Research and Development Technical Report
ECOM–7043

NIGHT VISION LABORATORY STATIC PERFORMANCE MODEL
FOR THERMAL VIEWING SYSTEMS

April 1975

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THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.
The NVL thermal model predicts system NEAT, 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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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, NE ΔT, 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

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 NVI 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 camoufl age, 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 $\Delta T$ 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

$$T_{AVG} = \frac{\sum A_i T_i}{\sum A_i}$$  \hspace{1cm} (1)

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

$$\Delta T_{AVG} = T_{AVG} - T_{BAC}$$  \hspace{1cm} (2)

A list of $\Delta T_{AVG}$’s and target dimensions from a typical field test is shown in Table 1.

<table>
<thead>
<tr>
<th>Target</th>
<th>$\Delta T_{AVG}$ (°C)</th>
<th>Area (m x m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank/Side</td>
<td>5.25</td>
<td>2.7 x 5.25</td>
</tr>
<tr>
<td>Tank/Front</td>
<td>6.34</td>
<td>2.7 x 3.45</td>
</tr>
<tr>
<td>2½-Ton/Side</td>
<td>10.40</td>
<td>0.83 x 4.22</td>
</tr>
<tr>
<td>2½-Ton/Front</td>
<td>8.25</td>
<td>2.03 x 1.67</td>
</tr>
<tr>
<td>APC/Side</td>
<td>4.67</td>
<td>1.8 x 4.8</td>
</tr>
<tr>
<td>APC/Front</td>
<td>5.65</td>
<td>1.8 x 2.09</td>
</tr>
<tr>
<td>Man</td>
<td>8.0</td>
<td>0.5 x 1.5</td>
</tr>
</tbody>
</table>

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, $\Delta T_{AVG}$ is converted to a power signal by using the Planck Radiation Law. For a given temperature $T$, $N_\lambda$ watts/cm²/sr/$\mu$ are emitted according to
\[ N_\lambda = \frac{2e^2h}{\lambda^4} \frac{\varepsilon(\lambda)}{\exp \left(hc/\lambda kT\right) - 1} \tag{3} \]

at wavelength \( \lambda \). Terms \( c, k, \) and \( h \) are the usual constants and \( \varepsilon(\lambda) \) 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

\[ T_A = \frac{0.57 [a(\lambda) - \log_{10}(R W)]^2}{1 + [0.5 a(\lambda) - \log_{10}(R W)]^2} \tag{4} \]

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

\[ W = \begin{cases} 
4.6 \times 10^{-3} + 2.1 \times 10^{-5} (T_{\text{AIR}} + 5)^2 \text{ R.H.} & \text{for H}_2\text{O} \\
1.0 & \text{for CO}_2.
\end{cases} \tag{5} \]

A list of \( a(\lambda) \)'s is given in the computer model in Appendix C. \( T_{\text{AIR}} \) : 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.\(^7\)

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

\[ T_S = e^{-\alpha(\lambda) R}, \]  

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

\[ V_{0.02} = 3.912/\alpha(5500 \text{ Å}), \]

where \( V_{0.02} \) is the visibility range for 2 percent contrast and \( \alpha(5500 \text{ Å}) \) 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 based on work by Dermendjian and Rensch. Table 2 shows a typical set of \( \alpha \)'s for the selected visibility ranges in Figure 1.

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

<table>
<thead>
<tr>
<th>Wavelength (μ)</th>
<th>Visibility Range (km)</th>
<th>Scattering Coefficients (km⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Clear</td>
<td>Light Haze</td>
<td>Heavy Haze</td>
</tr>
<tr>
<td>3.0</td>
<td>.0261</td>
<td>0.3</td>
</tr>
<tr>
<td>3.25</td>
<td>.0223</td>
<td>0.26</td>
</tr>
<tr>
<td>3.5</td>
<td>.0189</td>
<td>0.24</td>
</tr>
<tr>
<td>4.0</td>
<td>.014</td>
<td>0.20</td>
</tr>
<tr>
<td>4.25</td>
<td>.0126</td>
<td>0.17</td>
</tr>
<tr>
<td>4.5</td>
<td>.0109</td>
<td>0.16</td>
</tr>
<tr>
<td>5.0</td>
<td>.0088</td>
<td>0.15</td>
</tr>
<tr>
<td>8.0</td>
<td>.0079</td>
<td>.07</td>
</tr>
<tr>
<td>9.0</td>
<td>.0064</td>
<td>.05</td>
</tr>
<tr>
<td>9.5</td>
<td>.0058</td>
<td>.045</td>
</tr>
<tr>
<td>10.0</td>
<td>.0053</td>
<td>.035</td>
</tr>
<tr>
<td>10.5</td>
<td>.0048</td>
<td>.034</td>
</tr>
<tr>
<td>11.0</td>
<td>.0045</td>
<td>.032</td>
</tr>
<tr>
<td>12.0</td>
<td>.0038</td>
<td>.03</td>
</tr>
</tbody>
</table>

---

The total atmospheric transmission is then

\[ T^\text{TOTAL}_\lambda = T^S_\lambda \times T^A_\lambda \]  

(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

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.

\(^{12}\) Unpublished report on Atmospheric Models by R. Bergemann of NVL.
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 \(f\) in micrometers and at wavelength \(\lambda\) in micrometers is given by

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

where

\[
A = \lambda F_# f_x / \lambda.
\]

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

\[
H_{\text{BLUR}} = \exp(-b f_x^2).
\]

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

\[ f(\text{Hz}) = v \left( \text{MR/SEC} \right) f_x \left( \text{CY/MR} \right). \] (12)

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

\[ H_{\text{DET}}(f_x) = \sin \left( \pi f_x X \right) / (\pi f_x X), \] (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 carriers 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:

\[ H'_{\text{DET}}(f) = 1 / \left[ 1 + (f/f^*)^2 \right]^{\frac{1}{2}}, \] (14)

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

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

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,

\[ H_{\text{ELECT}}(f) = 1 / \left[ 1 + (f/f_o)^2 \right]^{\frac{1}{2}}, \] (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\textsuperscript{14} for the boost transfer function can be used given by

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

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

\textsuperscript{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

\[ H_{\text{LED}}(f_x) = \sin \left( \frac{\pi f_x X}{X} \right) \]  

(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

\[ H_{\text{CRT}}(f_x) = \exp \left( -a f_x^2 \right). \]

(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

\[ H_{\text{LOS}}(f_x) = \exp \left( -P f_x^2 \right), \]

(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.\(^{13}\) The MTF has the form

\[ H_{\text{EYE}}(f_x) = e^{-\Gamma f_x/M} \]

(20)

where \( \Gamma \) is a light-level-dependent parameter and \( M \) is the system magnification. Table 3 shows the dependence of \( \Gamma \) on the logarithm of the light level. The light level is determined by the average display brightness from the scene.

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

Table 3. $\Gamma$ as a Function of Log Light Level for the Eyeball MTF

<table>
<thead>
<tr>
<th>$\log_{10}$ (Light Level in $fL$)</th>
<th>$\Gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>.81333</td>
</tr>
<tr>
<td>2</td>
<td>.9598</td>
</tr>
<tr>
<td>1</td>
<td>1.0980</td>
</tr>
<tr>
<td>0</td>
<td>1.4650</td>
</tr>
<tr>
<td>-1</td>
<td>1.8300</td>
</tr>
<tr>
<td>-2</td>
<td>2.2773</td>
</tr>
<tr>
<td>-3</td>
<td>2.7653</td>
</tr>
<tr>
<td>-4</td>
<td>3.3347</td>
</tr>
<tr>
<td>-5</td>
<td>3.9040</td>
</tr>
</tbody>
</table>

$$\Delta f_n = \int_0^\infty S(f) H_{ELECT}^2(f) H_B^2(f) H_{MD}^2(f) df,$$

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 $f_0$) 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 $\Delta T$ measurement, an electronic filter with 3-dB cut-off at $\frac{1}{2}\tau$ hertz is used, where $\tau$ 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 $\frac{1}{2}\tau$. If $S(f)$ is white then equation (21) reduces to

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

where $\Delta f_e$ is the electronic bandwidth. The inverse of the dwell time $\tau$ is given by the number of resolution elements per second, or

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

where $\alpha$ and $\beta$ are the horizontal and vertical fields of view (FOV), $F_R$ is the frame rate, $\eta_{OVS}$ is the overscan ratio, $n$ is the number of detectors in parallel, $\Delta x$ and $\Delta y$ are the IFOV's in x and y, and $\eta_{SC}$ is the scan efficiency.

The NE $\Delta T$ for a detector-noise-limited system is given by
where $F$ is the objective F-number, $A_d$ is the detector area in square centimeters, $\tau_a$ is atmospheric transmission over the path the NE $\Delta T$ is measured, $\tau_o$ is the optical transmission, $\Delta \lambda$ is the spectral bandpass, $D^*$ is the detector specific detectivity, $N$ is the number of detectors in series, and $\eta'$ is the temperature derivative of the Planck radiation (equation (3)). The $N$ series detectors are assumed to have uniform $D^*$. A derivation is given in Appendix A. A shot-noise-limited system NE $\Delta T$ is given by

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

where $\theta$ is the cold shield angle of the detector geometry and $D^{**}$ 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 $\Delta T$ 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

$$MRT(f_x) = SNR \left( \frac{\pi^2}{4 \sqrt{14}} \frac{NE \Delta T}{MTF_{TOT}(f_x)} \left[ \frac{\Delta y \cdot f_x \cdot Q(f_x)}{\Delta f_n \cdot F \cdot \tau_F \cdot \eta_{OVS}} \right] \right)^{1/2} \left( 26 \right)$$

where

- $SNR$ = signal-to-noise ratio necessary to recognize the four-bar pattern.
- $MTF_{TOT}(f_x) = H_{OPT} \cdot H_{DET} \cdot H'_{DET} \cdot H_{ELECT} \cdot H_B \cdot H_{DISPLAY} \cdot H_{EYE} \cdot H_{LOS} = H_{D}(f_x)$.
- $\Delta y$ = 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 \\
\( \eta_{OVS} \) = overscan ratio \\
\( t_E \) = eye integration time \( \approx .2 \) second \\
\( Q \) = \\
\( \int_0^\infty S(f_x) H_N^2(f_x) H_w^2(f_x) H_{\text{EYE}}^2(f_x) \, df_x \) \\
\( S(f_x) \) = 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):

\[
\text{MRT}(f_y) = \text{SNR} \frac{\pi^2}{4\sqrt{14}} \frac{\text{NE} \Delta T}{\text{MTF}_{\text{OIF}}(f_y)} \left[ \frac{\Delta y \sqrt{f_y} \, \text{QQ}}{\Delta f_n \, F_r \, t_E \, \eta_{OVS}} \right]^\frac{1}{2}, \tag{27}
\]

where

\[
\text{MTF}_{\text{TOT}}(f_y) = \text{H}_{\text{OPT}} \cdot \text{H}_{\text{DET}} \cdot \text{H}_{\text{DISPLAY}} \cdot \text{H}_{\text{EYE}} \cdot \text{H}_{\text{LOS}} = \text{H}_{\text{D}}(f_y)
\]

\( f_y \) = target frequency in cycles per mr. \\
\( \text{QQ} \) = \\
\( \frac{7}{2f_y} \int_0^{\infty} \int_0^{\infty} S(f_x) H_N^2(f_x) H_L^2(f_x) H_{\text{EYE}}^2(f_x) H_{\text{D}}^2(f_x) H_{\text{W}}^2(f_y) H_{\text{N}}^2(f_y) H_{\text{EYE}}^2 \, df_x \, df_y \) \\
\( H_L^2 \) = 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 \( f_x \), there is a minimum temperature difference \( \Delta T_c \) necessary to resolve the four bars. There is a frequency \( f_y \) 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, \( f_y \) 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

\[
\text{MDT} = \frac{\text{NE} \Delta T S'}{A_T} \int H_T H_D \, d^2 f \left[ \frac{\Delta Y v}{\eta_{\text{OVSC}} F_R t_E \Delta f_n} \right]^{\frac{1}{2}} \\
\times \left[ \int \int S(x) H_{\text{ELECT}} H_{\text{DISPLAY}} H_{\text{EYE}} H_T H_D \, d^2 f \right]^{\frac{1}{2}}
\]  

(28)
where

\[ A_T = \text{target area in square milliradians} \]
\[ S' = \text{threshold signal-to-noise ratio} \]
\[ H_T = \text{target transform} = H_L \times H_w \]
\[ H_D = \text{total device and eyeball MTF} = MTF_{TOT}. \]

Figure 4 illustrates the form of MDT as a function of reciprocal target size. For any target size \( \alpha \) in milliradians, there is a \( \Delta T_D \) 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.](image)
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.\(^1\) 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 \(W_T f_0\), where \(W_T\) is the critical dimension of the target and \(f_0\) 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.\(^1\)

The probability of target recognition \(P_R\) is given in general by

\[
P_R = \int P(\text{REC} \mid \text{N CYCLES}) \rho \left( \text{N CYCLES} \right) \, dN,
\]

where \(P(\text{REC} \mid \text{N CYCLES})\) is the probability of target recognition given \(N\) cycles are resolvable across the critical dimension discussed above; \(\rho \left( \text{N CYCLES} \right)\) is the probability that the number of cycles which can be resolved is between \(N\) and \(N + dN\). In general, \(\rho \left( \text{N} \right)\) must be determined from probability versus signal-to-noise calculations. However, Johnson and Lawson\(^1\) have shown that there is no significant error introduced in \(P_R\) if \(\rho \left( \text{N} \right)\) is replaced by the delta function \(\delta \left( N - N_o \right)\), 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


\[ P_R = P(\text{REC} | N_0 \text{ cycles}). \]

The relationship between probability of recognition \( P(\text{REC} | N_0) \) 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>
<thead>
<tr>
<th>Prob of Recog</th>
<th># of Cycles</th>
<th># of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>.95</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>.80</td>
<td>6</td>
<td>4.5</td>
</tr>
<tr>
<td>.50</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>.30</td>
<td>3</td>
<td>2.25</td>
</tr>
<tr>
<td>.10</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>.02</td>
<td>1</td>
<td>.75</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The method of determining resolution across a target to establish \( P(\text{REC} | N_0) \) 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 \( \Delta T_e \) 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 $\alpha$ 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 $\Delta T$ is filtered by an atmosphere to give a $\Delta T_e$ 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 $\Delta T$ 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>
<thead>
<tr>
<th>Prob of Detection</th>
<th>No. of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>3</td>
</tr>
<tr>
<td>.95</td>
<td>2</td>
</tr>
<tr>
<td>.80</td>
<td>1.5</td>
</tr>
<tr>
<td>.50</td>
<td>1</td>
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<tr>
<td>.30</td>
<td>.75</td>
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<td>.10</td>
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<tr>
<td>.02</td>
<td>.25</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5. Probability of Detection as a Function of Number of Cycles Across Target Critical Dimension for Array Vehicles
As already mentioned, there are Army missions in which true "hot spot" or "star" detection occurs with thermal devices. An invading aircraft against a uniform sky background on an air defense perimeter is such a case. If the target is hot enough to activate oneIFOV, 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 (25) 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

\[
S = \frac{\Delta T(R) \cdot AT}{N \cdot \Delta T} \left[ \int H_T^2 H_D^2 f \left( \frac{\Delta \gamma \nu}{\eta_{OSC} F_R f_E D_f} \right)^{1/2} \right]^{-1} \times \left[ \int S(f_x) H_{ELECT}^2 H_{DISPLAY}^2 H_{EYE}^2 H_T^2 H_D^2 d^2 f \right]^{-1/2}
\]

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>
<thead>
<tr>
<th>Probability of Detection</th>
<th>Signal-to-Noise Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>5.5</td>
</tr>
<tr>
<td>.9</td>
<td>4.1</td>
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<tr>
<td>.8</td>
<td>3.7</td>
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<tr>
<td>.7</td>
<td>3.3</td>
</tr>
<tr>
<td>.6</td>
<td>3.1</td>
</tr>
<tr>
<td>.5</td>
<td>2.8</td>
</tr>
<tr>
<td>.4</td>
<td>2.5</td>
</tr>
<tr>
<td>.3</td>
<td>2.3</td>
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<tr>
<td>.2</td>
<td>2.0</td>
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<tr>
<td>.1</td>
<td>1.5</td>
</tr>
<tr>
<td>0</td>
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</tbody>
</table>

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.\textsuperscript{20} in summer 1971 and Aberdeen, Md., in winter and summer 1973.\textsuperscript{21,22} The fourth test was an airborne test in summer 1973 at Fort Polk, La.\textsuperscript{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 nonproprietary system descriptors.

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

<table>
<thead>
<tr>
<th>System</th>
<th>Application</th>
<th>Spectral Region (μm)</th>
<th>Scanner</th>
<th>Detector</th>
<th>Contractor</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>Missile</td>
<td>3-5</td>
<td>Parallel</td>
<td>PbSe</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>Missile</td>
<td>3-5</td>
<td>Parallel</td>
<td>PbSe</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>Missile</td>
<td>8-14</td>
<td>Serial</td>
<td>HgCdTe</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>Missile</td>
<td>8-14</td>
<td>Parallel</td>
<td>HgCdTe</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>Tank</td>
<td>8-14</td>
<td>Serial/</td>
<td>HgCdTe</td>
<td>2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Discoid</td>
<td></td>
<td></td>
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<tr>
<td>F</td>
<td>Tank</td>
<td>8-14</td>
<td>Parallel</td>
<td>HgCdTe</td>
<td>3</td>
</tr>
</tbody>
</table>


\textsuperscript{23} Unpublished test report of airborne FLIR against ground targets by NVL 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.

System E

System F
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(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 vehicle 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. 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, and a haze

Figure 10. Airborne FLIR vs tracked vehicles.
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

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 $\pm 20\%$ 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 through 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. 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.

Terminology:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE ΔT</td>
<td>Noise equivalent temperature</td>
</tr>
<tr>
<td>MRT</td>
<td>Minimum resolvable temperature</td>
</tr>
<tr>
<td>MDT</td>
<td>Minimum detectable temperature</td>
</tr>
<tr>
<td>t</td>
<td>time</td>
</tr>
<tr>
<td>i_o(t)</td>
<td>an output signal</td>
</tr>
<tr>
<td>i_i(t)</td>
<td>an input signal</td>
</tr>
<tr>
<td>*</td>
<td>convolution</td>
</tr>
<tr>
<td>h(t)</td>
<td>temporal response function</td>
</tr>
<tr>
<td>f</td>
<td>frequency</td>
</tr>
<tr>
<td>i_o(f)</td>
<td>fourier transform of i_o(t)</td>
</tr>
<tr>
<td>i_i(f)</td>
<td>fourier transform of i_i(t)</td>
</tr>
<tr>
<td>h(f)</td>
<td>transfer function (fourier transform of h(t))</td>
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<tr>
<td>OTF</td>
<td>optical transfer function</td>
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</table>

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>MTF</td>
<td>modulation transfer function</td>
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<td>S(f)</td>
<td>power spectrum</td>
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<td>⟨⟩</td>
<td>ensemble average</td>
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<tr>
<td>τ</td>
<td>time difference</td>
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<tr>
<td>σ</td>
<td>RMS value of a random process</td>
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<tr>
<td>r</td>
<td>detector response function</td>
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<tr>
<td>v_s(t)</td>
<td>a (voltage) signal</td>
</tr>
<tr>
<td>φ(λ)</td>
<td>watts/micron on the detector</td>
</tr>
<tr>
<td>D_{t_0}^*(λ)</td>
<td>detector detectivity</td>
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<tr>
<td>D_{t_0}^{**}(λ)</td>
<td>detector detectivity (no cold shielding)</td>
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<tr>
<td>l</td>
<td>focal length</td>
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<td>η_0(λ)</td>
<td>optical transmission</td>
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<tr>
<td>T</td>
<td>temperature</td>
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<tr>
<td>L</td>
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<td>HFOV</td>
<td>horizontal field of view</td>
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<td>VFOV</td>
<td>vertical field of view</td>
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<td>t_E</td>
<td>eye integration time</td>
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<tr>
<td>η_OVSC</td>
<td>overscan ratio</td>
</tr>
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<td>F_R</td>
<td>frame rate</td>
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<tr>
<td>n_s</td>
<td>number of detectors in series</td>
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<td>n_p</td>
<td>number of detectors in parallel</td>
</tr>
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<td>η_CS</td>
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<td>τ_D</td>
<td>picture element delay time</td>
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<td>θ</td>
<td>cold shield angle</td>
</tr>
<tr>
<td>W</td>
<td>an integral (equation 24)</td>
</tr>
<tr>
<td>i(x,y)</td>
<td>spatial signal</td>
</tr>
<tr>
<td>A</td>
<td>area (signal)</td>
</tr>
<tr>
<td>k</td>
<td>a constant</td>
</tr>
<tr>
<td>M</td>
<td>watts/area from display</td>
</tr>
<tr>
<td>Δy_i</td>
<td>distance between scan lines</td>
</tr>
</tbody>
</table>
\( v \) — scan velocity

\( f_0 \) — 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)

\( \mathcal{G} \) — a threshold signal-to-noise ratio

\( q_y \) — an integral (defined below equation (A45))

\( \rho_x \) — an integral (defined below equation (A45))

\( \rho_y \) — an integral (defined below equation (A45))

\( q_{xA} \) — an integral (defined below equation (A51))

\( \rho_{xA} \) — an integral (defined below equation (A51))

\( \rho_{yA} \) — 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.\(^2\) (It is possible to derive NE \( \Delta T \), MRT, etc. without employing these concepts; however, as with any process, employment of improper 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.,

\[
i_o(t) = i_1(t) \ast h(t) = \int_{-\infty}^{\infty} i_1(t')h(t-t')dt'
\]  

\( (A1) \)

where \( i_o(t), i_1(t), \) 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

\[
I_o(f) = I_1(f)H(f)
\]  

\( (A2) \)

is obtained. Here \( I_o(f), I_1(f), \) and \( H(f) \) are the fourier transforms of \( i_o(t), i_1(t), \) and \( h(t) \),

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 $I_1(f)$.

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 $i_1(t)$ 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

$$i_0(t) = i_1(t) * h_1(t) * h_2(t).$$  \hspace{1cm} (A3)

Correspondingly, the transform of $i_0(t)$ is given by

$$I_0(f) = I_1(f)H_1(f)H_2(f).$$  \hspace{1cm} (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 view- ers) can be characterized (in general, not fully) by its auto-correlation function

$$R(\tau) = R(t, t + \tau) = \langle n(t)n(t + \tau) \rangle$$  \hspace{1cm} (A5)

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

$$S(f) \equiv \int R(\tau) e^{-2\pi if\tau} d\tau.$$  \hspace{1cm} (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

$$S_0(f) = S_1(f)H^2(f)$$  \hspace{1cm} (A7)

where $S_0$ and $S_1$ 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

$$\sigma^2 = \int S(f)df.$$  \hspace{1cm} (A8)

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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

$$\sigma^2 = \int_{-\infty}^{\infty} S(f) df$$  \hspace{1cm} (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 $i(t - t_1)$. (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

$$I(f) = \int_{-\infty}^{\infty} i(t)e^{-2\pi ft} dt $$ \hspace{1cm} (A10)

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

$$H_m(f) \sim \int_{-\infty}^{\infty} i(-t)e^{-2\pi ft} dt = I^*(f).$$ \hspace{1cm} (A11)

**NE $\Delta T$ Derivation:**

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 $\text{NE} \Delta T$ definition provide at least part of the reason $\text{NE} \Delta T$ 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 $\text{NE} \Delta T$ 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. Nevertheless, NEAT 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 \( r(\lambda,t) \ast h_{\text{ELECT}}(t) \) where \( r(\lambda,t) \) is the response function of the detector in volts/watt and \( h_{\text{ELECT}} \) 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

\[
v_s(t) = \int_0^\infty \Delta \phi(\lambda) i(t) \ast r(\lambda,t) \ast h_{\text{ELECT}}(t) d\lambda
\]

\[
= \int_0^\infty e^{2\pi if} I(f) H_{\text{ELECT}}(f) \int_0^\infty \Delta \phi r(\lambda,f) d\lambda df
\]

where \( I(f) \), \( H_{\text{ELECT}}(f) \), and \( r(\lambda,f) \) are the Fourier transforms of \( i(t) \), \( h_{\text{ELECT}}(t) \), 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

\[
r(\lambda,f) = r(\lambda,f_0) \frac{r(\lambda,f)}{r(\lambda,f_0)}
\]

(13)

where \( r(\lambda,f_0) \) is a function of \( f \) since \( f_0 \) equals a constant and \( \frac{r(\lambda,f)}{r(\lambda,f_0)} \neq \text{constant} \) function of \( \lambda \) since \( r(\lambda,f) \) is assumed to be separable (i.e., \( r(\lambda,f) = g(\lambda) \ast f(f) \)).

