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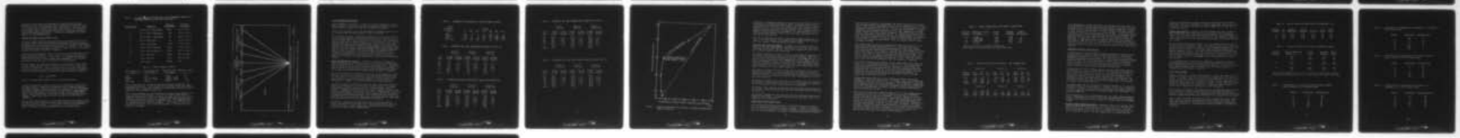

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SLANT AND RUNWAY VISUAL RANGE RELATIONSHIPS

William Lewis

Ernest E. Schlatter

JUNE 1977

FINAL REPORT

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

A study was conducted to determine if any significant relationships existed between horizontal and slant visibility during fog conditions. Approximately 11,000 sets of atmospheric transmittance observations in fog were obtained at six horizontal levels from 5 to 155 feet and from the 5- to 155-foot slant path by extinction-type transmissometers mounted on two airfield towers separated by 250 feet. Each observation set was classified into one of seven vertical profile classes according to the transmittance difference between the top (155-foot) and bottom (5-foot) transmissometers. The implications of the various fog structures for aircraft landings are discussed. Average 5- to 155-foot slant visual range versus 5-foot runway visual range (SVR-RVR) ratios and standard deviations of ratios were computed by profile class. An analysis showed that results are definitive and could form the basis of a procedure for estimating SVR from RVR through fog profile measurement. A multiple linear regression analysis to predict SVR from RVR, surface temperature, windspeed, and atmospheric stability showed RVR to be the best predictor of SVR, while the other variables showed some effect only with dense fog. These results are considered tentative, since they are based on a limited data sample. Fifteen-minute changes in SVR by profile class were examined for certain SVR ranges. Results showed that knowledge of the profile class would not significantly improve 15-minute persistence forecasts of SVR.

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INTRODUCTION

OBJECTIVE.

The objective of this effort is to compare horizontal and vertical measurements of atmospheric transmittance, during fog, to determine if any significant relationship exists between horizontal and slant visibility. An additional objective, if such relationship exists, is to determine if correlation could be enhanced by grouping fog classes by vertical temperature and wind distributions and to recommend procedures and conditions under which a report of horizontal visibility could be translated into a slant visibility value.

BACKGROUND.

Officially, aviation visibility parameters, as defined in a Federal Aviation Administration (FAA) Advisory Circular (reference 1), are as follows:

1. Prevailing Visibility - Prevailing visibility is the horizontal distance at which targets of known distance are visible over at least half of the horizon. It is determined by an observer viewing selected dark objects against the horizon sky during the day and moderate intensity unfocused lights at night.

2. Runway Visibility Value (RVV) - Runway visibility is the visibility along an identified runway. It can be measured by an instrument or by a human observer. Where a transmissometer is used for measurement, the instrument is calibrated in terms of a human observer, i.e., the sighting of dark objects against the horizon sky during daylight and the sighting of moderate-intensity unfocused lights of the order of 25 candelas at night.

3. Runway Visual Range (RVR) - Runway visual range in the United States is an instrumentally derived value that represents the horizontal distance a pilot will see down the runway from the approach end, or when additional transmissometers are installed, from that portion of the runway adjacent to the transmissometer location. It is based on the sighting of either high-intensity runway lights or on the visual contrast of other targets, whichever yields the greatest visual range.

All are descriptive of a horizontal, surface-based obstruction and make no provision for describing the effects of vertical visibility restrictions to the pilot. Some connotation of vertical visibility restrictions is conveyed to the pilot by the measurement and reporting of cloud bases or vertical visibility due to a partial or full sky obscuration, but it is only through experience that a pilot on approach can relate these parameters to the visibility parameter he is most dependent upon, slant visibility.

In fact, RVR, in deference to the official definition, is being used as a probability indicator for minimizing missed approaches by establishing RVR minima weather categories for instrument approach operations. The minima for these categories, as defined in an FAA Advisory Circular (reference 2), are the following:

Category	Decision Height	Visibility (RVR)
I	200 feet	1,800 feet (2,400 feet without touchdown zone and centerline lights)
II	100 feet	1,200 feet
IIIA	None	700 feet
IIIB	None	150 feet
IIIC	None	0 feet

Lack of an operational slant visibility measuring and reporting system prompted initiation of the approach zone use of RVR, which is satisfactory for category I conditions for several reasons. In a homogeneous fog or in a fog condition wherein fog density decreases with height, the approach pilot would find the slant visibility to be no lower than the RVR report and encounter no landing difficulty. In a fog condition wherein the fog density increased with height, the slant visibility, although less than the RVR report, would still permit pilot visual contact by decision height because of the relatively good surface visibility conditions.

However, as operations moved into category II and to a limited extent category III visibility, it was realized that the lower surface visibility and the lower yet slant visibility, when fog density increased with height, would lead to more missed approaches and an increase in the attendant risk factor.

Research efforts have been underway (reference 3) toward the development of a slant visual range (SVR) system. Operational system equipment, however, would probably be installed at only a few selected airports, yet RVR measurements of horizontal visibility are standard and available at all major airports. Possibly further investigation of the relationship of horizontal to slant visibility might provide a procedure to enable RVR-only airports to determine useful slant visibility information, even though not as exactly as a full SVR instrumented airport. Perhaps knowledge of the temperature or wind profile in the lowest 100 feet might serve to correlate well with the actual fog profile and thus help to predict SVR based on RVR.

DISCUSSION

INSTRUMENTATION.

The National Aviation Facilities Experimental Center (NAFEC) Metower Facility was used for the data acquisition program, because the existing tower-mounted transmissometer systems were previously used in the development of a SVR measurement system (reference 3). The facility (figure 1) consists of two 155-foot-high towers located in the northwest corner of the airfield, where distance from tree lines and buildings would not restrict or bias fog development or structure.

