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CALIBRATION OF A VIDEOGRAPH AGAINST METEOROLOGICAL OPTICAL RANGE DERIVED FROM STANDARD AES TRANSMISSOMETER MEASUREMENTS

by

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A Videograph Visibility Meter is calibrated against Meteorological Optical Range (MOR) derived from standard Atmospheric Environment Service transmissometer measurements. We found that the Videograph measures MOR to within a factor of two with 99% confidence. This error is as large as that found for the Videograph - prevailing visibility calibration data of 1970-1. A possible explanation of this unexpected result is the omission of obstruction to vision distinctions from the analysis. We recommend re-locating this experiment to Toronto International Observing Site to permit the inclusion of prevailing visibility, obstruction to vision and ambient illumination in the data base. With this additional information we can calibrate the Videograph or other scatter-type visibility sensors in terms of MOR for individual weather conditions. Also, we can calculate the meteorological observer's visual contrast threshold as a function of ambient illumination.

PECHES ET ENVIRONNEMENT CANADA
SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE
4905 rue Dufferin
Downsview (Ontario)

ÉTALONNAGE D'UN VIDÉOGRAPHE PAR RAPPORT À LA PORTÉE OPTIQUE MÉTÉOROLOGIQUE DÉTERMINÉE D'APRÈS DES MESURES EFFECTUÉES AVEC LE TRANSMISSIOMETRE ÉTALON DU SEA

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RÉSUMÉ

Un visibilimètre vidéographe est étalonné par rapport à la portée optique météorologique (POM) déterminée d'après des mesures effectuées avec le transmissiomètre étalon du Service de l'Environnement atmosphérique. Nous avons trouvé que le vidéographe mesure la POM à un facteur de deux près dans 99 % des cas. Cette marge d'erreur est la même que celle qu'on avait trouvée en 1970-71 pour les données d'étalonnage du vidéographe pour la visibilité dominante. Ce résultat inattendu s'explique peut-être par le fait qu'on néglige de distinguer entre facteurs d'obstruction visuelle dans l'analyse. Nous recommandons que l'expérience soit effectuée à nouveau au site d'observation de l'aéroport international de Toronto, en incluant cette fois à la base de données la visibilité dominante, l'obstruction visuelle et l'éclairement ambiant. Ces données supplémentaires doivent nous permettre d'étalonner le vidéographe ou d'autres détecteurs de la visibilité du type instruments de mesure de la rétrodiffusion en termes de POM pour des conditions atmosphériques particulières. De plus, nous pouvons calculer le seuil de contraste visuel de l'observateur comme fonction de l'éclairement ambiant.

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1. Introduction

The Videograph backscatter meter is accepted and used by the Atmospheric Environment Service in Canada, and the National Weather Service in the United States, as a visibility sensor in automated meteorological stations. It is also used internationally in the determination of visibility at airfields. Because of the proposed adoption of meteorological optical range (MOR) as the WMO standard parameter for both meteorological and aviation visibility, there is a renewed interest in relating visibility determined from backscatter measurements to MOR as calculated from transmissivity measurements (see Appendix A).

Co-located backscatter and transmission measurements have previously been compared by a number of agencies and researchers: Curcio and Knestrick in 1958 (1); Barteneva in 1960 (2); the Federal Aviation Agency (U.S.) in 1971 (3); and the National Weather Service (U.S.) in 1971 (4). No such experiment has been carried out by the Atmospheric Environment Service.

Extensive data has been collected by AES over the past seven years comparing Videograph outputs to prevailing visibility, as determined by meteorological observers at Toronto International Airport, under a variety of weather and illumination conditions. The results of an analysis of one year's data is given in reference 5.

The objective of this experiment is to establish the accuracy of the Videograph as a sensor of MOR. In theory, this should depend primarily on the constancy of the ratio of the backscatter to extinction coefficient for the various scattering media. This ratio varies with the size, shape and refractive index of the scatterer. For example, the results from the Toronto International tests (5) indicate that the ratio is higher in snow than rain, and therefore the Videograph would measure lower MOR in snow than in rain.