Equation (12) giving the signal \( v_s \) can now be simplified to

\[
v_s = \int_0^\infty e^{2\pi if} I(f) H_{\text{ELECT}}(f) \frac{r(\lambda,f)}{r(\lambda,f_0)} df \int_0^\infty \Delta \phi(\lambda) r(\lambda,f_0) d\lambda
\]

\[
= i'(t) \int_0^\infty \Delta \phi r(\lambda,f_0) d\lambda
\]

(14)

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 \( H_{\text{ELECT}}(f) \)) equals \( S(f)H_{\text{ELECT}}^2(f) \) and therefore the desired RMS noise is given by
\[ \sigma^2 = \int_{0}^{\infty} S(f) H_{\text{ELECT}}^2(f) df. \]  

(A15)

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

\[ \frac{S}{N} = \frac{\nu(t)}{\sigma} = \frac{\int_{0}^{\infty} r(\lambda, f_o) dx}{\left( \int_{0}^{\infty} S(f) H_{\text{ELECT}}^2(f) df \right)^{\frac{1}{2}}} \]  

(A16)

Equation (A16) yields the NE \( \Delta T \) once the various variables are recast into more useful forms, the \( S/N \) is set equal to 1 (note that the NE \( \Delta T \) definition can be recast to "that temperature difference such that \( S/N = 1 \)"), and \( \nu(t) \) is set equal to 1. The quantity \( \nu(t) \) can be set equal to 1 because the signal is measured (determined) at approximately the midpoint of an extended (large) signal; if \( \nu(t) = 1 \) at its midpoint then \( \nu(t) \) 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 \( D^*_{\lambda} \) is given by

\[ D_{\lambda}^* (f_o) = \frac{A_d^{\frac{3}{2}} r(\lambda, f_o)}{(S(f_o))^{\frac{3}{2}}} \]  

(A17)

where \( A_d \) equals the area of the detector.\(^{A3}\) (Those familiar with the expression

\[ D^* = \frac{(A_d \Delta f_n)^{\frac{1}{2}}}{\text{NEP}}, \]

where \( \Delta f_n \) is the bandwidth and NEP is noise-equivalent power, should note the following heuristic derivation:

Detector signal-to-noise ratio \( (S/N)_D \) = \[ \frac{\Delta \phi r}{\left( \int_{0}^{\infty} S(f) df \right)^{\frac{1}{2}}} \]

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

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

and, therefore, 

\[ D^* = \frac{A_d^{\frac{\nu}{2}} r(f_o)}{(S(f_o))^\frac{\nu}{2}} \]  

Q.E.D. 

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

\[ \frac{S}{N} = \frac{\int \Delta \phi_\lambda D_\lambda^* (\lambda) d\lambda}{\left( A_d \int \frac{S(f)}{S(f_o)} H^2_{\text{ELECT}} df \right)^\frac{\nu}{2}} \]  

(A18)

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

\[ \Delta \phi_\lambda = \frac{\pi A_d}{4 F^2} \eta_o(\lambda) \frac{\partial I_\lambda}{\partial T} \Delta T \]  

(A19)

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

\( F \) = the f/number

\( T \) = temperature

\( I_\lambda \) = watts/cm\(^2\)/steradian/micron from the source.

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

\[ \Delta f_n = \int S(f) \frac{H^2_{\text{ELECT}}}{S(f_o)} df, \]  

(A20)

equation (A18) becomes

\[ \frac{S}{N} = \frac{\pi A_d^{\frac{\nu}{2}} \Delta T \int \eta_o(\lambda) \frac{\partial I_\lambda}{\partial T} D_{f_o}^* (\lambda) d\lambda}{4 F^2 (\Delta f_n)^\frac{\nu}{2}} \]  

(A21)

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

The bandwidth to which NE \( \Delta T \) is commonly referenced is given by

\[ \Delta f_n = \frac{\pi}{2} f_o = \]

\[ \pi \left[ \frac{(HFOV)(VFOV) F_R \eta_{\text{OVSC}}}{2 n_p \Delta x \Delta y \eta_{\text{SC}}} \right] \]  

(A22)
where $HFOV = \text{device horizontal field of view (mr)}$

$VFOV = \text{device vertical field of view (mr)}$

$F_R = \text{frame rate}$

$\eta_{OVSC} = \text{overscan ratio for the device}$

$n_p = \text{number of detectors in parallel}$

$\Delta x = \text{horizontal detector size (mr)}$

$\Delta y = \text{vertical detector size (mr)}$

$\eta_{SC} = \text{scan efficiency (fraction of time spent in actually scanning the field)}.$

The initial form for $\Delta f_p$ 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 $H_{\text{ELECT}}^2$ to $1/(1 + (f/f_0)^2)$ corresponding to an exponential response function for the electronic circuitry. The expression for $f_p$ is simply derived by setting $f_p$ equal to $\tau_D$ where $\tau_D$ 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 $\tau_D$ corresponds to

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

which is the bandwidth associated with a rect function of duration $\tau_D$.

The use of the "standard" bandwidth given in equation (A22) in place of the bandwidth given in equation (A20) yields the NE AT 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 $H_{\text{ELECT}}$ includes any filtering by the measuring device); the S/N calculated using the "standard" bandwidth of equation (A22) would be measured only if $H_{\text{ELECT}}$ 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 AT) 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 usual. In this latter case, a reasonable approximation to the S/N is the S/N given in equation (A21) divided by $(n_p)^{1/2}$ where $n_p$ equals the number of detectors in series (assuming uniform $D^*$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, $D_\lambda^*$ is given by

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

where $D_\lambda^{**}$ is $D_\lambda^*$ for no cold shielding and 100% quantum efficiency

$\eta_q$ = quantum efficiency

$\eta_{CS}$ = the cold shield efficiency

$\theta$ = the cold shield angle.

Second, the quantity $W$ is defined by

$$W = \int_{\lambda_p}^{\infty} \frac{\eta_0(\lambda)}{\eta_0(\lambda_p)} \frac{D_{fo}^*(\lambda)}{D_{fo}(\lambda_p)} \frac{\partial L_{\lambda}}{\partial T} d\lambda \quad (A24)$$

where $\lambda_p$ = the wavelength for maximum $D_{fo}^*(\lambda)$. For hand calculations, Hudson notes that $\int_{3.2}^{\infty} \frac{\partial L_{\lambda}}{\partial T} d\lambda$ equals $5.2 \times 10^{-6}$ while $\int_{\lambda_p}^{\infty} \frac{\partial L_{\lambda}}{\partial T} d\lambda$ equals $7.4 \times 10^{-5}$; these quantities are obviously useful approximations to $W$.

To summarize, then, the NE $\Delta T$ using equation (A24) is given by

$$NE \Delta T = \frac{4F^2 (\Delta f_n)^{1/5}}{\pi A_d^{1/5} \eta_0(\lambda_p) D_{fo}^*(\lambda_p) W} \quad (A25)$$

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

$$A_d^{1/5} = \text{(focal length)} \times \text{(resolution in mr)/(1000).} \quad (A26)$$

---

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

\[ W = \int_{\eta_0(\lambda)/\eta_0(\lambda_p)}^{\eta_n(\lambda)/\eta_n(\lambda_p)} \frac{D^{*}_0(\lambda)}{D^{*}_0(\lambda_p)} \frac{\partial L_\lambda}{\partial T} \, d\lambda \]

and (A25) becomes

\[ \text{NE} \Delta T = \frac{4T^2 \sqrt{\Delta f_n}}{\pi \lambda_d^2 \eta_0(\lambda_p) \eta_n(\lambda_p) D^{*}_0(\lambda_p) W} \]

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 \( i(x,y) \cdot i(-x,-y) \) for \( x \) and \( y \) equal to zero which equals

\[
\int I^2 (f_x, f_y) d^2 f
\]

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

\[
\left( \int S(f_x, f_y) I^2 (f_x, f_y) d^2 f \right)^{\frac{1}{2}}
\]

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 \( I \) 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;\(^5\) 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 an 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 \( \Delta T \). Then, the signal energy per unit area from the display for a single frame will be equal to

\[
M(x,y) = \frac{k \Delta T i(x,y)}{\Delta y_1 \nu}
\]

(A27)

where \( \Delta y_1 \) = the distance between scan lines = \( \Delta y / \eta_{OVSC} \)

\( \nu \) = 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 \( \Delta y_1 \) is very small) the convolution of the original target with the system response function, i.e.,

\[
i(x,y) = i_T(x,y) * h_D(x,y)
\]

(A28)

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

\[ \text{Signal} = \text{MAX} \left[ \frac{k \Delta T}{\Delta y_1} i(x,y) \ast h_m \right] \]

(A29)

\[ = \frac{k \Delta T}{\Delta y_1} \int \infty \infty I(f_x, f_y) H_m d^2f, \]

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

\[ (\text{SIGNAL})_a = \frac{k \Delta T}{\Delta y_1} A_T \int \infty \infty H_T^2 \ (f_x, f_y) H_D^2 \ d^2f, \]

(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

\[ \text{SIGNAL} = \text{MAX} \left[ \frac{k \Delta T}{\Delta y_1} i(x,y) \ast h_m \right] \]

(A31)

\[ \ast \text{MIN} \left[ \frac{k \Delta T}{\Delta y_1} i(x,y) \ast h_m \right], \]

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,
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 when \( MTF(f_o) \) 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):

\[
(SIGNAL)_p = \frac{k}{\Delta y_1 v} \cdot MTF(f_o) \frac{4}{\pi} \Delta T \int^{x_T}_{x_0} \sin(2\pi f_o x) (2f_o) \, dx
\]

In equation (A33), the factor \( 2f_o \) in the first integral comes about because the horizontal filter (rect function) of width \( \frac{1}{2} f_o \) 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 \( L \cdot L_H \cdot M_D \), where \( M_D \) 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

\[
(SIGNAL)_p = \frac{k}{\Delta y_1 v} \cdot MTF(f_o) \frac{8}{\pi^2} \Delta T L \cdot L_H^2 \cdot M_D \, df_y. 
\]
The noise expressions for NIRT 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

\[ n(x,y) = \sum_i b_i(x) \delta (y - y_i) * h_d(y) = \sum_i b_i(x) h_d(y - y_i) \]  

(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 \( i \)th 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

\[
< n(x,y) n(x',y') > = \left< \sum_i \sum_j b_i(x) b_j(x') h_d(y - y_i) h_d(y' - y_j) \right>
\]

(A36)

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

\[
R(xx'yy') \triangleq < n(x,y) n(x',y') > = \sum_i < b_i(x) b_i(x') > h_d(y - y_i) h_d(y' - y_i).
\]

(A37)

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

\[
R(xx'yy') = < b(x) b(x') > \sum_i h_d(y - y_i) h_d(y' - y_i).
\]

(A37)

Approximating the summation by an integral, we have

\[
R(xx'yy') \approx < b(x) b(x') > \frac{1}{\Delta y_i} \int h_d(y - y_i) h_d(y' - y_i) dy_i
\]

\[
\approx - \frac{< b(x) b(x') >}{\Delta y_i} \int i_d(p) h_d(Y + p) dp \triangleq R(XY)
\]

(A39)

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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.,

\[
S(f_x, f_y) = \int \langle b(x) b(x') \rangle e^{-2\pi if_x X} \frac{1}{\Delta y_j} H_d(f_y) H_d^*(f_y). \quad (A40)
\]

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

\[
S(f) H_{ELECT}^2(f) \]

or

\[
(\text{constant}) \frac{S(f)}{S(f_0)} H_{ELECT}^2(f).
\]

In the second expression above, the constant obviously equals \( S(f_0) \) 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 \( \Delta T \) 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 \( \Delta T \), then NE \( \Delta T \) equals the \( \Delta T \) such that \( \Delta T/\sigma = 1 \) where \( \sigma \) is the RMS noise in appropriate units. Thus, the NE \( \Delta T \) equals \( \sigma \), and since

\[
\sigma^2 = \int \langle \text{constant} \frac{S(f)}{S(f_0)} H_{ELECT} \rangle df = (\text{constant}) \Delta f_n
\]

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

\[
\text{constant} = \frac{\text{NE} \Delta T^2}{\Delta f_n}
\]
(The quantity \[ \frac{NE}{A_f n} \Delta T^2 / \Delta f_n \] 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 \( \Delta f_n \), i.e., not the standardized ones, the last equation is valid regardless of which \( \Delta f_n \) is used provided the \( \Delta f_n \) in the denominator is the same as the \( \Delta f_n \) used to calculate the \( NE \Delta T \). Consequently, the voltage noise power spectrum referenced to temperature units equals

\[
\frac{NE \Delta T^2}{\Delta f_n} \left( \frac{S(f)}{S(f_0)} \right) H^2_{\text{ELECT}}(f) = \frac{S(f)}{S(f_0)} \left( \frac{S(f_x)}{S(f_{ox})} \right) H^2_{\text{ELECT}}(f_x).
\]

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

\[
NE \Delta T \Leftrightarrow k NE \Delta T (\text{energy/cm}),
\]

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

\[
\frac{S(f)}{S(f_0)} H^2_{\text{ELECT}}(f) = v \frac{S(f_x)}{S(f_{ox})} H^2_{\text{ELECT}}(f_x)
\]

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

\[
\int_\Delta < b(x) b(x') > e^{-2\pi i x} dX = k^2 NE \frac{\Delta T^2}{v^2} \frac{1}{\Delta f_n} v \frac{S(f_x)}{S(f_{ox})} H^2_{\text{ELECT}}(f_x)
\]

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

\[
S(f_x, f_y) = k^2 NE \frac{\Delta T^2}{\Delta y v \Delta f_n} \frac{S(f_x)}{S(f_{ox})} H^2_{\text{ELECT}} \cdot H^2_d(f_x, f_y).
\]

(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

\[
(\text{Noise})_p = \left( \frac{k^2 NE T^2}{\Delta y \Delta f_n^2} \int \int \frac{S(f_x)}{S(f_{ox})} H_E^2(f_x) H_d^2(f_x f_y) H_W^2(f_y) H_L^2(f_y) d_f_x d_f_y \right)^{\frac{1}{2}}
\]

(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 given by

\[
(\text{Noise})_a = \left( \frac{k^2 NE T^2}{\Delta y \Delta f_n^2} \int \int \frac{S(f_x)}{S(f_{ox})} H_E^2 H_d^2 H_T^2 H_D^2 d_f_x d_f_y \right)^{\frac{1}{2}}
\]

(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 \( \Delta T \) 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 \( E \). Thus, the MRT is given by (from equations (A34) and (A43)):

\[
\text{MRT} = \frac{\Delta y \pi^2}{8} \left[ \frac{NE \Delta T^2}{\Delta y \Delta f_n^2} \int \int \frac{S(f_x)}{S(f_{ox})} H_E^2 H_d^2 H_W^2 H_L^2 d_f_x d_f_y \right]^{\frac{1}{2}}
\]

(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)):

$$
\text{MDT} = \frac{\text{NE \Delta T}}{A_T \int \frac{H_T^2 H_D^2 \Delta f}{d f}} \left( \frac{\Delta y_i \nu}{F_R t_E \Delta f_n} \int \frac{S(f_x)}{S(t_{ox})} H_{\text{ELECT}}^2 H_d^2 H_T^2 H_D^2 \Delta f_x \Delta f_y \right)^{\frac{1}{2}}
$$

(A46)

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

$$
q_y \triangleq L \int \frac{H_L^2 H_D^2 \Delta f_y}{d f_y}
$$

$$
\rho_x \triangleq 2 W \int \frac{S}{S} H_{\text{ELECT}}^2 H_d^2 (f_x) \Delta f_x
$$

$$
\rho_y \triangleq L \int \frac{H_L^2 H_D^2 H_d^2 \Delta f_y}{d f_y}
$$

$$
L_o = \frac{7}{2f_{o}} \quad \text{(assuming bar length equals 7 times its width)}
$$

$$
W = \frac{1}{2f_{o}}
$$

Employing these last relations, the MRT reduces to

$$
\text{MRT} = \pi^2 \frac{S}{8} \frac{\text{NE \Delta T}}{\text{MTF} (f_o) \nu} \frac{q_y}{\rho_y} \left( \frac{\Delta y_i \nu}{F_R t_E \Delta f_n} \frac{2}{7} \frac{f^2}{f_{o}^2} \rho_x \rho_y \right)^{\frac{1}{2}}
$$

(A47)

This expression is further simplified by noting that $q_y$ and $\rho_y$ 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

$$
\text{MRT} = \pi^2 \frac{S}{4(14)^{\frac{1}{2}}} \frac{\text{NE \Delta T} f_o}{\text{MTF}(f_o)} \left( \frac{\Delta y_i \nu}{F_R t_E \Delta f_n \rho_x} \right)^{\frac{1}{2}}
$$

(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

\[
(Signal)_p = \frac{k \Delta T}{v} \text{MTF}(f_c) \frac{8}{\pi^2} \Delta T \text{ energy/cm}
\]

and a noise

\[
(Noise)_p = \left( \frac{k^2 NE \Delta T^2}{\Delta f_n v} \int_0^\infty \frac{S(f_y)}{S(f_{ox})} \Delta \text{ELECT} (f_y) H_d^2 (f_x) H_d^2 (f_y) df_x \right)^{\frac{1}{2}}
\]

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 quadratically, and since the bar extends over \((L/\Delta y_i)\) independent lines, the desired MRT signal-to-noise ratio is given by

\[
(S/N)_p = \frac{L}{\Delta y_i} \frac{k \Delta T}{v} \text{MTF}(f_o) \frac{8}{\pi^2} \Delta T
\]

\[
\left( \frac{L}{\Delta y_i} \frac{k^2 NE \Delta T^2}{\Delta f_n v} \int_0^\infty \cdots \cdots df_x \right)^{\frac{1}{2}}
\]

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

\[
Q = \rho f_o \frac{1}{N} \;
\]

others approximate the integrals such as

\[
\int H_L^2 H_D^2 \; df
\]

by

\[
\left( \frac{f_L^2 f_D^2}{f_L^2 + f_D^2} \right)^{\frac{1}{4}}
\]

where

\[
f_L = \int H_L^2 df \quad \text{and} \quad f_D = \int H_D^2 df \; ; \text{ etc.}
\]

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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 $S$ and $t_E$; again, unfortunately, universal values for these constants do not exist. The values recommended at this time are

$$S = 2.25,$$
$$t_E = 0.2.$$  \hspace{1cm} (A49)

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

$$\frac{v}{\Delta f} = \frac{2}{n} 2v \tau_D \approx \frac{4}{\pi} \Delta x$$

where $\Delta x$ is the detector width. Also $\Delta y_i$ is given by

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

where $\Delta y$ is the detector height and $\eta_{OVSC}$ is the overscan ratio. Finally, $\rho_x$ will equal approximately 1 for small $f_o$ while for any $f_o$ a respectable approximation, assuming $S(f_o)/S(f_o) = 1$, is

$$\rho_x = \frac{1}{(4f_o^2 (\Delta x)^2 + 1)^{1/4}}$$  \hspace{1cm} (A50)

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

$$\text{MRT} = 0.66 \frac{S}{\text{MTF}(f_o)} \left( \frac{4}{\pi} \frac{\Delta x \Delta y}{\eta_{OVSC} F_R t_E} \right)^{1/4} \left( 4f_o^2 (\Delta x)^2 + 1 \right)^{-1/4}$$  \hspace{1cm} (A51)

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

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

\[ \text{MDT} = \frac{g'\text{NE} \Delta T}{q_A} \left( \frac{\Delta y_i}{F_R t_e \Delta f_n} \frac{1}{2W^2} \rho_{xA} \rho_{yA} \right)^{\frac{1}{3}} \]  

(A52)

thru use of the definitions

\[ q_A = A_T \int_{-\infty}^{\infty} H_T^2 H_D^2 \, df \]

\[ \rho_{xA} = 2W \int_{0}^{\infty} \frac{S(f_i)}{S(f_{ox})} H_{\text{ELECT}}^2 H_d^2 H_w^2 H_D^2 \, df \]

\[ \rho_{yA} = W \int_{-\infty}^{\infty} H_w^2 H_d^2 H_D^2 \, df \]

where \( H_w \) is the transfer function corresponding to the side of the test square. Approximations to \( q_A, \rho_{xA}, \) and \( \rho_{yA} \) 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

\[ \text{MRT}_v = \left[ \text{MRT}^2(f_x) + \text{MRT}^2(f_y) \right]^{1/2} / \sqrt{2}. \]

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

\[ i(x,y) = \text{MTF}(f_{oy}) \frac{4}{\pi} \sin (2\pi f_{oy} y) i_x(x) + .5, \]  \hspace{1cm} (B1)

where \(i_x(x)\) is the degraded rect function in the x direction. Equation (A33) becomes

\[ \text{(SIGNAL)}_p = \frac{k}{\Delta y^V} \text{MTF}(f_{oy}) \frac{4}{\pi} \Delta T \int_{-\infty}^{\infty} \sin (2\pi f_{oy} y) (2f_{oy}) dy \]  \hspace{1cm} (B2)

\[ x \cdot \int_{-\infty}^{\infty} I_x H_x df_x, \]

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

\[ \text{(SIGNAL)}_p = \frac{k}{\Delta y^V} \text{MTF}(f_{oy}) \frac{8}{\pi^2} \Delta T L \int_{-\infty}^{\infty} H_L^2(f_x) H_D^2(f_x) df_x. \]  \hspace{1cm} (B3)

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

\[ S(f_x, f_y) = \frac{k^2 NE \Delta T^2}{\Delta y^V \Delta f_n} \frac{S(f_{ox})}{S(f_{ox})} H_L^2 \text{ELECT}(f_x) H_D^2(f_x,f_y), \]  \hspace{1cm} (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

\[
(\text{NOISE})_p = \left[ \frac{k^2 \text{NE} \Delta T^2}{\Delta y_1^2 \Delta f_n} \int \int \frac{S(f_x)}{S(f_{0x})} H^2_{\text{ELECT}} H^2_d(f_x, f_y) H^2_w(f_y) H^2_L(f_x) H^2_D(f_x) \right. \\
\left. \times d^2 f \right]^{1/2}.
\]  

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

\[
\text{MRT}(f_y) = \frac{\Delta y_1 \pi^2}{8} \frac{S}{\text{MTF}(f_y)} L \int H^2_L H^2_D df_x \left[ \frac{\text{NE} \Delta T^2}{\Delta y_1 \Delta f_n} \left( \frac{1}{F_{R} F_{E}} \right) \right. \\
\left. \times \int \int \frac{S(f_x)}{S(f_{0x})} H^2_{\text{ELECT}} H^2_d(f_x, f_y) H^2_w(f_y) H^2_L(f_x) H^2_D(f_x) \right. \\
\left. \times H^2_d(f_x) df_x df_y \right]^{1/2}.
\]  

Defining the quantities

\[
g_x = L \int H^2_L H^2_D df_x, \\
\rho_x = L \int \frac{S(f_x)}{S(f_{0x})} H^2_{\text{ELECT}} H^2_d H^2_L H^2_D df_x, \\
\rho_y = 2W \int H^2_w H^2_D df_y,
\]

where \( L = \frac{7}{2f_0} \) and \( W = \frac{1}{2f_0} \), then equation (B6) becomes

\[
\text{MRT}(f_y) = \frac{\pi^2}{8} \frac{S}{\text{MTF}(f_y)} \frac{\text{NE} \Delta T}{F_{R} F_{E} \Delta f_n} \left[ \frac{\Delta y_1 \pi^2}{2} \frac{2^2}{7} f_0^2 \rho_x \rho_y \right]^{1/2}.
\]
As in Appendix A, \( g_x \) approaches 1, however \( \rho_x \) will not asymptote as fast as before because of the additional electronic filtering \( H_{\text{ELECT}}^2 \). Putting this in a form which appears in the main section, we get

\[
\text{MRT}(f_y) = \frac{\pi^2}{4} \sqrt{\frac{\Delta T}{\text{MTF}(f_y)}} \sqrt{\frac{\Delta y_v f_y}{F_R f_E \Delta f_n}} \frac{\text{QQ}}{f_y}, \tag{B8}
\]

where

\[
\text{QQ} = f_y \rho_x \rho_y \int \int \frac{S(f_x)}{S(f_{ox})} H_{\text{ELECT}}^2 (f_x) H_L^2 (f_x) H_d^2 (f_x) H_D^2 (f_x) \times df_x \int H_W^2 (f_y) H_d^2 (f_y) df_y.
\]
SUBROUTINE FLOW CHART

