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NIGHT VISION LABORATORY STATIC PERFORMANCE MODEL FOR THERMAL VIEWING SYSTEMS

April 1975

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The NVL thermal model predicts system NE ΔT, MTF, MRT, and MDT for any infrared imaging system. It also predicts detection and recognition as a function of range for a given atmosphere and target signature. This model is documented, and the validation from laboratory measurements and field experiments is also presented. The computer program and an in-depth user's manual are given in the appendices. This model can be and has been used in military systems analyses to direct component research, evaluate contractor proposals, and aid project manager decisions.

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NIGHT VISION LABORATORY STATIC PERFORMANCE MODEL FOR THERMAL VIEWING SYSTEMS

I. INTRODUCTION

The Night Vision Laboratory (NVL) Thermal Performance Model is a computer model to predict the static detection and recognition performance of electro-optical imaging systems which are sensitive in the 3-5μm, and 8-14μm wavelength regions of the electromagnetic spectrum. It was developed at NVL to aid in the evaluation and design of infrared systems for Army missions, encompassing surveillance and target acquisition systems in missile, tank, airborne, and air defense applications. This model has been used by the Army to evaluate contractor proposals for devices to fulfill field requirements and to recommend and give guidance to various commands and their contractors on future system characteristics and configurations. Examples of calculations from this model can be found in several papers presented at the IRIS Specialty Group on Imaging.[1 2]

The model predictions are for detection and recognition as a function of range for a given target, aspect, and atmosphere. It is a static model since it considers target acquisition in which the target is in the device field of view and its position is a priori known to the observer. No search of the device field of view or a search field is involved.

The model simulates mathematically the real-world target, atmosphere, device, and observer; then it makes a calculation on the subjective detectability or recognizability of the target. The characterization of the target, background, atmosphere, device, and observer is a straightforward mathematical analysis. The method of representing the target and atmosphere and the equations for device MTF, NEΔT, MRT, and MDT are relatively simple. However, the subjective decision-making behavior must be empirically derived from existing field and laboratory perception data.[3 4 5 6] This

[1] W. R. Lawson and J. A. Ratches, "Thermal Imaging Systems Models," Proc of IRIS Specialty Group on Imaging, Nov. 1972 (Confidential).

[2] J. Johnson and W. R. Lawson, "Performance Modeling Methods and Problems," Proc of IRIS Specialty Group on Imaging, Jan. 1974 (Confidential).

[3] J. R. Moulton, *et al.*, "A Search Performance Test on Ground-Based Thermal Imaging and Pulse-Gated Intensifier Night Vision Systems," U.S. Army Electronics Command Report 7028, June 1973 (Confidential).

[4] J. Swistak, "Field Performance Evaluation of TINTS Night Sight Systems," U.S. Army Electronics Command Report 7035, Jan. 1975 (Confidential).

[5] J. Swistak, "Field Performance Evaluation of TOW Night Sight Systems," U.S. Army Electronics Command Report 7033, Jan. 1975 (Confidential).

[6] Unpublished test report of airborne FLIR against ground targets by NVL in summer 1973.

data base then represents the validation for the model; and the agreement with this data base, in turn, determines the reliability of the model.

The current computer model used by NVL for performance predictions is described in the following sections. The target, background, and atmosphere are considered together since they can be described rather easily after several simplifying assumptions. The device and eyeball are represented together in the MTF, NE ΔT, MRT, and MDT calculations which are straightforward but extensive. If experimental MTF, NE ΔT, and MDT were available, performance could be obtained from them. However, since the model is intended as a design aid, these quantities must be computed. Finally, the recognition and detection models are described, followed by the substantiating field data. The actual computer program and other documentations are found in Appendices A through D.

II. TARGET, BACKGROUND, AND ATMOSPHERE

One of the main problems in performance modelling is to obtain an exact target signature. The infrared (IR) signature of any target must be obtained by a ground-truth team in the spectral regions of interest. The problem is further complicated by the fact that one target can have many different signatures under various operational and environmental conditions. Besides the obvious case of camouflage, the differences between a running vehicle and a cold target are more than different radiance levels. "Hot spots" may appear on the running target which present features to the observer which can "cue" his detection or recognition. Wide distinctions among running vehicles or stationary vehicles occur due to meteorological conditions. Hence, whatever the target situation, thermographic data must be taken to document a field test or the target situation must be exactly specified to make predictions.

In the computer model, we cannot easily describe all the complex target characteristics corresponding to the real-world IR signature from execution time considerations. Therefore, we utilize only the overall general features of the target such as size and average temperature difference from the background. The resulting predictions then correspond to the results of a large ensemble of experiments. However, the results of any specific experiment with its unique target signature will not necessarily come close to the predictions for the general ensemble.

The model target is a rectangle with a uniform temperature difference ΔT from the background. Since only a uniform target is input, the model approximates the real target with varying credibility depending on the nature of the target cues. The dimensions of the target rectangle are chosen such that the areas of the real target and the rectangle are equal. The smaller model dimension is taken equal to the real target critical dimension – usually the minimum dimension. In the example of a side view of an American tank, its minimum dimension is 2.7 m and that is chosen as the rectangle height. The rectangle length is then whatever length gives an area equal to the real-world object.

The temperature difference ΔT associated with the target is an area-weighted average temperature difference across the entire signature. If an object's thermograph is divided into areas A_i of average constant temperature T_i, then the average target temperature is defined as

$$T_{AVG} = \frac{\sum_i A_i T_i}{\sum_i A_i} \tag{1}$$

The average temperature difference ΔT_{AVG} is then the difference between T_{AVG} and average background temperature T_{BAC}, i.e.,

$$\Delta T_{AVG} = T_{AVG} - T_{BAC} \; . \tag{2}$$

A list of ΔT_{AVG}'s and target dimensions from a typical field test is shown in Table 1.

Table 1. Average ΔT's and Dimensions for Military Targets in a Typical Summer Field Test

Target	ΔT_{AVG} (°C)	Area (m x m)
Tank/Side	5.25	2.7 x 5.25
Tank/Front	6.34	2.7 x 3.45
2½-Ton/Side	10.40	0.83 x 4.22
2½-Ton/Front	8.25	2.03 x 1.67
APC/Side	4.67	1.8 x 4.8
APC/Front	5.65	1.8 x 2.09
Man	8.0	0.5 x 1.5

The background temperature was specified by one temperature T_{BAC}. This is obviously a simplification for all scenarios except that of an aircraft against a uniform sky background. Hence, the predictions will predict field behavior only when background clutter does not have an effect on the performance.

Power difference is a more fundamental quantity than temperature difference. Therefore, ΔT_{AVG} is converted to a power signal by using the Planck Radiation Law. For a given temperature T, N_λ watts/cm^2/sr/μ are emitted according to

$$N_\lambda = \frac{2c^2h}{\lambda^5} \frac{\epsilon(\lambda)}{\exp(hc/\lambda kT) - 1} \qquad (3)$$

at wavelength λ. Terms c, k, and h are the usual constants and $\epsilon(\lambda)$ is the emissivity. The target model, therefore, gives approximately the same total emitted power as from the real target.

Atmospheric transmission is another major problem for modellers. In order to specify an atmosphere completely, the aerosol must be uniquely defined which implies knowledge of particle size and distribution. These last atmospheric parameters are difficult to measure and, consequently, seldom carried out. In addition, a model based on the exact Mie scattering theory would be too cumbersome and time consuming to use in performance model applications. Therefore, several simplifying assumptions must be made for a viable engineering model.

The atmosphere is assumed to be specified by three easily measurable parameters which are readily understood by field commanders. They are air temperature, relative humidity, and visibility. Although these parameters do not uniquely characterize the meteorological environment, it is assumed that the atmosphere can be broken up into an absorption component, which is determined by the air temperature and relative humidity, and a scattering component which is determined by the visibility. Transmission is calculated separately for each component, and total transmission is the product of the components.

One method to calculate the transmission through an absorbing atmosphere of water vapor and carbon dioxide is given by

$$T_\lambda^A = \frac{.57\,[a(\lambda) - LOG_{10}(RW)]^2}{1 + [.5\,a(\lambda) - LOG_{10}(RW)]^2)} \qquad (4)$$

where a (λ) is a spectrally dependent constant for water vapor or carbon dioxide, R is the range in kilometers, and

$$W = \begin{cases} 4.6 \times 10^{-3} + 2.1 \times 10^{-5}\,(T_{AIR} + 5)^2 \text{ R.H.} & \text{for } H_2O \\ 1.0 & \text{for } CO_2. \end{cases} \qquad (5)$$

A list of $\alpha(\lambda)$'s is given in the computer model in Appendix C. T_{AIR} is the air temperature in degrees Centigrade and R.H. is the relative humidity in percent. Equation (4) is a Lorentzian line shape fit to transmission data in the Geophysical Handbook.[7]

[7] J. N. Howard, "Atmospheric Absorption," S. L. Valley, Ed., Air Force Cambridge Res. Lab., Cambridge, Mass., 1965, Sec. 10.2.

The scattering part of the atmospheric model is a spectrally dependent Beer's Law function. The transmission due to scattering is given by

$$T_\lambda^S = e^{-\alpha(\lambda) R}, \tag{6}$$

where $\alpha(\lambda)$ is the scattering coefficient and R is the range in kilometers. We associate a set of $\alpha(\lambda)$'s for various visibility ranges, where visibility range is found by

$$V_{.02} = 3.912/\alpha\,(5500\ \text{Å}), \tag{7}$$

where $V_{.02}$ is the visibility range for 2 percent contrast and α (5500 Å) is the attenuation coefficient at 5500 Å. The relationship between $\alpha(\lambda)$ and visibility range can be taken from data such as that presented by Barhydt[8] based on work by Dermendjian[9] and Rensch.[10] Table 2 shows a typical set of α's for the selected visibility ranges in Figure 1.

Table 2. Scattering Coefficients as a Function of Wavelength for Several Visibilities

Wavelength (μ)	Visibility Range (km)			
	44.5	9.8	2.8	1.0
	Scattering Coefficients (km-1)			
	Clear	Light Haze	Heavy Haze	Light Fog
3.0	.0261	0.3	1.1	4.0
3.25	.0223	0.26	1.2	4.0
3.5	.0189	0.24	1.3	4.0
4.0	.014	0.20	1.4	4.0
4.25	.0126	0.17	1.6	4.0
4.5	.0109	0.16	1.8	4.0
5.0	.0088	0.15	2.0	4.0
8.0	.0079	.07	0.4	1.1
9.0	.0064	.05	0.35	1.06
9.5	.0058	.045	0.33	1.03
10.0	.0053	.035	0.30	1.0
10.5	.0048	.034	0.26	0.96
11.0	.0045	.032	0.23	0.93
12.0	.0038	.03	0.20	0.90

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8 H. Barhydt, "The Application of Infrared Technology for Aircraft Landing Aids," presented at Air Transport Assoc. Symposium on *Visual Enhancement in Poor Weather* (All-Weather Operations Committee, 8 May 1969).

9 D. Diermendjian, "Scattering and Polarization Properties of Polydispersed Suspensions with Partial Absorption," Electromagnetic Scattering (Proc. Interdisciplinary Conference on Electromagnetic Scattering), ed. M. Kerker, Pergamon Press, New York (1963), pp. 171-189.

10 D. Rensch, "Survey Report on Atmospheric Scattering," Ohio State University Electro-Science Laboratory, Columbus, Ohio, May 1968, AD 831666.

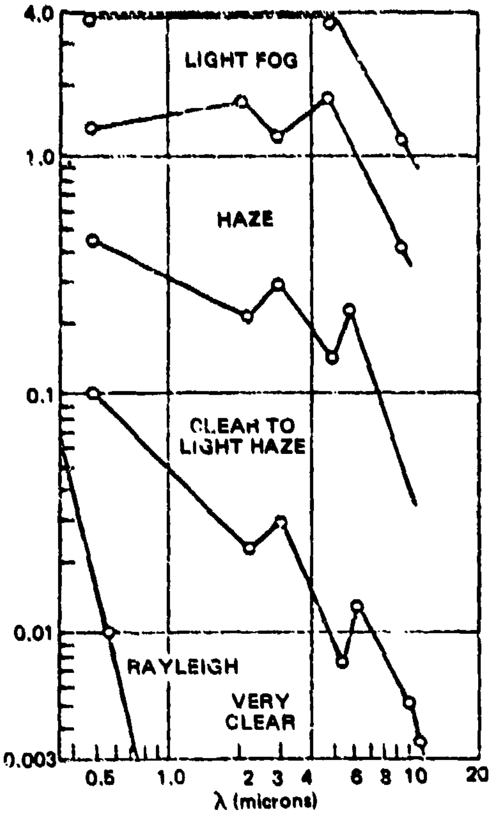

Figure 1. Relationship between scattering coefficient and wavelength for several visibilities (taken from D. Rensch).

The total atmospheric transmission is then

$$T_\lambda^{TOTAL} = T_\lambda^S \times T_\lambda^A \qquad (8)$$

where T^S and T^A are given by equations (6) and (4).

For most calculations when the visibility ranges are not too severe, a modified version of the Air Force Cambridge Research Laboratory (AFCRL) model LOWTRAN II is used to calculate transmission.[11] It has been modified to increase its execution speed by removing the slant-range calculation and doing the transmission calculations only over the infrared spectral band of interest. The only reservation in universal

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[11] R. A. McClatchey, *et al.*, "Optical Properties of the Atmosphere," D.D.C. No. AD 726-116, Air Force Cambridge Res. Lab., Cambridge, Mass. (1971).

application of LOWTRAN II is that it does not handle very low visibilities corresponding to thick fogs. Work is presently being done at AFCRL to extend the range of applicability of this model. Simple models for smoke, rain, and fog have been added to the LOWTRAN subroutine in the model. These, along with further explanations of the atmospheric models, will be found in a forthcoming report by Bergemann of NVL.[12]

III. DEVICE AND EYEBALL

The performance model described in this report predicts probability of recognition and detection based upon the predicted system minimum resolvable temperature (MRT) and minimum detectable temperature (MDT). It is the basic assumption of this model that these quantities directly determine field performance. These quantities are defined and derived in later sections and in Appendix A from the same signal-to-noise ratio expression.

In order to calculate MRT and MDT, we need to first predict the signal-transfer characteristics and noise characteristics of the device and eyeball. The signal transfer is represented by the transfer function or approximately by the modulation transfer function (MTF). The noise characteristics are specified by the noise equivalent temperature difference (NE ΔT). The next sections describe the MTF and NE ΔT calculation.

A. MTF. The signal out of a linear electronic processor is the convolution of the spread function of the processor with the input signal. If the processor is made up of several components, then each spread function must be convolved. This can be a tedious process. However, the output signal in frequency space is just the multiplication of the transform of the input signal and the transfer functions of the components. The transfer functions are the fourier transforms of the component spread functions, and the magnitude of the transfer function is the MTF.

Let us consider the breakdown of an infrared imaging system and eyeball into its component parts as shown in Figure 2. The objective optics focus the signal energy from the target which has been degraded by the atmosphere. A mechanical scanner paints the scene on the detector array. The photon-sensitive detector transduces the infrared signal into an electrical signal, and it is processed along with the system noise by the electronics. The processed signal and noise are finally re-imaged on a screen by the display. The visual scene on the display is filtered by the observer's eyeball, and a decision is then made according to the task assigned. We shall now consider the transfer characteristics for each of these component processes.

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12 Unpublished report on Atmospheric Models by R. Bergemann of NVL.

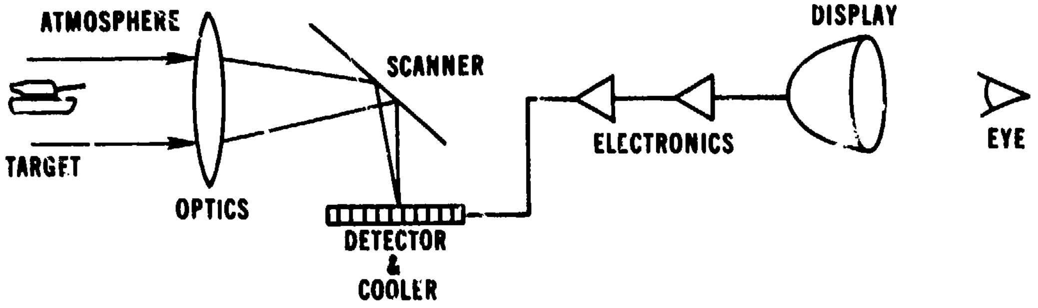

Figure 2. Block diagram of sensor/eyeball system components.

1. **Optics.** As in most calculations by this model, there are options to the method of MTF generation. If an exact MTF as a function of frequency is known, it may be read into the model directly; if not, an optical MTF is calculated from the product of a diffraction-limited transfer function and a geometric-blur transfer function. The diffraction-limited MTF[13] as a function of spatial frequency f_x (cycles/mr) for optics with F-number F# and focal length ℓ in micrometers and at wavelength λ in micrometers is given by

$$H_{OPT} = \frac{2}{\pi} \left[\cos^{-1}(A) - A\,(1 - A^2)^{1/2}\right], \qquad (9)$$

where

$$A = \lambda F_{\#} f_x / \ell. \qquad (10)$$

Cylindrical symmetry is assumed and equation (9) is used for the vertical direction transfer characteristic also. A gaussian geometric blur is assumed of the form

$$H_{BLUR} = \exp(-bf_x^2). \qquad (11)$$

The resultant optical MTF is then the product of the diffraction and geometric components.

2. **Detector.** The detector has two effects which contribute to the system-transfer characteristics. First, it acts as a spatial filter because of its finite size. Second, it acts as a temporal filter because of its finite response time. The spatial and temporal frequencies are related through the scan velocity v, by

[13] E. L. O'Neill, *Introduction to Statistical Optics*, Addison-Wesley (1963), p. 84.

$$f(Hz) = v\,(MR/SEC)\, f_x\ (CY/MR). \tag{12}$$

The detector spatial filtering in the horizontal or vertical direction is given by

$$H_{DET}(f_x) = \sin(\pi f_x X) / (\pi f_x X), \tag{13}$$

where X is the instantaneous field of view (IFOV) of the detector in that direction. The IFOV is the angular subtense of the detector in the objective focal plane. The detector temporal response contributes significantly to the horizontal spatial response when the detector dwell time is very short as in serial processors. In this case, the charge carri[illegible] in the detector material do not have enough time to fully react to the scene changes irradiating an IFOV. The temporal transfer function for this phenomenon is approximated by an RC roll-off:

$$H'_{DET}(f) = 1/[1 + (f/f^*)^2]^{1/2}, \tag{14}$$

where f^* is the 3-dB point in hertz of the detector response. Equation (14) becomes

$$H'_{DET}(f_x) = 1/[1 + (v\,f_x/f^*)^2]^{1/2},$$

using equation (12) to transform to spatial frequency space.

3. **Electronics.** Usually, the passband associated with the amplifiers is very broadband compared to other system component filters. However, if there is a non-negligible bandwidth in the electronics, it may be read as a model input or calculated using an RC-circuit roll-off again in temporal frequency space,

$$H_{ELECT}(f) = 1/[1 + (f/f_o)^2]^{1/2}, \tag{15}$$

where f_o is the 3-dB point on the RC filter. In the case where an electronic boost is present in the system, such as an aperture correction, the boost MTF may be read as an input; or a standard form[14] for the boost transfer function can be used given by

$$H_B(f) = 1 + (K-1)/2\,[1 - \cos(\pi f/f_{MAX})], \tag{16}$$

where K and f_{MAX} determine the amplitude and frequency of the boost. Equations (15) and (16) can be transformed to spatial frequency space through use of equation (12).

[14] Discussions with various engineers at Hughes Aircraft Co.

In a parallel scanning system which is electro-optically multiplexed, the LED emitters and TV vidicon must be included in the system-transfer characteristics. The LED filter function is

$$H_{LED}(f_x) = \sin(\pi f_x X)/(\pi f_x X) \quad (17)$$

in the two spatial directions, where x is the diode angular subtense in object space. The vidicon MTF is read in as a system input, including any boosting in the camera.

4. **Display.** The display transfer function is the fourier transform of the display spot size. In the case of an LED display, we use an MTF in both spatial dimensions similar to equation (17). For a CRT display, we assume a gaussian spot shape and, consequently, a gaussian transfer function. The exact form used is

$$H_{CRT}(f_x) = \exp(-a\, f_x^{\,2}). \quad (18)$$

5. **Stabilization.** Airborne FLIR's are operated on a stabilized platform to damp out aircraft vibration. The vibration cannot, however, be entirely removed, and it does degrade the image to the observer. We represent this vibration with an MTF "destroyer," or simply another MTF. This line of sight (LOS) stabilization MTF can either be read as a model input or assumed to be gaussian and have the form

$$H_{LOS}(f_x) = \exp(-Pf_x^{\,2}), \quad (19)$$

where P is calculated from the variance of the vibration stabilization.

6. **Eyeball.** The last system component is the observer's eye. The form used for the eyeball transfer function is a simplified version of the form found in work done by Kornfeld and Lawson.[15] The MTF has the form

$$H_{EYE}(f_x) = e^{-\Gamma f_x/M} \quad (20)$$

for the two spatial directions, where Γ is a light-level-dependent parameter and M is the system magnification. Table 3 shows the dependence of Γ on the logarithm of the light level. The light level is determined by the average display brightness from the scene.

B. NE ΔT. The noise equivalent temperature difference (NE ΔT) of a system is a measure of detector sensitivity. The NE ΔT used in this model is the peak signal-to-rms noise NE ΔT for an electronic noise bandpass of

15 G. Kornfeld and W. R. Lawson, "Visual Perception Model," J. Opt. Soc. Am. 61, 811 (1971).

Table 3. Γ as a Function of Log Light Level for the Eyeball MTF

Γ	Log (Light Level in fL)
.81333	3
.9598	2
1.0980	1
1.4650	0
1.8300	-1
2.2773	-2
2.7653	-3
3.3347	-4
3.9040	-5

$$\Delta f_n = \int_0^\infty S(f)\, H^2_{ELECT}(f)\, H^2_B(f)\, H^2_{MD}(f)\, df, \tag{21}$$

where the detector noise power spectrum S(f) is a normalized noise power spectrum from the detector (i.e., S(f) equals 1.0 at some measuring frequency f_o) and $H_{ELECT}(f)$ and $H_B(f)$ are defined in equations (15) and (16). $H_{MD}(f)$ is the measuring device MTF. In an NE ΔT measurement, an electronic filter with 3-dB cut-off at ½ τ hertz is used, where τ is the detector dwell time. Under these conditions H_{ELECT} and H_B are usually 1.0 and the H_{MD} filter is just equation (15) with f_o equal to ½ τ. If S(f) is known, then equation (21) is carried out exactly. However, if S(f) is white then equation (21) reduces to

$$\Delta f_n = \frac{\pi}{2} \Delta f_e = \frac{\pi}{2} \left(\frac{1}{2\tau}\right) \tag{22}$$

where Δf_e is the electronic bandwidth. The inverse of the dwell time τ is given by the number of resolution elements per second, or

$$\frac{1}{\tau} = \frac{\alpha \beta F_R\, \eta_{OVSC}}{n\, \Delta x\, \Delta y\, \eta_{SC}} , \tag{23}$$

where α and β are the horizontal and vertical fields of view (FOV), F_R is the frame rate, η_{OVSC} is the overscan ratio, n is the number of detectors in parallel, Δx and Δy are the IFOV's in x and y, and η_{SC} is the scan efficiency.

The NE ΔT for a detector-noise-limited system is given by

$$NE\,\Delta T = \frac{4F^2\,(\Delta f_n)^{1/2}}{\pi A_d^{1/2}\,\tau_o\,\tau_a\,\sqrt{N}\int_{\Delta\lambda} D_\lambda^*\,\eta_\lambda'\,d\lambda}\,, \tag{24}$$

where F is the objective F-number, A_d is the detector area in square centimeters, τ_a is atmospheric transmission over the path the NE ΔT is measured, τ_o is the optical transmission, $\Delta\lambda$ is the spectral bandpass, D_λ^* is the detector specific detectivity, N is the number of detectors in series, and η_λ' is the temperature derivative of the Planck radiation (equation (3)). The N series detectors are assumed to have uniform D_λ^*. A derivation is given in Appendix A. A shot-noise-limited system NE ΔT is given by

$$NE\,\Delta T = \frac{4F^2\,(\Delta f_n)^{1/2}\,\sin\,(\theta/2)}{\pi A_d^{1/2}\,\tau_a\,\tau_o\sqrt{N}\int_{\Delta\lambda} D_\lambda^{**}\,\eta_\lambda'\,d\lambda} \tag{25}$$

where θ is the cold shield angle of the detector geometry and D_λ^{**} is the shot-noise-limited specific detectivity which is independent of detector field of view.

C. **MRT.** The minimum resolvable temperature difference (MRT) in the scanning direction is defined as the minimum temperature difference needed to resolve a standard four-bar pattern with 7:1 aspect ratio oriented vertical to the scan. MRT will be a function of bar frequency. The MRT can be calculated once the NE ΔT and component MTF's have been computed, and its form is derived in Appendix A. In the scanning direction, i.e., the bars oriented vertically, MRT is given by

$$MRT(f_x) = SNR\,\frac{\pi^2}{4\sqrt{14}}\,\frac{NE\,\Delta T}{MTF_{TOT}(f_x)}\left[\frac{\Delta y\,v\,f_x\,Q\,(f_x)}{\Delta f_n\;F_R\;t_E\;\eta_{OVSC}}\right]^{1/2}, \tag{26}$$

where

SNR = signal-to-noise ratio necessary to recognize the four-bar pattern.

$MTF_{TOT}(f_x)$ = $H_{OPT}\cdot H_{DET}\cdot H'_{DET}\cdot H_{ELECT}\cdot H_B\cdot H_{DISPLAY}\cdot H_{EYE}\cdot H_{LOS} = H_D(f_x)$.

Δy = vertical IFOV in mr.

v = detector scan velocity in mr per second.

f_x = target frequency in cycles per mr.

F_R = frame rate per second

η_{OVSC} = overscan ratio

t_E = eye integration time $\simeq$ .2 second

Q $= \int_0^{\infty} S(f_x)\, H_N^2(f_x)\, H_W^2(f_x)\, H_{EYE}^2(f_x)\, df_x$

$S(f_x)$ = noise power spectrum out of detector

$H_W(f_x)$ = target filter function of bar-width w.

$H_N(f_x)$ = noise filter function from detector to display.

An MRT in the vertical direction, e.g., bars parallel to the scan direction, can be defined and is given by (Appendix B):

$$MRT(f_x) = SNR \frac{\pi^2}{4\sqrt{14}} \frac{NE\,\Delta T}{MTF_{OT}(f_y)} \left[\frac{\Delta y\, v\, f_y\, QQ}{\Delta f_n\, F_R\, t_E\, \eta_{OVSC}}\right]^{1/2}, \qquad (27)$$

where

$MTF_{TOT}(f_y) = H_{OPT} \cdot H_{DET} \cdot H_{DISPLAY} \cdot H_{EYE} \cdot H_{LOS} = H_D(f_y)$

f_y = target frequency in cycles per mr.

QQ $= \frac{7}{2f_y} \int_{-\infty}^{\infty}\int_0^{\infty} S(f_x)H_N^2(f_x)H_L^2(f_x)H_{EYE}^2(f_x)H_D^2(f_x)H_W^2(f_y)H_N^2(f_y)H_{EYE}^2\, d^2f$

H_L^2 = target filter function of bar length L = 7W.

This vertical MRT, in which sampling effects are averaged out, is an attempt to consider the effects of vertical resolution on overall system performance. It is still a controversial quantity and totally unvalidated. However, NVL is actively engaged in pursuing this concept as a measure of system behavior.

Figure 3 illustrates the form of MRT. At each frequency f_c, there is a minimum temperature difference ΔT_c necessary to resolve the four bars. There is a frequency f_R at which the MRT becomes infinite (the MTF equals zero), and no amount of signal will resolve the bars. For a system with no degradation after the detector, f_R equals the reciprocal of the IFOV. Although bars can theoretically be resolved beyond this frequency because of the wings of the sinc function, practically it is a limit to system resolution. Real systems attain only 60 to 90 percent of this theoretical cutoff f_R.

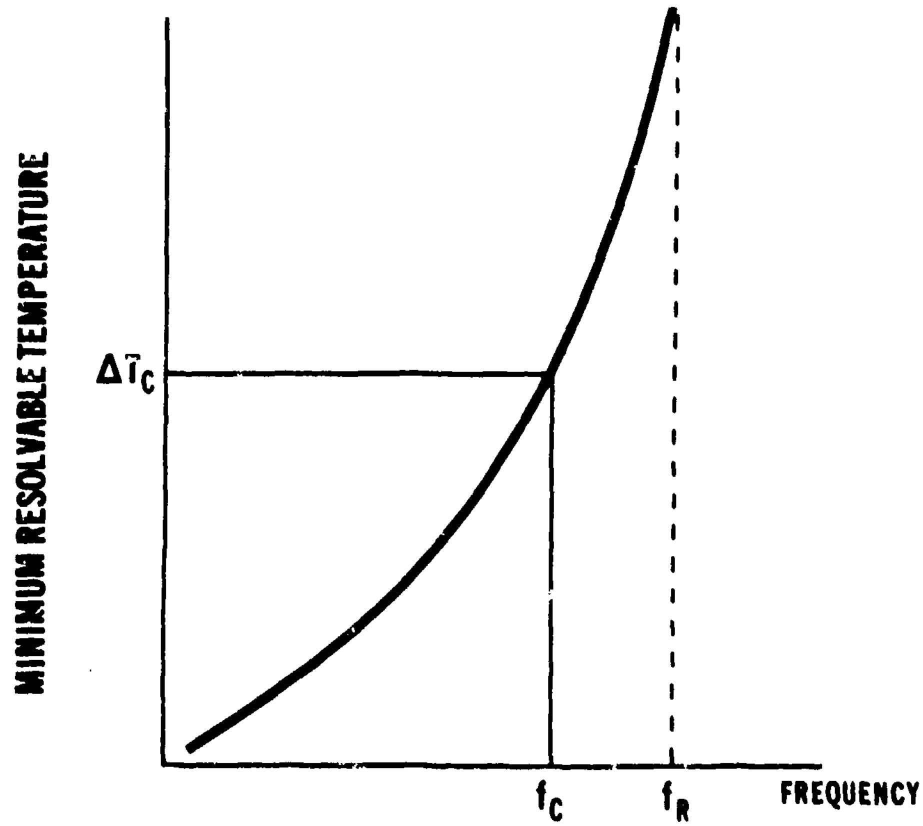

Figure 3. Representative MRT curve.

D. MDT. The minimum detectable temperature (MDT) of a thermal device is defined as the minimum temperature difference between a square (or circular) target and the background necessary for an observer to perceive the source through the device. MDT is then a function of target size and represents the threshold detection capability of the system. It can be derived from the same signal-to-noise expression as that used to derive MRT. The result from Appendix A is

$$MDT = \frac{NE\Delta T\, S'}{A_T \int_{-\infty}^{\infty} H_T^2\, H_D^2\, d^2 f} \left[\frac{\Delta y\, v}{\eta_{OVSC}\, F_R\, t_E\, \Delta f_n} \right]^{1/2} \tag{28}$$

$$\times \left[\int_{-\infty}^{\infty}\int_{0}^{\infty} S(f_x)\, H_{ELECT}^2\, H_{DISPLAY}^2\, H_{EYE}^2\, H_T^2\, H_D^2\, d^2 f \right]^{1/2}$$

where

A_T = target area in square milliradians

S' = threshold signal-to-noise ratio

H_T = target transform = $H_L \times H_W$

H_D = total device and eyeball MTF = MTF_{TOT}.

Figure 4 illustrates the form of MDT as a function of reciprocal target size. For any target size α in milliradians, there is a ΔT_D which is the minimum temperature difference necessary for the target to be detected. There is no asymptote for MDT as there is for MRT since any size source can be detected if hot enough. An arbitrarily small target can be detected if its signal strength is large enough to excite one IFOV, i.e., a thermal device is capable of "star detection."

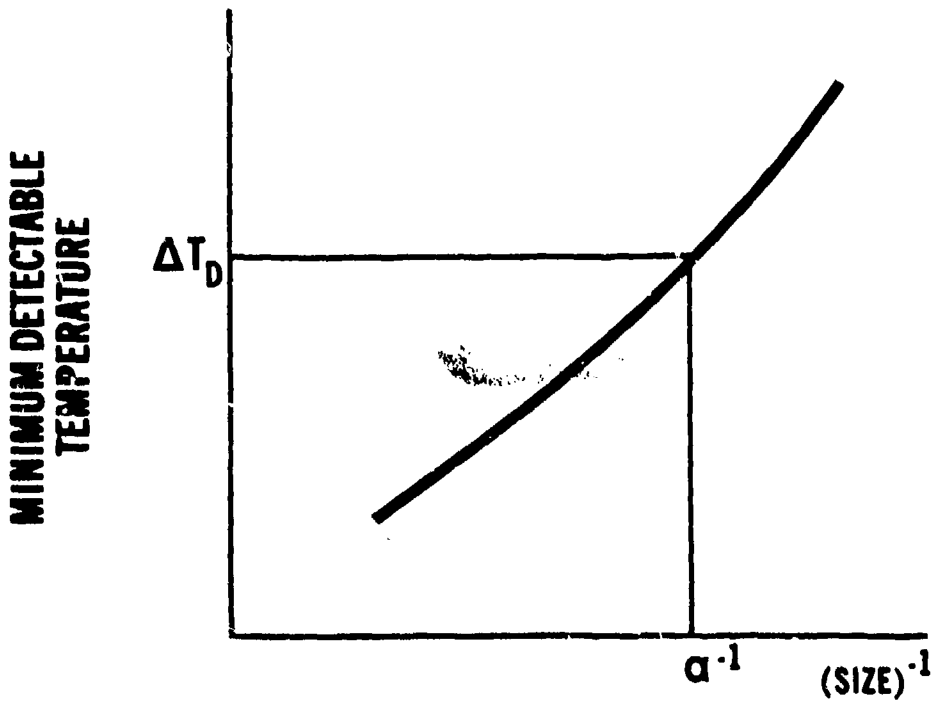

Figure 4. Representative MDT curve.

IV. RECOGNITION

Recognition is a level of discrimination between specific objects in a class of similar objects. The class of objects may be all vehicles of military interest. The specific objects are tank, APC, etc. The difficulty of the discrimination level varies with the amount of detail needed to make a distinction between targets, which in turn is a function of the number of objects in the class and the similarity of the objects. In typical Army surface-to-surface scenarios, the discrimination is usually between tank, APC, 2½-ton truck, jeep, and man in the front, side, or three-quarters aspect. Surface-to-air recognition is between fixed wing and rotary aircraft. The Naval recognition task may correspond to a warship or a cargo ship distinction.

The NVL model approach to recognition performance is based upon a concept originally proposed by Johnson.[16] This method assumes that target recognition probability is a function of the number of cycles of a "target equivalent" bar pattern which can be resolved across the minimum target dimension; a "target equivalent" bar pattern is one whose bars have a temperature difference equal to that of the target. In other words, recognition probability is a function of $W_T f_o$ where W_T is the critical dimension of the target and f_o is the maximum frequency bar target equivalent bar pattern (having bar temperature equal to the target temperature) which can be resolved by an observer looking at the bars through the device. This method has been further developed in a more recent paper by Johnson and Lawson.[17]

The probability of target recognition P_R is given in general by

$$P_R = \int P(\text{REC} \mid \text{N CYCLES})\, \rho\, (\text{N CYCLES})\, dN,$$

where P(REC | N CYCLES) is the probability of target recognition given N cycles are resolvable across the critical dimension discussed above and ρ (N Cycles) dN is the probability that the number of cycles which can be resolved is between N and N + dN. In general, ρ (N) must be determined from probability versus signal-to-noise calculations. However, Johnson and Lawson[18] have shown that there is no significant error introduced in P_R if ρ (N) is replaced by the delta function $\delta\,(N - N_o)$, where N_o is the number of cycles corresponding to the threshold frequency for the target temperature difference. Thus, in practice, P_R is given by

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16 J. Johnson, "Analysis of Image Forming Systems," Proc. of Image Intensifier Symposium, 1958, pp. 249-273.

17 J. Johnson and W. R. Lawson, "Performance Modeling Methods and Problems," Proc. of IRIS Specialty Group on Imaging, Jan. 1974 (Confidential).

18 J. Johnson and W. R. Lawson, "Performance Modeling Methods and Problems," Proc. of IRIS Specialty Group on Imaging, Jan. 1974 (Confidential).

$$P_R = P(REC \mid N_0 \text{ cycles}).$$

The relationship between probability of recognition $P(REC|N_0)$ and number of resolution cycles across a target is a fundamental relationship which must be determined on the basis of existing field data. Investigation of experimental results shows that this relationship is also dependent on the azimuth angle of the target. For example, whereas it might take three cycles across the side view of a vehicle for 50% probability of recognition, it takes four cycles across the front view to recognize with the same level of certainty. This variation with aspect is especially pronounced in tasks involving ship and aircraft targets. The resolution needed to recognize the bow aspect of a ship is in most cases many times greater than that needed for the beam aspect. Table 4 shows the several relationships which are prime candidates for this fundamental functional dependence of recognition on resolvable cycles for Army terrestrial targets and most side-view military targets. The most correct relationship is probably somewhere between these two extremes.

Table 4. Probability of Recognition as a Function of Number of Cycles Across Target Critical Dimension for Army Vehicles

Prob of Recog	# of Cycles	# of Cycles
1.0	12	9
.95	8	6
.80	6	4.5
.50	4	3
.30	3	2.25
.10	2	1.5
.02	1	.75
0	0	0

The method of determining resolution across a target to establish $P(REC|N_0)$ has been historically to use the horizontal or scanning direction resolution capability against the target minimum dimension which is usually vertical. This does not take into account vertical resolution or the sampling effects in that direction. Frequently, vertical resolution is noticeably worse than the resolution in the scanning direction, and some account should be taken of it. Work is presently being conducted to consider if some sort of averaging method between the two directions is desirable (gives better results). Considerations like these along with differences between field and laboratory results and uncertainty in the true critical dimension create uncertainty in the exact relationship between recognition probability and number of resolvable cycles.

The number of cycles across the target is obtained from the MRT curve. The temperature difference ΔT_c available at the sensor after attenuation by the atmosphere yields a resolvable frequency f_c through the device MRT curve (see Figure 3). The resolvable frequency f_c is the highest frequency in cycles per milliradian of a four-bar pattern which can be resolved by the device for the given temperature difference at the aperture. The number of cycles across the target is then f_c times the angular subtense α of the target critical dimension in milliradians as previously indicated. Probability of recognition is then directly relatable to number of cycles through Table 4. The correctness of this approach to recognition modeling is demonstrated in a following section on validation (Section VI) with field data.

The recognition model is summed up in the diagrams in Figure 5. The target ΔT is filtered by an atmosphere to give a ΔT_c at the sensor. The device MRT then gives the resolvable frequency f_c. Resolvable frequency f_c times the angular subtense of the target in milliradians gives the number of cycles across the critical dimension. The probability of recognition is obtained from the empirical relationship between P_R and number of cycles. Since the target subtense and ΔT are functions of range, recognition probability is a function of range.

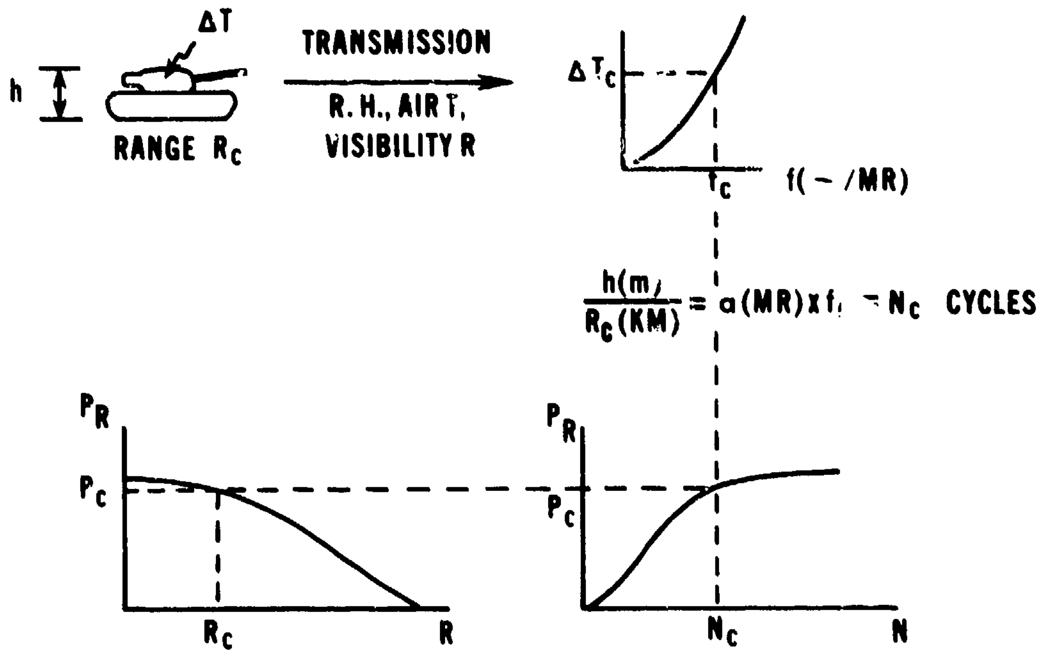


Figure 5. Diagram of Recognition Model.

V. DETECTION

Detection is a lower order discrimination than recognition. It is defined as the designation of a point as potentially of military interest. A hot spot that is brighter than other points in the scene is singled out for closer scrutiny when it is detected. Object motion is another target cue for detection. Whatever the reason, detection occurs when the observer's attention is called to a particular point.

There are two kinds of detection situations with a thermal imaging system. One, for terrestrial targets in a cluttered scene, is a low-order recognition task. The observer needs a small amount of resolution capability in order to see an edge or some internal feature so that he can distinguish the target from other confusing objects in the scene such as bushes and rocks. This kind of detection, for example, occurs when an observer is looking for a tank or other vehicles in a woodland scene. The second kind of detection occurs when there is little or no clutter, and the target is just brighter than anything else in the field of view. Such a situation occurs in air defense scenarios of aircraft against a uniform sky background.

The ability to detect a target in a cluttered background requires a low-order recognition capability. A level of detail is needed to separate the target from the background if the background clutter has a high degree of structure. As an example, in desert field tests, with infrared imaging systems cacti have been confused for men because they have the same approximate size and ΔT. Under this type of condition, a certain amount of resolution is needed to distinguish one object from another and to "pull out" the target. Field experience demonstrates that for general medium to low clutter approximately one-quarter the resolution is needed for detection as for recognition (3 to 4 cycles required). Table 5 gives such a relationship between detection probability and number of cycles across the target critical dimension.

Table 5. Probability of Detection as a Function of Number of Cycles Across Target Critical Dimension for Army Vehicles

Prob of Detection	No. of Cycles
1.0	3
.95	2
.80	1.5
.50	1
.30	.75
.10	.50
.02	.25
0	0

As already mentioned, there are Army missions in which true "hot spot" or "star" detection occurs with thermal devices. An incoming aircraft against a uniform sky background on an air defense perimeter is such a case. If the target is hot enough to activate one IFOV, although it subtends an angle much smaller, it stands out as a bright blur from the background. Under these conditions detection is a function of signal-to-noise ratio and not cycles across the target.

The signal-to-noise ratio used for this "star" detection is calculated using the MDT equation. Equation (28) can be turned around to calculate the signal-to-noise ratio S of a target of size given by H_T and signal strength ΔT. Then

$$S = \frac{\Delta T(R) \cdot A_T}{NE\,\Delta T} \int_{-\infty}^{\infty} H_D^2\, H_T^2\, d^2 f \left[\frac{\Delta y\, v}{\eta_{OVSC}\, F_R\, t_E\, \Delta f_n} \right]^{-1/2} \times \left[\int_{-\infty}^{\infty}\int_{0}^{\infty} S(f_x)\, H_{ELECT}^2\, H_{DISPLAY}^2\, H_{EYE}^2\, H_T^2\, H_D^2\, d^2 f \right]^{-1/2} \qquad (29)$$

S then varies with range R to the target.

The relationship between S and probability of detection must be empirically determined as in the case of recognition and subjective resolution. There is not a large data base of field data to determine this relationship. However, for the present, a function such as that determined by Rosell *et al.* from laboratory experiments can be used.[19] This relationship is shown in Table 6.

Table 6. Probability of Detection as a Function of Signal-to-Noise Ratio from Rosell

Probability of Detection	Signal-to-Noise Ratio
1.0	5.5
.9	4.1
.8	3.7
.7	3.3
.6	3.1
.5	2.8
.4	2.5
.3	2.3
.2	2.0
.1	1.5
0	0

[19] F. A. Rosell and R. H. Wilson, "Performance Synthesis of Electro-Optical Sensors," AFAL-TR-74-104, Air Force Avionics Laboratory, WPAFB, Ohio, April 1974, p. 17.

The detection model is not as well validated as the recognition model since there is a dearth of usable data. The best source of detection performance data is airborne tests. However, the target signatures – especially in-flight signatures – in these tests are poorly documented. Since aircraft travel fast, observer reaction time plays a role in detection range and, consequently, there are large error bars in this data. As new data are gathered, however, the validation procedure will continue until the model can be used with a high degree of confidence.

VI. VALIDATION

The reliability of any performance model must rest in its validation. In this section, we shall present the results of MRT measurements and four field tests in comparison to predictions as validation of this model. The MRT bench measurements were made at the Visionics Technical Area of the Night Vision Laboratory which also conducted the field tests. Three tests were ground-to-ground tests conducted at Warren Grove, N.J.[20] in summer 1971 and Aberdeen, Md., in winter and summer 1973.[21, 22] The fourth test was an airborne test in summer 1973 at Fort Polk, La.[23]

The two tests at Aberdeen, Md., included six systems from three different contractors. The range of resolutions was 1/6 mr to 1 mr, and the systems were prototypes for missile and tank-integrated systems. Table 7 is a list of unclassified and non-proprietary system descriptors.

Table 7. Partial List of System Parameters for Missile and Tank Systems Tested at Aberdeen, Md., in 1973

System	Application	Spectral Region (μm)	Scanner	Detector	Contractor
A	Missile	3-5	Parallel	PbSe	1
B	Missile	3-5	Parallel	PbSe	1
C	Missile	8-14	Serial	HgCdTe	2
D	Missile	8-14	Parallel	HgCdTe	3
E	Tank	8-14	Serial/ Discoid	HgCdTe	2
F	Tank	8-14	Parallel	HgCdTe	3

[20] J. R. Moulton, *et al.*, "A Search Performance Test on Ground-Based, Thermal Imaging and Pulse-Gated Intensifier Night Vision Systems," U.S. Army Electronics Command Report 7028, June 1973 (Confidential).

[21] J. Swistak, "Field Performance Evaluation of TINTS Night Sight Systems," U.S. Army Electronics Command Report 7035, Jan. 1975 (Confidential).

[22] J. Swistak, "Field Performance Evaluation of TOW Night Sight Systems," U.S. Army Electronics Command Report 7033, Jan. 1975 (Confidential)

[23] Unpublished test report of airborne FLIR against ground targets by NVL [illegible] summer 1973.

The comparison of measured and predicted MTF's for the four missile devices is shown in Figure 6(a). The MTF predictions for systems A and B underline one of the main problems in performance modelling of prototype systems. The MTF and MRT predictions must be made on the basis of numerous systems engineering inputs all of which are seldom known by contractor or government engineers. Especially in prototype systems, components are in a constant state of change or may not even be constructed at the time of the analysis. Consequently, sometimes obsolete inputs are used which have no relationship to the actual or real-time components or they have to be fabricated on a best-estimate basis. This establishing of system parameters turns out to be the most difficult task for the systems modeller. Systems A and B are devices which are not accurately specified.

Systems C and D in Figure 6(a) plus E and F in Figure 6(b) show reasonable agreement between predicted and measured MTF. Of these, system D shows the worst agreement; since the measured performance is noticeably less than predicted for such a straightforward quantity as MTF, the implication is that some system component is not performing up to specification and is causing a degradation.

The MRT calculations for these systems are found in Figures 7(a) and 7(b). They were all calculated using the SNR in equation (26) equal to 2.25. This value for SNR appears to give the best overall agreement between predicted and laboratory results.

Systems A and B in Figure 7(a) show some discrepancy in the resolution-limited region due to the difference in predicted and measured MTF already mentioned. The difference in the noise-limited region for System E in Figure 7(b) possibly implies some unaccounted for noise source or processing which is being neglected in the analysis.

Recognition performance against the side view of tanks is shown in Figures 8(a) and 8(b). All calculations were done with the 4 cycles equals 50 percent curve shown in Table 4. The data points are shown by circles, and the tank systems field test has error bars associated with each point. The tank was a hot-running signature under highly transmissive atmospheres (clear, low relative humidity night). The agreement in the tank test is excellent while predictions appear to be short in the missile test – especially for Systems A and B in Figure 8(a). This was due to cues that were present in this test. Tank drivers had comfort heaters on during this winter test causing obvious hot spots on the targets. The trained observers were quick to pick up this cue and use it as a recognition cue. This kind of field behavior underlines the need for a cued-target recognition model.

Performance of these six systems against front views of tanks is shown in Figures 9(a) and 9(b). The tank test again shows excellent agreement. The missile test results

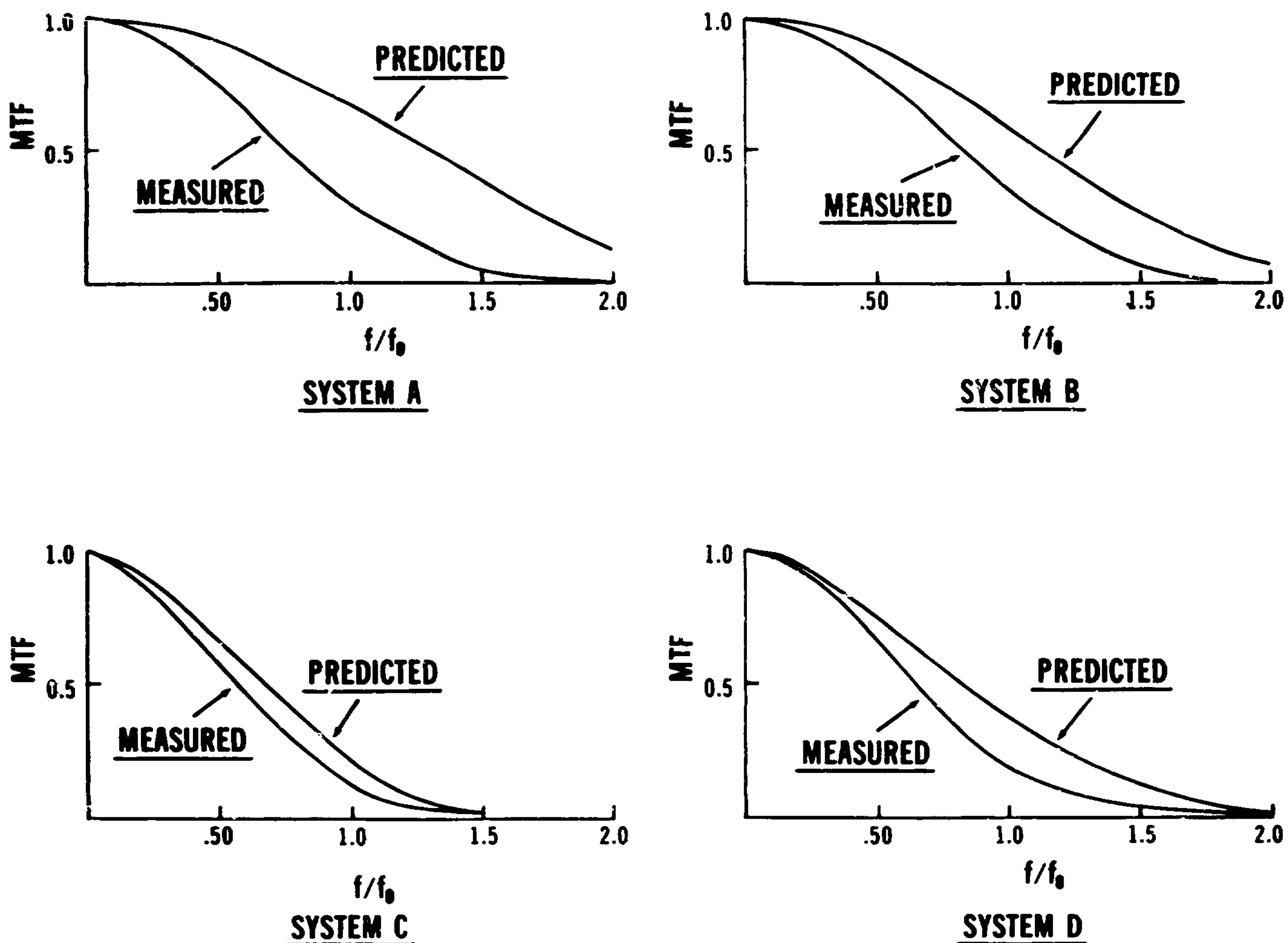
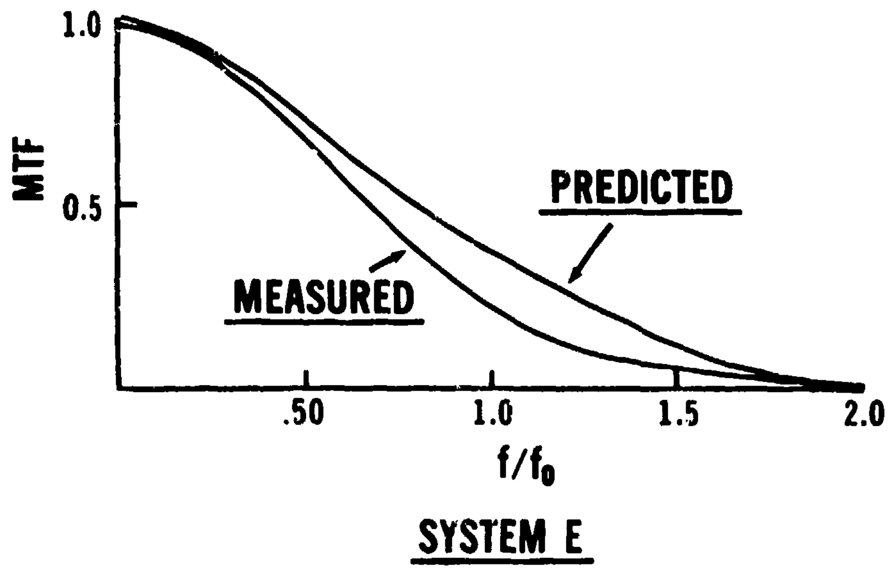


Figure 6(a). Predicted vs measured MTF's for missile systems.



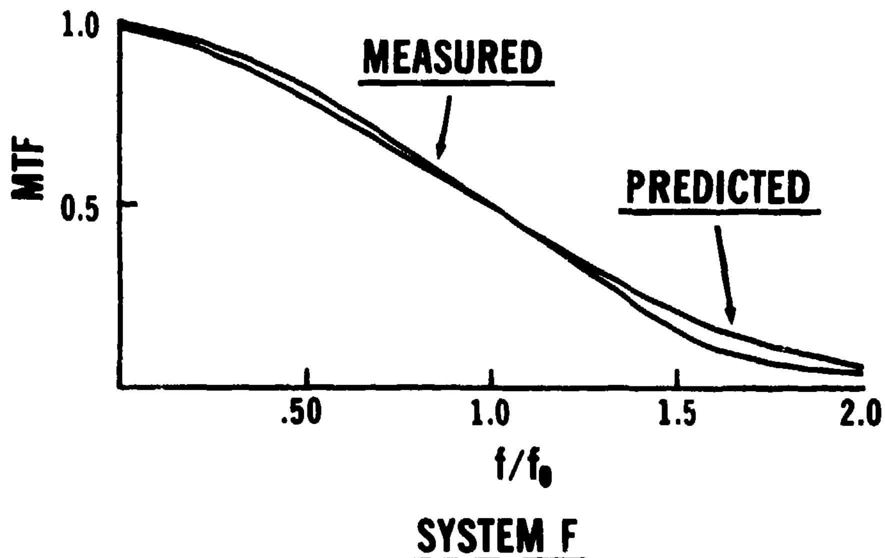


Figure 6(b). Predicted vs measured MTF's for tank systems.