2. Experiment

The instruments used for this comparison were a Sperry[(1)] Videograph (S/N 424) and a standard NBS-type[(2)] 500 foot baseline transmissometer located at the Instrument Test Site at the AES Headquarters in Downsview, Ontario. These are shown in Photograph 1. The Videograph was mounted on the transmissometer projector tower with the Videograph receiver's optical axis parallel to and about four feet below the transmissometer's projector beam. Figure 1 shows the relative geometry of the optical fields of view of the instruments and their atmospheric monitoring volumes.

Every 10 minutes the outputs from both instruments were integrated for a one minute period and recorded on teletype paper tape. The transmissometer outputs varied linearly over a nominal range of 0 to 4000 pulses for transmissions of 0 to 100% although counts exceeding 4000 were not uncommon. The Videograph output, 0 to 5 volts, was converted to a frequency for intergration purposes. Its recorded counts varied over a nominal range of 0 to 100.

During the four month test, both the transmissometer and Videograph required only routine maintenance. The transmissometer output was adjusted twice, after the passage of a cold front, to read approximately 100% transmission. The windows of both instruments were cleaned once.

3. Data Analysis

The data was processed and analyzed in five time periods of about three weeks each, starting 17 November 1976 to 15 March 1977. All records with format errors were discarded by computer program.

Because of changes in the transmissometer's 100% transmission point due to calibration, cleaning of the optics, or drift in the projector intensity, all counts were normalized. The maximum count occurring in a given time period was defined as the 100% transmission for this

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(1) Sperry Ottawa manufactured Videographs in Canada under license from Impulsphysik in Hamburg, Germany.

(2) Marsland Engineering Ltd., Waterloo, Ontario, manufactured the NBS transmissometer primarily for use by the Ministry of Transport for Runway Visual Range Measurements.

interval, and all other readings were linearly scaled. The start of the 5 normalization periods was defined by the time of the two calibration adjustments, the window cleaning and two other arbitrary dates.

The normalized transmission was then converted to meteorological optical range using the equation developed in Appendix A.

The Videograph "zero" readings for high transmission days were found to vary by less than 0.5% of full scale from one normalization period to another. This was not significant enough to warrant a "zero correction" of the Videograph data.

The data was then plotted on a semi-log axes with the Videograph on the linear vertical axis scaled from 0 to 100% of full scale and the MOR on the log axis scaled from 0.05 to 50.0 miles. This MOR scale was chosen to maximize the number of data points that could be plotted. However, it should be recognized that in practice the accuracy of transmissometer measurements decreases rapidly for MOR's less than 1/2 or greater than 20 times the baseline. This corresponds to about 0.05 to 2 miles for a 500 foot baseline installation.

Preliminary data analysis of the scatter diagrams for each normalization period indicated that there were no significant differences in the data distributions for each period and that the normalization procedure was successful. Therefore the combined data from the five periods was presented on a single scatter diagram in Figure 2.

Because of the importance of the relatively few points at the lower end of the MOR scale, we re-distributed the weighting of all values across the scale using the following technique. The scatter diagram was segmented into several sections by drawing arbitrary lines normal to the major axis of the distribution. The median of all the observations in each section was estimated visually. The co-ordinates of this set of medians was used in a simple linear regression program to determine a weighted best fit curve and plotted in Figure 2 as a solid line. A simple linear regression analysis was performed on all data pairs with Videograph output greater than 5% of full scale. The elimination of the remaining observations prevented the analysis from heavy biasing by high visibility data for which the transmissometer's accuracy is poor. The 99% confidence limits are a factor of two in MOR from the regression line and plotted in Figure 2 as dashed lines. The correlation coefficient is -0.93.