MAINPG
DATA
INIT
NEWINP—EXIT
YES IF READF
NRTINP = 2
NO
YES IF XNET = 0
DEVICE—OPTIC—ALINEY
ALINEY—NOISE
ALINEY—NOISE
EXP—DWP ALINEY NO ALINEY—EN SIN
QTFE SIN ALOG10—BDWT COS CAMERA—ALINEY
ALINEY—BDWT COS XRING —AMIN1 EMIT—SIN SIN
ALOG10 QTFE ALINEY ALINEY—DSPLY—EXP
COS EXP—PLANK ALOG STABLE—ALINEY
QTFE QTFE ALOG10 EYEBAL—ALINEY EXP
ALINEY—XRING—MDT ATAN AMAX1 ALOG10
ALOG ALINEY ATMCRL EXP
ALOG10 ALOG QTFE QTFE
ATAN ALOG10 SINC—SIN
EXP EXP MDTSNR—ALINEY AMAX1
QTFE XRING—ALINEY
SIN—SINC DEFAULT ALOG
ALOG10 ATAN EXP QTFE SIN—SIN
REAL IOTAU
REAL IRTRAN
DIMENSION AFCHL(161)
DIMENSION FURD(20)
DIMENSION DDT(50), YXK(50), XM(50), XM(50), XM(50)
DIMENSION YXK(50), XM(50), XM(50)
DIMENSION XMFF(20), XMFF(20), XMFF(20)
DIMENSION XXMTI(20), YMRTI(20), FFT(20)
DIMENSION xxmti(0), yymtf(20)
DIMENSION PROI(10), XNUM(10)
DIMENSION QQQI(20), QQQQ(20)
DIMENSION some(50), DRTX(50), DRTY(50)
DIMENSION CLAXK(20), YLNYM(20)
DIMENSION SIGMA(9), WAVE(9), IRTRAN(I61)
DIMENSION VIKAN(161)
DIMENSION OUTPUT(10), XINPUT(10)
DIMENSION HANO(161)
DIMENSION OOSTAR(10), XLMB(10)
DIMENSION RSPX(161)
DIMENSION XMXN(20), XM:NM(20)
DIMENSION H(0)
DIMENSION OQUN(20), OQQQ(20)
DIMENSION SOME(50), DRTX(50), DRTY(50)
DIMENSION ELANX(.20), ELAYM(20)
DIMENSION XMTF(.20), SYMTF(20)
DIMENSION FQQB(0), FQQB(0)
DIMENSION AD(10), YD(I0), XE(I0), XB(I0)
DIMENSION FQQB(0), FQQB(0), FQQB(0)
DIMENSION AD(10), YD(I0), XE(I0), XB(I0)
DIMENSION VIKAN(161)
DIMENSION VIKAN(161)
DIMENSION XMAX, XMAG, XNSC, DRTS, DRTA, S: DC, T:A, T:O, ANGLE, MS: N, R: T: AR,
2XLAM, MNP, E: FOC, XX, YMAX, XX, Y: ML, XX, X: MAX, XX: MAX, XX: MAX, XX: MAX,
XAVE=AVE1-0.1
I=IF(I((AVE2-AVE1)/2)<0.1)
RMAG=2.0*MHAU

XZ=SNH*3.14159/2.0*(14.0**0.5)*3.14159/2.0
CUTOFF=0.999*RUOF
IOTA=HFOV*VFOV*(17.5**2)*FR/YN/DELTA/F=DELTA/XNSC/OVERSC
VEL=DELTA*JUTAU
RSTAR=FSTAR/VEL
RELECT=FLECT/VEL
RMAX=FMAX/VEL
DO 101 KL=1,8

101 H(KL)=10.0*F(KL)/VEL
CALL DEVICE(XMTF, YMTF, XMTF, YMTF, FFF, XMTF, YMTF, FURD, FG, XD, YD, XD,
BYD, XD, YE, XTV, YTV, XM, YML, FQQ)
IF(XNET<EQ.0.0) CALL XNOISE(F0, CUTOFF, DSTAR, XLMBA, OPEAK, XB, FQQ)
XNET=XNET
CALL BWT(F0, DELTAF, CUTOFF, XB, FQQ)
XL=1./DELTA/20.
XCTFF=CUTOFF/VEL
FT=0.0
V=FR*LEYET
DO 102 K=1,20
FT=FT+XL
TARF=FT
GRUNT=1./2./TARF
RUNT=7.#GRUNT
CALL XRING(XCTFF, XMTF, FURD, 20.0, H, B, G, INT.1, ANS, 2.1, 0)
CALL XRING(XCTFF, XMTF, FURD, 20.0, H, B, G, INT.1, ANS, 2.1, 0)
CALL XRING(0.0, YMTF, FURD, 20.0, H, B, G, INT.1, ANS, 2.1, 0)
Q=ANS/2.0
Q0=ANR=ANT/2.0*RUNT
Q00(KK)=Q0
Q000(KK)=Q0
CALL ALINF(XXX, FFF, XMTF, FFF, 20)
CALL ALINF(YYY, YMTF, FFF, 20)
IF(XXX<EQ.0.0) XMTF=1.0E+60
IF(XXX<EQ.0.0) GO TO 466
XMTF=XXX*DELTA/TAY*VEL*FT/Q/Delta/F-R/EYT/TS/OLESC#0.5
IF(XXX/Lt.0.0) XMTF=XXX1*DEE0.0
IF(VLT<1.0) XMTF=XMTF*V**0.5
4650 CONTINUE
IF(YYY<EQ.0.0) YMTF=1.0E+60
IF(YYY<EQ.0.0) GO TO 4667
YMTF=XXX*DELTA/TAY*VEL*FT/Q/Delta/F-R/EYT/TS/OLESC#0.5
IF(YMTF<LT.0.0) YMTF=VLT+1.0E00
IF(VLT<1.0) YMTF=YMTF*V**0.5
4667 CONTINUE
XXMTF(KK)=XMTF
YYMTF(KK)=YMTF
FFT(KK)=FT
102 CONTINUE
IF(JPINT<EQ.0.0) GO TO 8000
IF(IFLAG<EQ.0) WRITE(6,711)
7000 FORMAT(4(J,5H1))
WRITE(6,711)
711 FORMAT(1H1,14HFILTERED NOISE)
WRITE(6,712)
712 FORMAT(1H1,14HFILTERED NOISE)
WRITE(6,712)
8000 CONTINUE
DO 8000 KK=1,20
XXMTF(KK)=XXMTF(KK)
XXMTF(KK)=XXMTF(KK)*3.5/FFT(KK)/7.0*FFT(20)*3.085
YVMRT(KK) = YYMRT(KK) * (3.5 / FFT(KK)) / 7.0 * FFT(201) ** 0.5
Rt45(KK) = (XMMRT(KK) ** 2 + YYMRT(KK) ** 2) ** 0.5

600 CONTINUE
IF (JPMMXT.EQ.0) GO TO 8009
IF (IFLAG .EQ. 1) WRITE(6, 7000)
WRITE(6, 322)

322 FORMAT(12H4)H*0)HO0)HPPREDICTED MINIMUM RESOLVABLE TEMPERATURE)
WRITE(6, 323) (323 FORMAT(12H4)H*0)HO0)HMRT(I), YMMRT(I), XMMRT(I), YMMRT(I), RTP45(I), I

8009 CONTINUE

C
C CONVERT DELTA T ON O/D TO DELTA POWER
C
C CONVERT MRT TO POWER
C
XLAM=XW
DO 6013 J=1, L
XLAM=XLAM+0.1
CALL ALINEY(ZZ, XLAM, DUSTAR, XLMA, 10)
IF (ZZZ .LT. 0.0) ZZZ=0.0

6013 FORMAT(ZZ)
BURR=OUTPUT(I)
DO 6003 I=1, 10
ORX=XINPUT(I)
IF (ORX .EQ. 0.0) BURR=OUTPUT(I)

6003 CONTINUE

DO 6005 K=1, L
6005 RAND(KK) = 1.0
DO 6007 KK=1, L
T=27.0 + XINPUT(KK)
IF (XINPUT(KK) .EQ. 0.0) GO TO 6007
CALL PLANK(-1.2700, XXP, RXND, RSPX)

6007 CONTINUE

RINPUT(KK) = XXP
FREE=27.0+XMEXP
CALL PLANK(FREE, 27.0, XPOX, RAND, RSPX)
DO 800 LON=1, 20
T=27.0+XMMRT(LON)
T5=27.0+YMMRT(LON)
XTOL=0.0
IF (XMMRT(LON) .EQ. 0.0) GO TO 801
CALL PLANK(T5, 27.0, XTOY, RXND, RSPX)
801 ELANX(LON)=XTOL
YTO=0.0
IF (YMMRT(LON) .EQ. 0.0) GO TO 800
CALL PLANK(T5, 27.0, YTO, RXND, RSPX)
800 ELANY(LON)=YTO
DD 8888 JK=1, 20
8888 ELANY(JK)= (ELANY(JK) ** 2 + ELANY(JK) ** 2) ** 0.5
CALL NDT(XMMX, YMMX, FFFF, XCTFF, H, SNR, DELTA)

C
WDOV SCALED MRT
C
DO 7119 J=1, 20
7119 WDOV(J) = FFT(J) / FACT

8007 CONTINUE
XXH=0.01

RANGE DO LOOP FOR RECOGNITION

DO 1066 IJK=1,LUPU
K=0
TTR=TTAC-DET trop
UU 500 II=1,MIN,IRMAX,DELTR
KK=KK+1
RANGE=I/100000
X=RANGE*100000
DO 2 JJ=1,1 LW
2 ITRAN(JJ)=1.0
CALL ATMCL(RVIS,RANGE,AIRP,XXR,.AVE1,.AVE2,IPRINT,1JK,STATE)
1AFCHL,IAFLG)
DO 5300 KISS=1,LW
5300 ITRAN(MISS)=AFCHL(MISS);;TRAN(MISS)
CALL UTEO(I,TRAN,TRAN,LW)
TRANS=TRAN(LW)/(WAVE2-AVE1)
CALL PLANCK(TTAR,TTAC,SPR,TRAN,RSPX)
DOT(KK)=TRANS
DET=DET*TRANS
C TLEN=.0*XMTAN/RANGE
TLEN=XMTAN/RANGE
DET=DET*(TLEN/7.0*FFT(20))**0.5
SUPH=SUP#*(TLEN/7.0*FFT(20))**0.5
XDR(KK)=RANGE
C X=WHT FOR DELTA T AND DELTA P
CALL ALINEY(W#W,DETE,FFT*XXMTL+20)
CALL ALINEY(HOGER,SPR,FFT*ELAX+20)
XNUM=XMTAR#RANGE
XXNUM=XMTAR#RANGE
CALL ALINEY(PO,XXNUM,PO,XXNUM+10)
CALL ALINEY(P#P,XXNUM,P#P,XXNUM+10)
IF(P#P<LT.0.0) PHOB=0.00
IF(P#P<LT.0.0) P#P=0.00
IF(P#P<LT.0.0) P#P=0.00
SUME(KK)=P#P
XFR(KK)=P#P
C Y=WHT FOR DELTA T AND DELTA P
CALL ALINEY(PR#UT,DETE,FFT,YMMT,20)
CALL ALINEY(HOT,SPR,FFT*ELANY+20)
XXNUM=XMTAR#PH/#HGL
XXNUM=XMTAR#RANGE
CALL ALINEY(PR#D,XXNUM,PO,XXNUM+10)
CALL ALINEY(S#P,XXNUM,P#P,XXNUM+10)
IF(S#P<LT.0.0) S#P=0.00
IF(S#P<LT.0.0) S#P=0.00
YPH(KK)=S#P
DRTY(KK)=S#P
CALL ALINEY(PR#D,XXNUM,PO,XXNUM+10)
CALL ALINEY(P#P,XXNUM,P#P,XXNUM+10)
IF(P#P<LT.0.0) P#P=0.00
C
45-JEGRLE MTF FOR DELTA T AND DELTA P
CALL ALINEY(FRT,DETE,FFT,RT45,20)
CALL ALINEY(MOWER, SUPER, FFT, ELANS, 20)
XXNUM=XHAT/RANGE
XXINM=XHAT/RANGE
CALL ALINEY(POWER, XXNUM, POWER, XXINM, 10)
CALL ALINEY(POWER, XXINM, POWER, XXNUM, 10)

IF (POWER.LT.0.0) POWER=0.0
X5T4(KK)=POWER
X4SP4(KK)=POWER
CALL ALINEY(POWER, XXINM, POWER, XXNUM, 10)
CALL ALINEY(POWER, XXNUM, POWER, XXINM, 10)

IF (POWER.LT.0.0) PROB=0.0
IF (POWER.LT.0.0) POWER=0.0
X5T3(KK)=POWER
X4BP3(KK)=POWER
DO6(KK)=DO6(KK)
DO7(KK)=DO7(KK)

500 CONTINUE
IF (PRINT.EQ.0) GO TO 8011
IF (IAFLG .NE. 1) WRITE(6,7000)
WRITE(6,325) DETEMP
8011 CONTINUE

C
520 FORMAT(1H12J1HRECOGNITION PERFORMANCE/
128H TARGET DELTA TEMPERATURE IS 15*10^2, 13H DEGREES C)
WRITE(6,327)
327 FORMAT(1H33TEMPERATURE DEPENDANT PERFORMANCE/
1H128X XHAT(RANGE), XNAT(RANGE), XHAT(RANGE), XNAT(RANGE), 1=1, KK)
326 FORMAT(1H33XHAT TRANS, XHAT TRANS, XHAT TRANS, XHAT TRANS, /)(1X*5, F12.2, F12.2, F12.2, F12.2)
325 FORMAT(1H33XHAT TRANS, XHAT TRANS, XHAT TRANS, XHAT TRANS, /)(1X*5, F12.2, F12.2, F12.2, F12.2)

2300 WRITE(6,377) XHAT(1), XHAT(1), SOME(1), YOR(1), X5T3(1), 1=1, KK)
377 FORMAT(1H33XHAT TRANS, XHAT TRANS, XHAT TRANS, XHAT TRANS, /)(1X*5, F12.2, F12.2, F12.2, F12.2)

820 FORMAT(1H27POWER DEPENDANT PERFORMANCE)
WRITE(6,326) (XOR(1), DORT(1), DORT(1), DORT(1), X4BP3(1), 1=1, KK)

2001 WRITE(6,377) XOR(1), DORT(1), XHAT(1), YF4(1), YF4(1), X4BP3(1), 1=1, KK)

C DETECTION
C
11=0
DU 5066 JK=INDIN, IRDAK, IDLLX
11=111
RANGE=JK/1000.0
XH=RANGE*1000.0
DU 5066 KLM=1.1 LW
CALL ATMCRL(RVIS,RANGE,ARMPK,WRH,WAPE1,WAPE2,PRINT,IK,ISTATE,)
CALL ATMCRL(IAPG)

DO 5790 MISS=1,LT
5790 IRTRAN(MISS)=ICRRL(MISS)*IRTRAN(MISS)
CALL QIFE(0,1,IRTRAN,TRTRAN,LW)
TRANS=IRTRAN(LW)/(WAPE2-WAPE1)
DO(IJ)=TRANS
CALL PLANK((3AR,TRAC,POWER,IRTRAN,RSPX)
DET=DETEMP*TRANS
TLEN=AR/RANGE
DET=DET*(TLEN/7.0*FFT(201)**0.5
POWER=POWER*(TLEN/7.0*FFT(201)**0.5
XOR(IJ)=RANGE
C XMAT FOR DELTA T AND DELTA P
CALL ALINEY(PROB,DETE,FXT,XXMR20)
CALL ALINEY(ROGER,POWER,FXT,ELAN20)
XXNUM=XHTAR*FRW/RANGE
XXN2M=XHTAR*ROGER/RANGE
CALL ALINEY(PROB,XXNUM,PRO,BETA,10)
CALL ALINEY(POWPRO,XXN2M,PRO,BETA,10)
IF(PROB.LT.0.0) PROB=0.00
IF(POWPRO.LT.0.0) POWPRO=0.00
XPR2(IJ)=PROB
DRTX(IJ)=POWPRO
C YMAT FOR DELTA T AND DELTA P
CALL ALINEY(FRW,DETE,FXT,YYMR20)
CALL ALINEY(ROGY,POWER,FXT,ELANY20)
XXNUM=XHTAR*FRW/RANGE
XXN2M=XHTAR*ROGY/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
YPR2(IJ)=PROB
DRTY(IJ)=SOWPRO
C APS-MAT FOR DELTA T AND DELTA P
CALL ALINEY(FRW,DETE,FXT,RT4S20)
CALL ALINEY(ROGER,POWER,FXT,ELAN5S20)
XXNUM=XHTAR*FRW/RANGE
XXN2M=XHTAR*ROGER/RANGE
CALL ALINEY(PROB,XXNUM,PRO,BETA,10)
CALL ALINEY(POWPRO,XXN2M,PRO,BETA,10)
IF(PROB.LT.0.0) PROB=0.00
IF(SOWPRO.LT.0.0) POWPRO=0.00
X4ST(IJ)=PROB
X4SPIJ)=POWPRO
C WDFX K-MAT FOR DELTA T AND DELTA P
CALL ALINEY(FRW,DETE,WFDV,XXMR20)
CALL ALINEY(ROGER,POWER,WFDV,ELANX20)
XXNUM=XHTAR*FRW/RANGE
XXN2M=XHTAR*ROGER/RANGE
CALL ALINEY(PROB,XXNUM,PRO,BETA,10)
CALL ALINEY(POWPRO,XXN2M,PRO,BETA,10)
IF(PROB.LT.0.0) PROB=0.00
IF(SOWPRO.LT.0.0) SOWPRO=0.00
SOME(IJ)=PROB
C WDFV Y-MAT FOR DELTA T AND DELTA P
CALL ALINEY(FRW,DETE,WFDV,YYMR20)
CALL ALINEY(ROGY,POWER,WFDV,ELANY20)
XXNUM=XHTAR*FRW/RANGE
CALL ALINEY(PR08, KNUM9, PRO, 10)
CALL ALINEY(SOWPRO, XXNUM, PHQ, BETA, 10)
IF (SOWPRO.LT.0.0) SOWPRO = 0.0
YFRW(11) = PROB
YFRW(11) = SOWPRO
C WFOV WITH 45-DEGREE MRT FOR DELTA T AND DELTA P
CALL ALINEY(IPT, DELTE, WFOV, HT45, 20)
CALL ALINEY(POWER, WFOV, ELAN45, 20)
XXNUM = XXNAM * FRW / RANGE
XXNAM = XXNAM * POWER / RANGE
CALL ALINEY(PHQB, XXNUM, PRO, BETA, 10)
CALL ALINEY(POWR, XXNAM, PRO, BETA, 10)
IF (POWPRO.LT.0.0) POWPRO = 0.0
X45P4(I) = POWPRO
X45P4(I) = POWPRO
CALL NETSNR(XXNUM, XWYN, 4FF, XCTR, H, DELTAF, RANGE, TRAN, SPROB, XXNET)
ROD0(I) = SPROB
DSN(11) = 0
C DETECTION WITH SIGNAL-TO-NOISE
C
ATT = XLTAR * XHTR
R2 = RANGE * 2
T0 = DETEMP * TRANS
ARC = (ATT / DELTA/DESTAY / R2 + 1.0)**0.5
TARC = (ATT / DELTA/DESTAY / R2 / FACT / FACT + 1.0)**0.5
BARC = DELTA / DELTA / R2 / ATT + 1.0
TEGR = DELTA / DELTA / FACT / FACT + 1.0
TEFR = EYF / FR
IF (TEFR.LT.1.0) TEFR = 1.0
TSE(I) = TO / XXNET / BARC * ARC * TEFR * 0.5
SSE(I) = TO / XXNET / TEBARC / TARC * TEFR * 0.5
6065 CONTINUE
IF (PRINT EQ 0.0) GO TO 8012
IF (IAFLG .EQ. 1) WRITE(6, 7000)
WRITE(6, 9020) DETEMP
9020 FORMAT(1X, 'DETECTION BASED ON NOT/IH/27HTARGET DELTA TEMPERATURE/1949.0, 10, 2, 13H DEGREES C/')
WRITE(6, 9021) (XDR(I), DDT(I), DSN(I), ROD(:I), I = 1, 11)
9021 FORMAT((8X, 5H RANGE, 6X, 5H ATTEM TRANS, 5X, 3H S N R, 5X, 11H IMPROBABILITY/10(I, 2X, F9.2, 3F1.3)))
IF (IAFLG .EQ. 1) WRITE(6, 7000)
WRITE(6, 9999) DETEMP
9999 FORMAT(1H, '22ND DETECTION PERFORMANCE/128H TARGET DELTA TEMPERATURE 15.0, 10.2, 13H DEGREES C')
WRITE(6, 9900)
9900 FORMAT(1H, '22ND DETECTION PERFORMANCE/34H TEMPERATURE DEPENDENT PERFORMANCE/1C')
WRITE(6, 9998) (XDR(I), DDT(I), XPR(I), YPR(I), X45T4(I), I = 1, 11)
IF (IAFLG .EQ. 1) GO TO 2002
WRITE(6, 7000)
WRITE(6, 9999) DETEMP
WRITE(6, 9980)
9980 FORMAT(1H, '22ND DETECTION PERFORMANCE/1C')
2002 WRITE(6, 9999) (XDR(I), DDT(I), XRTY(I), YRTY(I), X45P4(I), I = 1, 11)
IF (IAFLG .EQ. 1) WRITE(6, 7000)
WRITE(6, 9999) DETEMP
WRITE(6, 9979)
9797 FORMAT(IM, 16H#FOV PERFORMANCE/3#M TEMPERATURE DEPENDENT PERFORMANCE OF C1)
   WRITE(6,9898) (X(DR(I),ODT(I),SOME(I),YDR(I),XAT(I),I=1,11)
   IF (IFLAG, XNE=1) GO TO 2003
   WRITE(0,9999)
9999 FORMAT(IM, 16H#FOV PERFORMANCE OF C1)
   WRITE(6,9902)
   2003 WRITE(6,9899) (X(DR(I),ODT(I),XFR(I),YFR(I),XAT(I),I=1,11)
   9999 FORMAT(IM, 20H#MANGE, 6X, #HATM TRANS, 6X, #MX DET TO, 7HY DET TO, #BH
   15 DET 1/(1X,F5.2,F15.2,F13.2))
   9999 FORMAT(IM, 20H#POWER DEPENDENT PERFORMANCE OF C1)
   1 IM, #MANGE, 6X, #HATM TRANS, 6X, #MX DET TO, 7HY DET TO, #BH
   15 DET P/(1X,F5.2,F15.2,F13.2))
8012 CONTINUE
   DETEM=DETEN=ODTT
1006 CONTINUE
8025 CONTINUE
   IF (IPRINT.EQ.0) CALL DEFAULT (FFFF, XMAG, [11], [KK])
   IF (IPRINT.EQ.1) GO TO 8017
   KNET=SAVEKET
   GO TO 1400
8017 CONTINUE
   STOP
   END

BLOCK DATA

DIMENSION XINPUT(IO), OUTPUT(IO)
COMMON/NAMES/EFLG, IRPRINT, ODT, DETEM, DREAD, FACT, IDELTA/IDELTA/IDELTA/
1 IRAX, IORD, IRMAX, IRMIN, LUMO, OUTPUT, XHAT, XINPUT, XLAT, XW, XLW 
COMMON/NAME5/I0KOUNT, XMAG, PSTAR, FELECT, DUMP
COMMON/NAMES/UXM, ODLW, P1 (10), S(10), XNET, DDELTA, DELTA, EYEM, IMFPOV, 
1VFR, VMAX, XMAG, XMNC, ORES, EWHITE, SRTAO, DISC, TOA, TOA, ANGLE, NMAX, XSTAR, 
ZXL, AM, NUM, FOCD, XX, FMAG, XY, YX, XMAX, XSIGL, YSIGL, XSIGL, XA, YA, KKK,
3LUTA, VEL SELECT.