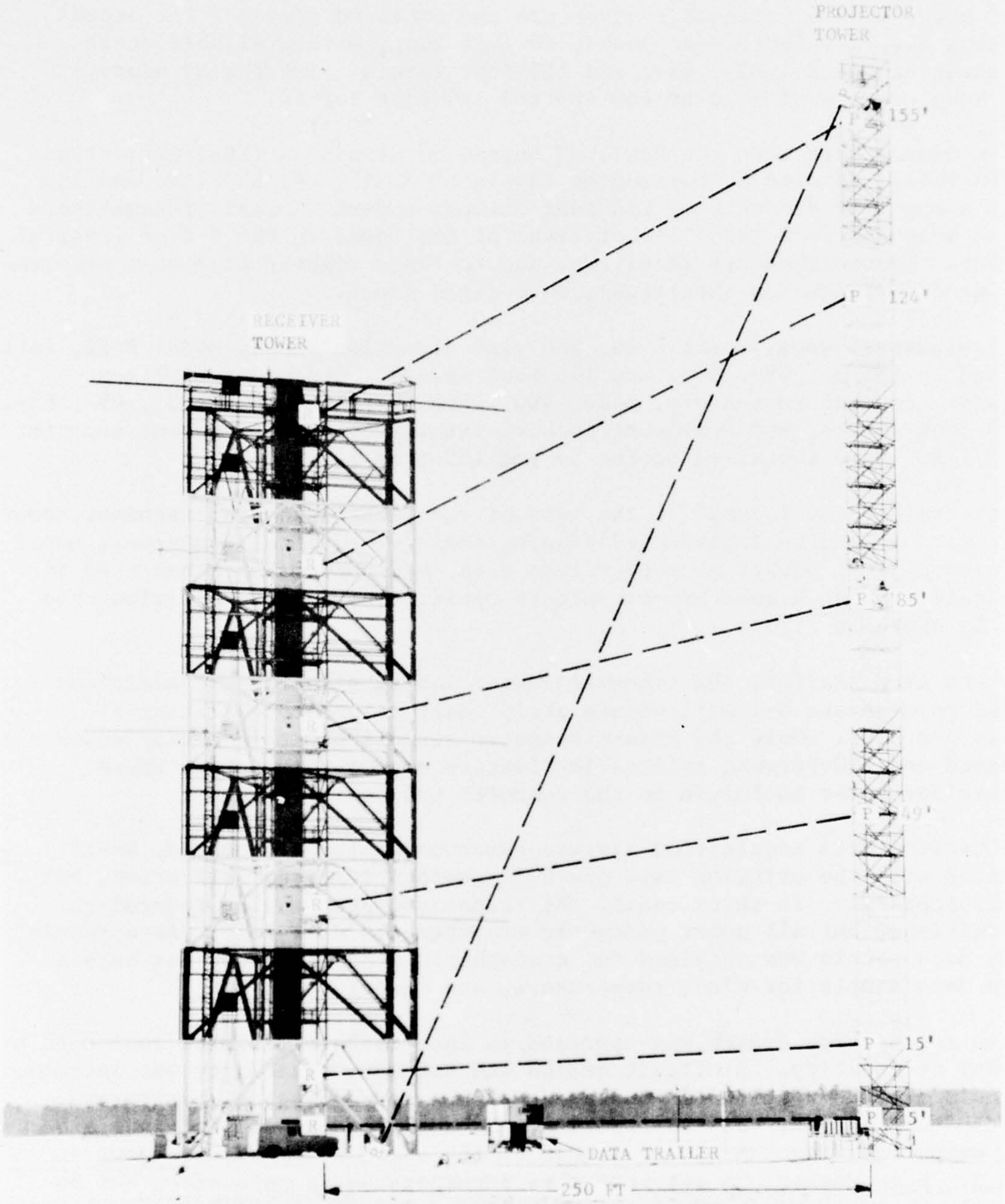

FIGURE 1. NAFEC METOWER FACILITY

The smaller tower is a 6-foot-square upright scaffold-type with a walkup stairway for access to working levels. The larger, more massive tower has a 40-foot base, with a triangular structure and enclosed elevator for access to working levels. Instrument booms, 20 feet long, were available on the large tower at the 5-, 20-, 85-, and 155-foot levels. Instrument booms, 5 feet long, were available at the 49- and 124-foot levels.

The transmissometers were the National Bureau of Standards (NBS) extinction-type (FA-7861), mounted at horizontal levels of 5, 15, 49, 85, 124, and 155 feet at a baseline distance of 250 feet between towers. Slant transmittance was also measured from the 155-foot level of one tower to the 5-foot level of the other. Transmissometer receivers, due to their tighter alignment requirements, were installed on the larger, more rigid tower.

Cardion windspeed cups, model B-20, and wind direction vanes, model B-21, were installed at the 5-, 49-, 85-, and 155-foot levels. Rosemount platinum resistance temperature sensors, model 400, were installed at the 5-, 49-, 85-, and 155-foot levels, and Rosemount/Foxboro lithium chloride dewpoint sensors, model 2711AG, were installed at the 5- and 155-foot levels.

The data trailer was located at the base of the transmissometer receiver tower (figure 1). A Cardion signal-conditioning analog-to-digital converter, model DA-1, with digital output on a 80-column data card punch system was used for data acquisition on a one-card-per-minute cycle. The data acquisition card format is shown in figure 2.

Within the data trailer, the transmissometer analog signals were additionally recorded on separate 0-1 milliampere strip chart recorders operating at 3 inches per hour. Only the transmissometer sensors had this backup capability. Background and 100-percent calibration factors were obtained from these recorders for later inclusion in the computer processing program.

In the Cardion data acquisition system, numerous failures occurred, mostly associated with the printing card punch. Numerous remedies were tried, but were unsuccessful. In these cases, the transmissometer analog recordings were digitized, but all other parameter measurements were lost. As a result, a large data sample was obtained for atmospheric transmittance, but only a limited data sample for wind, temperature, and dewpoint.

The data acquisition system was upgraded in late 1975 to minimize lost data by improving reliability. A circuit design and software capability was introduced that could provide continuous monitoring of all meteorological parameters, automatic turn ON/OFF, self-calibration, and real-time processing into a variety of output devices. A block diagram of the upgraded system is shown in figure 3. Some sensor changes were also incorporated at this time, but no data collection was obtained on the upgraded system due to project termination. Therefore, data obtained on the original system during the period September 8, 1972, to June 8, 1973, were used to investigate slant and runway visual range relationships. Approximately 190 hours of minute-to-minute, visibility-only readings and about 7 hours of visibility, temperature, wind, and dewpoint readings had been obtained.