4. Conclusions

These confidence intervals are similar to that for the Toronto International data where observers and Videograph were compared by visual analysis (c.f. Reference 5). In light of the fact that the subjectivity of the human observer and the non-representativeness of the sensor measurement have been removed as sources of error from this experiment, we might consider this an unexpected result. However, unlike the 1970-1 data we were unable to categorize the data according to the scattering medium (rain, snow, fog, etc.) because observer input was not available. It is expected that the primary scattering medium was snow.

From the present data, assuming no prior knowledge of the obstruction to vision, we conclude that the Videograph measures meteorological optical range to within a factor of two with 99% confidence.

5. Recommendations

We recommend re-locating this test to the Toronto International Airport Observing site to allow expansion of the data base to include information on the nature of the obscuring medium, the prevailing visibility, and the ambient illumination. This would require the installation of a transmissometer. The objectives of such an experiment would be twofold. The Videograph and other scatter-type sensors could be calibrated in terms of meteorological optical range for various obstructions to vision. Also, from the prevailing visibility observations and the transmission measurements, we can calculate the observer's visual contrast threshold as a function of ambient illumination.

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APPENDIX A

The Computation of Meteorological Optical Range from Transmission Measurements

Meteorological optical range is defined as the distance at which the brightness contrast ratio of a black target and its surrounding background decreases to 5%. In theory this should be determined with a variable baseline transmissometer. The distance between the projector and receiver is increased until the transmission is reduced to 5%. This baseline distance is then equal to the MOR. In practice a transmission measurement is made over a fixed baseline. The MOR is determined by assuming a uniform atmosphere, and calculating the baseline required for 5% transmission. By applying this definition to Koschmieder's theory we get:

$$.05 = e^{-\sigma(MOR)}$$

where σ is the extinction coefficient. This equation is developed in Chapter 6 of Middleton (8) using a brightness contrast ratio of 2%.

By definition, the extinction coefficient and the transmission (T) over a baseline (b) are related by:

$$e^{-\sigma} = T^{1/b}$$

and therefore: $.05 = T^{MOR/b}$

Re-arranging we get:

$$MOR = b \log .05/\log T$$

For MOR in statute miles and a baseline of 500 feet then

$$MOR = -.123/\log T$$

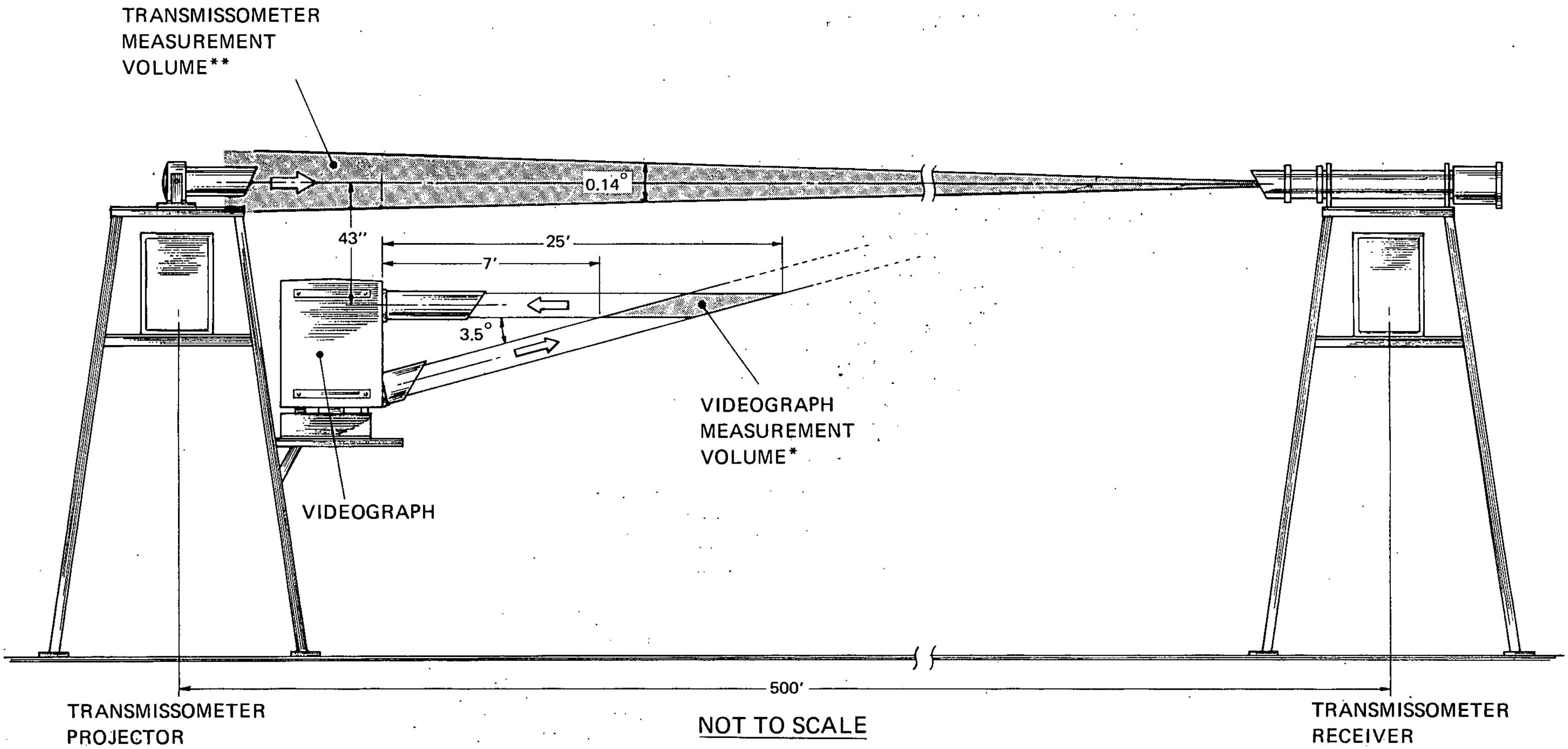


Figure 1. Atmospheric Measurement Volumes for the Transmissometer and Videograph Comparison Experiment.

NOTES:

* The Videograph measurement volume shown here assumes collimated projector and receiver optics. In practice, the volume is larger because the receiver's field of view has a cone angle of 7°, and the projector beam also spreads in a cone of similar size. However, the major portion of the backscatter return comes from the volume extending from 7 to 25 feet.

** The transmissometer's measurement volume shown here assumes no forward scattering of the projector beam into the receiver's field of view. Therefore the measurement volume is defined by a cone angle of 0.14° representing the receiver's field of view.