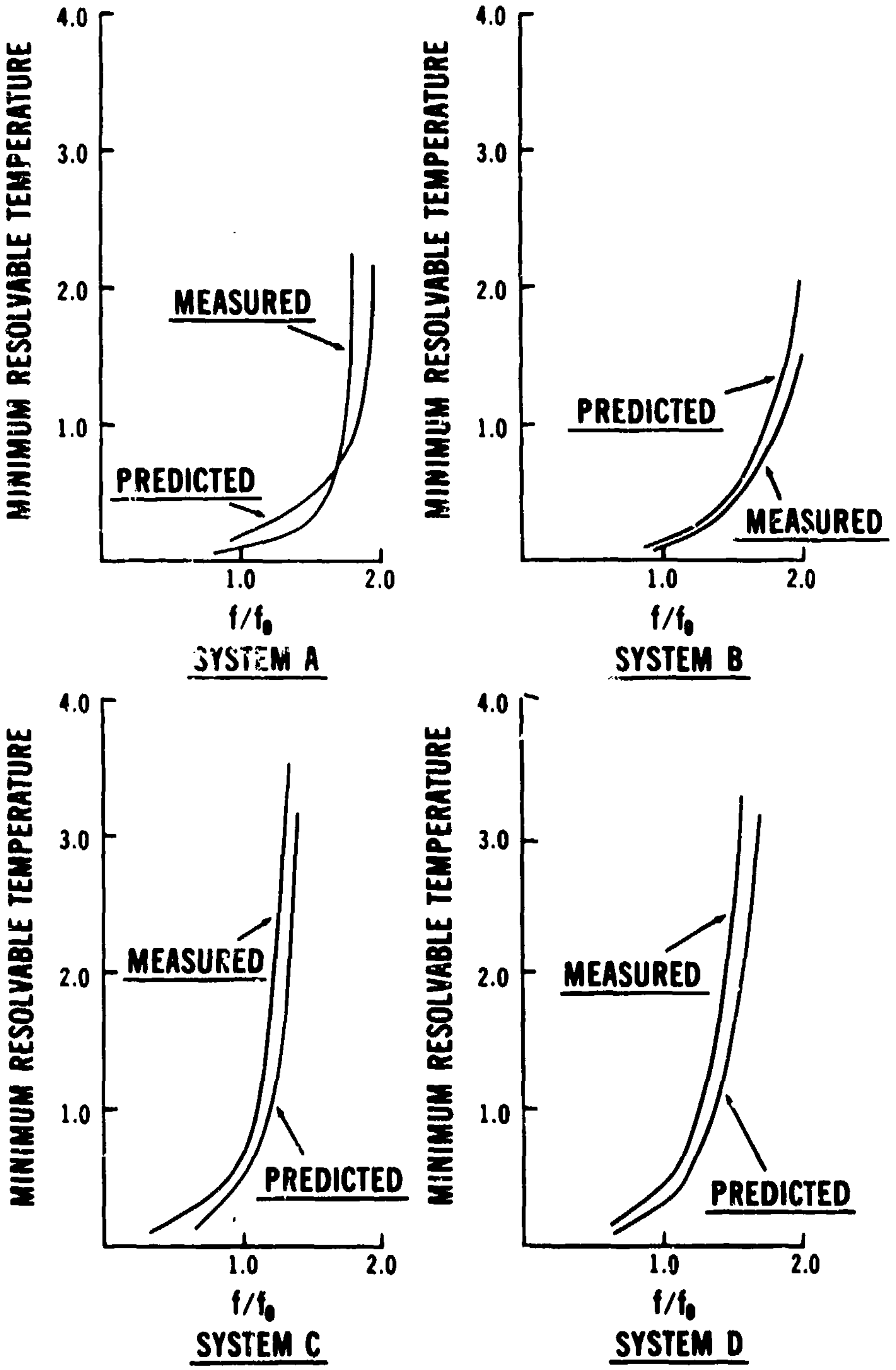


Figure 7(a). Predicted vs measured MRT's for missile systems.

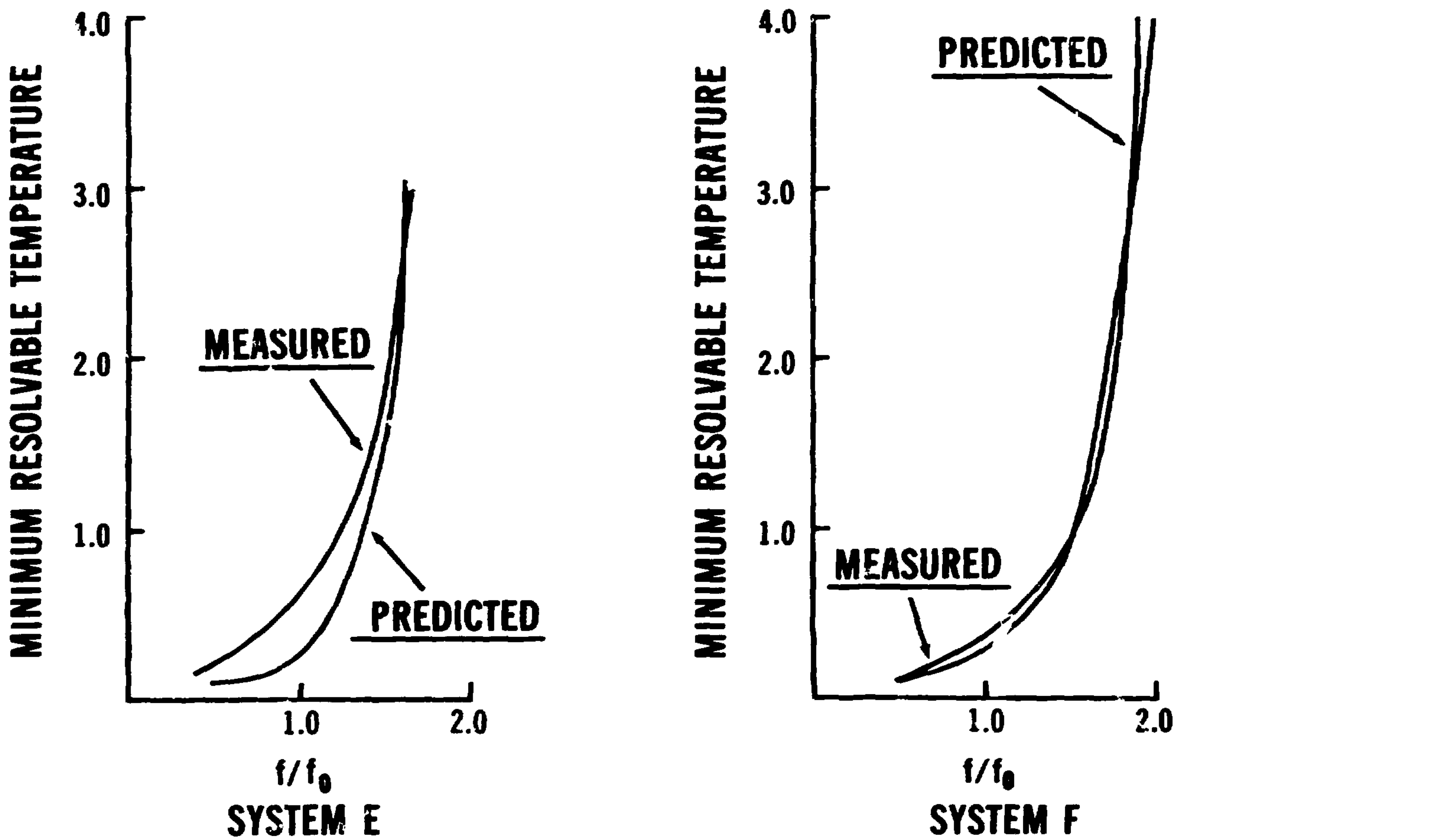


Figure 7(b). Predicted vs measured MRT's for tank systems.

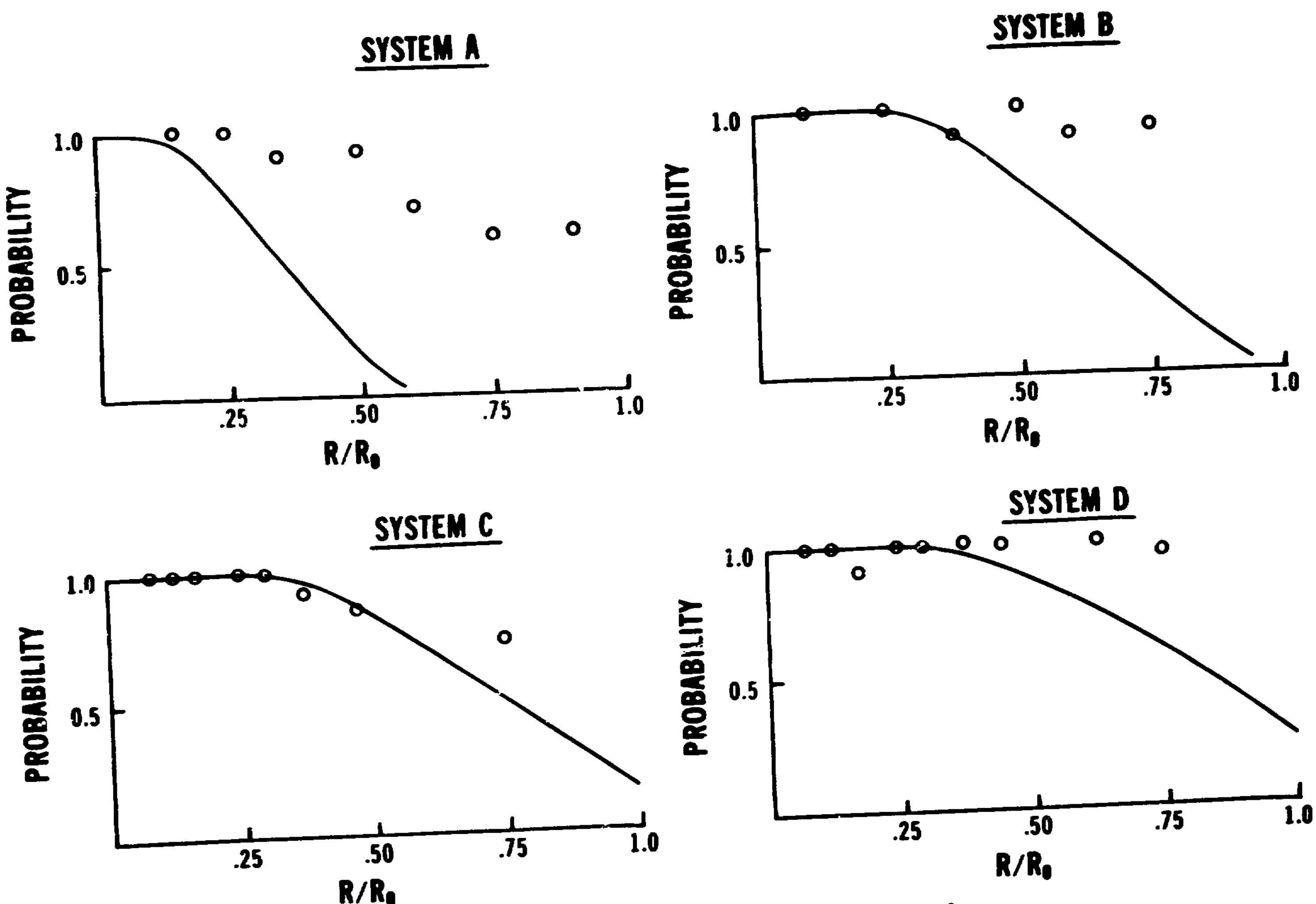


Figure 8(a). Recognition performance for missile systems vs tank side.

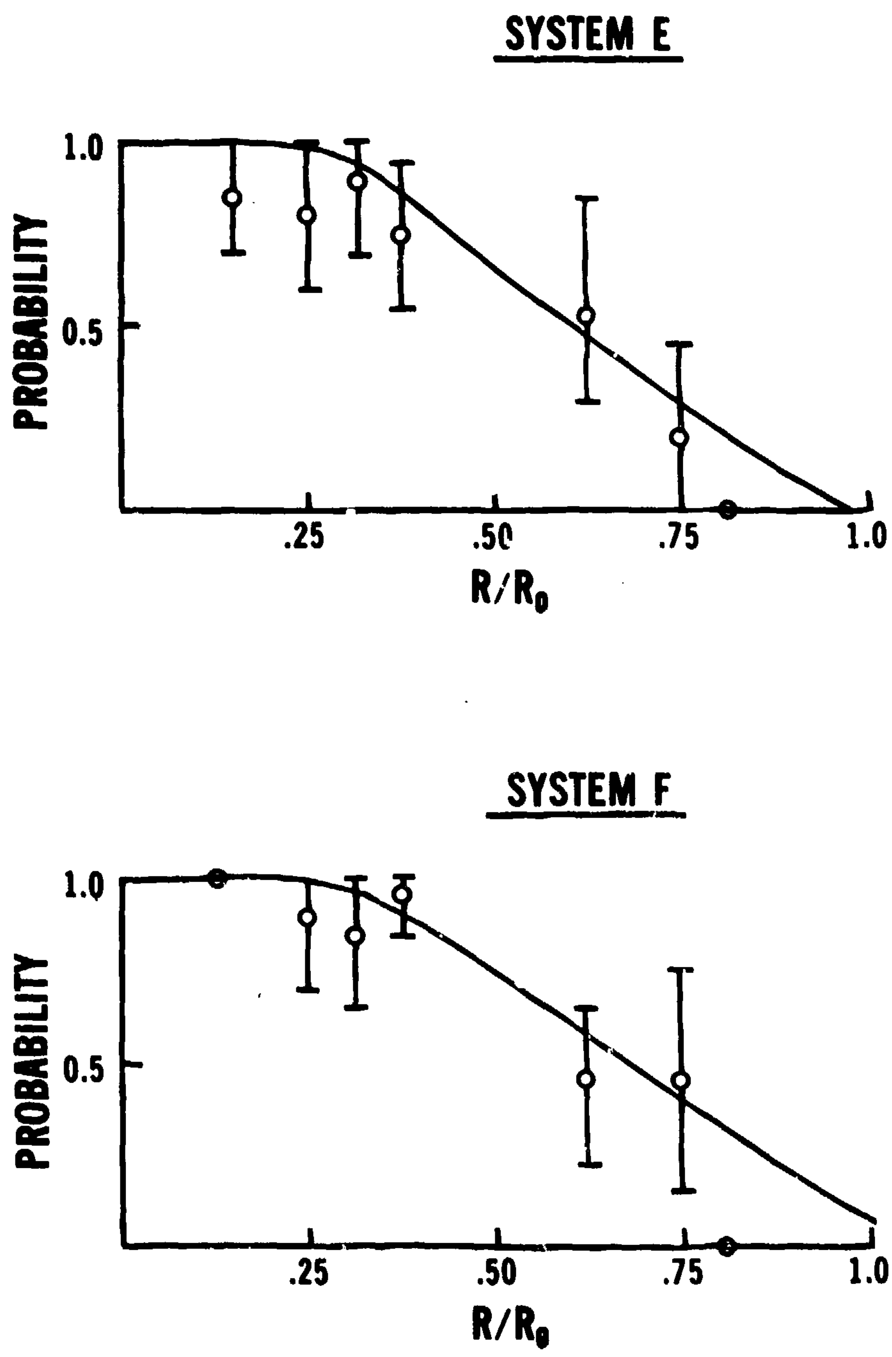


Figure 8(b). Recognition performance for tank systems vs tank side.

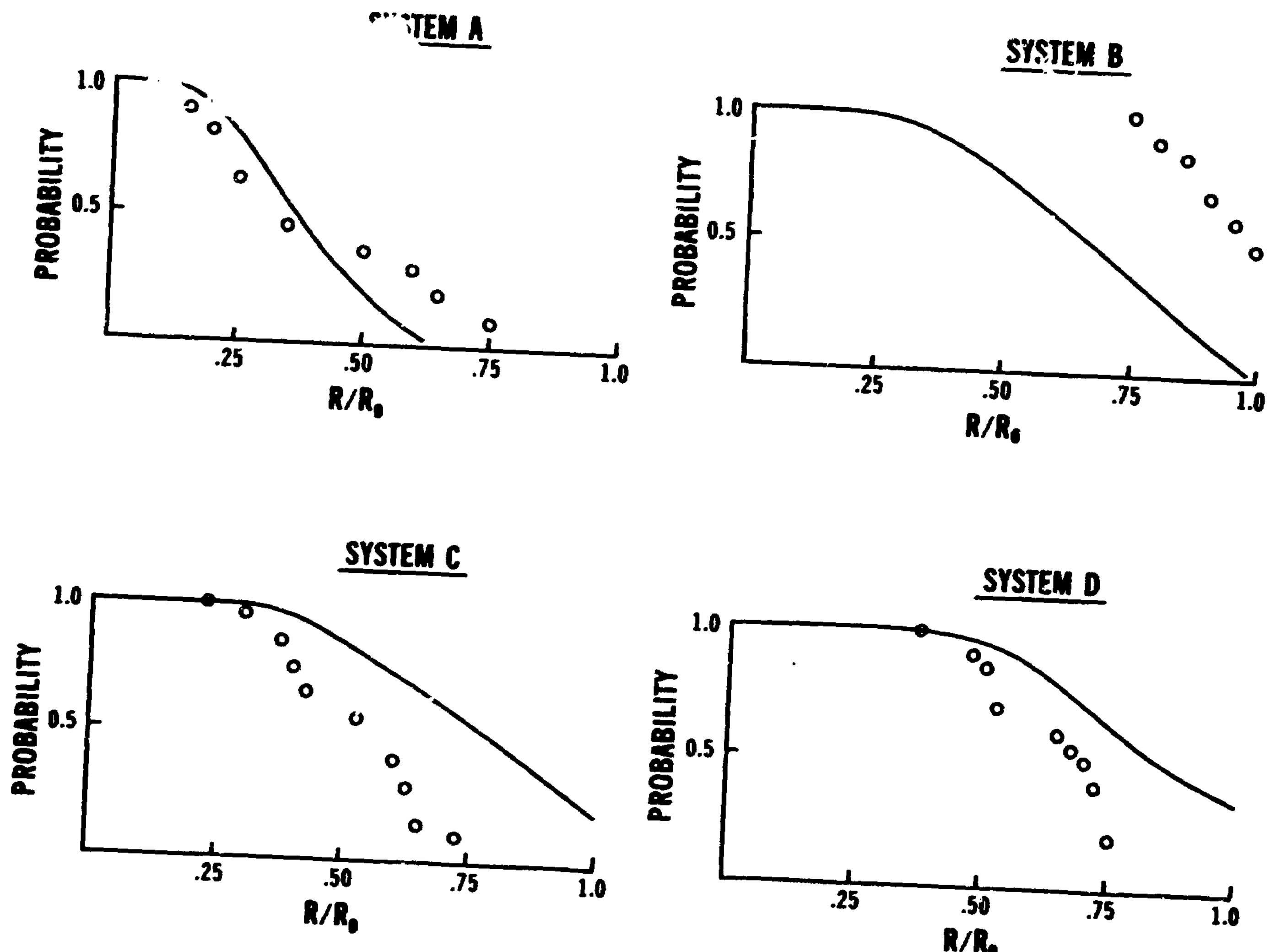


Figure 9(a). Recognition performance for missile systems vs tank front.

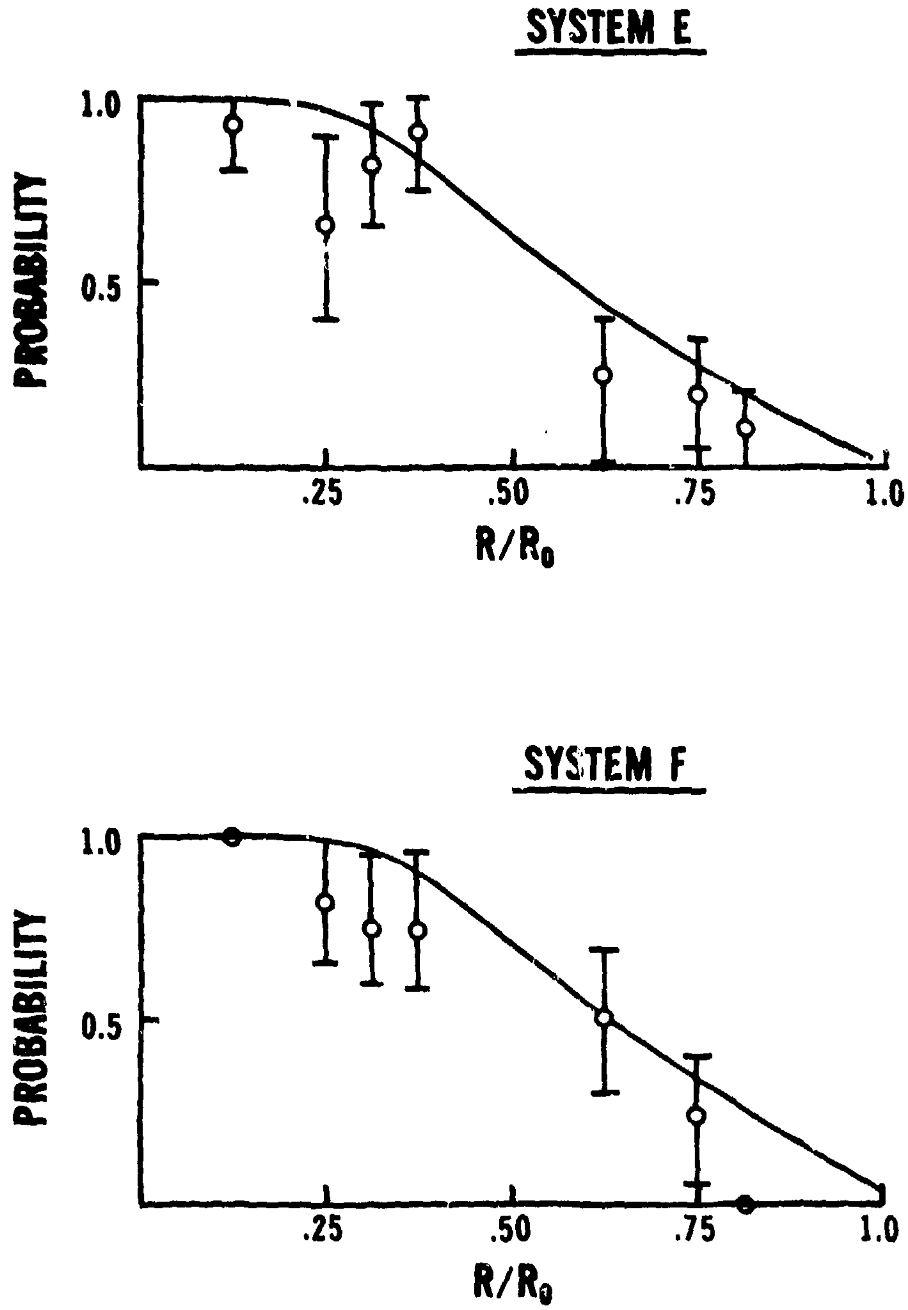


Figure 9(b). Recognition performance for tank systems vs tank front.

show a steeper slope than the predicted slope for Systems C and D in Figure 9(a). This was possibly caused by two different reasons. First, this was a method-of-limits test. The target vehicles started at a constant range and moved slowly toward the observation point until recognition was recorded. Hence, the performance as a function of range must go to zero at the starting range, causing the slope to be steeper than usual. Second, the targets approached the observers across a muddy field which tended to degrade the IR signature due to splattered mud and water on the vehicles.

The only airborne test with results applicable to the NVL model validation was conducted at Fort Polk, La., in 1973. Previous tests have tended to be operational tests not designed to acquire model validation data. A notable exception is the MAFLIR test conducted at Patuxent River by the Air Force.[24] The level of discrimination in this test, however, was not high enough to be of use for our purposes.

Detection and recognition performances are shown in Figure 10 for the Fort Polk test. The targets were operational vehicles in a clear atmosphere. The results plotted by circles and X's are empirical recognition and detection data of tracked vehicles. The predictions indicated by curves considered only a side-view tank with the four-cycle criterion for recognition at 50 percent and the Table 5 criterion for detection. Since the FLIR was mounted on a stabilized airframe platform, an LOS transfer function based on the stabilization of the gimbals was used. The agreement shown here is considered very good.

The graph shown in Figure 11 is for a ground surveillance thermal system that was tested at Warren Grove, N.J., in 1971. The target is an operational tank in the side aspect. The circles representing the data points give good agreement with the predicted curve.

The validation results shown in the figures represent an approximate accuracy of ± 20% in range which is considered state-of-the-art for modelling. However, all these results have been for optimum target and atmosphere. Degraded performance under adverse target and atmospheric conditions has not been validated because of the lack of field data for these conditions. Field performance against degraded targets and atmospheres has been attempted by this laboratory; however, such targets and atmospheres do not remain constant sufficiently long enough to obtain sufficient statistical data on them. A target's tracks can change temperature and a fog can roll in before two observations through a device have been made.

Recognition and detection performance can be seriously impacted by adverse target and atmospheric conditions. A passive target, a mud caked signature, a haze

[24] D. C. Winter, "Infrared Image Test Program – Variable Analysis," AFAL-TR-72-384, Air Force Avionics Laboratory, WPAFB, Ohio, March 1973 (Confidential).

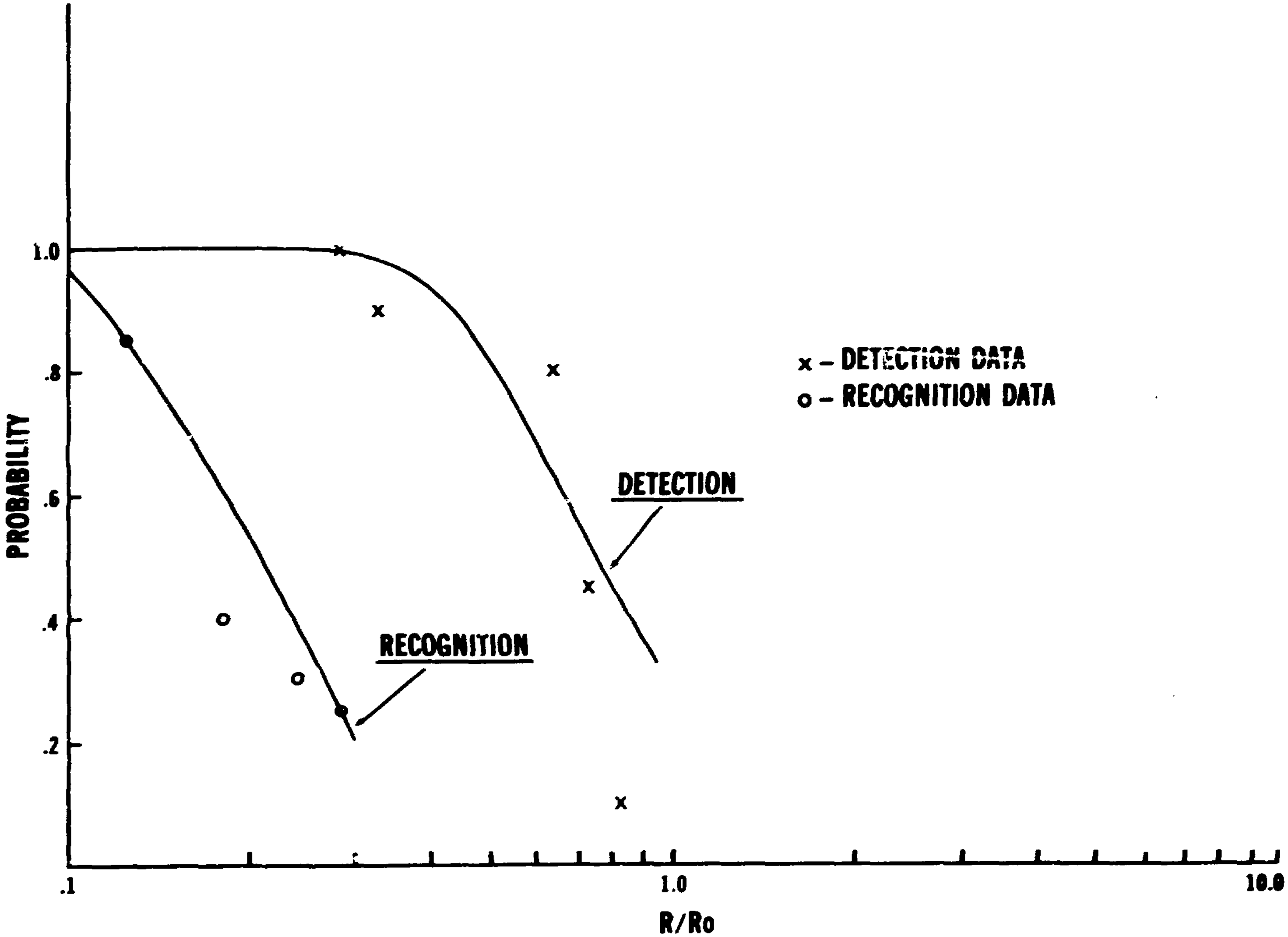


Figure 10. Airborne FLIR vs tracked vehicles.

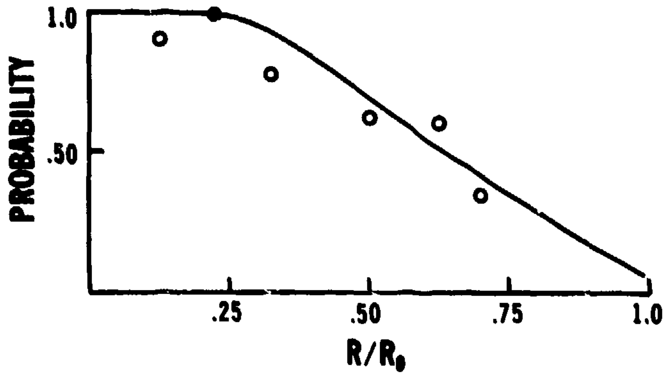


Figure 11. Recognition performance of ground surveillance system vs tank side.

with particle size that scatters IR radiation, or high relative humidity can cause significant performance range reduction. These conditions can have a high probability of occurring in such environments as those found in West Germany. An example of an atmospheric distribution is shown in Figure 12.[25]

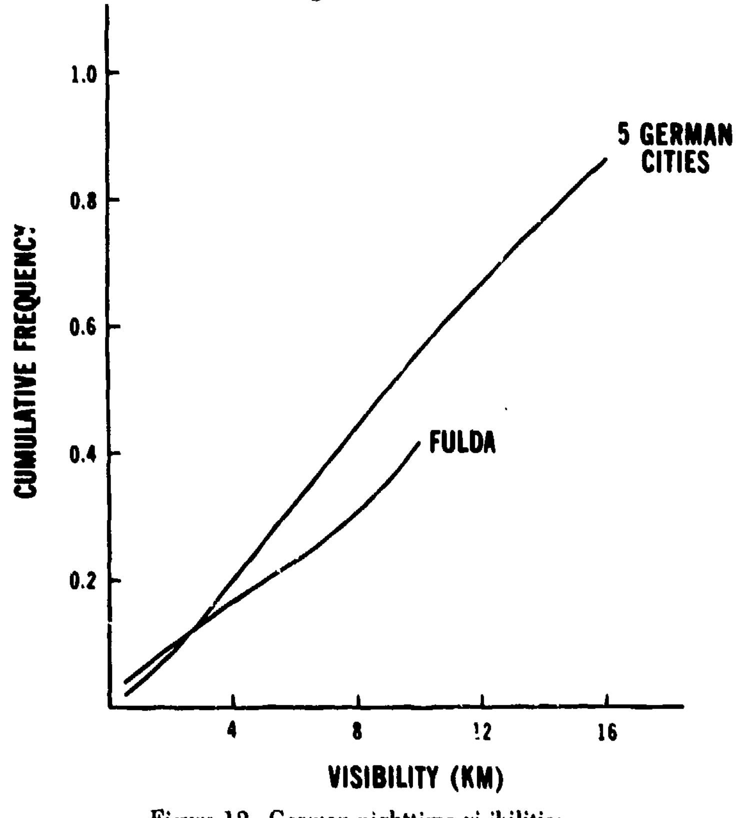


Figure 12. German nighttime visibilities.

[25] Unpublished report on environmental analysis by R. Bergemann of Visionics Technical Area, NVL.

VII. CONCLUSIONS

The present NVL and AMC static performance model for detection and recognition has been documented in the preceding text. The actual computer program is found in Appendix C along with its operational use. The model is in a constant state of evolution and refinement as new field data is incorporated into the validation data bank and new systems concepts must be analyzed. The present approach to detection uses a signal-to-noise ratio calculation based on MDT, and recognition utilizes the MRT which is derivable from the same signal-to-noise ratio. This approach gives a unified theory upon which detection and recognition are based. The relationships between detection and signal-to-noise ratio and recognition and resolution are fundamental and empirically derived functions. The accuracy of the present model is assumed to be ± 20% in range for recognition under favorable target and atmospheric conditions.

Work is presently being done on several areas of improvement needed in the model. The detection model must be validated as must the degraded conditions for recognition. These depend entirely on the acquisition of new field results with statistically valid data under these conditions as well as sufficient documentation of the target and atmospheric parameters. In addition, a complex target model can be developed to handle the more intricate target cues, and a low-transmission atmospheric capability for fogs, smoke, and dust can be added.

In the area of improved recognition models, we must include vertical resolution and possibly sampling effects. This is presently in the conceptual stage only since it is not yet fully understood how a vertical MRT should be measured and no data exist with respect to vertical resolution. Coupled with a vertical-resolution capacity, a more scientific method must be developed to choose the critical target dimension instead of minimum dimension. Further, the probability of recognition as a function of resolvable cycles must be amended with the variation of this function with target aspect.

While these limitations are being addressed and solved to an acceptable degree, the AMC static model must be incorporated into a general search model in order that all Army target acquisition problems concerning thermal imaging can be analyzed.

APPENDIX A

NE ΔT, MRT, AND MDT DERIVATIONS

In this Appendix, derivations are given of the noise equivalent temperature (NE ΔT), the minimum resolvable temperature (MRT), and the minimum detectable temperature (MDT). Complete and simplified expressions are given for each quantity; the complete expressions provide a basis for rigorous analyses while the simplified expressions provide a means for obtaining reasonable estimates thru use of hand calculations.

Neither the concepts nor the final relationships contained herein are new. The NE ΔT derivation is similar to an analysis in Jamieson.[A1] The MRT and MDT derivations are slightly different from others of which the author is aware. The techniques employed to derive MRT and MDT are equally applicable to the derivation of subjective resolution relationships for intensifier and LLLTV viewers.

<u>Terminology</u>:

NE ΔT	– Noise equivalent temperature
MRT	– Minimum resolvable temperature
MDT	– Minimum detectable temperature
t	– time
$i_o(t)$	– an output signal
$i_i(t)$	– an input signal
*	– convolution
$h(t)$	– temporal response function
f	– frequency
$I_o(f)$	– fourier transform of $i_o(t)$
[illegible]	– fourier transform of $i_i(t)$
$H(f)$	– transfer function (fourier transform of $h(t)$)
OTF	– optical transfer function

[A1] J. A. Jamieson, *et al.*, *Infrared Physics and Engineering*, McGraw-Hill, New York, 1963.

MTF – modulation transfer function

$R(\tau)$ – auto-correlation function

$S(f)$ – power spectrum

$\langle \ \rangle$ – ensemble average

τ – time difference

σ – RMS value of a random process

r – detector response function

$v_s(t)$ – a (voltage) signal

$\phi(\lambda)$ – watts/micron on the detector

$D^*_{f_o}(\lambda)$ – detector detectivity

$D^{**}_{f_o}(\lambda)$ – detector detectivity (no cold shielding)

l – focal length

$\eta_o(\lambda)$ – optical transmission

T – temperature

L – radiance from source (target)

HFOV – horizontal field of view

VFOV – vertical field of view

t_E – eye integration time

η_{OVSC} – overscan ratio

F_R – frame rate

n_s – number of detectors in series

n_p – number of detectors in parallel

η_{CS} – cold shield efficiency

τ_D – picture element delay time

η_{SC} – scan efficiency

θ – cold shield angle

W – an integral (equation 24)

$i(x,y)$ – spatial signal

A – area (signal)

k – a constant

M – watts/area from display

Δy_i – distance between scan lines

v	– scan velocity
f_o	– frequency of MRT bar pattern
L	– bar length in MRT bar pattern
b	– noise function along a line of the display
f_x	– spatial frequency (x or horizontal direction)
f_y	– spatial frequency (y or vertical direction)
$\mathcal{S}$	– a threshold signal-to-noise ratio
q_y	– an integral (defined below equation (A45))
ρ_x	– an integral (defined below equation (A45))
ρ_y	– an integral (defined below equation (A45))
q_A	– an integral (defined below equation (A51))
ρ_{XA}	– an integral (defined below equation (A51))
ρ_{YA}	– an integral (defined below equation (A51))

Preliminaries:

Throughout this section, elementary concepts and analysis techniques employed in electrical communication theory are used. The necessary relationships are presented below; the reader unfamiliar with these relationships could profitably read the first three or four chapters of Wozencraft and Jacobs.[A2] (It is possible to derive NE ΔT, MRT, etc. without employing these concepts; however, as with any process, employment of inproper tools to perform a task leads to clumsiness and inefficiency.)

An output signal from a linear system (circuit, optical device) is equal to the input signal convolved with the response function of that system, i.e.,

$$i_o(t) = i_i(t) * h(t) = \int_{-\infty}^{\infty} i_i(t')h(t-t')dt' \qquad \text{(A1)}$$

where $i_o(t)$, $i_i(t)$, and $h(t)$ equal the output signal, the input signal, and the system response function, respectively. The response function $h(t)$ is simply the system output for an input pulse approximating a Dirac delta function. If both sides of equation (A1) are fourier transformed, the expression

$$I_o(f) = I_i(f)H(f) \qquad \text{(A2)}$$

is obtained. Here $I_o(f)$, $I_i(f)$, and $H(f)$ are the fourier transforms of $i_o(t)$, $i_i(t)$, and $h(t)$,

[A2] J. W. Wozencraft and I. M. Jacobs, *Principles of Communication Engineering*, Wiley, New York, 1965.

respectively. The quantity H(f) is referred to as the transfer function of the system. The one-dimensional (spatial) version of H(f) (i.e., the fourier transform of the line spread function) for an optical system corresponds to the system's optical transfer function (OTF) whose absolute value equals the modulation transfer function (MTF) of the systems. In equation (A2), the quantity H(f) is said to "filter" the signal $I_i(f)$. Note that if a signal is passed thru two systems in series the output from the first system equals the input to the second; therefore, if $i_i(t)$ is the input signal and $h_1(t)$ and $h_2(t)$ are the response functions of the two systems, the output is given by

$$i_o(t) = i_i(t) * h_1(t) * h_2(t). \tag{A3}$$

Correspondingly, the transform of $i_o(t)$ is given by

$$I_o(f) = I_i(f)H_1(f)H_2(f). \tag{A4}$$

Thus, the "two-system" response and transfer functions equal $h_1(t) * h_2(t)$ and $H_1(f)H_2(f)$, respectively; e.g., the OTF of a complex optical system equals the product of the component OTF's (ignoring component interactions).

A wide-sense stationary random process (e.g., noise in most electro-optical viewers) can be characterized (in general, not fully) by its auto-correlation function

$$R(\tau) = R(t, t+\tau) = \langle n(t)n(t+\tau)\rangle \tag{A5}$$

where n(t) designates the random process and τ represents a time difference. The fourier transform of this function, called the power spectrum of the process, is given by

$$S(f) = \int_{-\infty}^{\infty} R(\tau)\, e^{-2\pi i f\tau}\, d\tau. \tag{A6}$$

The brackets in equation (A5) indicate an average over an ensemble of n(t) functions. The output power spectrum of noise processes passed thru (filtered by) a linear system is given by

$$S_o(f) = S_i(f)H^2(f) \tag{A7}$$

where S_o and S_i are the output and input power spectra, respectively. An extremely important relationship between the power spectrum and the variance (at a point) of the random process is

$$\sigma^2 = \int_{-\infty}^{\infty} S(f)df. \tag{A8}$$

Since engineers are reluctant to employ negative frequencies and since S(f) is an even function of frequency, it is common practice to redefine the power spectrum such that

$$\sigma^2 = \int_0^\infty S(f)df \tag{A9}$$

This latter power spectrum is just twice the one used in equation (A8); this power spectrum is used for the temporal voltage noise and the corresponding (horizontal) spatial noise since it is the one commonly employed by thermal viewer engineers. In the vertical direction, however, the power spectrum in equation (A8) is used.

A matched filter is a filter whose response function is a delayed (shifted), time-reversed (spatially reversed) version of the signal. Thus, if i(t) is the signal function, the response function of the matched filter is proportional to $i(t_1 - t)$. (In discussing time functions, casualty becomes a problem; however, the discussion here will not be complicated by this.) The matched filter is the filter which maximizes the signal-to-noise ratio (signal being the magnitude of the output from the matched filter and noise being the standard deviation of the noise fluctuations) at a time t_1 for the case that the noise is additive (independent of the signal) and white (the power spectrum equals a constant at all frequencies). Note that for the case of a symmetrical signal and for t_1 equal to zero the matched filter has precisely the same shape as the signal. (In general, the matched filter is the mirror image of the signal.) Also note that if

$$I(f) = \int_{-\infty}^{\infty} i(t)e^{-2\pi ift}\, dt \tag{A10}$$

then the frequency response of the matched filter is proportional to I*(f), i.e.,

$$H_m(f) \sim \int_{-\infty}^{\infty} i(-t)e^{-2\pi ift}\, dt = I^*(f). \tag{A11}$$

<u>NE ΔT Derivation:</u>

The noise equivalent temperature is defined as that input temperature difference for a "large" target (a large target being one whose size is large relative to the system response function) which is required to generate a signal (voltage amplitude) just prior to the display (or after the detector preamplifier) which is just equal to the RMS noise (voltage) at that point, assuming that the filtering action of the electronics prior to the measurement point corresponds to that of a "standard" filter. The ambiguities in this NE ΔT definition provide at least part of the reason NE ΔT is viewed with disfavor in some circles; the precise point of measurement and the "standard" filter are not necessarily identical from one measurement to the next. A second reason NE ΔT is viewed with disfavor is that it does not relate directly to the signal-to-noise ratios which are fundamental for perception of targets on the device display; it is not a display signal-to-noise ratio and it is a point signal-to-noise rather than one "averaged" over the target. Ne ertheless, NEΔT can be a useful indication of system sensitivity, and (although not necessary) it can be used to simplify the MRT and MDT relations; therefore, its derivation follows.

The detector plus its associated preamplifier is assumed to be a linear system with a response function $r(\lambda,t) * h_{ELECT}(t)$ where $r(\lambda,t)$ is the response function of the detector in volts/watt and h_{ELECT} is the amplifier (and other circuitry) response function. Therefore, if the signal onto the detector equals $\Delta\phi(\lambda)\, i(t)$ watts/micron, where $i(t)$ is a normalized time function, the response of (i.e., the signal from) the detector-amplifier system is given by

$$\begin{aligned} v_s(t) &= \int_0^\infty \Delta\phi(\lambda)\, i(t) * r(\lambda,t) * h_{ELECT}(t)\, d\lambda \\ &= \int_{-\infty}^\infty e^{2\pi i f t}\, I(f)\, H_{ELECT}(f) \int_0^\infty \Delta\phi\, r(\lambda,f)\, d\lambda\, df \end{aligned} \tag{A12}$$

where $I(f)$, $H_{ELECT}(f)$, and $r(\lambda,f)$ are the fourier transforms of $i(t)$, $h_{ELECT}(t)$, and $r(\lambda,t)$, respectively. Assume that $r(\lambda,f)$ (or $r(\lambda,t)$) is separable into a frequency and a wavelength dependent part; then

$$r(\lambda,f) = r(\lambda,f_o)\,\frac{r(\lambda,f)}{r(\lambda,f_o)} \tag{A13}$$

where $r(\lambda,f_o) \neq$ function of f since f_o equals a constant and $\frac{r(\lambda,f)}{r(\lambda,f_o)} \neq$ function of λ since $r(\lambda,f)$ is assumed to be separable (i.e., $r(\lambda,f) = g(\lambda)\, \ell(f)$).

Equation (A12) giving the signal v_s can now be simplified to

$$\begin{aligned} v_s &= \int_{-\infty}^\infty e^{2\pi i f t}\, I(f)\, H_{ELECT}(f)\, \frac{r(\lambda,f)}{r(\lambda,f_o)}\, df \int_0^\infty \Delta\phi(\lambda)\, r(\lambda,f_o)\, d\lambda \\ &= i'(t) \int_0^\infty \Delta\phi\, r(\lambda,f_o)\, d\lambda \end{aligned} \tag{A14}$$

where $i'(t)$ is defined in an obvious manner.

The RMS noise voltage corresponding to $v_s(t)$ must now be determined. Let S(f) equal the power spectrum of the noise from the detector. Then the power spectrum beyond the preamplifier (i.e., system with transfer function $H_{ELECT}(f)$) equals $S(f) H^2_{ELECT}(f)$ and therefore the desired RMS noise is given by

$$\sigma^2 = \int_0^\infty S(f)H^2_{ELECT}(f)df. \qquad (A15).$$

Combining equations (A14) and (A15), the signal-to-noise beyond the preamplifier is given by

$$S/N = \frac{v(t)}{\sigma} = \frac{i'(t) \int_0^\infty \Delta\phi\, r(\lambda, f_o)\, dx}{\left(\int_0^\infty S(f)\, H^2_{ELECT}(f)df\right)^{1/2}} \qquad (A16)$$

Equation (A16) yields the NE ΔT once the various variables are recast into more useful forms, the S/N is set equal to 1 (note that the NE ΔT definition can be recast to "that temperature difference such that S/N = 1"), and i′(t) is set equal to 1. The quantity i′(t) can be set equal to 1 because the signal is measured (determined) at approximately the midpoint of an extended (large) signal; if i(t) = 1 at its midpoint then i′(t) will also equal one since the signal is of much greater duration than the response function of the detector-amplifier system as assumed.

To recast the variables, first note that the detector detectivity D^*_λ is given by

$$D^*_\lambda(f_o) = \frac{A_d^{1/2}\, r(\lambda, f_o)}{(S(f_o))^{1/2}} \qquad (A17)$$

where A_d equals the area of the detector.[A3] (Those familiar with the expression

$$D^* = \frac{(A_d\, \Delta f_n)^{1/2}}{NEP},$$

where Δf_n is the bandwidth and NEP is noise-equivalent power, should note the following heuristic derivation:

$$\text{Detector signal-to-noise ratio } (S/N)_D = \frac{\Delta\phi\, r}{\left(\int_0^\infty S(f)df\right)^{1/2}}$$

$$\text{For a small bandwidth around } f_o,\ (S/N)_D = \frac{\Delta\phi\, r(f_o)}{(S(f_o)\,\Delta f_o)^{1/2}}$$

$$\text{Now, NEP} = \Delta\phi \text{ for } (S/N)_D = 1\text{; therefore, NEP} = \frac{(S(f_o)\,\Delta f_n)^{1/2}}{r(f_o)}$$

[A3] J. A. Jamieson, *et al.*, *Infrared Physics and Engineering*, McGraw-Hill, New York, 1963.

and, therefore, $D^* = \dfrac{A_d^{1/2}\; r(f_o)}{(S(f_o))^{1/2}}$ Q.E.D.

Solving equation (A17) for r and inserting into equation (A16), the signal-to-noise ratio is given by

$$S/N = \frac{\int_o^\infty \Delta\phi_\lambda \; D_\lambda^* (\lambda) d\lambda}{\left(A_d \int_o^\infty \frac{S(f)}{S(f_o)} \; H^2_{ELECT} \, df \right)^{1/2}} \tag{A18}$$

where $i'(t)$ has been set equal to 1. Next, note that for a simple imaging system

$$\Delta\phi_\lambda = \frac{\pi A_d}{4 F^2} \; \eta_o (\lambda) \frac{\partial L_\lambda}{\partial T} \Delta T \tag{A19}$$

where $\eta_o(\lambda)$ = the optical efficiency of the viewer

F = the f/number

T = temperature

L_λ = watts/cm²/steradian/micron from the source.

Finally, using equation (A19) for $\Delta\phi_\lambda$ and defining Δf_n by

$$\Delta f_n = \int_o^\infty \frac{S(f)}{S(f_o)} \; H^2_{ELECT} \; df, \tag{A20}$$

equation (A18) becomes

$$S/N = \frac{\pi A_d^{1/2} \Delta T \int_o^\infty \eta_o(\lambda) \frac{\partial L_\lambda}{\partial T} D^*_{fo} (\lambda) \, d\lambda}{4 F^2 \; (\Delta f_n)^{1/2}} . \tag{A21}$$

The ΔT in equation (A21) is the desired NE ΔT provided the S/N is set equal to 1 and provided the bandwidth equals the appropriate reference bandwidth.

The bandwidth to which NE ΔT is commonly referenced is given by

$$\Delta f_n = \pi/2 \; f_o =$$

$$\frac{\pi}{2} \left[\frac{(HFOV)\,(VFOV)\; F_R \; \eta_{OVSC}}{2\, n_p \; \Delta x \, \Delta y \quad \eta_{SC}} \right] \tag{A22}$$

where HFOV = device horizontal field of view (mr)

VFOV = device vertical field of view (mr)

F_R = frame rate

η_{OVSC} = overscan ratio for the device

n_p = number of detectors in parallel

Δx = horizontal detector size (mr)

Δy = vertical detector size (mr)

η_{SC} = scan efficiency (fraction of time spent in actually scanning the field).

The initial form for Δf_n in equation (A22) is obtained from equation (A20), first, by setting the power spectrum ratio equal to 1 (i.e., ignoring any low frequency 1/f component and high frequency roll off) and, second, by equating H^2_{ELECT} to $1/(1 + (f/f_o)^2)$ corresponding to an exponential response function for the electronic circuitry. The expression for f_o is simply derived by setting f_o equal to ½ τ_D where τ_D is the delay time for a picture element of size $\Delta x \, \Delta y$ (essentially the time the detector element spends on each picture element). The ½ τ_D corresponds to

$$\int_0^\infty \left(\frac{\text{SIN}\,(\pi f \tau_D)}{\pi f \tau_D} \right)^2 df$$

which is the bandwidth associated with a rect function of duration τ_D.

The use of the "standard" bandwidth given in equation (A22) in place of the bandwidth given in equation (A20) yields the NE ΔT values commonly used. Recognize, however, that the bandwidth given by equation (A20) is the true system noise bandwidth and, therefore, a measurement of the S/N will yield the value given by equation (A21) using this bandwidth (assuming H_{ELECT} includes any filtering by the measuring device); the S/N calculated using the "standard" bandwidth of equation (A22) would be measured only if H_{ELECT} in equation (A20) were so adjusted (e.g., by the measuring device) so as to make the true bandwidth of equation (A20) equal to the "standard" bandwidth of equation (A22).

The S/N (and the NE ΔT) obtained from equation (A21) is that for a single detector; this S/N is appropriate for parallel scanning thermal viewers; however, for discoid systems, the S/N obtained by summing the signals and noises from the number of detectors in series is more useful. In this latter case, a reasonable approximation to the S/N is the S/N given in equation (A21) divided by $(n_s)^{½}$ where n_s equals the number of detectors in series (assuming uniform D^*_λ's). In general, blind application of equation (A21) (as well as the MRT and MDT equations) to unconventional systems can lead to difficulties and incorrect conclusions; this problem is usually easily circumvented by simple adjustments to the equation which can be made by anyone having a decent understanding of the material presented herein. (More often than not, one only needs to recognize the fact that the noise variances add directly.)

Prior to summarizing the results, several additional expressions and definitions are useful. First, D^*_λ is given by

$$D^*_\lambda = \frac{D_\lambda^{**}}{\sin\theta/2} = \eta_q^{1/2}\ \eta_{CS}\ D^{**}_\lambda\ (2F) \tag{A23}$$

where D^{**}_λ is D^*_λ for no cold shielding and 100% quantum efficiency

η_q = quantum efficiency

η_{CS} = the cold shield efficiency

θ = the cold shield angle.

Second, the quantity W is defined by

$$W = \int_0^\infty \frac{\eta_o(\lambda)}{\eta_o(\lambda_p)}\ \frac{D^*_{fo}(\lambda)}{D^*_{fo}(\lambda_p)}\ \frac{\partial L_\lambda}{\partial T}\ d\lambda \tag{A24}$$

where λ_p = the wavelength for maximum $D^*_{fo}(\lambda)$. For hand calculations, Hudson notes that $\int_{3.2}^{4.8} \frac{\partial L_\lambda}{\partial T}\, d\lambda$ equals 5.2×10^{-6} while $\int_{8}^{13} \frac{\partial L_\lambda}{\partial T}\, d\lambda$ equals 7.4×10^{-5};[A4] these quantities are obviously useful approximations to W.

To summarize, then, the NEΔT using equation (A24) is given by

$$NE\Delta T = \frac{4F^2\ (\Delta f_n)^{1/2}}{\pi A_d^{1/2}\ \eta_o(\lambda_p)\, D^*_{fo}(\lambda_p)\ W} \tag{A25}$$

where equations (A22), (A23), and (A24) provide useful expressions for Δf_n, $D^*_{fo}(\lambda)$, and W. Also, note that A_d can be expressed in terms of focal length and nominal system resolution in milliradians, i.e.,

$$A_d^{1/2} = \text{(focal length) (resolution in mr)/(1000)}. \tag{A26}$$

[A4] R. D. Hudson, Jr., *Infrared System Engineering*, Wiley, New York, 1969.

(If we included atmospheric tran· nission over the short path length in the NE ΔT laboratory experiment, then (A24) becomes

$$W = \int_0^\infty \frac{\eta_o(\lambda)}{\eta_o(\lambda_p)} \frac{\eta_a(\lambda)}{\eta_a(\lambda_p)} \frac{D^*_{fo}(\lambda)}{D^*_{fo}(\lambda_p)} \frac{\partial L_\lambda}{\partial T} d\lambda$$

and (A25) becomes

$$NE\Delta T = \frac{4F^2 \sqrt{\Delta f_n}}{\pi A_d^{1/2} \eta_o(\lambda_p) \eta_a(\lambda_p) D^*_{fo}(\lambda_p) W}.)$$

MRT and MDT Derivations:

Basic Concepts: The minimum resolvable temperature (MRT) of a system is defined as the temperature difference relative to a background which the bars of a bar pattern must possess in order for a human observer to detect the individual bars when viewing the pattern thru the system. The minimum detectable temperature (MDT) is the temperature difference a square object must possess in order to be detectable. Obviously, the MRT is a function of the bar pattern spatial frequency while the MDT is a function of the object size.

Historically, the MRT bar pattern has been a 4-bar pattern whose bars had lengths equal to 7 times their width; also, the pattern has been oriented such that the bars are perpendicular to the detector scan direction. The derivation presented here assumes that both the pattern and the orientation correspond to these historical precedents. The derivation also assumes that there is no sampling in the direction (horizontal) along which the detectors are scanned. This latter assumption is not valid for all systems; specifically, the signals from the detectors of a parallel scanning system are sometimes multiplexed in a manner which provides a sampling effect in the scan direction. This sampling can introduce noise fold-over and signal aliasing effects; however, if the system is well designed these effects will not be severe and the equations derived herein can be applied to these systems.

The basic hypothesis underlying the theory of MRT and MDT is that visual thresholds correspond to a critical value of "matched filter" signal-to-noise ratios; i.e., the ratio formed from the maximum amplitude of the target and the RMS value of the noise obtained by passing the signal (target) and noise which are actually observed by an individual thru a filter matched to the observed signal. (Note that the signal and noise are not actually physically filtered by a matched filter; it is just hypothesized that the relevant signal-to-noise ratio for perceptual purposes is the signal-to-noise ratio obtained assuming that the signal and noise are filtered by the matched filter.) Thus, if the viewed object is characterized by the spatial function i(x,y), the signal will be proportional to $i(x,y) * i(-x,-y)$ for x and y equal to zero which equals

$$\int_{-\infty}^{\infty} I^2 (f_x, f_y) d^2 f$$

where $I(f_x, f_y)$ is the transform of i(x,y). Correspondingly, the noise will be proportional to

$$\left(\int S(f_x, f_y) I^2 (f_x, f_y) d^2 f \right)^{1/2}$$

where $S(f_x, f_y)$ is the power spectrum of the observed noise. (Throughout this section, the quantity $i_o(x,y)$ representing the undegraded target will be normalized such that its maximum value is 1 while the (matched) filter corresponding to this quantity, $H_{i_o}(f_x f_y)$, will be normalized such that $H_{i_o}(0,0) = 1$. Thus, for a uniform target,

$$I_o(f_x f_y) = A_T H_{i_o} (f_x f_y)$$

where A_T equals the area of the target.)

Although the determination of MDT is straightforward using the above hypothesis, an extension is required to determine MRT, i.e., the perception threshold for a periodic pattern. Specifically, the nature of the matched filter (and the signal) must be established for the (potentially) infinite periodic pattern. The assumption is made that the filter in the periodic direction is a rect function whose width is equal to the width of the bar while in the other direction the filter is simply the device degraded rect function corresponding to the length of the bar. (Note that a degraded periodic pattern retains its periodicity with unchanged spatial frequency.) Furthermore, the "signal" is assumed to be the difference between the "signal energy" coming thru the filter centered over the bar and a filter centered over the neighboring trough. (Note that in some sense this corresponds to taking the signal for an aperiodic pattern as the difference between the "signal energy" passed thru the matched filter centered over the target and the "energy" passed thru a filter centered over the background.) With these assumptions, calculation of the MRT becomes very straightforward.

In the above, the implication is made that the object and noise observed are the object and noise existing on the device display. More fundamentally, they are the object and noise projected on the retina of the eye or, still better, the object and noise interpreted by the observer, i.e., after degradation by the retina and nervous system. Given a transfer function for the eye, an effective power spectrum for the internal noise in the eye, and a knowledge of the actual extent of eye signal (and noise) summation, it is possible to extend the calculations to the retina and beyond. This extension will not be pursued here; rather, the assumption will be made that the eye transfer function and noise do not significantly alter the signal-to-noise ratio calculated using the displayed quantities. (In actual calculations, however, an eyeball term is included.)

A few comments concerning the (matched) filter formulation are possibly useful. The matched filter can be thought of as a window over which the signal and noise "energies" are summed to formulate a signal-to-noise ratio. This summation is similar to that performed by Rose in formulating S/N ratios which correlate with Blackwell's visual thresholds;[A5] in Rose's case, MTF type degradations were not considered and, consequently, the matched filter was just the target itself. Thus, a matched filter signal and noise are just slightly sophisticated versions of a signal and noise summed over the target; the matched filter procedure merely provides a consistent technique for handling degraded (blurred) targets. An equivalent (but, to this author's thinking, more cumbersome) formulation uses the total signal energy as the signal (i.e., sums all the signal energy) and then sums the noise over a equivalent target area which is larger than the original target as a result of MTF degradations.

The Derivations: The MRT and MDT equations can now be formulated rather easily, the only complication being that introduced by sampling.

