

Low-Visibility Lighting Criteria for Airports and Roadways

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The purpose of this paper is to present basic visibility information and criteria that are used for ground navigation of aircraft during low-visibility conditions. The information presented is also applicable to automobile and truck navigation and guidance in situations in which ground fog becomes a serious hazard to the motoring public.

The aeronautical ground lights located at airports are intended to provide visual approach and ground navigation guidance to aircraft pilots. Therefore, aeronautical ground lighting is considered to be a form of signal lighting.

The most important elements of aeronautical ground lighting are the configuration of the lighting system, the color of the lights, the beam coverage (vertical and horizontal), and the intensity of the lights under various conditions of visibility.

There are a number of configurations or signal patterns for lights at an airport. These basic patterns can be combined to provide visual guidance under a wide range of visibility conditions.

SIGNAL PATTERNS AT AIRPORTS

- Basic runway. White edge lights, green threshold lights, and red end lights.
- Runway for low-visibility landings. The items above, plus runway centerline lights, touchdown zone lights, and red filters in the last 3,000 ft of the centerline light and yellow filters in the last 2,000 ft of the edge lights.
- Taxiway lights. At most airports, low-intensity blue taxiway lights are used to mark the edges of taxiways in conditions of fair to good visibility under Visual Flight Rules (VFR). At big airports that must operate during low-visibility conditions, more intense green taxiway centerline lights are used for guidance. Taxiway centerline lights are about 200 cd average in green when used in low-visibility conditions.
- Approach lights. Several types of approach lights give directional and roll guidance during the final stages of a flight and assist the pilot during the approach to the runway.
- Light intensity. Each runway light has a specified beam intensity and distribution such that a well-balanced lighting system, free of optical illusion, is produced.
- Beam intensities and distribution. See Table 1. Complete specifications for all airport lights may be found in Annex 14, published by the International Civil Aviation Organization.

VISIBILITY

Visibility on an airport is measured by or referred to as Runway Visual Range (RVR). It is defined as the distance one can see a light of 10,000 cd intensity. (This would be applicable to highway guidance).

There is an instrument that is located next to the runway called a transmissometer. This calibrated instrument is a light source of known intensity shining at a receiver 250 ft away. As the transmissivity through the atmosphere decreases, a signal change from the transmissometer is sent to a computer. The computer then records the transmissivity factor T of the atmosphere.

In addition to the transmissometer connection, a current to voltage transformer is connected from the computer to the high-intensity runway edge-light circuit. This circuit, along with the approach, centerline, and touchdown-zone lights, have 5 intensities (100, 20, 4, 0.8, and 0.2 percent) that provide for a range of brightness. This allows for changes to the light intensity settings for any visibility condition.

Because the computer records the intensity of the lights and the transmissivity of the atmosphere, it continuously calculates and will display an RVR number to air traffic controllers. The controllers can improve (increase) the RVR number by increasing the light intensity within the limits of the system. The controllers have tables of suggested intensity settings for various visibility conditions. Intensity can also be changed by pilot request. These data could easily be processed automatically to change light settings on a roadway.

LIGHT INTENSITY VERSUS VISUAL RANGE

The visibility of a signal light under various conditions can be calculated using Allard's Law. A graphical solution to Allard's Law is shown in Figure 1. These data, which were supplied by the U.S. Coast Guard, can be applied to almost any situation and are not restricted to airports.

It can be shown that the distance a signal can be seen is dependent on background luminance, transmissivity through the atmosphere, and intensity of the light.

For example (using Figure 1), a light of 1 cd intensity on an exceptionally clear night ($T = 1.0$) could be seen for 1.3 mi. However, under similar conditions in a haze ($T = .30$), the range of the same light would be reduced to 0.75 mi.

LIGHT INTENSITY VERSUS RVR

The intensity of runway lights in low-visibility conditions (i.e., those not shown in Figure 1), are shown in Figures 2 and 3,