COMMON/BLUR/ABLUR
DATA HUV/60.0/, VUV/4.0/, TD/0.75/, FNUMB/2.20/, FDC/2.8/
DATA ANGLE/60.0/, SRTAO/0.00096/, DISC/1.0/, XM/64.0/, DELTAX/06/1
1 DELTAY/0.860/, NON/0/, PSTAR/100000000000/, DREAD/46/1
DATA FR/15.0/, XMNC/0.76/, ORES/1.00/
DATA ELEST/0.0/, XE/0.4/, FMAG/0.0/
DATA KKK/0.0/, EWHITE/50.0/, XY/0.0000/, XYL/0.0000/, XI/0.1689/, YA/0.1689/
DATA FACT/2.0/, EYEM/0.2/, XSIGL/0.0000/, YSIGL/0.0000/
DATA XMAG/4.800/, XNET/0.00/ 1
DATA XALT/5.25/, XHAT/2.7/, DETEM/1.1/, LUMO/1.00/, ODT/0.00/
DATA IRAX/500.0/, IRMAX/5000.0/, IORD/1000.0/, IRDAX/10000.0/
DATA INPUT/0.0/, 0.125/, 4.000000000000/, 0.125/, 0.100000000000/
DATA OUTPUT/2.000/, 1.1/, 0.2/, 0.3/, 0.4/, 0.5/, 0.6/, 0.7/, 0.8/, 0.9/, 0.000000000000/
END

70
SUBROUTINE INIT(IAFLG)
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 CONTROLS.
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 CVC6500
C * AND ONE FOR THE II/IBM360/44.
C *
C * THIS IS THE CVC6500 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 *
C  SWITCH=1
C *
C * CALL 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 *
C * THIS WILL RETURN THE STATUS OF ALL SWITCHES WHICH
C * ARE CURRENTLY *ON*.
C *
C * CALL SWITCH(IAFLG)
C IF (IAFLG .EQ. 1) GO TO 10
C BATCH, SKIP TO NEW PAGE, PRINT BANNER, AND RETURN.
WRITE(*,1000)
1000 FORMAT(IHI,13X,2BHNVL THERMAL SYSTEM MODEL,
13HINTERACTIVE CONNECT INPUT AND OUTPUT, SUPPRESS PAGE FULL
C * WAIT, CLEAR SCREEN, PRINT BANNER, AND RETURN.
C10 CALL CONNECT(SINPUT,0)
C10 CALL CONNECT(SOUTPUT,0)
C110 RETURN
C110 FORMAT(IHI)  
C1110 WRITE(*,10020)
C20 FORMAT(IHI)  
C20 FORMAT(IHI)  
C20 FORMAT(IHI)  
C20 FORMAT(IHI)  
C10 IF (IAFLG .EQ. 1) THEN
C 120 WRITE(IHI,120)
C 120 RETURN
C 120 RETURN
C END
<table>
<thead>
<tr>
<th>NAME</th>
<th>GROUP</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABLUR</td>
<td>SYST</td>
<td>SIZE OF OPTICS BLUR CIRCLE (MRAD)</td>
</tr>
<tr>
<td>AIRTP</td>
<td>ENV1</td>
<td>AIR TEMPERATURE (DEGREES C) OMITTED IF SIGMA AND WAVE ARE USED</td>
</tr>
<tr>
<td>ANGLE</td>
<td>DETR</td>
<td>COLD SHIELD ANGLE (DEGREES)</td>
</tr>
<tr>
<td>BETA</td>
<td>FDC1</td>
<td>NUMBER OF CYCLES ACROSS TARGET FOR 4-CYCLE DETECT. CHITKEN</td>
</tr>
<tr>
<td>PRO</td>
<td>CORRESPONDS TO PRO</td>
<td></td>
</tr>
<tr>
<td>BRITE DISP</td>
<td>AVERAGE DISPLAY BRIGHTNESS (FT-LAMBERTS)</td>
<td></td>
</tr>
<tr>
<td>CUTOFF</td>
<td>ELECTRON</td>
<td>LOWER CUTOFF FREQ. OF ELECTRONICS</td>
</tr>
<tr>
<td>DSDTAR</td>
<td>DSTD</td>
<td>DOE OF DETECTOR (10x10) (CM, Hz, %) PER WATT IN NORMALIZED FORM DMAX=1.0 CORRESPONDS TO XLMBA</td>
</tr>
<tr>
<td>DTTI</td>
<td>TARG</td>
<td>TARGET DELTA T INCREMENT SIZE (0.0 IF LUPD=1.0)</td>
</tr>
<tr>
<td>DELTAX</td>
<td>DETR</td>
<td>IFOV X-DIRECTION AT DETECTOR (MRAD)</td>
</tr>
<tr>
<td>DELTAY</td>
<td>DETR</td>
<td>IFOV Y-DIRECTION AT DETECTOR (MRAD)</td>
</tr>
<tr>
<td>DETEMP</td>
<td>TARG</td>
<td>TARGET DELTA T (DEGREES C)</td>
</tr>
<tr>
<td>DISC</td>
<td>DETR</td>
<td>NUMBER OF DETECTORS IN SERIES (MINIMUM=1.0)</td>
</tr>
<tr>
<td>DPEAK</td>
<td>DETR</td>
<td>PEAK DOE OF DETECTOR (10x10)</td>
</tr>
<tr>
<td>DMEAN</td>
<td>FLY</td>
<td>EYE INTEGRATION TIME -- CURRENTLY DEFINED AS 0.2 (SEC)</td>
</tr>
<tr>
<td>F</td>
<td>WNPX</td>
<td>NOISE POWER SPECTRA FREQ. (LOG Hz) CORRESPONDS TO S</td>
</tr>
<tr>
<td>FACT</td>
<td>FCTR</td>
<td>RATIO OF NEAPHER FREQ. AXIS -- CURRENTLY DEFINED AS 2.0</td>
</tr>
<tr>
<td>SELECT</td>
<td>ELECTR</td>
<td>3-DB POINT ON ELECTR. BANDPASS, ASSUMING RC ROLLOFF</td>
</tr>
<tr>
<td>DMAX</td>
<td>DETR</td>
<td>1/DELTAX OR 1/DELTAY, WHICHEVER IS GREATER (CALCULATED)</td>
</tr>
<tr>
<td>DMAXF</td>
<td>ELECTRON</td>
<td>FREQ. OF ANY ELECTR. APERTURE CONCEPTION (KHZ) LEAVE BLANK TO IGNORE CORRESPONDS TO XK</td>
</tr>
<tr>
<td>PHNUM</td>
<td>OPTI</td>
<td>F-NUMBER OF OBJECTIVE LENS SYSTEM</td>
</tr>
<tr>
<td>FD</td>
<td>ELECTRON</td>
<td>UPPER CUTOFF FREQ. USED AS NORMALIZATION POINT FOR POWER SPECTRA (S(FD)=1.0) (KHZ)</td>
</tr>
<tr>
<td>NAME</td>
<td>GROUP</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>FOC</td>
<td>OPTI</td>
<td>FOCAL LENGTH OF OBJECTIVE LENS SYSTEM (INCHES)</td>
</tr>
</tbody>
</table>
L**

PG FCMN

FRiEQ. (CYC./MIN.)--CORRESPONDS TO X0, Y0, XTV, YTV, XNL, E YML.

C**

FOU FLHZ

FREQ. (10**4(HZ))--CORRESPONDS TO X0, Y0, X., E, & XN.

C**

FK SCAN

FRAME RATE OF SCANNER (FRAMES/SEC.)

C**

FSRA DElS

3-DB POINT ON DETECTOR RESPONSE ROLLOFF (10**4(BHZ))

C**

MFUV OPTI

HORIZONTAL FIELD OF VIEW (DEGREES)

C**

IDRTH KANG

RANGE INCREMENTS FOR RECOG. DATA (CALCULATED)

C**

IDRLX KANG

RANGE INCREMENTS FOR DETEC. DATA (CALCULATED)

C**

INOAX RANG

MAXIMUM DETEC. RANGE REQUIRED (METERS)

C**

IRDIN RANG

MINIMUM DETEC. RANGE REQUIRED (METERS)

C**

INMAX RANG

MAXIMUM RECOG. RANGE REQUIRED (METERS)

C**

INMIN RANG

MINIMUM RECOG. RANGE REQUIRED (METERS)

C**

ISTATE ENVI

ATMOSPHERIC CONDITION FLAG--1.0=FOG W/ 1 KM, VIS.; 3.0=FOG W/ 200 M, VIS.; 4.0=FOG W/ 60 M, VIS.; 5.0=LIGHT RAIN W/ 12 KM, VIS.; 6.0=MOD, RAIN W/ 6 KM, VIS.; 7.0=HEAVY RAIN W/ 2 KM, VIS.; 8.0=VERY HEAVY RAIN W/ 500 M, VIS.; 30.0=BEHER'S LAW SCATTERING; 40.0=BLER'S LAW ALG.

C**

JNLNT ----

POINT OPTION:--

C**

KKK DISP

TYPE OF DISPLAY--0.0=CRT WITH GAUSSIAN SPOT SIZE; 1.0=LED WITH SIN X/PK Spot SIZE; 2.0=NO DISPLAY

C**

LNUM TANG

NUMBER OF ITERATIONS OF TARGET DELTA T

C**

LNUM DELTA

SYSTEM NOISE LIMITATION--0.0=DETECTOR NOISE LIMITED (0* MUST INCLUDE COLD SHIELD); 1.0=SHOT NOISE (BLIP) LIMITED 2.0=WHITE NOISE APPROXIMATION

C**

OUTPUT DBNC

DISPLAY BRIGHTNESS CURVE (FT. LAMBERTS)--CORRESPOND TO XINPUT

C**

OVERSC SCAN

OVERSCAN RATIO

C**

PKU FDKP

PHOT. Subtract FROM FIELD DATA FOR RECOG.---CORRESPOND TO XNUM & ANMB

C**

RM ENVI

RELATIVE HUMIDITY (%)--OMITTED OR =20.0 IF SIGMA AND WAVE ARE USED

C**

NAME GROUP

DESCRIPTION

C**

AVIS ENVI

VISIBILITY RANGE (KM.)--OMITTED IF SIGMA AND WAVE ARE USED

C**

S NPSF

NOISE POWER SPECTRA POWER (10**4 V/HZ**)--CORRESPOND TO F

C**

SIGMA SCAT

ATMOSPHERIC SCATTERING OR TRANSMISSION COEFFICIENTS--

C**

OR TOTAL CORRESPOND TO WAVE

C**

SNR SNAJ

SIGNAL TO NOISE RATIO TO RECOG. 4-BAR PATTERN--CURRENTLY DEFINED FROM EXPERIMENTAL WORK AS 2.25
--CORRESPONDS TO FQ

XSIGLS. STAB  EXP. CONSTANT TO GIVE GAUSSIAN FORM TO VIBRATION MTF--
(XSIGL)*2*(SIGMA X)**2 WHERE SIGMA X IS STD. DEV. OF
VIBRATION SPECTRUM IN X-DIRECTION

XTV  MNTK MTF OF VIDICON IN X-DIRECTION--CORRESPONDS TO FQ

XMT  MRTL MEASURED VALUES OF MTF * TO BE INPUT

MRT2  MRTL ON 2 CARDS IN VALUES OF MRT*0.001

C... COO

XY  ELIE X-DIMENSION OF LED IN EU MULTIPLEXER (MRAJ)

XYL  ELIE Y-DIMENSION OF LED IN EQ MULTIPLEXER (MRAJ)

YA  DISP Y-DIMENSION OF LED IN DISPLAY (MRAJ)

YO  DROY DETECTOR ROLLOFF MTF IN Y-DIRECTION IF NOT NORMAL RC

ROLLOFF--CORRESPONDS TO FQ

YL  LSSY MTF OF LINE-OF-SIGHT STABILIZATION IN Y-DIRECTION--CORRESPONDS

 TO FQ

YO  MTOY MTF OF OPTICS IN Y-DIRECTION (*0 IF DIFFRACTION-LIMITED)

--CORRESPONDS TO FQ

YSIGLS STAB  EXP. CONSTANT TO GIVE GAUSSIAN FORM TO VIBRATION MTF--

(XSIGL)*2*(SIGMA Y)**2 WHERE SIGMA Y IS STD. DEV. OF

VIBRATION SPECTRUM IN Y-DIRECTION

YTV  MNTY MTF OF VIDICON IN Y-DIRECTION--CORRESPONDS TO FQ


REAL NAME

DIMENSION T(10)

DIMENSION PRO(10),KNOH(10),KNOU(10),BETA(10)

DIMENSION FQG(10),PQ(10)

DIMENSION XX(10),XY(10),X3E(10),X3A(10)

DIMENSION XV(10),XY(10),XTV(10),YTV(10),XMLA(10),YML(10)

DIMENSION SSSTAR(10),XLMBA(10)

DIMENSION S3(10),SS(10),FJ(10),PS(10)

DIMENSION DS3(10),DS(10),XMLBA(10),XMLM(10)

DIMENSION OUTPUT(10),INPUT(10)

DIMENSION WAVE(9),WAVE(9),WAVE(9),SIGMA(9)

DIMENSION R(63)

DIMENSION DPRO(10),DNUM(10),DDETA(10),DFQG(10),DX(10),DY(10)

IDXY(10),DXY(10),DFQG(10),DXD(10),DYD(10),DXTV(10),DYTV(10),XMLA(10)
DATA DYD/10*1.0/
DATA DXTV/10*1.0/
DATA UTYV/10*1.0/
DATA DXML/10*1.0/
DATA DYM/10*1.0/
DU 950 I=1,10
PRQ(I)=PROH(I)
RNM8(I)=DAXNM8(I)
DNUM(I)=DAXNUM(I)
BETA(I)=DBETA(I)
FQ(I)=DFQ(I)
XD(I)=DXD(I)
YD(I)=DYD(I)
AE(I)=DXE(I)
XD(I)=DXB(I)
FD(I)=DFD(I)
XU(I)=DXU(I)
YO(I)=DYO(I)
XTV(I)=DXTV(I)
YTV(I)=DYTV(I)
XML(I)=DXML(I)
YML(I)=DYML(I)
950 CONTINUE
T:JAC=12.0
AIHTMP=15.0
H=45.99
IPHINT=0
ISTATE=0
HV=32.3
TA=0.95
DPEAK=DPEAK3
XLA=XLA3
DU VO J=1,10
S(I)=SI(J)
XOFJ(J)=DSJ(J)
XLMHA(J)=XLMHA3(J)
9610 F(J)=F3(J)
WAVE(J)=R(SI(J))
DO 2511 J=1,7
2511 WAVE(J+2)=WAVE(J)
WAVE=5.0
WAVE=3.0
ADJ=3.0
F0=10000.0
CUTOFF=10.0
SN=2.25
C**
C**
C**
1000 CONTINUE
IF(IAPL, ,NC. 1)GO TO 10
C* INPUT INACTIVE*
20 MTIE(B,1020)
1020 FNMAT(D2M ENTER DMU FOR USAGE INSTRUCTION OR CONTROL CARD ;
111(A4*1,1,1111))
READ(5,1030)NAM1,JFLAG,PRINT
1030 FNMAT(A4,1111)
GO TO 40
10 READ(3,1010)NAM1,JFLAG,PRINT
1010 FNMAT(A4,6X,11,9,11)
40 IF(NAM1+EJXH(I))GO TO 2000
IF(NAM1=0001)GO TO 3000
C**
CALCULATED INPUTS

DIAM=FOC/FNUM8
FMAX=1.0/DELTAX
FMAX=1.0/DELTA Y
IELR=(IMAX-IRMIN)/9
IDELX=(IRMAX-IRMIN)/9
IF(INAM1. EQ. R(0)) GOTO 5910
IF(INAM1. EQ. R(1)) GOTO 3140
IF(INAM1. EQ. R(2)) GOTO 3140
IF(INAM1. EQ. R(3)) GOTO 3140
IF(INAM1. EQ. R(4)) GOTO 3140
IF(INAM1. EQ. R(5)) GOTO 3140
IF(INAM1. EQ. R(6)) GOTO 3140
IF(INAM1. EQ. R(7)) GOTO 3140
IF(INAM1. EQ. R(8)) GOTO 3140
IF(INAM1. EQ. R(9)) GOTO 3140
5910 FORMAT(1X,7HEXOR HAS BEEN MADE ON INPUT CARD-DOES NOT CONFORM TO
1 PROPER CONVENTION/) CALL EXIT

INPUTS WITH F10.3 FORMAT (FQIN)

2000 CONTINUE
IF(IAFLG.EQ.1) WRITE(6,5921)
5922 FORMAT(12H8NEXT INPUT:)
READ(5,2010)T1,T2,(T(I),I=1,7)
2010 FORMAT(A4,2X,A4,7F10.3)
IF(IAFLG.NE.1) GOTO 2002
IF(T1.EQ.R(62)) GOTO 1000
DO 2004 =2,10
IF(T1.EQ.R(1)) GOTO 2014
2004 CONTINUE
DO 2006 =12,13
IF(T1.EQ.R(1)) GOTO 2014
2006 CONTINUE
DO 2008 =49,54
IF(T1.EQ.R(1)) GOTO 2014
2008 CONTINUE
DO 2012 =57,59
IF(T1.EQ.R(1)) GOTO 2014
2012 CONTINUE
WRITE(6,5920)
GO TO 2000
2014 WRITE(6,5921)
5921 FORMAT(2H6>.)
IF(IAFLG.NE.1) GOTO 2025
2002 - (T1.EQ.R(1)) GOTO 2025
IF(T1.EQ.R(2)) GOTO 2020
IF(T1.EQ.R(3)) GOTO 2030
IF(T1.EQ.R(4)) GOTO 2040
IF(T1.EQ.R(5)) GOTO 2050
IF(T1.EQ.R(6)) GOTO 2060
IF(T1.EQ.R(7)) GOTO 2070
IF(T1.EQ.R(8)) GOTO 2080
IF(T1.EQ.R(9)) GOTO 2090
IF(T1.EQ.R(10)) GOTO 2110
IF(T1.EQ.R(11)) GOTO 2120
IF(T1.EQ.R(12)) GOTO 2130
IF(T1.EQ.R(13)) GOTO 2140
IF(T1.EQ.R(14)) GOTO 2150
IF(T1.EQ.R(15)) GOTO 2160
IF(T1.EQ.R(16)) GOTO 2170
IF(T1.EQ.R(17)) GOTO 2180
IF(T1.EQ.R(18)) GOTO 2190
IF(T1.EQ.R(19)) GOTO 2200
IF(T1.EQ.R(20)) GOTO 2210
IF(T1.EQ.R(21)) GOTO 2220
IF(T1.EQ.R(22)) GOTO 2230
IF(T1.EQ.R(23)) GOTO 2240
IF(T1.EQ.R(24)) GOTO 2250
IF(T1.EQ.R(25)) GOTO 2260
IF(T1.EQ.R(26)) GOTO 2270
IF(T1.EQ.R(27)) GOTO 2280
IF(T1.EQ.R(28)) GOTO 2290
IF(T1.EQ.R(29)) GOTO 2300
IF(T1.EQ.R(30)) GOTO 2310
IF(T1.EQ.R(31)) GOTO 2320
IF(T1.EQ.R(32)) GOTO 2330
IF(T1.EQ.R(33)) GOTO 2340
IF(T1.EQ.R(34)) GOTO 2350
IF(T1.EQ.R(35)) GOTO 2360
IF(T1.EQ.R(36)) GOTO 2370
IF(T1.EQ.R(37)) GOTO 2380
IF(T1.EQ.R(38)) GOTO 2390
IF(T1.EQ.R(39)) GOTO 2400
IF(T1.EQ.R(40)) GOTO 2410
IF(T1.EQ.R(41)) GOTO 2420
IF(T1.EQ.R(42)) GOTO 2430
IF(T1.EQ.R(43)) GOTO 2440
IF(T1.EQ.R(44)) GOTO 2450
IF(T1.EQ.R(45)) GOTO 2460
IF(T1.EQ.R(46)) GOTO 2470
IF(T1.EQ.R(47)) GOTO 2480
IF(T1.EQ.R(48)) GOTO 2490
IF(T1.EQ.R(49)) GOTO 2500
IF(T1.EQ.R(50)) GOTO 2510
IF(T1.EQ.R(51)) GOTO 2520
IF(T1.EQ.R(52)) GOTO 2530
IF(T1.EQ.R(53)) GOTO 2540
IF(T1.EQ.R(54)) GOTO 2550
IF(T1.EQ.R(55)) GOTO 2560
IF(T1.EQ.R(56)) GOTO 2570
IF(T1.EQ.R(57)) GOTO 2580
IF(T1.EQ.R(58)) GOTO 2590
IF(T1.EQ.R(59)) GOTO 2600
IF(T1.EQ.R(60)) GOTO 2610
IF(T1.EQ.R(61)) GOTO 2620
IF(T1.EQ.R(62)) GOTO 2630
78
WRITE(6,5920)
5920 FORMAT(1X,501AN INPUT SYSTEMS CARD FOR FORI HAS NOT BEEN RECOGNIZE
1D/)
CALL EXIT

C**
C**
C**
2020 WAV*1=T(1)
WAVE2=T(2)
GO TO 2000
C**
C**
C**
2025 CJNTINUE
FNUMB=T(1)
FOC=T(2)
TO=T(3)
ASLUR=T(4)
XLAMB=T(5)
IF(XLAMB.EQ.1.E0)XLAMB=(WAVE1+WAVE2)/2.E0
IF(XLAMB.LE.5.E0.AND.XLAMB.GE.3.E0)GO TO 2000
IF(XLAMB.LE.1.E0.AND.XLAMB.GE.8.E0)GO TO 2000
WRITE(6,5930)XLAMB
C**
C**
C**
5930 FORMAT(1X,///,T30,6HYOUR INPUT VALUE OF XLAMB IS 
IF10.3,20X,3H AND IS NOT INSIDE THE SPECIFIED RANGE///,
CALL EXIT

C**
C**
C**
2030 DELTAX=T(1)
DELTAY=T(2)
XN=T(3)
DISC=T(4)
GRTEA=T(5)/1000.E0
QPEAK=T(6)
FO=1000.0*T(7)
GO TO 2000
C**
C**
C**
2040 FSTART=T(3)*1000.0
MUM=IFIX(T(2))
ANGLE=T(1)
GO TO 2000
C**
C**
C**
2050 FH=T(1)
XNSC=T(2)
OVERSC=T(3)
GO TO 2000
C**
C**
C**
2060 CUTOFF=T(1)
FELECT=T(2)
XY=T(3)
XYL=T(4)
KK=T(5)
FM*AF=1000.0*T(6)
GO TO 2000
C**
C**
C**
```
2070 KKK=IFIX(T(1))
    BRITE=T(2)
    XX=T(3)
    YR=T(4)
    G0 TO 2000

2080 XSIGLS=T(1)
    YSIGLS=T(2)
    G0 TO 2000

2090 SNH=T(1)
    G0 TO 2000
2110 LYETM=T(1)
    G0 TO 2000

2120 HFQV=T(1)
    VFQV=T(2)
    XMAG=T(3)
    FACT=T(4)
    XMNT=T(5)
    G0 TO 2000

4030 AIRTMP=T(1)
    RH=T(2)
    VRI=T(3)
    SSTATE=IFIX(T(4))
    IF(KINT=T(5)
    IF(RVIS<=0)0)RVIS=23.0
    Z1=1+0
    G0 TO 2000

4040 TA=T(1)
    TBAC=T(2)
    G0 TO 2000

4050 SIGMA(1)=T(1)
    SIGMA(2)=T(2)
    DO 4051 J=1,7
4051 SIGMA(J+1)=T(J)
    Z2=1+0
    G0 TO 2000

4060 WAVE(1)=T1
    WAVE(2)=T2
    DO 4061 J=1,7
4061 WAVE(J+2)=T(J)
```
GO TO 2000
C*  
C*  
4070 XLTAR=T(1)
   XMTAR=T(2)
   DETEMP=T(3)
   TBAC=T(4)
   IF(TBAC.EQ.0.0)TBAC=12.0
   GO TO 2000
C*  
C*  
4080 IRMIN=IFIXT(1))
   IRMAX=IFIXT(2))
   IRDIN=IFIXT(3))
   IRDA=IFIXT(4))
   GO TO 2000
C*  
C*  
RANGE REQUIREMENTS
C*  
C*  
INPUT VALUES FOR MEASURED MRT
C*  
C*  
3240 DO 3245 J=1,7
   3245 XMRT(J)=T(J)*0.001
   Z=1.0
   GO TO 2000
C*  
C*  
INPUTS WITH F3.2 FORMAT (FUK2)
C*  
C*  
3000 CONTINUE
   IF(IAFLG.EQ.1)WRITE(6,5922)
      READ(5,3010)T1,T2,T1,T1,1*10.10)
   3010 FORMAT(A+4,A+4,2F5.2)
      IF(IAFLG.EQ.1)GO TO 3002
      IF(TI.EQ.R(62))GO TO 1900
      DO 3004 I=20,41
         IF(TI.EQ.R(I))GO TO 3006
   3004 CONTINUE
      WRITE(6,5940)
      GO TO 3000
   3006 WRITE(6,5921)
      CALL READF(Y)
   3002 IF(TI.EQ.R(20))GO TO 3020
      IF(TI.EQ.R(21))GO TO 3030
      IF(TI.EQ.R(22))GO TO 3040
      IF(TI.EQ.R(23))GO TO 3050
      IF(TI.EQ.R(24))GO TO 3060
      IF(TI.EQ.R(25))GO TO 3070
      IF(TI.EQ.R(26))GO TO 3080
      IF(TI.EQ.R(27))GO TO 3090
      IF(TI.EQ.R(28))GO TO 3100
      IF(TI.EQ.R(29))GO TO 3110
      IF(TI.EQ.R(30))GO TO 3120
      IF(TI.EQ.R(31))GO TO 3130
      IF(TI.EQ.R(32))GO TO 3140
C*  
C*  
81
IF(TI.EQ.R(33))GO TO 3150
IF(TI.EQ.R(34))GO TO 3160
IF(TI.EQ.R(35))GO TO 3170
IF(TI.EQ.R(36))GO TO 3180
IF(TI.EQ.R(37))GO TO 3190
IF(TI.EQ.R(38))GO TO 3200
IF(TI.EQ.R(39))GO TO 3210
IF(TI.EQ.R(40))GO TO 3220
IF(TI.EQ.R(41))GO TO 3230
IF(TI.EQ.R(62))GO TO 1000
WRITE(6,5940)
5940 FORMAT(#x,54MAN INPUT SYSTEMS CARD FOR FOR2 HAS NOT BEEN RECOGNIZE)
10/
CALL EXIT
C**
C**
3020 DO 3021 J=1,10
3021 FQ0(J)=T(J)
GO TO 3000
C**
C**
3030 DO 3031 J=1,10
3031 XD(J)=T(J)
GO TO 3000
C**
C**
3040 DO 3041 J=1,10
3041 XD(J)=T(J)
GO TO 3000
C**
C**
3050 DO 3051 J=1,10
3051 KD(J)=T(J)
GO TO 3000
C**
C**
3060 DO 3061 J=1,10
3061 XD(J)=T(J)
GO TO 3000
C**
C**
3070 DO 3071 J=1,10
3071 KD(J)=T(J)
GO TO 3000
C**
C**
3080 DO 3081 J=1,10
3081 KD(J)=T(J)
GO TO 3000
C**
C**
3090 DO 3091 J=1,10
3091 XD(J)=T(J)
GO TO 3000

