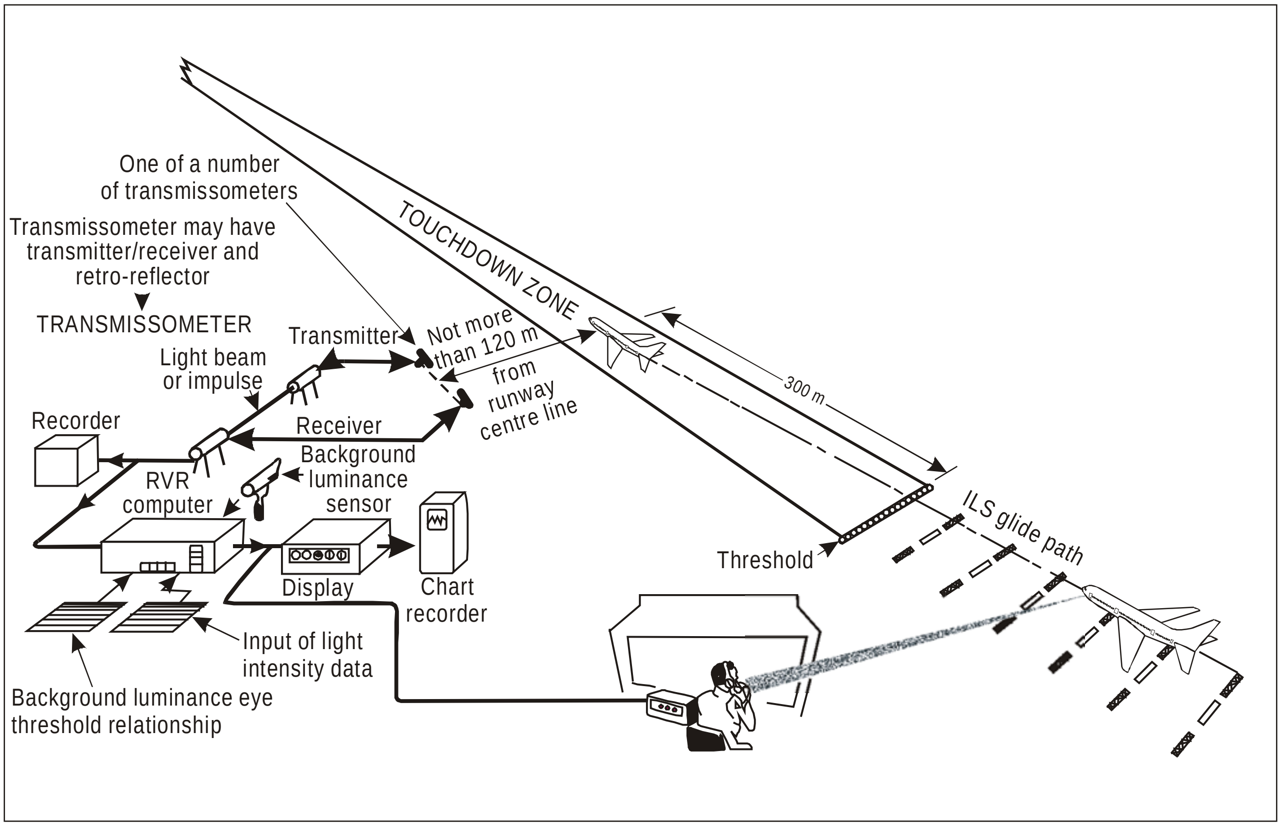


Figure 9-2. An example of an automated runway visual range system using transmissometer

9.1.7.3 A time analogue chart recorder may still be used, but a digital record is more common. It is common practice to record the RVR and the direct output of all instruments in operation, i.e. to record the transmittance or the extinction coefficient of the atmosphere at the various sites. Some States also record the intensity setting, visual threshold of illumination used, background luminance and sometimes the law (i.e. Allard's or Koschmieder's) used.

9.1.7.4 Basic data have to be smoothed to overcome noise and unimportant fluctuations, before they can be processed to obtain RVR. An averaging period of one minute, as recommended in Annex 3, Appendix 3, 4.3.4, should be used for local routine reports and local special reports. An averaging period of ten minutes should be used for METAR and SPECI (see Section 11.5).

9.2 PERFORMANCE CHECKS AND MAINTENANCE

9.2.1 It is normal practice to check the operation of instruments, sensors, computers and data systems at regular intervals, and to carry out maintenance. The maintenance constraints and periodicity depend on the type of instruments used, local conditions and the manufacturer's recommendations.

9.2.2 The proper performance of a transmissometer requires periodic attention (daily under certain conditions) to keep windows clear; ensure proper alignment of transmitters and receivers; and maintain the correct 100 per cent calibration.

9.2.2.1 The optimal performance of a transmissometer requires carefully cleaned optics. The instruments should be checked and the optics cleaned as necessary after atmospheric disturbances, since precipitation accompanied by strong winds can quickly contaminate or, in case of snow, obstruct the windows. Window losses can result in serious measurement errors.

9.2.2.2 Some transmissometers have an internal contamination compensation that reduces the need for cleaning the optics. However, the internal contamination compensation can introduce errors if the actual contamination is greater than assumed in the compensation. These errors can be identified by finding the measured transmittance to be too low under clear conditions.