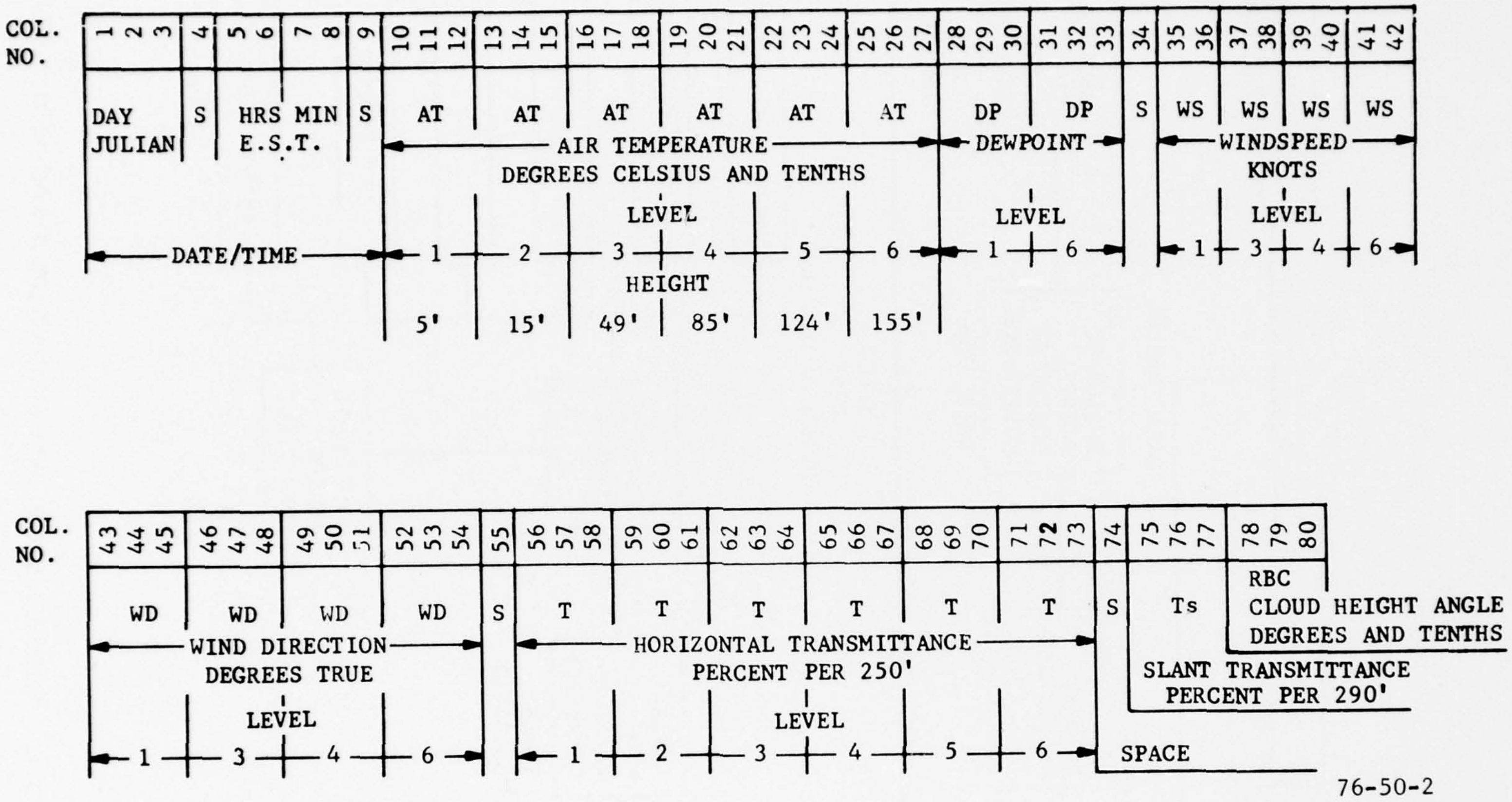

FIGURE 2. METOWER DATA ACQUISITION CARD FORMAT

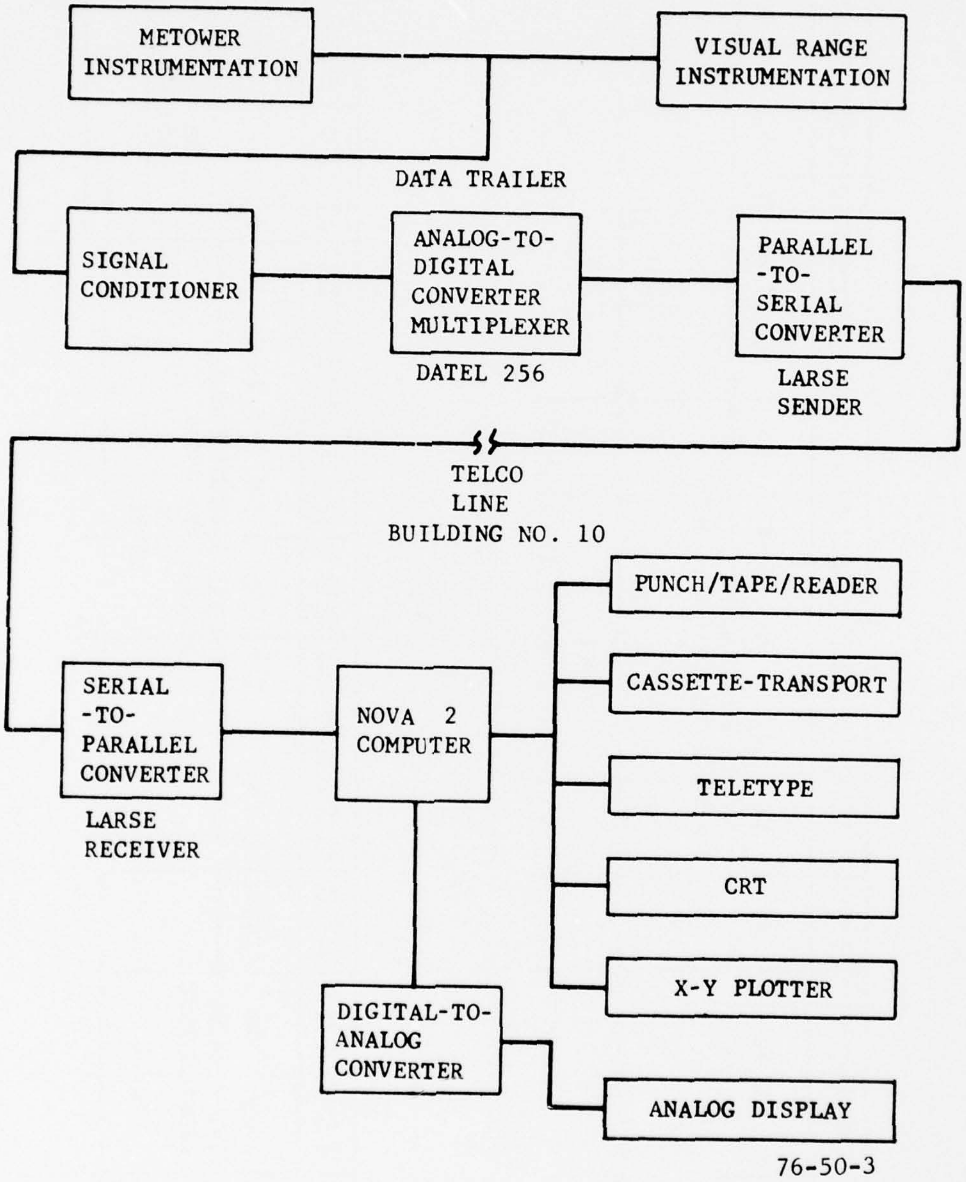

FIGURE 3. METEOROLOGICAL DATA ACQUISITION SYSTEM--BLOCK DIAGRAM

The data collection system was automatically turned ON when the slant transmittance fell below 92 percent and was automatically turned OFF when it rose to this level. The 92-percent level corresponds to a nighttime runway visual range of about 3 miles using runway light setting 4 (see appendix). On a day-night basis, approximately 70 percent of the data was obtained at night and 30 percent during the day. The data were processed by electronic computer through FORTRAN programs.

VERTICAL AND SLANT CLASSIFICATIONS OF FOG.

A total of 11,080 minute-interval observations was obtained from each of the seven instruments. These were arbitrarily classified into vertical profiles according to the difference between the top (155-foot) horizontal transmittance and the bottom (5-foot) horizontal transmittance. The profile classes, numbers of observations, and percentage occurrences are shown in table 1. The profile classes are graphically presented in figure 4.

Profile class 3 predominates, with over 65 percent of the observations, and is fog of some vertical extent. Profile class 2 is relatively rare and has a shallow ground fog character. Profile class 1 has considerable occurrence, and is fog with vertical extent tending toward homogeneity. The vertical structure of these fogs will be discussed later in more detail.

The data sample was further classified into four fog density classes (thick, moderate, light, and very light) according to the value of the slant (155- to 5-foot) transmittance. For the classifications, the slant transmittance was first converted to an equivalent 250-foot baseline value for consistency with the horizontal readings, by using the following exponential equation:

$$t_{250} = t_{290}^{(250/290)}$$

where t is transmittance measured over the subscripted baseline.