In order to perform a reasonably rigorous derivation, a consistent set of units must be used. Let k be defined such that $k\,\Delta T$ equals the watts emitted by a display element (spot, etc.) for a large target with a temperature difference ΔT. Then, the signal energy per unit area from the display for a single frame will be equal to

$$M(x,y) = \frac{k\,\Delta T\, i(x,y)}{\Delta y_i\, v} \tag{A27}$$

where Δy_i = the distance between scan lines = $\Delta y/\eta_{OVSC}$

v = the scan velocity of the display element

$i(x,y)$ = the spatial distribution function of the degraded target.

The quantity $i(x,y)$ will equal (ignoring sampling effects, a procedure completely legitimate only if Δy_i is very small) the convolution of the original target with the system response function, i.e.,

$$i(x,y) = i_T(x,y) * h_D(x,y) \tag{A28}$$

[A5] Albert Rose, "The Sensitivity Performance of the Human Eye on an Absolute Scale," J. Opt. Soc. Am. 35, 196 (1948).

or, taking transforms,

$$I(f_x f_y) = I_T(f_x, f_y)\, H_D(f_x, f_y),$$

where i_T is the target distribution and h_D is the system response function. (Note that for constant i(x,y) the formulation above will yield a uniform display brightness; thus, this formulation uses an average display radiance across scan lines.)

The aperiodic matched filter signal, using equation (A27), is given by

$$\text{Signal} = \text{MAX}\left[\frac{k\,\Delta T}{\Delta y_i v}\, i(x,y) * h_m\right] \tag{A29}$$

$$= \frac{k\,\Delta T}{\Delta y_i v} \int_{-\infty}^{\infty} I(f_x, f_y)\, H_m\, d^2 f,$$

where h_m and H_m are, respectively, the real space and the frequency space representations of the matched filter. (Note that "MAX" refers to the maximum value of convolution over x and y.) As indicated previously, H_m is simply the normalized version of $I(f_x, f_y)$ (the degraded target); therefore, the signal for the aperiodic target is

$$(\text{SIGNAL})_a = \frac{k\,\Delta T}{\Delta y_i v}\, A_T \int_{-\infty}^{\infty} H_T^2 (f_x, f_y)\, H_D^{\,2}\, d^2 f, \tag{A30}$$

where A_T is the area and H_T is the transfer function corresponding to the undegraded target.

The periodic matched filter signal, using equation (A27) is given by

$$\text{SIGNAL} = \text{MAX}\left[\frac{k\,\Delta T}{\Delta y_i v}\, i(x,y) * h_m\right] \tag{A31}$$

$$- \text{MIN}\left[\frac{k\Delta T}{\Delta y_i v}\, i(x,y) * h_m\right],$$

where i(x,y) is the degraded bar pattern and h_m is the undegraded rect function horizontally and the degraded rect function vertically. The quantity i (x,y) is approximated (horizontally) by the first harmonic of the square wave; therefore, since the amplitude of this harmonic is $4/\pi$ times the amplitude of the square wave,

$$i(x,y) = \left[\left(\begin{matrix} \text{square wave with} \\ \text{amplitude .5} \end{matrix} \right) + .5 \right] * h_D(x,y)$$

$$\cong MTF(f_o)\frac{4}{\pi}(.5)\sin(2\pi f_o x)\, i_y(y) + .5 \,, \quad \text{(A32)}$$

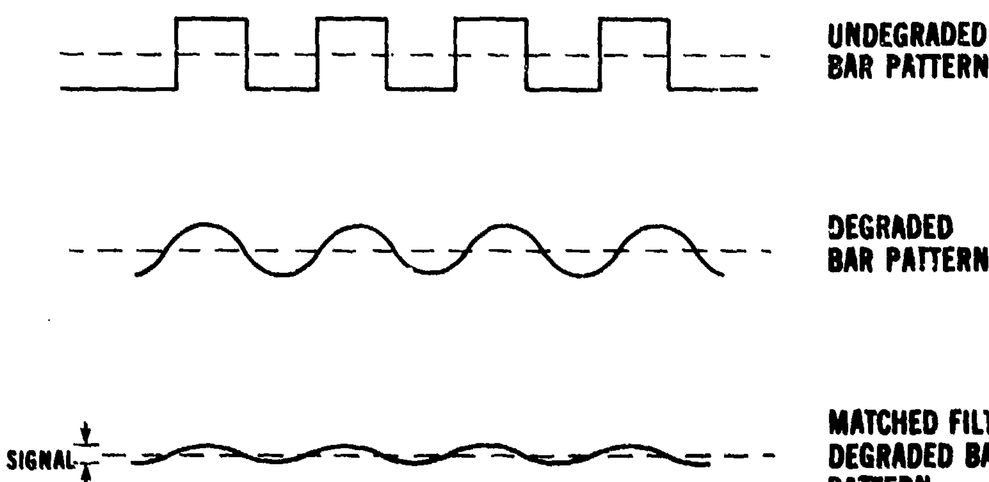
where f_o is the frequency of the bar pattern and i_y (y) is the degraded vertical rect function corresponding to the length of the bar. (The fact that i(x,y) will be negative where MTF (f_o) equals approximately unity is an unimportant consequence of using the first harmonic approximation.) Substitution of i(x,y) from equation (A32) into equation (A31) yields (evaluating the horizontal integrals in real space and the vertical integrals in frequency space):

$$(SIGNAL)_p = \frac{k}{\Delta y_i v} MTF(f_o)\frac{4}{\pi}\Delta T \int_0^{\frac{1}{2}f_o} \sin(2\pi f_o x)(2f_o)\, dx$$

$$\times \int_{-\infty}^{\infty} I_y H_y \, df_y \,. \quad \text{(A33)}$$

In equation (A33), the factor $2f_o$ in the first integral comes about because the horizontal filter (rect function) of width ½f_o has an amplitude of $2f_o$ under the normalization convention that $H(f_x) = 1$ for $f_x = 0$. Since the first integral in equation (A33) equals $2/\pi$ and since I_y equals $L\, H_L\, H_D$, where H_D is the transfer function of the device in the y direction and L is the length of the bars, equation (A33) can be simplified to

$$(SIGNAL)_p = \frac{k}{\Delta y_i v} MTF(f_o)\frac{8}{\pi^2}\Delta T L \int_{-\infty}^{\infty} H_L^2 H_D^2 \, df_y \,. \quad \text{(A34)}$$



HORIZONTAL FILTERING

The noise expressions for MRT and MDT must now be determined; this requires establishing the power spectrum of the noise displayed to the observer. The function describing the noise on the display is given by

$$n(x,y) = \sum_i b_i(x)\,\delta(y-y_i) * h_d(y) = \sum_i b_i(x)\,h_d(y-y_i) \qquad \text{(A35)}$$

where $h_d(y)$ is the impulse response of the display in the y direction and $b_i(x)$ is the function describing the horizontal noise function along the ith scan line. The form of equation (A34) arises as an obvious result of the sampled nature of the thermal image which consists of independent scan lines; the convolution is merely a manifestation of the fact that each line is "spread out" by the display element. The autocorrelation of the noise is given by

$$\begin{aligned} &\langle n(x,y)\,n(x',y')\rangle \\ &= \Big\langle \sum_i \sum_j b_i(x)\,b_j(x')\,h_d(y-y_i)\,h_d(y'-y_j) \Big\rangle \\ &= \sum_i \sum_j \langle b_i(x)\,b_j(x')\rangle\, h_d(y-y_i)\,h_d(y'-y_j). \end{aligned} \qquad \text{(A36)}$$

Assuming that $\langle b_i(x)\rangle$ equals zero, note that $\langle b_i(x)\,b_j(x')\rangle$ will equal zero unless $i = j$ since b_i and b_j are, otherwise, independent random processes. Thus

$$R(xx'yy') \triangleq \langle n(x,y)\,n(x',y')\rangle = \sum_i \langle b_i(x)\,b_i(x')\rangle\, h_d(y-y_i)\,h_d(y'-y_i). \qquad \text{(A37)}$$

Now $\langle b_i(x)\,b_i(x')\rangle$ is independent of i since all lines are (supposedly) the same and, therefore,

$$R(xx'yy') = \langle b(x)\,b(x')\rangle \sum_i h_d(y-y_i)\,h_d(y'-y_i). \qquad \text{(A37)}$$

Approximating the summation by an integral, we have

$$\begin{aligned} R(xx'yy') &\simeq \langle b(x)\,b(x')\rangle \frac{1}{\Delta y_i} \int_{-\infty}^{\infty} h_d(y-y_i)\,h_d(y'-y_i)\,dy_i \\ &= \frac{\langle b(x)\,b(x')\rangle}{\Delta y_i} \int_{-\infty}^{\infty} h_d(p)\,h_d(Y+p)\,d_p \triangleq R(XY) \end{aligned} \qquad \text{(A39)}$$

where $Y = y - y'$ and $X = x - x'$. ($\langle b(x)\, b(x')\rangle$ is assumed to be a function only of $x - x'$ which is true if the random process is wide-sense stationary.)

The power spectrum of the noise is just the fourier transform of R(X,Y), i.e.,

$$S(f_x, f_y) = \int_{-\infty}^{\infty} \langle b(x)\, b(x')\rangle\, e^{-2\pi i f X}\, dX\, \frac{1}{\Delta y_i}\, H_d(f_y)\, H_d^*(f_y). \qquad \text{(A40)}$$

Now b(x) corresponds to the "voltage" noise function which is transformed from a "voltage" to a one-dimensional radiant energy function by the display elements; therefore, the fourier transform of $\langle b(x)\, b(x')\rangle$ equals the "voltage" noise power spectrum provided the units are properly transformed from "voltage" and "voltage" space to radiant energy and display space. (This conversion, itemized below, is based upon the implicit assumption that voltage is linearly related to radiant energy.) As discussed prior to equation (A15), the "voltage" noise power spectrum equals

$$S(f)\, H^2_{ELECT}(f)$$

or

$$(\text{constant})\, \frac{S(f)}{S(f_o)}\, H^2_{ELECT}(f).$$

In the second expression above, the constant obviously equals $S(f_o)$ if the units of this expression are the same as those of the first expression (e.g., (volts) (second)); since the signal is given in terms of temperature units, the noise must also be and, therefore, the value of the constant is desired which references the power spectrum to temperature units, i.e., (temperature difference) (second). To establish the value of this constant, note that the NE ΔT equals the temperature difference such that the S/N ratio (voltage S/N ratio prior to the display) equals 1; therefore, if the signal, referenced to temperature units, is simply ΔT, then NE ΔT equals the ΔT such that $\Delta T/\sigma = 1$ where σ is the RMS noise in appropriate units. Thus, the NE ΔT equals σ, and since

$$\sigma^2 = \int_0^{\infty} (\text{constant})\, \frac{S(f)}{S(f_o)}\, H_{ELECT}\, df = (\text{constant})\, \Delta f_n$$

where equation (A20) has been used, the constant is given by

$$\text{constant} = \frac{NE\, \Delta T^2}{\Delta f_n}$$

(The quantity $NE\Delta T^2/\Delta f_n$ can be expressed in terms of detector sensitivity and device parameters using equation (A25). Note that although the above discussion uses the true $NE\Delta T$ and Δf_n, i.e., not the standardized ones, the last equation is valid regardless of which Δf_n is used provided the Δf_n in the denominator is the same as the Δf_n used to calculate the $NE\Delta T$.) Consequently, the voltage noise power spectrum referenced to temperature units equals

$$\frac{NE\Delta T^2}{\Delta f_n}\ \frac{S(f)}{S(f_o)}\ H^2_{ELECT}(f).$$

Now, converting from temperature to radiant energy thru use of the correspondence (see reasoning prior to equation (A27),

$$NE\Delta T \Leftrightarrow \frac{k\,NE\Delta T}{v}\ \text{(energy/cm)},$$

using the relation (valid since $f = v f_x$)

$$\frac{S(f)}{S(f_o)}\ H^2_{ELECT}(f) = v\ \frac{S(f_x)}{S(f_{ox})}\ H^2_{ELECT}(f_x)$$

where $S(f_x) = S(v f_x)$, etc., and, using the fact that the fourier transform of $\langle b(x)\,b(x')\rangle$ corresponds to the voltage power spectrum, the relation

$$\int_{-\infty}^{\infty} \langle b(x)\,b(x')\rangle\, e^{-2\pi i f X}\, dX = \frac{k^2\ NE\Delta T^2}{v^2}\ \frac{1}{\Delta f_n}\ v\ \frac{S(f_x)}{S(f_{ox})}\ H^2_{ELECT}(f_x) \qquad \text{(A41)}$$

is obtained (assuming that the display transfer function equals 1). A careful examination of equation (A40) shows that the units are $(\text{energy})^2/\text{cm}$ which are those desired of the one-dimensional "display" power spectrum. Combining equations (A41) and (A40) and including the display transfer function, $H_d(f_x)$, the desired (two-dimensional) noise power spectrum is given by

$$S(f_x f_y) = \frac{k^2\ NE\Delta T^2}{\Delta y_i v \Delta f_n}\ \frac{S(f_x)}{S(f_{ox})}\ H^2_{ELECT}\ H^2_d\ (f_x, f_y). \qquad \text{(A42)}$$

(The critical step in the derivation of $S(f_x, f_y)$ is equation (A39) where the sampling characteristic of the display is in a sense approximated away. Strictly speaking, the sampled noise process cannot be characterized by a power spectrum.)

Given the power spectrum $S(f_x, f_y)$, the (matched, filtered) noises required to establish MRT and MDT are easily determined. As previously indicated, the matched filter for the MRT calculation is

$$H_W (f_x) H_L (f_y) H_D (f_y)$$

where H_W, H_L, and H_D are the transfer functions corresponding to the width of the bar, the length of the bar, and the system impulse function in the y direction, respectively. Therefore, the MRT noise is given by

$$(\text{Noise})_p =$$

$$\left(\frac{k^2 \, NE\Delta T^2}{\Delta y_i \, \Delta f_n \, v} \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT} (f_x) H_d^2 (f_x f_y) H_W^2 (f_x) H_L^2 (f_y) H_D^2 (f_y) \, df_x df_y \right)^{1/2} \tag{A43}$$

The filter for the MDT is

$$H_T (f_x f_y) H_D (f_x f_y)$$

where H_T and H_D are the target and device transfer functions; therefore, the MDT noise is

$$(\text{Noise})a =$$

$$\left(\frac{k^2 \, NE\Delta T^2}{\Delta y_i \, \Delta f_n \, v} \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{S(f_x)}{S(f_{xo})} H^2_{ELECT} H_d^2 \, H_T^2 \, H_D^2 \, df_x df_y \right)^{1/2}. \tag{A44}$$

The ratio of the signal given in equation (A34) and the noise given in equation (A43) yields the fundamental signal-to-noise ratio for periodic patterns for a single frame. The MRT is simply the ΔT found by summing the signal and noise over the frames in an eye integration time and setting the signal-to-noise ratio equal to a threshold value $\mathcal{S}$. Thus, the MRT is given by (from equations (A34) and (A43)):

$$MRT = \frac{\Delta y_i \, v \frac{\pi^2}{8} \mathcal{S}}{MTF(f_o) \, L \int_{-\infty}^{\infty} H_L^2 H_D^2 \, df_y} \left[\frac{NE\Delta T^2}{\Delta y_i \, \Delta f_n \, v} \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT} H_d^2 H_W^2 H_L^2 H_D^2 \, df_x df_y \right.$$

$$\left. \times \frac{1}{F_R t_E} \right]^{1/2} = \frac{\pi^2}{8} \frac{\mathcal{S}}{MTF(f_o)} \frac{NE\Delta T}{L \int_{-\infty}^{\infty} H_L^2 H_D^2 \, df_y} \left[\frac{\Delta y_i v}{F_R t_E \, \Delta f_n} \int_{-\infty}^{\infty} \int_{0}^{\infty} \cdots d^2 f \right]^{1/2} \tag{A45}$$

where F_R is the frame rate of the system and t_E is the eye integration time. Similarly, the MDT is given by (using equations (A30) and A44)):

$$MDT = \frac{NE\,\Delta T\,S'}{A_T \int_{-\infty}^{\infty} H_T^2 H_D^2 \, d^2 f} \left(\frac{\Delta y_i \, v}{F_R \, t_E \, \Delta f_n} \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT} H_d^2 H_T^2 H_D^2 \, df_x \, df_y \right)^{1/2} \quad (A46)$$

The somewhat formidable equation (A45) can be expressed in a much more useful form thru use of the following definitions and relations:

$$q_y \triangleq L \int_{-\infty}^{\infty} H_L^2 \, H_D^2 \, df_y$$

$$\rho_x \triangleq 2W \int_{0}^{\infty} \frac{S}{S} \, H^2_{ELECT} \, H_d^2 (f_x) \, H_W^2 \, df_x$$

$$\rho_y \triangleq L \int_{-\infty}^{\infty} H_L^2 \, H_D^2 \, H_d^2 \, (f_y) \, df_y$$

$$L = \frac{7}{2f_o} \qquad \text{(assuming bar length equals 7 times its width)}$$

$$W = \frac{1}{2f_o} \, .$$

Employing these last relations, the MRT reduces to

$$MRT = \frac{\pi^2}{8} \; \frac{S}{MTF\,(f_o)} \; \frac{NE\,\Delta T}{q_y} \left(\frac{\Delta y_i \, v}{F_R \, t_E \, \Delta f_n} \; \frac{2}{7} \, f_o^2 \, \rho_x \, \rho_y \right)^{1/2} . \quad (A47)$$

This expression is further simplified by noting that q_y and ρ_y will equal approximately 1 for essentially all applications since the bar length will almost always be large compared to the system response function (for any reasonable f_o) in the y direction; therefore, the MRT is finally given by

$$MRT = \frac{\pi^2}{4(14)^{1/2}} \; \frac{S\,NE\,\Delta T\,f_o}{MTF(f_o)} \left(\frac{\Delta y_i \;\; v}{F_R \, t_E \, \Delta f_n \, \rho_x} \right)^{1/2} \quad (A48)$$

which is the recommended equation for calculating MRT. (This last approximate expression can be arrived at by a somewhat simpler argument which is perhaps useful. Calculate the one-dimensional matched filter signal and noise for a single scan line assuming that the bar length is greater than the height of a scan line. This calculation, as easily seen from the above analysis, yields a signal

$$(\text{Signal})_p = \frac{k\,\Delta T}{v}\ \text{MTF}(f_o)\ \frac{8}{\pi^2}\ \Delta T \quad \text{energy/cm}$$

and a noise

$$(\text{Noise})_p = \left(\frac{k^2\ NE\,\Delta T^2}{\Delta f_n\ v} \int_o^\infty \frac{S(f_y)}{S(f_{oy})}\ H^2_{ELECT}(f_x) H^2_d(f_x) H^2_W(f_x) df_x \right)^{1/2}$$

Since the "matched" filtering in the y direction corresponds to summing the signal and noise over the length of a bar, since signals add directly and noises add quadradically, and since the bar extends over $(L/\Delta y_i)$ independent lines, the desired MRT signal-to-noise ratio is given by

$$(S/N)_p = \frac{\frac{L}{\Delta y_i}\ \frac{k\,\Delta T}{v}\ \text{MTF}(f_o)\ \frac{8}{\pi^2}\ \Delta T}{\left(\frac{L}{\Delta y_i}\ \frac{k^2\ NE\,\Delta T^2}{\Delta f_n\ v} \int_o^\infty \text{---}\ df_x \right)^{1/2}}$$

which directly yields the MRT given in equation (A48).)

Unfortunately, each individual concerned with MRT has his own favorite form for the MRT equation derived by using different definitions and different approximations than those used above. For example, a quantity Q is used by some individuals where

$$Q = \rho_x\, f_o\ ;$$

others approximate the integrals such as

$$\int_{-\infty}^{\infty} H_L^2\ H_D^2\ df$$

by

$$\left(\frac{f_L^2\ f_D^2}{f_L^2 + f_D^2} \right)^{1/2}$$

where

$$f_L = \int_{-\infty}^{\infty} H_L^2\ df \qquad \text{and}$$

$$f_D = \int_{-\infty}^{\infty} H_D^2\ df \quad ;\ \text{etc.}$$

To the author's knowledge, however, all the expressions follow directly from equation (A45) using the appropriate definitions and approximations. (In one instance, an equation is used which is derived on the assumption that the "matched filter" for the bar pattern is a square whose side is equal to the width of the bar. Even in this case, the final equation reduces to equation (A48) except for a different constant.)

The use of equation (A48) requires establishing the values of $\mathcal{S}$ and t_E; again, unfortunately, universal values for these constants do not exist. The values recommended at this time are

$$\mathcal{S} = 2.25,$$
$$t_E = .2. \qquad \text{(A49)}$$

Several approximations and facts are useful for using equation (A48) to make quick calculations. First, from equation (A22) (and the material following (A22))

$$\frac{v}{\Delta f} = \frac{2}{\pi} \; 2\,v\,\tau_D \simeq \frac{4}{\pi}\,\Delta x$$

where Δx is the detector width. Also Δy_i is given by

$$\Delta y_i = \frac{\Delta y}{\eta_{OVSC}}$$

where Δy is the detector height and η_{OVSC} is the overscan ratio. Finally, ρ_x will equal approximately 1 for small f_o while for any f_o a respectable approximation, assuming $S(f_o)/S(f_{ox})$ equals 1, is

$$\rho_x = \frac{1}{(4f_o^2\,(\Delta x)^2 + 1)^{1/2}} \qquad \text{(A50)}$$

Therefore, a useful form of equation (A48) for hand calculations is

$$\text{MRT} = .66\,\mathcal{S}\,\frac{\text{NE}\,\Delta T\,f_o}{\text{MTF}(f_o)} \left(\frac{4}{\pi} \; \frac{\Delta x\,\Delta y}{\eta_{OVSC}\,F_R\,t_E} \right)^{1/2} \left(4f_o^2\,(\Delta x)^2 + 1 \right)^{-1/4} \qquad \text{(A51)}$$

where the last factor can be set equal to a 1 for many values of f_o.

The MDT given in equation (A46) can be simplified to

$$\text{MDT} = \frac{S'\text{NE}\,\Delta T}{q_A} \left(\frac{\Delta y_i \; v}{F_R \, t_E \, \Delta f_n} \; \frac{1}{2W^2} \, \rho_{xA} \, \rho_{yA} \right)^{1/2} \tag{A52}$$

thru use of the definitions

$$q_A = A_T \int_{-\infty}^{\infty} H_T^2 \, H_D^2 \, d^2 f$$

$$\rho_{xA} = 2W \int_{0}^{\infty} \frac{S(f_i)}{S(f_{ox})} \, H^2_{ELECT} \, H_d^2 \, H_W^2 \, H_D^2 \, df_x$$

$$\rho_{yA} = W \int_{-\infty}^{\infty} H_W^2 \, H_d^2 \, H_D^2 \, df_y$$

where H_W is the transfer function corresponding to the side of the test square. Approximations to q_A, ρ_{xA}, and ρ_{yA} can be formulated similar to those used to simplify the MRT; these will not be pursued here.

APPENDIX B

VERTICAL MRT

If sampling effects are assumed to be negligible, then a vertical MTF and MRT can be defined and an expression for them derived. A system's performance can then be a function of some combination of horizontal and vertical MRT. As an example, the MRT's in the two directions can be assumed to form an average MRT whose value is

$$MRT_v = [MRT^2(f_x) + MRT^2(f_y)]^{1/2}/\sqrt{2}.$$

Then, this MRT will directly give performance from an experimental relationship such as shown in Table 4 in the main section.

A vertical MRT (f_y) similar to the horizontal MRT (f_x) can be derived in the same manner utilized in Appendix A. The only difference is that the target bar pattern is now oriented with the long dimension parallel to the scan direction. Then returning to equation (A32) of Appendix A, we get

$$i(x,y) = MTF(f_{oy}) \frac{4}{\pi} (.5) \sin(2\pi f_{oy} y)\, i_x(x) + .5, \qquad (B1)$$

where $i_y(x)$ is the degraded rect function in the x direction. Equation (A33) becomes

$$(SIGNAL)_p = \frac{k}{\Delta y_i v} MTF(f_{oy}) \frac{4}{\pi} \Delta T \int_0^{\frac{1}{2} f_{oy}} \sin(2\pi f_{oy} y)(2f_{oy})\, dy \qquad (B2)$$

$$\times \int_{-\infty}^{\infty} I_x H_x\, df_x,$$

where now $I_x = L\, H_L(f_x)\, H_D(f_x)$. Hence, the signal for the case of horizontal bars is

$$(SIGNAL)_p = \frac{k}{\Delta y_i v} MTF(f_{oy}) \frac{8}{\pi^2} \Delta T\, L \int_{-\infty}^{\infty} H_L^2(f_x)\, H_D^2(f_x)\, df_x. \qquad (B3)$$

In deriving the noise power spectrum, we still get the result

$$S(f_x, f_y) = \frac{k^2 NE\Delta T^2}{\Delta y_i v \Delta f_n} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT}(f_x)\, H_d^2(f_x, f_y), \qquad (B4)$$

since the target plays no roll in the noise at this point. The matched filter for the horizontal case is

$$H_W(f_y)H_L(f_x)H_D(f_x).$$

Hence, the noise is

$$(\text{NOISE})_p = \left[\frac{k^2 NE\Delta T^2}{\Delta y_i v \Delta f_n} \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT} H^2_d(f_x, f_y) H^2_W(f_y) H^2_L(f_x) H^2_D(f_x) \times d^2 f \right]^{1/2}. \tag{B5}$$

Taking the ratio of equation (B3) to (B5), integrating over frames, and solving for MRT yields

$$\text{MRT}(f_y) = \frac{\Delta y_i v \frac{\pi^2}{8} \; S}{\text{MTF}(f_y)\, L \int_{-\infty}^{\infty} H^2_L H^2_D \, df_x} \left[\frac{NE\Delta T^2}{\Delta y_i \Delta f_n v} \cdot \left(\frac{1}{F_R t_E} \right) \times \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT}(f_x) H^2_d(f_x, f_y) H^2_W(f_y) H^2_L(f_x) \times H^2_D(f_x)\, df_x df_y \right]^{1/2}. \tag{B6}$$

Defining the quantities

$$g_x \equiv L \int_{-\infty}^{\infty} H^2_L H^2_D \, df_x$$

$$\rho_x \equiv L \int_{0}^{\infty} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT} H^2_d H^2_L H^2_D \, df_x$$

$$\rho_y \equiv 2W \int_{-\infty}^{\infty} H^2_W H^2_d \, df_y,$$

where $L = \frac{7}{2f_o}$ and $W = \frac{1}{2f_o}$, then equation (B6) becomes

$$\text{MRT}(f_y) = \frac{\pi^2}{8} \frac{S}{\text{MTF}(f_y)} \frac{NE\Delta T}{g_x} \left[\frac{\Delta y_i v}{F_R t_E \Delta f_n} \frac{2}{7} f_o^2 \rho_x \rho_y \right]^{1/2}. \tag{B7}$$

As in Appendix A, g_x approaches 1, however ρ_x will not asymptote as fast as before because of the additional electronic filtering H^2_{ELECT}. Putting this in a form which appears in the main section, we get

$$MRT(f_y) = \frac{\pi^2}{4\sqrt{14}} S \frac{NE\,\Delta T}{MTF(f_y)} \sqrt{\frac{\Delta y_i\, v\, f_y\, QQ}{F_R\, t_E\, \Delta f_n}} , \qquad \text{(B8)}$$

where

$$QQ = f_y\, \rho_x\, \rho_y$$

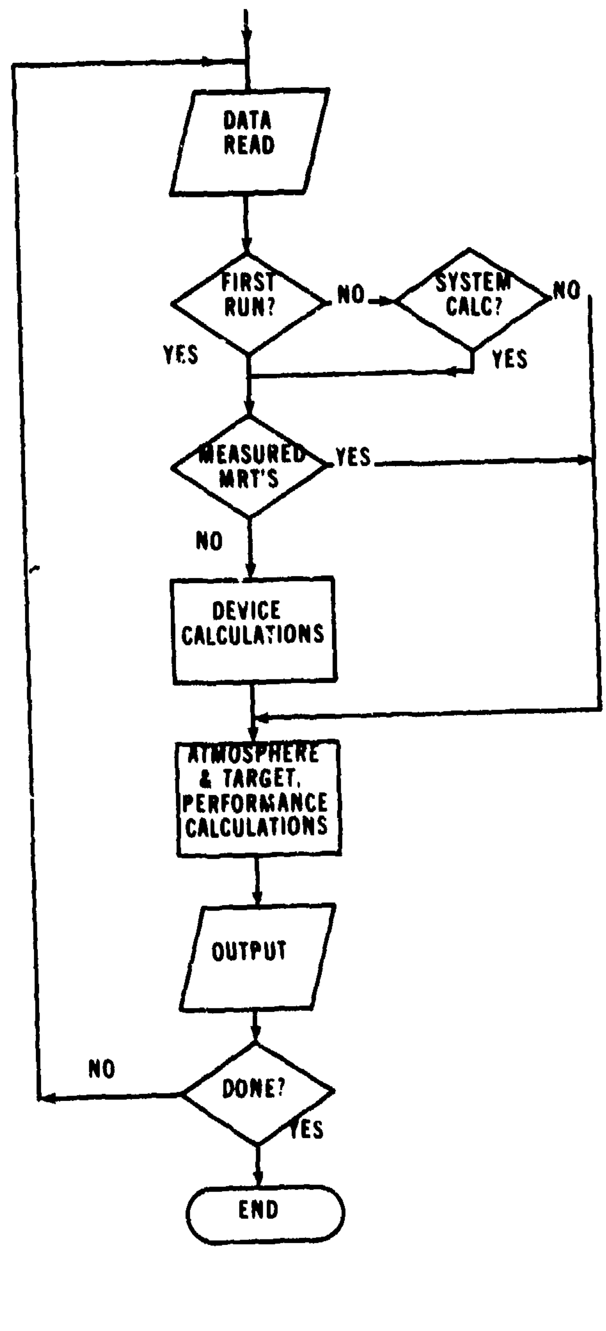
$$= \frac{7}{2f_y} \int_{-\infty}^{\infty} \int_{0}^{\infty} \frac{S(f_x)}{S(f_{ox})} H^2_{ELECT}(f_x)\, H^2_L(f_x)\, H^2_d(f_x)\, H^2_D(f_x)$$

$$\times\, df_x\, H^2_W(f_y)\, H^2_d(f_y)\, df_y \; .$$

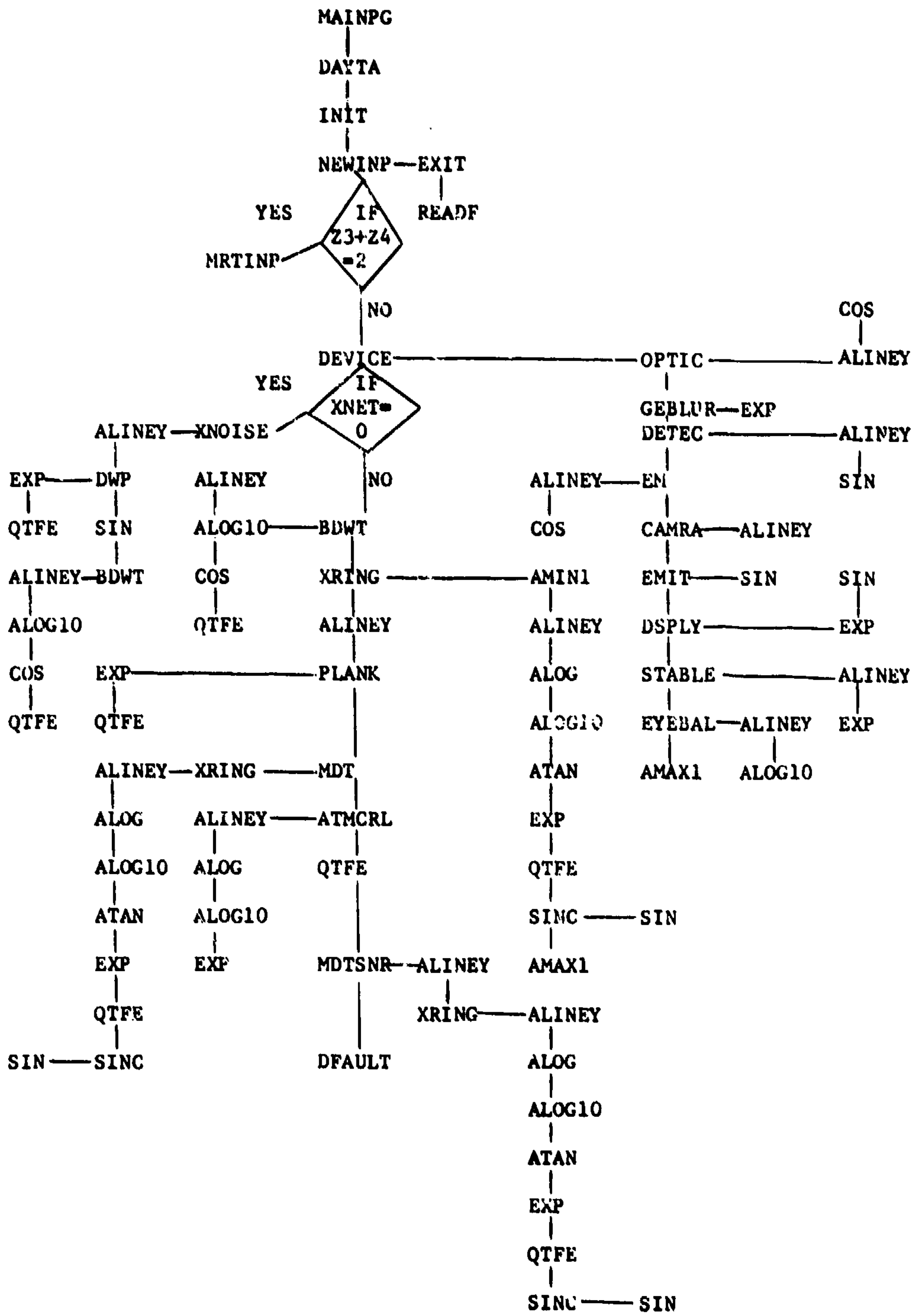
APPENDIX C

COMPUTER PROGRAM

PROGRAM FLOW CHART



SUBROUTINE FLOW CHART



```
      REAL IOTAU
      REAL IRTRAN
      DIMENSION AFCRL(161)
      DIMENSION FURD(20)
      DIMENSION DDT(50),XDR(50),XPR(50),XFRW(50)
      DIMENSION YDR(50),YPR(50),YFRW(50)
      DIMENSION XMTF(20),YMTF(20),FFFF(20)
      DIMENSION XXMRT(20),YYMRT(20),FFT(20)
      DIMENSION XXMTF(20),YYMTF(20)
       DIMENSION PRO(10),XNUM(10)
      DIMENSION QQQ(20),QQQQ(20)
      DIMENSION SOME(50),DRTX(50),DRTY(50)
      DIMENSION ELANX(20),ELANY(20)
      DIMENSION SIGMA(9),WAVE(9),IRTRAN(161)
      DIMENSION TRTRAN(161)
      DIMENSION OUTPUT(10),XINPUT(10)
      DIMENSION RAND(161)
      DIMENSION DDSTAR(10),XLMBA(10)
      DIMENSION RSPX(161)
      DIMENSION                      XMXM(20),YMYM(20)
      DIMENSION H(8)
      DIMENSION XNMB(10)
      DIMENSION               BETA(10)
      DIMENSION FQQ(10),FQ(10)
      DIMENSION XD(10),YD(10),XE(10),XB(10)
      DIMENSION XO(10),YO(10),XTV(10),YTV(10),XML(10),YML(10)
      DIMENSION XXXRT(20),YYYRT(20)
      DIMENSION WFOV(20),RT45(20),ELAN45(20)
      DIMENSION X45T3(50),X45P3(50),X45T4(50),X45P4(50)
      DIMENSION TSE(50),SSE(50)
      DIMENSION RINPUT(10)
      DIMENSION ROSD(10),DSN(10)
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,RMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,RSTAR,
     2XLAMB,FNUMB,FOC,XK,RMAXF,XY,XYL,FMAX,XSIGLS,YSIGLS,XA,YA,KKK,
     3IOTAU,VEL,RELECT
      COMMON /SPCATM/WAVE,SIGMA
      COMMON/NAME5/IKOUNT,XMAG,FSTAR,FELECT,FMAXF
      COMMON/NAME1/XDR,DDT,TSE,SSE,SOME,XFRW,DRTX,DETEM ,FFT,XXXRT
      COMMON/NAME3/JFLAG,JPRINT,DDTT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME8/XXMRT,Z3,Z4
      COMMON /BLUR/ABLUR
      COMMON/NAME6/DXDR(50),DDDT(50),DDRTX(50)
      CALL INIT(IAFLG)
      IKOUNT=0
 8400 CONTINUE
      IKOUNT=IKOUNT+1
      CALL        NEWINP(FQ,XO,YO,XD,YD,XB,XE,XTV,YTV,XML,FQQ,RUTOFF,
     1FO,DDSTAR,XLMBA,RH,AIRTMP,RVIS,TBAC, PRO,XNUM,BETA,YML,
     2WAVE1,WAVE2,ISTATE,SNR,IPRINT,XNMB,JOVER)
      SAVNET=XNET
       IF(Z3.EQ.1.0.AND.Z4.EQ.1.0) CALL MRTINP(RVIS,
     1RANGE,AIRTMP, RH,WAVE1,WAVE2,IPRINT,IJK,
     2ISTATE,AFCRL,PRO,XNUM,TBAC,XNMB,BETA,II,KK)
       IF(Z3.EQ.1.0.AND.Z4.EQ.1.0) GO TO 8025
       IF(IKOUNT.GT.1.AND.JFLAG.EQ.0) GO TO 8007
C
C
C     MRT CALCULATION
C
C
```

```
      XW=WAVE1-0.1
      NW=IFIX((WAVE2-WAVE1)/0.1)+1
      RMAG=2.0*XMAG
      XZ=SNR*3.14159/2.0/(14.0**0.5)*3.14159/2.0
      CUTOFF=0.999*RUTOFF
      IOTAU=HFOV*VFOV*(17.5**2)*FR/XN/DELTAX/DELTAY/XNSC*OVERSC
      VEL=DELTAX*IOTAU
      RSTAR=FSTAR/VEL
      RELECT=FELECT/VEL
      RMAXF=FMAXF/VEL
      DO 101 KLK=1,8
  101 H(KLK)=10.0**F(KLK)/VEL
      CALL DEVICE(XMTF,YMTF,XXMTF,YYMTF,FFFF,XMXM,YMYM,FURD,FQ,XO,YO,XD,
     8YD,XB,XE,XTV,YTV,XML,YML,FQQ)
      IF(XNET.EQ.0.0) CALL XNOISE(FQ,CUTOFF,DDSTAR,XLMBA,DPEAK,XB,FQQ)
      XXNET=XNET
      CALL BDWT(FQ,DELTAF,CUTOFF,XB,FQQ)
      XL=1./DELTAX/20.
      XCTFF=CUTOFF/VEL
      FT=0.0
      V=FR*EYETM
      DO 102 KK=1,20
      FT=FT+XL
      TARF=FT
      GRUNT=1./2./TARF
      RUNT=7.*GRUNT
      CALL XRING(XCTFF,XXMTF,FURD,20,H,8,GRUNT,1,ANS,2,1,0)
      CALL XRING(XCTFF,XXMTF,FURD,20,H,8,RUNT,1,ANR,2,1,0)
      CALL XRING(0.0,YYMTF,FURD,20,H,8,GRUNT,2,ANT,2,1,0)
      Q=ANS/2.0
      QQ=ANR*ANT/2.0*RUNT
      QQQ(KK)=Q
      QQQQ(KK)=QQ
      CALL ALINEY(XXXX,FT,XMTF,FFFF,20)
      CALL ALINEY(YYYY,FT,YMTF,FFFF,20)
      IF(XXXX.EQ.0.0) XMRT=1.0E+06
      IF(XXXX.EQ.0.0) GO TO 4666
      XMRT=XZ*XNET/XXXX*(DELTAY*VEL*FT*Q/DELTAF/FR/EYETM/OVERSC)**0.5
      IF(XMRT.LT.0.0)XMRT=KK*1.00E+06
      IF(V.LT.1.0) XMRT=XMRT*V**0.5
 4666 CONTINUE
      IF(YYYY.EQ.0.0) YMRT=1.0E+06
      IF(YYYY.EQ.0.0) GO TO 4667
      YMRT=XZ*XNET/YYYY*(DE  TAY*VEL*FT*QQ/DELTAF/FR/EYETM/OVE  C)**0.5
      IF(YMRT.LT.0.0)YMRT=KK*1.00E+06
      IF(V.LT.1.0) YMRT=YMRT*V**0.5
 4667 CONTINUE
       XXMRT(KK)=XMRT
      YYMRT(KK)=YMRT
       FFT(KK)=FT
  102 CONTINUE
      IF(JPRINT.EQ.0)GO TO 8008
      IF (IAFLG .EQ. 1)WRITE(6,7000)
 7000 FORMAT(34(/),5H '|',10X,17HTHMDL OUTPUT DATA,//)
      WRITE(6,711)
  711 FORMAT(1H1,14HFILTERED NOISE)
      WRITE(6,712)(FFT(I),QQQ(I),QQQQ(I),I=1,20)
  712 FORMAT(1H ,11X,4HFREQ,9X,1HQ,14X,2HQQ//(E14.3,E15.3,E15.3))
 8008 CONTINUE
       DO 600 KK=1,20
      XXXRT(KK)=XXMRT(KK)
      XXMRT(KK)=XXMRT(KK)*(3.5/FFT(KK)/7.0*FFT(20))**0.5
```

```
      YYYRT(KK)=YYMRT(KK)
      YYMRT(KK)=YYMRT(KK)*(3.5/FFT(KK)/7.0*FFT(20))**0.5
      RT45(KK)=(XXMRT(KK)**2+YYMRT(KK)**2)**0.5
  600 CONTINUE
      IF(JPRINT.EQ.0)GO TO 8009
      IF(IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,322)
  322 FORMAT(1H1,40HPREDICTED MINIMUM RESOLVABLE TEMPERATURE)
      WRITE(6,323)(FFT(I),XXXRT(I),YYYRT(I),XXMRT(I),YYMRT(I),RT45(I),I
     8=1,20)
  323 FORMAT(4X,4HFREQ,7X,5HX MRT,7X,5HY MRT,7X,5HXLMRT,7X,5HYLMRT
     1,7X,5H45MRT,//,(1X,6(1PE9.3,3X)))
 8009 CONTINUE
C
C
C     CONVERT DELTA T ON O/O TO DELTA POWER
C
C
C     CONVERT MRT TO POWER
C
C
      XLAM=XW
      DO 6013 IJ=1,LW
      XLAM=XLAM+0.1
      CALL ALINEY(ZZZZ,XLAM,DDSTAR,XLMBA,10)
      IF(ZZZZ.LT.0.0) ZZZZ=0.0
 6013 RSPX(IJ)=ZZZZ
      BURR=OUTPUT(1)
      DO 6003 I=1,10
      ORYX=XINPUT(I)
      IF(ORYX.EQ.0.0) BURR=OUTPUT(I)
 6003 CONTINUE
      DO 6005 KK=1,LW
 6005 RAND(KK)=1.0
      DO 6007 KK=1,10
      T3=27.0 + XINPUT(KK)
      XXP=0.0
      IF(XINPUT(KK).EQ.0.0) GO TO 6007
      CALL PLANK(T3,27.00,XXP,RAND,RSPX)
 6007 RINPUT(KK)=XXP
      FREE=27.0+XNET
      CALL PLANK(FREE,27.0,XPOX,RAND,RSPX)
      DO 800 LON=1,20
      T4=27.0+XXMRT(LON)
      T5=27.0+YYMRT(LON)
      XTOL=0.0
      IF(XXMRT(LON).EQ.0.0) GO TO 801
      CALL PLANK(T4,27.00,XTOL,RAND,RSPX)
  801 ELANX(LON)=XTOL
      YTOL=0.0
      IF(YYMRT(LON).EQ.0.0) GO TO 800
      CALL PLANK(T5,27.00,YTOL,RAND,RSPX)
  800 ELANY(LON)=YTOL
      DO 8888 JKJ=1,20
 8888 ELAN45(JKJ)=(ELANX(JKJ)**2+ELANY(JKJ)**2)**0.5
      CALL MDT(XMXM,YMYM,FFFF,XCTFF,H,SNR,DELTAF)
C
C     WFOV SCALED MRT
C
      DO 7119 J=1,20
 7119 WFOV(J)=FFT(J)/FACT
 8007 CONTINUE
```

```
      XRH=0.01*RH
C
C
C     RANGE DO LOOP FOR RECOGNITION
C
C
      DO 1066 IJK=1,LUPO
      KK=0
      TTAR=TBAC+DETEMP
      DO 500 II=IRMIN,IRMAX,IDELTR
      KK=KK+1
      RANGE=II/1000.0
      XR=RANGE*1000.0
      DO 2 JJ=1,LW
    2 IRTRAN(JJ)=1.0
      CALL ATMCRL(RVIS,RANGE,AIRTMP,XRH,WAVE1,WAVE2,IPRINT,IJK,ISTATE,
     1AFCRL,IAFLG)
      DO 5300 MISS=1,LW
 5300 IRTRAN(MISS)=AFCRL(MISS)*IRTRAN(MISS)
      CALL QTFE(0.1,IRTRAN,TRTRAN,LW)
      TRANS=TRTRAN(LW)/(WAVE2-WAVE1)
      CALL PLANK(TTAR,TBAC,SUPER,IRTRAN,RSPX)
      DDT(KK)=TRANS
      DETE=DETEMP*TRANS
C     TLENG=4.0*XHTAR/RANGE
      TLENG=XLTAR/RANGE
      DETE=DETE*(TLENG/7.0*FFT(20))**0.5
      SUPER=SUPER*(TLENG/7.0*FFT(20))**0.5
      XDR(KK)=RANGE
C     X-MRT FOR DELTA T AND DELTA P
       CALL ALINEY(FRW,DETE,FFT,XXMRT,20)
      CALL ALINEY(ROGER,SUPER,FFT,ELANX,20)
      XXNUM=XHTAR*FRW/RANGE
      XXN1M=XHTAR*ROGER/RANGE
       CALL ALINEY(PROB,XXNUM,PRO,XNUM,10)
      CALL ALINEY(POWPRO,XXN1M,PRO,XNUM,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      XPR(KK)=PROB
      DRTX(KK)=POWPRO
      DDRTX(KK)=DRTX(KK)
      CALL ALINEY(PROB,XXNUM,PRO,XNMB,10)
      CALL ALINEY(POWPRO,XXN1M,PRO,XNMB,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      SOME(KK)=PROB
      XFRW(KK)=POWPRO
C     Y-MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,FFT,YYMRT,20)
      CALL ALINEY(ROY,SUPER,FFT,ELANY,20)
      XXNUM=XHTAR*FRW/RANGE
      XXN2M=XHTAR*ROY/RANGE
      CALL ALINEY(PROB,XXNUM,PRO,XNUM,10)
      CALL ALINEY(SOWPRO,XXN2M,PRO,XNUM,10)
      IF(POWPRO.LT.0.0) POWPRO=0.00
      IF(PROB.LT.0.0) PROB=0.00
      IF(SOWPRO.LT.0.0) SOWPRO=0.00
      YPR(KK)=PROB
      DRTY(KK)=SOWPRO
      CALL ALINEY(PROB,XXNUM,PRO,XNMB,10)
      CALL ALINEY(POWPRO,XXN2M,PRO,XNMB,10)
      IF(PROB.LT.0.0) PROB=0.00
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      IF(POWPRO.LT.0.0) POWPRO=0.00
      YOR(KK)=PROB
      YFRW(KK)=POWPRO
C     45-DEGREE MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,FFT,RT45,20)
      CALL ALINEY(ROGER,SUPER,FFT,ELAN45,20)
      XXNUM=XHTAR*FRW/RANGE
      XXNIM=XHTAR*ROGER/RANGE
      CALL ALINEY(PROB,XXNUM,PRO,XNUM,10)
      CALL ALINEY(POWPRO,XXNIM,PRO,XNUM,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      X45T4(KK)=PROB
      X45P4(KK)=POWPRO
      CALL ALINEY(PROB,XXNUM,PRO,XNMB,10)
      CALL ALINEY(POWPRO,XXNIM,PRO,XNMB,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      X45T3(KK)=PROB
      X45P3(KK)=POWPRO
      DXDR(KK)=XDR(KK)
      DDDT(KK)=DDT(KK)
500    CONTINUE
      IF(JPRINT.EQ.0)GO TO 8011
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,325)DETEMP
  325 FORMAT(1H1,23HRECOGNITION PERFORMANCE/
     128H TARGET DELTA TEMPERATURE IS,F10.2,13H    DEGREES C)
      WRITE(6,327)
  327 FORMAT(1H ,33HTEMPERATURE DEPENDANT PERFORMANCE)
      WRITE(6,326)(XDR(I),DDT(I),XPR(I),YPR(I),X45T4(I),I=1,KK)
  326 FORMAT(1H ,    5HRANGE,6X,9HATM TRANS,1X,13HXCONSERVATIVE,1X,13HYC
     1ONSERVATIVE,1X,14H45CONSERVATIVE//(1X,F5.2,F12.2,F12.2,2F14.2))
      IF (IAFLG .NE. 1)GO TO 2000
      WRITE(6,7000)
      WRITE(6,325)DETEMP
      WRITE(6,327)
 2000 WRITE(6,377)(XDR(I),DDT(I),SOME(I),YOR(I),X45T3(I),I=1,KK)
  377 FORMAT(1H ,5HRANGE,6X,9HATM TRANS,2X,11HXOPTIMISTIC,4X,11HYOPTIMIS
     1TIC,6X,12H45OPTIMISTIC//(1X,F5.2,F12.2,F12.2,F15.2,F17.2))
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,325)DETEMP
      WRITE(6,820)
  820 FORMAT(1H ,27HPOWER DEPENDANT PERFORMANCE)
      WRITE(6,326) (XDR(I),DDT(I),DRTX(I),DRTY(I),X45P4(I),I=1,KK)
      IF (IAFLG .NE. 1)GO TO 2001
      WRITE(6,7000)
      WRITE(6,325)DETEMP
      WRITE(6,820)
 2001 WRITE(6,377)(XDR(I),DDT(I),XFRW(I),YFRW(I),X45P3(I),I=1,KK)
 8011 CONTINUE
C
C
C     DETECTION
C
C
      II=0
      DO 6065 JK=IRDIN,IRDAX,IDELX
      II=II+1
      RANGE=JK/1000.0
      XR=RANGE*1000.0
      DO 6066 KLM=1,LW
```

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6066  IRTRAN(KLW)=1.0
      CALL ATMCRL(RVIS,RANGE,AIRTMP,XRH,WAVE1,WAVE2,IPRINT,IJK,ISTATE,
     1AFCRL,IAFLG)
      DO 5790 MISS=1,LW
 5790 IRTRAN(MISS)=AFCRL(MISS)*IRTRAN(MISS)
      CALL QTFE(0.1,IRTRAN,TRTRAN,LW)
      TRANS=TRTRAN(LW)/(WAVE2-WAVE1)
      DDT(II)=TRANS
      CALL PLANK(TTAR,TBAC,POWER,IRTRAN,RSPX)
      DETE=DETEMP*TRANS
      TLENG=XLTAR/RANGE
      DETE=DETE*(TLENG/7.0*FFT(20))**0.5
      POWER=POWER*(TLENG/7.0*FFT(20))**0.5
      XDR(II)=RANGE
C     X MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,FFT,XXMRT,20)
      CALL ALINEY(ROGER,POWER,FFT,ELANX,20)
      XXNUM=XHTAR*FRW/RANGE
      XXN1M=XHTAR*ROGER/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      CALL ALINEY(POWPRO,XXN1M,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      XPR(II)=PROB
      DRTX(II)=POWPRO
C     Y-MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,FFT,YYMRT,20)
      CALL ALINEY(ROY,POWER,FFT,ELANY,20)
      XXNUM=XHTAR*FRW/RANGE
      XXN2M=XHTAR*ROY/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      CALL ALINEY(SOWPRO,XXN2M,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(SOWPRO.LT.0.0) SOWPRO=0.00
      YPR(II)=PROB
      DRTY(II)=SOWPRO
C     45-MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,FFT,RT45,20)
      CALL ALINEY(ROGER,POWER,FFT,ELAN45,20)
      XXNUM=XHTAR*FRW/RANGE
      XXN1M=XHTAR*ROGER/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      CALL ALINEY(POWPRO,XXN1M,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      X45T4(II)=PROB
      X45P4(II)=POWPRO
C     WFOV X-MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,WFOV,XXMRT,20)
      CALL ALINEY(ROGER,POWER,WFOV,ELANX,20)
      XXNUM=XHTAR*FRW/RANGE
      XXN1M=XHTAR*ROGER/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      CALL ALINEY(POWPRO,XXN1M,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      SOME(II)=PROB
      XFRW(II)=POWPRO
C     WFOV Y-MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,WFOV,YYMRT,20)
      CALL ALINEY(ROY,POWER,WFOV,ELANY,20)
      XXNUM=XHTAR*FRW/RANGE
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      XXN2M=XHTAR*ROY/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      CALL ALINEY(SOWPRO,XXN2M,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(SOWPRO.LT.0.0) SOWPRO=0.00
      YOR(II)=PROB
      YFRW(II)=SOWPRO
C     WFOV WITH 45-DEGREE MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,WFOV,RT45,20)
      CALL ALINEY(ROGER,POWER,WFOV,ELAN45,20)
      XXNUM=XHTAR*FRW/RANGE
      XXN1M=XHTAR*ROGER/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      CALL ALINEY(POWPRO,XXN1M,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
      IF(POWPRO.LT.0.0) POWPRO=0.00
      X45T3(II)=PROB
      X45P3(II)=POWPRO
      CALL MDTSNR(XMXM,YMYM,FFFF,XCTFF,H,DELTAF,RANGE,TRANS,SPROB,XXNET
     1,DS)
      ROSD(II)=SPROB
      DSN(II)=DS
C
C     DETECTION WITH SIGNAL-TO-NOISE
C
      ATT=XLTAR*XHTAR
      R2=RANGE**2
      TD=DETEMP*TRANS
      ARC=(ATT/DELTAX/DELTAY/R2+1.)**0.5
      TARC=(ATT/DELTAX/DELTAY/R2/FACT/FACT+1.)**0.5
      BARC=DELTAX*DELTAY*R2/ATT+1.
      TEBARC=DELTAX*DELTAY*FACT*FACT*R2/ATT+1.
      TEFR=EYETM*FR
      IF(TEFR.LT.1.0) TEFR=1.0
      TSE(II)=TD/XXNET/BARC*ARC*TEFR**0.5
      SSE(II)=TD/XXNET/TEBARC*TARC*TEFR**0.5
 6065 CONTINUE
      IF(JPRINT.EQ.0)GO TO 8012
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,9020)DETEMP
 9020 FORMAT(1H1,22HDETECTION BASED ON MDT/1H ,27HTARGET DELTA TEMPERATU
     1RE IS,F10.2,11H  DEGREES C//)
      WRITE(6,9021)(XDR(I),DDT(I),DSN(I),ROSD(I),I=1,II)
 9021 FORMAT(8X,5HRANGE,6X,9HATM TRANS,5X,3HS/N,5X,11HPROBABILITY//
     1(8X,F5.2,3F13.3))
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,9999)DETEMP
 9999 FORMAT(1H1,21HDETECTION PERFORMANCE/
     128H TARGET DELTA TEMPERATURE IS,F10.2,13H    DEGREES C)
      WRITE(6,9900)
 9900 FORMAT(1H ,16HNFOV PERFORMANCE/34H TEMPERATURE DEPENDENT PERFORMAN
     1CE)
      WRITE(6,9898) (XDR(I),DDT(I),XPR(I),YPR(I),X45T4(I),I=1,II)
      IF (IAFLG .NE. 1)GO TO 2002
      WRITE(6,7000)
      WRITE(6,9999)DETEMP
      WRITE(6,9901)
 9901 FORMAT(1H ,16HNFOV PERFORMANCE  )
 2002 WRITE(6,9899) (XDR(I),DDT(I),DRTX(I),DRTY(I),X45P4(I),I=1,II)
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,9999)DETEMP
      WRITE(6,9797)
```

```
9797 FORMAT(1H ,16H*FOV PERFORMANCE/34H TEMPERATURE DEPENDENT PERFORMAN
    1CE)
     WRITE(6,9898) (XDR(I),DDT(I),SOME(I),YDR(I),X45T3(I),I=1,II)
     IF (IAFLG .NE. 1)GO TO 2003
     WRITE(6,7000)
     WRITE(6,9999)DETEMP
     WRITE(6,9902)
9902 FORMAT(1H ,16H*FOV PERFORMANCE    )
2003 WRITE(6,9899) (XDR(I),DDT(I),XFRW(I),YFRW(I),X45P3(I),I=1,II)
9898 FORMAT(1H ,5HRANGE,6X,9HATM TRANS,6X,7HX DET T,6X,7HY DET T,6X,8H4
    15 DET T//(1X,F5.2,F15.2,3F13.2))
9899 FORMAT(1H ,27HPOWER DEPENDENT PERFORMANCE/
    1         1H ,5HRANGE,6X,9HATM TRANS,6X,7HX DET P,6X,7HY DET P,6X,8H4
    15 DET P//(1X,F5.2,F15.2,3F13.2))
8012 CONTINUE
     DETEMP=DETEMP+DDTT
1066 CONTINUE
8025 CONTINUE
     IF(JPRINT.EQ.0)CALL DFAULT (FFFF,XMXM,II,KK)
     IF(JOVER.EQ.1) GO TO 8017
     XNET=SAVNET
     GO TO 8400
8017 CONTINUE
     STOP
     END
```