9.2.2.3 Alignment errors are particularly likely in areas where frost heaves are common.

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 Annex 3, Attachment A. 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 (σ) 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 reference value may be taken minute by minute as the median of the MOR values from the different instruments. When comparing instruments, it is necessary to check the homogeneity of fog. Non-homogeneous fogs may strongly disturb the MOR distribution ratio of an instrument. Therefore, such periods must be identified and excluded from the data analysis. An automatic criterion to detect and exclude non-homogeneous periods is described in 9.4.8.

9.4.4 External factors affecting the instruments

9.4.4.1 The output of an instrument may be influenced by external factors, such as:

a) precipitation;

b) type of precipitation;

c) ambient luminance; and

d) temperature.

The performance of an instrument should be tested for the relevant conditions, all of which should be homogeneous, e.g.:

— liquid precipitation;

— solid precipitation (snow);

— day conditions without precipitation;

— night conditions without precipitation; and

— temperature extremes.

9.4.4.2 Furthermore, in the evaluation of a forward-scatter meter the following issues should be considered:

a) *The median forward-scatter meter response which may be different for the various weather phenomena affecting RVR.* For example, at one aerodrome, fog and snow may be the phenomena most frequently producing reduced RVR, while at another aerodrome, the low RVR values are exclusively associated with fog."

b) *The consistency of the median fog response from unit to unit.* A number of units should be tested, preferably from different production lots.

c) *The accumulation of window contamination during the test.* It is important to find out whether window contamination affected the test results. Window contamination can be assessed by measuring an SCU (Section 8.3) before and after window cleaning.

9.4.5 Presentation of results

The results should be expressed with graphics showing the distribution of the ratio between the tested instrument output and the reference value. This ratio should be on one-minute averages and calculated every minute. The distribution should be computed for the following ranges of MOR: 0 – 100, 100 – 200,..., 800 – 900, 900 – 1 000, 1 000 – 1 200, 1 200 – 1 500 and 1 500 – 2 000 m. In a typical graphic representation (see Figure 9-3), an X represents the median, a rectangle represents the 50 per cent interval (i.e. 25 and 75 per cent limits), a horizontal line represents the 90 per cent interval (i.e. 5 and 95 per cent limits). The X (ratio) and Y (reference MOR) scales are logarithmic. Symbols **|**, > and < indicate the 99 per cent limit, minimum and maximum values, respectively. The number of selected data points is indicated on the right-hand side of the figure.

9.4.6 Test period

A test period should cover at least ten separate events with MOR below 500 m. Where applicable, at least three snow events and three liquid precipitation events should be observed. A winter test period of six months is generally suitable. The instrument data should be recorded every minute during the test period. A human observer, or a present-weather sensor, should be used to stratify the test period into the following classes:

a) no precipitation;

b) liquid precipitation; or

c) solid precipitation (snow).

9.4.7 Test field

In the field, the installation conditions laid down by the manufacturer for the instrument must be respected. In this regard, the instruments should be placed as close as possible to each other, taking account of mutual interference, and no more than 50 m from the reference instruments. All instruments should be mounted at a uniform height (maximum deviation of 20 per cent). The location of the test should be chosen to be able to test the instruments in poor visibility (MOR below 200 m), preferably with liquid and solid precipitation events. Specific locations may be used for sand and dust conditions.

9.4.8 Detection of homogeneous periods

The data analysis must be conducted only during “homogeneous” events. Past experience shows that it is 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 over 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