The slant transmittance ranges selected for the fog density classifications are based closely on ranges used to determine official airfield aviation categories at night. Aviation categories are ranges of RVR steps determined from runway transmittance through Allard's or Koschmieder's Laws (appendix). Table 2 shows the fog density classes in relation to slant transmittance ranges, corresponding ranges of SVR steps at night, and equivalent aviation category. Runway light setting 4 (LS-4) was used for the SVR intervals (appendix).

The fact that some 30 percent of the fog observations was made during the day does not necessarily invalidate the LS-4 night conversion of transmittance to visual range for these data. The LS-4 night conversion simply provides a frame of reference for computing SVR/RVR ratios as discussed later.

TABLE 1. FOG PROFILE CLASSIFICATIONS BASED ON THE ATMOSPHERIC TRANSMITTANCE DIFFERENCE BETWEEN 155-FOOT AND 5-FOOT LEVELS

Profile Class	Definition	Number of Observations	Percentage Occurrences
1	155 ft & 5 ft within ±10%	2,911	26.3 of total
2a	155 ft >10% to ≤30% greater	280	30.2 of class 2
2b	155 ft >30% to ≤50% greater	221	23.8 of class 2
2c	155 ft >50% greater	427	46.0 of class 2
2	155 ft >10% greater	928	8.4 of total
3a	155 ft >10% to ≤30% less	2,430	33.6 of class 3
3b	155 ft >30% to ≤50% less	2,877	39.7 of class 3
3c	155 ft >50% less	1,934	26.7 of class 3
3	155 ft >10% less	7,241	65.3 of total
1, 2, 3	Total Sample	11,080	100

TABLE 2. SLANT FOG DENSITY CLASSES

Slant Fog Density Class	Slant Transmittance Per 250 Feet	*SVR Steps (Feet) LS-4, Night	**Aviation Category
Thick	<10.1%	≤1,000	III
Moderate	10.1 to <30.1%	1,200 to 1,800	II
Light	30.1 to <72.0%	2,000 to 5,000	I-L
Very Light	≥ 72.0%	≥5,500	I-H

*Visual range steps are in 200-foot increments starting with 600 feet and ending with 3,000 feet. After 3,000 feet the intervals are 500 feet, ending with 6,000 feet. Values below the 600-foot step are 600-, and values above the 6,000-foot step are 6,000+ (reference 4).

**In the United States, the aviation visibility category is determined by the runway (15-foot) transmissometer. There are no official "SVR" aviation visibility categories. The official category II upper limit may be as low as 1,600 feet and as high as 2,200 feet, depending upon runway instrumentation. The 1,800-foot step was chosen as a compromise value. The 2,000-foot step is the corresponding lower limit for category I. Also, there is no official breakdown of category I into low (L) and high (H). It is used here for the purposes of the study.

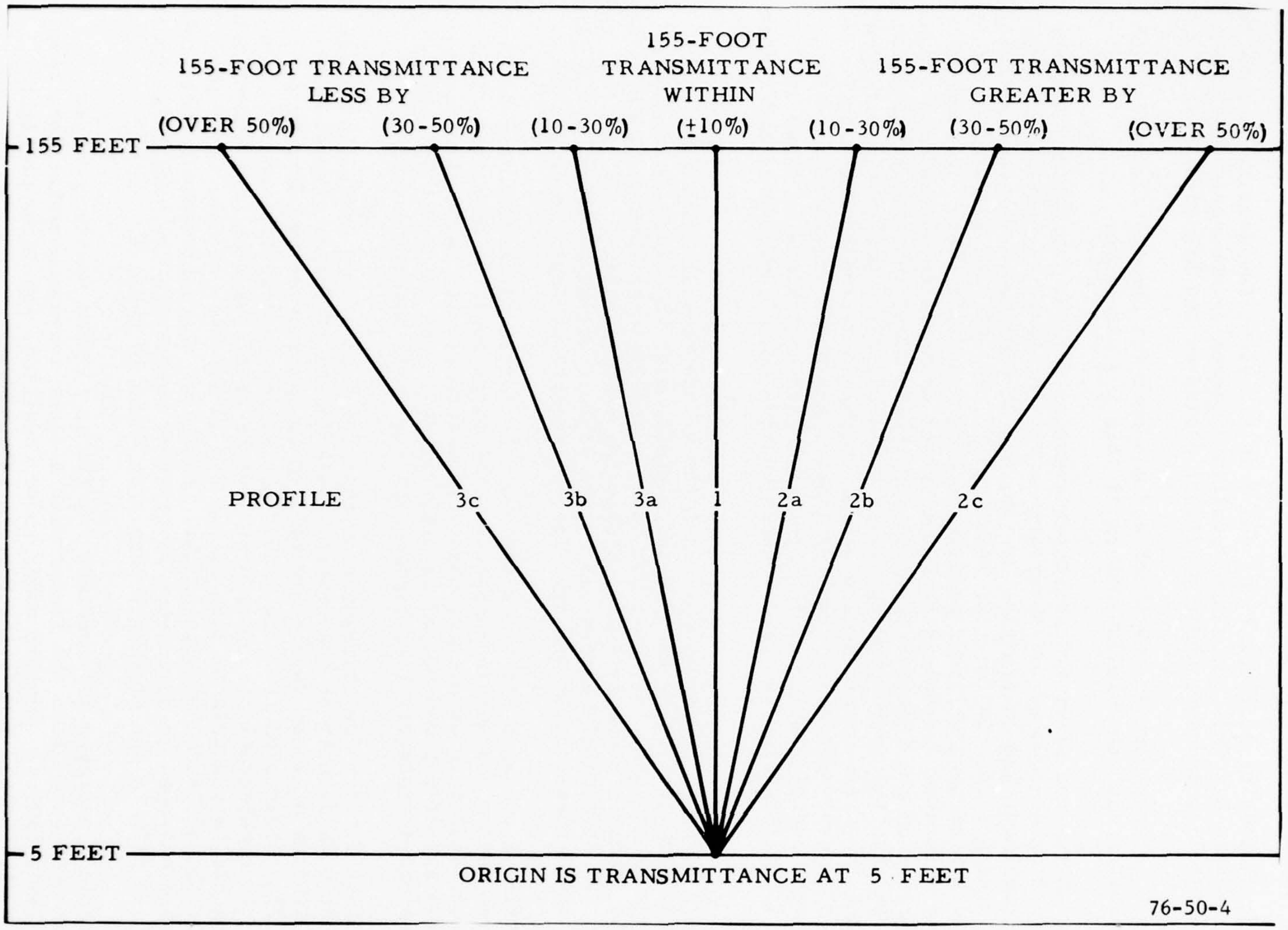

FIGURE 4. GRAPHICAL REPRESENTATION OF FOG PROFILE CLASSIFICATIONS

FOG DISTRIBUTION AND AVERAGES.

The distribution of profiles 1, 2, and 3 in the slant fog density classes is shown in table 3. This shows that profile 3 generally dominates the lowest three visibility classes, while profile 1 dominates the highest.

Profile 2 is very rare in the thick and moderate fog density classes, which is consistent with the shallow nature of this fog structure.

The horizontal and slant transmittance averages for the fog density classes of table 3 were computed for observations in profile 1, in profiles 2a, 2b, and 2c combined, and in profiles 3a, 3b, and 3c combined. The corresponding linear averages for the interior levels of 15, 49, 85, and 124 feet were also computed by assuming a linear profile between 5 and 155 feet. The linear averages were then subtracted from the actual averages to determine average departures from the linear. Negative departures meant that the actual values were less than the corresponding linear averages, while positive departures mean that they were greater. The actual averages, including the slant averages and the departures from the linear, are shown in tables 4 to 7. A graphical representation of the profile 2 data of table 4 is shown in figure 5 to illustrate the relationship between actual horizontal and linear averages.