```
 BLOCK DATA
 DIMENSION  XINPUT(10) ,OUTPUT(10)
 COMMON/NAME3/JFLAG,JPRINT,DDTT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
 COMMON/NAME5/IKOUNT,XMAG,FSTAR,FELECT,DUMB
 COMMON/NAME4/DXW,DLW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
1VFOV,RMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,BSTAR,
2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLS,XA,YA,KKK,
3IUTAU,VEL,BELECT
 COMMON/BLUR/ABLUR
 DATA HFOV/6.0/,VFOV/4.0/,TO/0.75/,FNUMB/1.20/,FOC/3.6/
 DATA ANGLE/60.0/,SRTAD/.003096/,DISC/1.0/,XN/64./,DELTAX/.86/,
1       DELTAY/0.860/,MOM/0/,FSTAR/10000000.0/,DPEAK/6.8/
 DATA FR/15.0/,XNSC/0.76/,OVERSC/1.00/
 DATA FELECT/0.0/,XK/0.0/,FMAXF/0.0/
 DATA KKK/0/,BRITE/50.0/,XY/0.00/,XYL/0.00/,XA/0.1689/,YA/0.1689/
 DATA FACT/2.0/,EYETM/0.2/,XSIGLS/0.0/,YSIGLS/0.0/
 DATA XMAG/4.80/,XNET/0.0/
 DATA XLTAR/5.25/,XHTAR/2.7/,DETEMP/11.1/,LUPO/1/,DDTT/0.0/
 DATA IRMIN/500/,IRMAX/5000/,IRDIN/1000/,IRDAX/10000/
 DATA XINPUT/0.0,1.0,2.0,3.0,4.0,5.0,6.0,7.0,10.0,20.0/
 DATA OUTPUT/2*0.1,1.0,2.0,3.0,4.0,5.0,3*6.0/
 END
```

```
      SUBROUTINE INIT(IAFLG)
C*
C*    THIS SUBROUTINE INITIATES THE I/O. IT DETERMINES IF
C*    THE JOB IS TO BE RUN IN AN INTERACTIVE OR BATCH MODE
C*    AND PRINTS A BANNER WHICH IDENTIFIES THE PROGRAM
C*    USING APPROPRIATE SCREEN/CARRIAGE CONTROL.
C*
C*    THE VALUE OF IAFLG IS CHANGED TO REFLECT THE
C*    RESULT OF THE INTERACTIVE/BATCH DECISION AS FOLLOWS:
C*
C*          IAFLG=1      INTERACTIVE JOB.
C*          IAFLG=1      BATCH JOB.
C*
C*    THIS SUBROUTINE IS NECESSARILY SYSTEM DEPENDENT.
C*    THERE ARE TWO VERSIONS - ONE FOR THE CDC6600
C*    AND ONE FOR THE IBM360/44.
C*
C*    THIS IS THE CDC6600 VERSION. IT RELIES ON THE
C*    SETTING OF SENSE SWITCH 1 TO MAKE THE BATCH/
C*    INTERACTIVE DECISION AS FOLLOWS:
C*
C*          SSW1=ON      INTERACTIVE JOB.
C*          SSW1=OFF     BATCH JOB.
C*
C*    SENSE SWITCH 1 MAY BE SET BY USE OF THE SCOPE 4.2
C*    COMMAND
C*              SWITCH,1
C*    CARE SHOULD BE TAKEN TO USE THIS COMMAND ONLY
C*    ONCE PER SIGNON AS REPEATED USE RESETS SWITCH 1.
C*    THE CURRENT STATUS OF SWITCH 1 MAY ALWAYS BE
C*    FOUND VIA THE COMMAND
C*              ASSETS
C*    THIS WILL RETURN THE STATUS OF ALL SWITCHES WHICH
C*    ARE CURRENTLY *ON*.
C*
C*     CALL SSWTCH(1 IAFLG)
C      IF(IAFLG .EQ.1)GO TO 10
C*     BATCH. SKIP TO NEW PAGE. PRINT BANNER, AND RETURN.
       WRITE(6,1000)
 1000  FORMAT(1H1,16X,25HNVL THERMAL SYSTEM MODEL ,
      116H*BATCH* 12/05/74,///)
C*     INTERACTIVE. CONNECT INPUT AND OUTPUT, SUPPRESS PAGE FULL
C*     WAIT, CLEAR SCREEN, PRINT BANNER, AND RETURN.
C*10   CALL CONNEC(5LINPUT,0)
C*     CALL CONNEC(6LOUTPUT,0)
C      WRITE(6,1010)
C1010  FORMAT(1HQ)
C      WRITE(6,1020)
C1020  FORMAT(5H '|',,13X,25HNVL THERMAL SYSTEM MODEL ,
C     122H(INTERACTIVE) 12/05/74,/)
       RETURN
       END
```

```
      SUBROUTINE NEWINP(FQ,XO,YO,XD,YD,XB,XE,XTV,YTV,XML,FQQ,CUTOFF,
     1F0,DDSTAR,XLMBA,RH,AIRTMP,RVIS,TBAC,PRO,XNUM,BETA,YML,
     2WAVE1,WAVE2,ISTATE,SNR,IPRINT,XNMB,IOVER)
C**
C**                                    GLOSSARY OF INPUT VARIABLES
C**                                    -------- -- ----- ---------
C**
C**     NAME     GROUP  DESCRIPTION
C**     ----     -----  -----------
C**
C**
C**     ABLUR    SYST   SIZE OF OPTICS BLUR CIRCLE (MRAD.)
C**
C**     AIRTMP   ENVI   AIR TEMPERATURE (DEGREES C)--OMITTED IF SIGMA AND WAVE ARE
C**                        USED
C**
C**     ANGLE    DETR   COLD SHIELD ANGLE (DEGREES)
C**
C**     BETA     FDC1   NUMBER OF CYCLES ACROSS TARGET FOR 4-CYCLE DETEC. CRITERION
C**                        --CORRESPONDS TO PRO
C**
C**     BRITE    DISP   AVERAGE DISPLAY BRIGHTNESS (FT.-LAMBERTS)
C**
C**     CUTOFF   ELEC   LOWER CUTOFF FREQ. OF ELECTRONICS
C**
C**     DDSTAR   DSTD   D* OF DETECTOR (10**(10) (CM.HZ.**.5)PER WATT)--IN NORMAL-
C**                        IZED FORM D*MAX =1.0--CORRESPONDS TO XLMBA
C**
C**     DDTT     TARG   TARGET DELTA T INCREMENT SIZE (0.0 IF LUPO=1.0)
C**
C**     DELTAX   DETR   IFOV X-DIRECTION AT DETECTOR (MRAD)
C**
C**     DELTAY   DETR   IFOV Y-DIRECTION AT DETECTOR (MRAD)
C**
C**     DETEMP   TARG   TARGET DELTA T (DEGREES C)
C**
C**     DISC     DETR   NUMBER OF DETECTORS IN SERIES (MINIMUM=1.0)
C**
C**     DPEAK    DET2   PEAK D* OF DETECTOR (10**(10)).
C**
C**     EYETM    EYEB   EYE INTEGRATION TIME -- CURRENTLY DEFINED AS 0.2 (SEC.)
C**
C**     F        NPSF   NOISE POWER SPECTRA FREQ. (LOG HZ.)--CORRESPONDS TO S
C**
C**     FACT     FCTR   RATIO OF NEQV/NEQV FREQ. AXIS--CURRENTLY DEFINED AS 2.0
C**
C**     FELECT   ELEC   3-DB POINT ON ELECTR. BANDPASS, ASSUMING RC ROLLOFF
C**
C**     FMAX     DETR   1/DELTAX OR 1/DELTAY, WHICHEVER IS GREATER (CALCULATED)
C**
C**     FMAXE    ELEC   FREQ. OF ANY ELECTR. APERTURE CORRECTION (KHZ.)--(LEAVE
C**                        BLANK TO IGNORE)--CORRESPONDS TO XK
C**
C**     FNUMB    OPTI   F-NUMBER OF OBJECTIVE LENS SYSTEM
C**
C**     FO       ELEC   UPPER CUTOFF FREQ. USED AS NORMALIZATION POINT FOR POWER
C**                        SPECTRA (S(FO)=1.0)--(KHZ.)
C**     NAME     GROUP  DESCRIPTION
C**     ----     -----  -----------
C**
C**     FOC      OPTI   FOCAL LENGTH OF OBJECTIVE LENS SYSTEM (INCHES)
C**
```

```
C**    FQ       FCMR    FREQ. (CYC./MRAD.)--CORRESPONDS TO XO,YO,XTV,YTV,XML,& YML
C**
C**    FQU      FLHZ    FREQ. (10**(7)HZ))--CORRESPONDS TO XD, YD, XE, & XB
C**
C**    FR       SCAN    FRAME RATE OF SCANNER (FRAMES/SEC.)
C**
C**    FSTAR    DET2    3-DB POINT ON DETECTOR RESPONSE ROLLOFF (10**(8)HZ.)
C**
C**    HFOV     OPTI    HORIZONTAL FIELD OF VIEW (DEGREES)
C**
C**    IDELTR   RANG    RANGE INCREMENTS FOR RECOG. DATA (CALCULATED)
C**
C**    IDELX    RANG    RANGE INCREMENTS FOR DETEC. DATA (CALCULATED)
C**
C**    IRDAX    RANG    MAXIMUM DETEC. RANGE REQUIRED (METERS)
C**
C**    IRDIN    RANG    MINIMUM DETEC. RANGE REQUIRED (METERS)
C**
C**    IRMAX    RANG    MAXIMUM RECOG. RANGE REQUIRED (METERS)
C**
C**    IRMIN    RANG    MINIMUM RECOG. RANGE REQUIRED (METERS)
C**
C**    ISTATE   ENVI    ATMOSPHERIC CONDITION FLAG--1.0=FOG W/ 1 KM. VIS.; 3.0=
C**                        FOG W/ 200 M. VIS.; 4.0=FOG W/ 60 M. VIS.; 5.0=LIGHT
C**                        RAIN W/ 12 KM. VIS.; 6.0=MOD. RAIN W/ 6 KM. VIS.; 7.0=
C**                        HEAVY RAIN W/ 2 KM. VIS.; 8.0=VERY HEAVY RAIN W/ 500 M.
C**                        VIS.; 30.0=BEER'S LAW SCATTERING; 40.0=BEER'S LAW ATTEN.
C**
C**    JPRINT   ----    PRINT OPTION --
C**
C**    KKK      DISP    TYPE OF DISPLAY--0.0=CRT WITH GAUSSIAN SPOT SIZE; 1.0=LED
C**                        WITH SIN X/X SPOT SIZE; 2.0=NO DISPLAY
C**
C**    LUPO     TARG    NUMBER OF ITERATIONS OF TARGET DELTA T
C**
C**    MOM      DETR    SYSTEM NOISE LIMITATION--0.0=DETECTOR NOISE LIMITED (D*
C**                        MUST INCLUDE COLD SHIELD); 1.0=SHOT NOISE (BLIP) LIMITED
C**                        2.0=WHITE NOISE APPROXIMATION
C**
C**    OUTPUT   DBRC    DISPLAY BRIGHTNESS CURVE (FT. LAMBERTS)--CORRESP. TO XINPUT
C**
C**    OVERSC   SCAN    OVERSCAN RATIO
C**
C**    PRO      FDRP    PROB. ARRAY FROM FIELD DATA FOR RECOG.--CORRESP. TO XNUM
C**                        & XNMB
C**
C**    RH       ENVI    RELATIVE HUMIDITY (%)--OMITTED OR =0.0 IF SIGMA AND WAVE
C**                        ARE USED
C**
C**    NAME     GROUP   DESCRIPTION
C**    ----     -----   -----------
C**
C**    RVIS     ENVI    VISIBILITY RANGE (KM.)--OMITTED IF SIGMA AND WAVE ARE USED
C**
C**    S        NPSP    NOISE POWER SPECTRA POWER (10**(-9) V.HZ.**.5)--CORRESPONDS
C**                        TO F
C**
C**    SIGMA    SCAT    ATMOSPHERIC SCATTERING OR TRANSMISSION COEFFICIENTS--
C**           OR TOTL      CORRESPONDS TO WAVE
C**
C**    SNR      SN4B    SIGNAL TO NOISE RATIO TO RECOG. 4-BAR PATTERN--CURRENTLY
C**                        DEFINED FROM EXPERIMENTAL WORK AS 2.25
```

```
C**
C**   SRTAD    DETR    DETECTOR SIZE (10**(-3) IN.)--SQUARE ROOT OF AREA
C**
C**   TA       TRAN    ATMOSPHERIC TRANSMISSION--CURRENTLY DEFINED AS 0.95
C**
C**   TBAC     TRAN    BACKGROUND TEMPERATURE (DEGREES C)
C**
C**   TO       OPTI    AVERAGE OPTICAL TRANSMISSION OF DEVICE
C**
C**   VFOV     OPTI    VERTICAL FIELD OF VIEW (DEGREES)
C**
C**   WAVE     ATEW    WAVELENGTH FOR ATMOSPHERIC ATTENUATION COEFFICIENTS
C**                       (MICRONS)--CORRESPONDS TO SIGMA
C**
C**   WAVE1    OPTI    BEGINNING DETECTOR WAVELENGTH (MICRONS)
C**
C**   WAVE2    OPTI    ENDING DETECTOR WAVELENGTH (MICRONS)
C**
C**   XA       DISP    X-DIMENSION OF LED IN DISPLAY (MRAD)
C**
C**   XB       BMTF    BOOST MTF--CORRESPONDS TO FQQ
C**
C**   XD       DROX    DETECTOR ROLLOFF MTF IN X-DIRECTION IF NOT NORMAL RC
C**                       ROLLOFF--CORRESPONDS TO FQQ
C**
C**   XE       EMTF    ELECTR. MTF-- CORRESPONDS TO FQQ
C**
C**   XHTAR    TARG    TARGET WIDTH (METERS)
C**
C**   XINPUT   DBDT    DISPLAY BRIGHTNESS CURVE DELTA T INPUT
C**
C**   XK       ELEC    AMPLITUDE OF ANY ELECTR. APERTURE CORRECTION (LEAVE BLANK
C**                       TO IGNORE)--CORRESPONDS TO FMAXF
C**
C**   XLAMB    OPTI    WAVELENGTH USED TO CALCULATE DIFFRACTION-LIMITED OPTICAL
C**                       MTF (MICROMETERS)--USUALLY TAKEN AS AVE. BAND WAVELENGTH
C**
C**   XLMBA    DSTL    WAVELENGTHS FOR D*--CORRESPONDS TO DDSTAR
C**
C**   XLTAR    TARG    TARGET LENGTH (METERS)
C**
C**   NAME     GROUP   DESCRIPTION
C**   ----     -----   -----------
C**
C**   XMAG     SYST    SYSTEM MAGNIFICATION
C**
C**   XML      LSSX    MTF OF LINE-OF-SIGHT STABILIZATION IN X-DIRECTION--CORRESP.
C**                       TO FQ
C**
C**   XN       DETR    NUMBER OF DETECTORS IN PARALLEL (MINIMUM=1.0)
C**
C**   XNET     SYST    NE DELTA T--IF =0.0, THEN PROGRAM CALCULATES NE DELTA T
C**
C**   XNM3     FRC3    NUMBER OF CYCLES ACROSS TARGET FOR 3-CYCLE RECOG. CRITERION
C**                       --CORRESPONDS TO PRO
C**
C**   XNSC     SCAN    SCAN EFFICIENCY IN X- AND Y-DIRECTIONS--PRODUCT OF X & Y
C**
C**   XNUM     FRC4    NUMBER OF CYCLES ACROSS TARGET FOR 4-CYCLE RECOG. CRITERION
C**                       --CORRESPONDS TO PRO
C**
C**   XO       MTOX    MTF OF OPTICS IN X-DIRECTION (0.0 IF DIFFRACTION-LIMITED)
```

```
C**                          --CORRESPONDS TO FQ
C**
C**   XSIGLS   STAB   EXP. CONSTANT TO GIVE GAUSSIAN FORM TO VIBRATION MTF--
C**                      =2(PI)**2*(SIGMA X)**2 WHERE SIGMA X IS STD. DEV. OF
C**                      VIBRATION SPECTRUM IN X-DIRECTION
C**
C**   XTV      VMTX   MTF OF VIDICON IN X-DIRECTION--CORRESPONDS TO FQ
C**
C**   XXMRT    MRT1           MEASURED VALUES OF MRT . TO BE INPUT
C**            MRT2           ON 2 CARDS IN VALUES OF MRT*0.001
C**            MRT3
C**
C**
C**   XY       ELEC   X-DIMENSION OF LED IN EO MULTIPLEXER (MRAD)
C**
C**   XYL.     ELEC   Y-DIMENSION OF LED IN EO MULTIPLEXER (MRAD)
C**
C**   YA       DISP   Y-DIMENSION OF LED IN DISPLAY (MRAD)
C**
C**   YD       DROY   DETECTOR ROLLOFF MTF IN Y-DIRECTION IF NOT NORMAL RC
C**                      ROLLOFF--CORRESPONDS TO FQO
C**
C**   YML      LSSY   MTF OF LINE-OF-SIGHT STABILIZATION IN Y-DIRECTION--CORRESP.
C**                      TO FQ
C**
C**   YO       MTOY   MTF OF OPTICS IN Y-DIRECTION (0.0 IF DIFFRACTION-LIMITED)
C**                      --CORRESPONDS TO FQ
C**
C**   YSIGLS   STAB   EXP. CONSTANT TO GIVE GAUSSIAN FORM TO VIBRATION MTF--
C**                      =2(PI)**2*(SIGMA Y)**2 WHERE SIGMA Y IS STD. DEV. OF
C**                      VIBRATION SPECTRUM IN Y-DIRECTION
C**
C**   YTV      VMTY   MTF OF VIDICON IN Y-DIRECTION--CORRESPONDS TO FQ
C**
C**
C**
C**
C**
C**
C**
C**
C**
C**
C**
C**
C**
C**
      REAL NAM1
      DIMENSION T(10)
      DIMENSION PRO(10),XNUM(10),XNMB(10),BETA(10)
      DIMENSION FQO(10),FQ(10)
      DIMENSION XD(10),YD(10),XE(10),XB(10)
      DIMENSION XO(10),YO(10),XTV(10),YTV(10),XML(10),YML(10)
      DIMENSION DDSTAR(10),XLMBA(10)
      DIMENSION S3(10),S8(10),F3(10),F8(10)
      DIMENSION DS3(10),DS8(10),XLMBA3(10),XLMBA8(10)
      DIMENSION OUTPUT(10),XINPUT(10)
      DIMENSION WAVE3(9),WAVE8(9),WAVE(9),SIGMA(9)
      DIMENSION R(63)
      DIMENSION DPRO(10),DXNUM(10),DBETA(10),DFQO(10),DXD(10),DYD(10),
     1DXE(10),DXB(10),DFQ(10),DXO(10),DYO(10),DXTV(10),DYTV(10),DXML(10)
```

```
     2,DYML(10),DXNMB(10)
      DIMENSION XXMRT(20)
      COMMON/NAME3/JFLAG,JPRINT,DUTT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME4/DXW,DLW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,ZMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,ZSTAR,
     2XLAMB,FNUMB,FOC,XK,ZMAXF,XY,XYL,FMAX,XSIGLS,YSIGLS,XA,YA,KKK,
     3IOTAU,VEL,ZELECT
      COMMON /SPCATM/WAVE,SIGMA
      COMMON/BLUR/ABLUR
      COMMON/NAME5/IKOUNT,XMAG,FSTAR,FELECT,FMAXF
       COMMON/NAME1/XDR,DOT,TSE,SSE,SONE,XFRW,DRTX,DETEM,FFT,XXXRT
      COMMON/NAME8/XXMRT,Z3,Z4
      Z1=0.0
      Z2=0.0
      Z3=0.0
      Z4=0.0
      IF(IKOUNT.GT.1)GO TO 1000
C*********************************************************************
C*********************************************************************
C
C************************  DATA NOT IN DATA BLOCK JRDAYTA  ************
C
C*********************************************************************
C*********************************************************************
      DATA R/4HFOR1,4HBAND,4HOPTI,4HDETR,4HDET2,4HSCAN,4HELEC,4HDISP,
     14HSTA3,4HSN4B,4HFCTR,4HEYEB,4HSYST,4H    ,4H    ,4H    ,4H    ,
     24HFOR2,4H    ,4HFLHZ,4HDROX,4HDROY,4HEMTF,4HBMTF,4HFCNR,4HMTOX,
     34HMTOY,4HVMTX,4HVMTY,4HLSSX,4HLSSY,4HNPSF,4HNPSP,4HDSTL,4HDSTD,
     44HDBDT,4HDBRC,4HFRC3,4HFRC4,4HFDRP,4HFDC1,4H    ,4H    ,4H    ,
     54H    ,4H    ,4H    ,4HENVI,4HTRAN,4HSCAT,4HATEW,4HTARG,4HPANG,
     64HTOTL,4H    ,4H    ,4HMRT3,4HMRT2,4HMRT1,4HIGNR,4HDONE,4HENDS,
     74HSHOW,4HLOAD,4HSAVE,4HGO  ,4HFIX /
C**
C**                     DETECTION + RECOGNITION PROBABILITIES.
C**
      DATA DBETA/12.5,5.0,3.0,2.0,1.5,1.0,.75,.5,.25,0.0/
      DATA DPRO/1.0,1.0,1.0,.95,.80,.50,.30,.10,.02,0.0/
      DATA DXNUM/50.0,20.0,12.0,8.0,6.0,4.0,3.0,2.0,1.0,0.0/
      DATA DXNMB/37.5,15.0,9.0,6.0,4.5,3.0,2.25,1.5,.75,0.0/
C**
C**                     DEFAULT INPUTS FOR 'UNIVERSAL' SYSTEMS
C**
      DATA S3/64.0,32.7,16.0,7.12,4.0,3*1.0,2*0.0/
      DATA F3/1.0,1.3,2.0,2.7,3.0,4.0,5.0,6.0,2*0.0/
      DATA DS3/.23,.38,.5,.58,.73,.78,.88,2*1.0,.25/
      DATA XLMBA3/1.0,1.5,2.0,2.5,3.0,3.5,4.0,4.5,5.0,5.5/
      DATA WAVE3/3.0,3.25,3.50,4.0,4.25,4.50,5.0/
      DATA DPEAK3/3.0/,XLAMB3/4.0/
      DATA S8/32.0,16.0,4.0,2.25,4*1.0,2*0.0/
      DATA F8/0.0,1.0,2.0,3.0,3.3,4.0,5.0,6.0,2*0.0/
      DATA DS8/0.36,0.84,0.86,0.92,1.0,1.4,1.0,0.9,0.74,0.24/
      DATA XLMBA8/7.5,8.0,8.5,9.0,9.5,10.0,10.5,11.0,12.0,13.0/
      DATA WAVE8/8.0,9.0,10.0,11.0,12.0,13.0,14.0/
      DATA DPEAK8/1.4/,XLAMB8/11.0/
      DATA DFQ0/0.0,0.01,0.1,0.2,0.3,0.5,0.6,0.7,1.0,10.0/
      DATA DXQ/10*1.0/
      DATA DYD/10*1.0/
      DATA DXE/10*1.0/
      DATA DXB/10*1.0/
      DATA DFQ/0.0,1.0,2.0,3.0,3.5,4.0,4.5,5.0,6.0,7.0/
      DATA DXO/10*1.0/
```

```
      DATA DYO/10*1.0/
      DATA DXTV/10*1.0/
      DATA DYTV/10*1.0/
      DATA DXML/10*1.0/
      DATA DYML/10*1.0/
      DO 950 I=1,10
      PRO(I)=DPRO(I)
      XNMB(I)=DXNMB(I)
      XNUM(I)=DXNUM(I)
      BETA(I)=DBETA(I)
      FQQ(I)=DFQQ(I)
      XD(I)=DXD(I)
      YD(I)=DYD(I)
      XE(I)=DXE(I)
      XB(I)=DXB(I)
      FQ(I)=DFQ(I)
      XO(I)=DXO(I)
      YO(I)=DYO(I)
      XTV(I)=DXTV(I)
      YTV(I)=DYTV(I)
      XML(I)=DXML(I)
      YML(I)=DYML(I)
  950 CONTINUE
      TBAC=12.0
      AIRTMP=15.0
      RH=45.99
      IPRINT=0
      ISTATE=0
      RVIS=23.0
      TA=0.95
      DPEAK=DPEAK3
      XLAMB=XLAMB3
      DO 9610 J=1,10
      S(J)=S3(J)
      DDSTAR(J)=DS3(J)
      XLMBA(J)=XLMBA3(J)
 9610 F(J)=F3(J)
      WAVE(1)=R(51)
      DO 2511 J=1,7
 2511 WAVE(J+2)=WAVE3(J)
      WAVE2=5.00
      WAVE1=3.0
      ABLUR=0.0
      F0=10000.0
      CUTOFF=10.0
      SNR=2.25
C**
C**                                         PROGRAM READS FORMAT INPUT CARD
C**
 1000 CONTINUE
      IF(IAFLG .NE. 1)GO TO 10
C*    INPUT INTERACTIVELY.
   20 WRITE(6,1020)
 1020 FORMAT(52H ENTER @SHOW@ FOR USAGE INSTRUCTION OR CONTROL CARD ,
     111H(A4,I1,I1):)
      READ(5,1030)NAM1,JFLAG,JPRINT
 1030 FORMAT(A4,2I1)
      GO TO 40
   10 READ(5,1010)NAM1,JFLAG,JPRINT
 1010 FORMAT(A4,6X,I1,9X,I1)
   40 IF(NAM1.EQ.R(1))GO TO 2000
      IF(NAM1.EQ.R(18))GO TO 3000
```

```
C**
C**                                               CALCULATED INPUTS
C**
      DIAM=FOC/FNUMB
      FMAX=1.0/DELTAX
      IF(DELTAX.GT.DELTAY)FMAX=1.0/DELTAY
      IDELTR=(IRMAX-IRMIN)/9
      IDELX=(IRDAX-IRDIN)/9
      IF(NAM1 .EQ.R(61)).OR.NAM1 .EQ.R(62)) GO TO 5000
      WRITE(6,5910)
 5910 FORMAT(1X,71HERROR HAS BEEN MADE ON INPUT CARD-DOES NOT CONFORM TO
     1 PROPER CONVENTION//)
      CALL EXIT
C**
C**                                               INPUTS WITH F10.3 FORMAT (FOR1)
C**
 2000 CONTINUE
      IF(IAFLG.EQ.1)WRITE(6,5922)
 5922 FORMAT(12H&NEXT INPUT:)
      READ(5,2010)T1,T2,(T(I),I=1,7)
 2010 FORMAT(A4,2X,A4,7F10.3)
      IF(IAFLG.NE.1)GO TO 2002
      IF(T1.EQ.R(62))GO TO 1000
      DO 2004 I=2,10
      IF(T1.EQ.R(I))GO TO 2014
 2004 CONTINUE
      DO 2006 I=12,13
      IF(T1.EQ.R(I))GO TO 2014
 2006 CONTINUE
      DO 2008 I=48,54
      IF(T1.E .R(I))GO TO 2014
 2008 CONTINUE
      DO 2012 I=57,59
      IF(T1.EQ.R(I))GO TO 2014
 2012 CONTINUE
      WRITE(6,5920)
      GO TO 2000
 2014 WRITE(6,5921)
 5921 FORMAT(2H&>)
      CALL READF(T)
 2002 IF(T1.EQ.R(3))GO TO 2025
      IF(T1.EQ.R( 2))GO TO 2020
      IF(T1.EQ.R( 4))GO TO 2030
      IF(T1.EQ.R( 5))GO TO 2040
      IF(T1.EQ.R( 6))GO TO 2050
      IF(T1.EQ.R( 7))GO TO 2060
      IF(T1.EQ.R( 8))GO TO 2070
      IF(T1.EQ.R( 9))GO TO 2080
      IF(T1.EQ.R(10))GO TO 2090
      IF(T1.EQ.R(12))GO TO 2110
      IF(T1.EQ.R(13))GO TO 2120
      IF(T1.EQ.R(48))GO TO 4030
      IF(T1.EQ.R(49))GO TO 4040
      IF(T1.EQ.R(50))GO TO 4050
      IF(T1.EQ.R(51))GO TO 4060
      IF(T1.EQ.R(52))GO TO 4070
      IF(T1.EQ.R(53))GO TO 4080
      IF(T1.EQ.R(54))GO TO 4050
      IF(T1.EQ.R(59)) GO TO 3240
      IF(T1.EQ.R(58)) GO TO 3250
      IF(T1.EQ.R(57)) GO TO 3260
      IF(T1.EQ.R(62))GO TO 1000
```

```
      WRITE(6,5920)
 5920 FORMAT(1X,54HAN INPUT SYSTEMS CARD FOR FOR1 HAS NOT BEEN RECOGNIZE
     1D//)
      CALL EXIT
C**
C**                                                     OPTICS INPUTS
C**
 2020 WAVE1=T(1)
      WAVE2=T(2)
      GO TO 2000
 2025 CONTINUE
      FNUMB=T(1)
      FOC=T(2)
      TO=T(3)
      ABLUR=T(4)
      XLAMB=T(5)
      IF(XLAMB.EQ.0.0)XLAMB=(WAVE1+WAVE2)/2.0
      IF(XLAMB.LE. 5.0.AND.XLAMB.GE.3.0)GO TO 2000
      IF(XLAMB.LE.14.0.AND.XLAMB.GE.8.0)GO TO 2000
      WRITE(6,5930)XLAMB
 5930 FORMAT(1X,///,T30,40(1H*),//20X,30H YOUR INPUT VALUE OF XLAMB IS ,
     1F10.3,/20X,39H AND IS NOT INSIDE THE SPECIFIED RANGES///)
      CALL EXIT
C**
C**                                                     DETECTOR INPUTS
C**
C**
 2030 DELTAX=T(1)
      DELTAY=T(2)
      XN=T(3)
      DISC=T(4)
      SRTAD=T(5)/1000.0
      DPEAK=T(6)
      FO=1000.0*T(7)
      GO TO 2000
C**
C**
C**
 2040 FSTAR=T(3)*1000.0
      MOM=IFIX(T(2))
      ANGLE=T(1)
      GO TO 2000
C**
C**                                                     SCANNER INPUTS
C**
 2050 FR=T(1)
      XNSC=T(2)
      OVERSC=T(3)
      GO TO 2000
C**
C**                                                     ELECTRONICS INPUTS
C**
 2060 CUTOFF=T(1)
      FELECT=T(2)
      XY=T(3)
      XYL=T(4)
      XK=T(5)
      FMAXF=1000.0*T(6)
      GO TO 2000
C**
C**                                                     DISPLAY INPUTS
C**
```

```
 2070 KKK=IFIX(T(1))
      BRITE=T(2)
      XA=T(3)
      YA=T(4)
      GO TO 2000
C**
C**
C**                                                      STABILIZATION INPUTS
 2080 XSIGLS=T(1)
      YSIGLS=T(2)
      GO TO 2000
C**
C**
C**                                                      CONSTANTS (OVERRIDE)
C**                                                      SN4B, FCTR, EYEB
 2090 SNR=T(1)
      GO TO 2000
 2110 EYETM=T(1)
      GO TO 2000
C**
C**
C**                                                      SYSTEM INPUTS
 2120 HFOV=T(1)
      VFOV=T(2)
      XMAG=T(3)
      FACT=T(4)
      XNET=T(5)
      GO TO 2000
C**
C**
C**                                                      ENVIRONMENTAL INPUTS
 4030 AIRTMP=T(1)
      RH=T(2)
      RVIS=T(3)
      ISTATE=IFIX(T(4))
      IPRINT=T(5)
      IF(RVIS.EQ.0.0)RVIS=23.0
      Z1=1.0
      GO TO 2000
C**
C**
C**
 4040 TA=T(1)
      TBAC=T(2)
      GO TO 2000
C**
C**
C**                                                      ATMOS. SCATTERING COEFF.
C**                                                      OR TRANSMISSION COEFF.
 4050 SIGMA(1)=T1
      SIGMA(2)=T2
      DO 4051 J=1,7
 4051 SIGMA(J+2)=T(J)
      Z2=1.0
      GO TO 2000
C**
C**
C**                                                      WAVELENGTHS FOR ATEN
 4060 WAVE(1)=T1
      WAVE(2)=T2
      DO 4061 J=1,7
 4061 WAVE(J+2)=T(J)
```

```
      GO TO 2000
C**
C**                                                   TARGET  INPUTS
C**
 4070 XLTAR=T(1)
      XHTAR=T(2)
      DETEMP=T(3)
      TBAC=T(4)
      IF(TBAC.EQ.0.0)TBAC=12.0
      GO TO 2000
C**
C**                                                   RANGE  REQUIREMENTS
C**
 4080 IRMIN=IFIX(T(1))
      IRMAX=IFIX(T(2))
      IRDIN=IFIX(T(3))
      IRDAX=IFIX(T(4))
      GO TO 2000
C**
C**                                   INPUT  VALUES  FOR  MEASURED  MRT
C**
 3240 DO 3245 J=1,7
 3245 XXMRT(J)=T(J)*0.001
      Z3=1.0
      GO TO 2000
 3250 DO 3255 J=8,14
 4255 XXMRT(J)=T(J-7)*0.001
      GO TO 2000
 3260 DO 3265 J=15,20
 3265 XXMRT(J)=T(J-14)*0.001
      XXMRT(20)=XXMRT(20)*100000.
      Z4=1.0
      GO TO 2000
C**
C**                                          INPUTS  WITH  F5.2  FORMAT  (FOR2)
C**
 3000 CONTINUE
      IF(IAFLG.EQ.1)WRITE(6,5922)
      READ(5,3010)T1,T2,(T(I),I=1,10)
 3010 FORMAT(A4,A6,10F5.2)
      IF(IAFLG.NE.1)GO TO 3002
      IF(T1.EQ.R(62))GO TO 1000
        DO 3004 I=20,41
      IF(T1.EQ.R(I))GO TO 3006
 3004 CONTINUE
      WRITE(6,5940)
      GO TO 3000
 3006 WRITE(6,5921)
      CALL READF(T)
 3002 IF(T1.EQ.R(20))GO TO 3020
      IF(T1.EQ.R(21))GO TO 3030
      IF(T1.EQ.R(22))GO TO 3040
      IF(Y1.EQ.R(23))GO TO 3050
      IF(T1.EQ.R(24))GO TO 3060
      IF(T1.EQ.R(25))GO TO 3070
      IF(T1.EQ.R(26))GO TO 3080
      IF(T1.EQ.R(27))GO TO 3090
      IF(T1.EQ.R(28))GO TO 3100
      IF(T1.EQ.R(29))GO TO 3110
      IF(T1.EQ.R(30))GO TO 3120
      IF(T1.EQ.R(31))GO TO 3130
      IF(T1.EQ.R(32))GO TO 3140
```

```
      IF(T1.EQ.R(33))GO TO 3150
      IF(T1.EQ.R(34))GO TO 3160
      IF(T1.EQ.R(35))GO TO 3170
      IF(T1.EQ.R(36))GO TO 3180
      IF(T1.EQ.R(37))GO TO 3190
      IF(T1.EQ.R(38))GO TO 3200
      IF(T1.EQ.R(39))GO TO 3210
      IF(T1.EQ.R(40))GO TO 3220
      IF(T1.EQ.R(41))GO TO 3230
      IF(T1.EQ.R(62))GO TO 1000
      WRITE(6,5940)
 5940 FORMAT(1X,54HAN INPUT SYSTEMS CARD FOR FOR2 HAS NOT BEEN RECOGNIZE
     1D//)
      CALL EXIT
C**
C**                                          FREQ. (LOG HZ) FOR ELECTR.
C**
 3020 DO 3021 J=1,10
 3021 FQO(J)=T(J)
      GO TO 3000
C**
C**                                          MTF DETECTOR ROLLOFF-X
C**
 3030 DO 3031 J=1,10
 3031 XD(J)=T(J)
      GO TO 3000
C**
C**                                          MTF DETECTOR ROLLOFF-Y
C**
 3040 DO 3041 J=1,10
 3041 YD(J)=T(J)
      GO TO 3000
C**
C**                                          MTF ELECTRONIC
C**
 3050 DO 3051 J=1,10
 3051 XE(J)=T(J)
      GO TO 3000
C**
C**                                          MTF BOOST
C**
 3060 DO 3061 J=1,10
 3061 XB(J)=T(J)
      GO TO 3000
C**
C**                                          MTF FREQ. FOR SYSTEMS
C**
 3070 DO 3071 J=1,10
 3071 FQ(J)=T(J)
      GO TO 3000
C**
C**                                          MTF OPTICS-X
C**
 3080 DO 3081 J=1,10
 3081 XO(J)=T(J)
      GO TO 3000
C**
C**                                          MTF OPTICS-Y
C**
 3090 DO 3091 J=1,10
 3091 YO(J)=T(J)
      GO TO 3000
```

```
C**
C**                                              MTF VIDICON-X
C**
 3100 DO 3101 J=1,10
 3101 XTV(J)=T(J)
      GO TO 3000
C**
C**                                              MTF VIDICON-Y
C**
 3110 DO 3111 J=1,10
 3111 YTV(J)=T(J)
      GO TO 3000
C**
C**                                              MTF STABILIZATION-X
C**
 3120 DO 3121 J=1,10
 3121 XML(J)=T(J)
      GO TO 3000
C**
C**                                              MTF STABILIZATION-Y
C**
 3130 DO 3131 J=1,10
 3131 YML(J)=T(J)
      GO TO 3000
C**
C**                                              NOISE POWER SPECTRA FREQ.
C**
 3140 DO 3141 J=1,10
 3141 F(J)=T(J)
      GO TO 3000
C**
C**                                              NOISE POWER SPECTRA POWER
C**
 3150 DO 3151 J=1,
 3151 S(J)=T(J)
      GO TO 3000
C**
C**                                              LAMBDAS FOR D*
C**
 3160 DO 3161 J=1,10
 3161 XLMBA(J)=T(J)
      GO TO 3000
C**
C**                                              NORMALIZED D*
C**
 3170 DO 3171 J=1,10
 3171 DDSTAR(J)=T(J)
      GO TO 3000
C**
C**                                              DISP. DELTA T INPUT
C**
 3180 DO 3181 J=1,10
 3181 XINPUT (J)=T(J)
      GO TO 3000
C**
C**                                              DISP. BRIGHTNESS OUTPUT
C**
 3190 DO 3191 J=1,10
 3191 OUTPUT(J)=T(J)
      GO TO 3000
C**
C**                                              FREQ. FOR 3-CYCLE RECOG.
```

```
C**
 3200 DO 3201 J=1,10
 3201 XNMB(J)=T(J)
      GO TO 3000
C**
C**                                                   FREQ. FOR 4-CYCLE RECOG.
C**
 3210 DO 3211 J=1,10
 3211 XNUM(J)=T(J)
      GO TO 3000
C**
C**                                                   FREQ. DISTRIB. RECOG. PROB.
C**
 3220 DO 3221 J=1,10
 3221 PRO(J)=T(J)
      GO TO 3000
C**
C**                                                   FREQ. FOR 1-CYCLE DETEC.
C**
 3230 DO 3231 J=1,10
 3231 BETA(J)=T(J)
      GO TO 3000
C**
C**                                              DEFAULT INPUTS FOR GENERAL SYSTEM
C**
C**
C**                                              PRINTOUT FORMATS FOR INPUT DATA
C**
C**                                                       FOR1 INPUTS
C**
 5000 CONTINUE
      IF(Z1.EQ.1.0.AND.Z2.EQ.0.0) SIGMA(1)=0.0
      IF(NAM1.EQ.R(61)) JOVER=1
      IF (IAFLG .EQ. 1)WRITE(6,7000)
 7000 FORMAT(34(/),5H '|',,20X,10HINPUT DATA,//)
      IF (IAFLG .NE. 1)WRITE(6,5010)
 5010 FORMAT(1H1,     10HINPUT DATA///)
      WRITE(6,5016)IKOUNT
 5016 FORMAT(1H ,     10HRUN NUMBER,I5//)
      WRITE(6,5031)WAVE1,WAVE2
 5031 FORMAT(1H ,21HYOUR SPECTRAL BAND IS,F10.3,6H     TO,F10.3,
     111H     MICRONS//)
      WRITE(6,5041)DIAM,FNUMB,FOC,TO,XLAMB,ABLUR
 5041 FORMAT(1H ,     6HOPTICS//
     3   T6,30HDIAMETER                     ,F10.3,10H     INCHES/
     4   T6,30HF-NUMBER                     ,F10.3/
     5   T6,30HFOCAL LENGTH                 ,F10.3,10H     INCHES/
     7  T6,30HAVG. OPTICAL TRANSMISSION     ,F10.3/
     9  T6,30HWAVELENGTH FOR DIFFRACTION    ,F10.3,11H     MICRONS/
     3  T6,30HGEOMETRIC BLUR SPOT SIZE      ,F10.3,9H     MRAD.//)
      WRITE(6,5051)DELTAX,DELTAY,XN,DISC,SRTAD,DPEAK,FC,ANGLE
 5051 FORMAT(1H ,     8HDETECTOR//
     5  T6,30HHORIZONTAL IFOV               ,F10.3,9H     MRAD./
     6   T6,30HVERTICAL IFOV                ,F10.3,9H     MRAD./
     4   T6,30HDETECTORS IN PARALLEL        ,F10.0/
     3   T6,30HDETECTORS IN SERIES          ,F10.0/
     2   T6,30HDETECTOR SIZE                ,F10.5,10H     INCHES/
     6  T6,30HPEAK D*                       ,F10.2,
     724H  (1E10)CM-SQRT(HZ)/WATT      ,/
     8  T6,30HMEASURING FREQUENCY OF D*    ,F10.0,9H     HERTZ/
     1   T6,30HCOLD SHIELD ANGLE            ,F10.3,11H     DEGREES)
      IF(NUM.EQ.0)WRITE(6,5053)
```