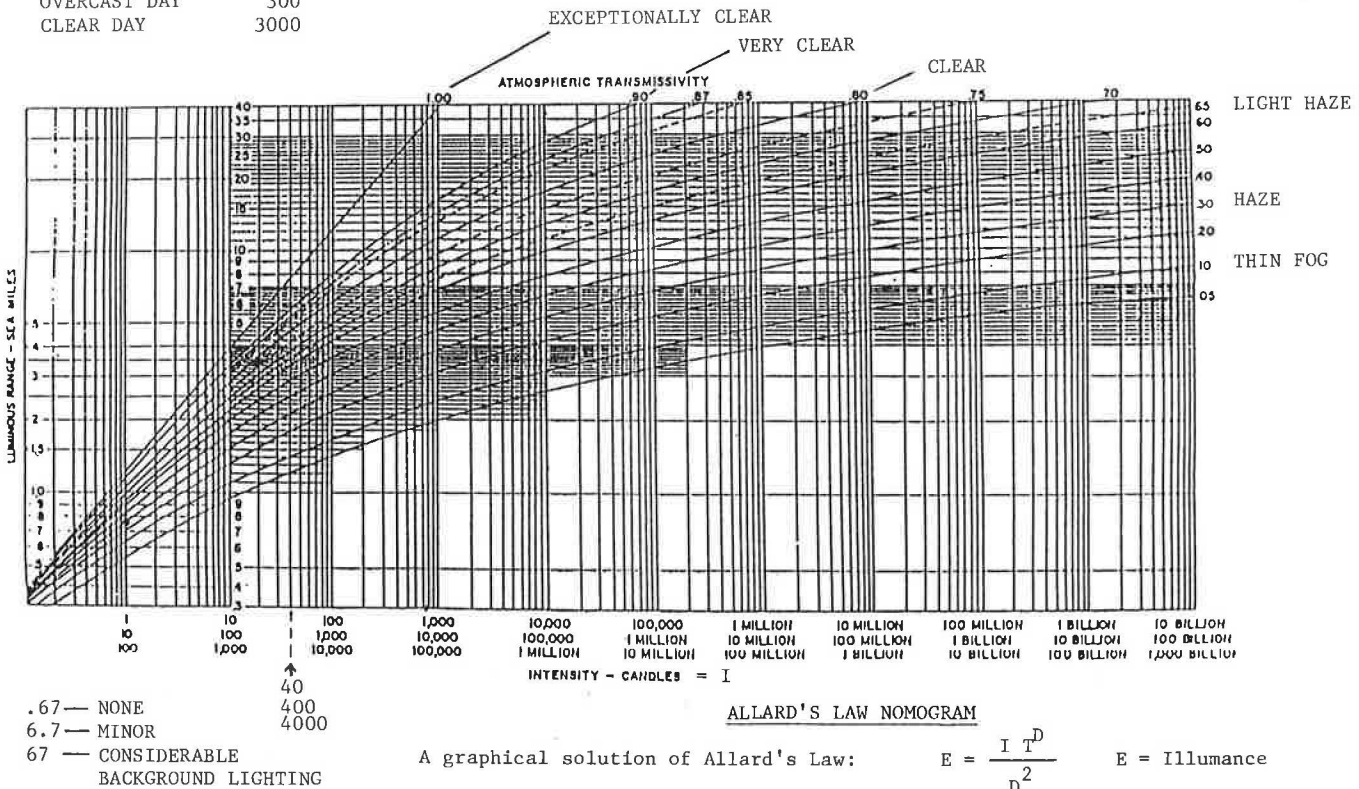
TABLE 1 LIGHT CHARACTERISTICS FOR CATEGORIES I, II, AND III PRECISION APPROACH RUNWAYS

Light	Colour	Minimum Beam Coverage						Minimum average intensity in specified colours Cd x 10 ³	Limits of Average Intensity Ratio	Angular Settings	
		Main Beam		10%		5%				Elevation (degrees)	Toe-in (degrees)
		H	V	H	V	H	V				
1	2	3	4	5	6	7	8	9	10	11	12
Approach centre line and crossbars	White	20	11	28	13	30	17	20	1.5-2 max.	8-5.5	0-2
Approach side row	Red	14	10	23	12	33	16	5	0.5-1	6.5 - 5.5	2
Threshold	Green	11	9	15	12	18	17	10	1.0 - 1.5	5.5	3.5
Threshold wing bar	Green	14	10	23	12	33	16	10	1.0 - 1.5	5.5	2
Touchdown zone	White	10	7	14	12	17	17	5	0.5-1	5.5	4
Runway centre line (15 m)	White/Red	10	9	14	17	17	20	2.5	0.25-0.5	4.5	0
Runway end	Red	12	4.5	15	10	18	13	2.5	0.25-0.5	2.5	0
Runway edge (45 m runway)	White	11	7	15	12	18	17	10	1.0	3.5	3.5

BACKGROUND LUMINANCE

CANDLES/M²

CLEAR MOONLIGHT .03
 TWILIGHT 3.
 OVERCAST DAY 300
 CLEAR DAY 3000



ILLUMINATION AT THE EYE
 IN SEA-MILE-CANDLES

With a fixed transmissivity T and background illumination E, the graph relates range D to effective intensity I. The three intensity scales indicate levels of background lighting.