THICK AND MODERATE FOG AVERAGES. In table 4, the profile 1 averages for thick fog show the fog to be very dense aloft, with the slant average somewhat lower than those for the lower two (5- and 15-foot) levels. Departures from the linear are mostly small, indicating quasilinearity. In general, the SVR and RVR (officially determined by the 15-foot transmissometer) would be so low under these conditions that landing operations would be suspended.

The profile 2 averages for thick fog show the fog at the lowest four levels to be very dense and quasihomogeneous. The large negative departures from the linear result in an average slant transmittance well below the linear mean (average of top and bottom transmittances). The slant and 15-foot averages are in category III, barring landing under these conditions.

The profile 3 thick fog averages show that the fog is very dense aloft, but thins out considerably at the lowest levels (5 and 15 feet). The average transmittances at these levels are well up in night aviation category I (table 2). Departures from the linear are slight to moderate, and the slant average is considerably lower than at 5 or 15 feet. Landing under these conditions should be possible as long as the SVR is adequate to site the runway at the 100-foot-altitude decision height. Note that the difference between top and bottom averages is only about 19 percent, reflecting the very large number of profile 3a's in the profile 3 sample as shown in table 3.

The profile 1 averages for moderate fog (table 5) show mostly moderate negative departures from the linear with a slant average somewhat less than at the lower levels. Landing under these conditions should be straightforward, with proper runway instrumentation.

TABLE 3. OCCURRENCE OF FOG PROFILES IN SLANT FOG DENSITY CLASSES

Slant Fog Density Class	Profile						
	1	2a	2b	2c	3a	3b	3c
Thick	172	9	1	6	392	43	2
Moderate	186	9	4	31	1,142	1,463	388
Light	138	30	50	196	152	380	1,378
Very Light	2,415	232	166	194	744	491	166

TABLE 4. HORIZONTAL AND SLANT TRANSMITTANCE AVERAGES FOR THICK FOG

	Profile 1 (172 obs)		Profile 2 (16 obs)		Profile 3 (437 obs)	
Level (ft)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)
155	3.9	--	53.8	--	3.3	--
124	4.9	-0.4	32.1	-12.0	5.1	-2.1
85	5.9	-1.1	6.8	-25.2	8.2	-3.9
49	5.3	-3.3	4.4	-16.3	8.7	-8.0
15	10.8	+0.6	5.6	- 4.5	18.7	-2.2
5	10.6	--	7.0	--	22.1	--
Slant	6.1	--	5.8	--	8.0	--

TABLE 5. HORIZONTAL AND SLANT TRANSMITTANCE AVERAGES FOR MODERATE FOG

	Profile 1 (186 obs)		Profile 2 (44 obs)		Profile 3 (2,993 obs)	
Level (ft)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)
155	25.0	--	77.8	--	8.9	--
124	15.6	-10.2	54.5	-10.6	9.6	-6.4
85	20.4	- 6.2	35.2	-13.6	18.5	-6.6
49	19.5	- 8.0	19.7	-14.4	25.4	-8.1
15	28.4	0.0	18.5	- 1.7	39.3	-2.1
5	28.8	--	16.1	--	43.8	--
Slant	20.3	--	24.1	--	18.6	--

TABLE 6. HORIZONTAL AND SLANT TRANSMITTANCE AVERAGES FOR LIGHT FOG

	Profile 1 (138 obs)		Profile 2 (276 obs)		Profile 3 (2,410 obs)	
Level (ft)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)
155	55.8	--	94.7	--	26.1	--
124	31.3	-24.8	89.6	+ 8.0	32.3	-4.5
85	42.9	-13.6	75.6	+10.6	52.8	+2.5
49	50.9	- 5.9	41.6	- 8.2	66.8	+4.0
15	61.3	+ 4.2	31.5	- 3.9	77.1	+2.5
5	57.2	--	31.2	--	78.1	--
Slant	41.9	--	57.2	--	50.0	--

TABLE 7. HORIZONTAL AND SLANT TRANSMITTANCE AVERAGES FOR VERY LIGHT FOG

	Profile 1 (2,415 obs)		Profile 2 (592 obs)		Profile 3 (1,401 obs)	
Level (ft)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)	Average Tr.(%)	Average Dep.(%)
155	93.4	--	94.9	--	60.0	--
124	92.8	- 016	94.6	+ 7.8	73.3	+ 6.1
85	93.9	+ 0.4	92.4	+15.9	87.5	+12.3
49	93.2	- 0.3	84.2	+17.2	90.8	+ 8.2
15	94.3	+ 0.7	66.7	+ 8.6	92.7	+ 3.1
5	93.6	--	55.4	--	91.6	--
Slant	91.6	--	89.2	--	83.0	--