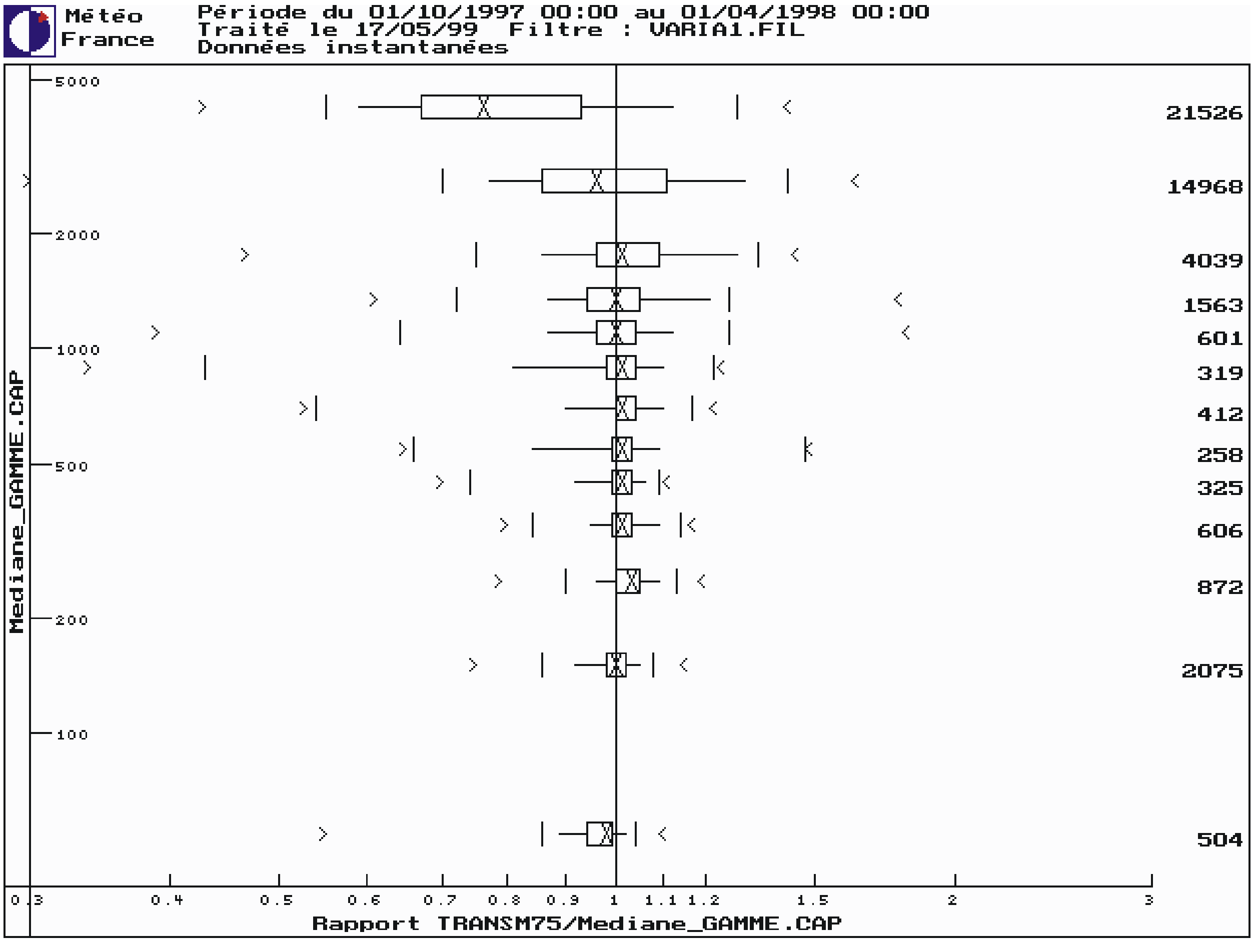


Figure 9-3 a). Example of a box plot diagram for a transmissometer for a six-month period (1 October 1997 to 1 April 1998)

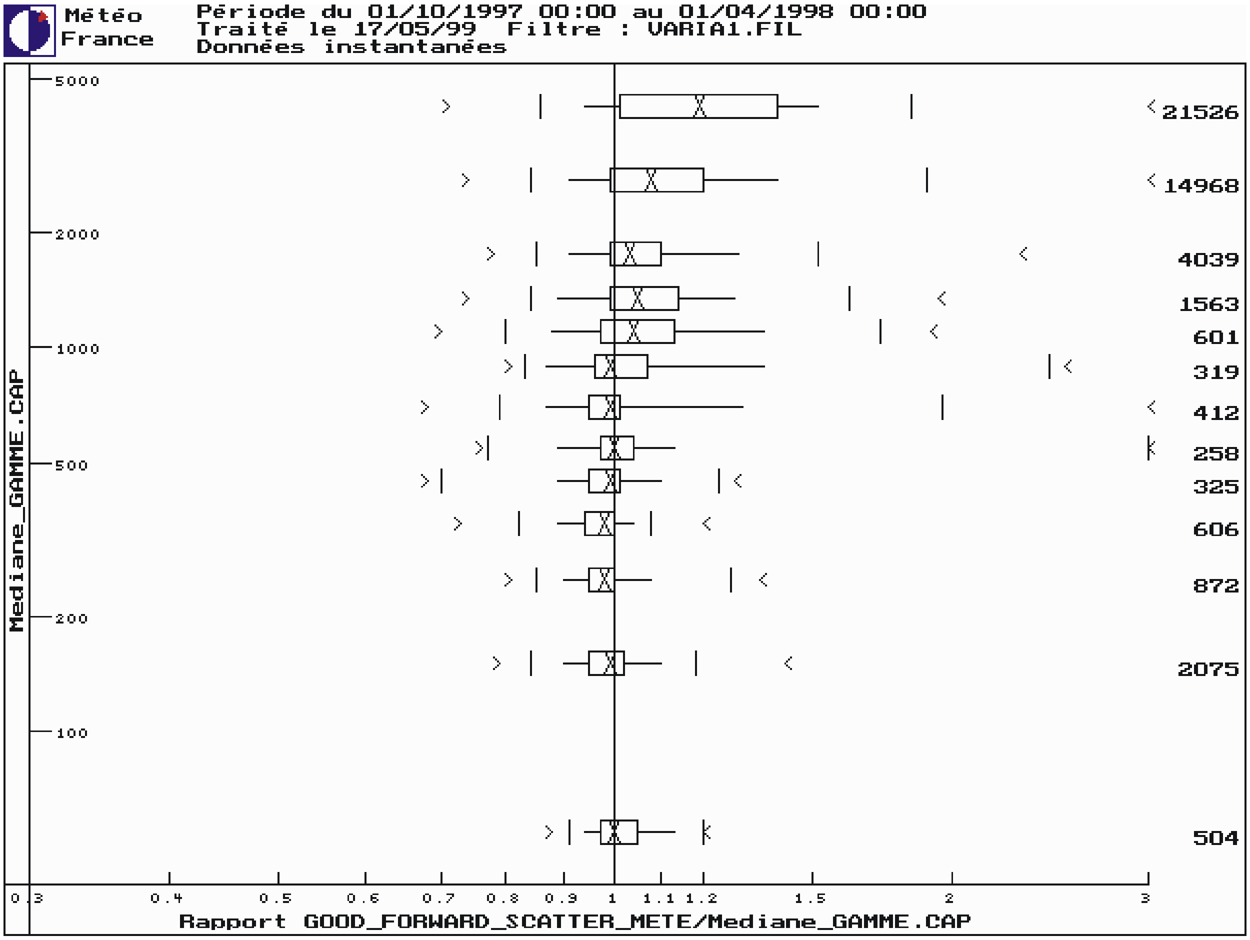


Figure 9-3 b). Example of a box plot diagram for a forward-scatter meter with good performance for a six-month period (1 October 1997 to 1 April 1998)