FIGURE 1 Graphical solution of Allard's Law.

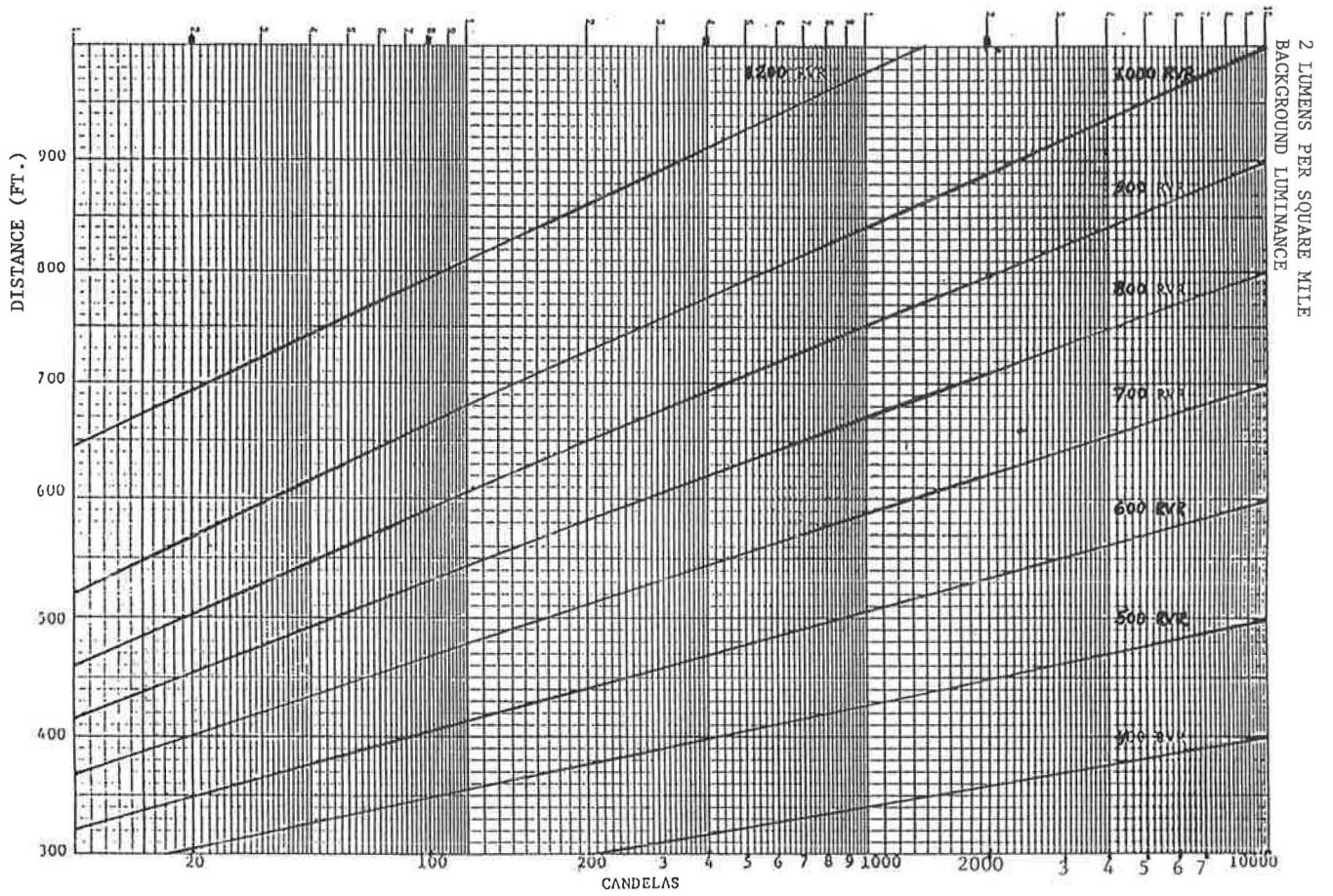


FIGURE 2 Visibility distance versus light source candle power at night.