```
      IF(MOM.EQ.1)WRITE(6,5055)
      IF(MOM.EQ.2)WRITE(6,5057)
 5053 FORMAT(1H ,T6,30HLIMITING NOISE                                ,6X,8HDETECTOR)
 5055 FORMAT(1H ,T6,30HLIMITING NOISE                                ,6X,4HSHOT)
 5057 FORMAT(1H ,T6,30HLIMITING NOISE                                ,6X,19HWHITE APPR
     1OXIMATION)
      WRITE(6,5059)FSTAR
 5059 FORMAT(1H ,T6,30HDETECTOR RESPONSE,3-DB POINT     ,E13.3,9H    HERT
     1Z//)
      IF (IAFLG.EQ. 1)WRITE(6,7000)
      WRITE(6,5061)FR,XNSC,OVERSC
 5061 FORMAT(1H ,    7HSCANNER//
     1  T6,30HFRAME RATE                       ,F10.3,17H    FRAMES/SECONL
     1/
     2  T6,30HSCAN EFFICIENCY                  ,F10.3/
     3  T6,30HOVERSCAN RATIO                   ,F10.3//)
      WRITE(6,5071)CUTOFF,FELECT,XY,XYL,XK,FMAXF
 5071 FORMAT(1H ,    11HELECTRONICS//
     1  T6,30HPREAMP,LOW FREQ 3-DB CUT-ON      ,F10.3,9H    HERTZ/
     2  T6,30HAMPLIFIER,3-DB POINT             ,F10.3,9H    HERTZ/
     6  T6,30HE/O LED WIDTH                    ,F10.5,9H    MRAD./
     7  T6,30HE/O LED LENGTH                   ,F10.5,9H    MRAD./
     4  T6,30HAPERTURE CORRECTION AMPLITUDE    ,F10.3/
     5  T6,30HAPERTURE CORRECTION FREQUENCY    ,F10.0,9H    HERTZ//)
      IF (IAFLG .NE. 1)WRITE(6,5010)
      WRITE(6,5081)
 5081 FORMAT(1H ,    7HDISPLAY/)
      IF(KKK.EQ.0)WRITE(6,5083)XA,YA,BRITE
      IF(KKK.EQ.1)WRITE(6,5086)XA,YA,BRITE
      IF(KKK.EQ.2)WRITE(6,5089)
 5083 FORMAT(1H ,T6,30HTYPE                              ,11HCRT DISPLAY/
     1  T6,30HX SPOT SIZE                      ,F10.3,9H    MRAD./
     2  T6,30HY SPOT SIZE                      ,F10.3,9H    MRAD./
     3  T6,30HAVERAGE BRIGHTNESS               ,F10.3,16H    FT. LAMBERTS/
     4/)
 5086 FORMAT(1H ,T6,30HTYPE                              ,11HLED DISPLAY/
     1  T6,30HX LED SIZE                       ,F10.3,9H    MRAD./
     2  T6,30HY LED SIZE                       ,F10.3,9H    MRAD./
     3  T6,30HAVERAGE BRIGHTNESS               ,F10.3,16H    FT. LAMBERTS/
     4/)
 5089 FORMAT(1H ,T6,30HTYPE                              ,10HNO DISPLAY//)
      IF (IAFLG .EQ.1)WRITE(6,7000)
      WRITE(6,5092)HFOV,VFOV,XMAG,FACT,XNET
 5092 FORMAT(1H ,6HSYSTEM//
     1  T6,30HHORIZONTAL FOV                   ,F10.3,11H    DEGREES/
     2  T6,30HVERTICAL FOV                     ,F10.3,11H    DEGREES/
     3  T6,30HMAGNIFICATION                    ,F10.3/
     4  T6,30HWFOV/NFOV                        ,F10.3/
     5  T6,30HNOISE EQUIV. DELTA T             ,F10.3,13H    DEGREES C//)
      IF(XSIGLS.EQ.0.0.AND.YSIGLS.EQ.0.0.AND. XML(1).EQ.1.0.AND. XML(10)
     1.EQ.1.0.AND. YML(1).EQ.1.0.AND. YML(10).EQ.1.0)GO TO 5095
      WRITE(6,5091)XSIGLS,YSIGLS
 5091 FORMAT(1H ,    13HSTABILIZATION//
     3  T6,30HSYSTEM STATE                     ,12HUNSTABILIZED/
     1  T6,30HX VIBRATION CONSTANT             ,F10.3/
     2  T6,30HY VIBRATION CONSTANT             ,F10.3//)
      GO TO 5100
 5095 WRITE(6,5096)
 5096 FORMAT(1H ,    13HSTABILIZATION//
     3  T6,30HSYSTEM STATE                     ,10HSTABILIZED/
     1  T6,40HX VIBRATION CONSTANT                       0.00/
     2  T6,40HY VIBRATION CONSTANT                       0.00/ /)
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5100 WRITE(6,5101)EYETM,SNR
5101 FORMAT(1H ,15HSTANDARD INPUTS//
     1   T6,30HEYE INTEGRATION TIME                    ,F10.3,10H   SECONDS/
     2  T6,30HTHRESHOLD SIGNAL/NOISE                   ,F10.3//)
     IF (IAFLG .NE. 1)WRITE(6,5010)
     WRITE(6,5400)
5400 FORMAT(1H ,22HATMOSPHERIC PARAMETERS/)
     IF(Z1.EQ.1.0.AND.Z2.EQ.0.0) GO TO 6000
     IF(SIGMA(1).EQ.R(50)) GO TO 5430
     IF(SIGMA(1).EQ.R(54)) GO TO 5420
6000 CONTINUE
     IF(ISTATE.NE.0.0) GO TO 5410
     IF(RVIS.LE.1.0) RH=100.0
     IF(RVIS.GT.23.0)WRITE(6,5402)
     IF(RVIS.LE.23.0.AND.RVIS.GT.10.0)WRITE(6,5403)
     IF(RVIS.LE.10.0.AND.RVIS.GT. 6.0)WRITE(6,5404)
     IF(RVIS.LE. 6.0.AND.RVIS.GT. 3.0)WRITE(6,5405)
     IF(RVIS.LE. 3.0.AND.RVIS.GT. 1.0)WRITE(6,5406)
     IF(RVIS.LE. 1.0.AND.RVIS.GT. 0.5)WRITE(6,5407)
     IF(RVIS.LE. 0.5.AND.RVIS.NE. 0.0)WRITE(6,5408)
5402 FORMAT(T6,30HCONDITION                             ,10HVERY CLEAR)
5403 FORMAT(T6,30HCONDITION                             ,10H     CLEAR)
5404 FORMAT(T6,30HCONDITION                             ,10HLIGHT HAZE)
5405 FORMAT(T6,30HCONDITION                             ,10H      HAZE)
5406 FORMAT(T6,30HCONDITION                             ,10HHEAVY HAZE)
5407 FORMAT(T6,30HCONDITION                             ,9HLIGHT FOG)
5408 FORMAT(T6,30HCONDITION                             ,9HHEAVY FOG)
     WRITE(6,5401)RVIS,RH,AIRTMP
5401 FORMAT(
     1    T6,30HVISIBILITY RANGE                       ,F10.3,14H    KILOMETERS/
     2    T6,30HRELATIVE HUMIDITY                      ,F10.3,11H    PERCENT/
     3    T6,30HAIR TEMPERATURE                        ,F10.3,13H    DEGREES C/)
     GO TO 5450
5410   CONTINUE
     IF(ISTATE.NE.1.0) GO TO 5412
     RVIS=12.0
     WRITE(6,5411)
     WRITE(6,5401)RVIS,RH,AIRTMP
5411   FORMAT(T6,30HCONDITION                             ,10HLIGHT RAIN)
     GO TO 5450
5412   CONTINUE
     IF(ISTATE.NE.2.0) GO TO 5414
     RVIS=6.0
     WRITE(6,5413)
     WRITE(6,5401)RVIS,RH,AIRTMP
5413 FORMAT(T6,30HCONDITION                             ,13HMODERATE RAIN)
     GO TO 5450
5414 CONTINUE
     IF(ISTATE.NE.3.0) GO TO 5416
     RVIS=2.0
     WRITE(6,5415)
     WRITE(6,5401)RVIS,RH,AIRTMP
5415 FORMAT(T6,30HCONDITION                             ,10HHEAVY RAIN)
     GO TO 5450
5416 CONTINUE
     IF(ISTATE.NE.4.0) GO TO 5418
     RVIS=0.5
     RH=100.0
     WRITE(6,5417)
     WRITE(6,5401)RVIS,RH,AIRTMP
5417 FORMAT(T6,30HCONDITION                             ,15HVERY HEAVY RAIN)
     GO TO 5450
```

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5418 CONTINUE
      IF(ISTATE.EQ.31.0) WRITE(6,5441)
5441 FORMAT(1H1,1H ,40H**********YOU ARE MISSING THE  SCAT CARD*)
      IF(ISTATE.EQ.41.0)WRITE(6,5442)
5442 FORMAT(1H1,1H ,40H**********YOU ARE MISSING THE  TOTL CARD*)
      WRITE(6,5419)
5419 FORMAT(1H1,1H ,40H************YOUR ISTATE IS NOT RECOGNIZED)
      IF (IAFLG .EQ. 1)GO TO 1000
      CALL EXIT
5420 CONTINUE
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,5400)
      WRITE(6,5421)
5421 FORMAT(T6,30HCONDITION
     134HBEER)S LAW ATTENUATION CALCULATION ,/)
      WRITE(6,5422)(SIGMA(I),WAVE(I),I=1,9)
5422 FORMAT(T6,21HTOTAL TRANSMISSION/KM,10X,
     121HWAVELENGTH (MICRONS),/,(T13,F7.3,27X,F7.3))
      GO TO 5450
5430 CONTINUE
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,5400)
      WRITE(6,5431)RH,AIRTMP
5431 FORMAT(//
     1    T6,30HRELATIVE HUMIDITY                ,F10.3,11H    PERCENT/
     2    T6,30HAIR TEMPERATURE                  ,F10.3,13H    DEGREES C/)
      WRITE(6,5432)
5432 FORMAT(T6,30HCONDITION                          ,33HBEER*S LAW SCATTERI
     1NG CALCULATION)
      WRITE(6,5433)(SIGMA(I),I=3,9),(WAVE(I),I=3,9)
5433 FORMAT(//1H ,T6,38HSCATTERING TRANSMISSION PER KILOMETER:/,T10,7F7
     1.3//T6,21HWAVELENGTH (MICRONS):/,T10,7F7.3//)
5450 CONTINUE
      IF (IAFLG .EQ. 1 )WRITE(6,7000)
      WRITE(6,5481)XLTAR,XHTAR,DETEMP,TBAC
5481 FORMAT(1H ,      19HTARGET & BACKGROUND//
     1    T6,30HTARGET LENGTH                    ,F10.3,10H    METERS/
     2    T6,30HTARGET WIDTH                     ,F10.3,10H    METERS/
     3    T6,30HTARGET DELTA T                   ,F10.3,13H    DEGREES C/
     6    T6,30HBACKGROUND TEMPERATURE           ,F10.3,13H    DEGREES C//)
      WRITE(6,5491)IRMIN,IRMAX,IDELTR,IRDIN,IRDAX,IDELX
5491 FORMAT(1H ,      18HRANGE REQUIREMENTS//
     1    T6,30HMIN. REQUIRED RANGE FOR RECOG.,I10,10H    METERS/
     2    T6,30HMAX. REQUIRED RANGE FOR RECOG.,I10,10H    METERS/
     3    T6,30HRANGE INCREMENTS FOR RECOG.   ,I10,10H    METERS/
     4    T6,30HMIN. REQUIRED RANGE FOR DETEC.,I10,10H    METERS/
     5    T6,30HMAX. REQUIRED RANGE FOR DETEC.,I10,10H    METERS/
     6    T6,30HRANGE INCREMENTS FOR DETEC.   ,I10,10H    METERS//)
C**
C**                                                     FOR2 INPUTS
C**
      IF (IAFLG .NE. 1)WRITE(6,5010)
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,5211)FQQ,XD,YD,XE,XB
      WRITE(6,5201)FQ,XD,YO,XTV,YTV,XML,YML
5211 FORMAT(1H ,14HTEMPORAL MTF*S//
     1    1H ,22HFREQ. (LOG HERTZ)       ,10F5.2/
     1    1H ,22H---------------------- ,10(5H ----)//
     2    1H ,22HDETECT. ROLLOFF MTF(X)  ,10F5.2/
     3    1H ,22HDETECT. ROLLOFF MTF(Y)  ,10F5.2/
     4    1H ,22HELECTRONIC MTF          ,10F5.2/
     5    1H ,22HBOOST MTF               ,10F5.2//)
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5201 FORMAT(1H ,24HSPATIAL COMPONENTS MTF S//
     1    1H ,22HFREQ. (CYC./MRAD.)          OF5.2/
     1    1H ,22H----------------------  ,10(5H ----)//
     2    1H ,22HOPTICS MTF (X)            ,10F5.2/
     3    1H ,22HOPTICS MTF (Y)            ,10F5.2/
     4    1H ,22HVIDICON MTF (X)           ,10F5.2/
     5    1H ,22HVIDICON MTF (Y)           ,10F5.2/
     6    1H ,22HSTABILIZATION MTF (X)     ,10F5.2/
     7    1H ,22HSTABILIZATION MTF (Y)     ,10F5.2//)
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,5221)F,S
5221 FORMAT(1H ,37HNOISE POWER SPECTRUM (VOLTS/SQRT(HZ))//
     1    1H ,18HFREQ.(LOG HERTZ)          ,4F6.2,6F5.2/
     2    1H ,18HPOWER(TIMES 1E-9)         ,4F6.2,6F5.2//)
      WRITE(6,5231)XLMBA,DDSTAR
5231 FORMAT(1H ,    36HD* OF DETECTOR (CM.*SQRT(HZ.) /WATT)//
     1    1H ,22HWAVELENGTH (MICRONS)      ,10F5.2/
     2    1H ,22HD* (TIMES 1E10)           ,10F5.2//)
      IF (IAFLG .NE. 1)WRITE(6,5010)
      WRITE(6,5251)BETA,XNMB,XNUM,PRO
5251 FORMAT(1H ,43HDETECTION & RECOGNITION PROBABILITY DENSITY//
     1    1H ,18HDETECTION FREQ.           ,4F6.2,6F5.2/
     2    1H ,18HBEST RECOG. FREQ.         ,4F6.2,6F5.2/
     3    1H ,18HWORST RECOG. FREQ.        ,4F6.2,6F5.2/
     3    1H ,18HPROBABILITY               ,4F6.2,6F5.2//)
      IF (IAFLG .NE. 1)GO TO 9000
9001 WRITE(6,7005)
7005 FORMAT(34(/),5H '|',,11(/),
    157H ENTER =FIX= TO CORRECT ANY BAD ENTRIES OR =GO= TO BEGIN ,
    213HCOMPUTATIONS.)
      READ(5,1030)OK
      IF (OK .EQ. R(67))GO TO 1000
      IF (OK .NE. R(66))GO TO 9001
9000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE READF(T)
C*
C*    THIS SUBROUTINE READS INPUT VARIABLES IN FREE FIELD
C*    FORMAT. IT IS SYSTEM DEPENDENT AND MUST
C*    HAVE TWO DIFFERENT VERSIONS - ONE FOR THE  CDC6600
C*    AND ONE FOR THE IBM360/44.DATA IS READ INTO THE T ARRAY.
C*
C*    THIS IS THE CDC6600 VERSION. IT USES THE FORTRAN
C*    FREE FIELD INPUT WHICH IS AVAILABLE UNDER SCOPE 4.2.
C*
      DIMENSION T(10)
C*    READ(5,*)(T(I),I=1,10)
      RETURN
      END
```

```
      SUBROUTINE MRTINP(RVIS,RANGE,AIRTMP, RH,WAVE1,WAVE2,IPRINT,IJK,
     1ISTATE,AFCRL,PRO,XNUM,TBAC,XNMB,BETA,II,KK)
      REAL IRTRAN
      DIMENSION FFT(20),XXMRT(20),XXXRT(20),WFOV(20),IRTRAN(161),
     1AFCRL(161),TRTRAN(161),DDT(50),XDR(50),SOME(50),WAVE(9),SIGMA(9),
     2XPR(50),PRO(10),BETA(10),XNMB(10),XNUM(10)
      DIMENSION XINPUT(10),OUTPUT(10)
       DIMENSION TSE(50),SSE(50),XFRW(50),DRTX(50)
      COMMON/NAME4/ XM, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,RMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,RSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLS,XA,YA,KKK,
     3IOTAU,VEL,RELECT
      COMMON /SPCATM/WAVE,SIGMA
      COMMON/NAME5/IKOUNT,XMAG,FSTAR,FELECT
      COMMON/NAME1/XDR,DDT,TSE,SSE,SOME,XFRW,DRTX,DETEM ,FFT,XXXRT
      COMMON/NAME3/JFLAG,JPRINT,DDTT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME8/XXMRT,Z3,Z4
       COMMON/NAME6/DXDR(50),DDDT(50),DDRTX(50)
      LW=IFIX((WAVE2-WAVE1)/0.1)+1
       JPRINT=0
      XL=1./DELTAX/20.
      FT=0.0
      DO 102 KK=1,20
      FT=FT+XL
  102 FFT(KK)=FT
       DO 600 KK=1,20
      XXXRT(KK)=XXMRT(KK)
      XXMRT(KK)=XXMRT(KK)*(3.5/FFT(KK)/7.0*FFT(20))**0.5
  600 CONTINUE
C
C     WFOV SCALED MRT
      DO 7119 J=1,20
 7119 WFOV(J)=FFT(J)/FACT
      XRH=0.01*RH
C
C
C     RANGE DO LOOP FOR RECOGNITION
C
C
      DO 1066 IJK=1,LUPO
      KK=0
      TTAR=TBAC+DETEMP
      DO 500 II=IRMIN,IRMAX,IDELTR
      KK=KK+1
      RANGE=II/1000.0
      XR=RANGE*1000.0
      DO 2 JJ=1,LW
    2 IRTRAN(JJ)=1.0
      CALL ATMCRL(RVIS,RANGE,AIRTMP,XRH,WAVE1,WAVE2,IPRINT,IJK,ISTATE,
     1AFCRL,IAFLG)
      DO 5300 MISS=1,LW
 5300 IRTRAN(MISS)=AFCRL(MISS)*IRTRAN(MISS)
      CALL QTFE(0.1,IRTRAN,TRTRAN,LW)
      TRANS=TRTRAN(LW)/(WAVE2-WAVE1)
      DDT(KK)=TRANS
      DETE=DETEMP*TRANS
      TLENG=XLTAR/RANGE
      DETE=DETE*(TLENG/7.0*FFT(20))**0.5
C     X-MRT FOR DELTA T AND DELTA P
       CALL ALINEY(FRW,DETE,FFT,XXMRT,20)
      XXNUM=XHTAR*FRW/RANGE
```

```
      CALL ALINEY(PROB,XXNUM,PRO,XNUM,10)
      IF(PROB.LT.0.0) PROB=0.00
      XPR(KK)=PROB
      CALL ALINEY(PROB,XXNUM,PRO,XNMB,10)
      IF(PROB.LT.0.0) PROB=0.00
        DDDT(KK)=DDT(KK)
        DXDR(KK)=RANGE
  500 DDRTX(KK)=PROB
C
C
C     DETECTION
C
C
      II=0
      DO 6065 JK=IRDIN,IRDAX,IDELX
      II=II+1
      RANGE=JK/1000.0
      XR=RANGE*1000.0
      DO 6066 KLM=1,LW
 6066 IRTRAN(KLM)=1.0
        CALL ATMCRL(RVIS,RANGE,AIRTMP,XRH,WAVE1,WAVE2,IPRINT,IJK,ISTATE,
     1AFCRL,IAFLG)
      DO 5790 MISS=1,LW
 5790 IRTRAN(MISS)=AFCRL(MISS)*IRTRAN(MISS)
      CALL QTFE(0.1,IRTRAN,TRTRAN,LW)
      TRANS=TRTRAN(LW)/(WAVE2-WAVE1)
      DOT(II)=TRANS
      DETE=DETEMP*TRANS
      TLENG=XLTAR/RANGE
      DETE=DETE*(TLENG/7.0*FFT(20))**0.5
      XDR(II)=RANGE
C     X MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,FFT,XXMRT,20)
      XXNUM=XHTAR*FRW/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
      DRTX(II)=PROB
C     WFOV X-MRT FOR DELTA T AND DELTA P
      CALL ALINEY(FRW,DETE,WFOV,XXMRT,20)
      XXNUM=XHTAR*FRW/RANGE
      CALL ALINEY(PROB,XXNUM,PRO ,BETA,10)
      IF(PROB.LT.0.0) PROB=0.00
 6065 XFRW(II)=PROB
 1066 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DEVICE(XMTF,YMTF,XXMTF,YYMTF,FREQ,XMXM,YMYM,FURD,FQ,XO,
     1YO,XD,YD,XB,XE,XTV,YTV,XML,YML,FQQ)
      REAL IOTAU
      COMMON /DEVMDT/XNMTF(20),YNMTF(20)
      DIMENSION FURD(20)
      DIMENSION XXMTF(20),YYMTF(20)
      DIMENSION XMTF(20),YMTF(20)
      DIMENSION FREQ(20)
      DIMENSION XMXM(20),YMYM(20)
      DIMENSION FQ(10),FQQ(10),XEMTF(20),YEMTF(20)
      DIMENSION XOMTF(20),YOMTF(20),XO(10),YO(10)
      DIMENSION XDMTF(20),YDMTF(20)
      DIMENSION XDPMTF(20),YDPMTF(20),XD(10),YD(10)
      DIMENSION ELMTF(20),BMTF(20),XB(10),XE(10)
      DIMENSION XTVMTF(20),YTVMTF(20),XTV(10),YTV(10)
      DIMENSION XDSMTF(20),YDSMTF(20)
      DIMENSION XMTFLS(20),YMTFLS(20),XML(10),YML(10)
      DIMENSION XEYMTF(20),YEYMTF(20)
      DIMENSION XGBMTF(20),YGBMTF(20),RQQ(10)
      DIMENSION XINPUT(10),OUTPUT(10)
      COMMON/NAME3/JFLAG,JPRINT,QQIT,DETEM ,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      COMMON /BLUR/ABLUR
      COMMON/NAME2/XOMTF,XGBMTF,XDMTF,XDPMTF,ELMTF,BMTF,XTVMTF,XEMTF,
     1XDSMTF,XMTFLS,XEYMTF
      DO 40 LL=1,10
   40 RQQ(LL)=10.**FQQ(LL)
      DO 41 K=1,10
41    RQQ(K)=RQQ(K)/VEL
      DF=FMAX/20.0
      C=-DF
      DO 612 J=1,20
      C=C+DF
      FREQ(J)=C
      CALL OPTIC(XO,YO,FQ,CRUP,CROP,C)
      YOMTF(J)=CROP
      CALL GEBLUR(XRUP,YRUP,C)
      XGBMTF(J)=XRUP
      YGBMTF(J)=YRUP
      CALL DETEC(XD,YD,RQQ,XDM,YDM,DRUP,DROP,C)
      XDMTF(J)=XDM
      YDMTF(J)=YDM
      XOMTF(J)=CRUP
      XDPMTF(J)=DRUP
      YDPMTF(J)=DROP
      CALL EM(XE,XB,RQQ,ERUP,FRUP,C)
      ELMTF(J)=ERUP
  501 BMTF(J)=FRUP
      CALL CAMRA(XTV,YTV,FQ,GRUP,GROP,C)
      XTVMTF(J)=GRUP
      YTVMTF(J)=GROP
      CALL EMIT(RUP,ROP,C)
      XEMTF(J)=RUP
      YEMTF(J)=ROP
      CALL DSPLY(ZUP,ZOP,C)
      XDSMTF(J)=ZUP
      YDSMTF(J)=ZOP
      CALL STABLE(XML,YML,FQ,HRUP,ORUP,C)
```

```
      YMTFLS(J)=HRUP
      YMTFLS(J)=ORUP
      CALL EYEBAL(URP,ORP,C)
      XEYMTF(J)=URP
      YEYMTF(J)=ORP
C
C     TOTAL SYSTEM MTF
C
      XMTF(J)=XOMTF(J)*XDMTF(J)*XDPMTF(J)*ELMTF(J)*BMTF(J)*
     3XTVMTF(J)*XEMTF(J)*XDSMTF(J)*XMTFLS(J)*XGBMTF(J)
      YMTF(J)=YOMTF(J)*YDMTF(J)*1.0000000*YTVMTF(J)*YEMTF(J)*YDSMTF(J)*
     4YMTFLS(J)*YGBMTF(J)
      XXMTF(J)=ELMTF(J)*BMTF(J)*XTVMTF(J)*XEMTF(J)*XMTFLS(J)*XDSMTF(J)
      YYMTF(J)=YTVMTF(J)*YEMTF(J)*YDSMTF(J)*YMTFLS(J)
      XMXM(J)=XMTF(J)
      YMYM(J)=YMTF(J)
      FURD(J)=FREQ(J)
      XNMTF(J)=XXMTF(J)
      YNMTF(J)=YYMTF(J)
  612 CONTINUE
      IF(JPRINT.EQ.0)GO TO 8000
      IF (IAFLG .EQ. 1)WRITE(6,7000)
 7000 FORMAT(34(/),5H *|*,,10X,18HDEVICE OUTPUT DATA,//)
      WRITE(6,3001)
 3001 FORMAT(1H1,22X,31HX MODULATION TRANSFER FUNCTIONS)
      WRITE(6,3999)
      WRITE(6,3000)(FREQ(I),XOMTF(I),XGBMTF(I),XDMTF(I),XDPMTF(I),ELMTF(
     1I),BMTF(I),XTVMTF(I),XEMTF(I),XDSMTF(I),XMTFLS(I),XEYMTF(I),I=1,20
     2)
 3999 FORMAT(1H , 4HFREQ,1X,6H OPTIC,1X,5HGBLUR,1X,5HDETEC,1X,5HRSPNS
     1,1X, 5HELECT,1X,5HBOOST,1X,5HVIDCN,2X,3HLED,2X,5HDSPLY,2X,3HLOS,4X,
     23HEYE//)
 3000 FORMAT(1X,F5.2,11F6.2)
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,3002)
 3002 FORMAT(1H1,31HY MODULATION TRANSFER FUNCTIONS)
      WRITE(6,3003)(FREQ(I),YOMTF(I),YGBMTF(I),YDMTF(I),YTVMTF(I),YEMTF
     5(I),YDSMTF(I),YMTFLS(I),YEYMTF(I),I=1,20)
 3003 FORMAT(1H ,6X,4HFREQ,2X,5HOPTIC,1X,6HGOBLUR,2X,5HDETEC,2X,5HVIDCN,
     14X,3HLED,2X,5HDSPLY,4X,3HLOS,4X,3HEYE,//(6X,F5.2,8F7.2))
 8000 CONTINUE
      IF(XXMTF(20).LT.0.01.AND.YYMTF(20).LT.0.01) GO TO 5000
C
C
C     XY, XYL MUST BOTH BE ZERO OR NON-ZERO, SAME FOR XA,YA
C
C
C
C
C     FIND ZERO FOR NOISE FILTER
C
C
      IF(XY.EQ.0.0.AND.XA.GT.0.0) BLUM=AMAX1(1.0/XA,1.0/YA)
      IF(XY.GT.0.0.AND.XA.EQ.0.0) BLUM=AMAX1(1.0/XY,1.0/XYL)
      IF(XY.GT.0.0.AND.XA.GT.0.0) BLUM=AMAX1(AMAX1(1.0/XA,1.0/YA)
     1,AMAX1(1.0/XY,1.0/XYL))
      IF(XY.EQ.0.0.AND.XA.EQ.0.0) BLUM=10000.0
      DOOM=FURD(20)
      IF(DOOM.GT.BLUM) GO TO 5000
      TACO=2.*DOOM
 5100 CONTINUE
      CALL EM(XE,XB,RQQ,ERUP,FRUP,TACO)
```

```
      CALL CAMRA(XTV,YTV,FQ,GRUP,GROP,TACO)
      CALL EMIT(RUP,ROP,TACO)
      CALL DSPLY(ZUP,ZOP,TACO)
      CALL STABLE(XML,YML,FQ,HRUP,ORUP,TACO)
      FTMX=ERUP*FRUP*GRUP*RUP*ZUP*HRUP
      FTMY=GROP*ROP*ZOP*ORUP
      IF(FTMX.GT.0.01.OR.FTMY.GT.0.01) TACO=2.*TACO
      IF(FTMX.GT.0.01.OR.FTMY.GT.0.01) GO TO 5100
      DOOM=TACO
      DDF=TACO/20.0
      CC=-DDF
      DO 5001 KLM=1,20
      CC=CC+DDF
      FURD(KLM)=CC
      CALL EM(XE,XB,RQQ,ERUP,FRUP,CC)
      CALL CAMRA(XTV,YTV,FQ,GRUP,GROP,CC)
      CALL EMIT(RUP,ROP,CC)
      CALL DSPLY(ZUP,ZOP,CC)
      CALL STABLE(XML,YML,FQ,HRUP,ORUP,CC)
      XXMTF(KLM)=ERUP*FRUP*GRUP*RUP*ZUP*HRUP
      YYMTF(KLM)=GROP*ROP*ZOP*ORUP
5001  CONTINUE
5000  CONTINUE
      IF(JPRINT.EQ.0)GO TO 8001
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,3010)
3010  FORMAT(1H1, 5X,22HPREDICTED SYSTEM MTF,9X,16HPREDICTED NOISE
     113HFILTERING MTF)
      WRITE(6,3011)(FREQ(I),XMTF(I),YMTF(I),FURD(I),XXMTF(I),YYMTF(I),
     1I=1,20)
3011  FORMAT(1H ,1X,4HFREQ,8X,5HX MTF,8X,5HY MTF,5X,4HFREQ,8X,5HX MTF,
     18X,5HY MTF//(1X,F5.2,2F13.2,F9.2,2F13.2))
8001  CONTINUE
      DO 1 IJ=1,20
      XMTF(IJ)=XMTF(IJ)*XEYMTF(IJ)
      YMTF(IJ)=YMTF(IJ)*YEYMTF(IJ)
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OPTIC(XO,YO,FREQ,CRUP,CRUP,FLAM)
C
C     OPTICAL MTF
C
      DIMENSION XO(10),YO(10),FREQ(10)
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,HRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXC,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FLECT
      CRAP=XO(1)
      IF(CRAP.GT.0.0) CALL ALINEY(CRUP,FLAM,XO,FREQ,10)
      IF(CRAP.GT.0.0) CALL ALINEY(CROP,FLAM,YO,FREQ,10)
      IF(CRAP.GT.0.0) GO TO 300
      XXF=FLAM/FOC/2.54
      A=XXF*XLAMB*0.1*FNUMB
      IF(A.LE.1.0) CRUP=2.0/3.14*(ARCOS(A)-A*(1.-A**2)**0.5)
      IF(A.GT.1.0) CRUP=0.0
      CROP=CRUP
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GEBLUR(XRUP,YRUP,FLAM)
C
C  OPTICAL GEOMETRIC BLUR MTF
C
      COMMON /BLUR/ABLUR
      XRUP=EXP(-ABLUR*FLAM**2)
      YRUP=XRUP
      RETURN
      END
```

```
      SUBROUTINE DETEC(XD,YD,FREQ,XDM,YDM,DRUP,DROP,FLAM)
C
C     DETECTOR SPATIAL MTF
C
C
C     DETECTOR TEMPORAL RESPONSE
C
      REAL IOTAU
      DIMENSION XD(10),YD(10),FREQ(10)
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      XFDET=1./2./DELTAX
      YFDET=1./2./DELTAY
      IF(FLAM.EQ.0.0) GO TO 301
      XDM=SIN(3.14*FLAM/2.0/XFDET)/3.14/FLAM*2.0*XFDET
      YDM=SIN(3.14*FLAM/2.0/YFDET)/3.14/FLAM*2.0*YFDET
  301 IF(FLAM.EQ.0.0) XDM=1.0
      IF(FLAM.EQ.0.0) YDM=1.0
      DRAP=XD(1)
      IF(DRAP.GT.0.0) CALL ALINEY(DRUP,FLAM,XD,FREQ,10)
      IF(DRAP.GT.0.0) CALL ALINEY(DROP,FLAM,YD,FREQ,10)
      IF(DRAP.GT.0.0) GO TO 400
      DRUP=1./(1.+(FLAM/FSTAR)**2)**0.5
      DROP=DRUP
  400 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EM(XE,XB,FREQ,ERUP,FRUP,FLAM)
C
C     ELECTRONIC AND BOOST MTF
C
      REAL IOTAU
      DIMENSION XE(10),XB(10),FREQ(10)
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      ERAP=XE(1)
      IF(ERAP.GT.0.0) CALL ALINEY(ERUP,FLAM,XE,FREQ,10)
      IF(ERAP.GT.0.0) GO TO 500
      ERUP=1./(1.+(FLAM/FELECT)**2)**0.5
  500 CONTINUE
      FRAP=XB(1)
      IF(FRAP.GT.0.0) CALL ALINEY(FRUP,FLAM,XB,FREQ,10)
      IF(FRAP.GT.0.0) GO TO 501
      FRUP=(1.+((XK-1.)/2.)*(1.-COS(3.14*FLAM/FMAXF)))
  501 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CAMRA(XTV,YTV,FREQ,GRUP,GROP,FLAM)
C
C     TV CAMERA MTF
C
      DIMENSION XTV(10),YTV(10),FREQ(10)
      CALL ALINEY(GRUP,FLAM,XTV,FREQ,10)
      CALL ALINEY(GROP,FLAM,YTV,FREQ,10)
      RETURN
      END




      SUBROUTINE EMIT(RUP,ROP,FLAM)
C
C     LED EMITTER MTF
C
      REAL IOTAU
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MUM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      IF(XY.EQ.0.0) GO TO 708
      IF(FLAM.EQ.0.0) RUP=1.0
      IF(FLAM.EQ.0.0) ROP=1.0
      IF(FLAM.GT.0.0) RUP=SIN(3.14*FLAM*XY)/(3.14*FLAM*XY)
      IF(FLAM.GT.0.0) ROP=SIN(3.14*FLAM*XYL)/(3.14*FLAM*XYL)
  708 IF(XY.EQ.0.0) RUP=1.0
      IF(XYL.EQ.0.0) ROP=1.0
      RETURN
      END




      SUBROUTINE DSPLY(ZUP,ZOP,FLAM)
C
C     DISPLAY MTF
C
      REAL IOTAU
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MUM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      IF(KKK.GT.1) GO TO 807
      IF(KKK.EQ.0) ZUP=EXP(-XA*FLAM**2)
      IF(KKK.EQ.0) ZOP=EXP(-YA*FLAM**2)
      IF(KKK.EQ.1.AND.FLAM.EQ.0.0) ZUP=1.0
      IF(KKK.EQ.1.AND.FLAM.EQ.0.0) ZOP=1.0
      IF(KKK.EQ.1.AND.FLAM.GT.0.0) ZUP=SIN(3.14*FLAM*XA)/3.14/FLAM/XA
      IF(KKK.EQ.1.AND.FLAM.GT.0.0) ZOP=SIN(3.14*FLAM*YA)/3.14/FLAM/YA
  807 IF(KKK.GT.1) ZUP=1.0
      IF(KKK.GT.1) ZOP=1.0
      RETURN
      END
```

```
      SUBROUTINE STABLE(XML,YML,FRFQ,HRUP,ORUP,FLAM)
C
C     LOS STABILIZATION
C
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLS,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DIMENSION XML(10),YML(10),FRFQ(10)
      HRAP=XML(1)
      ORAP=YML(1)
      IF(HRAP.GT.0.0) CALL ALINEY(HRUP,FLAM,XML,FRFQ,10)
      IF(ORAP.GT.0.0) CALL ALINEY(ORUP,FLAM,YML,FRFQ,10)
      IF(HRAP.EQ.0.0) HRUP=EXP(-XSIGLS*FLAM**2)
      IF(ORAP.EQ.0.0) ORUP=EXP(-YSIGLS*FLAM**2)
      RETURN
      END
```

```
      SUBROUTINE EYEBAL(URP,ORP,FLAM)
C
C     EYEBALL MTF
C
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DIMENSION SLS(9),XL(9.
      DATA SLS/1.,1.18,1.35,1.8,2.25,2.8,3.4,4.1,4.8/
      DATA XL/3.,2.,1.,0.,-1.,-2.,-3.,-4.,-5./
      XXXL=ALOG10(BRITE)
      CALL ALINEY(SSLS,XXXL,SLS,XL,9)
      GAMMA=SSLS*1.62666
      URP=EXP(-GAMMA*FLAM/XMAG)
      ORP=EXP(-GAMMA*FLAM/XMAG)
      RETURN
      END
```

```
      SUBROUTINE XNOISE(FO,CUTOFF,DDSTAR,XLMBA,GUMO,XB,FQQ)
      REAL IOTAU
      COMMON/NAME3/JFLAG,JPRINT,DDIT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DIMENSION DDSTAR(10),XB(10),FQQ(10)
      DIMENSION DSTAR(161)
      DIMENSION XLMBA(10)
      DIMENSION XINPUT(10),OUTPUT(10)
      FN=FNUMB
      DELAM=0.1
      XL=XW
      DO 612 J=1,LW
      XL=XL+DELAM
      CALL ALINEY(DD,XL,DDSTAR,XLMBA,10)
  612 DSTAR(J)=GUMO*DD*1.00E+10
      PI=3.14159
      CALL DWP(300.0,HZ,DSTAR,DELAM)
      CALL BDWT(FO,DELTAF,CUTOFF,XB,FQQ)
      BETA=ANGLE*0.0175
      IF(MOM.EQ.0) XNET=4.0*FN**2*DELTAF**0.5/PI/(SRTAD*2.54)/TA/TO/HZ/
     4(DISC**0.5)
      IF(MOM.EQ.1) XNET=4.0*FN**2*DELTAF**0.5/PI/(SRTAD*2.54)/TA/TO/HZ/
     4(DISC**0.5)*SIN(BETA)
      IF(MOM.EQ.2) XNET=4.0*FN**2*(PI*IOTAU/4.0)**0.5/PI/(SRTAD*2.54)
     5/TA/TO/HZ/(DISC**0.5)
      DDFF=PI*IOTAU/4.0
      IF(JPRINT.EQ.0) GO TO 1500
      IF (IAFLG.EQ. 1)WRITE(6,7000)
 7000 FORMAT(34(/),5H '|',,10X,18HXNOISE OUTPUT DATA,//)
      WRITE(6,1000) HZ,DELTAF,DDFF
 1000 FORMAT(1H1,27HINTEGRAL OF D-STAR*W-PRIME*,E10.3/,1H ,22HEXACT NOIS
     1E BANDWIDTH*,E10.3/,1H ,22HWHITE NOISE BANDWIDTH*,E10.3/)
      WRITE(6,1011) VEL
 1011 FORMAT(1H ,24HSCAN VELOCITY IN MR/SEC*,E10.3)
      IF(MOM.EQ.0) WRITE(6,155) XNET
      IF(MOM.EQ.1) WRITE(6,161) XNET
      IF(MOM.EQ.2) WRITE(6,666) XNET
  155 FORMAT(1H ,22HDET NOISE LIMITED NET*,E10.3)
  161 FORMAT(1H ,23HSHOT NOISE LIMITED NET*,E10.3)
  666 FORMAT(1H ,16HWHITE NOISE NET*,E10.3)
 1500 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DWF(T,HZ,DSTAR,DELAM)
      REAL K,LAM
      REAL IOTAU
      DIMENSION DSTAR(161),RAD1(161),A(161)
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DATA H/6.63E-34/,C/3.00E+08/,K/1.38E-23/
      C1=2.0*H*C**2
      C2=H*C/K
      LAM=XW*1.00E-06
      DO 100 J=1,LW
      LAM=LAM+DELAM*1.00E-06
      D2=C2/(T*LAM)
      DD3=EXP(D2)
      D4=C2/(T**2)/LAM
      RAD1(J)=C1*D4*DD3/((DD3-1.)**2)/(LAM**5)
      RAD1(J)=RAD1(J)*DSTAR(J)
  100 CONTINUE
      CALL QTFE(DELAM,RAD1,A,LW)
      HZ=A(LW)*1.00E-10
      RETURN
      END
```

```
      SUBROUTINE BDWT(FO,DELTAF,CUTOFF,XB,FQQ)
      REAL IOTAU
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DIMENSION B(15),T(15)
      DIMENSION XB(10),FQQ(10)
      XFO=ALOG10(FO)
      CALL ALINEY(SFO,XFO,S,F,8)
      FM=FMAXF*VEL
      XLFREQ=0.5
      DO 10 J=1,15
      XLFREQ=XLFREQ+0.5
      CALL ALINEY(TT,XLFREQ,S,F,8)
      IF(TT.LT.0.0) TT=0.0
      FZERO=IOTAU/2.0
      FREQ=10.0**XLFREQ
      IF(FREQ.LT.CUTOFF) GG=0.0
      IF(FREQ.GE.CUTOFF) GG=1./(1.+((FREQ-CUTOFF)/FZERO)**2)**0.5
      IF(XK.EQ.0.0) CALL ALINEY(HH,XLFREQ,XB,FQQ,10)
      IF(XK.GT.0.0) HH=(1.+((XK-1.)/2.0)*(1.-COS(3.14*FREQ/FM)))
   10 T(J)=TT*(GG**2)*HH**2*10.**XLFREQ/SFO*2.30
      CALL QTFE(0.5,T,B,15)
      DELTAF=B(15)
      RETURN
      END
```

```
      SUBROUTINE XRING(CUTOFF,XH,FF,NXH,FFF,NS,A,NCH,ANS,N,GORN)
C
C
C      NCH = 1 INCLUDESS,    EQUALS 2 NO S
C      XH,FF ARRAYS TO BE INTEGRATED OVER
C      S,F POWER SPECTRUM OF NOIISE ARRAYS                        6
C      A EQUALS WIDTH OF THE BAR
C      XMAG = SYSTEM MAGIFICATIION
C      BB = DISPLAY BRIGHTNESS
C      NXH = NUMBER OF POINTS IN ARRAY XH
C      CUTOFF = LOW FREQUENCY CUTOFF
C      NS = NUMBER OF POINTS IN ARRAY S
C
C
      REAL IOTAU
      DIMENSION XH(1),FF(1),FFF(1),X(1000),GAM(10),BBB(10)
      COMMON/NAME4/ W, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,NOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DATA GAM/1.63,1.92,2.2,2.93,3.67,4.56,5.55,6.68,7.11,9.0/
C
C
C      BBB = LOG OF THE BRIGHTNESS
C
C
      BB=BRITE
      DATA BBB/3.,2.,1.,0.,-1.,-2.,-3.,-4.,-5.,-6./
       BBW=ALOG10(BB)
       CALL ALINEY(GAMM,BBW,GAM,BBB,10)
      GAMMA=GAMM/XMAG*GORN
      WEG=200.0
      IEG=200
      GF=AMAX1(A,1./FF(NXH))
      GF=1./GF
      DF=GF
100    CONTINUE
       DF=DF/2.
      CALL ALINEY(T,GF,XH,FF,NXH)
      IF(NCH.EQ.1) CALL ALINEY(G,GF,S,FFF,NS)
       IF(NCH.EQ.2) G=1.
      P=1.0-CUTOFF/(CUTOFF**2+GF**2)**0.5
      T=G*(T*EXP(-GAMMA*GF)*SINC(GF*A)*P)**N
      IF(T.GT.0.5+0.01) GF=GF+DF
      IF(T.GT.0.5+0.01) GO TO 100
      IF(T.LT.0.5-0.01) GF=GF-DF
      IF(T.LT.0.5-0.01) GO TO 100
      DELF=GF*30./WEG
C
C      WEG SHOULD AT LEAST EQUAL 100
C
      DELF=AMIN1(DELF,FF(NXH)/WEG)
       DO 200 J=1,IEG
      GF=J*DELF
      CALL ALINEY(T,GF,XH,FF,NXH)
      IF(NCH.EQ.1) CALL ALINEY(G,GF,S,FFF,NS)
      IF(G.LT.0.0) G=0.0
       IF(NCH.EQ.2) G=1.
      P=1.0-CUTOFF/(CUTOFF**2+GF**2)**0.5
      X(J)=G*(T*SINC(GF*A)*EXP(-GAMMA*GF)*P)**N
200    CONTINUE
       CALL QTFE(DELF,X,X,IEG)
```

```
      A1=X(IEG)*2.
      A2=DELF
      IF(NCH.EQ.2) GO TO 400
      CRASS=1.0+CUTOFF**2/DELF**2
      CCC=CRASS**0.5
      GRASS=1.0+DELF**2/CUTOFF**2
      GGG=GRASS**0.5
      FPRIME=0.0
      DO 300 LLL=1,8
      SQ1=S(LLL)
      SQ2=S(LLL+1)
      IF(SQ1.GT.1.0.AND.SQ2.EQ.1.0) FPRIME=FFF(LLL+1)
  300 CONTINUE
      IF(FPRIME.EQ.0.0) GO TO 400
      A2=0.3*DELF-1.*CUTOFF*ALOG(DELF/CUTOFF+GGG)+CUTOFF*0.5*ATAN(DELF/
     1CUTOFF)+FPRIME/2.*ALOG(DELF/4.0/CUTOFF/(CUTOFF**2/DELF**2+CRASS
     2-2.0*CUTOFF/DELF*CCC)/CCC)
  400 ANS=A1+A2*2.0
      RETURN
      END
```

```
      SUBROUTINE PLANK(T1,T2,P,ARTRAN,RSPX)
C
C
C      DELTA W IN W/CM-2/MICRON, TRANSMISSION AND D-STAR UNITLESS. T1
C      CALCULATES INTEGRAL OF DELTA W X TRANSMISSION X D-STAR WHERE
C      AND T2 IN DEGREES C, P IN W/CM-2
C
C
      REAL IOTAU
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAU,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DIMENSION ARTRAN(100),RSPX(20)
      DIMENSION RAD1(100),RAD2(100),RAD3(100),A(100)
      DATA C2/1.438E+04/,CX/3.7399E+04/
      T1T1=T1+273.
      T2T2=T2+273.
      XLAM=XW
      DO 100 J=1,LW
      XLAM=XLAM+0.1
      RAD1(J)=CX/(XLAM**5.0)/(EXP(C2/XLAM/T1T1)-1.)
      RAD2(J)=CX/(XLAM**5.0)/(EXP(C2/XLAM/T2T2)-1.)
  100 RAD3(J)=ARTRAN(J)*RSPX(J)*(RAD1(J)-RAD2(J))
      CALL QTFE(0.1,RAD3,A,LW)
      P=A(LW)
      RETURN
      END
```

```
      SUBROUTINE MDT(XMXM,YMYM,FFFF,XCTFF,H,SNR,DELTAF)
      DIMENSION XMXM(1),YMYM(1),FFFF(1),H(1)
      DIMENSION DMDT(25),DMRAD(25)
      DIMENSION XINPUT(10),OUTPUT(10)
      COMMON /SNRMDT/DXMTF(20),DYMTF(20)
      COMMON /DEVMDT/XNMTF(20),YNMTF(20)
      COMMON/NAME3/JFLAG,JPRINT,DDTT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,ZNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLC,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DO 101 KK=1,20
      DXMTF(KK)=XMXM(KK)*XNMTF(KK)
      DYMTF(KK)=YMYM(KK)*YNMTF(KK)
101   CONTINUE
      XL=DELTAX/5.0
      KK=0
      XSIDE=0.0
102    CONTINUE
      KK=KK+1
      XSIDE=XSIDE+XL
      YSIDE=XSIDE
      CALL XRING(XCTFF,DXMTF,FFFF, 20,H,8,XSIDE,1,ANS,2,1.0)
      CALL XRING(0.0,DYMTF,FFFF, 20,H,8,YSIDE,2,ANT,2,1.0)
      QD=ANS/2.0*ANT
      CALL XRING(0.0,XMXM,FFFF, 20,H,8,XSIDE,2,ANS,2,1.0)
      CALL XRING(0.0,YMYM,FFFF, 20,H,8,YSIDE,2,ANT,2,1.0)
      QQD=ANS*ANT
      DMDT(KK)=XNET*SNR/XSIDE/YSIDE/QQD*(DELTAY*VEL*QD/DELTAF/FR/EYETM/O
     1VERSC)**0.5
      DMRAD(KK)=1.0/XSIDE
      IF(KK.EQ.25) GO TO 103
      IF(DMDT(KK).GE.0.001.OR.KK.LT.10) GO TO 102
103    CONTINUE
      IF(JPRINT.EQ.0) GO TO 1000
      IF (IAFLG .EQ. 1)WRITE(6,7000)
7000  FORMAT(34(/),5H '|',,10X,15HMDT OUTPUT DATA,//)
      WRITE(6,84)
   84 FORMAT(1H1,40HPREDICTED MINIMUM DETECTABLE TEMPERATURE)
      WRITE(6,83)(DMRAD(I),DMDT(I),I=1,KK)
   83 FORMAT(2X,17HTARGET SIZE<**-1,7X,3HMDT//(8X,E10.3,5X,E10.3))
1000  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ATMCRL(VIS,RANGE,TEMP,HUMIDY,WAVE1,WAVL2,IPRINT,IGO,IST
     AATE,AFCRL)
C
C
C     THIS SUBROUTINE COMPUTES GROUND LEVEL ATMOSPHERIC TRANSMISSION PER .1 MICRON
C     INTERVAL FOR ANY BAND BETWEEN 2.0 AND 16.0 MICRONS.  IT IS A SIMPLIFIED
C     VERSION OF LOWTRAN, THE AFCRL ATMOSPHERIC MODEL AS OF JUNE 1974.
C
C
C     DIMENSION AFCRL(161) IN THE CALLING ROUTINE.
C
C     INCLUDE THE STATEMENT WITH ARRAYS OF DIMENSION 9
C          COMMON /SPCATN/SPCLAM,SPCTRN
C     IN THE CALLING ROUTINE.  THESE TWO ARRAYS SUPPLY INFORMATION FOR OPTIONAL
C     BEERS LAW ROUTINES.  WHEN SUCH CALCULATIONS ARE REQUIRED, SPCLAM(1) IS AL-
C     WAYS EQUAL TO ATEW AND SPCLAM(2) IS ALWAYS 4 BLANKS.  THE OTHER 7 ELEMENTS
C     ARE WAVELENGTHS BETWEEN 2.0 AND 16.0 MICRONS CORRESPONDING TO DATA IN
C     SPCTRN.  FOR THE CASE OF A BEERS LAW ATTENUATION CALCULATION, SPCTRN(1)
C     EQUALS TOTL, SPCTRN(2) IS ALWAYS 4 BLANKS, AND THE OTHER 7 ELEMENTS ARE
C     TOTAL TRANSMISSIONS PER KILOMETER FOR EACH WAVELENGTH IN SPCLAM.  FOR THE
C     CASE OF A BEERS LAW SCATTERING CALCULATION, SPCTRN(1) EQUALS SCAT, SPCTRN(2)
C     IS ALWAYS 4 BLANKS, AND THE OTHER 7 ELEMENTS ARE SCATTERING TRANSMISSIONS
C     PER KILOMETER FOR EACH WAVELENGTH IN SPCLAM.  TOTAL TRANSMISSION IS CALCU-
C     LATED IN THIS CASE BY COMBINING THIS ROUTINE WITH THE ATMCRL ABSORPTION ROU-
C     TINE.  ALL COEFFICIENTS PER .1 MICRON INTERVAL ARE OBTAINED BY LINEAR INTER-
C     POLATION USING SUBROUTINE ALINEY.  CONSEQUENTLY, THIS SUBROUTINE IS NOW AN
C     INTEGRAL PART OF ATMCRL.
C
C
C
C     ARGUMENTS:
C            VIS - VISIBILITY RANGE IN KILOMETERS.
C            RANGE - PATHLENGTH IN KILOMETERS.
C            TEMP - TEMPERATURE IN DEGREES C FROM -29 DEGREES TO +38 DEGREES.
C            HUMIDY - RELATIVE HUMIDITY AS A DECIMAL.
C            WAVE1 - THE FIRST WAVELENGTH IN MICRONS FOR WHICH TRANSMISSION IS RE-
C                    QUIRED.  IT MUST BE A MULTIPLE OF .1 AND CAN BE FROM 2.0 TO
C                    15.9 MICRONS.
C            WAVE2 - THE LAST WAVELENGTH IN MICRONS FOR WHICH TRANSMISSION IS RE-
C                    QUIRED.  IT ALSO MUST BE A MULTIPLE OF .1 AND CAN BE FROM 2.1
C                    TO 16.0 MICRONS.
C            IPRINT - A DIAGNOSTIC PRINT VARIABLE WHICH CAN TAKE ON THREE VALUES:
C                 0 OR BLANK - NO PRINTOUT FROM SUBROUTINE.
C                 1          - ABBREVIATED PRINTOUT LISTING INITIAL CONDITIONS AND
C                              ABSORBER CONCENTRATIONS PER KILOMETER.
C                 2          - DETAILED PRINTOUT LISTING INITIAL CONDITIONS,
C                              ABSORBER CONCENTRATIONS PER KILOMETER AND ALL COM-
C                              PUTED CONSTITUENT TRANSMISSIONS.
C            IGO - INDEX USED TO DESIGNATE BYPASSING PART OF THE SUBROUTINE WHEN
C                  ALL CONDITIONS ARE THE SAME EXCEPT FOR THE RANGE AND/OR IPRINT.
C                  IT CAN TAKE ON 2 VALUES:
C                 1 - ABSORBER CONCENTRATIONS ARE COMPUTED.
C                 2 - TRANSMISSION IS COMPUTED DIRECTLY FROM ABSORBER CONCENTRA-
C                     TIONS CALCULATED FROM A PREVIOUS CALL TO THIS ROUTINE.
C                     INITIAL CONDITIONS AND ABSORBER CONCENTRATIONS WILL NOT BE
C                     REPRINTED, BUT IF IPRINT EQUALS 2, TOTAL AND CONSTITUENT
C                     TRANSMISSIONS WILL BE LISTED FOR EACH .1 MICRON INTERVAL.
C            ISTATE - INDEX WHICH KEYS SPECIAL CALCULATIONS.  INDICES 1-4 ARE RAIN
C                     MODELS.  THE VISIBILITY NEED NOT BE DEFINED FOR RAIN CALCULA-
C                     TIONS SINCE IT IS DEFINED IMPLICITLY IN THE INDEX.
C                     WHEN 31 IS USED, SPCLAM AND SPCTRN MUST BE FILLED IN THE
C                     CALLING ROUTINE AND SPCTRN(1) MUST BE SCAT.  WHEN 41 IS USED,
C                     THE SAME IS TRUE ONLY SPCTRN(1) MUST BE TOTL.
```

```
C                             01 - LIGHT RAIN - 12 KILOMETER VISIBILITY
C                             02 - MODERATE RAIN - 6 KILOMETER VISIBILITY
C                             03 - HEAVY RAIN - 2 KILOMETER VISIBILITY
C                             04 - VERY HEAVY RAIN - 0.5 KILOMETER VISIBILITY
C                             31 - BEERS LAW SCATTERING
C                             41 - BEERS LAW ATTENUATION
C
C
C     IN ORDER TO APPROXIMATE THE SIX MODEL ATMOSPHERES IN LOWTRAN, INPUT THE
C     TEMPERATURE AND RELATIVE HUMIDITY COMBINATIONS LISTED BELOW ALONG WITH A
C     VISIBILITY RANGE OF EITHER 5.0 OR 23.0 KILOMETERS.
C
C       ATMOSPHERE            TEMPERATURE(C)        RELATIVE HUMIDITY
C
C      US STANDARD               15.0                    .4599
C        TROPICAL                26.84                   .75
C       MIDLAT SUMMER            20.84                   .75
C      MIDLAT WINTER             -1.16                   .75
C      SUBARCTIC SUMMER          13.84                   .75
C     SUBARCTIC WINTER          -15.06                   .75
C
C
C     THIS PROGRAM DETERMINES .1 MICRON INTERVAL TRANSMISSION BETWEEN 3.0 AND 16.0
C     MICRONS TO WITHIN 3 PERCENT OF THE .1 MICRON INTERVAL TRANSMISSION CALCU-
C     LATED BY AVERAGING THE TOTAL WEIGHTED TRANSMISSIONS IN THE INTERVAL AS COM-
C     PUTED BY LOWTRAN AT ITS FINEST RESOLUTION.  .1 MICRON INTERVAL TRANSMISSION
C     BETWEEN 2.0 AND 3.0 MICRONS IS ALSO CALCULATED TO WITHIN 3 PERCENT EXCEPT
C     FOR THE 2.0,2.2 AND 2.5 MICRON INTERVALS WHICH ARE CALCULATED TO WITHIN 6,4
C     AND 5 PERCENT ACCURACY RESPECTIVELY OVER THE RANGE OF THE TEST VALIDATION.
C     .1 MICRON INTERVAL TRANSMISSION GENERALLY COMPARES TO WITHIN 1 PERCENT FOR
C     WAVELENGTH INTERVALS GREATER THAN 7.5 MICRONS.  SOME MINOR ADJUSTMENTS TO
C     THE C1 AND C2 ARRAYS HAVE BEEN MADE TO ACHIEVE THIS ACCURACY.  THE RESULTS
C     OF THIS PROGRAM HAVE BEEN VALIDATED TO THE FOLLOWING TWO CONDITIONS:
C               1 KM PATHLENGTH, 9 KM VISIBILITY RANGE, US STANDARD ATMOSPHERE
C              15 KM PATHLENGTH, 23 KM VISIBILITY RANGE, US STANDARD ATMOSPHERE
C
C
C
      DIMENSION AFCRL(161)
      DIMENSION SPCLAM(9),SPCTRN(9),PLAY1(7),PLAY2(7)
      DIMENSION STORE(161),ALPHA(4),BETA(4)
      DIMENSION W(7),TX(8),EQ(7)
      DIMENSION TR(67),FW(67),FD(67),VADENS(69)
      DIMENSION C1(141),C2(141),C3(130),C4(12),C5(15),C7(28),VX(28)
      DIMENSION XNAME(8)
      COMMON /SPCATM/SPCLAM,SPCTRN
      DATA TEST1,TEST2,TEST3/4HTOTL,4HSCAT,4HATEW/
      DATA ALPHA/12.0,6.0,2.0,0.5/
      DATA XNAME/4HLT  ,4HRAIN,4HMOD ,4HRAIN,4HHVY ,4HRAIN,4HVHVY,4HRAIN
     A/
      DATA TR/
     1 0.999, 0.998, 0.996, 0.994, 0.992, 0.990, 0.980, 0.970, 0.960,
     2 0.950, 0.940, 0.930, 0.920, 0.910, 0.900, 0.880, 0.860, 0.840,
     3 0.820, 0.800, 0.780, 0.760, 0.740, 0.720, 0.700, 0.680, 0.660,
     4 0.640, 0.620, 0.600, 0.580, 0.560, 0.540, 0.520, 0.500, 0.480,
     5 0.460, 0.440, 0.420, 0.400, 0.380, 0.360, 0.340, 0.320, 0.300,
     6 0.280, 0.260, 0.240, 0.220, 0.200, 0.180, 0.160, 0.140, 0.120,
     7 0.100, 0.080, 0.060, 0.040, 0.030, 0.020, 0.015, 0.010, 0.008,
     8 0.006, 0.004, 0.002, 0.001/
      DATA FW/
     
     *-2.3468,-2.0362,-1.6990,-1.4815,-1.3279,-1.2007,-0.7825,-0.5229,
     *-0.3468,-0.1938,-0.0655, 0.0414, 0.1353, 0.2430, 0.3324, 0.4342,
```

```
* 0.6128, 0.7243, 0.8261, 0.9191, 1.0000, 1.0792, 1.1461, 1.2122,
* 1.2672, 1.3284, 1.3892, 1.4409, 1.4955, 1.5441, 1.5966, 1.6435,
* 1.6857, 1.7340, 1.7782, 1.8261, 1.8692, 1.9191, 1.9638, 2.0086,
* 2.0607, 2.1038, 2.1461, 2.1875, 2.2304, 2.2798, 2.3263, 2.3717,
* 2.4183, 2.4698, 2.5159, 2.5740, 2.6284, 2.6902, 2.7559, 2.8261,
* 2.9031, 3.0000, 3.0607, 3.1461, 3.2041, 3.2718, 3.3054, 3.3444,
9 3.3979, 3.4914, 3.5682/
 DATA FU/
*-1.6778,-1.1398,-1.1192,-0.9508,-0.8239,-0.7258,-0.4318,-0.2366,
*-0.1074,-0.0    , 0.0969, 0.1761, 0.2304, 0.3010, 0.3522, 0.4624,
* 0.5563, 0.6435, 0.7243, 0.7924, 0.8573, 0.9191, 0.9731, 1.0253,
* 1.0719, 1.1173, 1.1614, 1.2095, 1.2480, 1.2900, 1.3263, 1.3617,
* 1.3979, 1.[illegible]93, 1.4698, 1.4983, 1.5314, 1.5682, 1.6021, 1.6335,
* 1.6721, 1.7076, 1.7482, 1.7924, 1.8325, 1.8865, 1.9395, 2.0000,
* 2.0607, 2.1206, 2.1903, 2.2552, 2.3385, 2.4313, 2.5185, 2.6435,
* 2.7853, 2.9777, 3.1072, 3.2553, 3.3617, 3.4771, 3.5563, 3.6233,
9 3.7076, 3.8325, 3.9345/
 DATA VADENS/
1    .496 ,   .542 ,   .592 ,   .646 ,   .705 ,   .758 ,   .836 ,
2    .909 ,   .988 ,  1.074 ,  1.165 ,  1.264 ,  1.369 ,  1.483 ,
3   1.605 ,  1.736 ,  1.876 ,  2.026 ,  2.186 ,  2.358 ,  2.541 ,
4   2.737 ,  2.946 ,  3.169 ,  3.407 ,  3.66  ,  3.930 ,  4.217 ,
5   4.523 ,  4.847 ,  5.192 ,  5.559 ,  5.947 ,  6.360 ,  6.797 ,
6   7.260 ,  7.750 ,  8.270 ,  8.819 ,  9.399 , 10.01  , 10.66  ,
7 11.35   , 12.07   , 12.83   , 13.63   , 14.84   , 15.37   , 16.21   ,
8 17.30   , 18.34   , 19.43   , 20.58   , 21.78   , 23.05   , 24.38   ,
9 25.78   , 27.24   , 28.78   , 30.38   , 32.07   , 33.83   , 35.68   ,
, 37.61   , 39.63   , 41.75   , 43.96   , 46.26   , 48.67   /
 DATA VX/
1    2.0   ,    2.5   ,    2.7   ,    3.0   ,    3.2   ,    3.3923,
2    3.5   ,    3.75  ,    4.0   ,    4.5   ,    5.5   ,    6.0   ,
3    6.5   ,    7.2   ,    7.9   ,    8.2   ,    8.5   ,    8.7   ,
4    9.0   ,    9.2   ,    9.5   ,   10.0   ,   10.591 ,   11.0   ,
5   13.0   ,   14.8   ,   15.0   ,   17.2   /
 DATA C1/
1 0.97,-0.43,-0.14,-1.35, 0.59, 2.24, 4.38, 4.10, 3.69, 2.51, 2.17,
2 2.24, 2.02, 1.97, 1.28, 0.62, 0.56, 0.33, 0.08,-0.75,-2.52,-2.51,
3-1.43,-0.68, 0.[illegible], 0.38, 0.58, 1.01, 1.22, 1.72, 2.15, 2.37, 2.75,
4 2.78, 3.21, 3.31, 3.83, 4.04, 4.[illegible]7, 4.44, 4.20, 4.23, 3.80, 3.35,
5 4.28, 4.56, 4.62, 4.22, 4.02, 3.80, 3.69, 3.57, 3.57, 3.23, 2.91,
6 2.73, 2.41, 1.91, 2.00, 1.99, 1.41, 1.02, 1.18, 0.88, 0.71, 0.75,
7 0.54, 0.22, 0.02, 0.00, 0.26, 0.11,-0.27,-0.13,-0.05,-0.22,-0.33,
8-0.19,-0.18,-0.21,-0.40,-0.82,-0.51,-0.37,-0.39,-0.50,-0.60,-0.88,
9-0.77,-0.39,-0.40,-0.48,-0.42,-0.31,-0.35,-0.37,-0.03, 0.09, 0.08,
,-0.01,-0.21,-0.21,-0.08, 0.32, 0.63, 0.80, 0.83, 0.73, 0.67, 0.52,
1 0.51, 0.43, 0.53, 0.86, 0.99, 0.79, 0.71, 0.60, 0.49, 0.69, 0.89,
2 1.12, 1.36, 1.54, 1.53, 1.47, 1.33, 1.21, 1.18, 1.19, 1.18, 1.25,
3 1.25, 1.30, 1.39, 1.51, 1.71, 1.80, 1.80, 1.83, 1.84/
 DATA C2/
1 0.55,-1.78,-5.00,-5.00,-5.00,-3.45,-3.04, 3.19, 2.31,-2.51,-2.20,
2-5.00,-0.00, 0.32, 0.23,-1.63,-1.88,-2.87,-2.51,-0.46,-2.16,-1.20,
3 2.10, 4.61, 2.98, 1.91, 0.62,-0.81,-0.08,-0.63,-3.09,-1.91,-0.63,
4-2.01,-2.83,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-2.03,-1.71,-2.27,
5-2.64,-1.38,-2.99,-2.48,-1.94,-1.69,-2.00,-5.00,-1.89,-0.12, 0.02,
6 0.78, 0.69, 1.44, 1.08, 1.07, 0.57,-0.01,-0.68,-1.17,-1.15,-1.21,
7-1.20,-1.13,-1.89,-2.58,-3.09,-2.11,-1.07,-0.79,-0.87,-0.91,-1.18,
8-1.59,-2.09,-2.71,-2.51,-1.66,-1.11,-1.01,-1.10,-1.09,-1.13,-1.32,
9-1.71,-2.19,-2.47,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-2.91,
,-2.72,-2.51,-2.10,-1.86,-1.61,-1.18,-1.00,-0.88,-0.91,-0.74,-0.53,
1-0.17, 0.23, 0.67, 1.08, 1.37, 1.63, 1.77, 1.89, 2.01, 2.17, 2.31,
2 2.52, 2.73, 2.86, 3.17, 3.38, 3.58, 3.73, 3.86, 3.88, 3.86, 3.79,
3 3.79, 3.69, 3.56, 3.37, 3.12, 2.90, 2.90, 2.72, 2.31/
```

```
      DATA C3/
     1-2.13,-0.76, 0.49,-1.09,-5.00,-0.19,-0.98,-5.00,-5.00,-5.00,-5.00,
     2-5.00,-5.00,-3.07,-1.26,-0.40, 1.23, 1.20,-0.10,-0.88,-1.59,-1.98,
     3-1.77,-0.90,-0.64,-0.84,-0.80,-0.18,-0.35,-1.26,-1.86,-3.05,-5.00,
     4-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,
     5-5.00,-5.00,-5.00,-4.16,-3.00,-2.46,-1.90,-1.33,-0.89,-0.41,-0.02,
     6 0.19, 0.48, 0.58, 0.53, 0.36, 0.30, 0.43, 1.01, 2.07, 2.82, 2.59,
     7 2.70, 2.80, 2.58, 2.23, 1.90, 1.30, 0.59,-0.08,-0.68,-1.20,-1.78,
     8-2.41,-3.14,-3.50,-4.46,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,-5.00,
     9-3.94,-3.59,-2.83,-2.47,-2.11,-1.40,-1.17,-0.86,-0.51,-0.35,-0.14,
     . 0.02, 0.14, 0.26, 0.42, 0.49, 0.56, 0.68, 0.78, 0.80, 0.83, 0.83,
     1 0.79, 0.68, 0.64, 0.68, 0.72, 0.76, 0.79, 0.72, 0.65, 0.58, 0.52,
     2 0.52, 0.43, 0.32, 0.24, 0.12, 0.02, 0.02,-0.10,-0.29/
      DATA C4/
     13.36E-04,1.70E-03,7.00E-03,3.10E-02,8.65E-02,1.11E-01,1.60E-01,
     27.84E-02,4.60E-02,2.16E-02,3.36E-03,3.86E-04/
      DATA C5/
     126.7 ,20.7 ,14.0 ,10.7 , 9.02, 7.08, 6.68, 5.68, 5.34, 5.34, 5.34,
     2 5.34, 3.56, 1.73, 0.00/
      DATA C7/
     1    .0351 ,    .0266 ,    .0267 ,    .0224 ,    .0215 ,    .0209 ,
     2    .021  ,    .0195 ,    .0182 ,    .0167 ,    .0136 ,    .0119 ,
     3    .0121 ,    .0133 ,    .00784,    .00809,    .0153 ,    .0219 ,
     4    .0238 ,    .0235 ,    .0185 ,    .0157 ,    .0135 ,    .0122 ,
     5    .00938,    .00827,    .0101 ,    .011   /
      IMA=IFIX((WAVE1+.001)*10.)
      IMO=IFIX((WAVE2+.001)*10.)
      IF(SPCTRN(1).EQ.TEST1.OR.SPCTRN(1).EQ.TEST2) GO TO 150
    3 IF(IGU.EQ.2) GO TO 7
      IF(ISTATE.GE.1.AND.ISTATE.LE.4) VIS=ALPHA(ISTATE)
      RELHUM=HUMIDY
      XTEM=TEMP
      IF(XTEM)4,5,5
    4 KEP=30-IFIX(ABS(XTEM))
      PIE=VADENS(KEP)+(XTEM-IFIX(XTEM))*(VADENS(KEP)-VADENS(KEP-1))
      GO TO 6
    5 KEP=30+IFIX(XTEM)
      PIE=VADENS(KEP)+(XTEM-IFIX(XTEM))*(VADENS(KEP+1)-VADENS(KEP))
    6 IF(VIS.LE.1.0) RELHUM=1.0
      WH=RELHUM*PIE
      XTEM=XTEM+273.16
      PPW=4.56E-06*WH*XTEM
      HAZE=70023.44/VIS-214.448
      WO=0.54000E-04
      TS=273.16/XTEM
      D=0.1*WH
      W(1)=D*TS**0.45
      W(2)=TS**1.375
      W(3)=46.6667*WO*TS**0.2
      W(4)=0.8*TS**1.5
      W(5)=(PPW+0.005*(1.-PPW))*D
      W(6)=TS
      W(7)=3.5336E-04*HAZE
      IF(IPRINT.EQ.0) GO TO 13
      XTEM=XTEM-273.16
      IF (IAFLG .EQ. 1)WRITE(6,7000)
 7000 FORMAT(34(/),5H '1',,10X,18HATMCRL OUTPUT DATA  ,//)
      WRITE(6,200)
      WRITE(6,201)
      WRITE(6,202) WAVE1,WAVE2
      WRITE(6,203)VIS
      JJ=2*ISTATE-1
```

```
      IF(ISTATE.GT.0.AND.ISTATE.LT.50) GO TO 2
      WRITE(6,212)
      GO TO 1
    2 IF(ISTATE.LT.30) WRITE(6,211)XNAME(JJ),XNAME(JJ+1)
      IF(ISTATE.EQ.31) WRITE(6,213)
    1 WRITE(6,204)RANGE
      WRITE(6,205)XTEM
      WRITE(6,206)RELHUM
      WRITE(6,207)
      WRITE(6,208)(W(K),K=1,7)
      IF(ISTATE.GT.0.AND.ISTATE.LT.50) WRITE(6,217)
   13 CONTINUE
      ICOUNT=0
    7 CONTINUE
      DO 9 I=1,7
    9 EQ(I)=W(I)*RANGE
      DO 10 I=1,161
   10 AFCRL(I)=0.0
      ICOUNT=0
      GO TO 11
C                   ROUTINE FOR USING CONSTANT SCATTERING OR ATTENUATION
  150 IF(IGO.EQ.2) GO TO 153
      DO 151 I=1,7
      PLAY1(I)=SPCLAM(I+2)
  151 PLAY2(I)=SPCTRN(I+2)
      DO 152 J=IMA,IMO
      XLAMDA=.1*J
      CALL ALINEY(AA,XLAMDA,PLAY2,PLAY1,7)
      IF(AA.GT.1.0) AA=1.0
      IF(AA.LE.0.0) GO TO 155
      STORE(J)=-ALOG(AA)
      GO TO 152
  155 STORE(J)=999.
  152 CONTINUE
  153 IF(SPCTRN(1).EQ.TEST2) GO TO 3
      IF(IPRINT.EQ.0) GO TO 156
      IF (IAFLG .EQ. 1) WRITE(6,7000)
      WRITE(6,216)
      IF(IPRINT.EQ.2) WRITE(6,214)
  156 DO 154 I=IMA,IMO
      XLAMDA=.1*I
      AFCRL(I-IMA+1)=EXP(-STORE(I)*RANGE)
      IF(IPRINT.EQ.2) WRITE(6,215)XLAMDA,AFCRL(I-IMA+1)
  154 CONTINUE
      GO TO 96
C          BEGINNING OF TRANSMISSION CALCULATIONS
   11 DO 90 I=IMA,IMO
      XLAMDA=.1*I
      WL=1.0E4/XLAMDA
      L=WL
      L1=L/5
      IV=5*L1
      XL=IV
      IF((WL-XL).GT.2.5) IV=IV+5
      IF(ICOUNT.EQ.0) GO TO 15
      IF(ICOUNT.EQ.50) GO TO 15
      GO TO 16
   15 ICOUNT=0
      IF (IAFLG .EQ. 1 .AND. IPRINT .EQ. 2)WRITE(6,7000)
      IF(IPRINT.EQ.2) WRITE(6,209)
   16 SUM=0.0
      DO 17 K=1,8
```

```
      TX(K)=0.0
      IF(K.LT.4) TX(K)=1.0
   17 CONTINUE
      ICOUNT=ICOUNT+1
      IF(WL.LT.1400.) GO TO 20
      IF(WL.LT.2740) GO TO 30
C                 MOLECULAR SCATTERING
      C6=9.807E-20*(WL**4.0117)
      TX(6)=C6*EQ(6)
      SUM=SUM+TX(6)
      GO TO 40
C              WATER VAPOR CONTINUUM
   20 IF(WL.LT.670.) GO TO 40
      IF(WL.LT.700.) GO TO 25
      XI=(WL-700.)/50.+1.
      DO 22 NH=1,15
      XH=XI-FLOAT(NH)
      IF(XH)24,23,22
   22 CONTINUE
   23 TX(5)=C5(NH)
      GO TO 26
   24 TX(5)=C5(NH)+XH*(C5(NH)-C5(NH-1))
      GO TO 26
   25 TX(5)=(WL-670.)*0.69
   26 TX(5)=EQ(5)*TX(5)
      SUM=SUM+TX(5)
      GO TO 40
C              NITROGEN CONTINUUM
   30 IF(WL.LT.2080.) GO TO 40
      MY=I-36
      TX(4)=C4(MY)*EQ(4)
      SUM=SUM+TX(4)
C                 WATER VAPOR
   40 KI=1
      IF(EQ(1).LT.1.0E-20) GO TO 44
      MY=I-19
      WS1=ALOG10(EQ(1))+C1(MY)
      IF(WS1.LT.-2.23468) GO TO 44
      IF(WS1.GT.3.5682) GO TO 43
      IF(WS1.GT.2.0) KI=40
      DO 41 K=KI,67
      IF(WS1.LE.FW(K)) GO TO 42
   41 CONTINUE
   42 TX(1)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS1)/(FW(K)-FW(K-1))
      GO TO 44
   43 TX(1)=0.0
   44 CONTINUE
C                 UNIFORMLY MIXED GASES(CO2)
      KI=1
      WS2=ALOG10(EQ(2))+C2(MY)
      IF(WS2.LT.-2.3468) GO TO 54
      IF(WS2.GT.3.5682) GO TO 53
      IF(WS2.GT.2.0) KI=40
      DO 51 K=KI,67
      IF(WS2.LE.FW(K)) GO TO 52
   51 CONTINUE
   52 TX(2)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS2)/(FW(K)-FW(K-1))
      GO TO 54
   53 TX(2)=0.0
   54 CONTINUE
C                 OZONE
      IF(WL.GT.3270.) GO TO 63
```

```
      K1=1
      MY=I-30
      IF(EQ(3).LT.1.0E-20) GO TO 63
      WS3=ALOG10(EQ(3))+C3(MY)
      IF(WS3.LT.-1.6778) GO TO 63
      IF(WS3.GT.3.9345) GO TO 62
      IF(WS3.GT.1.5) K1=36
      DO 65 K=K1,67
      IF(WS3.LE.FO(K)) GO TO 61
   65 CONTINUE
   61 TX(3)=TR(K)-(TR(K)-TR(K-1))*(FO(K)-WS3)/(FO(K)-FO(K-1))
      GO TO 63
   62 TX(3)=0.0
   63 CONTINUE
C                    AEROSOL EXTINCTION
      XX=0.0
      IF(SPCTRN(1).EQ.TEST2) GO TO 160
      DO 71 N=1,28
      XD=XLAMDA-VX(N)
      IF(XD)72,71,71
   71 CONTINUE
   72 XX=C7(N)+(C7(N)-C7(N-1))*XD/(VX(N)-VX(N-1))
      TX(7)=XX*EQ(7)
      IF(VIS.LE.1.0) GO TO 100
      SUM=SUM+TX(7)
      GO TO 85
  160 SUM=SUM-TX(6)
      TX(6)=0.0
      TX(7)=STORE(I)*RANGE
      SUM=SUM+TX(7)
      GO TO 86
C                    FOG MODEL
  100 RAP=.02*XLAMDA+.052
      IF(XLAMDA.LT.2.0) RAP=0.0
      TZ=3.912/VIS*EXP(-.106*VIS**.818*((XLAMDA-.55)/.55))-RAP
      TZ=TZ*RANGE
      IF(TZ.LT.TX(7)) GO TO 107
      IF(TZ.LT.0.0) TZ=0.0
      TX(7)=TZ
  107 SUM=SUM+TX(7)
      GO TO 86
   85 IF(ISTATE.GE.1.AND.ISTATE.LE.4) GO TO 110
      IF(ISTATE.LE.8) GO TO 120
      IF(ISTATE.LE.12) GO TO 130
      GO TO 86
C                    RAIN MODEL
  110 TY=0.0
      IF(ISTATE.EQ.1) TY=.326*RANGE+TX(7)/EQ(7)*RANGE*1.985
      IF(ISTATE.EQ.2) TY=.652*RANGE+TX(7)/EQ(7)*RANGE*4.048
      IF(ISTATE.EQ.3) TY=1.956*RANGE+TX(7)/EQ(7)*RANGE*12.290
      IF(ISTATE.EQ.4) TY=7.824*RANGE+TX(7)/EQ(7)*RANGE*49.411
      SUM=SUM-TX(7)
      TX(7)=TY
      SUM=SUM+TX(7)
      GO TO 86
  120 CONTINUE
  130 CONTINUE
  140 CONTINUE
C                    TOTAL TRANSMISSION
   86 TX(3)=SUM
      DO 80 K=4,6
      IF(TX(K).LE.0.0) GO TO 81
```