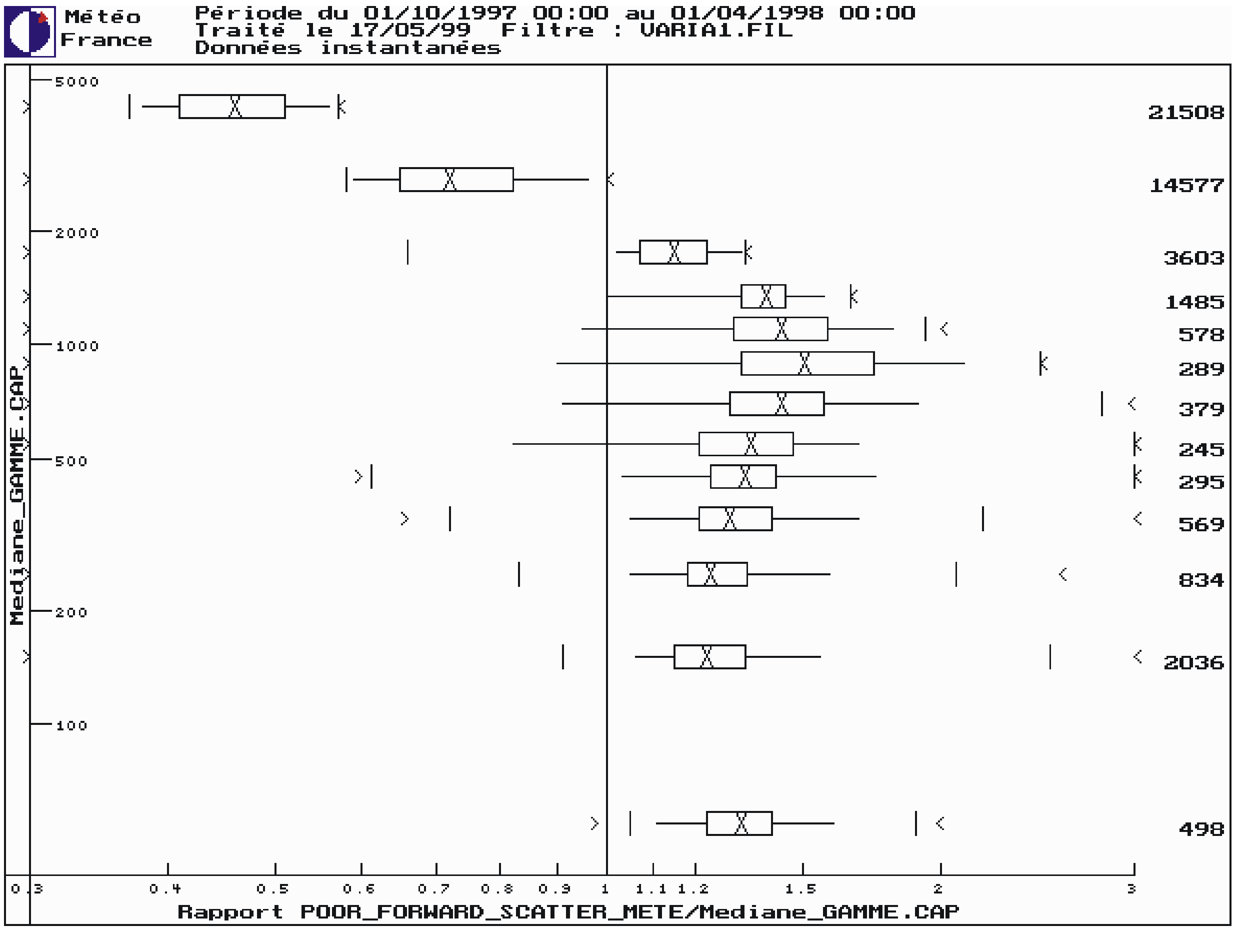


Figure 9-3 c). Example of a box plot diagram for a forward-scatter meter with poor performance for a six-month period (1 October 1997 to 1 April 1998)

— 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.

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 assessments 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 assessments 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.

10.3 CALIBRATION OF VISUAL OBSERVATIONS

10.3.1 Because the RVR assessment point is different from that located at a height of 5 m above the centre line of the runway, a calibration of the system must be carried out. The calibration is also important when special, dedicated light rows, in lieu of edge or centre line lights, are used. It is done by simultaneous counting by at least two observers of the number of lights visible from: a) the observing point (often located on the ground) and b) the reference point, i.e. the centre line of the runway at a height of 5 m. This must be carried out in a variety of visibilities covering the required reporting range of RVR. Based on a statistically sufficient sample of paired observations, a conversion table similar to the example shown in Table 10-1 is built up. Theoretically, the conversion table should be based on various conditions of ambient light illumination (e.g. night, twilight, day, bright day). However, trials in the United Kingdom have indicated that there is little difference in calibrations in various ambient light conditions and that it is very difficult, if not impossible, to distinguish individual lights for calibration in daylight. This kind of calibration method sets great demands on the weather conditions during which the calibration is performed. Any non-homogeneous weather phenomena (e.g. patchy fogs) should be excluded.