82
C**
C**
3100 DO 3101 J=1,10
3101 XT(V(J))=T(J)
    GO TO 3000
C**
C**
3110 DO 3111 J=1,10
3111 YT(V(J))=T(J)
    GO TO 3000
C**
C**
3120 DO 3121 J=1,10
3121 XM(L(J))=T(J)
    GO TO 3000
C**
C**
3130 DO 3131 J=1,10
3131 YM(L(J))=T(J)
    GO TO 3000
C**
C**
3140 DO 3141 J=1,10
3141 F(J)=T(J)
    GO TO 3000
C**
C**
3150 DO 3151 J=1,10
3151 S(J)=T(J)
    GO TO 3000
C**
C**
3160 DO 3161 J=1,10
3161 XLMSA(J)=T(J)
    GO TO 3000
C**
C**
3170 DO 3171 J=1,10
3171 UDSTAR(J)=T(J)
    GO TO 3000
C**
C**
3180 DO 3181 J=1,10
3181 XI NPUT(J)=T(J)
    GO TO 3000
C**
C**
3190 DO 3191 J=1,10
3191 OUTPUT(J)=T(J)
    GO TO 3000
C**
C**
NOISE POWER SPECTRA FREQ.
3141
DO
J=1,10
F(J)=T(J)
GO TO 3000
C**
C**
NOISE POWER SPECTRA POWER
3151
DO
J=1,10
S(J)=T(J)
GO TO 3000
C**
C**
LAMBIAS FOR D*
3161
DO
J=1,10
XLMSA(J)=T(J)
GO TO 3000
C**
C**
NORMALIZED D*
3171
UDSTAR(J)=T(J)
GO TO 3000
C**
C**
DISP. DELTA T INPUT
3181
XI NPUT(J)=T(J)
GO TO 3000
C**
C**
DISP. BRIGHTNESS OUTPUT
3191
OUTPUT(J)=T(J)
GO TO 3000
C**
C**
FREQ. FOR 3-CYCLE RECOS.
C
3200 DO J201 J=1,10
J201 XNUM(J)=T(J)
GU TO 3000
C
FREQ. FOR 4-CYCLE RECOG.
C
3210 DO J211 J=1,10
3211 XNUM(J)=T(J)
GU TO 3000
C
FREQ. DISTRIBUTION RECOG. PROB.
C
3220 DO J221 J=1,10
3221 PN(J)=T(J)
GU TO 3000
C
FREQ. FOR 1-CYCLE DETECTION
C
3230 DO J231 J=1,10
3231 DATA(J)=T(J)
GU TO 3000
C
DEFAULT INPUTS FOR GENERAL SYSTEM
C
C
PRINTOUT FORMATS FOR INPUT DATA
FOR 1 INPUTS
C
C
5006 CONTINUE
IF (IAFLG .GT. 0) WRITE(6,5006)
5006 WRITE(6,5006)

5010 FNUMAT(IH) = 1000000 DATA/"
WRITE(6,5031) WAVE1, WAVE2
5031 FORMAT(IH =) YUHR SPECTRAL BAND IS, F10.3, 0H 10, F10.3;
11 IM M1100.000"
WRITE(6,5041) OPTICS/
5041 FORMAT(IH =) OPTICS/
3.0 J0HJIAKETH / F10.3, 11M INCHES/
4 J0HJ-NUMBER / F10.3/
5 J0HFUCAL LENGTH / F10.3, 110 M INCHES/
7 J0HAMA, OPTICAL TRANSMISSION / F10.3/
9 J0HAWAVELENGTH FUN DOPHACTI ON / F10.3, 11M M1100.000/
3 J0HULOMETRIC BLUER SPLIT SIZE / F10.3, 11M M1100.000/
WRITE(6,5051) DELTAX, QLMTY, AX, 13, SHTAD, DPEAK, FC, ANGLE
5051 FORMAT(IH =) BDECTOR/
5 J0HORIZONTAL IFQV / F10.3, 11M M1100.000/
6 J0HVERTICAL IFQV / F10.3, 11M M1100.000/
4 J0HDTECTORS IN PARALLEL / F10.00/
3 J0HDTECTORS IN SERIES / F10.00/
2 J0H-DTECTORS SIZE / F10.3, 11M M1100.000/
6 J0HPEAK D* 724H (1B.1B) CM-SORT(HZ)/ WATT /
9 J0HMEASURING FREQUENCY UP D* / F10.3, 11M M1100.000/
1 J0HCOLED SHIELD ANGLE / F10.3, 11M M1100.000/
IF (NUM.EQ.0) WRITE(6,5053)
84
IF (IFLAG.EQ.4) WRITE(6,5085)
IF (IFLAG.EQ.2) WRITE(6,5087)
5053 FORMAT(1H,T6,30H, LIMITING NOISE )
5055 FORMAT(1H,T6,30H LIMITING NOISE)
5057 FORMAT(1H,T6,30H LIMITING NOISE)
IDXNATION)
WRITE(6,5059) ISTAR
5059 FORMAT(1H,T6,30H, DETECTOR RESPONSE, 3-08 POINT)
12///)
IF (IFLAG.EQ.1) WRITE(6,5060)
WRITE(6,5061) VSX, OVERSC.
5061 FORMAT(1H,T7SCANNER/)
1/ T6,30H FRAME RATE )10,3,F1H, FRAME/SEC.
2 T6,30HSCAN EFFICIENCY )10,3/F1H, Efficiency/
3 T6,30HOVERSCAN RATIO )10,3/F1H, Ratio/)
WRITE(6,5071) CRT AREA,ELECT, XY, XYL, XX, FNMAX
5071 FORMAT(1H,T1H, ELECTRONICS/)
1 T6,30HPREAMP, LOW FREQ 3-08 CUT-ON )10,3/F1H, LIMIT /
2 T6,30HAMPLIFIER, 3-08 POINT )10,3/F1H, LIMIT/
3 T6,30HEO LED WIDTH )10,3/F1H, LIMIT /
7 T6,30HEO L ED LENGTH )10,3/F1H, LIMIT /
4 T6,30HAPERTURE CORRECTION AMPLITUDE )10,3/F1H, LIMIT /
5 T6,30HAPERTURE, CORRECTION FREQUENCY )10,3/F1H, LIMIT/)
IF (IFLAG.EQ.1) WRITE(6,5080)
WRITE(6,5081)
5081 FORMAT(1H,T7DS, DISPLAY/)
IF (KKK.EQ.0) WRITE(6,5083) XA, YA, BR TIE
IF (KKK.EQ.1) WRITE(6,5086) XA, YA, BR TIE
5083 FORMAT(1H,T6,30HTYPE)
1 T6,30HX SPOT SIZE )10,3/F1H, LIMIT /
2 T6,30HY SPOT SIZE )10,3/F1H, LIMIT /
3 T6,30H, H AVERAGE BRIGHTNESS )10,3/F1H, LIMIT /
4/)
5086 FORMAT(1H,T6,30HTYPE)
1 T6,30HX LED SIZE )10,3/F1H, LIMIT /
2 T6,30HY LED SIZE )10,3/F1H, LIMIT /
3 T6,30H AVERAGE BRIGHTNESS )10,3/F1H, LIMIT/
4/)
5089 FORMAT(1H,T6,30HTYPE)
IF (IFLAG.EQ.4) WRITE(6,7000)
WRITE(6,5092) PFOV, VF0V, XMAX, FACT, XNET
5092 FORMAT(1H,THY STEM/)
1 T6,30HORIZONTAL PFOV.. )10,3/F1H, DEGREES/
2 T6,30HORIZONTAL VFOV.. )10,3/F1H, DEGREES/
3 T6,30HORIZONTAL MAGNIFICATION )10,3/F1H, DEGREES/
4 T6,30HORIZONTAL EQUAL, DELTA T )10,3/F1H, DEGREES/
5 T6,30HORIZONTAL, EQUIL, DELTA T )10,3/F1H, DEGREES/
IF (SIGLS.EQ.0.0 .AND. SIGLS.EQ.0.0 .AND. XML(1).EQ.0.0. .AND. XML(10).EQ.0.0. AND. XML(10).EQ.0.0.) WRITE(6,5091) XSIGLS, YSIGLS
5091 FORMAT(1H,13H, STABILIZATION/)
1 T6,30HSYSTEM STATE )10H, UNSTABILIZED/
2 T6,30H VIBRATION CONSTANT )10,3/F1H, DEGREES/
GO TO 5100
5095 WRITE(6,5095)
5096 FORMAT(1H,13H, STABILIZATION/)
1 T6,40HX VIBRATION CONSTANT )0,00/
2 T6,40HY VIBRATION CONSTANT )0,00/
5100...
5100 WRITE(6,5101) EVETM, SHR
5101 FORMAT('U15 STANDARD INPUTS/
     1 TIME INTEGRATION TIME
     2 THIRD THRESHOLD SIGNAL/NOISE
     IF (IAFLG NE 1) WRITE(6,5100)
WRITE(6,5400)
5400 FORMAT('U12 ATMOSPHERIC PARAMETERS/
     IF (RVIS LE 1.0 AND RVIS GT 10.0) WRITE(6,5402)
     IF (RVIS LE 23.0 AND RVIS GT 10.0) 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)
     WRITE(6,5401) RVIS, RH, AIRTMP
5401 FORMAT( 1 T3.30HVISIBILITY RANGE
            2 T3.30HRELATIVE HUMIDITY
            3 T3.30HAR TEMPERATURE
            GO TO 5450
5410 CONTINUE
     IF (STATE NE 1.0) GO TO 5412
     RVIS=12.0
     WRITE(6,5411)
WRITE(6,5401) RVIS, RH, AIRTMP
5411 FORMAT('T3.30HCONDITION
            GO TO 5450
5412 CONTINUE
     IF (STATE NE 2.0) GO TO 5414
     RVIS=6.0
     WRITE(6,5413)
WRITE(6,5401) RVIS, RH, AIRTMP
5413 FORMAT('T3.30HCONDITION
            GO TO 5450
5414 CONTINUE
     IF (STATE NE 3.0) GO TO 5416
     RVIS=2.0
     WRITE(6,5415)
WRITE(6,5401) RVIS, RH, AIRTMP
5415 FORMAT('T3.30HCONDITION
            GO TO 5450
5416 CONTINUE
     IF (STATE NE 4.0) GO TO 5418
     RVIS=0.5
     RH=100.0
     WRITE(6,5417)
WRITE(6,5401) RVIS, RH, AIRTMP
5417 FORMAT('T3.30HCONDITION
            GO TO 5450
IF (STATE.EQ.31) WRITE(6,5441)
5441 FORMAT(1X,'YOU ARE MISSING THE SCAT CARD!')
IF (STATE.EQ.41) WRITE(6,5442)
5442 FORMAT(1X,'YOU ARE MISSING THE TOTAL CARD!')
IF (STATE.EQ.41) WRITE(6,5419)
5419 FORMAT(1X,'YOUR STATE IS NOT RECOGNIZED')
IF (IAFLAG.EQ.1) GO TO 1030
CALL EXIT

5420 CONTINUE
IF (IAFLAG.EQ.1) WRITE(6,7000)
WHITE(6,5400)
WRITE(6,5421)

5421 FORMAT(T6,13MCONDITION)
1 JHSEEK(1) LAW ATTENUATION CALCULATION */
WHITE(6,5422)(SIGMA1),WAVE(1),I=1,9)
5422 FORMAT(T6,2HMUAT TRANSMISSION KM=10X,
12H*WAVELENGTH (MICRUNS) /*(113,F7.1,27X,F7.3))
GO TO 390

5430 CONTINUE
IF (IAFLAG.EQ.1) WRITE(6,7000)
WHITE(6,5400)
WRITE(6,5431)RH,AIRTMP

5431 FORMAT(/:
1 T0=30HUMAIVATE HUMIDITY ,F10.3,11H PERCENT/
2 T0=30HAIR TEMPERATURE ,F10.3,13H DEGREES C/
WHITE(6,5432)

5432 FORMAT(T6,13MCONDITION)
1 JHSEEK(1) LAW SCATTERING HUM CALCULATION *)
WHITE(6,5433)(SIGMA1),I=1,9),WAVE(1),I=3,9)
5433 FORMAT(/1M ,T0=30HSCATTERING TRANSMISSION PER KILOMETER:/*110,7F7
13H /T0=21HMWAVELENGTH (MICRUNS) /*(113,F7.1,27X,F7.3))
GO TO 390

5450 CONTINUE
IF (IAFLAG.EQ.1) WRITE(6,7000)
WHITE(6,5481)XLTAX,XTAX,TEMPEXT

5481 FORMAT(T1H ,1MXTARGET & BACKGROUND/,
1 T0=30HTARGET LENGTH ,F10.3,10H METERS/
2 T0=30HTARGET WIDTH ,F10.3,10H METERS/
3 T0=30HTARGET DELTA T ,F10.3,13H DEGREES C/
6 T0=30HBACKGROUND TEMPERATURE ,F10.3,13H DEGREES C/
WHITE(6,5491)RMIN,RMAX,DELXI,INDX1,INDEX2

5491 FORMAT(T1H ,1MXRANGE REQUIREMENTS/,
1 T0=30HRMIN, REQUIRED RANGE FOR RECOG,,110,10H METERS/
2 T0=30HRMAX REQUIRED RANGE FOR RECOG,,110,10H METERS/
3 T0=30HH RANGE INCREMENTS FOR RECOG,,110,10H METERS/
4 T0=30HRMIN REQUIRED RANGE FOR DETEC,,110,10H METERS/
5 T0=30HRMAX REQUIRED RANGE FOR DETEC,,110,10H METERS/
6 T0=30HR RANGE INCREMENTS FOR DETEC,,110,10H METERS/
)

C##
C## FOR2 INPUTS
C##
IF (IAFLAG.EQ.1) WRITE(6,5010)
IF (IAFLAG.EQ.1) WRITE(6,7000)
WHITE(6,5211)FQQ,XYD,XE,XB
WHITE(6,5201)FQQ,XYD,KTV,YTV,XML,XML

5211 FORMAT(T1H ,14HTEMPORAL MTF'S/,
1 IM ,23H mũ (LOG MEAN), 10F5.2/
1 IM ,23H------------------ ,10(3H ----/)
4 IM ,22HDETECT ROLL OFF MTF (X) ,10F5.2/
3 IM ,22HDETECT ROLL OFF MTF (Y) ,10F5.2/
4 IM ,22HLOCATION MTF ,10F5.2/
5 IM ,22HBOOST MTF ,10F5.2/)
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 COCO600
C AND ONE FOR THE IBM360/60. DATA IS READ INTO THE T ARRAY.
C
C THIS IS THE COCO600 VERSION. IT USES THE FORMAT
C FREE FIELD INPUT WHICH IS AVAILABLE UNDER SCOPE 4.2.
C
C DIMENSION T(10)
C
C READ(3,1030)UK
C IF (UK .EQ. H(67)) GO TO 1000
C IF (UK .NE. H(66)) GO TO 9001
C
C CONTINUE
C RETURN
C END

5201 FORMAT(1H *24HSpatial Components MTF */
1 1H *22HFREU (CYC./NHAD.)* 0F5.2/
1 1H *22H---*24HSPATIAL COMPONENTS MTF */
2 1H *22H---*24HSPATIAL COMPONENTS MTF */
3 1H *22H---*24HSPATIAL COMPONENTS MTF */
4 1H *22H---*24HSPATIAL COMPONENTS MTF */
5 1H *22H---*24HSPATIAL COMPONENTS MTF */
6 1H *22H---*24HSPATIAL COMPONENTS MTF */
7 1H *22H---*24HSPATIAL COMPONENTS MTF */
IF (IAFLG 6EQ. 1) WRITE(6,7000)
WRITE(6,5221)F.S
5221 FORMAT(1H *37HNoise Power Spectrum (Volts/SORT(HZ))/
1 1H *18H---*24HLG Hertz)* 1F6.2,6F5.2/
2 1H *18H---*24HTIMES 1E-9) 1F6.2,6F5.2/
WRITE(6,5231)XLMB,QLDSRAN
5231 FORMAT(1H *30H# of Detector (CH.*SORT(HZ.))/WATT//
1 1H *22H---*24HMCRUNS ) 10F5.2/
2 1H *22H---*24HTIMES 1E10) 10F5.2/
IF (IAFLG 6NE. 1) WRITE(6,5U10)
WRITE(6,5251)HBT,AXMB,AXNUM,PRO
5251 FORMAT(1H *35HDETECTION & RECOGNITION PROBABILITY DENSITIES//
1 1H *18HDETECTION FREQ. 1F6.2,6F5.2/
2 1H *18H---*24HBEST RECOG. FREQ. 1F6.2,6F5.2/
3 1H *18H---*24HOREST RECOG. FREQ. 1F6.2,6F5.2/
3 1H *18H---*24HPROBABILITY 1F6.2,6F5.2/
IF (IAFLG 6NE. 1) GO TO 9000
9001 WRITE(6,7005)
7005 FORMAT(34F7.1,5H 1F11.17/)
15TH ENTER #FIX TO CORRECT ANY BAD ENTRIES OR #GOB TO BEGIN
213HCOMPUTATIONS)
READ(3,1030)UK
IF (UK .EQ. H(67)) GO TO 1000
IF (UK .NE. H(66)) GO TO 9001
9000 CONTINUE
RETURN
END
SUBROUTINE MHTINP(RVIS, RANGE, AIRTMP, 
KH, MAVE1, MAVE2, IPRINT, IJK, 
ISTATE, AFCRL, PRO, XNUM, TBAC, XNMA, ULFA, I, KK)

REAL ITRAN

DIMENSION F(T(20)), XXXRT(20), WUV(20), ITRAN(J(1)), 
I AFCRL(161), ITRAN(161), OUT(50), XCHR(50), SO(50), 
MAVE(9), SIGMA(9), 
KPH(50), PRO(10), ULFA(10), XNUM(10), XNUM(10)

DIMENSION XINPUT(10), OUTPUT(10)

DIMENSION TS(50), SS(50), XFR(50), DRTX(50)

COMMON/NAMES/XK, LWF(10), S(10), XNET, DLTAK, ULLTAK, YEIM, FNR, FQV,
1, WQV, XMAG, XMAG, DMSC, BRITE, SHTAU, US, TA, T2, ANGLE, MOM, RSTAR,
2, XLAMW, FMNUM, FC, XX, FMAX, XSLG, XSIGLS, YSIGLS, XAYA, KKK+
3, OTA, VEL, REFLECT

COMMON /SPCATM/ SHEL, SIGMA

COMMON/NAMES/ KXKUNT, XMAG, PSTAR, FELECT

COMMON/NAMES/XKR, DOUT, TS, SS, SS, XFR, DRTX, OLET, T, FT, XXXRT,
COMMON/NAME3/ 4FLAG, JPRINT, DOTT, DETEMP, DPTF, FACT, ICELT, IJELX,
1, IOKAX, IRDIN, INMAX, INMIN, LU, OUT, XHTAN, XINPUT, XTRAN, IAFLG

COMMON/NAMES/UIKRT, TJ, IE

COMMON/NAMES/DXO(50), DROT(50), DRTX(50)

LH=FIX(TAVL-2*AVE(1)/(0,1)+1)

JPRINT=0

XL1=DELTA/20.