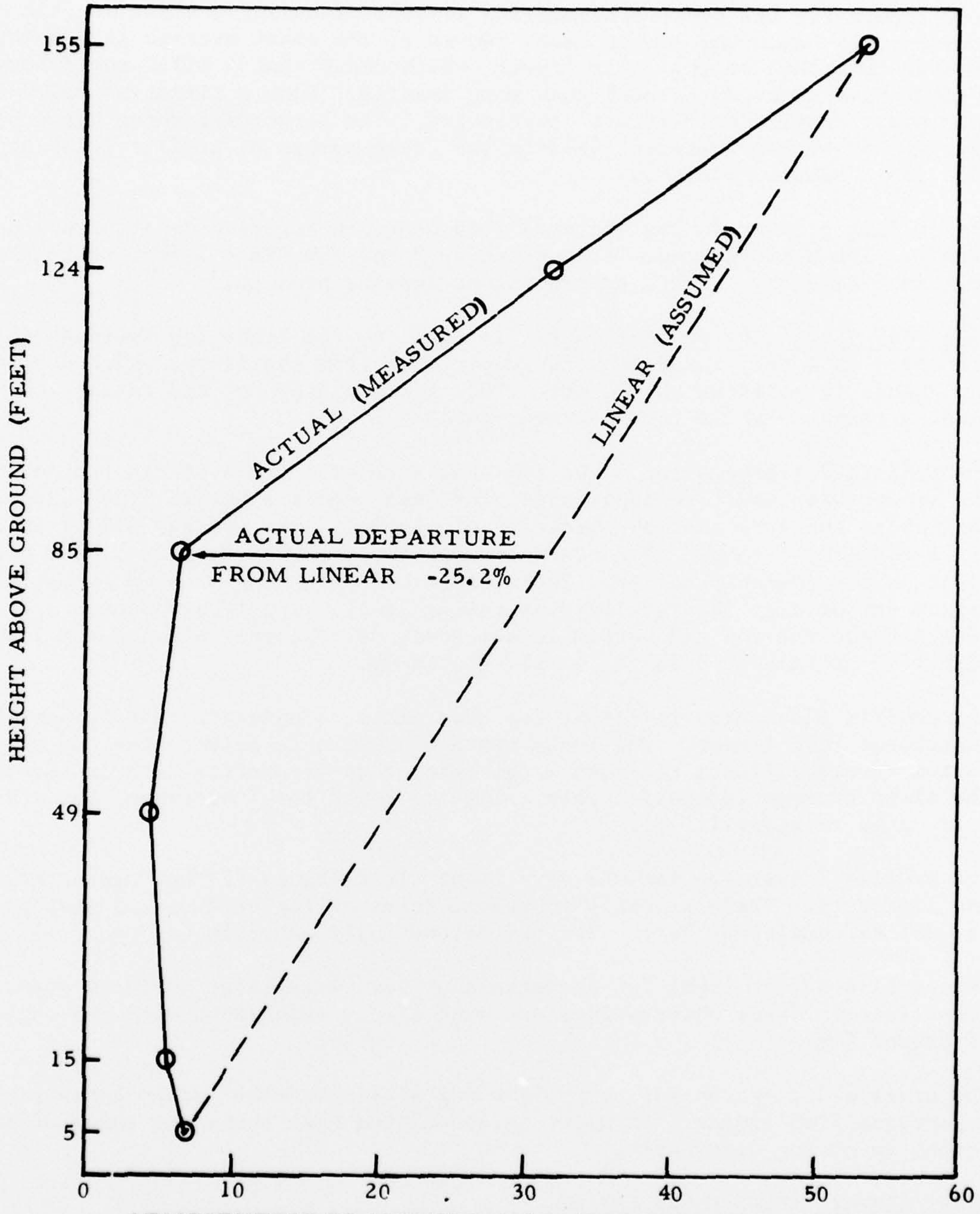

FIGURE 5. GRAPHICAL REPRESENTATION OF PROFILE 2, AVERAGE DEPARTURES FROM LINEAR IN THICK FOG

The profile 2 averages for moderate fog show rather large negative departures from linear for the upper intermediate levels, producing a slant average considerably below the linear mean. However, the slant average is somewhat greater than that at the lower levels, which means that a pilot would have greater visibility on descent than when landing. Such a situation could be dangerous, particularly if not anticipated. The large difference between the top and bottom averages reflects the large number of profile 2c's in this small sample (table 3).

The profile 3 moderate fog averages show moderate negative departures from linear. The slant average is in category 2 and the RVR (15-foot average) well into category I, thus presenting no landing problem.

LIGHT AND VERY LIGHT FOG AVERAGES. In table 6, the light fog averages for profile 1 show very large negative departures from the linear which dampen and change to positive on descent. This pattern produces the rather low slant average relative to the linear mean.

The profile 2 averages for light fog show a reverse trend of departures from the linear with positive departures aloft and negative below. These are related to the very shallow character of the fog. The average RVR at 15 feet is in category I (above 30 percent transmittance for LS-4, night), and the slant is considerably higher. There would be no landing problem except the disconcerting drop in visibility at runway level. The large average difference between the top and bottom levels (over 60 percent) reflects the large number of profile 2c's in the sample (table 3).

The profile 3 averages for light fog show small to moderate, mostly positive departures from linear. The large average difference between the top and bottom levels reflects the very large percentage of profile 3c's in the sample. The slant average is considerably below the lower level averages, but still well up in category I.

The profile 1 averages for the very light class (table 7) show near homogeneity and linearity. These probably represent cases of fog breakup and dissipation as well as conditions before fog has become fully established.

The profile 2 very light fog averages show some very large positive departures from linear. These observations are most likely associated with the beginning of ground fog.

The profile 3 averages for very light fog also show some rather large positive departures from linear. It might be speculated that these are cases of fog coming in or fog dissipating.

SLANT/RUNWAY VISUAL RANGE RATIOS.

The relationship between SVR and RVR is of particular interest for landing aircraft as has been indicated in tables 4 through 7. However, in practice it is the RVR that determines the aviation category, not the slant transmittance, which is not yet available. Accordingly, the profile data have been reclassiwhich is not yet available. Accordingly, the profile data have been reclassified into four aviation categories, using the 5-foot transmittance as the determinant. This was used rather than the "official" 15-foot transmittance in order to maintain consistency with the 155- to 5-foot slant transmittance. Average SVR/RVR ratios and standard deviations of ratios were computed for the seven profile classes in the four aviation categories. Results are shown in table 8 (profile 1) and table 9 (profiles 2 and 3). In assessing these results, consider that routine landings are not yet permitted under category III conditions. Thus, category II results are of most interest for landing, with those for category I-low having some application. Data for category I-high are mostly of academic interest.

Table 8 shows that the profile 1 average ratios range from about 0.7 to 1.0 with standard deviations from about 0.2 to 0.5. The lowest deviation is associated with the important-for-landing category II situations, showing fairly good potential predictability of SVR from RVR. With category II SVR/RVR ratios approaching 1, large changes in visibility upon descent would not be likely. The category I-L data show a rather low average ratio (0.68). These data were rerun for the 2,000 to 3,000-foot RVR range, producing an average ratio of 0.82 with standard deviation 0.08 for 77 cases. Thus, SVR would not be much less than RVR for approaches under low category I-L conditions.

The profile 2 average ratios (table 9) for the larger sample sizes range from about 2 to 5, with standard deviations of about 1 to 3. These high average multiples and variabilities are logically the result of the different fog heights and densities associated with the essentially ground fog situations represented here. In category II, practically all of the sample falls under profile 2c, with very high average ratios and standard deviations. An inspection of individual cases showed that 80 percent of the ratios were greater than 2, with none below 1.2.

Landing under these conditions could be hazardous, because of the abrupt lowering of visibility at runway level. In category I-low, there is good representation in all three profile 2 subclasses. Both average ratios and standard deviations increase with increasing skewness of the profile. Landing under these conditions would not be particularly hazardous except perhaps with some profile 2c situations where the abrupt lowering of visibility with descent would be disconcerting at best.

The profile 3 average ratios range from about 0.4 to 0.7 with standard deviations of about 0.1 to 0.2. The latter shows how very stable the SVR/RVR relationships are with profile 3 situations. Data for category III for all profile 3 subclasses, and for category II under profiles 3b and 3c are totally absent, due to the low visibilities at 5 feet. The standard deviations for category II and category I-low are remarkably small and uniform, showing the very high predictability of SVR for these profile 3 situations. With profile 3 landings, the visibility would increase upon descent, a generally desirable condition. However, with RVR in category II or in category I-low with profile 3b, the SVR could be so low that the runway could not be sighted at the 100-foot decision height, thus causing a missed approach.

TABLE 8. AVERAGE SVR/RVR RATIOS FOR PROFILE 1 OBSERVATIONS

*Aviation Category	**RVR Steps, (feet) LS-4 Night	Average Ratio	Standard Deviation	Number Observations
III	≤ 1,000	1.01	0.46	71
II	1,200-1,800	0.91	0.17	234
I-L	2,000-5,000	0.68	0.25	157
I-H	≥ 5,500	0.95	0.42	2,449

*Based on the 5-foot horizontal transmittance.
**See table 2 for further details on visual range steps.