10.3.2 The method described in 10.3.1 is difficult to apply since relevant visibility conditions for calibration purposes are not readily available. Alternatively, the calibration can be determined from a knowledge of the light intensities beamed towards the observer and the pilot (see Figure 6-2). In the United Kingdom, the calibration is determined by using a Gold visibility meter. This comprises an infinitely variable density filter through which a given runway edge light can be seen. Each light is viewed through the Gold meter from the RVR assessment point at the observer's normal eye height and then from the runway centre line abeam the RVR assessment 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 assessment 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.

Table 10-1. Sample conversion table in the case where the edge lights are 60 m apart and where the first light is 50 m from the observer. The reporting increments are those used in the European Region (see 11.4.2). The minimum and maximum values reported are 50 and 1 200 m, respectively.

Number of edge lights visible to an observer at observing position	*RVR observed (in m)*	*RVR to be reported (in m)*
1	50	50
2	110	100
3	170	150
4	230	225
5	290	275
6	350	350
7	410	400
8	470	450
9	530	500
10	590	550
11	650	650
12	710	700
13	770	750
14	830	800
15	890	800
16	950	900
17	1 010	1 000
18	1 070	1 000
19	1 130	1 100
20	1 190	1 100
21	1 250	1 200

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 assessments. 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.

Chapter 11

TRANSMISSION AND REPORTING PRACTICES

11.1 METHODS OF TRANSMISSION AND DISPLAY OF RVR

11.1.1 Where assessed by instrumented RVR systems, the RVR must be presented automatically in the meteorological station using digital real-time RVR displays; equivalent RVR displays, related to the same locations of observation and connected to the same measuring devices, must be installed in the appropriate air traffic services (ATS) units (Annex 3, Appendix 3, 4.3.3.1, and Annex 11, 7.1.4.4, refer).

11.1.2 The usual method of transmitting human RVR assessments from the runway observing site to the ATS unit is by telephone or radiotelephone. Practice varies with regard to the stage at which observations of lights or markers are converted into RVR. In some cases, the observer makes the conversion; in others, the number of lights or markers visible is reported to the tower and the conversion is made there.

11.2 REPORTING PROCEDURES

11.2.1 RVR information is included in local routine reports, local special reports, METAR and SPECI whenever either the visibility or RVR is observed to be less than 1 500 m (see 5.2.3). These reports are passed to aircraft by ATS units, data link (i.e. D-ATIS, D-VOLMET) and/or aeronautical broadcasts (i.e. ATIS, VOLMET). They are also available through various dissemination systems to pilots and aeronautical personnel on the ground at the local aerodrome and at many other aerodromes for briefing or other purposes.

11.2.2 Those responsible for carrying out the human observations should report RVR to the appropriate local ATS unit(s) whenever there is a change in the value to be reported in accordance with the reporting scale in use. According to Annex 3, Appendix 3, 4.3.3.2, arrangements for the transmission of the reports to ATS units concerned should be such that transmission is normally completed within fifteen seconds after the termination of the observation. However, where RVR is assessed with instrumented systems, with the corresponding displays at the appropriate ATS units (see 11.1.1 above), arrangements are normally in force for the use of these displays to meet the needs for local routine reports and local special reports, eliminating the need to report changes in RVR to the local ATS units.

11.2.3 Special reports (i.e. both local special reports and SPECI) should be made when the RVR changes to or passes values that most closely correspond with the operating minima of the operators using the aerodrome and 50, 175, 300, 550 or 800 m, which correspond to the agreed changeover value between categories of operation being supported at airports. However, where real-time displays exist in the ATS units (see 11.1.1 above), local special reports prompted by changes in RVR need not be issued (provided that arrangements have been made to use this display in view of meeting the needs for local routine reports and local special reports). Meanwhile, SPECI are required to be issued; a SPECI representing a deterioration in RVR should be disseminated immediately after the observation, while one representing an improvement in RVR should be disseminated only after the improvement has been maintained for 10 minutes.

11.2.4 In local routine reports and local special reports, the value for the touchdown zone (about 300 m from the threshold) should be included without any indication of location, if the RVR is assessed from only one location along the runway. If, however, the RVR is assessed from more than one location along the runway, the value representative of the touchdown zone should be given first, followed in sequence by the values representative of the mid-point (if available) and stop-end. The locations for which these values are representative should be indicated as “TDZ”, “MID” and “END”, respectively. The detailed structure of reports is included in Table 11-1.

11.2.5 In METAR and SPECI, only the value representative of the touchdown zone should be given, and no indication of location on the runway should be included. When there is more than one runway available for landing, touchdown-zone RVR values for all such runways, up to a maximum of four, should be included. The selection of the four runways to be included should be in accordance with the agreement between the authorities and the operators concerned. The runways to which the values refer should be indicated in the form shown in Table 11-2 which displays the detailed structure of METAR and SPECI.

11.3 RANGE OF VALUES TO BE REPORTED

11.3.1 The lower limit of the reporting range should be 50 m. Below this limit, reports should merely indicate that the RVR is less than 50 m, as shown in Tables 11-1 and 11-2. When the RVR is below the minimum value that can be determined by the system in use, it should be reported using the abbreviations “BLW” (in local routine reports and local special reports) and “M” (in METAR and SPECI) followed by the minimum value that can be determined by the system.