FT=0.0

DO 102 KK=1,20

FT=FT*XL

102 FT(KK)=FT

DO 500 KK=1,20

XXXRT(1)=XXXRT(KK)

XXXRT(KK)=XXXRT(KK)*(J=5/FT(KK)/7.0*FFI(20))**0.5

600 CONTINUE

C

C #JY SCALED MRT

C DO 719 JF=1,20

7119 #FQV(J)=FFF(J)/FACT

XMM=0.01*XM

C

C RANGE DO LUPUP FUN RECOGNITION

C

DO 1066 JJK=1,LUPU

KL=0

ITAR=TBAC*DETETMP

DO 500 J=IMIN, INMAX, IDELTH

KK=KK+1

RANGE=J/1000.0

XR=RANGE*1000.0

DO 2 JJ=1, LK

2 INTRAN(JJ)=1.0

CALL ATMCRL(RVIS, RANGE, AIRTMP, XHM, MAVE1, MAVE2, IPRINT, IJK, ISTATE,
AFCRL, IAFLG)

DO 5300 MISS=1,LW

5300 INTRAN(MISS)=AFCRL(MISS)*INTRAN(MISS)

CALL QTIE(J, INTRAN, AIRTMP, LW)

TRANS=INTRAN(LW)/AMAV2-AMAV1

DOTE=INTRAN

DETE=DETEMPL*TRANS

TLENG=XTAN/ RANGE

X=MRT FUN DELTA T AND DELTA P

CALL ALINEY(FH, DOTE, FTT, XXMRK, 10)

XNUM=XHTAN*FH/RANGE
CALL ALINEY(Prob, XNUM, PRO, XNUM, 10)
IF(Prob LT 0.0) Prob = 0.0
XPD(KK) = Prob
CALL ALINEY(Prob, XNUM, PRO, XNUM, 10)
IF(Prob LT 0.0) Prob = 0.0
DUD(KK) = DUT(KK)
DXK(KK) = RANGE
910 DUTX(KK) = Prob

C
C
C
DETECTION
C
II = 0
DII GOOD JK = 0, DII, XII, IDLX
II = II + 1
RANGE = JK / 1000.O
XR = RANGE / 1000.O
DII GOOD KLM = 1.0
0046 IRTRAN(KLM) = II 0
CALL ATNCHL(NVIS, RANGE, AIKMP, XNUM, WAVE1, WAVE2, IPRINT, IJK, ISSTATE, IACCL, IAFLG)
DII 5790 MISS = 1.0
3740 IRTRAN(MISS) = ACLAIM(MISS) IRTRAN(MISS)
CALL QTRB(0.1, IRTRAN, IRTRAN, LW)
TRAN = TRAVEL(LW) / (WAVE2 - WAVE1)
DII (II) = TRANS
DTE = DTEC * TRANS
TLLNG = XLTR / RANGE
DTE = DTEC * (TLLNG) * (OFF (20)) * 0.3
XORC(II) = RANGE
C X MAT FOR DELTA T AND DELTA P
CALL ALINEY(F4X, DETE, FFT, XMMT, 20)
XNUM = XMTAB(RWF, RANGE)
CALL ALINEY(Prob, XNUM, PHO, BETA, 10)
IF(Prob LT 0.0) Prob = 0.0
DRTX(II) = Prob
C
WFUV X-MAT FOR DELTA T AND DELTA P
CALL ALINEY(F4X, DETE, WFUV, XMMT, 20)
XNUM = XMTAB(RWF, RANGE)
CALL ALINEY(Prob, XNUM, PHO, BETA, 10)
IF(Prob LT 0.0) Prob = 0.0
6005 XFR(II) = Prob
1060 CJNTLINE
RETURN
END
CALL CAMRA(XTV, YTV, FG, GUP, GRUP, TACO)
CALL EMTRUP(RUP, RUC)
CALL DSPLY(ZUP, ZUP, TACO)
CALL STABLE(XML, YML, FG, HRUP, GRUP, TACO)
FTMY = ERUP*FRUP*GUP*GRUP*ZUP*HRUP
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
DOJMN = TACO
ODF = TACO/20.0
CC = -ODF
DO 5001 KLM = 1, 20
CC = CC + ODF
FUNO(KLM) = CC
CALL EMTRUP(XM, RUP, ERUP, FRUP, CC)
CALL CAMRA(XTV, YTV, FG, GUP, GRUP, CG)
CALL EMT(RUP, RGUP, CC)
CALL DSPLY(ZUP, ZOP, CC)
CALL STABLE(XML, YML, FG, HRUP, ORUP, CC)
XXMTF(KLM) = ERUP*FRUP*GUP*GRUP*ZUP*HRUP
YXMTF(KLM) = GUP*HRUP*ZOP*GRUP
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, 2HMPREDICTED SYSTEM MTF, 9X, 16HMPREDICTED NOISE
113MPREDICTING MTF)
WRITE(6, 3011)(FREQ(I), XMTF(I), YMTF(I), FURD(I), XXMTF(I), YXMTF(I),
I = 1, 20)
3011 FORMAT(1H1, 1X, 14HMPREDICTED MTF, 8X, SHY MTF, 8X, SHY MTF, 5X, 16HMPREDICTED NOISE
113MPREDICTING MTF, (1X, F5.2, 2F13.2, F9.2, 2F13.2))
8001 CONTINUE
DO 1 IJ = 1, 20
XMTF(IJ) = XMTF(IJ)*XYMTF(IJ)
YMTF(IJ) = YMTF(IJ)*XYMTF(IJ)
1 CONTINUE
RETURN
END
SUBROUTINE OPTIC(XO,YO,FREQ,CROP,FLAM)
C
C OPTICAL MTF
C
DIMENS: XI(10), YU(10), FHL(10)
COMMON/XNAME/VAX, LAX(10), VAX(10), XNL1, DELTA, DELTAY, YETMX, F, HFUV,
LVEV, X4G, XN, XNLX, OVLHSC, MTHF, ORTAD, DISCT, ATT, ANGLE, NUM, STAH,
ZALAMC, FNUMR, FOC, XX, FMAX; XY, YMAX, XSTOL, YSTOL, X, YA, KK
JUITAU, VEL; SELECT
CRA=0X(1)
IF (CRA.UT.0.0) CALL ALINXY(CRUP,FLAM,XU,FHL(10))
IF (CRA.UT.0.0) CALL ALINLY(CRUP,FLAM,YU,FHL(10))
IF (CRA.UT.0.0) GOTO 300
A=FLAM/FOC/2*34
A=XXF*ALAMC*0.1#FNUMH
IF (ALAMC.1.0) CRUP=2.0/3.14*(ARCOS(A)-A*(1.-A**2)**0.5)
IF (ALAMC.1.0) CRUP=C+C
CRUP=CRUP
300 CONTINUE
RETURN
END

SUBROUTINE GEBLUR(XRUP,YRUP,FLAM)
C
C OPTICAL GEOMETRIC BLUR MTF...
C
COMMON/BLUR/ABLUR
XRUP=XP(-ABLUR*FLAM**2)
YRUP=XRUP
RETURN
END
SUBROUTINE DETECT(XD,YD,FREQ,XDM,YDM,DRUP,DRUP,FLAM)

DETECTOR SPATIAL MTF

REAL IOTAU
DIMENSION XD(10), YD(10), FREQ(10)
COMMON/NAME4/ XW, LW, F(I10), S(I10), XNET, DELTA, DELTA, FT, FREQ, IFOV, IFOV, XMAX, XMIN, XSC, YMAX, YMIN, STAD, DISC, TA, TD, ANG, MOM, FSTAR...
2XLM, FNUM, FOC, XX, FMAX, XY, YXL, FMAX, XSIGL, YSIGL, XAX, YAX, KKK
3 IOTAU, VEL, FELECT
XFDET=1./2./DELTAX
YFDET=1./2./DELTAY
IF (FLAM+0.0 GT. 0.0) GO TO 301
XD=IN(3.14*FLAM/1.0/XFDET)/3.14/FLAM*2.*C*XDET
YD=IN(3.14*FLAM/1.0/YFDET)/3.14/FLAM*2.*C*YD
301 IF (FLAM+0.0 GT. 0.0) XD=1.0
IF (FLAM+0.0 GT. 0.0) YD=1.0
DRUP=XX(I)
IF (DRAP+0.0 GT. 0.0) CALL ALINEY(DRUP, FLAM, XD, FREQ, 10)
IF (DRAP+0.0 GT. 0.0) CALL ALINEY(DRUP, FLAM, YD, FREQ, 10)
IF (DRAP+0.0 GT. 0.0) GO TO 400
DRUP=1.75(1.0+F(EQFLAM/FSTAR)**2)**0.5
END

SUBROUTINE LM(XE, XB, FREQ, ERUP, FRUP, FLAM)

ELECTRONIC AND BOOST MTF

REAL IOTAU
DIMENSION XE(10), XB(10), FREQ(10)
COMMON/NAME4/ XE, LW, F(I10), S(I10), XNET, DELTA, DELTA, FT, FREQ, IFOV, IFOV, XMAX, XMIN, XSC, YMAX, YMIN, STAD, DISC, TA, TD, ANG, MOM, FSTAR...
2XLM, FNUM, FOC, XX, FMAX, XY, YXL, FMAX, XSIGL, YSIGL, XAX, YAX, KKK
3 IOTAU, VEL, FELECT
FRAP=XX(I)
IF (FRAP+0.0 GT. 0.0) CALL ALINEY(FRUP, FLAM, XE, FREQ, 10)
IF (FRAP+0.0 GT. 0.0) GO TO 500
500 ERUP=1.75(1.0+F(EQFLAM/FELECT)**2)**0.5
500 CONTINUE
FRAP=XX(I)
IF (FRAP+0.0 GT. 0.0) CALL ALINEY(FRUP, FLAM, XB, FREQ, 10)
IF (FRAP+0.0 GT. 0.0) GO TO 501
FRUP=1.75(1.0+F(FLAM/2.)**4)**0.5
501 CONTINUE
END

RETURN
END

95
SUBROUTINE CAMHA(XTV,YTV,FLAM,GROUP,GRP,FLAM)

TV CAMHA MTF

DIMENSION XTV(10),YTV(10),FLAM(10)
CALL ALINEY(GROUP,FLAM,XTV,FLAM,10)
CALL ALINEY(GROUP,FLAM,YTV,FLAM,10)
RETURN
END

SUBROUTINE EMIT(RUP,DISP,FLAM)

LED EMIT TRK MTF

REAL IDTAV
COMMON/NAME/ XTV, LAMP(10), S(10), XNET, DELTAX, DELTAY, XYTM, FR, HFOV,
1 YF0V, XMA*G, XN, XNSEC, SRTAU, DISC, TAN, ANGLES, NUM, FSTAM,
2 XLMAB, FNUMB, FOC, XX, FMAXXY, XYL, FMAXXXS, YSIGLC, XAYA, KKK
JOUTAV, VEL, FELECT

IF(XY*EQ.0.0) GO TO 709
IF(FLAM*EQ.0.0) RUP=1.0
IF(FLAM*EQ.0.0) RUP=1.0
IF(FLAM*GT.0.0) RUP=SIN(3.14*FLAM*XY)/(3.14*FLAM*XY)
IF(FLAM*GT.0.0) HUP=SIN(3.14*FLAM*XY)/(3.14*FLAM*XY)
709 IF(XY*EQ.0.0) RUP=1.0
IF(XY*EQ.0.0) HUP=1.0
RETURN
END

SUBROUTINE DISPL(YAM,FLAM)

DISPLAY MTF

REAL IDTAV
COMMON/NAME/ XTV, LAMP(10), S(10), XNET, DELTAX, DELTAY, XYTM, FR, HFOV,
1 YF0V, XMA*G, XN, XNSEC, SRTAU, DISC, TAN, ANGLES, NUM, FSTAM,
2 XLMAB, FNUMB, FOC, XX, FMAXXY, XYL, FMAXXXS, YSIGLC, XAYA, KKK
JOUTAV, VEL, FELECT

IF(KKK*EQ.1) GO TO 807
IF(KKK*EQ.0) ZUP=EXP(-XAM*Y*2)
IF(KKK*EQ.0) ZUP=EXP(-XAM*Y*2)
IF(KKK*EQ.1*AND*FLAM*EQ.0.0) ZUP=1.0
IF(KKK*EQ.1*AND*FLAM*EQ.0.0) ZUP=1.0
IF(KKK*EQ.1*AND*FLAM*EQ.0.0) ZUP=SIN(3.14*FLAM*XY)/3.14/FLAM*XY
IF(KKK*EQ.1*AND*FLAM*EQ.0.0) ZUP=SIN(3.14*FLAM*XY)/3.14/FLAM*XY
807 IF(KKK*EQ.1) ZUP=1.0
IF(KKK*EQ.1) ZUP=1.0
RETURN
END
SUBROUTINE STABLE(XML,YML,FX,HUP,YP,FLAM)

COMMON/NAME4/ XML,YML,FX(H(10),3(10)),XNET,DELTA,DELTA,E,YETM,FR,HEV,Y,
    FXDV,XMAG,XN,XNSC,OVERSC, URTL, SATAD, DISC, TA, ANGLE, MDM, FSTAH,
    2XLAM, FNUMB,FOC, XX, FMAX, XY, XYL, FMAX, XSIGLS, YSIGLS, XA, YA, XX,
    YL, FHL, FLECK

DIMENSION XML(10), YML(10), XLSL(10)
   H=AP=4XL
   D=AP=YML
   IF(HAP+GT+.O) CALL ALINEY(HNP,FLAM,XML,FXHF,10)
   IF(JAP+GT+.O) CALL ALINEY(JHUP,FLAM+YML,FHL,10)
   IF(JHAP+GT+.O) HUP=3P(-XSIGLS*FLAM**2)
   IF(JHAP+GT+.O) UHUP=3P(-YSIGLS*FLAM**2)
   RETURN
   END

SUBROUTINE EYEBAL(URP,ORP,FLAM)

COMMON/NAME4/ XML, YML, FX(H(10),3(10)), XNET, DELTA, DELTA, E, YETM, FR, HEV, Y,
    FXDV, XMAG, XN, XNSC, OVERSC, URTL, SATAD, DISC, TA, ANGLE, MDM, FSTAH,
    2XLAM, FNUMB, FOC, XX, FMAX, XY, XYL, FMAX, XSIGLS, YSIGLS, XA, YA, XX,
    YL, FHL, FLECK

DIMENSION SLSL(9), XL(9)
   DATA SLS/1,2,3,4,5,6,7,8,9/;
   DATA XL/1,2,3,4,5,6,7,8,9/;
   XXXL=ALOG10(RHTE)
   CALL ALINEY(SLSL, XXXL, SLSL, XL, 9)
   GAMMA=SSL(9); 6266
   UHP=EXP(-GAMMA*FLAM/XMAG)
   ORP=EXP(-GAMMA*FLAM/XMAG)
   RETURN
   END

97
SUBROUTINE NOISE(FO, CUTOFF, DOSTAR, XLBMA, GUAO, XB, FG)
REAL IOHAU
COMMON/NAME/IFLAG, JPRINT, DDT, DETERM, DPEAK, FACT, IDLMT, IDELX
DIMAX, IORD, HRMIN, LUP, OUTPUT, XSTAR, XINPUT, XLTM, IFLG
COMMON/NAME/XX, LW, XFL(10), SFL(10), XNET, DELTA, XLTAY, EYTM, FR, MFQV,
VFUFF, XMAG, XN, XNSC, OVEBSC, BRITE, SR, TAD, DISC, TA, ANGLE, NON, FST.
DIMENSION XSTAR(10), XB(10), DOSTAR(10)
DIMENSION XSTAR(10), XB(10)
DIMENSION XSTAR(10), XB(10), DOSTAR(10)
FN=FNMU
DELAM=0.1
XI=XW
UJ=12
XL=XL+DELAM
CALL AL(NEY, UD, XL, DOSTAR, XLBMA, 10)
DO 125 DOSTAR(J)=GUMO*DD*1.000E+10
PI=3.14159
CALL DXP(300.0, HZ, DOSTAR, DELAM)
CALL AD(P(300.0, DELTA, CUTOFF, XB, FG)
DEL=ANGLE*0.0175
IF(MON+EQ, .0) XNET+4.0*FN**2*DELTA*DELTA/PI/(SRTAD2.54)/TA/TO/HZ/
D+DELTA**2.5
IF(MON+EQ, .0) XNET+4.0*FN**2*DELTA*DELTA/PI/(SRTAD2.54)/TA/TO/HZ/
+DELTA**2.5+SIN(UTI)
IF(MON+EQ, .0) XNET+4.0*FN**2*DELTA*DELTA/PI/(SRTAD2.54)/TA/TO/HZ/
+DELTA**2.5+SIN(UTI)
DFF=I(IOHAU/4.0)
IF(IFL(3, 900) GO TO 1500
IF (IFLAG, G10) WRITE(6, 7000)
7000 FORMAT(34/, 3H '111101X, 1M, XNOISE OUTPUT DATA//' )
WRITE(6, 7000) HZ, DELTA, CUTOFF
1000 FORMAT(1M 127H INTEGRAL OF USTAR# = PRIME# E 10.3/1M, 22HEXACT NOIS
1E BANDWIDTH, E 10.3/1M, 22H WHITE NOISE BANDWIDTH, E 10.3/
WRITE(6, 1011) VEL
1011 FORMAT(1H, 2H SCAN VELOCITY IN MH/SEC, E 10.3)
IF(MON+EQ, 0) WRITE(6, 155) XNET
IF(MON+EQ, 0) WRITE(6, 161) XNET
IF(MON+EQ, 0) WRITE(6, 166) XNET
155 FORMAT(1H, 2H DMC NOISE LIMITED NET#, E 10.3)
161 FORMAT(1H, 2H DMC NOISE LIMITED NET#, E 10.3)
565 FORMAT(1H, 16H WHITE NOISE LIMIT, NET#, E 10.3)
RETURN
END
SUBROUTINE UW (T, M2, DELTR, DELAM)
REAL K, L, M
REAL M2, DELTR
DIMENSION USTAR(161), USTAR1(161), A(161)
COMMON /NAME/ X, K, LW, F(10), S1(10), XNRM, DELTA, T, TAY, EYLT, A, FH, NH, OS
1V FX, XMAG, XN, XNSC,osome, XTE, SHTAU, UTSC, T, AC, A, AK, FSTAH, 1
2XLAM, FNUR, FUC, XK, FMAAF, X, XYL, FMAX, XS13, YS13, XS1GLC, XA, YA, AK
JU TAU, VEL, FELECT
DATA H/6, 0, 1/4, C/3, CCE/CO/, A/1, 30E-23/
C1=J+J+J+J
C2=H*K
LAM=LM1/1, 00E-09
DO 100 J=1, LAM
LAM=LAM+FLAM1/1, 0ML-Ge
D2=C2/(1, LAM)
DO 10 J=1, LAM
RAU(J)=C48)4*00J7/(DD3-1, 1)*2)/(LAM**5)
RAU(J)=RAU(J)+USTA(J)
100 CONTINUE
CALL JTFE (DELAM, RAD, A, LAM)
M2=ALW/1, 1+00E-10
HTUHN
END

SUBROUTINE BWF (FO, DELTAF, CUTOFF, UK, FQ)
REAL IO TAU
COMMON /NAME/ X, XNM, LWF(10), S1(10), XNRM, DELTA, TAY, AEIM, FH, NH, OS
1V FX, XMAG, XN, XNSC, XNSC, XTE, SHTAU, UTSC, T, AC, A, AK, FSTAH, 1
2XLAM, FNUR, FUC, XK, FMAAF, X, XYL, FMAX, XS13, YS13, XS1GLC, XA, YA, AK
JU TAU, VEL, FELECT
DIMENSION S(15), T(15)
DIMENSION XH(10), FQ(10)
JFO=ALDGO1*80
CALL ALINEY (SFO, XF0, S+F, 8)
FM=FMAAF*VEL
XLFR=0.5
DO 10 J=1, 15
XLFR=XLFR+0.5
CALL ALINEY (L, XLFR, S+F, 8)
IF (T) LT+0.0) T=0.0
FZERO=UJUITAO/2.0
FREQ=10.0**2*XLFRQ
IF (FREQ LT CUTOFF) FREQ=0.0
IF (FREQ GE CUTOFF) G=1.0/(1.0+(FREQ-CUTOFF)/FZERO)**2)**0.5
IF (K=EQ+0.9) CALL ALINEY (HM, X, XNF, XF0, S+F, 10)
10 (J=EQ+0.9) HM=1.0*(1.0-0.2*(1.0-COS(3.0*FREQ/FH)))
CALL QTR (0.5, T, B, 15)
DELTA VB(1C)
RETURN
END
SUBROUTINE XHING(CUTOFF, XM, FF, XH, NF, FF, MS, A, NCH, ANS, M, GORN)

NCH = 1 INCLUDES EQUALS 2 NO S
XM, FF ARRAYS TO BE INTEGRATED OVER
S, F POWER SPECTRUM OF NOISE ARRAYS
A EQUALS WIDTH OF THE BAR
XMAG = SYSTEM MAGNIFICATION
BB = DISPLAY BRIGHTNESS
NXH = NUMBER OF POINTS IN ARRAY XM
CUTOFF = LOW FREQUENCY CUTOFF
NS = NUMBER OF POINTS IN ARRAY S

REAL IDT, A
DIMENSION XM(1), FF(1), FF(1), R(1000), GAM(10), BBB(10)
COMMON/NAME3/ WS, LWF(10), S(10), XET, DELTA, DELTA, SYST, FR, WGOV,
1FRDV, XHGR, XHNSC, XOLSC, BRITE, SRTAD, DISC, TA, TO, ANG, NRM, PSTAR,
2FLAM, PNUM, FC, XM, MAE, FX, YL, FMAX, XSIGL, YSIGL, XA, YA, XX
3ICXNU, VEL, NPAIR
DATA GAM/1.0311, 0.92, 2.2, 2.9, 3.1, 3.7, 6.5, 5.5, 6.0, 7.1, 9.0/

BBBB = LOG OF THE BRIGHTNESS

BBBB / 
DATA BBBBBB / 3.21.05, -1.0, -2.1, -3.4, -5.8, -6.7/
BBB = LOG10(BBB)
CALL ALINEY(GAM, BBBBBB, GAM, BBB, 10)
GAMMA=GAM/XHMAU*GORN
E=200
E=200
GF=ANAXI(A, 1, FF(NXH))
GF=10.0/GF
GF=GF
100 CONTINUE
GF=GF/2.
CALL ALINEY(T, GF, XM, FF, XH)
IF(NCH-EQ.0) CALL ALINEY(G, GF, S, FF, NS)
IF(NCH-EQ.2) G=1
P=1.0-CUTOFF/(CUTOFF**2*GF**2)*0.5
T=G(T, EXP(-GAMMA*GF)*SING(GF*A)*PN)
IF(T-GT.05,9,0.01) GF=GF-DGF
IF(T-GT.05,9,0.01) GF=GF-1
IF(T-LT.09,9,0.01) GF=GF-DGF
IF(T-LT.09,9,0.01) GF=GF-1
DEL=GF+30./WEG

IFG SHOULD AT LEAST EQUAL 100

DEL=ANMIN(DEL, FF(NXH), WEG)
DO 200 I=1, IEG
GF=J*DEL
CALL ALINEY(T, GF, XM, FF, XH)
IF(NCH-EQ.0) CALL ALINEY(G, GF, S, FF, NS)
IF(T-LT.09,9,0.01) GF=90.
IF(NCH-EQ.2) G=1
P=1.0-CUTOFF/(CUTOFF**2*GF**2)*0.5
X(I)=GF(T, SING(GF*A)*EXP(-GAMMA*GF)*PN)
200 CONTINUE
CALL GF(E, DEL, X, X, IEG)

100
A1=10*(IE+1)**2,
A2=U/LLP
IF(INCH=0.2) GO TO 400
CRASS=1.0+CUTOFF*2/DELF**2
CC=CHASS**0.5
GRASS=1.0+DELF**2*CUTOFF**2
GH=GRASS**0.5
FUNCTION=S+C
DO 300 LLL=1,8
S10=5/LLL
S10=5/LLL+1
IF(SUL+0.0 AND* S02-E.U+1.0) FRHS=QFF(LLL+1)
300 CONTINUE
IF(FRHS+S1.0.0) GO TO 400
A20=3.0*DELF+1.0*CUTOFF*ALOG/(ILDP/CUTOFF+GGG)+CUTOFF+0.5*ATAN(DELFL/
(CUTOFF+PRIME/2.0*ALOG/DELFL+GG/CUTOFF+DELFF**2/DELF**2*CRASS
-2.0*CUTOFF/DELF**1/CC))/CC)
400 A10=A10+2*2
RETURN
END

SUBROUTINE PLANK(T1,T2,P,ARTHAN,RSPX)

DELTA W IN W/CM-2/MICRON, TRANSMISSION AND D-STAR UNITLESS; T1
CALCULATES INTEGRAL OF DELTA * X TRANSMISSION X D-STAR WHERE
AND T2 IN DEGREES C, P IN W/CM-2

REAL IOTAU
COMMON NAMES/* K, L=F(10),S(10),XNET,DFLTAX+U,LTAY,EY,FMX+FMX,FUX+FUX,
MYDFUV,XXAG,XXAG,XXNSC,XXVRSC,XXUNIT,XXTAU+XXC,TUAMG,L5M+FRST,
2XLB9,NUMB,FOC,XX+FMX,XY+FMX,XY+FMX,XY+FMX,XY+FMX,XY+FMX,XY+FMX,XY+FMX
31OATAX+VEL,ELECT
DIMENSION ARTHAN(100),RSPX(100)
DIMENSION RAD(100),RAD2(100),RAD3(100),A(100)
DATA C2/1.438E+04/,C2/3.739E+04/
T11=T1+273
T22=T2+273
KLAM*X
DO 100 J=1,W
KLAM=KLAM+0.1
RAD1(J)=CX*(KLAM**5.0)/EXP(C2/KLAM/T11)-1.0
RAD2(J)=CX*(KLAM**5.0)/EXP(C2/KLAM/T22)-1.0
RAD3(J)=ARTHAN(J)*RSPX(J)*(RAD1(J)-RAD2(J))
CALL QF(E(0.1,RAD3,A,W)
P=A(L#)
RETURN
END

101
SUBROUTINE MDTF(XMM, YMM, FFFF, XGTF, SM, DELTA)
DIMENSION XMM(1), YMM(1), FFFF(1), H(1)
DIMENSION DMTF(25), UMRAD(25)
DIMENSION XINPUT(10), OUTPUT(10)
COMMON /SNMDF/, DMTF(20), DYNF(20)
COMMON /SDMTF/, DMTF(20), YNMTF(20)
COMMON/NAM1/, JFLG, JPRINT, UDNT, DETEMP, DPEAK, FACT, IDELT, IDLBX
IUN, IJLR, IJMAX, IJMIN, UPD, OUTPUT, IHTAR, XINPUT, XLTAR, IAPLG
COMMON/NAM2/ XE, LE, F(10), SI1101, XNET, DELTXA, DELTAY, EYTM, PRED, MEQV
IJVX, XAMG, XNS, OVERSEC, BRITE, SHAT, DISC, TAE, TANG, ANGLE, XON, FSTAR,
XLANV, XNUMF, FOG, XFRX, XYL, FMAX, XSL, YSL, XSG, XSG, XRR, YRR
SUTAU, VEL, PECLET
GO TO 101
001 KE = 1
002 XMTP(KK) = XMM(KK) * XNMTF(KK)
003 YNMTF(KK) = YMM(KK) * YNMTF(KK)
101 CONTINUE
XL = DELTA + S
KE = 0
102 CONTINUE
KK = KK + 1
XSIDE = XSIDE + XL
YSIDE = YSIDE + XL
CALL XING(K(1) * XMM, FFFF, 20 * XSIDE + 1, AN, 2 * 10)
CALL XING((0, 0) * DYNF, FFFF, 20 * XSIDE + 2 * AN, 2 * 10)
QD = AN + 2 * 10
CALL XING((0, 0) * XMM, FFFF, 20 * XSIDE + 2 * AN, 2 * 10)
CALL XING((0, 0) * YMM, FFFF, 20 * XSIDE + 2 * AN, 2 * 10)
QD = AN + 10
DMTF(KK) = XMM(KK) + YMM(KK) / XSIDE / YSIDE / JD * (DELTAY + VEL * QU / DELTA / FR / EYTM / O)
IVESC(1) = 0
DMTF(KK) = 1.0 / XSIDE
IF (KK = EQ(25)) GO TO 103
IF (UMRDT(KK) + GE + 0.001 + UR + KK + LT = 10) GO TO 102
103 CONTINUE
IF (JPRINT + EQ + 0) GO TO 1000
IF (IJFLG + EQ + 1) WRITE(6, 1000)
1000 WRITE(6, 104)
H4 WRITE(6, 103)
H3 WRITE(6, 102)
1000 CONTINUE
RETURN
END
SUBROUTINE ATMCRU(VIS, RANGE, TEMP, HUMIDY, WAVE1, WAVE2, IPRINT, IGO, ISTATE, AFCRL)


DIMENSION AFCRL(10) IN THE CALLING ROUTINE.