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      IF(TX(K).LE.0.1) GO TO 82
      IF(TX(K).GT.20.) GO TO 83
      TX(K)=EXP(-TX(K))
      GO TO 80
   81 TX(K)=1.0
      GO TO 80
   82 TX(K)=1.0-TX(K)+0.5*TX(K)*TX(K)
      GO TO 80
   83 TX(K)=0.
   80 CONTINUE
      AFCRL(I)=TX(1)*TX(2)*TX(3)*TX(8)
      IF(IPRINT.EQ.2) WRITE(6,210)IV,XLAMDA,AFCRL(I),(TX(K),K=1,7)
   90 CONTINUE
C
      ILT=IMO-IMA+1
      DO 95 I=1,ILT
   95 AFCRL(I)=AFCRL(IMA-1+I)
   96 CONTINUE
  200 FORMAT(70H FAST GROUND LEVEL VERSION OF AIR FORCE ATMOSPHERIC PROG
     ARAM,LOWTRAN II,//)
  201 FORMAT(10X,27H1962 US STANDARD ATMOSPHERE)
  202 FORMAT(10X,14HBANDWIDTH      ,F4.1,3H - ,F4.1,32H MICRONS IN .1 MIC
     ARON INCREMENTS)
  203 FORMAT(10X,19HVISIBILITY RANGE # ,F5.2,4H KM.)
  204 FORMAT(10X,13HPATHLENGTH # ,F5.1,11H KILOMETERS)
  205 FORMAT(10X,14HTEMPERATURE # ,F5.1,10H DEGREES C)
  206 FORMAT(10X,20HRELATIVE HUMIDITY # ,F4.2////)
  207 FORMAT(11X,42HEQUIVALENT SEA LEVEL ABSORBER AMOUNTS PER ,
     19HKILOMETER,/,2X,9HH2O VAPOR,2X,8HCO2 ETC.,4X,5HOZONE,
     23X,8HN2XCONT<,2X,9HH2OXCONT<,1X,8HMOL.SCAT,3X,
     37HAEROSOL,/,3X,7HGM CM-2,6X,2HKM,6X,6HATM CM,
     46X,2HKM,7HGM CM-2,5X,2HKM,8X,2HKM,/)
  208 FORMAT(1X,7(2X,E8.3))
  209 FORMAT(1H1,5H FREQ,2X,6HLAMBDA,2X,5HTOTAL,3X,
     13HH2O,3X,4HCO2E,3X,5HOZONE,1X,6HN2#CNT,1X,
     27HH2O-CNT,1X,8HMOL SCAT,1X,7HAEROSOL,/,2X,
     34HCM-1,4X,2HUM,4X,5HTRAMS,5(2X,5HTRANS),4X,
     45HTRANS,3X,5HTRANS)
  210 FORMAT(1X,I6,6(1X,F6.4),2(2X,F6.4),3X,F6.4)
  211 FORMAT(10X,21HWEATHER CONDITION IS ,2A4)
  212 FORMAT(10X,26HWEATHER CONDITION IS CLEAR)
  213 FORMAT(10X,28HBEERS LAW SCATTERING ASSUMED)
  214 FORMAT(10X,21H  WAVELENGTH  TOTAL  ,/14X,7HMICRONS,3X,5HTRANS/)
  215 FORMAT(11X,2F9.4)
  216 FORMAT(10X,29HBEERS LAW ATTENUATION ASSUMED,///)
  217 FORMAT(119H0   THE SCATTERING EQUIVALENT SEA LEVEL ABSORBER AMOUNT
     AS ARE NOT APPLICABLE TO THE FOLLOWING TRANSMISSION CALCULATIONS.)
      RETURN
      END
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      SUBROUTINE MDTSNR(XMXM,YMYM,FFFF,XCTFF,H,DELTAF,RANGE,TRANS,SPROB,
     1SNET,D)
      DIMENSION XMXM(1),YMYM(1),FFFF(1),H(1)
      DIMENSION OUTPUT(10),XINPUT(10)
      DIMENSION ROSSNR(11),PROBD(11)
      COMMON /SNRMDT/DXMTF(20),DYMTF(20)
      COMMON/NAME3/JFLAG,JPRINT,DDTT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUFO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME4/ XW, LW,F(10),S(10),XNET,DELTAX,DELTAY,EYETM,FR,HFOV,
     1VFOV,XMAG,XN,XNSC,OVERSC,BRITE,SRTAD,DISC,TA,TO,ANGLE,MOM,FSTAR,
     2XLAMB,FNUMB,FOC,XK,FMAXF,XY,XYL,FMAX,XSIGLS,YSIGLS,XA,YA,KKK,
     3IOTAU,VEL,FELECT
      DATA ROSSNR/5.5,4.1,3.7,3.3,3.1,2.8,2.5,2.3,2.0,1.5,0.0/
      DATA PROBD/1.0,0.9,0.8,0.7,0.6,0.5,0.4,0.3,0.2,0.1,0.0/
C     IF (IAFLG .EQ. 1)WRITE(6,7000)
 7000 FORMAT(34(/),5H '|',,10X,18HMDTSNR OUTPUT DATA,//)
C     IF (IAFLG .NE. 1)WRITE(6,31)
      XSIDE=XLTAR/RANGE
      YSIDE=XHTAR/RANGE
      TAMRD=XSIDE*YSIDE
      TD=DETEMP*TRANS
C     IF (IAFLG .EQ. 1)WRITE(6,7000)
      CALL XRING(XCTFF,DXMTF,FFFF, 20,H,8,XSIDE,1,ANS,2,1.0)
      CALL XRING(0.0,DYMTF,FFFF, 20,H,8,YSIDE,2,ANT,2,1.0)
C     IF (IAFLG .EQ. 1)WRITE(6,7000)
      QD=ANS/2.0*ANT
      CALL XRING(0.0,XMXM,FFFF, 20,H,8,XSIDE,2,ANS,2,1.0)
      CALL XRING(0.0,YMYM,FFFF, 20,H,8,YSIDE,2,ANT,2,1.0)
      QQD=ANS*ANT
      D=TD*TAMRD*QQD/SNET*1.0/(DELTAY*VEL*QD/DELTAF/FR/EYETM/OVERSC)**.5
      CALL ALINEY(SPROB,D,PROBD,ROSSNR,11)
      IF(SPROB.LT.0.0) SPROB=0.0
      IF(SPROB.GT.1.0)SPROB=1.0
      RETURN
      END
```

```
      SUBROUTINE DFAULT (FREQ,XMTF,II,KK)
      DIMENSION XDR(50),DDT(50),TSE(50), SSE(50),SOME(50),XFRW(50),DRTX
     1(50),FFT(20),XXXRT(20),FREQ(20),XMTF(20),XOMTF(20),XGBMTF(20),
     2XDMTF(20),XDPMTF(20),ELMTF(20),BMTF(20),XTVMTF(20),XEMTF(20),
     4XDSMTF(20),XMTFLS(20),XEYMTF(20),AXMRT(20)
      DIMENSION XINPUT(10),OUTPUT(10)
      COMMON/NAME1/XDR,DDT,TSE,SSE,SOME,XFRW,DRTX,DETEM ,FFT,XXXRT
      COMMON/NAME2/XOMTF,XGBMTF,XDMTF,XDPMTF,ELMTF,BMTF,XTVMTF,XEMTF,
     1XDSMTF,XMTFLS,XEYMTF
      COMMON/NAME3/JFLAG,JPRINT,DDTT,DETEMP,DPEAK,FACT,IDELTR,IDELX,
     1IRDAX,IRDIN,IRMAX,IRMIN,LUPO,OUTPUT,XHTAR,XINPUT,XLTAR,IAFLG
      COMMON/NAME5/IKOUNT
      COMMON/NAME6/DXDR(50),DDDT(50),DDRTX(50)
       IF(Z3.EQ.1.0.AND.Z4.EQ.1.0)GO TO 8008
      IF(IAFLG .NE. 1)WRITE(6,8010)
      IF (IAFLG .EQ. 1)WRITE(6,7000)
7000  FORMAT(34(/),5H '|',,15X,11HOUTPUT DATA,//)
8010  FORMAT(1H1,11HOUTPUT DATA///)
      IF(IKOUNT.GT.1.AND.JFLAG.EQ.0) GO TO 8007
      WRITE(6,8020)
8020  FORMAT(1H ,22X,31HX MODULATION TRANSFER FUNCTIONS//)
      WRITE(6,8029)
      WRITE(6,8030)(FREQ(I),XOMTF(I),XGBMTF(I),XDMTF(I),XDPMTF(I),ELMTF(
     1I),BMTF(I),XTVMTF(I),XEMTF(I),XDSMTF(I),XMTFLS(I),XEYMTF(I),I=1,20
     2)
8029  FORMAT(1H , 4HFREQ,1X,6HOPTICS,1X,5HGBLUR,1X,5HDETEC,1X,5HRSPNS
     1,1X,5HELECT,1X,5HBOOST,1X,5HVIDCN,2X,3HLED,2X,5HDSPLY,2X,3HLOS,4X,
     23HEYE//)
8030  FORMAT(1X,F5.2,11F6.2)
      IF(IAFLG .NE. 1)WRITE(6,8010)
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,8040)
8040  FORMAT(1H ,35HSYSTEM MODULATION TRANSFER FUNCTION)
      WRITE(6,8050)(FREQ(I),XMTF(I),I=1,20)
8050  FORMAT(7X,4HFREQ,8X,5HX MTF//(6X,F5.2,F13.2))
8008   CONTINUE
      IF(IAFLG .NE. 1)WRITE(6,8010)
      IF (IAFLG .EQ. 1)WRITE(6,7000)
      WRITE(6,8060)
8060  FORMAT(1H ,40HPREDICTED MINIMUM RESOLVABLE TEMPERATURE)
      WRITE(6,8070)(FFT(I),XXXRT(I),I=1,20)
8070  FORMAT(1H ,8X,4HFREQ,15X,5HX MRT//(1PE12.3,1PE20.3))
      IF(IAFLG .NE. 1)WRITE(6,8010)
8007  CONTINUE
      IF (IAFLG .EQ. 1) WRITE(6,7000)
      WRITE(6,8080)DETEMP
8080  FORMAT(1H ,5X,8HDELTA T=,E10.3)
      WRITE(6,8090)
8090  FORMAT(1H ,5X,21HDETECTION PERFORMANCE/5X,15HNFOV PERFORMANCE)
      WRITE(6,8100)(XDR(I),DDT(I),DRTX(I),I=1,II)
8100  FORMAT(5X,5HRANGE,5X,12HTRANSMISSION,5X,11HX DETECTION/32X,11HPROB
     1ABILITY/(3X,F5.2,F15.2,F17.2))
      WRITE(6,8110)
8110  FORMAT(/,1H ,5X,16HWFOV PERFORMANCE)
      WRITE(6,8100)(XDR(I),DDT(I),XFRW(I),I=1,II)
      IF(IAFLG .NE. 1)WRITE(6,8010)
      IF (IAFLG .NE. 1)GO TO 2000
      WRITE(6,7000)
      WRITE(6,8080)DETEMP
2000  WRITE(6,8120)
8120  FORMAT(1H ,5X,23HRECOGNITION PERFORMANCE/5X,27HPOWER DEPENDANT PER
     1FORMANCE)
```

```
      WRITE(6,8130)(DXOR(I),ODDT(I),ODRTX(I),I=1,KK)
8130  FORMAT(5X,5HRANGE,5X,12HTRANSMISSION,5X,13HX RECOGNITION/33X,11HPR
     1OBABILITY//(5X,F5.2,F13.2,F19.2))
      RETURN
      END
```

```
        SUBROUTINE ALINEY(AA,BB,A,B,N)
      DIMENSION A(1),B(1)
      IF( B(1).GT. B(2)) GO TO 2
      IF(BB.LE.B(1)) GO TO 40
      IF(BB.GE.B(N)) GO TO 50
      LF=1
      LL=N
10    CONTINUE
      J=(LL+LF)/2
      IF(BB.LT.B(J)) GO TO 5
      IF(BB.GE.B(J)) GO TO 15
5     LL=J
      IF(LL-1.EQ.LF) GO TO 30
      GO TO 10
15    LF=J
      IF(LF+1.EQ.LL) GO TO 30
      GO TO 10
30    AA=A(LF)+(A(LL)-A(LF))/(B(LL)-B(LF))*(BB-B(LF))
      RETURN
40    AA=A(1)+(A(1)-A(2))/(B(1)-B(2))*(BB-B(1))
      RETURN
50    AA=A(N)+(A(N-1)-A(N))/(B(N-1)-B(N))*(BB-B(N))
      RETURN
2     IF(BB.GE.B(1)) GO TO 40
      IF(BB.LE.B(N)) GO TO 50
      LL=1
      LF=N
60    CONTINUE
      J=(LL+LF)/2
      IF(BB.LT.B(J)) GO TO 65
      IF(BB.GT.B(J)) GO TO 70
65    LL=J
      IF(LL+1.EQ.LF) GO TO 30
      GO TO 60
70    LF=J
      IF(LF-1.EQ.LL) GO TO 30
      GO TO 60
      END
```

```
      SUBROUTINE QTFE(H,Y,Z,NDIM)
C        SUBROUTINE QTFE
C
C        PURPOSE
C           TO COMPUTE THE VECTOR OF INTEGRAL VALUES FOR A GIVEN
C           EQUIDISTANT TABLE OF FUNCTION VALUES.
C
C        USAGE
C           CALL QTFE (H,Y,Z,NDIM)
C
C        DESCRIPTION OF PARAMETERS
C           H      - THE INCREMENT OF ARGUMENT VALUES.
C           Y      - THE INPUT VECTOR OF FUNCTION VALUES.
C           Z      - THE RESULTING VECTOR OF INTEGRAL VALUES. Z MAY BE
C                    IDENTICAL WITH Y.
C           NDIM   - THE DIMENSION OF VECTORS Y AND Z.
C
C        REMARKS
C           NO ACTION IN CASE NDIM LESS THAN 1.
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           BEGINNING WITH Z(1)=0, EVALUATION OF VECTOR Z IS DONE BY
C           MEANS OF TRAPEZOIDAL RULE (SECOND ORDER FORMULA).
C           FOR REFERENCE, SEE
C           F.B.HILDEBRAND, INTRODUCTION TO NUMERICAL ANALYSIS,
C           MCGRAW-HILL, NEW YORK/TORONTO/LONDON, 1956, PP.75.
C
C     ..................................................................
C
C
C
      DIMENSION Y(1),Z(1)
C
      SUM2=0.
      IF(NDIM-1)4,3,1
    1 HH=.5*H
C
C     INTEGRATION LOOP
      DO 2 I=2,NDIM
      SUM1=SUM2
      SUM2=SUM2+HH*(Y(I)+Y(I-1))
    2 Z(I-1)=SUM1
    3 Z(NDIM)=SUM2
    4 RETURN
      END
```

IBM Application Program, System/360 Scientific Subroutine Package, Version III, (360A-CM-03X)

```
      FUNCTION SINC(X)
      DATA PI/3.141592654/
      IF(X.EQ.0.000) GO TO 10
      A=PI*X
      SINC=SIN(A)/A
      RETURN
10    SINC=1.000
      RETURN
      END
```