11.3.2 The upper limit of the reporting range should be 2 000 m. Above this limit, reports should merely indicate that the RVR is more than 2 000 m, as shown in Tables 11-1 and 11-2. When the RVR is above the maximum value that can be determined by the system in use, it should be reported using the abbreviations “ABV” (in local routine reports and local special reports) and “P” in (METAR and SPECI) followed by the maximum value that can be determined by the system.

11.4 STEPS IN THE REPORTING SCALE

11.4.1 Because of operational decisions, sometimes with legal implications, taken on the basis of RVR reported, some precision in the reporting scale is essential. Too fine a scale is not justified, since RVR values cannot be completely representative of viewing conditions from the cockpit because of variations in time and space and the limitations of observing techniques.

11.4.2 Annex 3, Appendix 3, 4.3.6.1, specifies that a reporting step of 25 m shall be used up to 400 m RVR, a reporting step of 50 m shall be used between 400 and 800 m RVR and a reporting step of 100 m shall be used for values of RVR above 800 m. Table 11-3 displays the ranges and resolutions of RVR information included in meteorological reports. Any observed RVR value that does not fit the reporting scale in use should be rounded down to the nearest lower reporting step in the scale.

Table 11-1. Detailed structure of RVR information included in local routine reports and local special reports[1]

Detailed content	*Template*	*Examples*
Name of the element	RVR	RVR RWY 10 BLW 50M;
Runway [2]	RWY nn[L] *or* RWY nn[C] *or* RWY nn[R]	RVR RWY 14 ABV 2000M;
Runway section [3]	TDZ	RVR RWY 32L 400M;
RVR	[ABV *or* BLW] nn[n][n]M	RVR RWY 16 TDZ 600M MID 500M END 400M;
Runway section [3]	MID	RVR RWY 26 500M RWY 20 800M;
RVR	[ABV *or* BLW] nn[n][n]M	RVR RWY 20R 500M;
Runway section [3]	END	RVR RWY 12 ABV 1200M;
RVR	[ABV *or* BLW] nn[n][n]M	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 and SPECI[1]

Detailed content	*Template*	*Examples*
Name of the element	R	R10/M0050; R14L/P2000;
Runway	nn[L]/ *or* nn[C]/ *or* nn[R]/	R32/0400; R16L/0650 R16C/0500 R16R/0450; R17L/0450;
RVR	[P *or* M]nnnn	R10/M0050; R20/P2000;
RVR past tendency [2]	U, D *or* N	R12/P1200U; R10/M0150V0500D

Notes. —
1. *RVR to be included if visibility or RVR < 1 500 m for up to a maximum of four runways.*
2. *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.*

Table 11-3. Ranges and resolutions for RVR information included in local routine reports and local special reports

Element		Range		Resolution
		Local routine report and local special report	METAR and SPECI	
Runway	(no units)	01 – 36	01 – 36	1
RVR	M M M	0 – 400 400 – 800 800 – 2000	0000 – 0400 0400 – 0800 0800 – 2000	25 50 100

11.5 AVERAGING PERIOD AND UPDATING FREQUENCY

Note.— Requirements for averaging and updating of RVR cannot be met by the human observer system.

11.5.1 Fluctuations tend to be over-emphasized by transmissometers and forward-scatter meters because they sample the atmosphere over a distance that is usually shorter than the visual range. Averaging can eliminate or, at least, reduce this over-emphasis. At the same time, it can make observations representative of a larger area than the immediate neighbourhood of the instrument where the atmosphere is sampled. However, averaging must not be carried so far that important variations and trends are obscured. Annex 3 recognizes these points by specifying that instrumented measurements shall be averaged over a period of one minute.

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 routine reports and local special 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 METAR and SPECI, 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 SPECI (i.e. 175, 300, 550 or 800 m).

11.5.4 Annex 3, Appendix 3, 4.3.4, specifies that instrumented measurements must be updated at least every 60 seconds to permit the provision of current, representative values of RVR. 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 METAR AND SPECI

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 METAR and SPECI. 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 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 12

PROMULGATION OF INFORMATION ON RVR SYSTEM

12.1 The *Procedures for Air Navigation Services — Aeronautical Information Management* (PANS-AIM, Doc 10066) requires that the Aeronautical Information Publications (AIP) contain information on the specific type of observation system and number of observation sites used to observe and report RVR (PANS-AIM (Doc 10066), Appendix 2, GEN 3.5.3, 4)). Further description and examples of how this information could be included in the AIP are contained in the *Aeronautical Information Services Manual* (Doc 8126, Appendix to Chapter 5, GEN 3.5, 3 d)) and Specimen AIP therein (Table GEN 3.5.3).

12.2 Annex 3, Chapter 4, 4.6.3.5, requires that the units providing ATS and aeronautical information service for an aerodrome shall be kept informed without delay of changes in the serviceability status of the RVR observing system. In all cases it is necessary to have arrangements for informing the ATS units whenever the instrumented RVR system develops a fault.

12.3 Annex 4 — *Aeronautical Charts*, 13.6.1 l), requires that the position of RVR instruments be shown on aerodrome charts. The *Aeronautical Chart Manual* (Doc 8697) contains an example of the portrayal of RVR sites on Specimen Chart No. 11.