INCLUDE THE STATEMENT WITH ARRAYS OF DIMENSION 9

COMMON /SPCTRN/SPCLAM, SPCTRN

IN THE CALLING ROUTINE, THESE TWO ARRAYS SUPPLY INFORMATION FOR OPTIONAL BEERS LAW CALCULATIONS. WHEN SUCH CALCULATIONS ARE REQUIRED, SPCLAM(1) IS ALWAS EQUAL TO AER AND SPCLAM(2) IS ALWAYS 4 BLANKS. THE OTHER 7 ELEMENTS ARE WAVELENGTHS BETWEEN 2.0 AND 16.0 MICRONS CORRESPONDING TO DATA IN SPCTRN. FOR THE CASE OF A BEERS LAW ATTENUATION CALCULATION, SPCTRN(1) EQUALS TOTAL, SPCTRN(2) IS ALWAYS 4 BLANKS, AND THE OTHER 7 ELEMENTS ARE TOTAL TRANSMISSION PER KILOMETER FOR EACH WAVELENGTH IN SPCLAM. FOR THE CASE OF A BERS LAW SCATTERING CALCULATION, SPCTRN(1) IS ALWAYS SCAT, SPCTRN(2) IS ALWAYS 4 BLANKS, AND THE OTHER 7 ELEMENTS ARE SCATTERING TRANSMISSIONS PER KILOMETER FOR EACH WAVELENGTH IN SPCLAM. TOTAL TRANSMISSION IS COMPUTED IN THIS CASE BY COMBINING THIS ROUTINE WITH THE ATMCRL ABSORPTION ROUTINE. ALL COEFFICIENTS PER 1 MICRON INTERVAL ARE OBTAINED BY LINEAR INTERPOLATION USING SUBROUTINE ALINEY. CONSEQUENTLY, THIS SUBROUTINE IS NOT AN INTEGRAL PART OF ATMCRL.

ARGUMENTS:
VIS - VISIBILITY RANGE IN KILOMETERS
RANGE - WAVELENGTH IN KILOMETERS
TEMP - TEMPERATURE IN DEGREES C FROM -29 DEGREES TO +16 DEGREES
HUMIDY - RELATIVE HUMIDITY AS A DECIMAL
WAVE1 - THE FIRST WAVELENGTH IN MICRONS FOR WHICH TRANSMISSION IS REQUIRED. IT MUST BE A MULTIPLE OF 0.1 AND CAN BE FROM 2.0 TO 15.9 MICRONS
WAVE2 - THE LAST WAVELENGTH IN MICRONS FOR WHICH TRANSMISSION IS REQUIRED. IT ALSO MUST BE A MULTIPLE OF 0.1 AND CAN BE FROM 2.1 TO 16.0 MICRONS

IPRINT - A DIAGNOSTIC PRINT VARIABLE WHICH CAN TAKE ON THREE VALUES:
0 OR BLANK - NO PRINTOUT FROM SUBROUTINE
1 - ABBREVIATED PRINTOUT LISTING INITIAL CONDITIONS AND ABSORBER CONCENTRATIONS PER KILOMETER
2 - DETAILED PRINTOUT LISTING INITIAL CONDITIONS, ABSORBER CONCENTRATIONS PER KILOMETER, AND ALL COMPUTED CONTRIBUTIONS TRANSITIONS

IGO - INDEX USED TO DESIGNATE BYPASSING PART OF THE SUBROUTINE WHEN ALL CONDITIONS ARE THE SAME EXCEPT FOR THE RANGE AND/OR IPRINT
1 - ABSORBER CONCENTRATIONS ARE COMPUTED
2 - TRANSMISSION IS COMPUTED DIRECTLY FROM ABSORBER CONCENTRATIONS CALCULATED FROM A PREVIOUS CALL TO THIS ROUTINE. INITIAL CONDITIONS AND ABSORBER CONCENTRATIONS WILL NOT BE REPRINTED, BUT IF IPRINT EQUALS 2, TOTAL AND CONTRIBUTORY TRANSMISSIONS WILL BE LISTED FOR EACH 0.1 MICRON INTERVAL

ISTATE - INDEX WHICH KEYS SPECIAL CALCULATIONS. INDICES 1-4 ARE MASI MODELS. THE VISIBILITY NEED NOT BE DEFINED FOR MAIN CALCULATIONS SINCE IT IS DEFINED IMPLICITLY IN THE INDEX. WHEN 1 IS USED, SPCLAM AND SPCTRN MUST BE FILLED IN THE CALLING ROUTINE AND SPCTRN(1) MUST BE SCAT. WHEN 1 IS USED, THE SAME IS TRUE ONLY SPCTRN(1) MUST BE TOTAL.

103
01 - LIGHT RAIN - 12 KILOMETER VISIBILITY
02 - MODERATE RAIN - 6 KILOMETER VISIBILITY
03 - HEAVY RAIN - 2 KILOMETER VISIBILITY
04 - VERY HEAVY RAIN - 0.5 KILOMETER VISIBILITY
05 - MILLER LAW SCATTERING
06 - MILLER LAW ATTENUATION

IN ORDER TO APPROXIMATE THE SIX MODEL ATMOSPHERES IN LONTRAN, IMPUT THE
TEMPERATURE AND RELATIVE HUMIDITY COMBINATIONS LISTED BELOW ALONG WITH A
VISIBILITY RANGE OF EITHER 5.0 OR 23.0 KILOMETERS.

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THIS PROGRAM DETERMINES A 1 MICRON INTERVAL TRANSMITTANCE BETWEEN 3.0 AND 16.0
MICRONS TO WITHIN 3 PERCENT OF THE 1 MICRON INTERVAL TRANSMITTANCE CALCULATED
BY AVERAGING THE TOTAL WEIGHTED TRANSMISSIONS IN THE INTERVAL AS COMPUTED BY
LONTRAN AT ITS FINEST RESOLUTION. A 1 MICRON INTERVAL TRANSMITTANCE BETWEEN
2.0 AND 3.0 MICRONS IS ALSO CALCULATED TO WITHIN 3 PERCENT EXCEPT FOR
THE 2.0, 2.2 AND 2.5 MICRON INTERVALS WHICH ARE CALCULATED TO WITHIN 5.4
AND 5 PERCENT ACCURACY RESPECTIVELY OVER THE RANGE OF THE TEST VALIDATION.
A 1 MICRON INTERVAL TRANSMITTANCE GENERALLY COMPARES TO WITHIN 1 PERCENT FOR
WAVELENGTH INTERVALS GREATER THAN 7.5 MICRONS. SOME MINOR ADJUSTMENTS TO
THE C1 AND C2 ARRAYS HAVE BEEN MADE TO ACHIEVE THIS ACCURACY. THE RESULTS
OF THIS PROGRAM HAVE BEEN VALIDATED TO THE FOLLOWING TWO CONDITIONS:
1 KM PATHLENGTH, 9 KM VISIBILITY RANGE; US STANDARD ATMOSPHERE
15 KM PATHLENGTH, 23 KM VISIBILITY RANGE; US STANDARD ATMOSPHERE

DIMENSION AFCH1(161)
DIMENSION SPCAM(9),SPCTRAN(9),PLAY1(7),PLAY2(7)
DIMENSION STORE(161),ALPHA(4),BETA(4)
DIMENSION W(7),FX(9),EU(7)
DIMENSION TRI(67),FW(67),FO(67),VADES(69)
DIMENSION C1(141),C2(141),C3(130),C4(12),C5(15),C7(28),VX(28)
DIMENSION XNAME(9)
COMMON /SPCCTM/SPCAM,SPCTRAN
DATA TEST1,TEST2,TEST3,ARIDT,4MSCAT,4HATEW,
DATA ALPHA/12.0,6.0,2.0,0.0,5./
DATA XNAME/4HIL,4RAIN,4MOD,4HPAIN,4HNYV,4HRAIN,4HHWV,4HRAIN
DATA TR/
1 0.999, 0.998, 0.996, 0.994, 0.992, 0.990, 0.988, 0.980, 0.970, 0.9600
2 0.950, 0.940, 0.930, 0.920, 0.910, 0.900, 0.880, 0.860, 0.840, 0.820
30 0.820, 0.800, 0.780, 0.760, 0.740, 0.720, 0.700, 0.680, 0.660, 0.640
4 0.640, 0.620, 0.600, 0.580, 0.560, 0.540, 0.520, 0.500, 0.480, 0.460
50 0.440, 0.420, 0.400, 0.380, 0.360, 0.340, 0.320, 0.300, 0.280, 0.260
6 0.240, 0.220, 0.200, 0.180, 0.160, 0.140, 0.120, 0.100, 0.080, 0.060
7 0.080, 0.060, 0.040, 0.020, 0.015, 0.010, 0.008, 0.006, 0.004, 0.002
8 0.002, 0.001 /
DATA FW/
#-1.340892,3.0362,1.69902,1.48155,1.8279,1.02079,0.47825,0.25229,
-0.34869,0.14839,0.0005,0.0414,0.1553,0.2430,0.33244,0.43424.

104
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5 5 0 0 .5 0 0 .5 0 0 .4 1 6 .3 0 0 .2 4 0 .1 9 0 .1 3 0 .0 1 2 .0 1 0 .1 0 0
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7 7 7 0 .2 0 .2 5 8 .2 2 3 .1 9 0 .1 3 0 .0 5 4 .0 0 4 .0 0 4 .0 0 4 .0 0 4
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2 5 .3 4 3 3 .9 0 1 1 .7 0 .0 0

DATA C6/
1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1 .0 2 6 1
IF (STATE.GT.0 .AND. STATE.LT.50) GO TO 2
WRITE(6,212)
GO TO 1
2 IF (STATE.LT.30) WRITE(6,211) XNAME(JJ), XNAML(JJ+1)
IF (STATE.EQ.31) WRITE(6,213)
1 WRITE(6,204) RANGE
WRITE(6,205) ATOM
WRITE(6,206) HELUMH
WRITE(6,207)
WRITE(6,208)(W(K), K=1,7)
IF (STATE.GT.0 .AND. STATE.LT.50) WRITE(6,217)
13 CONTINUE
ICOUNT=0
7 CONTINUE
DO 9 I=1,7
9 CU(I)=CU(I)*RANGE
DO 10 I=1,101
10 AFCRCL(I)=I=0.0
ICOUNT=0
GO TO 11
C Routines for using constant scattering or attenuation
.150 IF (IGJ.EQ.2) GO TO 153
DO 151 J=1,7
PLAY2(J)=SPCLAM(J+2)
151 DO 152 J=1,7
JAMA(J+1)=SPCTAN(J+1)
UJ 152 J=IMA(J+1)
XLAMDA(I,J)=1.0
CALL ALINEY(AA, XLAMDA, PLAY2, PLAY1, 7)
IF (AA.GT.1.0) AA=1.0
IF (AA.LE.0.0) GO TO 155
STO4(J)=ALUG(AA)
GO TO 152
155 STO4(J)=999.
152 CONTINUE
153 IF (SPCTAN(J+1), LU, TEST2) GO TO 3
IF (IPRTN.EQ.0) GO TO 156
IF (IAFLG .EQ. 1) WRITE(6,7000)
WRITE(6,216)
IF (IPRTN.EQ.2) WRITE(6,214)
156 DO 154 I=IMA(J+1)
XLAMDA(I,J)=1.0
AFCRCL(I-IMA+1)=EXP(-STOR(J)*RANGE)
IF (IPRTN.EQ.2) WRITE(6,215) XLAMDA, AFCRCL(I-IMA+1)
154 CONTINUE
GO TO 96
C Beginning of transmission calculations
11 DO 100 I=IMA, 1
XLAMDA(I)=1.0
WL=1.0E4/XLAMDA
L=WL
LI=L/5
LV=L*1
XL=LV
IF (WL-XL).GT.2.5) LV=LV*5
IF (ICOUNT.EQ.0) GO TO 15
IF (ICOUNT.EQ.50) GO TO 15
GO TO 10
10 ICOUNT=0
IF (IAFLG .EQ. 1) AND (IPRTN .EQ. 2) WRITE(6,700)
IF (IPRTN.EQ.2) WRITE(6,209)
10 SUM=0.0
DO 17 K=1,8
17
CONT
MOLAR SCATTERING
\[ C_6 = 9.807 \times 10^{-20} \times WL^4 \times T_{th} \]
SUM = \text{SUM} + TX(6)
GO TO 40

WATER VAPOR CONTINUUM
20 IF(WL \leq 670) GO TO 40
IF(WL > 670) GO TO 25
\[ X_1 = \frac{WL - 700}{50} \]
DO 22 NH = 1, 15
XH = X1 - FLOAT(NH)
IF(XH)24, 23, 22
22 CONTINUE
23 TX(5) = CS(NH)
GO TO 20
24 TX(5) = CS(NH) + XH * (CS(NH) - CS(NH - 1))
GO TO 25
25 TX(5) = (WL - 670) / 0.69
26 TX(5) = EQ(5) * TX(5)
SUM = \text{SUM} + TX(5)
GO TO 40

NITROGEN CONTINUUM
30 IF(WL \leq 2080) GO TO 40
MY = 1, 36
TX(4) = CA(MY) * EW(4)
SUM = \text{SUM} + TX(4)

WATER VAPOR
40 K1 = 1
IF(EQ(1) \lt LT, 1 + 10) GO TO 44
MY = 1, 19
WS = ALG10(EQ(1) + 1) * EW(MY)
IF(WS \lt LT - 2.2346) GO TO 44
IF(W51 \gt T = 3.5682) GO TO 43.
IF(W51 \gt T = 2.20) K1 = 40
DO 41 K = K1, 67
41 CONTINUE
42 TX(1) = TR(K) + TR(K - 1) - TR(K) * (FW(K) - WS) / (FW(K) - FW(K - 1))
GO TO 44
43 TX(1) = 0.0
44 CONTINUE

UNIFORMLY MIXED GASES(CO2)
45 K1 = 1
WS = ALG10(EQ(2) + 1) * EW(MY)
IF(W52 \lt LT, 2.3468) GO TO 54.
IF(W52 \gt T = 3.5682) GO TO 53.
IF(W52 \gt T = 2.20) K1 = 40
DO 51 K = K1, 67
51 CONTINUE
52 TX(2) = TR(K) + TR(K - 1) - TR(K) * (FW(K) - WS) / (FW(K) - FW(K - 1))
GO TO 54
53 TX(2) = 0.0
54 CONTINUE

OZONE
IF(WL \gt LT, 3270) GO TO 63
K1=1
MY=1-J0
IF((EU(J)LT.1.00E-20) GO TO 03
  S3=AL0U10(C,E3(J))*CJ(MY)
  IF(S3.LT.1.0E71) GO TO 03
  IF(S3.LE.U3.04) GO TO 02
  IF(S3.GT.1.0) K1=30
  GO 65 X=K1.67
  IF(S3.LE.FU(K)) GO TO 01
65 CONTINUE
b1 TX(J)=O.0-(TK(K)-TR(K-1))*F(U(K)-S3)/(F(U(K)-F(U(K-1)))
GO TO 63
b2 TX(J)=O.0
b3 CONTINUE
C  AEROSOL EXTINCTION
  AX=O.0
  IF(SPCTRN(I).NE.0)GO TO 150
  DT I=1,29
  XD=KALAMDA-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(I)=XX*EQ(7)
  IF(VIC.LT.1.0) GO TO 100
  SUM=SUM+TX(I)
GO TO 85
100 SUM=SUM-TX(I)
  TX(I)=O.0
  TX(I)=STORE(I)*CHANGE
  SUM=SUM+TX(I)
GO TO 86
C  FUS MODLL
100 NA=O.02*KALAMDA+0.02
  IF(KALAMDA.LT.2.0) HAP=O.0
  TZ=3.912/VS*EXP(-1.0C*VS**0.001131/((KALAMDA-.5)/.5))HAP
  TZ=TZ*CHANGE
  IF(TZ.LT.TX(I)) GO TO 1C7
  IF(TZ.LT.0.0) TZ=O.0
  TX(I)=TZ
107 SUM=SUM+TX(I)
GO TO 86
85 IF(ISTATE .EQ.1.AND.ISTATE .LE.5) GO TO 112
  IF(ISTATE .LE.5) GO TO 120
  IF(ISTATE .LE.12) GO TO 1J0
GO TO 86
C  RAIN MODLL
110 TY=O.0
  IF(ISTATE .EQ.1) TY=JO24/HANGE+TX(I)/FJ(I)*RANGE*4.0
  IF(ISTATE .EQ.2) TY=6.92*RANGE+TX(I)/FJ(I)*RANGE*4.0
  IF(ISTATE .EQ.3) TY=1.96*HANGE+TX(I)/FJ(I)*RANGE*12.*TY
  IF(ISTATE .EQ.4) TY=7.824*RANGE+TX(I)/FJ(I)*RANGE*4.0
  IF(ISTATE .EQ.4) SUM=SUM-TX(I)
  IF(TI7)TY
  SUM=SUM+TX(I)
GO TO 86
120 CONTINUE
1J0 CONTINUE
1J0 CONTINUE
C  TOTAL TRANSMISSION
  66 TX(J)=SUM
  DO 80 K=4,6
  IF(TX(K).LE.O.0) GO TO 81
  80 CONTINUE
IF(T(K).LE.0.0) GOTO 82
IF(TX(K).GT.200) GOTO 83
TX(K)=TX(K)+0.9*TX(K)*TX(K)
GOTO 80
81 TX(K)=1.0
GOTO 80
82 TX(K)=0.9
83 CONTINUE
AFCHL(1)=TX(1)*T(2)*TX(3)*TX(8)
IF(1*INT.EQ.2) WRITE(6,210) IV,VLAMDA,AFCCHL(1),(TX(K),K=1,7)
90 CONTINUE
C
ILT=IMA-IMA+1
DD # I=1,ILT
95 AFCCHL(1)=AFCCHL(IMA-1+1)
90 CONTINUE
200 FORMAT(FHM FAST GROUND LEVEL VERSION OF AIR FORCE ATOMIC HERIC PROG
AHA.L,LOWTHAI II,//)
201 FORMAT(10X,2TH1962 US STANDARD ATMOSPHERE)
202 FORMAT(10X,14HAND WIDTH ,1F4.1,13H = ,1F4.1,13H MICRONS IN 1 MIC
AKON INCREMENT)
203 FORMAT(10X,1HVISIBILITY RANGE ,1F5.2,1H KM)
204 FORMAT(10X,1HPATHLENGTH ,1F5.2,1H KILOMETERS)
205 FORMAT(10X,1HTEMPERATURE ,1F5.1,1H DEGREES C)
206 FORMAT(10X,20HRELATIVE HUMIDITY ,1F4.2,1H//)
207 FORMAT(11X,43HEQUIVALENT SEA LEVEL ABSORBER AMOUNT PER ,
19HKILOMETERS ,1X,2X,1YMH20 VAPOR ,2X,1H4CO2 ETC.,4X,1H50ZONE ,
2X,1H90X2CNTC ,2X,1YMH20X2CNT<1X,1HMMGL,SCAT,3X ,
37HAEN05JL ,1X,1X,7GM CM=2.6X2,2KMI0X0,6MAT CM ,
4X,1HM KGM CM=2.5X2,2KMI0X0,6MAT CM/)
208 FORMAT(1X,7(2A,6.3))
209 FORMAT(1H1,5M PREJ,2X,1HMLAMDA,2X,1HS1,3X,1HTOTAL,3X ,
13HM20,3X,1H4CO2 ,3X,1H50ZONE,1X,1H6MH2CNT,1X ,
27HH20-CN1,1X,1HMMGL SCAT,1X,1H7AEROSUL ,1X,2X ,
3XHM=1.4X,1HZUM,4X,1S1,3X,1HS1RANS,5(2X,1S1RANS),4X,1
4S1RANS,3X,1S1RANS)
210 FORMAT(1X,7(A6.4),2(2X,6.4),3X,6.4)
211 FORMAT(10X,2HWEATHER CONDITION IS 12A)
212 FORMAT(10X,2HWEATHER CONDITION IS CLEAR)
213 FORMAT(10X,2HBEERS LAW SCATTERING ASSUMED)
214 FORMAT(10X,2HWEATHER CONDITION IS CLEAR)
215 FORMAT(10X,2HWEATHER CONDITION IS CLEAR)
216 FORMAT(10X,2HBEERS LAW ATTENUATION ASSUMED)
217 FORMAT(11H90 THE SCATTERING EQUIVALENT SEA LEVEL ABSORBER AMOUNT
AS ARE NOT APPLICABLE TO THE FOLLOWING TRANSMISSION CALCULATIONS.)
RETURN
END

110
SUBROUTINE MDTSNR(XMM, YMM, FFFF, XCTFF, H, DELTA, RANGE, TRANS, SPROB,
SNET, D)

DIMENSION XMM(1), YMM(1), FFFF(1), H(1)
DIMENSION OUTPUT(10), XINPUT(10)
DIMENSION ROSSNR(11), SPOBH(11)
COMMON /SNROD/ QXMTF(20), DQMTF(20)
COMMON /NAME3/ IFLAG, JPRINT, DDETT, OPEAK, FAC, IDELT, IDLX,
1 IDAX, IRIN, IRMAX, IRMIN, LUPD, OUTPUT, XHTAN, XINPUT, XLTAN, IFLAG
COMMON /NAME4/ XM, ILMFL(10), SLDI, XNET, DELTAX, DELTAB, XEYTM, FFRAC,
1 IPRD, XMAG, XSC, OVERSC, BRITE, SRATX, DISCTA, TO, ANGLE, MUK, FSTAR,
2 XLAMB, FANG, FOC, XX, FMAXF, XY, XYL, FMAX, XSIGS, YSIGS, XA, YA, KK,
3 XDTAu, VEL, FEELECT
DATA ROSSNR/5.5, 4.1, 3.7, 3.3, 3.1, 2.8, 2.5, 2.3, 2.1, 2.0, 2.0, 2.0 /
DATA PRODD/1.00, 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(6,7900)
7900 FORMAT(3X,/) , SH *'***', 10X, 1841MTSNR OUTPUT DATA, /)
C IF (IAFLG .EQ. 1) WRITE(6,7900)
XSID=XTAR/RANGE
YSIDE=XHTAR/RANGE
TAMD=XSIDE*YSIDE

C IF (IAFLG .EQ. 1) WRITE(6,7900)
QD=ANS/2.0*0*0*0*0*
C IF (IAFLG .EQ. 1) WRITE(6,7900)
CALL XRING(XCTFF,DXMTF, FFFF, 20, H, XSIDE, 1, ANS, 2, 1, 0)
CALL XRING(0,0, DQMTF, FFFF, 20, H, 8, YSIDE, 2, ANT, 2, 1, 0)
QD=ANS*0*0*0*0*
D=TO*TAMD*QD/SPRO*SNET*1.00 (DELTAY, VEL*QA/DELTAFR/LYTM/OVERSC)**, 5
CALL ALINEY(SPOBH, DQMTF, ROSSNR, 11)
IF (SPOBH .LT. 0.7) SPROB=0.0
1SSLPCDQI, 1.0, 0.1, SPROB=1.0
RETURN
END
SUBROUTINE ALINK(Y('A*BB+A.B*N))
DIMENSION A(1),B(1)
IF (B(1)*GT*(J(2))) GO TO 2
IF (B=B*LE*(B(1))) GO TO 40
IF (B=B*GE*(B(1))) GO TO 50
LF=1
LL=4
10 CONTINUE
J=LL+LF/2
IF (B=B*LT*U(J)) GO TO 2
IF (B=B*GE*U(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
RETURN
40 A=A(1)*(A(1)-A(2))/(H(1)-d(1))*((U-D(1)))
RETURN
50 A=A(N)*A(N-1)-A(N)/B(N-1)-d(N)*((U-N(N))
RETURN
2 IF (B=B*GL*H(1)) GO TO 40
IF (B=B*LE*B(N)) GO TO 50
LL=1
LF=N
60 CONTINUE
J=LL+LF/2
IF (B=B*LT*L(J)) GO TO 45
IF (B=B*GT*L(J)) GO TO 70
65 LL=J
IF (LL+1*EQ*LL) GO TO 30
GO TO 60
70 LF=J
IF (LF-1*EQ*LL) GO TO 30
GO TO 60
END
SUBROUTINE UTFE(H,Y,Z,NDIM)
SUBROUTINE UTFE

PURPOSE
TO COMPUTE THE VECTOR OF INTEGRAL VALUES FOR A GIVEN
EQUIDISTANT TABLE OF FUNCTION VALUES.