```
      FUNCTION ARCOS(X)
      ARCOS=ACOS(X)
      RETURN
      END
```

APPENDIX D

NIGHT VISION LABORATORY STATIC PERFORMANCE MODEL FOR THERMAL VIEWING SYSTEMS

USER'S GUIDE

CONTENTS

I. Introduction

The NVL Static Performance Model for Thermal Viewing Systems has been constructed so that it is now possible for a person who has some familiarity with thermal imaging systems to perform sophisticated analyses of complete sensors in a relatively simple fashion. Furthermore, the capabilities of this model allow the user to easily perform parametric sensitivity studies. The user has at his disposal the ability to put together systems, component by component, and to see what effects different subsystem characteristics have on device performance. He can also test his system against a wide variety of environmental conditions that will be of interest.

Essentially, the model generates a target representation and modifies it first by accounting for any atmospheric effects. Then, the attenuated scene representation is taken through each of the major system components successively. The result is further modified by the observer's response using standard information theory techniques. There are basically six performance measures that are calculated:

1. System Modulation Transfer Function (MTF)
2. Minimum Resolvable Temperature (MRT)
3. Minimum Detectable Temperature (MDT)
4. System NEΔT
5. Static Recognition Probability vs Range
6. Static Detection Probability vs Range

Probability predictions can be specified as either power based or temperature based, and they are performed for both the x and y dimensions.

This program has been specifically designed for ease of use and, while it may at first look foreboding, a little time spent with it will show that it is not difficult to use. Data can be entered into the program in either of two ways. All input data is printed out clearly so that the user can easily check to see if he is modelling the system he really wants. Various error checks are made on the input data, and many of the obvious errors that we anticipate will be made are flagged. Certain limited default features exist in this version. Also, the program has the ability to do several performance calculations using one input deck.

In the following pages, we will go through in detail the procedure to be used when predictions are required from the NVL Static Performance Model for Thermal Viewing Systems. We will discuss how you should look at your system in a way that will aid you in understanding the computer program requirements. We will [illegible]efully go through what parameters you must specify and how you must specify [illegible]. We will cover all aspects of physically setting up the required data deck. W[illegible]xplain what procedures are necessary in order to run multiple-performance calculations with the same deck. An example will be completely worked out including a copy of the program printout.

II. Systems Analysis

In general, a certain amount of preliminary analysis is needed before a data deck can be set up for the systems performance model. This point cannot be overemphasized because it is likely that most errors will arise because of invalid inputs. Many problems will be avoided if the user takes a few minutes to check his input parameters in a logical way each time he attempts to run the model.

Table D1 provides the starting point. For conceptual purposes, the systems performance model can be thought of as a collection of modules which correspond to the different processing steps experienced by an image as it moves from its origin, through the system, and to the observer. These modules are listed under the heading of Program Modules in the first column of Table D1. It is obvious that most of these modules correspond to major device subsystems. Several others, such as TARGET, ATMOSPHERE, and EYE, correspond to signal generation, preprocessing of the signal, and post processing of the signal.

Table D1. System Analysis Procedure

Program Modules	Applicable Card Identifiers	User Aid Supplement
TARGET	TARG, RANG	1
ATMOSPHERE	ENVI, TOTL, ATEW	2
OPTICS	OPTI, MTOX, MTOY	3
SCANNER	SCAN	4
DETECTOR	DETR, DET2, DROX, DROY, NPSP, NPSF, DSTL, DSTD	5
ELECTRONICS	ELEC, EMTF, BMTF, VMTX, VMTY	6
DISPLAY	DISP	7
SYSTEM*	SYST, BAND	8
STABILIZATION	STAB, LSSX, LSSY	9
EYE	EYEB	10
PROGRAM CARDS**	SN4B, FLHZ, FCMR, FDRP, FDC1, FRC3, FRC4	11

*The variables on this card pertain to the system as a whole and not to any particular component of the system.

**Certain cards are required by the program to set up initial conditions, etc.

In order to use the systems performance model, it is necessary to assign values to all variables in each of the modules. In some cases, if the variables are not defined, devault options are assumed. In other cases, the program simply will not run. Pay careful attention to the assignment of values to variables.

All input cards have a four-letter identifier in the first four columns of a card. These identifiers tell the program what data is on the card. They also identify the card for the user. Look at column 2 in Table D1. This column shows what cards pertain to each program module. It is not always necessary to have every one of these cards each time the program is used. It is necessary, however, to always make sure that all of the proper cards are being used and that none of them are being left out.

Data following the identifier is positioned on a card according to one of two formats. In general, the first format, FOR1, is used for cards defining several different single-valued variables. FOR2 is used to read in arrays of multivalued variables.

Every card identifier listed in column 2 of Table D1 can be found in the first column of Table D2. Here, the identifiers are classified according to the format that must be followed when data is entered upon the card. While it may be a little confusing at first to locate card identifiers from Table D1 in Table D2, you will shortly see that Table D2 is a great aid in physically setting up a data deck.

Table D2 summarizes the input variables that need to be defined for the systems performance model. Each card inputs to the program one or more variables. The variable names on each card are listed in column 2. Column 5 briefly defines these variables and column 6 defines the units that the data must be in. For example, let us look at the first entry in Table D2. The card identified is BAND, and these four letters will appear in the first four columns of a data card. There are two variables on this card -- WAVE1 and WAVE2. Columns 5 and 6 indicate that these variables define the spectral bandwidth of the system in microns. The data is entered on the card under the format FOR1.

Up to seven pieces of data can be entered on a FOR1 card. The corresponding value of a variable must be located at a specific designated position on a card. These positions, called fields, are associated with each input variable and can be found in column 3 of Table D2. The size of these fields will be discussed later. Note that for FOR2 cards, ten pieces of data may be entered and hence there are ten data fields on these cards.

The gathering of data inputs for the program perhaps causes the greatest difficulty when a user attempts to run this model. It is helpful to continually remember that all input data falls in one of the program modules listed in Table D1. There are certain general considerations that should be kept in mind when data is gathered for the variables

Table D2. Data Cards for the NVL Thermal Performance Model

I. Format FOR1 (A4, 6X, 7F10.3)

Card Identifier	Variable Name	Field on Card	Supplement Note	Description	Units	Default
BAND				Bandwidth of calculation		
	WAVE1	1	8.5	Beginning wavelength	microns	
	WAVE2	2	8.5	Ending wavelength	microns	
OPTI				Optical parameters		
	FNUMB	1	3.1	F-number of objective lens		
	FOC	2	3.1	Focal length of objective lens	inches	
	TØ	3	3.2	Average optical transmission of system	decimal	
	ABLUR	4	3.3	Rel[illegible] spot size of geo blur	$mrad^2$	
	XLAMB	5	3.4	Wav[illegible] for diffraction	microns	
DETR				Detector parameters		
	DELTAX	1	5.1	Instantaneous field of view in the x-direction of the detector	mrad	
	DELTAY	2	5.1	Instantaneous field of view in the y-direction of the detector	mrad	
	XN	3	5.2	Number of detectors in parallel		
	DISC	4	5.3	Number of detectors in series		
	SRTAD	5	5.4	Effective detector size	10^{-3} inches	
	DPEAK	6	5.5	Peak D* (λ, f_o) value	10^{10} Cm-SQRT (Hz)/Watt	
	FØ	7	5.6	Measuring frequency f_o of D* (λ, f_o)	K hertz	
DET2				Detector parameters (continued)		
	ANGLE	1	5.7	Cold shield angle	degrees	60.0
	MOM	2	5.8	Limiting noise: 0.0 = detector noise limited (D* must include cold shield) 1.0 = shot noise limited (BLIP) 2.0 = white noise approximation		0.0
	FSTAR	3	5.9	Frequency of the 3-dB point of detector response	k hertz	10000.0

Table D2 (continued)

I. Format FOR1 (A4, 6X, 7F10.3)

Card Identifier	Variable Name	Field on Card	Supplement Note	Description	Units	Default
SCAN				Scanner parameters		
	FR	1	4.1	Frame rate	frames/second	
	XNSC	2	4.2	Overall scan efficiency	decimal	
	OVERSC	3	4.3	Overscan ratio		
ELEC				Electronic parameters		
	CUTOFF	1	6.1	Frequency of the 3-dB preamp cut-on	hertz	
	FELECT	2	6.1	Frequency of the 3-dB amplifier cutoffs	hertz	
	XY	3	6.2	Width of electro-optic multiplexor LED	mrad	
	XYL	4	6.2	Length of electro-optic multiplexor LED	mrad	
	XK	5	6.3	Electronic boost amplitude		
	FMAXF	6	6.3	Electronic boost frequency	K hertz	
DISP				Display parameters		
	XKK	1	7.1	Type of display 0.0 = CRT display (Gaussian spot size) 1.0 = LED display 2.0 = no display		
	BRITE	2	7.2	Average display brightness	footlamberts	
	XA	3	7.3	x-dimension of LED or related to CRT spot size of display	mrad/LED $mrad^2$/CRT	
	YA	4	7.3	y-dimension of LED or related to CRT spot size of display	mrad/LED $mrad^2$/CRT	
SYST				System parameters		
	HFOV	1	8.1	System horizontal field of view	degrees	
	VFOV	2	8.1	System vertical field of view	degrees	
	XMAG	3	8.2	System magnification		
	FACT	4	8.3	Ratio of wide field of view to narrow field of view		
	XNET	5	8.4	Noise equivalent delta temperature	degrees C	0.0

Table D2 (continued)

Card Identifier	Variable Name	Field on Card	Supplement Note	Description	Units	Default
				I. Format FOR1 (A4, 6X, 7F10.3)		
STAB				Stabilization parameters		
	XSIGLS	1	9.2	x-direction vibration constant	$mrad^2$	0.0
	YSIGLS	2	9.2	y-direction vibration constant	$mrad^2$	0.0
ENVI				Atmospheric parameters		
	AIRTMP	1	2.1	Air temperature	degrees C	15.0
	RH	2	2.2	Relative humidity	percent	45.99
	RVIS	3	2.3	Visibility range	kilometers	23.0
	ISTATE	4	2.4	Special atmospheric condition 1.0 – rain-light, 12-km visibility 2.0 – rain-moderate, 6-km visibility 3.0 – rain-heavy, 2-km visibility 4.0 – rain-very heavy, 500-m visibility		0.0
TOTL (optional)	SIGMA	1-7	2.5	Atmospheric transmission per kilometer for any 7 wavelengths in the band where the system operates	decimal	0.0
ATEW (optional)	WAVE	1-7	2.5	Wavelengths corresponding to atmospheric transmission values on TOTL	microns	For 3-5 micron system: 3.0, 3.25, 3.5, 4.0, 4.3, 4.5, 5.0
TARG				Target parameters		
	XLTAR	1	1.1	Target length	meters	5.25
	XHTAR	2	1.1	Target height	meters	2.7
	DETEMP	3	1.2	Target delta temperature	degrees C	11.1
	TBAC	4	1.2	Background temperature	degrees C	12.0

Table D2 (continued)

I. Format FOR1 (A4, 6X, 7F10.3)

Card Identifier	Variable Name	Field on Card	Supplement Note	Description	Units	Default
RANG				Range parameters		
	IRMIN	1	1.3	Minimum recognition range	meters	500.0
	IRMAX	2	1.3	Maximum recognition range	meters	5000.0
	IRDIN	3	1.3	Minimum detection range	meters	1000.0
	IRDAX	4	1.3	Maximum detection range	meters	10000.0
SN4B						
	SNR	1	11.1	Threshold signal-to-noise ratio		2.25
EYEB						
	EYETM	1	10.0	Integration time of the eye	seconds/frame	0.2

Table D2 (continued)

II. Format FOR2 (A4, 6X, 10F5.2)

Card Identifier	Variable Name	Field on Card	Supplement Note	Description	Units	Default
FLHZ	FQQ	1-10	11.4	Frequencies corresponding to MTF's of detector response, electronics, and boost	log hertz	0.0, 0.01, 0.1, 0.2, 0.3, 0.5, 0.6, 1.0, 10.0
DROX	XD	1-10	5.10	MTF of detector temporal response in the x-direction, corresponding to frequencies FQQ		all 1.0's
DROY	YD	1-10	5.10	MTF of detector temporal response in the y-direction, corresponding to frequencies FQQ		all 1.0's
EMTF	XE	1-10	6.4	MTF of the electronics, corresponding to frequencies FQQ		none
BMTF	XB	1-10	6.5	MTF of electronic boost, corresponding to frequencies FQQ		all 1.0's
FCMR	FQ	1-10	11.3	Frequencies corresponding to MTF's of optics, vidicon, and stabilization	cycles/mrad	0.0, 1.0, 2.0, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0
MTOX	XO	1-10	3.5	MTF of optics in x-direction, corresponding to frequencies FQ		all 1.0's

Table D2 (continued)

II. Format FOR2 (A4, 6X, 10F5.2)

Card Identifier	Variable Name	Field on Card	Note	Description	Units	Default
MTOY						
	YO	1-10	3.5	MTF of optics in y-direction, corresponding to frequencies FQ		all 1.0's
VMTX						
	XTV	1-10	6.6	MTF of vidicon in x-direction, corresponding to frequencies FQ		all 1.0's
VMTY						
	YTV	1-10	6.6	MTF of vidicon in y-direction corresponding to frequencies FQ		all 1.0's
LSSX						
	XML	1-10	9.1	MTF of stabilization in x-direction, corresponding to frequencies FQ		all 1.0's
LSSY						
	YML	1-10	9.1	MTF of stabilization in y-direction corresponding to frequencies FQ		all 1.0's
NPSF						
	F	1-8	5.12	Frequencies corresponding to variable S	log hertz	
NPSP						
	S	1-8	5.11	Normalized noise power spectrum		
DSTL						
	XLMBA	1-10	5.14	Wavelengths corresponding to variable DDSTAR	microns	

Table D2 (continued)

II. Format FOR2 (A4, 6X, 10F5.2)

Card identifier	Variable Name	Field on Card	Supplement Note	Description	Units	Default
LSTD						
	DDSTAR	1-10	5.13	D* (λ, f_o) of detector normalized so that maximum is 1.0		
FDRP						
	PRO	1-10	11.2	Probability of recognition or detection as a function of cycles across the target	decimal	1.0, 1.0, 1.0, 0.95, 0.8, 0.5, 0.3, 0.1, 0.02, 0.0
FDC1						
	BETA	1-10	11.2	Number of cycles across target for detection, corresponding to PRO		12.5, 5.0, 3.0, 2.0, 1.5, 1.0, 0.75, 0.5, 0.25, 0.0
FRC3						
	XNMB	1-10	11.2	Number of cycles across target for optimistic recognition, corresponding to PRO		37.5, 15.0, 9.0, 6.0, 4.5, 3.0, 2.25, 1.5, 0.75, 0.0
FRC4						
	XNUM	1-10	11.2	Number of cycles across target for conservative recognition, corresponding to PRO		50.0, 20.0, 12.0, 8.0, 6.0, 4.0, 3.0, 2.0, 1.0, 0.0

in each module. These general considerations are contained in a set of supplements, 1-12, which has several functions. The supplements discuss in some detail the operation of each module in the program. Many times, changing the value of one variable may require something to be done with some of the other variables. This is explained in the supplements along with certain options and shortcuts that can be used and also warnings on things not to do. After a general discussion of these points, there are notes on many of the specific variables used in the program. Column 4 of Table D2 references the supplements. The user will find under the appropriate supplement a more complete description, a definition of limits (if any), the defaults and options (if any), any recommended values, and any peculiarities that might exist. Column 7 of Table D2 lists certain defaults that are available to the user. These defaults are the values that the program automatically assigns to the appropriate input variables when the input card is left out of the data deck. However, certain variables on a card may also be left blank (or zero), and reasonable values for these are automatically assigned. It is always wise to check the supplements when any defaults and options are used. The solution to many of the problems that the user will have can be found in the supplements. They contain the accumulated experience of many runs with this model. Use them.

Also incorporated into this model are some highly specialized options and diagnostics which generally will not be of interest to the average user. However, for completeness, the documentation associated with these additional features can be found in Supplement 12.

III. A Simple Data Deck

Assuming that the data for a particular system of interest has been gathered, the next order of business is to put together a card deck. For terminal users utilizing keyboard input, the data must nevertheless be organized according to the following form. Figure D1 shows the basic structure of a simple input deck.

The first and last cards of this deck are control cards. They are really not data input to the program but are there to satisfy the requirements of the computer system. Always make sure that one of the control cards at the beginning of the deck calls the program up from storage. The specific format for these cards will vary from machine to machine.

Table D3 lists four special cards that must appear in every input deck. A card containing the four letters FOR1 on the first four columns must appear directly after the last control card at the beginning of the deck. This card merely tells the program that all cards following it are to be read according to the format that reads up to seven variables from a card. All of the data cards that have this format are placed behind the FOR1 card. An ENDS card is now entered behind the last card with a FOR1 format.

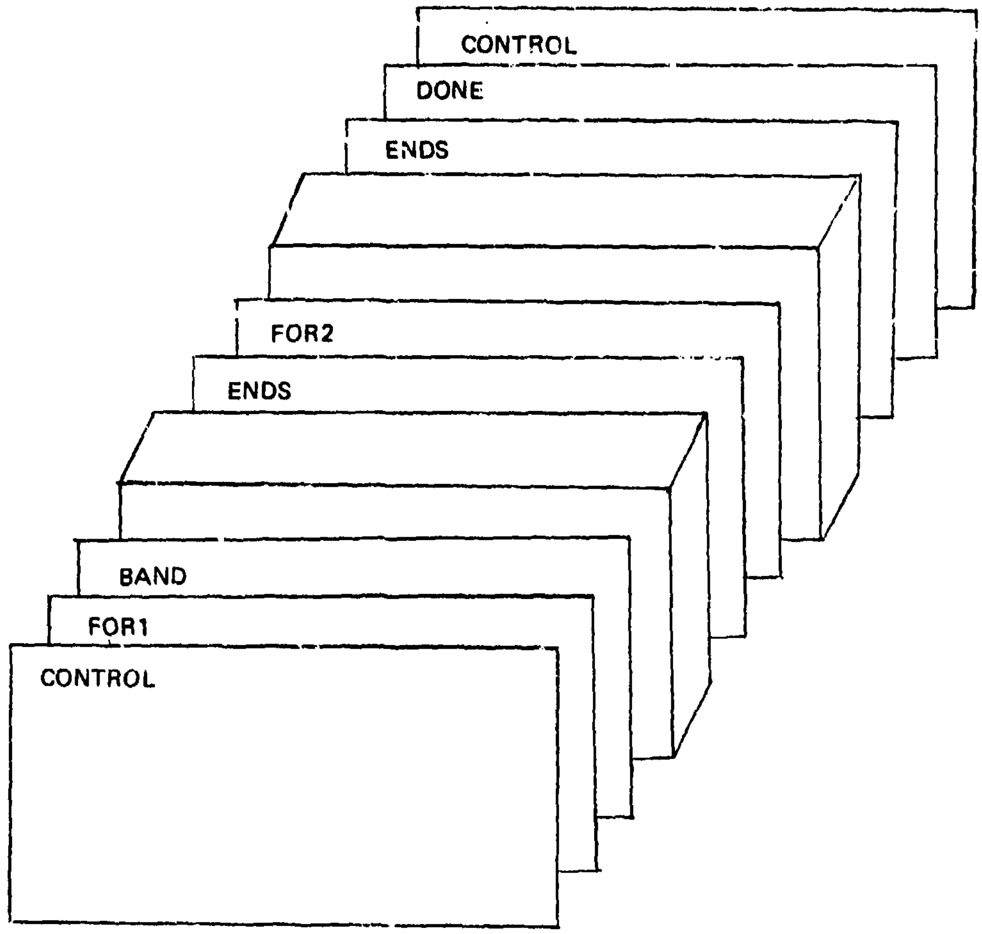


Figure D1. A simple data deck.

Table D3. Special Input Cards

Card	Description
FOR1	Designates cards with up to 7 data elements per card
FOR2	Designates cards with up to 10 data elements per card
ENDS*	Defines the end of a set of FOR1 or FOR2 cards
DONE*	Defines the end of a data deck

*For additional functions, see section on multiple runs. Also, see example for output print options contained on these cards.

The ENDS card tells the program that all data in a particular format has been read. The card itself simply contains the four letters ENDS in the first four columns.

In a like manner, the card FOR2 appears next. It identifies all of the input cards that have up to ten elements of data per card. After these cards are placed in the input deck, another ENDS card must appear. Finally, after all data have been read into the program, the DONE card is used. It defines the end of the data deck for the program.

There is only one simple rule that must be followed concerning the order of cards after the FOR1 card or the FOR2 card. This rule states that the card BAND must appear immediately after the FOR1 card. This applies to any execution of the program which defines the spectral bandwidth of the system. Otherwise, data cards grouped by identical format can appear in any order.

Information is entered on a card using a FOR1 format in the following way. As was stated earlier, the first four columns always contain one of the identifiers listed in Tables D1 and D2. The next six columns are always blank. Starting with column 11, there are seven ten-column fields into which data can be entered. Field 1 consists of columns 11 to 20, field 2 consists of columns 21 to 30, etc. The fields on each data card are allocated to particular variables so care must be taken to enter data entirely in the proper field. A decimal point must always be included with data. This rule even applies to variables which are not normally considered to have fractional values such as DISC—the number of detectors in series. Note this point well because the program will very likely read your data incorrectly if you violate this rule. In checking to see that data appears in the appropriate field, it is useful to always enter data in the same column of a field. In other words, regardless of the FOR1 format identifier, always start putting data for field 1 in column 11, for field 2 in column 21, etc. In this way, it is easy to check among cards to see if any data is out of its field.

In a similar manner, data is entered on cards that use a FOR2 format. Again, the first four columns contain the card identifier and the next six columns are blank. Starting in column 11, ten fields of five columns each are allocated to ten values of one particular variable. Thus, data will be contained in columns 11 to 15, 16 to 20, ... 56 to 60. As before, decimal points must be included with each entry.

Many times, two sets of identifiers are related. For example, consider the detector response card DROX. This card contains the detector MTF as a function of frequency. The corresponding frequencies are found on the card FLHZ or are default values as listed in column 7 of Table D2. In either case, care should be taken to make sure that the data in field 1 of one card corresponds to the data in the first field of the other card or the first default value. Make sure that the other fields similarly correspond.

Table D2 will aid you in setting up the desired data cards. All FOR1 formatted cards are listed first in this table. In addition, BAND is the first identifier in this table because it is the first card appearing after the FOR1 card in the data deck. After all of the FOR1 identifiers, you will find identifiers for the FOR2 formatted cards. If you set up your data deck in the same order as this table, it will automatically be correct in form; and all that is required is the insertion of the FOR1, FOR2, ENDS, and DONE cards at the appropriate places.

IV. Multiple-Run Data Decks

As you become more familiar with the Systems Performance Model, you will often wish to run the model several times. This can easily be accomplished by using only one execution deck. This expanded deck may be set up in either one of two ways. If you want to change the target or the atmosphere between runs, Figure D2 illustrates the arrangement of such a deck. When the system parameters are to be varied, Figure D3 shows how this is done. The way in which these two decks differ is described in paragraphs A and B.

A. Changing the Target or the Atmosphere.

Let us first go through the basic structure of the deck in Figure D2. It should be immediately apparent that this deck is identical to the deck in Figure D1 up to the first ENDS card after the FOR2 card. Instead of a DONE card following, however, we see a second ENDS card. This second ENDS card always tells the program to get ready to do another calculation. Now, since all of the target and atmosphere cards (as shown in Tables D1 and D2) are of the FOR1 format, we require a FOR1 card after this second ENDS card. We can now place any target and atmosphere card in the deck. Both target and atmosphere may be changed at the same time although in Figure D2 we have only changed the atmosphere by using the ENVI card. Following this card, we use one ENDS card to tell the computer that the new FOR1 data has been completely read and another ENDS card to indicate that we wish to perform a third calculation. At this point, the model is executed a second time. It uses all of the input parameters previously read in except for the new parameters read from the ENVI card.

After the second calculation finishes, another FOR1 card is processed. On this third run we will change the target with the card TARG. Since this is all we will change, we follow with the usual ENDS card; and since this will be the last run, we now use a DONE card to indicate the end of the entire data deck. Even though we have ended with three runs, there is no limit to the number of runs we can make with one deck.

It is important to realize that the third calculation will use the atmosphere defined for the second run. The atmosphere initially read in will not be used. In general, once

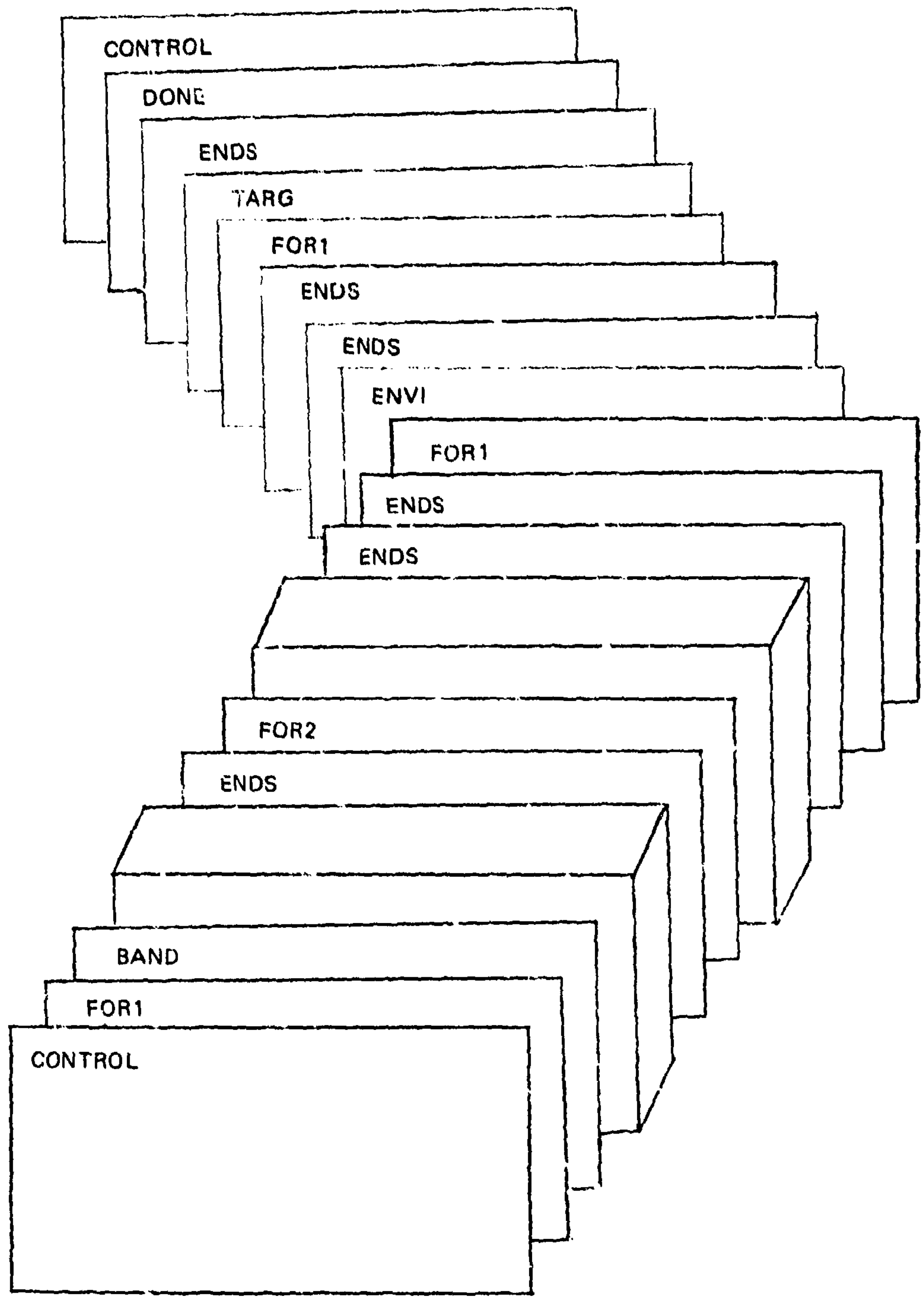


Figure D2. Multiple run data deck: changing target or atmosphere.

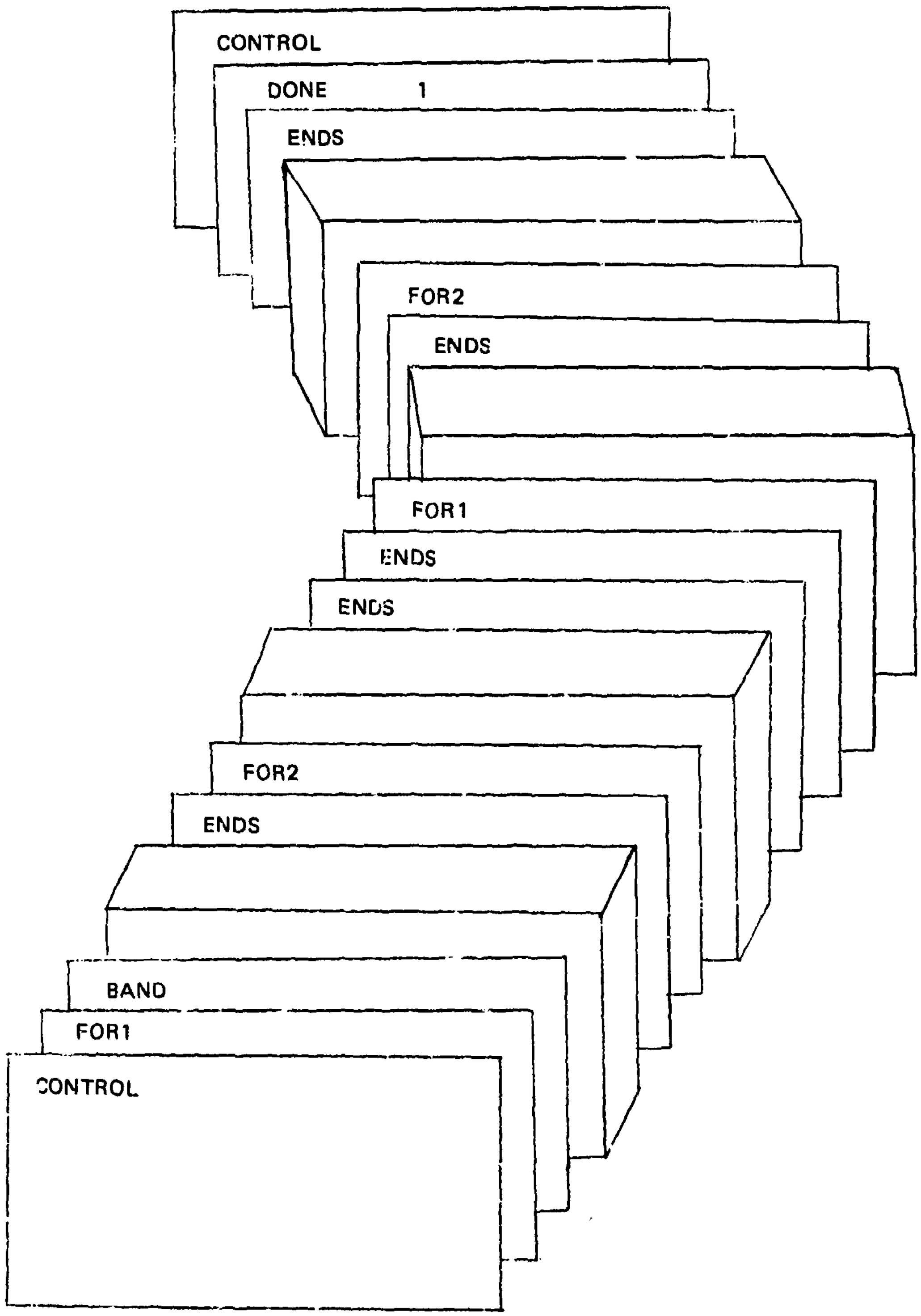


Figure D3. Multiple run data deck: changing system parameters.

a target or an atmosphere is changed, it carries through to any subsequent calculation that may be performed.

Whenever predictions are required for different targets or different atmospheres, the type of deck described here should be used. It is quite acceptable to use the deck structure of Figure D1 (run several times) to do this same task, but many unnecessary calculations will be performed in the process. This can be seen rather easily. The systems performance model in one sense is composed of two parts. The more involved part performs systems calculations. The remainder deals with the effects external to the system itself. After the complicated systems calculations are performed once, it is not necessary to do them again if only targets and atmospheres are changed. The optimized deck structure described here allows the program to bypass systems calculations after they have been executed once. The advantages are twofold. The program runs much more efficiently, saving considerable computer time. Additionally, the user only has to check one set of cards that define his system parameters. This latter point can be very helpful at times when unexpected results appear.

B. Changing System Parameters.

All multiple-run decks conform to the underlying principle that you only have to consider the cards that change from one run to the next. The program retains all other defined quantities. Figure D3 shows how you would go about applying this principle when you wish to change system parameters. Two runs can be made with this deck. but in practice there is no limit to the number that can be made with a deck of this type.

The deck shown in Figure D3 can be viewed as divided into two sections. Both have the structure of a simple deck. Each section may have a set of FOR1 formatted cards and a set of FOR2 formatted cards. Every set of FOR1 formatted cards is preceded by a FOR1 card and followed by an ENDS card. Likewise, every set of FOR2 formatted cards is prefaced by a FOR2 card and terminated with an ENDS card. All sections are separated by an additional ENDS card. The DONE card appears after the last ENDS card.

Figure D3 shows the number 1 appearing in column 11 of the DONE card. This number 1 signals the program to do the second systems calculation. To explain when the number 1 is used, we are required to look at the deck structure again. In any deck, a second ENDS card or a DONE card tells the program that all of the data for a particular run has been read and that the program should begin executing the computations. In other words, the second ENDS card or the DONE card must be seen as the last card read for a particular run. We must associate the second ENDS card in Figure D3 with the first execution of the program and the DONE card with the second execution of the program. The number 1 in column 11 tells the program that system calculations need to be performed on the second run.

The implications of this are clear. A second ENDS card must be viewed as doing more than just telling the program that there will be more data for another run coming. In a similar manner, the DONE card does more than tell the program that there will be no more inputs. It is thus natural to find options on the DONE card that pertain to the data just read. The same options apply to the second ENDS card. Let us imagine that we are putting together a deck to do three sets of systems calculations. There would be three sections to this deck. Each section would be separated by an additional ENDS card. Now, since we wish to do systems calculations in each run, the number 1 is also required in column 11 of each second ENDS card and the DONE card. The program automatically does a systems calculation for the first complete data set in any deck, however. Thus, the number 1 does not need to appear on the ENDS card between the first and second sections of this deck. This is also the reason why a number 1 does not appear on the DONE card in Figure D1 and on the second ENDS card in Figure D2.

To summarize, use a number 1 in column 11 of a second ENDS or DONE card when multiple systems calculations are required from the same run. Failure to observe this rule anywhere except on the second ENDS card following the first complete set of data will cause incorrect calculations to be performed. Do not worry about this feature if you are only changing targets or atmospheres.

Returning to Figure D3, we note that the second set of FOR1 and FOR2 formatted cards are only those cards which have been changed from the first run. All other necessary information is just carried over from the first run to the second. Remember that if you change the card BAND it must come right after the FOR1 card. Target and atmosphere cards can be changed just like any of the others.

It is quite possible that all of the system changes that you wish to make are of the FOR1 format. In this case, just leave out the set of FOR2 cards. If there are no cards with a FOR1 format, do not include a set of FOR1 cards.

Decks can be set up to efficiently do calculations when the user desires to vary both system parameters and targets or atmospheres. An example will help to illustrate. Let us assume that we wish to analyze two systems against three targets. We could set up six decks like in Figure D1. We could also set up two decks according to Figure D2 and run multiple targets on each. But we can set up one deck by using Figure D3. We do this very efficiently by working with two decks formed according to Figure D2. First, we remove all the control cards. We replace one of the DONE cards with an ENDS card. In the other deck, we place a number 1 in column 11 of the second ENDS card following that part of the deck which redefines the system parameters. We put this deck behind the other and put control cards back at the beginning and at the end of the deck. This is a mixed, multiple-run deck that combines the best features illustrated in Figures D2 and D3. There is only one special ENDS card because there is really only one change in system parameters. The versatility of the multiple-run option contained within this program should now be apparent.

One final note should be made with regard to changing system parameters. With a bit of experience, the user will find it relatively easy to manipulate the input variables of this program. It is easy to change a system variable using the multiple-run feature. But the variation of system parameters cannot be made without continually keeping in mind the realizable values of these variables and the impact that variations have on other system inputs. So use this option carefully in conjunction with the information contained in the supplements.

V. An Example

In this section, we will apply the methods and formalism thus far developed to a practical problem. Let us assume that we wish to predict the performance of a certain prototype system. Our system will operate in the 8-14 micrometer region and have a CRT display. Specifications that might be commonly available are shown in Table D4. With this information, we wish to use the NVL Static Performance Model for Thermal Viewing Systems to predict the system MTF, the NEΔT, the MRT, the MDT, and the probabilities of detection and recognition. How this is done follows.

A. The Simple Input Deck.

Figure D1 shows the basic form of the deck that we will be setting up. In this example, we will include for completeness all of the cards listed in Table D2, even though a careful reading of this documentation will reveal that some of these cards can be left out. The cards that can be left out are those whose inputs are identical to the default values listed in column 7 of Table D2. Figures D4 and D5 show a chart of all the cards that a simple deck can contain. The appropriate input cards can be directly keypunched from this chart when it is filled out. We shall now systematically go through Table D2, card by card, in order to demonstrate how we have used the data in Table D4 to obtain the entries for Figures D4 and D5. Consult the supplements when any of the following explanations appear incomplete.

BAND

The operating bandwidth of the system is 8-14 micrometers, and it is these numbers that appear for WAVE1 and WAVE2.

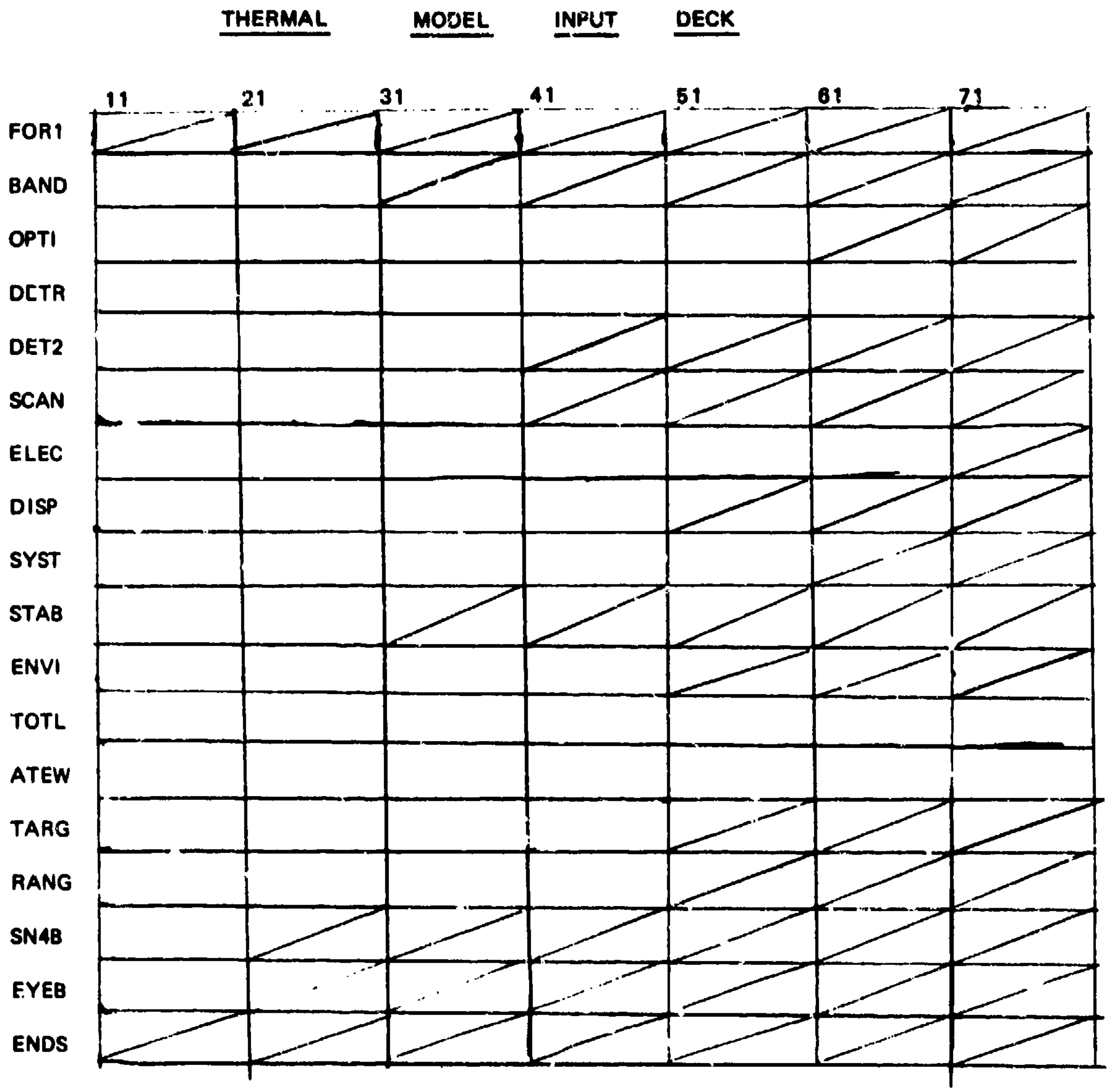


Figure D4. Chart of all cards that a simple deck can contain.

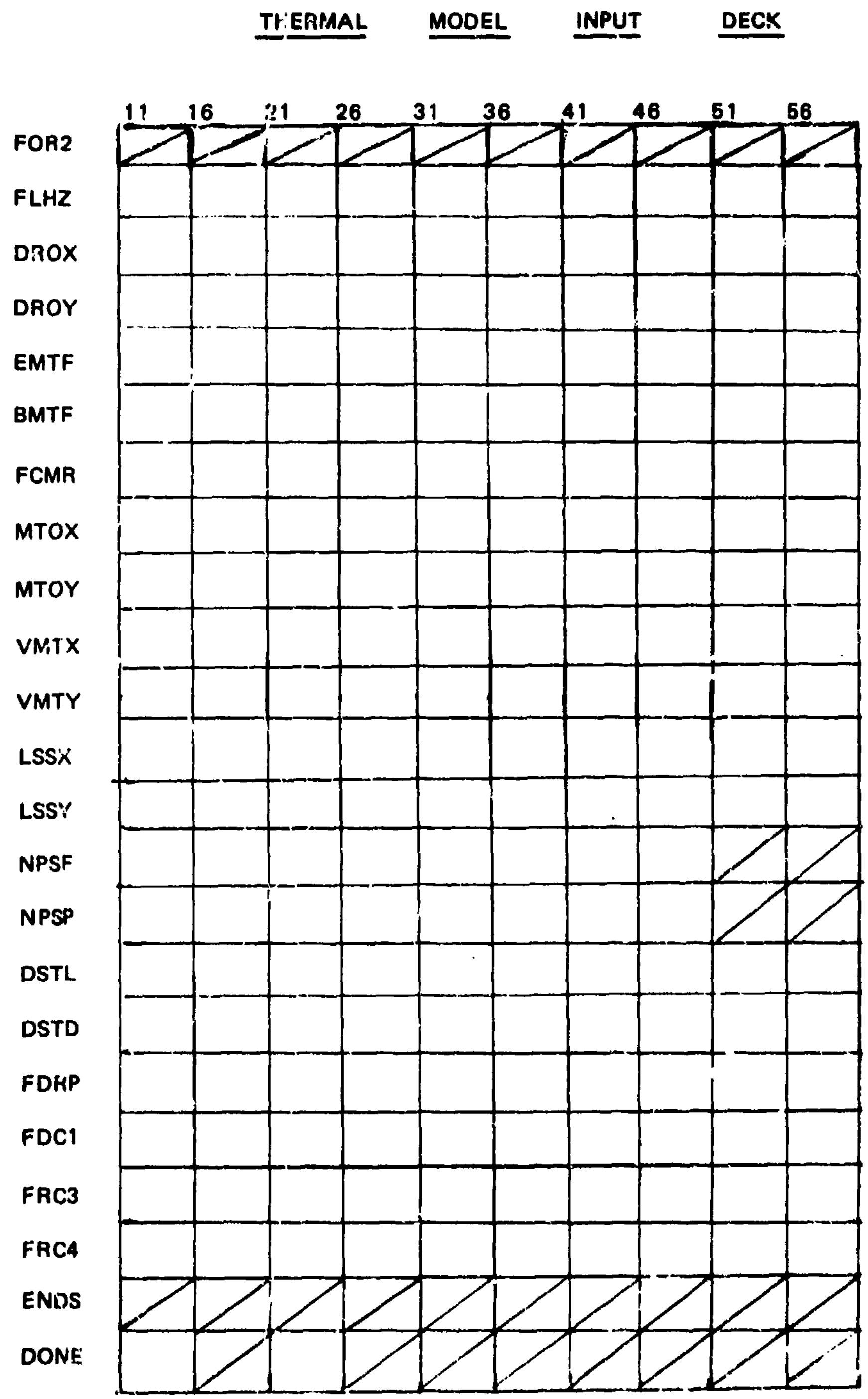


Figure D5. Continued chart of all cards that a simple deck can contain.

Table D4. System Specifications

Parameter	Specification
System Type	8-14 μm
Diameter of Optics	4 in.
F-number of Objective Lens	2.0
Optical Transmission	60%
Instantaneous Field of View	.25 mr
Detector Type	HgCdTe
Detectors in Parallel	60
Detector Size	.002 in. x .002 in.
Peak D*	2.0×10^{10} cm(Hz)$^{1/2}$ w^{-1}
Frame Rate	30 frames/s
Scan Efficiency	75%
Horizontal Field of View	2.7°
Vertical Field of View	2.0°
System Magnification	12X
Display Type	CRT
Spot Size on CRT	.044 mr
Average Brightness of Display	50 fL
Active IR Lines on Display*	140 active raster lines/frame

*The interlace in this example is not the usual integer value.

OPTI

The F-number of the objective lens (FNUMB) and the optical transmission (TØ) are given in Table D4. The focal length (FOC) is easily derived from the F-number and the diameter of the objective lens. The applicable equation can be found in Supplement 3. We have no information on geometric blur so we assume there is none and set ABLUR = 0.0. This leads to the assumption that we have diffraction-limited optics. We pick a diffraction wavelength (XLAMB) of 10 micrometers since we are usually comparing different systems; in doing this, we like to keep the diffraction wavelength the same for systems of approximately the same operating bandwidth.

DETR

Based on the detector size from Table D4, the instantaneous field of view is the same in the x-direction (DELTAX) as in the y-direction (DELTAY). The effective detector size (SRTAD) is given along with the number of detectors (XN) and the peak D* value (DPEAK). A parallel-scan system implies that the number of detectors in series (DISC) is equal to 1.0. Finally, we input the measuring frequency (FØ) of D* as 10.0 K hertz. This number has been historically valid for most detectors (except principally for the low-performance detectors such as PbS), and lacking other information we chose it.

DET2

We will assume that our system is detector-noise-limited and thus MOM = 0.0. Under a detector-noise-limited condition, the cold shield angle (ANGLE) is not used, and we have arbitrarily assigned it the value of 60.0 degrees.

The HgCdTe detector is generally considered of high performance. In addition, a parallel array of these detectors indicates that the dwell time on each detector is relatively long. Therefore, in this example, we do not worry about the detector response rolling off before we have transferred a maximum amount of information. The bandwidth of this system is determined by the electronics and is approximated by using equations (22) and (23) in the main body of the report. For our prototype system, the minimum required electronic bandwidth is computed to be 8,770 hertz. Since the roll-off of the detector response is negligible compared to the information rate bandwidth from the detector, an arbitrarily large number is used for FSTAR (a megahertz).

SCAN

The frame rate (FR) and the overall scan efficiency (XNSC) are given in Table D4. The overscan ratio is computed from the equation noted in Supplement 4 and comes out to 1.0.

ELEC

The low-frequency 3-dB point (CUTOFF) associated with the electronics is not given. It frequently is found to range between 3 and 7 hertz. We will choose 3 hertz. We are also not given any information on the high-frequency amplifier 3-dB point. We will assume that our electronics are of sufficient bandwidth such that they do not degrade. Therefore, we set FELECT equal to 0.0 so we can read in an electronics MTF which we will set equal to 1.0. There are no LED's in the system so their widths (XY) and lengths (XYL) are all 0.0. Since there is no electronic boost in the system, the electronic aperture correction amplitude (XK) and the electronic aperture correction frequency (FMAXF) are set to values of 0.0.

DISP

The system has a CRT display so that KKK = 0.0. The average brightness (BRITE) on the display is given as 50.0 fL. In order to assign values to XA and YA, the two variables associated with the spot size, several assumptions must be made. We will assume that the spot is Gaussian in shape, that it is symmetrical about the x and y axes, that it has been measured by the shrinking raster method, and that the spot size quoted in Table D4 is the length w in Supplement 3 under 3.3, ABLUR, (4) (a). (See Supplement

7 for further explanation.) The values for XA and YA can now be computed directly: (XA = YA = 0.019 $mrad^2$).

SYST

The horizontal field of view (HFOV), the vertical field of view (VFOV), and the system magnification (XMAG) are taken directly from Table D4. Our system only has one field of view; so FACT – 1.0. We wish to predict the NEΔT; so XNET = 0.0.

STAB

There is no indicated degradation due to vibration; so XSIGLS = YSIGLS = 0.0.

ENVI

We will predict performance through an atmosphere with an air temperature (AIRTMP) of 15° C, a relative humidity (RH) of 50%, and a visibility range (RVIS) of 23.0 kilometers. This clear atmosphere requires the special atmospheric condition designator (ISTATE) to be equal to 0.0.

TARG

We will choose a hot tank target whose length (XLTAR) is 5.25 meters, whose width (XHTAR) is 2.7 meters, and whose temperature (DETEMP) is 11.1° C above the background temperature (TBAC) of 12.0° C. The tank dimensions are discussed in Supplement 1. The target and the background parameters are the default values.

RANG

Supplement 1.3 indicates that if we have a detector-limited system, the 50% probability of detection will occur at a maximum of 10,800 meters and the 50% proability of recognition will be at a maximum of 2,700 meters. In an attempt to calculate most of the detection and recognition probability distributions, we chose the detection calculations to be performed between 2,000 meters (IRDIN) and 20,000 meters (IRDAX). The recognition calculations will be done between 1,000 meters (IRMIN) and 10,000 meters (IRMAX).

SN4B

For the threshold signal-to-noise ratio (SNR), we use the default value of 2.25.

EYEB

For the integration time of the eye (EYETM), we use the default value of 0.2.

FLHZ

We use the default values for frequencies in log hertz corresponding to the MTF's of the electronics, the boost, and the detector temporal response.

DROX

Since we have already determined that the detector will have sufficient time to respond to an incident signal, we do not expect any associated detector MTF degradation. Consequently, we set this MTF in the x direction equal to 1.0.

DROY

The MTF in the y direction due to detector temporal response is 1.0 for the same reason as it is in the x direction.

EMTF

We have already decided that the MTF due to the electronics will be considered as 1.0. We enter this on the card at all frequencies.

BMTF

We have no electronic boost in this system so the MTF on this card is unity.

FCMR

We use the default values for frequencies in cycles/mrad corresponding to the MTF's of the optics, the vidicon, and any unstabilizing factors.

MTOX

Our system is diffraction limited, so we must set all MTF values for the x direction equal to 0.0.

MTOY

All MTF values in the y direction are set equal to 0.0 for the same reason as those in the x direction.

VMTX

There is no vidicon in the system so the MTF at all frequencies is equal to 1.0 in the x direction.

VMTY

Similarly, the MTF at all frequencies for the vidicon in the y direction is equal to 1.0.

LSSX

We input the default values of 1.0 for the stabilization MTF in the x direction since we have assumed no vibration.

LSSY

As on LSSX, the MTF for stabilization in the y direction is 1.0.

NPSF

These are the frequencies in log hertz that correspond to the noise power spectrum on NPSP.

NPSP

No noise power spectrum is given for the detector. It must be obtained from published material on detectors or from direct measurement. We have chosen a representative noise power spectrum of HgCdTe and normalized it to 1.0 at frequency FØ for this example.

DSTL

These are the wavelengths in micrometers that correspond to the D* values on DSTD.

DSTD

No detector performance curve is given in Table D4. This also must be determined from published material or from direct measurement. Note that in using any of the standard curves, they must be normalized to a maximum of 1.0. We use here a typical D* curve for HgCdTe.

FDRP

We will predict the probability of detection and recognition using the validation upon which this program is based. Consequently, this card, as well as the next three, will contain the default values found in Table D2. This card shows a set of probabilities.

FDC1

The number of cycles needed for detection at various probabilities of detection can be found on this card. The probabilities are those on FDRP.

FRC3

The number of cycles needed for optimistic recognition at various probabilities of recognition can be found on this card. The probabilities are those on FDRP.

FRC4

The number of cycles needed for conservative recognition at various probabilities of recognition can be found on this card. The probabilities are those on FDRP.

The FRC4 card is the last input data card. We have now assigned values to all of the input variables. The simple deck we have just generated is illustrated in Figures D6 and D7. It is complete with the addition of a DONE card after the last card in Figure D7. This input deck quantifies the system described in Table D4. In general, errors will occasionally be made in the preparation of a data deck. Many of these mistakes can be caught by carefully scrutinizing the first five tables in the output listing of any run. These tables reproduce an easily readable listing of the input quantities. For our example, Tables D5(a)–D5(e) were generated. It is easy and necessary to always check to validate the accuracy of the inputs.

B. Output Listings.

There are essentially two types of output listings that can be obtained from the model. Tables D6(a)–D6(e) show the program output for the simple input deck that has so far been described. The individual modulation transfer functions that must be considered in the x direction can be found in Table D6(a). These transfer functions correspond to the diffraction limit of the optics (OPTICS), the geometrical blur of the optics (GOBLUR), the spatial transfer aspects of the detector (DETEC), the temporal aspects of the detector (RSPNS), the electronics (ELECT), the electronic boost (BOOST), the vidicon (VIDCN), any LED arrays (LED), the display (DSPLY), the degradation due to the destabilization (LOS), and the eye (EYE). Table D6(a) is in spatial frequency and can only correspond to Table D5(d) for the inputs given in spatial frequency. All other MTF's in Table D6(a) have been either converted to spatial frequency space or calculated. The overall system MTF in the x direction is shown in Table D6(b). Table D6(c) displays the predicted minimum resolvable temperature in the x direction for our system. Finally, the expected power-based detection and recognition performance probabilities in the x direction appear in Tables D6(d) and D6(e). Since there is only one field of view for the system, the two performance predictions in Table D6(d) are identical.

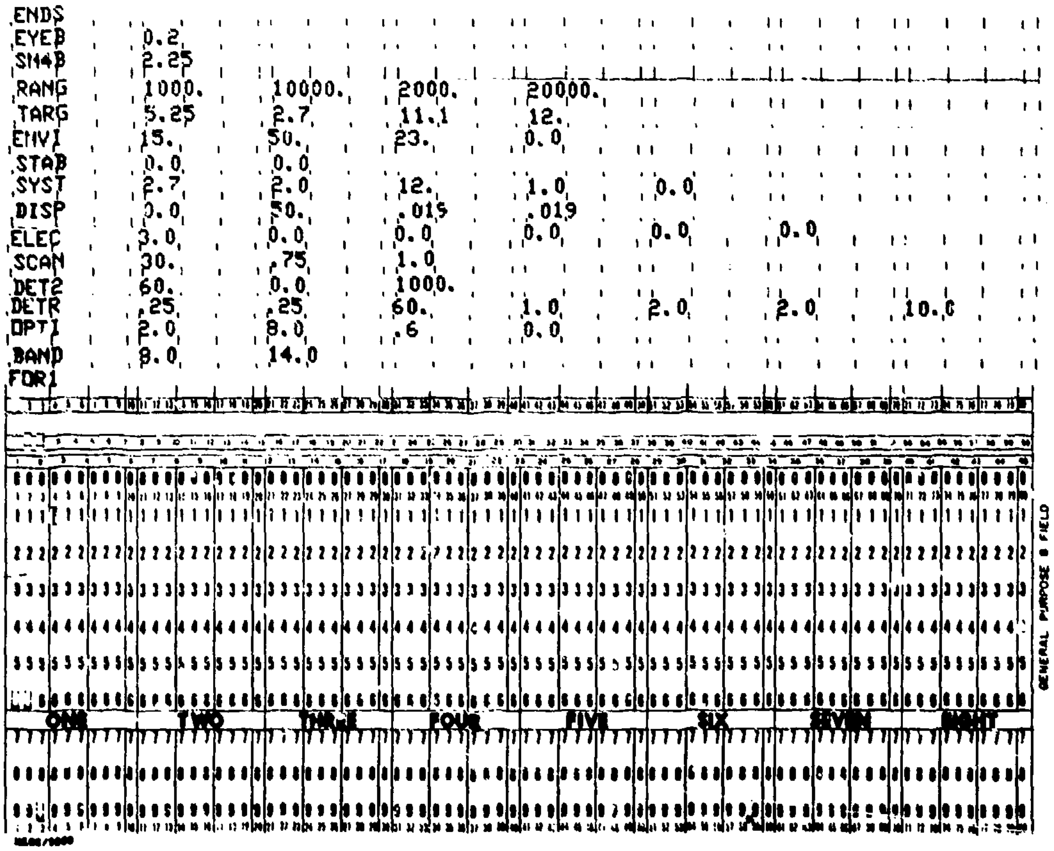


Figure D6. A simple deck.

ENDS										
FRC4	50.	20.	12.	8.0	6.0	4.0	3.0	2.0	1.0	0.0
FRC3	37.5	15.	9.0	6.0	4.5	3.0	2.25	1.5	.75	0.0
FDC1	12.5	5.0	3.0	2.0	1.5	1.0	.73	0.5	.25	0.0
FDRP	1.0	1.0	1.0	.95	0.8	0.5	0.3	0.1	.02	0.0
DSTD	.45	.52	.75	.80	.88	.92	1.0	.97	.90	0.0
DSTL	8.0	9.5	9.5	10.5	11.	12.	12.5	13.	13.5	14.
NPSP	32.	16.	4.0	2.25	1.0	1.0	1.0	1.0	0.0	0.0
NPSF	0.0	1.0	2.0	3.0	3.3	4.0	5.0	6.0	0.0	0.0
LSSY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
LSSX	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
VMTY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
VMTX	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
MTDY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MTDX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FCMR	0.0	1.0	2.0	3.0	3.5	4.0	4.5	5.0	6.0	7.0
BMTC	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CMTF	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
DRDY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
DRDX	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
FLHZ	0.0	.01	0.1	0.2	0.3	0.5	0.6	0.7	1.0	10.
FDR2										

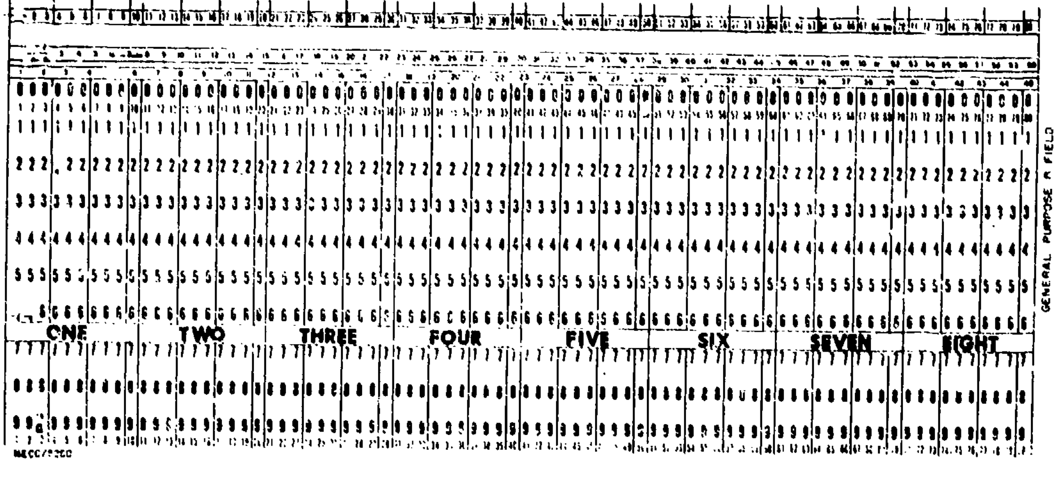


Figure D7. Continuation of a simple deck.

Table D5(a). Input Data

RUN NUMBER 1

YOUR SPECTRAL BAND IS . 8.000 TO 14.000 MICRONS

OPTICS

DIAMETER	4.000	INCHES
F-NUMBER	2.000	
FOCAL LENGTH	8.000	INCHES
AVG. OPTICAL TRANSMISSION	0.600	
WAVELENGTH FOR DIFFRACTION	10.000	MICRONS
GEOMETRIC BLUR SPOT SIZE	0.0	MRAD.

DETECTOR

HORIZONTAL IFOV	0.250	MRAD.
VERTICAL IFOV	0.250	MRAD.
DETECTORS IN PARALLEL	60.	
DETECTORS IN SERIES	1.	
DETECTOR SIZE	0.00200	INCHES
PEAK D*	2.00	10**(10)CM-SQRT(HZ)/WATT
MEASURING FREQUENCY OF D*	10000.	HERTZ
COLD SHIELD ANGLE	60.000	DEGREES
LIMITING NOISE	DETECTOR	
DETECTOR RESPONSE,3-DB POINT	0.100E 07	HERTZ

SCANNER

FRAME RATE	30.000	FRAMES/SECOND
SCAN EFFICIENCY	0.750	
OVERSCAN RATIO	1.000	

ELECTRONICS

PREAMP,LOW FREQ 3-DB CUT-ON	3.000	HERTZ
AMPLIFIER,3-DB POINT	0.0	HERTZ
E/O LED WIDTH	C.0	MRAD.
E/O LED LENGTH	0.0	MRAD.
APERTURE CORRECTION AMPLITUDE	0.0	
APERTURE CORRECTION FREQUENCY	C.	HERTZ

Table D5(b). Input Data

DISPLAY		
TYPE	CRT DISPLAY	
X SPOT SIZE	0.019	MRAD.
Y SPOT SIZE	0.019	MRAD.
AVERAGE BRIGHTNESS	50.000	FT. LAMBERTS
SYSTEM		
HORIZONTAL FOV	2.700	DEGREES
VERTICAL FOV	2.000	DEGREES
MAGNIFICATION	12.000	
WFOV/NFOV	1.000	
NOISE EQUIV. DELTA T	0.0	DEGREES C
STABILIZATION		
SYSTEM STATE	STABILIZED	
X VIBRATION CONSTANT	0.00	
Y VIBRATION CONSTANT	0.00	
STANDARD INPUTS		
EYE INTEGRATION TIME	0.200	SECONDS
THRESHOLD SIGNAL/NOISE	2.250	

Table D5(c). Input Data

ATMOSPHERIC PARAMETERS		
CONDITION	CLEAR	
VISIBILITY RANGE	23.000	KILOMETERS
RELATIVE HUMIDITY	50.000	PERCENT
AIR TEMPERATURE	15.000	DEGREES C
TARGET & BACKGROUND		
TARGET LENGTH	5.250	METERS
TARGET WIDTH	2.700	METERS
TARGET DELTA T	11.100	DEGREES C
BACKGROUND TEMPERATURE	12.000	DEGREES C
RANGE REQUIREMENTS		
MIN. REQUIRED RANGE FOR RECOG.	1000	METERS
MAX. REQUIRED RANGE FOR RECOG.	10000	METERS
RANGE INCREMENTS FOR RECOG.	1000	METERS
MIN. REQUIRED RANGE FOR DETEC.	2000	METERS
MAX. REQUIRED RANGE FOR DETEC.	20000	METERS
RANGE INCREMENTS FOR DETEC.	2000	METERS

Table D5(d). Input Data

TEMPORAL MTF'S

FREQ. (LOG HERTZ)	0.0	0.01	0.10	0.20	0.30	0.50	0.60	0.70	1.00	10.00
DETECT. ROLLOFF MTF (X)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DETECT. ROLLOFF MTF (Y)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ELECTRONIC MTF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BOOST MTF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

SPATIAL COMPONENTS MTF'S

FREQ. (CYC./MRAD.)	0.0	1.00	2.00	3.00	3.50	4.00	4.50	5.00	6.00	7.00
OPTICS MTF (X)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OPTICS MTF (Y)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VIDICON MTF (X)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
VIDICON MTF (Y)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
STABILIZATION MTF (X)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
STABILIZATION MTF (Y)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

NOISE POWER SPECTRUM (VOLTS/SQRT(HZ))

FREQ. (LOG HERTZ)	0.0	1.00	2.00	3.00	3.30	4.00	5.00	6.00	0.0	0.0
POWER (TIMES 10**(-9))	32.00	16.00	4.00	2.25	1.00	1.00	1.00	1.00	0.0	0.0

D* OF DETECTOR (CM.*SQRT(HZ.) /WATT)

WAVELENGTH (MICRONS)	8.00	8.50	9.50	10.50	11.00	12.00	12.50	13.00	13.50	14.00
D* (TIMES 10**(10))	0.45	0.52	0.75	0.80	0.83	0.92	1.00	0.97	0.90	0.0

Table D5(e). Input Data

DETECTION & RECOGNITION PROBABILITY DENSITY

DETECTION FREQUENCY	12.50	5.00	3.00	2.00	1.50	1.00	0.75	0.50	0.25	0.0
OPTIMISTIC RECOG. FREQ.	37.50	15.00	9.00	6.00	4.50	3.00	2.25	1.50	0.75	0.0
CONSERVATIVE RECOG. FREQ.	50.00	20.00	12.00	8.00	6.00	4.00	3.00	2.00	1.00	0.0
PROBABILITY	1.00	1.00	1.00	0.95	0.80	0.50	0.30	0.10	0.02	0.0

Table D6(a). Output Data

X MODULATION TRANSFER FUNCTIONS

FREQ	OPTICS	GDBLUR	DETEC	RSPNS	ELECT	BOOST	VIDCN	LED	DSPLY	LOS	EYE
0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.20	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98
0.40	0.95	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97
0.60	0.93	1.00	0.96	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.95
0.80	0.90	1.00	0.94	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.94
1.00	0.88	1.00	0.90	1.00	1.00	1.00	1.00	1.00	0.98	1.00	0.92
1.20	0.85	1.00	0.86	1.00	1.00	1.00	1.00	1.00	0.97	1.00	0.90
1.40	0.83	1.00	0.81	1.00	1.00	1.00	1.00	1.00	0.96	1.00	0.89
1.60	0.80	1.00	0.76	1.00	1.00	1.00	1.00	1.00	0.95	1.00	0.88
1.80	0.78	1.00	0.70	1.00	1.00	1.00	1.00	1.00	0.94	1.00	0.86
2.00	0.75	1.00	0.64	1.00	1.00	1.00	1.00	1.00	0.93	1.00	0.85
2.20	0.73	1.00	0.57	1.00	1.00	1.00	1.00	1.00	0.91	1.00	0.83
2.40	0.70	1.00	0.50	1.00	1.00	1.00	1.00	1.00	0.90	1.00	0.82
2.60	0.68	1.00	0.44	1.00	1.00	1.00	1.00	1.00	0.88	1.00	0.80
2.80	0.65	1.00	0.37	1.00	1.00	1.00	1.00	1.00	0.86	1.00	0.79
3.00	0.63	1.00	0.30	1.00	1.00	1.00	1.00	1.00	0.84	1.00	0.78
3.20	0.61	1.00	0.23	1.00	1.00	1.00	1.00	1.00	0.82	1.00	0.77
3.40	0.58	1.00	0.17	1.00	1.00	1.00	1.00	1.00	0.80	1.00	0.75
3.60	0.56	1.00	0.11	1.00	1.00	1.00	1.00	1.00	0.76	1.00	0.74
3.80	0.54	1.00	0.05	1.00	1.00	1.00	1.00	1.00	0.76	1.00	0.73

Table D6(b). Output Data

SYSTEM MODULATION TRANSFER FUNCTION

FREQ	X MTF
0.0	1.00
0.20	0.97
0.40	0.93
0.60	0.89
0.80	0.83
1.00	0.77
1.20	0.71
1.40	0.64
1.60	0.58
1.80	0.51
2.00	0.44
2.20	0.38
2.40	0.32
2.60	0.26
2.80	0.21
3.00	0.16
3.20	0.12
3.40	0.08
3.60	0.05
3.80	0.02

Table D6(c). Output Data

PREDICTED MINIMUM RESOLVABLE TEMPERATURE

FREQ	X MRT
2.000E-01	1.345E-02
4.000E-01	2.326E-02
6.000E-01	3.270E-02
8.000E-01	4.295E-02
1.000E 00	5.454E-02
1.200E 00	6.845E-02
1.400E 00	8.523E-02
1.600E 00	1.063E-01
1.800E 00	1.329E-01
2.000E 00	1.673E-01
2.200E 00	2.128E-01
2.400E 00	2.743E-01
2.600E 00	3.599E-01
2.800E 00	4.834E-01
3.000E 00	6.702E-01
3.200E 00	9.718E-01
3.400E 00	1.510E 00
3.600E 00	2.650E 00
3.800E 00	6.220E 00
4.000E 00	2.000E 07

Table D6(d). Output Data

DELTA T= 0.111E 02
DETECTION PERFORMANCE
NFOV PERFORMANCE

RANGE	TRANSMISSION	X DETECTION PROBABILITY
2.00	0.66	1.00
4.00	0.51	0.98
6.00	0.40	0.85
8.00	0.32	0.63
10.00	0.26	0.46
12.00	0.21	0.31
14.00	0.17	0.20
16.00	0.14	0.12
18.00	0.12	0.08
20.00	0.10	0.06

WFOV PERFORMANCE

RANGE	TRANSMISSION	X DETECTION PROBABILITY
2.00	0.66	1.00
4.00	0.51	0.98
6.00	0.40	0.85
8.00	0.32	0.63
10.00	0.26	0.46
12.00	0.21	0.31
14.00	0.17	0.20
16.00	0.14	0.12
18.00	0.12	0.08
20.00	0.10	0.06

Table D6(e). Output Data

RECOGNITION PERFURMANCE
POWER DEPENDANT PERFORMANCE

RANGE	TRANSMISSION	X RECOGNITION PROBABILITY
1.00	0.78	0.98
2.00	0.66	0.67
3.00	0.58	0.38
4.00	0.51	0.21
5.00	0.45	0.10
6.00	0.40	0.07
7.00	0.36	0.05
8.00	0.32	0.04
9.00	0.29	0.03
10.00	0.26	0.02

This output listing is inadequate if you desire any of the following optional outputs:

1. information on y or diagonal direction signal processing
2. noise-filtering MTF
3. exact or white noise bandwidth
4. scan velocity
5. NEΔT
6. constant length MRT
7. MDT
8. temperature and MDT based detection performance; temperature based recognition performance; optimistic recognition performance
9. Special expressions used in hand calculations

In order to obtain these quantities from the program, you must assign the number 1 to a special print variable. This variable is located in column 21 of the DONE card for the simple deck that we have been discussing. (See Figure D1.) For any type of multiple-run deck, the variable is located in column 21 of either the DONE card or any of the second ENDS cards. You must request a supplemental listing for every run in a multiple-deck run where such a listing is desired. For example, Figure D2 shows a deck containing three runs. Let us say that we wish to have the supplemental output listing for the first and the third runs. The last card in the first run within this deck is an ENDS card. Since we desire a supplemental output listing here, we put a number 1 in column 21 of this ENDS card. In the second run, we change only the atmosphere. We do not want the supplemental listing for this run so the second ENDS card after the ENVI card (see Figure D2) remains blank. Finally, since we again want the supplemental listing in the third run, we place a number 1 in column 21 of the DONE card. Remember, there are two optional variables on the DONE card and all second ENDS cards. If a number 1 appears in column 11 (Section IV B), system calculations will be performed. When a number 1 appears in column 21, an extended-output listing is printed.

The long output contains all the information printed out from the abbreviated output plus the nine optional outputs. Tables D7(a)–D7(l) show the form of this output for our example. Table D7(a) is identical to Table D6(a). Table D7(b) contains the individual MTF's that must be considered in the y direction. In Table D7(c), we find the system MTF in both the x and the y direction. We also find the noise-filtering MTF. This MTF indicates how the detected signal and noise are modulated by system components beyond the detector.

An additional feature of the long printout is that it provides enough information

Table D7(a). Long Output Data

X MODULATION TRANSFER FUNCTIONS

FREQ	OPTIC	GOBLUR	DETEC	RSPNS	ELECT	BOOST	VIDCN	LED	DSPLY	LNS	EYE
0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.20	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98
0.40	0.95	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97
0.60	0.93	1.00	0.96	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.95
0.80	0.90	1.00	0.94	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.94
1.00	0.88	1.00	0.90	1.00	1.00	1.00	1.00	1.00	0.98	1.00	0.92
1.20	0.85	1.00	0.86	1.00	1.00	1.00	1.00	1.00	0.97	1.00	0.90
1.40	0.83	1.00	0.81	1.00	1.00	1.00	1.00	1.00	0.96	1.00	0.89
1.60	0.80	1.00	0.76	1.00	1.00	1.00	1.00	1.00	0.95	1.00	0.88
1.80	0.78	1.00	0.70	1.00	1.00	1.00	1.00	1.00	0.94	1.00	0.86
2.00	0.75	1.00	0.64	1.00	1.00	1.00	1.00	1.00	0.93	1.00	0.85
2.20	0.73	1.00	0.57	1.00	1.00	1.00	1.00	1.00	0.91	1.00	0.83
2.40	0.70	1.00	0.50	1.00	1.00	1.00	1.00	1.00	0.90	1.00	0.82
2.60	0.68	1.00	0.44	1.00	1.00	1.00	1.00	1.00	0.88	1.00	0.80
2.80	0.65	1.00	0.37	1.00	1.00	1.00	1.00	1.00	0.86	1.00	0.79
3.00	0.63	1.00	0.30	1.00	1.00	1.00	1.00	1.00	0.84	1.00	0.78
3.20	0.61	1.00	0.23	1.00	1.00	1.00	1.00	1.00	0.82	1.00	0.77
3.40	0.58	1.00	0.17	1.00	1.00	1.00	1.00	1.00	0.80	1.00	0.75
3.60	0.56	1.00	0.11	1.00	1.00	1.00	1.00	1.00	0.78	1.00	0.74
3.80	0.54	1.00	0.05	1.00	1.00	1.00	1.00	1.00	0.76	1.00	0.73

Table D7(b). Long Output Data

Y MODULATION TRANSFER FUNCTIONS

FREQ	OPTIC	GOULUR	DETEC	VIDCN	LED	DSPLY	LOS	EYE
0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.20	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.98
0.40	0.95	1.00	0.98	1.00	1.00	1.00	1.00	0.97
0.60	0.93	1.00	0.96	1.00	1.00	0.99	1.00	0.95
0.80	0.90	1.00	0.94	1.00	1.00	0.99	1.00	0.94
1.00	0.88	1.00	0.90	1.00	1.00	0.98	1.00	0.92
1.20	0.85	1.00	0.86	1.00	1.00	0.97	1.00	0.90
1.40	0.83	1.00	0.81	1.00	1.00	0.96	1.00	0.89
1.60	0.80	1.00	0.76	1.00	1.00	0.95	1.00	0.88
1.80	0.78	1.00	0.70	1.00	1.00	0.94	1.00	0.86
2.00	0.75	1.00	0.64	1.00	1.00	0.93	1.00	0.85
2.20	0.73	1.00	0.57	1.00	1.00	0.91	1.00	0.83
2.40	0.70	1.00	0.50	1.00	1.00	0.90	1.00	0.82
2.60	0.68	1.00	0.44	1.00	1.00	0.88	1.00	0.80
2.80	0.65	1.00	0.37	1.00	1.00	0.86	1.00	0.79
3.00	0.63	1.00	0.30	1.00	1.00	0.84	1.00	0.78
3.20	0.61	1.00	0.23	1.00	1.00	0.82	1.00	0.77
3.40	0.58	1.00	0.17	1.00	1.00	0.80	1.00	0.75
3.60	0.56	1.00	0.11	1.00	1.00	0.78	1.00	0.74
3.80	0.54	1.00	0.05	1.00	1.00	0.76	1.00	0.73

Table D7(c). Long Output Data

PREDICTED SYSTEM MTF			PREDICTED NOISE FILTERING MTF		
FREQ	X MTF	Y MTF	FREQ	X MTF	Y MTF
0.0	1.00	1.00	0.0	1.00	1.00
0.20	0.97	0.97	1.52	0.96	0.96
0.40	0.93	0.93	3.04	0.84	0.84
0.60	0.89	0.89	4.56	0.67	0.67
0.80	0.83	0.83	6.08	0.50	0.50
1.00	0.77	0.77	7.60	0.33	0.33
1.20	0.71	0.71	9.12	0.21	0.21
1.40	0.64	0.64	10.64	0.12	0.12
1.60	0.58	0.58	12.16	0.06	0.06
1.80	0.51	0.51	13.68	0.03	0.03
2.00	0.44	0.44	15.20	0.01	0.01
2.20	0.38	0.38	16.72	0.00	0.00
2.40	0.32	0.32	18.24	0.00	0.00
2.60	0.26	0.26	19.76	0.00	0.00
2.80	0.21	0.21	21.28	0.00	0.00
3.00	0.16	0.16	22.80	0.00	0.00
3.20	0.12	0.12	24.32	0.00	0.00
3.40	0.08	0.08	25.84	0.00	0.00
3.60	0.05	0.05	27.36	0.00	0.00
3.80	0.02	0.02	28.88	0.00	0.00

Table D7(d). Long Output Data