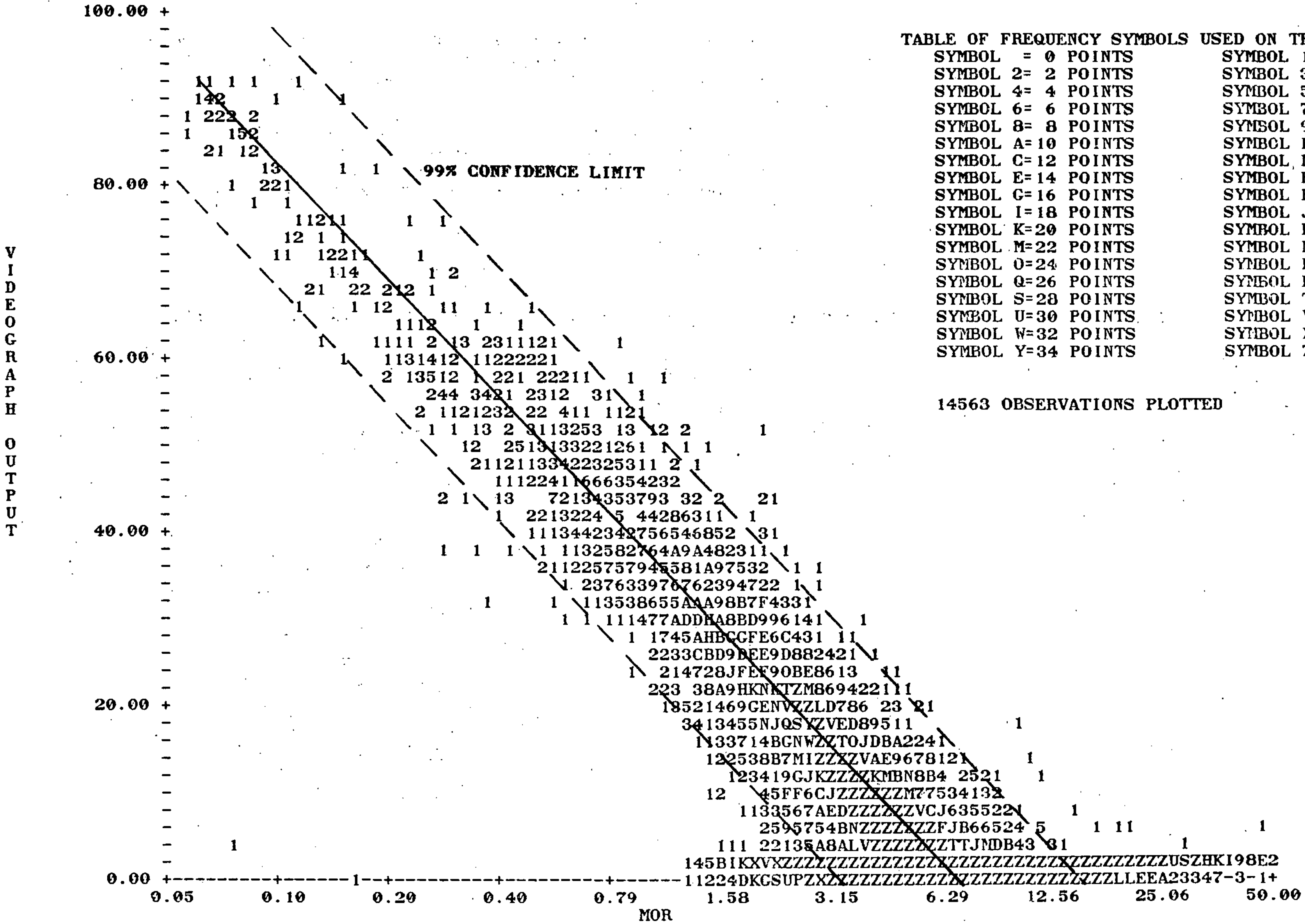
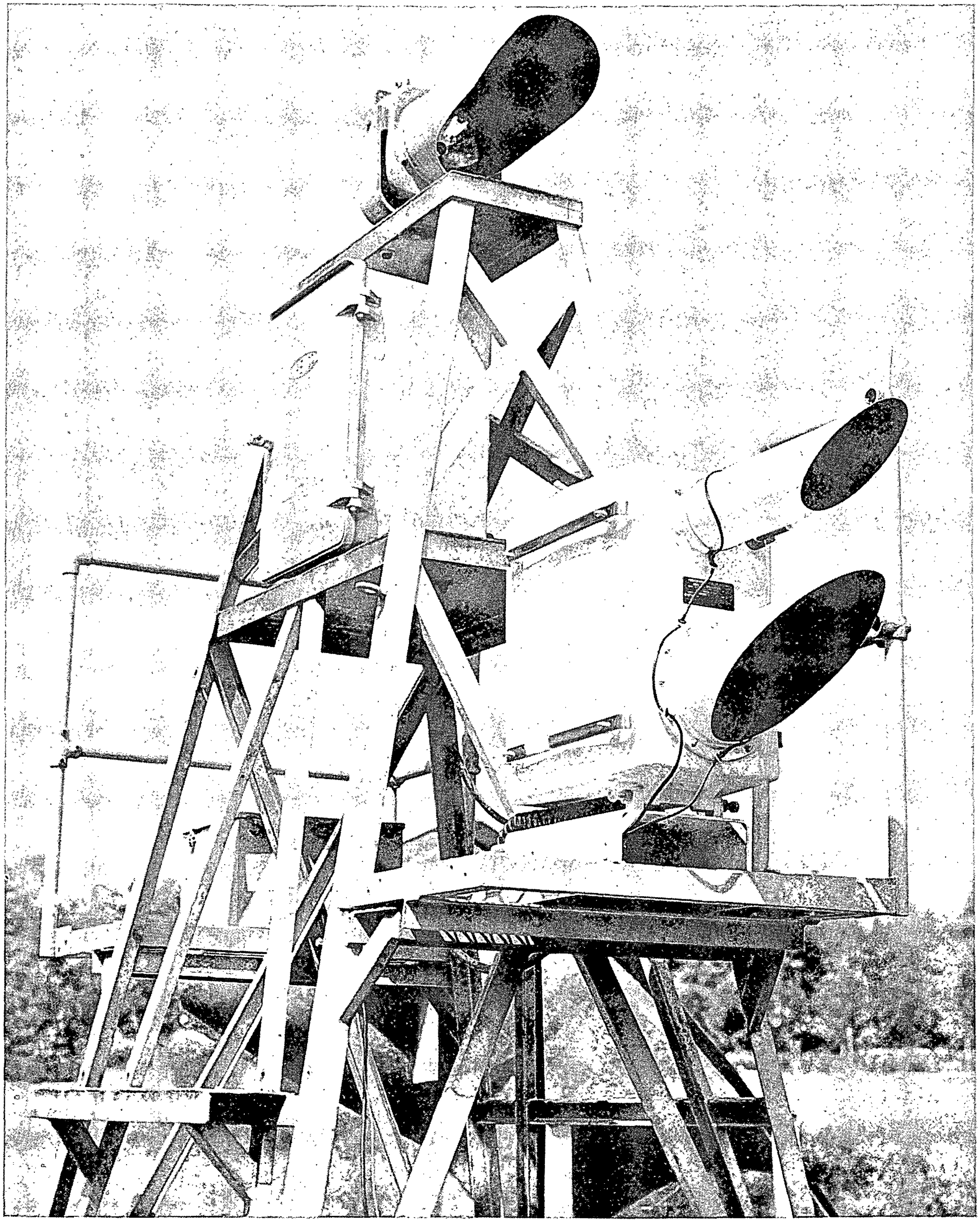