12.4 The detailed operational requirements for the provision of RVR assessments for each runway section (i.e. TDZ, MID, END) are shown in Table AOP of the respective Regional Air Navigation Plans.

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 (σ). The relationship between them is as follows:

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

where ln denotes the natural logarithm,

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

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

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 (σ). 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 $x = R$:

$$E_T = \frac{IT^R}{R^2} = \frac{Ie^{-\sigma R}}{R^2} \qquad (7)$$

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

$$E_T = \frac{It_b^{R/b}}{R^2} \qquad (8)$$

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

Appendix B

KOSCHMIEDER'S LAW

Note. — This appendix provides the detailed equations to support Section 6.3, which deals with RVR based on markers or other black or dark objects.

1. By day, an object displays a particular photometric brightness or luminance (*L*) as a consequence of the incident light and its reflective properties. It is visible when it contrasts sufficiently with the background.

2. An object close to an observer is said to have an inherent luminance. At a greater distance the luminance is less, owing to the effect of the intervening atmosphere, and it is called the apparent luminance.

3. The contrast of an object with the background against which the object is viewed can be expressed as the difference in luminance between the object and the background, divided by the luminance of the background. This is known as the luminance contrast (*C*). The relationship between the apparent luminance contrast (C_x) and the inherent luminance contrast (C_0) is given by Koschmieder's law.

$$C_x = C_0 T^x = C_0 e^{-\sigma x} \qquad (9)$$

where T = transmissivity of the atmosphere; and
σ = extinction coefficient.

4. A black object has an inherent luminance of zero, but when viewed from a distance it has an apparent luminance due to scattered light from the intervening atmosphere. Thus, the inherent luminance contrast is unity and therefore Equation 9 becomes:

$$C_x = T^x = e^{-\sigma x} \qquad (10)$$

5. As such an object recedes into the distance it remains visible until the apparent luminance contrast (C_x) becomes numerically equal to the contrast threshold (ε) at distance (x), hence:

$$\varepsilon = T^x = e^{-\sigma x} \qquad (11)$$

6. Black or very dark objects of suitable size viewed against the sky or fog background are used, in principle, by the meteorological observer in assessing meteorological visibility by day. The visual range is assumed to be independent of the luminance of the background and direction of view of the observer with respect to the sun.

7. Investigations made in several States into the visual range of objects showed that the contrast threshold varies with the size of the object. For sensibly square objects subtending more than 0.5 degrees, the contrast threshold (ε) that applies is of the order of 0.02 and it is 0.05 for objects subtending less than 0.15 degrees. Experimental results from observations made in the field, in a wide range of visibility conditions, including fog, on black marker boards confirmed the validity of Koschmieder's law and suggested

the use of a contrast threshold close to 0.05. ICAO and the World Meteorological Organization (WMO) consider that a value of 0.05 is appropriate to visibility observations. Therefore, from using this value in Equation 11 it follows that:

$$e^{-\sigma x} = 0.05 \qquad (12)$$

therefore, $x = \frac{-ln(0.05)}{\sigma} \simeq \frac{3}{\sigma} \equiv MOR$ (13)

8. The distance as defined by Equation 13 is known as the Meteorological Optical Range (MOR).

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	0.8
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 D

CONSIDERATIONS OF BASELINE LENGTH

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. From Equation 1 (Appendix A) it can be shown that the maximum length of a transmissometer baseline is given by:

$$b' = \frac{\ln t_{b'}}{\ln T_{b'}} = \frac{\ln t_b}{-\sigma} \qquad (14)$$

$$b' = \frac{R \ln t_{b'}}{\ln E_T + 2 \ln R - \ln I} \qquad (14a)$$

when

b' is the maximum baseline length
$T_{b'}$ is the minimum transmissivity to be measured
$t_{b'}$ is the minimum transmittance that can be measured by the instrument
E_T is the visual threshold of illumination
R is the visual range, and
I is the luminous intensity.

A good performance of modern instruments is represented by a minimum transmittance value of 0.005 when the visual range (*R*) (or RVR) is of the order of 100 m.

Using Equation (14a) with a luminous intensity (*I*) of 10 000 cd, two examples are provided below:

For a *day case:*

let $E_T = 10^{-4}$ lx and RVR = 100 m

since $t_{b'} = 0.005$, $\ln t_{b'} = -5.3$

hence $b' = \frac{5.3}{0.092} = 57.5$ m

Similarly, for a *night case:*

let $E_T = 10^{-6}$ lx, RVR = 100 m

hence $b' = 38.4$ m

This illustrates the fact that the maximum baseline length (*b′*) is dominated by night-time conditions, intensity and minimum transmittance being the same.

Table D-1. Numerical relationship between the minimum transmittance $t_{b'}$ and maximum baseline length *b′* for day and night case

Day		*Night*	
$t_{b'}$ (%)	*b′* (m)	$t_{b'}$ (%)	*b′* (m)
5	32.5	5	21.6
1	50	1	33.3
0.5	57.5	0.5	38.4
0.1	75	0.1	50
0.05	82.5	0.05	55
0.01	100	0.01	66.7
0.005	107.5	0.005	71.7

Table D-1 demonstrates that an accuracy (i.e. the minimum transmittance that can be measured by the instrument) multiplied by one hundred allows only about doubling of the maximum baseline length.