```
INTEGRAL OF D-STAR*W-PRIME= 0.126E 07
EXACT NOISE BANDWIDTH= 0.168E 05
WHITE NOISE BANDWIDTH= 0.139E 05

SCAN VELOCITY IN MR/SEC= 0.441E 04
DET NOISE LIMITED NET= 0.180E 00
```

Table D7(e). Long Output Data

FILTERED NOISE

FREQ	Q	QQ
0.200E 00	0.105E 01	0.247E 01
0.400E 00	0.140E 01	0.352E 01
0.600E 00	0.161E 01	0.428E 01
0.800E 00	0.178E 01	0.472E 01
0.100E 01	0.192E 01	0.513E 01
0.120E 01	0.206E 01	0.549E 01
0.140E 01	0.218E 01	0.575E 01
0.160E 01	0.230E 01	0.594E 01
0.180E 01	0.241E 01	0.607E 01
0.200E 01	0.252E 01	0.617E 01
0.220E 01	0.262E 01	0.623E 01
0.240E 01	0.271E 01	0.626E 01
0.260E 01	0.280E 01	0.626E 01
0.280E 01	0.288E 01	0.626E 01
0.300E 01	0.295E 01	0.623E 01
0.320E 01	0.302E 01	0.620E 01
0.340E 01	0.308E 01	0.615E 01
0.360E 01	0.314E 01	0.611E 01
0.380E 01	0.320E 01	0.605E 01
0.400E 01	0.325E 01	0.600E 01

Table D7(f). Long Output Data

PREDICTED MINIMUM RESOLVABLE TEMPERATURE

FREQ	X MRT	Y MRT	XLMRT	YLMRT	45MRT
2.000E-01	1.345E-02	2.061E-02	4.254E-02	6.516E-02	7.782E-02
4.000E-01	2.326E-02	3.684E-02	5.200E-02	8.239E-02	9.743E-02
6.000E-01	3.270E-02	5.325E-02	5.969E-02	9.721E-02	1.141E-01
8.000E-01	4.295E-02	6.985E-02	6.790E-02	1.104E-01	1.297E-01
1.000E 00	5.454E-02	8.929E-02	7.713E-02	1.263E-01	1.480E-01
1.200E 00	6.845E-02	1.118E-01	8.837E-02	1.443E-01	1.692E-01
1.400E 00	8.523E-02	1.384E-01	1.019E-01	1.654E-01	1.943E-01
1.600E 00	1.063E-01	1.707E-01	1.138E-01	1.909E-01	2.248E-01
1.800E 00	1.329E-01	2.109E-01	1.401E-01	2.223E-01	2.628E-01
2.000E 00	1.673E-01	2.619E-01	1.673E-01	2.619E-01	3.108E-01
2.200E 00	2.128E-01	3.282E-01	2.029E-01	3.130E-01	3.730E-01
2.400E 00	2.743E-01	4.168E-01	2.504E-01	3.805E-01	4.535E-01
2.600E 00	3.599E-01	5.385E-01	3.156E-01	4.723E-01	5.681E-01
2.800E 00	4.834E-01	7.129E-01	4.085E-01	6.025E-01	7.280E-01
3.000E 00	6.702E-01	9.741E-01	5.472E-01	7.954E-01	9.654E-01
3.200E 00	9.718E-01	1.392E 00	7.682E-01	1.101E 00	1.342E 00
3.400E 00	1.510E 00	2.133E 00	1.158E 00	1.636E 00	2.004E 00
3.600E 00	2.650E 00	3.694E 00	1.976E 00	2.753E 00	3.389E 00
3.800E 00	6.220E 00	8.555E 00	4.512E 00	6.206E 00	7.673E 00
4.000E 00	2.000E 07	2.000E 07	1.414E 07	1.414E 07	2.000E 07

Table D7(g). Long Output Data

RECOGNITION PERFORMANCE
TARGET DELTA TEMPERATURE IS 11.10 DEGREES C
TEMPERATURE DEPENDANT PERFORMANCE

RANGE	ATM TRANS	XCONSERVATIVE	YCONSERVATIVE	45CONSERVATIVE
1.00	0.75	0.98	0.98	0.98
2.00	0.66	0.67	0.67	0.67
3.00	0.58	0.38	0.38	0.37
4.00	0.51	0.21	0.20	0.20
5.00	0.45	0.10	0.10	0.10
6.00	0.40	0.07	0.07	0.07
7.00	0.35	0.05	0.05	0.05
8.00	0.32	0.04	0.03	0.03
9.00	0.29	0.03	0.02	0.02
10.00	0.26	0.02	0.02	0.02

RANGE	ATM TRANS	XOPTIMISTIC	YOPTIMISTIC	45OPTIMISTIC
1.00	0.78	1.00	1.00	1.00
2.00	0.66	0.86	0.86	0.86
3.00	0.58	0.58	0.58	0.57
4.00	0.51	0.38	0.37	0.36
5.00	0.45	0.24	0.23	0.22
6.00	0.40	0.14	0.13	0.13
7.00	0.36	0.09	0.09	0.08
8.00	0.32	0.07	0.07	0.06
9.00	0.29	0.05	0.05	0.05
10.00	0.26	0.04	0.04	0.04

Table D7(h). Long Output Data

RECOGNITION PERFORMANCE
TARGET DELTA TEMPERATURE IS 11.10 DEGREES C
POWER DEPENDANT PERFORMANCE

RANGE	ATM TRANS	XCONSERVATIVE	YCONSERVATIVE	45CONSERVATIVE
1.00	0.78	0.98	0.98	0.98
2.00	0.66	0.67	0.67	0.67
3.00	0.58	0.38	0.38	0.37
4.00	0.51	0.21	0.20	0.19
5.00	0.45	0.10	0.10	0.10
6.00	0.40	0.07	0.07	0.07
7.00	0.36	0.05	0.05	0.05
8.00	0.32	0.04	0.03	0.03
9.00	0.29	0.03	0.02	0.02
10.00	0.26	0.02	0.02	0.02

RANGE	ATM TRANS	XOPTIMISTIC	YOPTIMISTIC	45OPTIMISTIC
1.00	0.78	1.00	1.00	1.00
2.00	0.66	0.86	0.86	0.86
3.00	0.58	0.58	0.58	0.57
4.00	0.51	0.38	0.37	0.36
5.00	0.45	0.24	0.23	0.22
6.00	0.40	0.14	0.13	0.13
7.00	0.36	0.09	0.09	0.08
8.00	0.32	0.07	0.07	0.06
9.00	0.29	0.05	0.05	0.05
10.00	0.26	0.04	0.04	0.03

Table D7(i). Long Output Data

PREDICTED MINIMUM DETECTABLE TEMPERATURE

(TARGET SIZE)**-1	MDT
0.200E 02	0.718E 01
0.100E 02	0.183E 01
0.667E 01	0.869E 00
0.500E 01	0.524E 00
0.400E 01	0.363E 00
0.333E 01	0.275E 00
0.286E 01	0.221E 00
0.250E 01	0.185E 00
0.222E 01	0.159E 00
0.200E 01	0.140E 00
0.182E 01	0.126E 00
0.167E 01	0.114E 00
0.154E 01	0.105E 00
0.143E 01	0.969E-01
0.133E 01	0.903E-01
0.125E 01	0.846E-01
0.118E 01	0.797E-01
0.111E 01	0.754E-01
0.105E 01	0.716E-01
0.100E 01	0.682E-01
0.952E 00	0.651E-01
0.909E 00	0.624E-01
0.870E 00	0.599E-01
0.833E 00	0.576E-01
0.800E 00	0.556E-01

Table D7(j). Long Output Data

DETECTION BASED ON MDT
TARGET DELTA TEMPERATURE IS 11.10 DEGREES C

RANGE	ATM TRANS	S/N	PROBABILITY
2.00	0.663	389.808	1.000
4.00	0.509	160.298	1.000
6.00	0.401	84.332	1.000
8.00	0.322	46.964	1.000
10.00	0.260	30.031	1.000
12.00	0.212	19.143	1.000
14.00	0.173	12.539	1.000
16.00	0.143	8.435	1.000
18.00	0.118	5.775	1.000
20.00	0.097	4.020	0.880

Table D7(k). Long Output Data

DETECTION PERFORMANCE
TARGET DELTA TEMPERATURE IS 11.10 DEGREES C
NFOV PERFORMANCE
TEMPERATURE DEPENDENT PERFORMANCE

RANGE	ATM TRANS	X DET T	Y DET T	45 DET T
2.00	0.66	1.00	1.00	1.00
4.00	0.51	0.98	0.98	0.97
6.00	0.40	0.85	0.84	0.83
8.00	0.32	0.63	0.61	0.59
10.00	0.26	0.46	0.43	0.41
12.00	0.21	0.31	0.28	0.26
14.00	0.17	0.20	0.17	0.15
16.00	0.14	0.12	0.10	0.09
18.00	0.12	0.08	0.07	0.06
20.00	0.10	0.05	0.05	0.04

POWER DEPENDENT PERFORMANCE

RANGE	ATM TRANS	X DET P	Y DET P	45 DET P
2.00	0.66	1.00	1.00	1.00
4.00	0.51	0.98	0.98	0.97
6.00	0.40	0.85	0.84	0.83
8.00	0.32	0.63	0.61	0.59
10.00	0.26	0.46	0.43	0.40
12.00	0.21	0.31	0.28	0.26
14.00	0.17	0.20	0.17	0.15
16.00	0.14	0.12	0.10	0.09
18.00	0.12	0.08	0.07	0.06
20.00	0.10	0.06	0.05	0.04

Table D7(l). Long Output Data

DETECTION PERFORMANCE
TARGET DELTA TEMPERATURE IS 11.10 DEGREES C
WFOV PERFORMANCE
TEMPERATURE DEPENDENT PERFORMANCE

RANGE	ATM TRANS	X DET T	Y DET T	45 DET T
2.00	0.66	1.00	1.00	1.00
4.00	0.51	0.98	0.98	0.97
6.00	0.40	0.65	0.64	0.83
8.00	0.32	0.63	0.61	0.59
10.00	0.26	0.46	0.43	0.41
12.00	0.21	0.31	0.28	0.26
14.00	0.17	0.20	0.17	0.15
16.00	0.14	0.12	0.10	0.09
18.00	0.12	0.08	0.07	0.06
20.00	0.10	0.06	0.05	0.04

POWER DEPENDENT PERFORMANCE

RANGE	ATM TRANS	X DET P	Y DET P	45 DET P
2.00	0.66	1.00	1.00	1.00
4.00	0.51	0.98	0.98	0.97
6.00	0.40	0.65	0.84	0.83
8.00	0.32	0.63	0.61	0.59
10.00	0.26	0.46	0.43	0.40
12.00	0.21	0.31	0.28	0.26
14.00	0.17	0.20	0.17	0.15
16.00	0.14	0.12	0.10	0.09
18.00	0.12	0.08	0.07	0.06
20.00	0.10	0.06	0.05	0.04

for hand calculations of performance. Such calculations may be used to check the program computations. The two quantities in Table D7(e) and the first four quantities in Table D7(d) reference variables in the mathematical formulation of the static performance model. See equations (26), (27), (24), (21), (22), and (12) in the main body of the report for their definition and use. The last item in Table D7(d) is the NEΔT of the system.

Table D7(f) contains various predicted system MRT's. Those in the x-direction (XMRT) and y-direction (YMRT) correspond to laboratory measurements. XLMRT and YLMRT are MRT's in the x and y directions adjusted so that the length of a superimposed bar pattern will match the target length. These MRT's are used in the calculation of performance. The 45° MRT is the square root of the sum of the squared x direction MRT and the squared y direction MRT. Table D7(i) presents the system MDT.

Detection performance based on temperature and power for three directions and two fields of view can be found in Tables 7(k) and D7(l). Detection probability based on the MDT and Rosell's criteria can be located in Table D7(j). Finally, in Tables D7(g) and D7(h), we have the power- and temperature-based recognition performance in three directions. The conservative and optimistic predictions correspond to a recognition criteria based on 4 cycles and 3 cycles, respectively. Note that the short listing displays the conservative prediction.

C. A Multiple-Run Deck with Target and Atmospheric Changes.

In order to illustrate the multiple-run features of this program, we will expand our example a bit in the next three sections. In this section, we will develop a deck along the lines of Figure D2 where we do three runs changing the atmosphere and then the target. We know that the simple deck discussed in Sections A and B and portrayed in Figures D6 and D7 is complete with the addition of a DONE card after the last card in Figure D7. When we change this card to an ENDS card, we are ready for more runs. Let us first do predictions when the air temperature rises to 20° C. Then, we will see what happens when the target temperature is lowered to 5° C over the background. The total deck for this multiple run will consist of the cards illustrated in Figures D6, D7, and D8. Note that the first and the third listing will be in the extended form.

For economy, the output from this multiple deck will differ from what would be expected if three decks were run separately. Three listings of the inputs will be printed since the inputs change each time. System calculations are performed only once, however, so they are printed only once. In this case, Tables D7(a)–D7(f) and Table D7(i) define the system predictions and will be produced by the first run along with Tables D7(g), D7(h), D7(j), and D7(l). The second run will produce results consisting of the new input listing and tables in the form of D6(d) and D6(e). Finally, the last run of

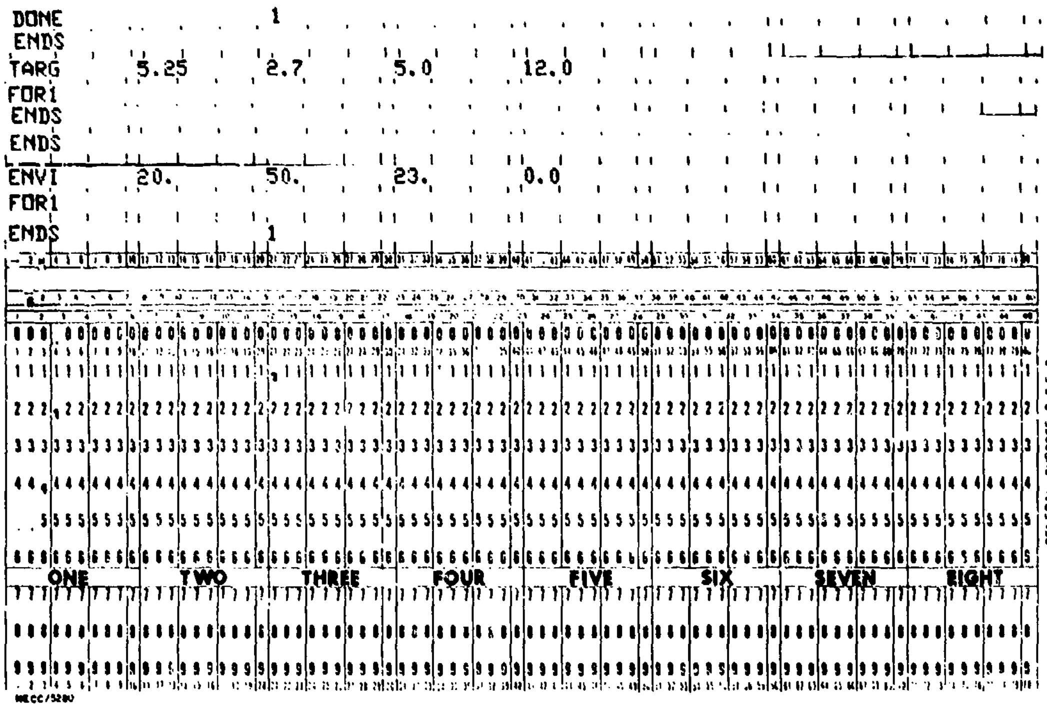


Figure D8. Part of a multiple-run deck.

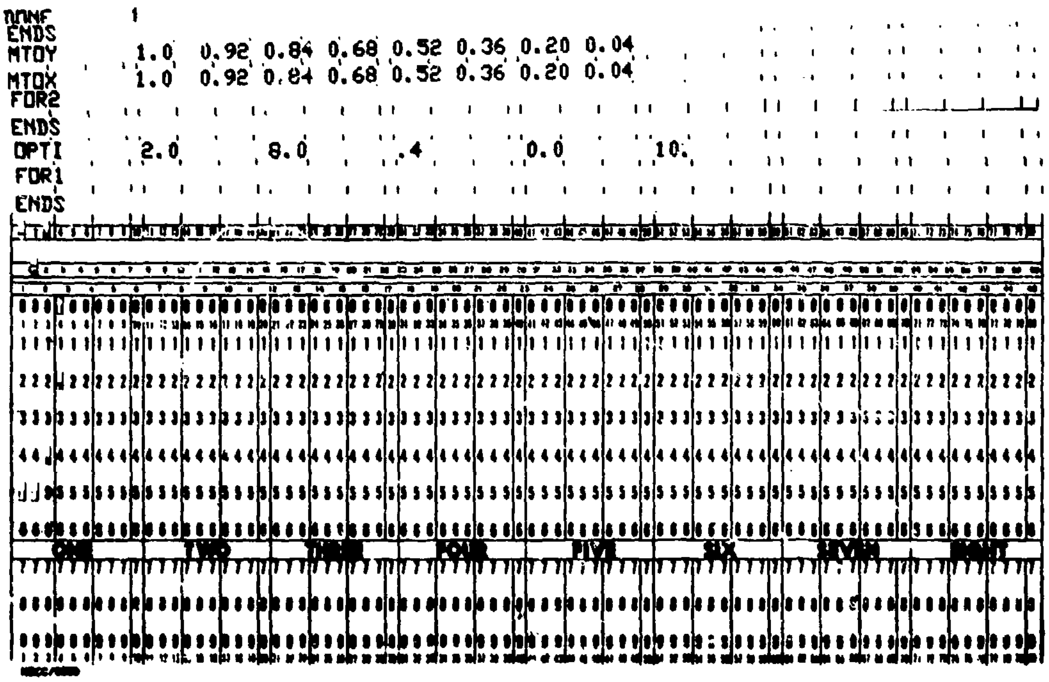


Figure D9. Part of a multiple-run deck.

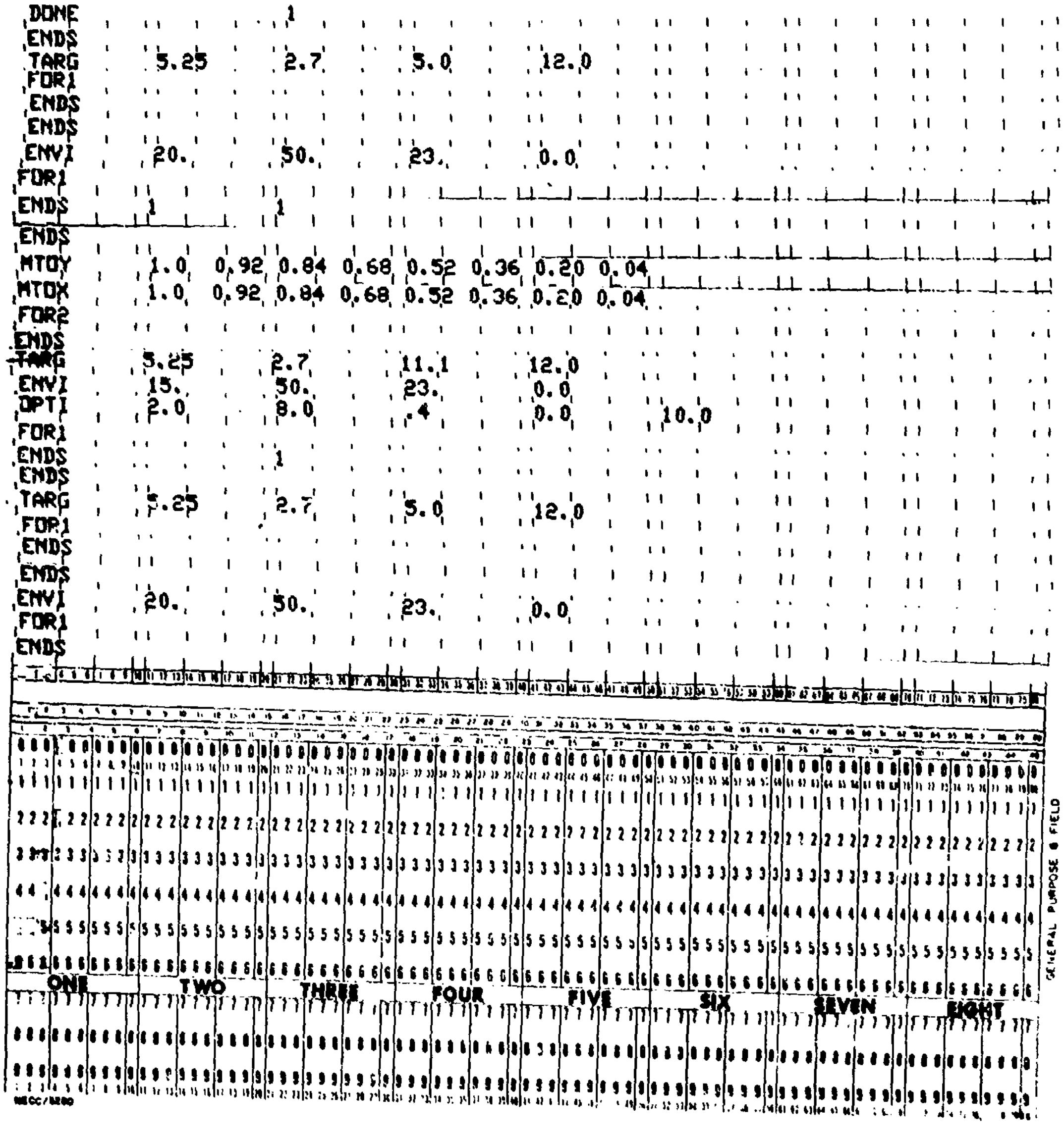


Figure D10. Part of a mixed, multiple-run deck.

this deck prints another input listing and a new set of tables in the form of D7(h)–D7(l). Remember that these last tables pertain to predictions made for an atmospheric air temperature of 20° C and a target temperature of 5° C. All changes carry through to subsequent runs.

D. A Multiple-Run Deck with System Parameter Changes.

In like manner, we put together a multiple-run deck with system changes according to Figure D3. Let us consider a new optical system for our example which has an MTF in the x and y directions as well as a transmission of 40%. The multiple-run deck we obtain is the combination of Figures D6, D7, and D9. There will be two sets of Tables D5 and D6 in our output listing.

E. A Mixed, Multiple-Run Deck.

Finally, let us take the two systems in Section D and predict performance for the three conditions in Section C. The single deck that will do these six runs can be constructed by bringing together Figures D6, D7, and D10, successively. The output listing will follow the patterns sketched in Sections B, C, and D.

VI. Supplements

The supplements contain many specific references to the theoretical treatment of the Night Vision Laboratory Static Performance Model for Thermal Viewing Systems. All references to "the main body of this report" refer to pages 1-34. Specific equations from the main body of the report are referenced whenever appropriate.

Supplement 1

Target

A discussion of the target model can be found in the theoretical treatment of the performance model under Section II, Target, Background, and Atmosphere. Table 1, Section II, describes a selection of target models that can be used as inputs. These models are for a tank, an APC, a 2½-ton truck, and a man.

The TARG card may be excluded from the input deck: (1) if one has no particular target requirement, or (2) if one is only interested in the predicted system MRT or MDT rather than field performance. When the TARG card is not included in the data deck, the default parameters listed in Table D2 are input to the model.

Probabilities of system performance are predicted as a function of range. Range is defined as the distance between the observer and the target. The RANG card specifies the positions of the target which are of interest to the user for detection and recognition performance. Ideally, one would receive an adequate span of range predictions to plot a continuous curve of the probabilities from 100% to 0% of detection and recognition. Possibly, one would only have interest in a range of specified probability. However, at this time, there is no search procedure for the initial, terminal, or percentage of interest range.

1.1 XLTAR, XHTAR – The real target's critical dimension is XHTAR. For most Army vehicular targets and for all targets used in the validation of the main body of this report, the critical dimension is the minimum dimension whether it be the width of a man or the height of a tank. The real target is modelled in the computer program by a rectangle with uniform ΔT. The smaller dimension of this rectangle is XHTAR. XLTAR is the rectangle length that when multiplied by the critical dimension will yield the thermal area of the real target. As an example, Table 1 shows that for a tank/side, XHTAR = 2.7 m and XLTAR = 5.25 m. All dimensions are in meters and may take on any value greater than 0.0.

1.2 DETEMP, TBAC – DETEMP is the absolute value of the average temperature difference ΔT_{AVG} defined by equations (1) and (2). DETEMP must be greater than 0.0° C; negative differences are not valid inputs. TBAC, the background temperature, is usually 12.0° C. If the user omits the value of TBAC on his data card or inputs 0.0, the value of 12.0 will be input. Therefore, it is impossible to specify a 0.0° background which may be a true representation of a sky background. To dodge this fault, input 0.01° C or some very small number to approximate 0.0° C.

1.3 IRMIN, IRMAX, IRDIN, IRDAX – The minimum and maximum ranges of interest for recognition, IRMIN and IRMAX, respectively, and for detection, IRDIN and IRDAX, are required by the program. Given a minimum range and maximum range for recognition performance, the model will calculate the probability of recognition starting at the minimum range, continuing for additional ranges in increments of (IRMAX–IRMIN)/9 until the maximum range is reached for a total of ten ranges. Likewise, the model will calculate the probability of detection starting at range IRDIN to range IRDAX in increments of (IRDAX–IRDIN)/9. IRMAX must be greater than IRMIN and IRDAX must be greater than IRDIN. All four ranges must be greater than 0.0 and in units of meters.

The RANG card may be omitted from the data deck and the default option in Table D2 will be input. Selection of input ranges comes with experience. Theoretically, if everything is ideal and the system is only limited by the detector, the 50% probability range of system performance can be approximated by

$$\text{RANGE} = \frac{\text{XHTAR} * 1000}{\text{DELTAX} * \text{XCYCLES}}$$

where XCYCLES is 1.0 for the suggested detection criteria. XCYCLES is 4.0 for the suggested recognition criteria. Where no prior knowledge of system performance exists, it is suggested that the user first try the default to the RANG card. Then, adjust the RANG card based on these results.

Supplement 2

Atmosphere

In this program, there are two different ways to account for atmospheric effects. A modified version of an atmospheric transmission model developed by the Air Force Cambridge Research Laboratory can be used by placing an ENVI card in the input deck. This card supplies the inputs to the atmospheric model.

The model requires values for the relative humidity, the air temperature, and the visibility range of the atmosphere. These are all continuous variables and any number, subject to certain restrictions, can be used. In order to aid the user, however, Table D8 associates typical discrete values of these variables with commonly observed atmospheric conditions. Temperature and relative humidity are grouped into three classes. These two variables together determine the water vapor concentration of the atmosphere which is often the predominant cause of atmospheric attenuation in the IR. Figure D11 can be used as a guide in determining an appropriate temperature-relative humidity combination. When using low visibility ranges, check to make sure that the RANG card is specified properly. In general, below a 2-kilometer visibility range, anticipate the possibility of low performance ranges.

Table D8. Atmospheric Models and Inputs

Type	Visibility Range (km)	Temperature/Relative Humidity*
Very clear	40	I
Clear	23	I
Light haze	9	II
Haze	5	II
Heavy haze	2	II
Light fog	1	III
Heavy fog	.2	III
Light rain	12	II
Moderate rain	6	II
Heavy rain	2	III
Very heavy rain	.5	III

* I – low water vapor content.
II – moderate water vapor content.
III – high water vapor content.

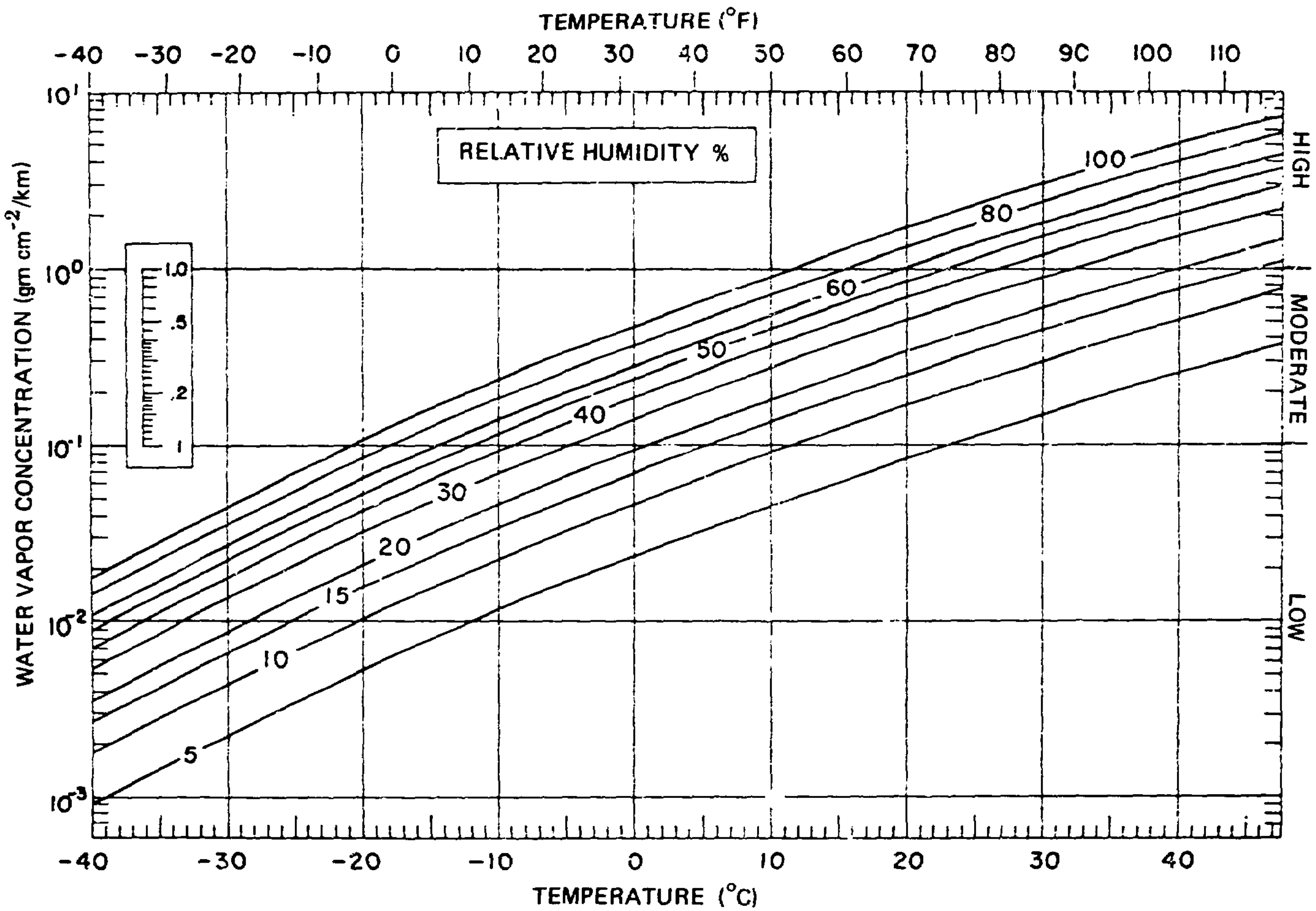


Figure D11. Water vapor concentration per kilometer path length as a function of temperature and relative humidity (*Optical Properties of the Atmosphere*, McClatchey *et al.*).

If spectral atmospheric transmission data per kilometer is available, a simple Beer's Law attenuation calculation can be performed. Atmospheric transmission is determined in 0.1-micron intervals by linearly interpolating data supplied by the TOTL card. When TOTL is used, the ENVI card is not necessary. If the transmissions on the TOTL card correspond to the default wavelengths for a 3-5 micrometer system stored in the WAVE array (see Table D2), the card ATEW is not needed when using TOTL. When the user has a choice between the two methods of accounting for atmospheric effects, he should use the transmission model needing the ENVI input card. It has more validity than a Beer's Law calculation.

It is perfectly correct to exclude all atmospheric cards. In this case, calculations are performed for a clear standard atmosphere having a visibility range of 23.0 kilometers, an air temperature of 15.0° C, and a relative humidity of 46%. Specific reference notes on individual parameters follow:

2.1 AIRTMP – the air temperature may take on any value from -29.0° C to 38.0° C. See Figure D11, RVIS (2.3), and ISTATE (2.4).

2.2 RH – the relative humidity may take on any value from 0.0 to 100.0. See Figure D11, RVIS (2.3), and ISTATE (2.4).

2.3 RVIS – the visibility range in kilometers may take on any value greater than zero. A visibility range of less than or equal to 1.0 kilometer is defined as a fog. RH is ignored when RVIS ≤ 1.0 and set equal to 100%. See Table D8 and ISTATE (2.4).

2.4 ISTATE – is an index which designates special atmospheric conditions that may occur. If ISTATE equals 1-4, a rain model is used. RVIS is predefined according to Table D2, so any RVIS input is ignored. However, AIRTMP and RH must still be defined. The only exception to this is when ISTATE equals 4. Then, any RH input is ignored and RH is set equal to 100%. When ISTATE equals 1-3, a recommended value for RH is 75%.

2.5 SIGMA, WAVE – are each arrays having seven fields and, whenever they are used, all seven fields must contain values. If only the band transmission per kilometer is known, repeat the same transmission seven times on the TOTL card. Then, assume either the default wavelengths for SIGMA or select seven wavelengths contained between WAVE1 and WAVE2 on the BAND card. Any wavelengths contained on the ATEW card need not start exactly at the beginning of the band or end exactly at the end of the band but they must increase monotonically from smaller to larger values. Wavelengths do not need to be equally spaced from one another. When the default option is used for ATEW, the appropriate 3-5 micrometer spectral band is supplied.

Supplement 3

Optics

The specifications for the system's optics are on cards OPTI, MTOX, and MTOY. Cards MTOX and MTOY describe the MTF of the optics in the horizontal and vertical directions, respectively. Input values for these two cards need not be the same. The total MTF of the optical component is the product of the MTF of the optics (Note 3.5) and the MTF due to geometric blur (Note 3.3). Notes on the individual inputs follow:

3.1 FNUMB, FOC – FNUMB is the F-number of the objective lens. The F-number is a positive, unitless decimal number. Reference Section III, par. A1, MTF, OPTICS, equation (10), (F#), and Section III, par. B, NEΔT, equations (24) and (25), (F), for its use. FOC is the focal length of the objective lens. It is a positive decimal value in inches. Reference Section III, par. A1, MTF, OPTICS, equation (10) for its use. An example of interaction of variables is illustrated by the following relationship.

FNUMB = FOC/Diameter of the objective lens (inches).

Although the diameter of the objective lens is not an input, the diameter which satisfies the above equation should be checked to see if it is within reasonable bounds of technology. Another example of interaction which must be hand checked by the user for consistency is

$$\text{DELTAX} = \begin{cases} \text{SRTAD/FOC} & \text{for square detectors} \\ \dfrac{\text{x-dimension of detector (mils)}}{\text{FOC}} & \text{otherwise} \end{cases}$$

DELTAX, the detector IFOV in the x-direction in units of milliradians, and SRTAD, the square root of the detector area in units of mils, are defined in Supplement 5. It is important to note that FOC is related to detector characteristics and that a change in any of the three variables above affects at least one of the other two.

3.2 TØ – TØ is the optical transmission averaged over the spectral bandwidth which is specified by card BAND. For perfect transmission, TØ = 1.0; otherwise, 0.0 < TØ ≤ 1.0. TØ (τ_o) appears in equations (24) and (25).

3.3 ABLUR – The purpose of ABLUR is to calculate an MTF due to the geometric blur of the optics. An assumption necessary to the model is that the spot size of the geometric blur is gaussian and, therefore, the fourier transform of the spot size results in a gaussian MTF. The form of the MTF (H_{BLUR}) is in Section III, par. A1, MTF, OPTICS, equation (11), and is repeated below for further reference:

$$H_{BLUR} = EXP(-bf_x^2)$$

where f_x is the spatial frequency in cycles/milliradian and b is ABLUR in square mrads. Calculate ABLUR by one of the following four methods:

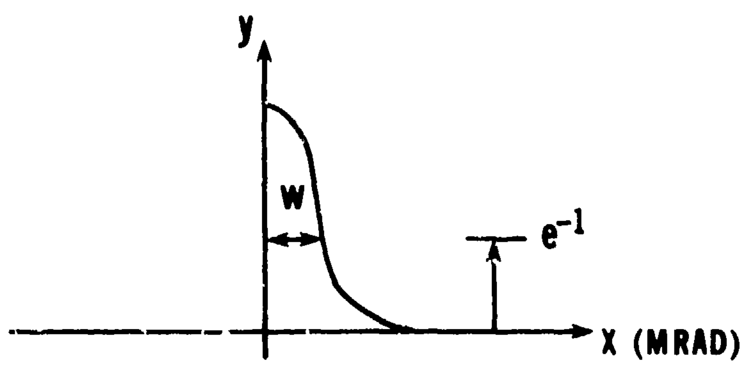
(1) If there is no system degradation due to geometric blur specified for the optics, then ABLUR = 0.0 and the resultant MTF will be 100% at all frequencies; i.e., there will be no degrading effect on system performance. If a blank is left in the fourth field of the OPTI card, 0.0 will be substituted for ABLUR.

(2) If degradation due to geometric blur is taken into account in a given total optics MTF, ABLUR = 0.0. The total optics MTF is input on cards MTOX and MTOY which are described in Note 3.5.

(3) Consider the case where the user has a given geometric blur MTF. At the present time, there is no way to input this MTF directly. Solve for ABLUR by choosing an MTF value (usually 50%) and its corresponding frequency and substituting in equation (11). The goodness of fit between the calculated and given curves is dependent on the assumption of a gaussian MTF.

(4) Finally, the user may have a given geometric blur spot size. When given the spot size, it is necessary to ask: Is the spot size, noted by w, the full spread of the function or is it the half value, and to which value of the spread function does w refer? ABLUR is calculated for several common points of measurement below: (If some other point of measurement is given, the procedure is analogous.)

(a) A common method of spot-size measurement is the shrinking-raster method. The given spot size is the w illustrated below:



• The gaussian spread function is $e^{-\alpha x^2}$.

- Given the w above, $e^{-\alpha x^2} = e^{-1}$ at w or $\alpha = \frac{1}{w^2}$.

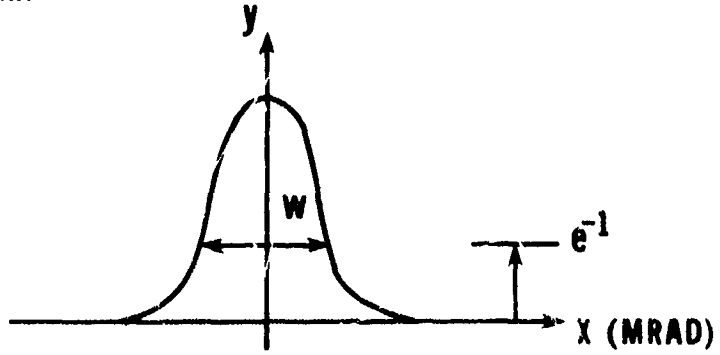
- Taking the fourier transform of the spread function

$$MTF = e^{-4\pi^2 f^2/(4\alpha)} = e^{-\pi^2 f^2/\alpha}$$

- ABLUR = π^2/α from equation (11).

- In this case, ABLUR $\pi^2 w^2$ is the input.

(b) The spot size may be measured between the two points on the spread function:



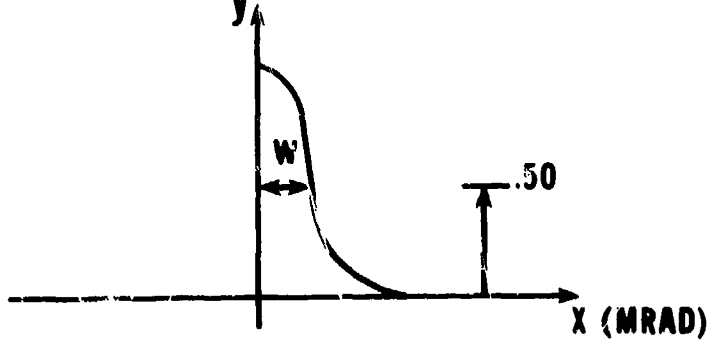
- Given this w, $e^{-\alpha x^2} = e^{-1}$ at w/2 or $\alpha = 4/w^2$.

- $MTF = e^{-\pi^2 f^2/\alpha}$

- ABLUR = π^2/α

- ABLUR = $\pi^2 w^2/4$ is the input.

(c) Another common measurement of spot size is the 50% point of the spread function:



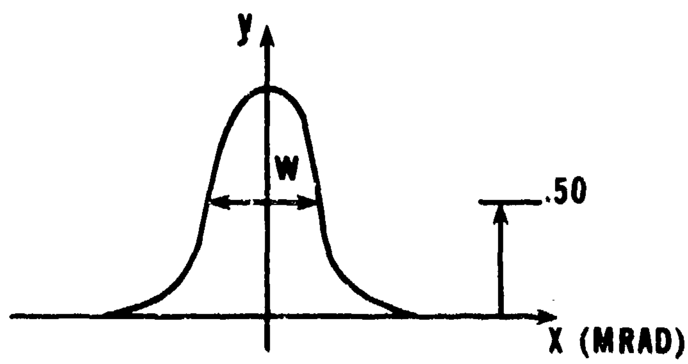
- $e^{-\alpha x^2} = .50$ at w or $\alpha = \dfrac{-\ln(.50)}{w^2}$

- $MTF = e^{-\pi^2 f^2/\alpha}$

- $ABLUR = \pi^2/\alpha$

- $ABLUR = \dfrac{\pi^2 w^2}{-\ln(.50)}$ is the input.

(d) If spot size is measured between the two points on the spread function:



- $e^{-\alpha x^2} = .50$ at w/2 or $\alpha = \dfrac{-4\ln(.50)}{w^2}$

- $MTF = e^{-\pi^2 f^2/\alpha}$

- $ABLUR = \pi^2/\alpha$

- $ABLUR = \dfrac{\pi^2 w^2}{-4\ln(.50)}$ is the input.

(e) The user may develop his own techniques.

3.4 XLAMB – XLAMB is the wavelength of diffraction (λ) in equation (10). Acceptable values are $3.0 \leq XLAMB \leq 5.0$, $8.0 \leq XLAMB \leq 14.0$, and XLAMB = 0.0. If the input value of XLAMB is not in the defined ranges, an error message is printed and the program ceases execution. (See Supplement 12 for the error message.) Usually, the middle of the system's operating bandwidth is a reasonable input. If a value of 0.0 or a blank is input as XLAMB, the program sets XLAMB = (WAVE1+WAVE2)/2.0 where WAVE1 and WAVE2 are inputs from the BAND card. Perhaps in comparing several systems of approximately the same operating bandwidth, one will choose a common value of XLAMB. If the user is assuming a diffraction limited MTF of the optics as in equations (9) and (10), XLAMB is used in the predictions. However, if an optics MTF is input, predictions do not depend on XLAMB.

3.5 XO, YO – XO is an array on card MTOX of the MTF values of the optics in the x-direction which corresponds to the array of increasing spatial frequencies on card FCMR. YO is an array on card MTOY of the MTF values of the optics in the y-direction which corresponds to the array of increasing spatial frequencies on card FCMR. Acceptable values range from 1.0 to 0.0. Three methods exist for inputs to cards MTOX and MTOY:

(1) If there is no system degradation due to the optics (i.e., an MTF of 100%), input ten 1.0's for arrays XO and YO. If the MTOX card or MTOY card or both are left out, the default option is all 1.0's for the respective array.

(2) If one is given a measured or known optical MTF, input ten MTF values off this known curve which correspond to the FQ array on the FCMR card for the related card (MTOX, MTOY, or both).

(3) If a predicted MTF based on the assumption of a diffraction-limited system is desired, input ten 0.0's for arrays XO and YO. A diffraction-limited MTF as a function of spatial frequency may be calculated in both the x and y directions by equations (9) and (10).

Supplement 4

Scanner

The inputs of the SCAN card are essential to the NEΔT, MRT, and MDT predictions. Notes on the individual variables follow:

4.1 FR – FR is the frame rate of the scanning system in frames/second. The frame time is the time required for one complete scan of the field of view; frame rate is the inverse of frame time. Any positive value of FR is acceptable. FR(F_R) is an input to the calculation of the number of resolution elements in Section III, par. B, NEΔT, equation (23); the MRT prediction in Section III, par. C, MRT, equations (26) and (27); and the MDT prediction in Section III, par. D, MDT, equation (28).

4.2 XNSC – XNSC, the overall scan efficiency, is the percent of time the scanner is on the detectors. XNSC is a decimal greater than 0.0 and less than or equal to 1.0. An input of 1.0 means 100% scan efficiency. "Overall" in the above definition means that the scan efficiency is the product of the horizontal scan efficiency and the vertical scan efficiency. XNSC is an input to equation (23).

4.3 OVERSC – OVERSC is the overscan in the IR field by the detectors and is defined by the following ratio:

$$\text{OVERSC} = \frac{\text{DELTAY}}{\text{raster spacing (mrad)}}$$

where

$$\frac{1}{\text{raster spacing}} = \frac{\text{\#active raster lines/frame}}{\text{VFOV x 17.45 (mrad/deg)}}$$

where DELTAY is the vertical instantaneous field of view of the detector input on card DETR and VFOV is the system's vertical field of view input on card SYST. OVERSC is positive and unitless. Equations (23), (26), (27), and (28) are a function of OVERSC. For overscan on the display, see Supplement 10.

Supplement 5

Detector

Characteristics of the detector are input on cards DETR, DET2, DROX, DROY, NPSP, NPSF, DSTD, and DSTL. The user may exclude the DET2, DROX, or DROY card, and the default options listed in Table D2 will be input.

Notes on the individual variables on card DETR follow:

5.1 DELTAX, DELTAY – DELTAX and DELTAY are the instantaneous fields of view of the detector in the horizontal and vertical directions, respectively. DELTAX, DELTAY > 0.0 and are in units of milliradians. Both variables (Δx, Δy) are necessary inputs to calculate the number of resolution elements/s in Section III, par. B, NEΔT, equation (23). DELTA Y (Δy) is used in MRT calculations, equations (26) and (27), and in the MDT calculation, equation (28). Interactions with other system inputs include:

$$\text{DELTAX} = \begin{cases} \text{SRTAD/FOC} & \text{square detector} \\ \dfrac{\text{x-dimension of detector (mils)}}{\text{FOC}} & \text{otherwise} \end{cases}$$

and

$$\text{OVERSC} = \frac{\text{DELTAY}}{\text{raster spacing (mrad)}} .$$

5.2 XN – XN is the number of active detectors in parallel. XN $\geq$ 1.0. XN (n) is used to calculate the number of resolution elements/s in equation (23).

5.3 DISC – DISC is the number of active detectors in each row of the detector array, i.e., in series. DISC $\geq$ 1.0. DISC (N) is a necessary input to the NEΔT calculation in equation (24) or (25).

5.4 SRTAD – The effective detector size in units of mils (10^{-3} in.) is calculated as follows:

$$\text{SRTAD} = \sqrt{\text{width of the detector (mils) x height of the detector (mils)}} \, .$$

SRTAD > 0.0. SRTAD ($A_d^{1/2}$) is used in the NEΔT calculation in equations (24) or (25). It interacts with other inputs by

DELTAX = SRTAD/FOC. (for square detectors)

5.5 DPEAK – DPEAK is the peak $D^*(\lambda, f_o)$ value in units of 10^{10} cm-sqrt (hertz)/watt. DPEAK > 0.0. The DDSTAR array is input on card DSTD as a relative curve normalized such that the input $D^*(\lambda, f_o)$ at DPEAK equals 1.0. The program then calculates $D^*(\lambda, f_o)$ = DPEAK * DDSTAR.

5.6 FØ – FØ is the measuring frequency of $D^*(\lambda, f_o)$. FØ > 0.0 and is input in units of K hertz. For most HgCdTe detectors, FØ = 10.0 K hertz. See Supplement 5.11 where S(FØ) = 1.0.

Notes on the individual variables on card DET2 follow:

5.7 ANGLE – ANGLE is the cold shield half angle in degrees. ANGLE ≥ 0.0. ANGLE ($\theta/2$) is used in the shot-noise-limited system NEΔT calculation in equation (25). If MOM = 0.0 is input in field two of this card, then the value of ANGLE is not used in any system calculations and therefore may be input as anything.

5.8 MOM – MOM indicates to the computer program which of three methods to choose for the NEΔT calculation. If MOM = 0.0, the NEΔT for a detector-noise-limited system in equation (24) is computed:

$$NE\Delta T = \frac{4F^2 (\Delta f_n)^{1/2}}{\pi A_d^{1/2}\ \tau_o\ \tau_a\ \sqrt{N}\ \int_{\Delta\lambda} D^*_\lambda\ n'_\lambda d\lambda}$$

where the bandwidth Δf_n is defined by equation (21) and the input DDSTAR array is D^*_λ which was measured in the dewar with its internal cold shield. If MOM = 1.0, the NEΔT for the shot-noise-limited system in equation (25) is computed:

$$NE\Delta T = \frac{4F^2 (\Delta f_n)^{1/2}\ \mathrm{Sin}\ (\theta/2)}{\pi A_d^{1/2}\ \tau_a\ \tau_o\ \int\sqrt{N}\ \int_{\Delta\lambda} D^{**}\ n'_\lambda\ d\lambda}$$

where Δf_n is defined by equation (21) and the input DDSTAR array is D^{**} which was not measured to include the cold shield. If MOM = 2.0, the NEΔT is calculated by equation (24); however, Δf_n is the white noise approximation defined in equation (22). MOM must be equal to either 0.0, 1.0, or 2.0.

5.9 FSTAR – FSTAR is the frequency of the 3-dB point of the detector response. It is an input to the calculation of the detector's temporal transfer function in equation (14). (f*). For this calculation, FSTAR > 0.0 and in units of K hertz. The detector's temporal MTF's are calculated by the program only if either array XD on card DROX or YD on card DROY is all zeros. If the detector temporal MTF's are not calculated, FSTAR is not used in any system calculations; thus, the user may input any value for

FSTAR.

Notes on the input arrays on cards DROX and DROY follow:

5.10 XD, YD – Array XD on card DROX is the MTF of the detector's temporal response in the x-direction. Array YD on card DROY is the MTF of the detector's temporal response in the y-direction. Both arrays XD and YD correspond to the increasing temporal frequencies of array FQQ on card FLHZ. Acceptable values for arrays XD and YD range from 1.0 to 0.0. The three input methods for MTF's XD and YD are as follows:

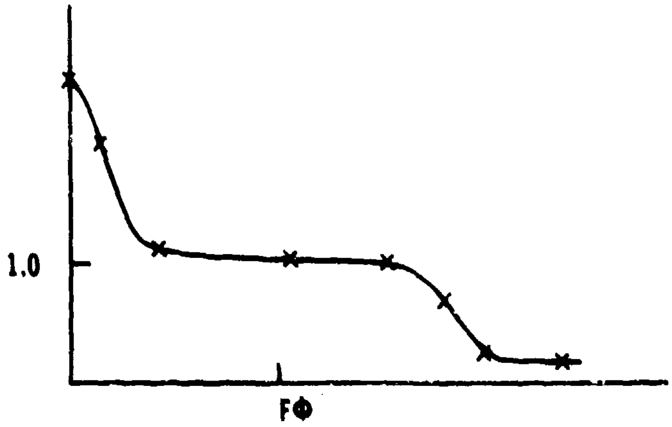
(1) If there is no system degradation due to the detector's temporal MTF, input ten 1.0's for arrays XD and YD. If either card DROX or card DROY is left out of the data deck, the default option in Table D2 is to input all 1.0's for the respective array.

(2) If one is given a measured or known detector temporal MTF, input ten MTF values off the known curve which correspond to the FQQ array on FLHZ.

(3) If a predicted MTF is desired, input ten 0.0's for arrays XD and YD. The temporal MTF will be calculated by equation (14) of Section III, par. A2, MTF, Detector, (H'_{DET}), using the input value of FSTAR on card DET2.

Notes on the input arrays of cards NPSP and NPSF follow:

5.11 S – S is an array of the adjusted noise power spectrum. Determine the normalization factor such that the detector noise power spectrum in units of 10^{-9} volts/Hz$^{1/2}$ is adjusted to 1.0 at frequency FØ, the measuring frequency of the D* array which was input on card DETR. All elements of array S on card NPSP are values of the noise power spectrum which have been adjusted by the same factor. Although ten is the usual formatted array size, only eight values of the S array will be read and used by the program. The first value of the S array must be greater than but not equal to 1.0. Pick off eight points from the adjusted noise power spectrum which reflect the curvature and input these as S. A typical adjusted noise power spectrum on which each x represents an element of S is illustrated in the following figure:



FREQUENCY (LOG_{10}HZ)

The computer program interpolates and extrapolates to find the adjusted noise power spectrum value at the frequencies required for the program calculations. The elements of S correspond to the logarithmic frequencies of array F on card NPSF. S is used in the electronic noise bandpass calculation in Section III, par. B, NEΔT, equation (21), (S(f)); in the calculation of Q in Section III, par. C, MRT, equation (26) and QQ in equation (27); and in the calculation of MDT in Section III, par. D, MDT, equation (28).

5.12 F – The elements of array F are the frequencies in Log_{10} hertz which correspond to the input elements of array S. F is input on card NPSF and must consist of eight positive and increasing values.

Notes on the input arrays on cards DSTD and DSTL follow:

5.13 DDSTAR – DDSTAR is a relative spectral curve of the D* (λ, f_o) which has been normalized to 1.0 at DPEAK.

$$DDSTAR_{\lambda} = \frac{D^* (\lambda, f_o)}{DPEAK} \; .$$

Ten positive values may be input in array DDSTAR on card DSTD to represent the relative curve. The computer program interpolates and extrapolates values from DDSTAR. Elements of DDSTAR correspond to the wavelengths of array XLMBA input on card DSTL. DDSTAR is used in NEΔT calculations in equations (24), (D*), and (25), (D**).

5.14 XLMBA – XLMBA on card DSTL is the array of ten increasing wavelengths (λ) in units of micrometers which correspond to the input DDSTAR array. The spectral bandwidth defined by variables WAVE1 and WAVE2 on the BAND card limits the bandwidth used in system predictions regardless of the input to XLMBA.

Supplement 6

Electronics

The system's electronics are described by the input on cards ELEC, EMTF, BMTF, VMTX, and VMTY. Default values for cards BMTF, VMTX, and VMTY are listed in Table D2. Default options do not exist for cards ELEC and EMTF. Since four of these cards, EMTF, BMTF, VMTX, and VMTY, represent component MTF's, the general procedure for MTF data is outlined below. Deviations from the general procedure will be explained in the notes on the individual variables.

General Procedure for Inputs of MTF's

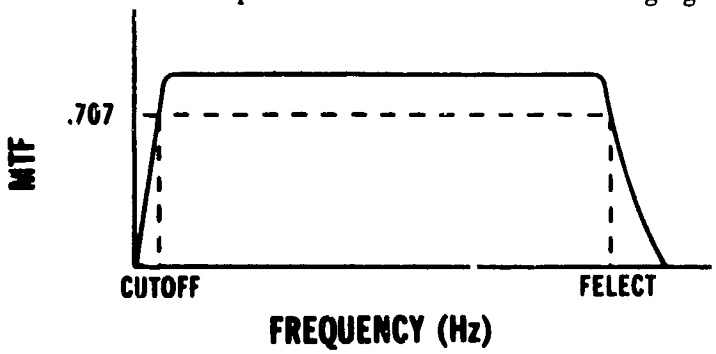
(1) If there is no system degradation due to the component (i.e., an MTF of 100%) or if the component is not a part of the system, input ten 1.0's for the array.

(2) If one is given a measured or known MTF, input ten values off this known curve which correspond to the ten frequencies on FCMR for spatial response or FLHZ for temporal response.

(3) If a predicted MTF is desired, input ten 0.0's and the required variables for calculations.

Notes on the individual variables on card ELEC follow:

6.1 CUTOFF, FELECT – CUTOFF is the frequency of the 3-dB preamplifier cut-on in units of hertz. CUTOFF > 0.0. Common values of CUTOFF range between 3.0 and 7.0 hertz. FELECT is the frequency of the 3-dB amplifier cutoff in units of hertz. FELECT > 0.0. Both inputs are illustrated in the following figure:



The value of CUTOFF is a necessary input; however, FELECT is not. FELECT is used by the program in the prediction of the electronic MTF, Section III, par. A3, MTF, Electronics, equation (15), (f_o). The electronic MTF (H_{ELECT}) is predicted only if array XE on card EMTF is all 0.0's. If H_{ELECT} is not calculated, FELECT is not used by the program and may be input as anything.

6.2 XY, XYL – XY and XYL are the angular subtense in object space in the x-direction and the y-direction, respectively, of the electro-optic multiplexor LED. If the system has no multiplexor, then XY and XYL = 0; otherwise, XY, XYL > 0.0 and are in units of milliradians. XY and XYL are used to predict the LED filter function (H_{LED}) in equation (17), (x).

6.3 XK, FMAXF – XK is the amplitude of the electronic boost at frequency FMAXF. If the system does not have an electronic boost, then XK and FMAXF = 0.0. If a predicted boost MTF is desired as in equation (16), (H_B), then XK(K) > 0, FMAXF (f_{MAX}) > 0, and FMAXF is in units of K hertz. The boost MTF is predicted only if the array XB on card BMTF is all 0.0's. If a known boost MTF is input on card BMTF, then XK = 0.0 and FMAXF = 0.0.

Notes on card EMTF follow:

6.4 XE – XE is the MTF of the electronics. XE is an array of 10 values which correspond to the increasing frequencies of array FQQ on card FLHZ. All values of XE must be ≥ 0.0. The general procedure for input of MTF's is applicable. The required input for method (3) of the general procedure is FELECT on card ELEC. The predicted MTF is calculated by equation (15). There is no default option.

Notes on card BMTF follow:

6.5 XB – XB is the MTF of the electronic boost. XB is an array of 10 values which correspond to the increasing frequencies of array FQQ on card FLHZ. All values of XB must be ≥ 0.0. The general procedure for input of MTF's is applicable. The required inputs for method (3) of the general procedure are XK and FMAXF on card ELEC. The predicted MTF is calculated by equation (16). The default option in Table D2 is to assign all 1.0's to the array BMTF.

Notes on cards VMTX and VMTY follow:

6.6 XTV, YTV – XTV and YTV are the MTF's of the vidicon in the x-direction and y-direction, respectively. Both XTV and YTV are arrays of 10 values which correspond to the increasing spatial frequencies of array FQ on card FCMR. All values of XTV and YTV must be ≥ 0.0. Methods (1) and (2) of the general procedure for input of MTF's apply. Method (3) does not exist as an option, i.e., there is no option to predict the MTF of the vidicon. The default option in Table D2 is to assign all 1.0's to the arrays XTV and YTV.

Supplement 7

Display

Three display options exist to the user of the thermal model: a CRT display, a LED display, or no display. In each case, the MTF of the display is calculated by the program in both spatial dimensions. Presently, there is no available method to directly input a display MTF. For overscan on the display, see Supplement 10. Notes on individual parameters of the DISP card follow:

7.1 KKK – KKK indicates the type of display. Three correct inputs exist:

- 0.0 = CRT display. Based on the assumption of a gaussian spot size and a gaussian transfer function, the display MTF is calculated in Section III, par. A4, MTF, Display, equation (18), which is

$$H_{CRT}(f) = EXP(-af^2).$$

The spatial frequency f is in units of cycles/milliradian. The variable a is defined in 7.3.

- 1.0 = LED display. The MTF calculation for this display is described in Section III, par. A3 and A4, MTF, Electronics and Display, equation (17).

- 2.0 = no display. An MTF of 100% is calculated in both spatial dimensions for the display. A warning is due here. If the noise-filter function from the detector to the display $H_N(f)$ in Section III, par. C, MRT, equation (26), does not roll off in both the x-direction and the y-direction, the computer program will blow up. The noise-filtering MTF's in the x-direction and y-direction, respectively, are:

$$H_N(f_x) = H_{ELECT} \cdot H_B \cdot H_{VID} \cdot H_{LED} \cdot H_{LOS} \cdot H_{DISPLAY}$$

and

$$H_N(f_y) = H_{VID} \cdot H_{LED} \cdot H_{LOS} \cdot H_{DISPLAY}$$

where H_{ELECT} = electronic MTF

H_B = boost MTF

H_{VID} = vidicon MTF

H_{LED} = LED MTF

H_{LOS} = stabilization MTF

$H_{DISPLAY}$ = display MTF.

7.2 BRITE – BRITE is the average display brightness from the scene in units of footlamberts. The MTF of the eyeball is a function of BRITE (light level) as explained in Section III, par. A6, MTF, Eyeball, equation (20) and Section III, par. A6, Table 3. A typical value is 10.0 fL.

7.3 XA, YA –

- If KKK = 0.0, then XA and YA are the inputs to the MTF calculation of the CRT display in equation (18) (the value of a) for the horizontal and vertical spatial dimensions, respectively. XA and YA are to be calculated in the same manner as ABLUR by methods (3) and (4) of Supplement 3, par. 3.3. Acceptable inputs are positive and in units of square milliradians.

- If KKK = 1.0. XA and YA are the angular subtense of the LED in the horizontal and vertical dimensions then the display MTF is a sinc function. XA and YA are the values of x in equation (17). Acceptable inputs are positive and in units of milliradians. If one is given an MTF of an LED display, solve equation (17) by method (3), ABLUR, Supplement 3, par. 3.3.

- If KKK = 2.0, the values of XA and YA are overridden.

Supplement 8

System

Input variables on the SYST card and the BAND card pertain to the whole system rather than to any particular component. Notes on individual variables follow:

8.1 HFOV, VFOV – HFOV and VFOV are the system's field of view in the horizontal and vertical directions, respectively. Both inputs must be greater than 0.0 and less than or equal to 360.0 in units of degrees. In Section III, par. B, NEΔT, equation (23), the number of resolution elements per second is dependent upon the system's field of view. An important check must be made by the user to insure consistency:

$$VFOV = \frac{\#\ \text{active raster lines/frame} \times DELTAY}{OVERSC \times 17.45}$$

This is the same relationship as stated in Supplement 4.3. A change in one variable will affect another. One is often given specifications for a particular aspect ratio for the field of view. An example of a chain of interactions which might occur is if one changes DELTAY which affects VFOV which affects HFOV to maintain an aspect ratio.

8.2 XMAG – XMAG is the system's magnification. XMAG $\geq$ 0.0. XMAG is used in the calculation of the eyeball MTF of Section III, par. A6, MTF, Eyeball, equation (20), (M). The system includes the device and observer; therefore, magnification is dependent on where the observer is in relation to the display. One method to calculate XMAG follows:

$$XMAG = \frac{\text{display size (in.)} \times 1000}{\text{viewing distance (in.)} \times VFOV \times 17.45}.$$

Note that a change in VFOV will affect XMAG. However, since the viewing distance is usually arbitrary, there is no need to adjust XMAG for every small change in VFOV.

8.3 FACT – FACT is the ratio of the wide VFOV to the narrow VFOV of a system. Some systems operate in either a narrow field of view or a wide field of view mode. The wide field of view is usually preferred for a detection task. Predictions for recognition are in the input field of view but predictions for detection are in both the input (usually narrow) and adjusted (wide) fields of view. The narrow field of view system and wide field of view system differ in inputs of HFOV, VFOV, XMAG, DELTAX, DELTAY, FQ, FNUMB, XY, XYL, XSIGLS, YSIGLS, XA, and YA by a constant factor. This constant is FACT. In order to save the user from making all these adjustments and running a second system, the model automatically calculates a detection prediction based on the wide field of view system. FACT > 0.0. If the system has only one mode of operation, input FACT = 1.0 and ignore the output for detection in the wide field of view.

8.4 XNET – Two options exist for input to XNET:

(1) If the user wishes the model to predict the noise equivalent temperature difference (NEΔT) by the definitions of Section III, par. B, NEΔT, then input XNET = 0.0.

(2) If the user wishes to specify the NEΔT and not use the model's calculation, he may input the value for XNET. XNET $>$ 0.0 and in units of degrees centigrade.

Inputs of the BAND card follow:

8.5 WAVE1, WAVE2 – WAVE1 and WAVE2 define the spectral bandwidth for all system and atmospheric calculations executed by the program. Values for WAVE1 and WAVE2 are determined by the operating spectral bandwidth of the system and are in units of micrometers. WAVE1 $\geq$ 2.0 and WAVE2 $\leq$ 16.0. Throughout this report, wavelength is noted by λ and the spectral bandpass, by $\Delta\lambda$.

Supplement 9

Stabilization

The line of sight stabilization is discussed in Section III, par. A5, MTF, Stabilization. Three input cards, STAB, LSSX, and LSSY, generate the stabilization MTF. Inputs of LSSX and LSSY follow:

9.1 XML, YML – XML of card LSSX is the array of MTF values of the stabilization in the x-direction, and YML of card LSSY is the MTF of the stabilization in the y-direction. The arrays of MTF values correspond to the array of spatial frequencies on card FCMR. Acceptable values range from 1.0 to 0.0. Input values of arrays XML and YML need not be the same. Three options exist for inputs to the XML and YML arrays:

(1) If there is no system degradation due to the lack of stabilization, input ten 1.0's; or because the default option is all 1.0's, leave cards LSSX and LSSY out of the data deck.

(2) If one is given a measured or known stabilization MTF, input ten MTF values off this known curve which correspond to the FQ array on the FCMR card.

(3) If ten 0.0's are input for arrays XML and YML, an MTF which is assumed to be gaussian is calculated from equation (19). Inputs XSIGLS and YSIGLS replace p in equation (19) and are necessary inputs on card STAB.

Inputs of the STAB card follow:

9.2 XSIGLS, YSIGLS – XSIGLS, the x-direction vibration constant, and YSIGLS, the y-direction vibration constant, are necessary for the calculation of the stabilization MTF in method (3) in par. 9.1. If method (3) is not used to generate the MTF, the values on the STAB card are overridden. Default values are XSIGLS = 0.0 and YSIGLS = 0.0. XSIGLS and YSIGLS need not be equal but must be $\geq$ 0.0 and in units of square milliradians. Refer to Supplement 3.3 and the description of ABLUR for the method to calculate XSIGLS and YSIGLS.

Supplement 10

Eye

EYETM on card EYEB is the integration time of the eye. It is used in the MRT predictions in Section III, par. C, MRT, equations (26) and (27), (t_E), and in Section III, par. D, MDT, equation (28). Most model validation of predicted MRT versus measured MRT and predicted performance versus measured field performance is based on EYETM = 0.2 second/frame. If there is any overscan in the display, EYETM may be something other than 0.2. Overscan in the display exists if, for any scan of the detector elements, the display element is greater than the detector's instantaneous field of view in the vertical direction. The overscan in the display is not to be confused with the variable OVERSC, the overscan in the IR field, in Supplement 4.3. The input value of EYETM which includes any overscan in the display is calculated by:

$$EYETM = 0.2 * \frac{\text{vertical IFOV}_{LED}}{\text{vertical IFOV}_{DET}}$$

where the vertical $IFOV_{LED}$ is the input variable YA for an LED display on card DISP and $IFOV_{DET}$ is the input variable DELTAY on card DETR. The default for leaving card EYEB out of the data deck is EYETM = 0.2.

Supplement 11

Program Cards

Most users should not input cards SN4B, FDRP, FDC1, FRC3, and FRC4. If the cards are excluded from the data deck, the default values in Table D2 will be substituted. The validation of the model is based on the default inputs. The option to input values other than the default is for research purposes only but is presented here for completeness.

11.1 SNR on card SN4B is the threshold signal-to-noise ratio used in Section III, par. C, MRT, equations (26) and (27), (SNR), and MDT predictions in Section III, par. D, MDT, equation (28), (S'). Validation performed to date is based on SNR = 2.25. By excluding the SN4B card from the data deck, the default option sets SNR = 2.25.

11.2 Cards FDRP, FDC1, FRC3, and FRC4 express the relationship between probability of recognition or detection and the number of resolution cycles across a target's critical dimension. The relationship is based on the Johnson method. FDRP contains the decreasing probabilities of recognition or detection which range from 1.0 to 0.0. FRC3 and FRC4 contain the number of cycles across a target which are required for recognition and correspond to the probabilities on FDRP. At 50% probability, three bars are the default value on FRC3 and four bars on FRC4; the model output describes these as optimistic and conservative criteria. The Recognition section (IV) in the main body of the report considers other alternatives. The field to model comparisons in the Validation section (VI) in the main body of the report are based on the four-cycle criteria. Therefore, unless the user has measured data supporting another criteria, he should use the default options of FRC4 and FRC3. Finally, FDC1 contains the number of cycles required for detection. These cycles correspond to the probabilities on FDRP. The default option in Table D2 is the same as listed in Table V of the Detection section (V) of the main body of the report. Input values on FDRP are in descending order, but on FDC1, FRC3, and FRC4 input values are in ascending order.

11.3 FQ of the FCMR card is an array of ten spatial frequencies in units of cycles/milliradian. MTF values of the optics input on cards MTOX and MTOY, vidicon input on cards VMTX and VMTY, and stabilization input on cards LSSX and LSSY must correspond to the spatial frequencies on FCMR. Frequencies must be in ascending order. A default option is listed in Table D2. If no given MTF's are input on any of the above cards, then array FQ is not used. In this case, input any values on FCMR or leave the card out of the data deck.

11.4 FQQ on the FLH2 card is an array of ten temporal frequencies in $\log_{10}$ hertz. MTF values of the detector response input on cards DROX and DROY, electronics input on EMTF, and the boost input on BMTF must correspond to the temporal frequencies on FLH2. Array values must be in ascending order on FLH2. A default option is listed in Table D2. If no given MTF's are input on any of the above cards, array FQQ is not used and the user may input any values on FCMR or exclude the card from the data deck.

Supplement 12

Specialized Options and Diagnostics

There are several special options which have been included in the model. These options have to do with environmental inputs, measured MRT inputs, and an interactive terminal user mode.

12.1 ENVIRONMENTAL INPUTS – Variable ISTATE has two other values which give special options. If ISTATE = 31.0, certain write statements are set up in the atmospheric subroutine and the Beer's Law scattering option is used. It must be used with a SCAT card (below) and IPRINT (below). If ISTATE = 41.0, certain write statements are set up in the atmosphere subroutine and the Beer's Law total attenuation option is used. It must be used with a TOTL card and IPRINT (below).

Variable IPRINT is an option which prints certain diagnostic information directly from the atmospheric subroutine. It can also be used to find out atmospheric constituent transmission as a function of wavelength. IPRINT is the fifth variable on the ENVI card. It can take on 3 values:

0 or blank – no printout

1 – abbreviated printout listing initial conditions and absorber concentrations per kilometer.

2 – detailed printout listing initial conditions, absorber concentrations per kilometer, and all computed constituent transmissions as a function of wavelength.

Another option is to input atmospheric scattering transmission per kilometer on the SCAT card where the scattering transmission is in decimal form for any seven wavelengths within the band in which the system operates. A FOR1 format is required. All seven fields must be filled and, like the TOTL card, it requires the ATEW card or uses the WAVE defaults (see Table D2). This option allows the user to directly input scattering attenuation (if any) and to let the program compute the attenuation due to absorption (H_2O, CO_2, etc.). Consequently, an ENVI card is required to initially define the temperature and relative humidity unless the default options are desired. The variables RVIS and ISTATE are always ignored when using this option so the rain and fog models cannot be used along with SCAT.

12.2 Measured MRT – This option allows the user to input a measured MRT for performance calculations. It might be of interest to a user who wishes to compare measured MRT performance with predicted MRT performance. Twenty values are needed for an MRT These correspond to specific frequencies within the spatial frequency resolution band of the device. The MRT values are to be input on the following cards: MRT1 (fields 1-7), MRT2 (fields 1-7), and MRT3 (fields 1-6). These cards all use the FOR1 format. The selected MRT values must correspond to frequencies that the program will generate. These frequencies are defined by the variable DELTAX on the card DETR. Frequency increments are calculated by

$$XL = \frac{1.0}{20.0\ DELTAX} .$$

In field one on card MRT1, a measured MRT is entered which corresponds to the spatial frequency XL. In field two, enter the measured MRT that corresponds to two times XL. Similarly, continue until fields 1-7 on card MRT1 and MRT2 are filled as well as fields 1-6 on card MRT3. All MRT values should be in units of 10^{-3} ° C.

The following cards must be used when inputting a measured MRT: BAND, DETR, SYST, DSTD, and DSTL. In addition, the ENVI, TARG, and RANG cards are most often included when using this option. The output listing is always in the abbreviated format; however, the detection and recognition performance is temperature dependent.

12.3 INTERACTIVE – There exists an ability to use the thermal model in an interactive mode. The interactive aspects can be used with a CDC 6600 computer and a 4012 Tektronix terminal. Subroutine INIT checks to find out if the user is running batch or interactive mode. In order to run interactive, the user must give the command: SWITCH, 1. IAFLG is the variable used to indicate batch (IAFLG = 0) or interactive (IAFLG = 1) mode. Subroutine READF allows the interactive user to input his variables in a free-field format.

In order to enter input data, the four-letter identifier should be entered first. Then, after prompting, all inputs may be typed in. Each must be separated by a comma. Under this format, decimal points may be omitted for integer values. At the end of the data list associated with an identifier, a slash (/) must be entered. All program cards and data cards are entered in a similar manner. After the DONE card is input, the program begins execution and prints out an input listing similar to the computer printout.

Before any calculations take place, the program will ask if any values need correcting. Entries are corrected by first typing in "fix." This command readies the program to receive corrections. Next type FOR1 or FOR2. Read in the appropriate identifiers and associated values for the variables to be changed. After all changes have been made, finish with the usual ENDS and DONE combination. When all inputs are correct, enter "go" and the program will execute. Input and output listings are essentially the same as those obtained when the program is used non-interactively. Some small modifications have been made, however, so all listings will easily fit on the CRT display. Hard copies can be made directly from the CRT display when the appropriate hardware is available.

12.4 DIAGNOSTICS – There are four diagnostic messages that may appear in this version of the thermal model:

(1) Error has been made on input card – does not conform to proper convention.

(2) An input system card for FOR1 has not been recognized.

(3) An input system card for FOR2 has not been recognized.

(4) Your input value of XLAMB is xxx.xx and is not inside the specified ranges.

Error message (1) flags an invalid special input card. Error messages (2) and (3) inform the user that an attempt has been made to read an invalid identifier in either the FOR1 or FOR2 format. Check all identifiers and special input cards against Tables D2 and D3. Also make sure that all FOR1 and FOR2 formatted cards are behind their appropriate special input card.

Error message (4) pertains to the variable XLAMB on the <u>OPTI</u> card. Check Supplement 3 in order to identify the problem.