TABLE OF FREQUENCY SYMBOLS USED ON THE GRAPH

SYMBOL = 0 POINTS	SYMBOL 1= 1 POINTS
SYMBOL 2= 2 POINTS	SYMBOL 3= 3 POINTS
SYMBOL 4= 4 POINTS	SYMBOL 5= 5 POINTS
SYMBOL 6= 6 POINTS	SYMBOL 7= 7 POINTS
SYMBOL 8= 8 POINTS	SYMBOL 9= 9 POINTS
SYMBOL A=10 POINTS	SYMBOL B=11 POINTS
SYMBOL C=12 POINTS	SYMBOL D=13 POINTS
SYMBOL E=14 POINTS	SYMBOL F=15 POINTS
SYMBOL G=16 POINTS	SYMBOL H=17 POINTS
SYMBOL I=18 POINTS	SYMBOL J=19 POINTS
SYMBOL K=20 POINTS	SYMBOL L=21 POINTS
SYMBOL M=22 POINTS	SYMBOL N=23 POINTS
SYMBOL O=24 POINTS	SYMBOL P=25 POINTS
SYMBOL Q=26 POINTS	SYMBOL R=27 POINTS
SYMBOL S=28 POINTS	SYMBOL T=29 POINTS
SYMBOL U=30 POINTS	SYMBOL V=31 POINTS
SYMBOL W=32 POINTS	SYMBOL X=33 POINTS
SYMBOL Y=34 POINTS	SYMBOL Z≥35 POINTS

Figure 2

Videograph Calibration in Met Optical Range (5% contrast threshold)



Photograph 1. Videograph Installation on Transmissometer Projector Tower

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