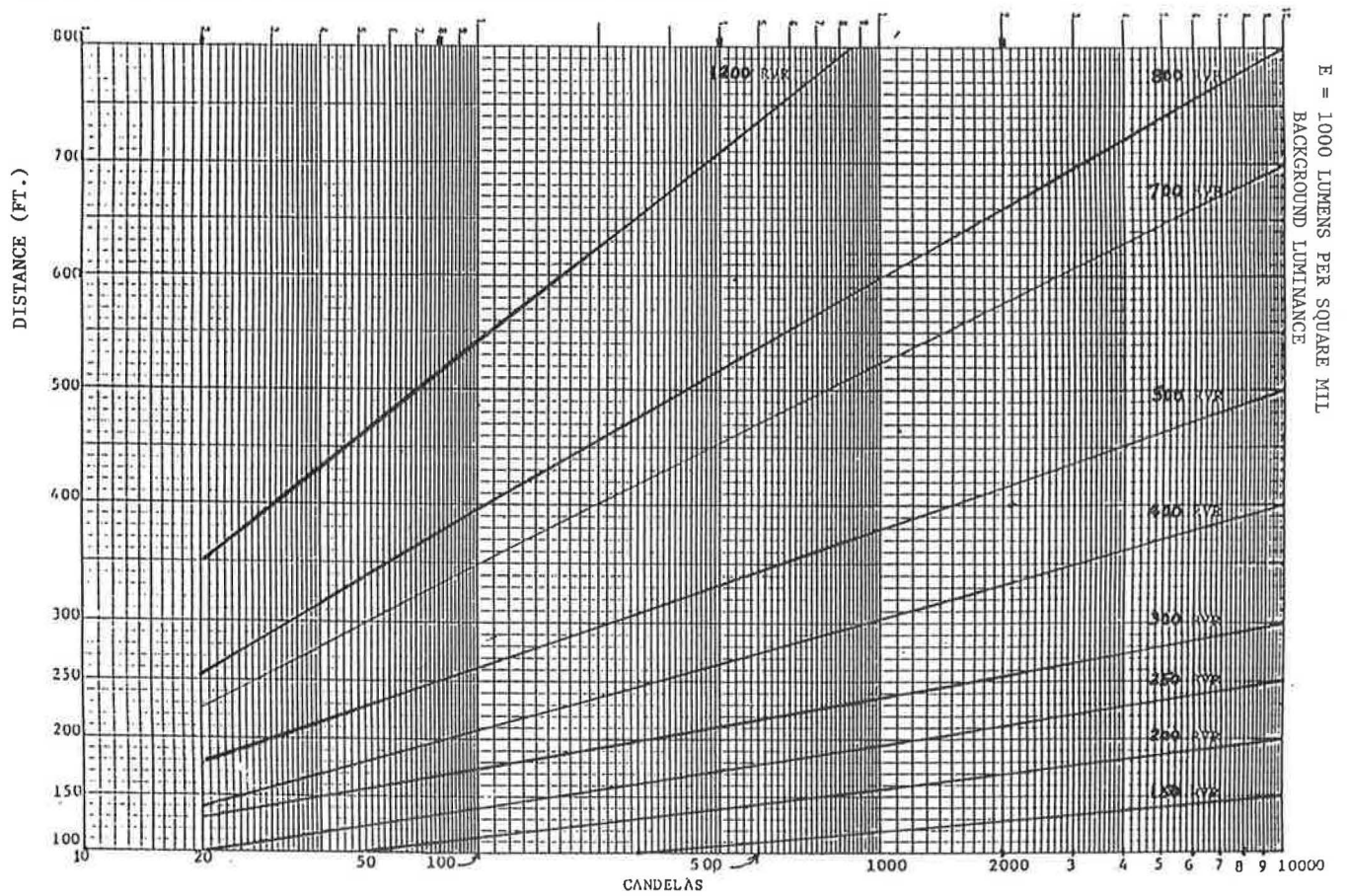


FIGURE 3 Visibility distance versus light source candle power during the day.

and Tables 2 and 3. Data were supplied by the Port Authority of New York and New Jersey. It must be remembered that the definition of RVR is based on a high-intensity light of 10,000 cd.

In the airport environment, visibility conditions are defined as follows:

- VFR. VFR apply when meteorological visibility (outside controlled airspace) is greater than 1 mi during the day and 3 mi at night. Cloud data are not included here because they are not applicable to the discussion.

- Category I. An instrument runway served by Instrument Landing System (ILS) and visual aids intended for operations down to a 60-m (200-ft) decision height and down to an RVR of 800 m (2,600 ft).

- Category II. An instrument runway served by ILS and visual aids intended for operations down to a 30-m (100-ft) decision height and down to an RVR of 400 m (1,300 ft).

- Category IIIA. This category is the same as Category II except RVR is 200 m (650 ft), with no minimum decision height and visual aids used during the final phase of landing.