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 transmissometers, are as follows:

a) Signal offset Δt_o to < 0.001 good; < 0.005 fair

b) Scaling error Δt_s < 0.005 very good; < 0.01 good

c) Signal drift Δt_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.

Appendix F

CALCULATIONS OF THE EFFECT ON RVR OF MOR (VISIBILITY) ERROR, LIGHT INTENSITY ERROR AND ERROR OF VISUAL THRESHOLD OF ILLUMINATION

Note.— The following is based on the common method of error estimation in cases of independent influences by several factors. For simplicity, V is used instead of MOR and R instead of RVR. This appendix is the analytical version of the analysis in Section 6.7.

1. The influence of the errors in the a) illumination threshold, b) light intensity and c) MOR (or extinction) on the errors of RVR can be determined using the following three equations:

a) Influence of illumination threshold

$$\frac{\Delta R/R}{\Delta E_T/E_T} = \frac{-1}{2+3R/V} \qquad (17)$$

b) Influence of light intensity

$$\frac{\Delta R/R}{\Delta I_V/I_V} = \frac{1}{2+3R/V} \qquad (18)$$

c) Influence of MOR, or alternatively, extinction

$$\frac{\Delta R/R}{\Delta V/V} = \frac{1}{1+2V/3R} \qquad (19a)$$

or

$$\frac{\Delta R/R}{\Delta \sigma/\sigma} = \frac{-1}{1+2V/3R} \qquad (19b)$$

2. The quantities $\Delta E_T/E_T$, $\Delta I_V/I_V$ and $\Delta\sigma/\sigma$ are known as fractional errors of E_T, I_V, V or σ, respectively. Using the fractional errors, the maximum error of $\Delta R/R$ can be assumed to be as follows:

$$\Delta R/R = [(\Delta E_T/E_T)-(\Delta I_V/I_V)]\frac{1}{2+3R/V} + (\Delta V/V)\frac{1}{1+2V/3R} \qquad (20)$$

3. If the absolute errors with sign and value are unknown but $\overline{\Delta E_T}/E_T$; $\Delta I_V/I_V$ and $\overline{\Delta\sigma}/\sigma$ or are assumed as probable errors, the resulting probable RVR error has to be obtained by averaging squared values of the random errors:

$$\overline{\Delta R}/R = \sqrt{[(\overline{\Delta E_T}/E_T)^2 + (\overline{\Delta I_V}/I_V)^2](\tfrac{1}{2+3R/V})^2 + (\overline{\Delta V}/\mathrm{V})^2(\tfrac{1}{1+2V/3R})^2} \quad (21)$$

4. Note that the influence of errors in the four parameters E_T, I_V, V (i.e. MOR) and σ on RVR has only two functional relationships, i.e. two pairs (E_T and I_V; V (MOR) and σ). Table F-1 shows how the errors depend upon the ratio RVR/MOR for the parameter having a positive error correlation (I_V and V). Note that the ratio of the fractional errors is a factor of 3 to 4 lower for E_T and I_V errors than for V (MOR) and σ errors. (Figures 6-11 through 6-14 also show plots of these relationships.)

5. Tables F-2 and F-3 show how the errors depend upon RVR and MOR as independent variables. Again the parameters giving a positive error correlation are listed. The alternative parameters (E_T and σ) simply have the signs reversed. Note that, when E_T and I_V errors become large, the differential analysis of Equations 17 to 21 can become inappropriate. Figures 6-15 and 6-16 show the results for large errors (factors of 2 and 4) in I_V.

Table F-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 F-2. Dependence of $(\Delta R/R)/(\Delta I_V/I_V)$ on RVR and MOR

RVR	MOR							
	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		
1 000	0.003	0.007	0.016	0.031	0.059	0.125	0.200	
2 000	0.002	0.003	0.008	0.016	0.031	0.071	0.125	0.200

Table F-3. Dependence of *(∆R/R)/(∆V/V)* on RVR and MOR

RVR	MOR							
	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		
1 000	0.993	0.987	0.968	0.938	0.882	0.75	0.600	
2 000	0.997	0.993	0.984	0.968	0.938	0.857	0.750	0.600

Appendix G

OUTSTANDING ISSUES

1. A most important matter is the need to achieve RVR values that apply worldwide to the same visual distances. In this respect, continuing efforts towards standardizing current and projected RVR systems and operational practices are required. Present-day trends towards increased traffic and operations in ever lower visibility conditions emphasize this need.

2. The following may also need further study and consideration:

a) variations in fog density with time and distance;

Studies of fog have been conducted in the past by a number of States, but the effect of variability in RVR has not been resolved. It would be desirable to develop guidance or procedures for processing RVR data recorded in variable conditions, so as to provide the most useful kind of report.

b) cumulative effect of lights in a row, due to lights merging because of the spacing and the angle at which they are viewed by the pilot*;

This matter is of special interest in connection with the observation of runway centre line lights in various visibility conditions.

c) eye illumination threshold (E_T), taking into account the viewing conditions that apply to the pilot* ;

d) effect on RVR and on c) above of viewing through a windscreen;

e) effect of human factors (e.g. tiredness and other physiological conditions) on the pilot's perception of lights and assessment of RVR;

f) short period forecasting of RVR;

This is of particular importance as RVR is currently a basic factor in the statement of operating minima.

g) RVR in obscuration other than mist or fog (e.g. sandstorm, snowstorm, etc.).

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* Recommended for study by the Fourth Meeting of the All Weather Operations Panel.

Appendix H

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