TABLE 9. AVERAGE SVR/RVR RATIOS FOR PROFILE 2 AND 3 OBSERVATIONS

	Profile 2a			Profile 2b			Profile 2c		
Aviation Category	Avg. Ratio	Std. Dev.	No. Obs.	Avg. Ratio	Std. Dev.	No. Obs.	Avg. Ratio	Std. Dev.	No. Obs.
III	1.75	1.19	11	1.08	0.22	2	3.44	2.02	70
II	0.88	0.08	3	1.12	0.09	2	4.19	2.73	220
I-Low	2.56	1.36	80	3.31	1.96	217	4.86	3.02	137
I-High	2.33	0.89	186	--	--	--	--	--	--
	Profile 3a			Profile 3b			Profile 3c		
III	--	--	--	--	--	--	--	--	--
II	0.73	0.09	809	--	--	--	--	--	--
I-Low	0.67	0.09	818	0.53	0.08	1,809	0.42	0.09	551
I-High	0.68	0.22	803	0.49	0.14	1,068	0.36	0.10	1,383

It is interesting to compare the data of tables 8 and 9 with the results of fog studies made in England and Holland and reported on by Johnson and Puffett (reference 5). In one study made at Bedford, England, 12,866 sets of minute-interval visibility observations in fog were obtained by observing a series of lights mounted at certain levels on a 100-foot mast. It was found that the probability of the ratio of SVR, measured from 100 feet, to horizontal visual range, measured at 6 feet, being less than one varied from 97 percent, with horizontal visibility 100 meters, to 80 percent with horizontal visibility 600 meters. In the present study, a computer inspection of the category II (RVR 1,200 to 1,800 feet, 365 to 550 meters) data of tables 8 and 9 revealed that 80 percent of the ratios were less than one. Thus, there is considerable similarity between the English and NAFEC data, indicating a basic fog-structure character.

TEMPERATURE AND WIND CONSIDERATIONS.

A limited amount of wind and temperature data was obtained concurrently with transmittance data from the original Metower configuration. The wind and temperature data were used in two ways. The first was to use the surface windspeed and temperature (both measured at 5 feet) and the stability (155-foot temperature minus the 5-foot temperature), along with RVR, as predictors of SVR in a multiple linear regression analysis. The second was to compute average SVR/RVR ratios and corresponding standard deviations of ratios for discrete classes of surface wind, temperature, and stability.

Transmittances at 5 feet, 155 feet, and for the slant path between them were all required to be less than 76.9 percent. This restricted the analysis to cases of what was defined as thick fog, i.e., fog extending to at least the 155-foot level with transmittance below the 76.9-percent threshold. The 76.9-percent threshold level was chosen because it was just above the last (6,000-foot) step of the light setting 4 (LS-4) night scale (table 2). The LS-4 night constants were used for converting transmittance to visual range as was done in the previous analysis.

The limited sample analysis was made for aviation categories I, II, and III as determined by the 5-foot transmittance. Categories II and III are as defined in table 8. Category I covers the visual range steps from 2,000 to 6,000 feet and thus contains two additional steps beyond category I-low (table 8), i.e., 5,500 and 6,000 feet.

Surface temperatures in the limited sample were all greater than zero degrees Celsius. Windspeeds were all less than 8 knots, and temperature differences between 155 feet and 5 feet were all equal to or greater than zero (considered stable).

MULTIPLE LINEAR REGRESSION ANALYSIS. Essential results of the multiple linear regression analysis are shown in table 10. RVR is found to be the best predictor of SVR in all three categories--a not unexpected result. The other three factors appear to have some effect in category III SVR predictions, but not in categories I and II. The high standard error of estimate (SE) for category I predictions most likely reflects the much larger range (1,900 to 6,250 feet) relative to categories II (1,100 to 1,900 feet) and III (less than 1,100 feet). In view of the small and limited sample, these results must be considered tentative.

SVR/RVR RATIO ANALYSIS. Results of the ratio analysis are shown in table 11. Here the data have been broken down into two surface (5-foot) temperature ranges: 0° to 10° Celsius and greater than 10° Celsius. Surface windspeed was in one class, and in all cases, less than 8 knots. The temperature difference between 155 and 5 feet was in one class which was equal to or greater than zero, i.e., stable.

The most significant feature of table 11 is that standard deviations are much lower for the lower temperature range. This indicates that better results would be obtained with a regression analysis if surface temperature ranges were used. Another feature of table 11 is the trend toward increasing SVR/RVR ratios between categories I and II. This can be seen also with the all transmittance data of table 8 for the profile 1 cases and table 9 for the profile 3a cases. The trend does not hold for the profile 2 cases which, however, are few in the table 11 samples due to the requirement for all transmittances to be below 76.9 percent.

It is recognized that a study has been conducted by Stalenhoef of the Royal Netherlands Meteorological Institute on slant/runway ratios in relation to wind, temperature, and stability (reference 6). However, classes of variables and analysis procedures were so different that their results cannot be compared directly with those of table 11.

SVR 15-MINUTE TRENDS.

Changes in SVR after 15 minutes were examined for certain SVR ranges under each vertical fog profile class, for possible forecast application to air traffic control. A 15-minute interval was chosen as representative of the time required for an aircraft to depart the holding fix and land. The SVR ranges were: the 2,000-foot (lowest) interval of category I, category II, the 1,200 foot (lowest) interval of category II, and category III. Results are shown in tables 12, 13, 14, and 15, respectively (see table 2 for SVR categories).

Table 12 shows the number of SVR observations in the 2,000-foot (lowest) interval of category I for each profile class and the percentage dropping into category II after 15 minutes. The data indicate that only with profile 3a would there be a significant probability of SVR lowering to category II in 15 minutes.

Table 13 shows the number of SVR observations in category II for each profile class, and the percentage dropping into category III after 15 minutes. The table shows that none of the profiles had a large percentage of observations dropping to category III. This basically reflects the rarity of category III conditions.

TABLE 10. PARTIAL CORRELATION COEFFICIENTS FOR PREDICTORS OF SVR

Aviation Category	RVR	Surface Temperature	Surface Windspeed	Stability	S.E. (Feet)	Number Cases
I	0.62	0.08	0.07	0.28	330	214
II	0.63	0.01	0.18	0.17	94	176
III	0.63	0.43	0.38	0.56	75	94

TABLE 11. AVERAGE SVR/RVR RATIOS FOR SURFACE TEMPERATURE CLASSES

Aviation Category	Surface Temperature (Degrees C)	Average Ratio	Standard Deviation	Number Cases
I	0-10	0.65	0.06	153
	>10	0.48	0.13	61
II	0-10	0.75	0.05	128
	>10	0.77	0.15	48
III	0-10	0.86	0.02	69
	>10	0.95	0.12	25

Note: Surface windspeeds were all less than 8 knots, and the 155- to 5-foot temperature differences all equal to or greater than zero (stable conditions).

TABLE 12. FIFTEEN-MINUTE SVR TRANSITIONS FROM THE LOWEST CATEGORY I STEP TO CATEGORY II BY FOG PROFILE CLASS

Profile	Observations	Percent to CII
1	63	38
2a	1	0
2b	3	0
2c	16	44
3a	46	65
3b	136	51
3c	181	43

TABLE 13. FIFTEEN-MINUTE SVR TRANSITIONS FROM CATEGORY II TO CATEGORY III BY FOG PROFILE CLASS

Profile	Observations	Percent to CIII
1	186	9
2a	9	0
2b	4	0
2c	31	6
3a	1,142	6
3b	1,463	3
3c	388	3

TABLE 14. FIFTEEN-MINUTE SVR TRANSITIONS FROM THE LOWEST CATEGORY II STEP TO CATEGORY III BY FOG PROFILE CLASS

Profile	Observations	Percent to CIII
1	53	30
2a	0	0
2b	1	0
2c	1	0
3a	543	12
3b	373	12
3c	18	39

TABLE 15. FIFTEEN-MINUTE SVR TRANSITIONS FROM CATEGORY III TO CATEGORIES II OR I BY FOG PROFILE CLASS

Profile	Observations	Percent to CII or I
1	172	20
2a	9	11
2b	1	0
2c	6	100
3a	392	25
3b	43	44
3c	2	0

Table 14 shows the number of SVR observations in the 1,200-foot (lowest) interval of category II for each profile class and the percentage dropping into category III after 15 minutes. The table shows that the percentages of SVR observations dropping into category II have increased considerably over the corresponding figures of table 13 for most profile classes. However, the largest percentages of occurrence are still well below 50 percent.