- Category IIIB. RVR is 50 m (160 ft), with no minimum decision height and no visual aids used for landing.

In referring to Figure 2 and Table 2, it can be seen that an intensity setting at Step 4 (2,000 cd on the edge lights spaced at 200 ft) and (1,000 cd on the runway touchdown zone lights spaced at 100 ft) provides 800 ft of visibility at 900 RVR. At Step 5 (10,000 cd on the Edge Light and 5,000 on the Touchdown Zone Lights) the visibility is increased to 900 ft. In

TABLE 2 VISUAL RANGE UNDER LOW RVR CONDITIONS AT NIGHT

INTENSITY OF SOURCE (CANDELAS)	VISUAL RANGE OF SOURCE (FEET)					
	150'	200'	250'	300'	400'	500'
1	75	97	118	133	178	216
10	92	122	149	177	230	282
30	102	134	165	196	256	315
100	112	147	182	217	285	352
300	121	159	198	236	312	387
1,000	131	173	216	258	342	425
3,000	140	186	232	278	369	460
10,000	150	200	250	300	400	500
100,000	170	227	285	343	459	576
1,000,000	190	255	320	386	519	654

RVR IS THE VISUAL RANGE OF A 10,000 CANDELA SOURCE. THE ILLUMINANCE THRESHOLD IS 2 MILE CANDELAS.

TABLE 3 VISUAL RANGE UNDER LOW RVR CONDITIONS DURING THE DAY

INTENSITY OF SOURCE (CANDELAS)	VISUAL RANGE OF SOURCE (FEET)					
	150'	200'	250'	300'	400'	500'
1	43	52	60	68	80	89
10	66	83	99	114	141	165
30	78	100	120	140	176	210
100	92	118	145	170	218	263
300	105	138	169	200	259	316
1,000	120	158	196	233	305	376
3,000	134	178	221	264	350	434
10,000	150	200	250	300	400	500
100,000	181	243	306	370	500	631
1,000,000	212	288	365	443	603	767

RVR IS THE VISUAL RANGE OF A 10,000 CANDELA LIGHT. THE ILLUMINANCE THRESHOLD IS 1,000 MILE CANDELA.

other words, 5 times more light is needed to obtain another 100 ft of usable visibility. Similar examples can be given for daytime conditions from Figure 3 and Table 3.

AIRPORT DATA APPLICABLE TO ROADWAYS

The low-visibility systems used at airports are applicable to roadways under conditions of heavy fog when the transmissivity of the atmosphere falls below $T = 0.05$.

Such a condition takes place in Virginia on Afton Mountain on Interstate 64. The Virginia Highway Department, after trying many types and combinations of signs and reflectors, installed roadway inpavement (airport) lights to provide guidance for the motoring public under sudden and severe low-visibility conditions when clouds would suddenly cover the mountain and drivers would become instantly lost in the fog.

The Virginia Highway Department, in conjunction with the Virginia Highway Research Council, determined that inpavement runway lights were the only practical solution to this difficult and extremely dangerous highway guidance problem.

A system of lights using a modified runway touchdown-zone light and a detection system to determine fog density was installed on a 6.25-mi section of divided highway. The lights were located 200 ft apart on both sides of the road in a manner similar to runway edge lights. These inpavement lights have been in service for 10 years, and the results have been more than favorable.

The use of aeronautical ground lights for low-visibility roadway application is a subject that requires additional study to determine the effects of these navigational lights on drivers

of various ages, optimum operating speeds, and whether other colors or patterns would improve the Afton Mountain installation. Recent accidents on highways during low-visibility conditions, when no lighting was available, indicate the potential for this kind of system.

OTHER POTENTIAL HIGHWAY APPLICATIONS

Another attribute of runway lights is that they are placed in a position in which the pilot or motorist is normally looking. For instance, inset red lights could be placed within a railroad crossing area instead of overhead. Even someone with poor eyesight or someone whose mind is on another subject could not help but see the red signal. In many applications, the intensity of inpavement lights for roadway applications could be on the order of 200 cd (similar to airport taxiway centerline lights) if the spacing were reduced to 25 ft. If spacing were greater, then a higher intensity would be required.

SUMMARY

In summary, Allard's Law is applicable to all signal visibility conditions. Special attention must be given to intensity, spacing, color, and patterns to provide the visual guidance needed for various conditions of vehicle operation by people 16 years of age and older.

With ever-increasing traffic, the problem of guidance in low-visibility conditions must be addressed if highway accidents involving scores of vehicles are to be avoided.