Table 15 shows the number of SVR observations in category III for each profile class and the percentage increasing to category II or I after 15 minutes. Only very small percentages of the SVR observations changed to category I, except for profile 2c, where five of six changed to category I. The table shows that except for profile 2c, which is a very small sample, only profile 3b had a percentage change approaching 50 percent.

In general, the data of tables 12, 13, and 14 indicate that knowledge of the profile would not significantly improve 15-minute down-trend forecasts of SVR over persistence or an increase of SVR. Table 15 indicates no improvement over a forecast of persistence of category III SVR conditions.

AVIATION APPLICATION.

An objective of this study was to investigate possible correlations between slant/runway visual range ratios and such parameters as wind, temperature, and atmospheric stability. Instrumentation to measure these parameters should be simpler and more economical to operate than that required to measure visibility directly. This objective was not sufficiently met with the data obtained and must be reserved for possible future effort. However, the relationships that were established between the vertical fog profiles and slant/runway visual range ratios are considered definitive and have a potential for operational use. These relationships should apply regardless of climatological regime or airport location, since the fog profile, as measured, essentially reflects the existing fog structure.

In the simplest operational application, a very short baseline transmissometer could be installed on an existing airfield tower or on the control tower to obtain the high-level reading. The low-level reading would come from the runway touchdown transmissometer which would also determine RVR and aviation category. With such an arrangement, the high- and low-level readings would be separated by a few thousand feet. Thus it would be desirable to conduct further tests with this type of configuration including an investigation of slant/runway visual range ratios from heights lower than 155 feet.

In this connection, it is interesting to note that Johnson and Puffet (para. 5, reference 5) state that for an operational system, it would probably be sufficient to measure the atmospheric transmittance of the fog at heights of 6 and 75 feet and to relate the operational limits to the visibility at 6 feet and the gradient between the two heights. The 75-foot height seems low for the "high" reading, but may be adequate for the fog regimes found in England. At the NAFEC location, however, inspection of the average departure columns of tables 4 through 7 indicates that caution should be exercised in classifying profiles based on any upper level reading lower that the existing operational decision height.

Finally, a factor that needs clarification is the conversion of transmittance to visual range. In this study, the conversion was made using Allard's Law with the night illuminance constant and light setting 4 (appendix). Thus, the results apply for night conditions only. For day conditions, a different illuminance constant would be used along with (normally) light setting 5. Also Koschmieder's Law would enter in at the higher visual ranges (4,000 feet and above). The day values would have the effect of expanding the aviation categories up the transmittance scale. Some differences, probably not major, would be expected for profile 1 and 2 situations. Only minor differences would be expected with profile 3 situations.

CONCLUSIONS

1. Knowledge of the surface horizontal transmittance is, by itself, insufficient to be used as a predictor of specific slant-path atmospheric transmittance, since fog is not usually homogeneous with height.

2. Knowledge of the linear fog density profile from near the surface to about 150 feet can provide a useful estimate of slant visual range (SVR) in terms of being greater than, about equal to, or less than RVR.

3. Based on a limited data sample, surface temperature, windspeed, and atmospheric stability appear to be of some value in improving predictions of SVR derived from RVR in very low visibility conditions.

4. Knowledge of the linear fog density profile with height would not significantly improve 15-minute persistence forecasts of SVR.

RECOMMENDATIONS

1. Conduct further studies to determine if fog profile relationships to SVR/RVR ratios are valid when the high-level transmissometer is separated from the low-level (runway touchdown) transmissometer by a few thousand feet.

2. Conduct additional studies of SVR/RVR ratios in relation to temperature, windspeed, atmospheric stability, and vertical motion.

REFERENCES

1. Runway Visibility Measurements, Federal Aviation Administration Advisory Circular AC No. 00-13A, February 24, 1965.

2. Runway Visual Range (RVR), Federal Aviation Administration Advisory Circular No. 97-1, November 4, 1976.

3. Slant Visual Range (SVR) Approach Light Contact Height (ALCH) Measurement System: Evaluation in Fog prepared for FAA by NAD, Crane,
System: Evaluation in Fog, prepared for FAA by NAD, Crane, Indiana, FAA-RD-74-7, July 1974.

4. U.S. Dept. of Commerce - Weather Bureau, 1970: Surface Observations. Abridged from Federal Meteorological Handbook No. 1 for FAA, LAWR, SAWR, and A-type stations., P. A3-22 (Table A3-11C), Government Printing Office, Washington, D.C.

5. Johnson D. and Puffett, A. W., An Attempt to Relate Slant Visibility with Horizontal Visibility and Height Based on Limited Data from Various Experimental Studies of Fog, Royal Aircraft Establishment, 1974.

6. Stalenhoef, A. H. C., Slant Visibility During Fog Related to Windspeed, Air Temperature, and Stability, Royal Netherlands Meteorological Institute, 1974.

APPENDIX

DETERMINATION OF RUNWAY VISUAL RANGE

At night and under daytime conditions when the high-intensity runway edge lights are the most dominant target for the pilot's sighting, RVR is derived from Allard's Law:

$$E_t = \cfrac{\cfrac{I(t_b)^{V/b}}{V^2}}{5280}$$

where:

E_t = pilots's visual illuminance threshold (mile-candles)

I = intensity of light target (candelas)

t = atmospheric transmittance

b = path length over which atmospheric transmittance is sampled (feet)

V = visual range from pilot to appropriate light target, RVR (feet)

Under certain bright daytime conditions when the meteorological visibility of objects contrasted against the sky yields a greater visual range than light targets, RVR is derived from Koschmieder's Law:

$$e_o = (t_b)^{V/b}$$

where:

e_o = pilot's contrast threshold (dimensionless)

t = atmospheric transmittance

b = path length over which atmospheric transmittance is sampled (feet)

V = visual range from pilot to appropriate contrast target (feet)

Inputs to the RVR equations are selected empirical constants, and measurements made by relatively simple instruments. Currently, they are:

1. e_o. Empirically selected as .055.

2. E_t. Empirically selected as 1,000 mile-candles under daylight conditions, and 2 mile-candles at night.

3. t. A measurement by a transmissometer of the transmittance of light made along a specified path in the aircraft landing/takeoff zone.

4. b. The path length for t (feet)

5. I. The representative step intensities (light settings) of the high-intensity runway edge lights have been accepted as step 5, 10,000; step 4, 2,000; and step 3, 400 candelas.

6. Day/night. Divided by incident illumination of about 2-foot candles as determined by an elementary illuminometer.

It should be noted that while a single value of e_o and two of E_t are used in practice, actual values may vary widely between and within individual pilots, depending on human factors and observational environment.