USAGE
CALL UTFE(H,Y,Z,NDIM)

DESCRIPTION OF PARAMETERS
H = THE INCREMENT OF ARGUMENT VALUES.
Y = THE INPUT VECTOR OF FUNCTION VALUES.
Z = THE RESULTING VECTOR OF INTEGRAL VALUES. Z MAY BE
IDENTICAL WITH Y.
NDIM = THE DIMENSION OF VECTORS Y AND Z.

REMARKS
NO ACTION IN CASE NDIM LESS THAN 1.

SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED.
NONE

METHOD
BEGINNING WITH Z(1)=0, EVALUATION OF VECTOR Z IS DONE BY
MEANS OF TRAPEZOIDAL RULE (SECOND ORDER FORMULA).
FOR REFERENCE, SEE
F. B. HILDEBRAND, INTRODUCTION TO NUMERICAL ANALYSIS,
McGRAW-HILL, NEW YORK/TORONTO/LONDON, 1956, PP.75.

*******************************************************************************

DIMENSION Y(1),Z(1)

SUM2=0.
IF(NDIM-1)4,3,1
1 HH=H*H

C INTEGRATION LOOP
DJ Z Z(I)=Z(I),NDIM
SUM1=SUM2
SUM2=SUM2+H*Y(I)*Y(I-1))
Z(I-1)=SUM1
3 Z(NJ14)=SUM2
4 RETURN
END

IRM Application Program. System/360 Scientific Subroutine Package.

Version 111. (360A-CM-03X)
FUNCTION SINC(X)
DATA PI/3.141592654/
IF(X<_0.0) GO TO 10
A=PI*X
SINC=SINC(A)/A
RETURN
10 SINC=1.000
RETURN
END

FUNCTION ACOS(X)
ACOS=ACOS(X)
RETURN
END
## APPENDIX D

**NIGHT VISION LABORATORY STATIC PERFORMANCE MODEL FOR THERMAL VIEWING SYSTEMS**

**USER'S GUIDE**

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1. 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 NFΔT
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 carefully go through what parameters you must specify and how you must specify them. We will cover all aspects of physically setting up the required data deck. We will explain 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.

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<tr>
<td>OPTICS</td>
<td>OPTI, MTOX, MTOY</td>
<td>3</td>
</tr>
<tr>
<td>SCANNER</td>
<td>SCAN</td>
<td>4</td>
</tr>
<tr>
<td>DETECTOR</td>
<td>DETR, DET2, DROX, DROY, NPSP, NPSF, DSTD</td>
<td>5</td>
</tr>
<tr>
<td>ELECTRONICS</td>
<td>ELEC, EMTF, BMTF, VMTX, VMTY</td>
<td>6</td>
</tr>
<tr>
<td>DISPLAY</td>
<td>DISP</td>
<td>7</td>
</tr>
<tr>
<td>SYSTEM*</td>
<td>SYST, BAND</td>
<td>8</td>
</tr>
<tr>
<td>STABILIZATION</td>
<td>STAB, LSSX, LSSY</td>
<td>9</td>
</tr>
<tr>
<td>EYE</td>
<td>EYEB</td>
<td>10</td>
</tr>
<tr>
<td>PROGRAM CARDS**</td>
<td>SN4B, FLHIZ, FCMR, FDRP, FDC1, FRC3, FRC4</td>
<td>11</td>
</tr>
</tbody>
</table>

*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, default 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)

<table>
<thead>
<tr>
<th>Card Identifier</th>
<th>Variable Name</th>
<th>Field on Card</th>
<th>Supplement Note</th>
<th>Description</th>
<th>Units</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAND</td>
<td>WAVE1</td>
<td>1</td>
<td>8.5</td>
<td>Beginning wavelength</td>
<td>microns</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WAVE2</td>
<td>2</td>
<td>8.5</td>
<td>Ending wavelength</td>
<td>microns</td>
<td></td>
</tr>
<tr>
<td>OPTI</td>
<td>FNUMB</td>
<td>1</td>
<td>3.1</td>
<td>F-number of objective lens</td>
<td>inches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FOC</td>
<td>2</td>
<td>3.1</td>
<td>Focal length of objective lens</td>
<td>inches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TØ</td>
<td>3</td>
<td>3.2</td>
<td>Average optical transmission of system</td>
<td>decimal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ABLUR</td>
<td>4</td>
<td>3.3</td>
<td>Rel+ spot size of geo blur</td>
<td>mrad²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XLAMB</td>
<td>5</td>
<td>3.4</td>
<td>Wagden* for diffraction</td>
<td>microns</td>
<td></td>
</tr>
<tr>
<td>DETR</td>
<td>DELTAX</td>
<td>1</td>
<td>5.1</td>
<td>Instantaneous field of view in the x-direction of the detector</td>
<td>mrad</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DELTAY</td>
<td>2</td>
<td>5.1</td>
<td>Instantaneous field of view in the y-direction of the detector</td>
<td>mrad</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XN</td>
<td>3</td>
<td>5.2</td>
<td>Number of detectors in parallel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DISC</td>
<td>4</td>
<td>5.3</td>
<td>Number of detectors in series</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SRTAD</td>
<td>5</td>
<td>5.4</td>
<td>Effective detector size</td>
<td>$10^{-3}$ inches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DPEAK</td>
<td>6</td>
<td>5.5</td>
<td>Peak D* ($\lambda$, $f_0$) value</td>
<td>$10^{10}$ Cm·SQRT(Hz)/Watt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FØ</td>
<td>7</td>
<td>5.6</td>
<td>Measuring frequency $f_0$ of D* ($\lambda$, $f_0$)</td>
<td>K hertz</td>
<td></td>
</tr>
<tr>
<td>DET2</td>
<td>ANGLE</td>
<td>1</td>
<td>5.7</td>
<td>Cold shield angle</td>
<td>degrees</td>
<td>60.0</td>
</tr>
<tr>
<td></td>
<td>MOM</td>
<td>2</td>
<td>5.8</td>
<td>Limiting noise:</td>
<td></td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0 = detector noise limited</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(D* must include cold shield)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0 = shot noise limited (BLIP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.0 = white noise approximation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FSTAR</td>
<td>3</td>
<td>5.9</td>
<td>Frequency of the 3-dB point of detector response</td>
<td>k hertz</td>
<td>10000.0</td>
</tr>
</tbody>
</table>
## Table D2 (continued)

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

<table>
<thead>
<tr>
<th>Card Identifier</th>
<th>Variable Name</th>
<th>Field on Card</th>
<th>Supplement Note</th>
<th>Description</th>
<th>Units</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCAN</td>
<td>FR</td>
<td>1</td>
<td>4.1</td>
<td>Scanner parameters</td>
<td>frames/second</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XNSC</td>
<td>2</td>
<td>4.2</td>
<td>Overall scan efficiency</td>
<td>decimal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OVERSC</td>
<td>3</td>
<td>4.3</td>
<td>Overscan ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELEC</td>
<td>CUTOFF</td>
<td>1</td>
<td>6.1</td>
<td>Frequency of the 3-dB preamp cut-on</td>
<td>hertz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FELECT</td>
<td>2</td>
<td>6.1</td>
<td>Frequency of the 3-dB amplifier cutoffs</td>
<td>hertz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XY</td>
<td>3</td>
<td>6.2</td>
<td>Width of electro-optic multiplexor LED</td>
<td>mrad</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XYL</td>
<td>4</td>
<td>6.2</td>
<td>Length of electro-optic multiplexor LED</td>
<td>mrad</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XK</td>
<td>5</td>
<td>6.3</td>
<td>Electronic boost amplitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FMAXF</td>
<td>6</td>
<td>6.3</td>
<td>Electronic boost frequency</td>
<td>K hertz</td>
<td></td>
</tr>
<tr>
<td>DISP</td>
<td>XKK</td>
<td>1</td>
<td>7.1</td>
<td>Display parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0 = CRT display (Gaussian spot size)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0 = LED display</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.0 = no display</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BRITE</td>
<td>2</td>
<td>7.2</td>
<td>Average display brightness</td>
<td>footlamberts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XA</td>
<td>3</td>
<td>7.3</td>
<td>x-dimension of LED or related to CRT</td>
<td>mrad/LED</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>spot size of display</td>
<td>mrad²/CRT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>YA</td>
<td>4</td>
<td>7.3</td>
<td>y-dimension of LED or related to CRT</td>
<td>mrad/LED</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>spot size of display</td>
<td>mrad²/CRT</td>
<td></td>
</tr>
<tr>
<td>Syst</td>
<td>HFOV</td>
<td>1</td>
<td>8.1</td>
<td>System horizontal field of view</td>
<td>degrees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VFOV</td>
<td>2</td>
<td>8.1</td>
<td>System vertical field of view</td>
<td>degrees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>XSIG</td>
<td>3</td>
<td>8.2</td>
<td>System magnification</td>
<td>degrees</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FACT</td>
<td>4</td>
<td>8.3</td>
<td>Ratio of wide field of view to narrow field of view</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>XNET</td>
<td>5</td>
<td>8.4</td>
<td>Noise equivalent delta temperature</td>
<td>degrees C</td>
<td>0.0</td>
</tr>
<tr>
<td>Card Identifier</td>
<td>Variable Name</td>
<td>Field on Card</td>
<td>Supplement Note</td>
<td>Description</td>
<td>Units</td>
<td>Default</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>--------------------------------------------------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>STAB</td>
<td>XSIGLS</td>
<td>1</td>
<td>9.2</td>
<td>Stabilization parameters</td>
<td>mrad²</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>YSIGLS</td>
<td>2</td>
<td>9.2</td>
<td></td>
<td>mrad²</td>
<td>0.0</td>
</tr>
<tr>
<td>ENVI</td>
<td>AIRTMP</td>
<td>1</td>
<td>2.1</td>
<td>Atmospheric parameters</td>
<td>°C, grees C</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>RH</td>
<td>2</td>
<td>2.2</td>
<td>Air temperature</td>
<td>percent</td>
<td>45.99</td>
</tr>
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<td></td>
<td>RVIS</td>
<td>3</td>
<td>2.3</td>
<td>Relative humidity</td>
<td>kilometers</td>
<td>23.0</td>
</tr>
<tr>
<td></td>
<td>ISTATE</td>
<td>4</td>
<td>2.4</td>
<td>Visibility range</td>
<td>kilometers</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Special atmospheric condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0 — rain-light, 12-km visibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.0 — rain-moderate, 6-km visibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.0 — rain-heavy, 2-km visibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.0 — rain-very heavy, 500-m visibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTL</td>
<td>SIGMA</td>
<td>1-7</td>
<td>2.5</td>
<td>Atmospheric transmission per kilometer for any 7 wavelengths in the band where the system operates</td>
<td>decimal</td>
<td>0.0</td>
</tr>
<tr>
<td>(optional)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ATEW</td>
<td>WAVE</td>
<td>1-7</td>
<td>2.5</td>
<td>Wavelengths corresponding to atmospheric transmission values on TOTL</td>
<td>microns</td>
<td>For 3-5 microns: 3.0, 3.25, 3.5, 4.0, 4.3, 4.5, 5.0</td>
</tr>
<tr>
<td>(optional)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TARG</td>
<td>XLTAR</td>
<td>1</td>
<td>1.1</td>
<td>Target parameters</td>
<td>meters</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>XHTAR</td>
<td>2</td>
<td>1.1</td>
<td>Target length</td>
<td>meters</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>DETEMP</td>
<td>3</td>
<td>1.2</td>
<td>Target height</td>
<td>degrees C</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td>TBAC</td>
<td>4</td>
<td>1.2</td>
<td>Target delta temperature</td>
<td>degrees C</td>
<td>12.0</td>
</tr>
<tr>
<td>Card Identifier</td>
<td>Variable Name</td>
<td>Field on Card</td>
<td>Supplement Note</td>
<td>Description</td>
<td>Units</td>
<td>Default</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------</td>
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<td>-----------------</td>
<td>-------------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>RANG</td>
<td>IRMIN</td>
<td>1</td>
<td>1.3</td>
<td>Range parameters</td>
<td>meters</td>
<td>500.0</td>
</tr>
<tr>
<td></td>
<td>IRMAX</td>
<td>2</td>
<td>1.3</td>
<td>Minimum recognition range</td>
<td>meters</td>
<td>5000.0</td>
</tr>
<tr>
<td></td>
<td>IRDIN</td>
<td>3</td>
<td>1.3</td>
<td>Maximum detection range</td>
<td>meters</td>
<td>10000.0</td>
</tr>
<tr>
<td></td>
<td>IRDAX</td>
<td>4</td>
<td>1.3</td>
<td>Minimum detection range</td>
<td>meters</td>
<td></td>
</tr>
<tr>
<td>SN4B</td>
<td>SNR</td>
<td>1</td>
<td>11.1</td>
<td>Threshold signal-to-noise ratio</td>
<td></td>
<td>2.25</td>
</tr>
<tr>
<td>EYEB</td>
<td>EYETM</td>
<td>1</td>
<td>10.0</td>
<td>Integration time of the eye</td>
<td>seconds/frame</td>
<td>0.2</td>
</tr>
<tr>
<td>Card Identifier</td>
<td>Variable Name</td>
<td>Field on Card</td>
<td>Supplement Note</td>
<td>Description</td>
<td>Units</td>
<td>Default</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>-------------</td>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td>FLHZ</td>
<td>FQQ</td>
<td>1-10</td>
<td>11.4</td>
<td>Frequencies corresponding to MTF's of detector response, electronics, and boost</td>
<td>log hertz</td>
<td>0.0, 0.01, 0.1, 0.2, 0.3, 0.5, 0.6, 1.0, 10.0</td>
</tr>
<tr>
<td>DROX</td>
<td>XD</td>
<td>1-10</td>
<td>5.10</td>
<td>MTF of detector temporal response in the x-direction, corresponding to frequencies FQQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>DROY</td>
<td>YD</td>
<td>1-10</td>
<td>5.10</td>
<td>MTF of detector temporal response in the y-direction, corresponding to frequencies FQQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>EMTF</td>
<td>XE</td>
<td>1-10</td>
<td>6.4</td>
<td>MTF of the electronics, corresponding to frequencies FQQ</td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>BMTF</td>
<td>XB</td>
<td>1-10</td>
<td>6.5</td>
<td>MTF of electronic boost, corresponding to frequencies FQQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>FCMR</td>
<td>FQ</td>
<td>1-10</td>
<td>11.3</td>
<td>Frequencies corresponding to MTF's of optics, vidicon, and stabilization</td>
<td>cycles/μrad</td>
<td>0.0, 1.0, 2.0, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0</td>
</tr>
<tr>
<td>MTOX</td>
<td>XO</td>
<td>1-10</td>
<td>3.5</td>
<td>MTF of optics in x-direction, corresponding to frequencies FQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
</tbody>
</table>
### Table D2 (continued)

<table>
<thead>
<tr>
<th>Card Identifier</th>
<th>Variable Name</th>
<th>Field on Card</th>
<th>Note</th>
<th>Description</th>
<th>Units</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTO</td>
<td>YO</td>
<td>1-10</td>
<td>3.5</td>
<td>MTF of optics in ( \xi )-direction, corresponding to frequencies FQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>VMTX</td>
<td>XTV</td>
<td>1-10</td>
<td>6.6</td>
<td>MTF of vidicon in ( x )-direction, corresponding to frequencies FQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>VMTY</td>
<td>YTV</td>
<td>1-10</td>
<td>6.6</td>
<td>MTF of vidicon in ( y )-direction, corresponding to frequencies FQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>LSSX</td>
<td>XML</td>
<td>1-10</td>
<td>9.1</td>
<td>MTF of stabilization in ( x )-direction, corresponding to frequencies FQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>LSSY</td>
<td>YML</td>
<td>1-10</td>
<td>9.1</td>
<td>MTF of stabilization in ( y )-direction, corresponding to frequencies FQ</td>
<td></td>
<td>all 1.0's</td>
</tr>
<tr>
<td>NPSF</td>
<td>F</td>
<td>1-8</td>
<td>5.12</td>
<td>Frequencies corresponding to variable ( S )</td>
<td>log hertz</td>
<td></td>
</tr>
<tr>
<td>NPSN</td>
<td>S</td>
<td>1-8</td>
<td>5.11</td>
<td>Normalized noise power spectrum.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSTD</td>
<td>XLMBA</td>
<td>1-10</td>
<td>5.14</td>
<td>Wavelengths corresponding to variable DOSTAR</td>
<td>microns</td>
<td></td>
</tr>
<tr>
<td>Card identifier</td>
<td>Variable Name</td>
<td>Field on Card</td>
<td>Supplement Note</td>
<td>Description</td>
<td>Units</td>
<td>Default</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>-------------</td>
<td>-------</td>
<td>---------</td>
</tr>
<tr>
<td>LSTD</td>
<td>DSTAR</td>
<td>1-10</td>
<td>5.13</td>
<td>$D^* (\lambda, f_v)$ of detector normalized so that maximum is 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDR1</td>
<td>PRO</td>
<td>1-10</td>
<td>11.2</td>
<td>Probability of recognition or detection as a function of cycles across the target</td>
<td>decimal</td>
<td>1.0, 1.0, 1.0, 0.95, 0.8, 0.5, 0.3, 0.1, 0.05, 0.0</td>
</tr>
<tr>
<td>FDC1</td>
<td>BETA</td>
<td>1-10</td>
<td>11.2</td>
<td>Number of cycles across target for detection, corresponding to PRO</td>
<td></td>
<td>12.5, 5.0, 3.0, 2.0, 1.5, 1.0, 0.75, 0.5, 0.25, 0.0</td>
</tr>
<tr>
<td>FRC3</td>
<td>XNMB</td>
<td>1-10</td>
<td>11.2</td>
<td>Number of cycles across target for optimistic recognition, corresponding to PRO</td>
<td></td>
<td>37.5, 15.0, 9.0, 6.5, 4.5, 3.0, 2.25, 1.5, 0.75, 0.0</td>
</tr>
<tr>
<td>FRC4</td>
<td>XNUM</td>
<td>1-10</td>
<td>11.2</td>
<td>Number of cycles across target for conservative recognition, corresponding to PRO</td>
<td></td>
<td>50.0, 20.0, 12.0, 8.0, 6.0, 4.0, 3.0, 2.0, 1.0, 0.0</td>
</tr>
</tbody>
</table>

Table D2 (continued)
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

<table>
<thead>
<tr>
<th>Card</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOR1</td>
<td>Designates cards with up to 7 data elements per card</td>
</tr>
<tr>
<td>FOR2</td>
<td>Designates cards with up to 10 data elements per card</td>
</tr>
<tr>
<td>ENDS*</td>
<td>Defines the end of a set of FOR1 or FOR2 cards</td>
</tr>
<tr>
<td>DONE*</td>
<td>Defines the end of a data deck</td>
</tr>
</tbody>
</table>

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

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

**OPTI**

The F-number of the objective lens (FNUMB) and the optical transmission (TF0) 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 (F0) 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 $\text{MOM} = 0.0$. 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 $\text{FSTAR}$ (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 $\text{FELECT}$ equal to 0.0 so we can read 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 $\text{KKK} = 0.0$. The average brightness (BRITE) on the display is given as 50.0 FL. In order to assign values to $\text{XA}$ and $\text{YA}$, 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
For further explanation.) The values for \( XA \) and \( YA \) can now be computed directly: 
\( XA = YA = 0.019 \text{ mrad}^2 \).

**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 \( \text{FACT} = 1.0 \). We wish to predict the NEAT; 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\(^\circ\) 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\(^\circ\) C above the background temperature (TBAC) of 12.0\(^\circ\) 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\% probability 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.
Similarly, the MTF at all frequencies for the vidicon in the y direction is equal to 1.0.

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

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

These are the frequencies in log hertz that correspond to the noise power spectrum on 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 F0 for this example.

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

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

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.

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.
Table: Data for a simple deck.

<table>
<thead>
<tr>
<th>ENDS</th>
<th>FRC1</th>
<th>FRC2</th>
<th>FDC1</th>
<th>FDC2</th>
<th>HDRP</th>
<th>DSTP</th>
<th>DSTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0</td>
<td>12.0</td>
<td>9.0</td>
<td>3.0</td>
<td>1.0</td>
<td>0.0</td>
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<tr>
<td>37.5</td>
<td>15.0</td>
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<td>3.0</td>
<td>1.0</td>
<td>0.0</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<td>0.5</td>
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</tbody>
</table>

Figure 1.7. Continuation of a simple deck.
### Table D5(a). Input Data

<table>
<thead>
<tr>
<th>RUN NUMBER</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>YOUR SPECTRAL BAND IS</td>
<td>8.000 TO 14.000 MICRONS</td>
</tr>
</tbody>
</table>

#### OPTICS

- **Diameter**: 4.000 INCHES
- **F-Number**: 2.000
- **Focal Length**: 8.000 INCHES
- **Average Optical Transmission**: 0.600
- **Wavelength for Diffraction**: 10.000 MICRONS
- **Geometric Blur Spot Size**: 0.0 MRADE

#### DETECTOR

- **HORIZONTAL IF0V**: 0.250 MRADE
- **VERTICAL IF0V**: 0.250 MRADE
- **Detectors in Parallel**: 60
- **Detectors in Series**: 1
- **Detector Size**: 0.00200 INCHES
- **Peak**: 2.00 10**(10)CM-SQRT(HZ)/WATT
- **Measuring Frequency of Peak**: 10000 HERTZ
- **Cold Shield Angle**: 60.000 DEGREES
- **Limiting Noise**: DETECTOR
- **Detector Response, J-DB Point**: 0.100 07 HERTZ

#### SCANNER

- **Frame Rate**: 30.000 FRAMES/SECOND
- **Scan Efficiency**: 0.750
- **Overscan Ratio**: 1.000

#### ELECTRONICS

- **Preamp, Low Freq, 3-DB Cut-Off**: 3.000 HERTZ
- **Amplifier, J-DB Point**: 0.0 HERTZ
- **E/O LED Width**: 0.0 MRADE
- **E/O LED Length**: 0.0 MRADE
- **Aperture Correction Amplitude**: 0.0
- **Aperture Correction Frequency**: 6.0 HERTZ
### Table D5(b). Input Data

**DISPLAY**

<table>
<thead>
<tr>
<th>Type</th>
<th>CRT Display</th>
<th>MRAD.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Spot Size</td>
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<td></td>
</tr>
<tr>
<td>Y Spot Size</td>
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<td></td>
</tr>
<tr>
<td>Average Brightness</td>
<td>50.000</td>
<td>FT. LAMBERTS</td>
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</tbody>
</table>

**SYSTEM**

| Horizontal FOV        | 2.700       | DEGREES |
| Vertical FOV          | 2.000       | DEGREES |
| Magnification         | 12.000      |         |
| WFOV/NFOV             | 1.000       |         |
| Noise Equiv. Delta T  | 0.00        | DEGREES C |

**STABILIZATION**

<table>
<thead>
<tr>
<th>System State</th>
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</thead>
<tbody>
<tr>
<td>X Vibration Constant</td>
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</tr>
<tr>
<td>Y Vibration Constant</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**STANDARD INPUTS**

| Eye Integration Time  | 0.200       | SECONDS |
| Threshold Signal/Noise| 2.250       |         |
Table D5(c). Input Data

<table>
<thead>
<tr>
<th>ATMOSPHERIC PARAMETERS</th>
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</thead>
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<tr>
<td>CONDITION</td>
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<tr>
<td>VISIBILITY RANGE</td>
<td>23.000 KILOMETERS</td>
</tr>
<tr>
<td>RELATIVE HUMIDITY</td>
<td>50.000 PERCENT</td>
</tr>
<tr>
<td>AIR TEMPERATURE</td>
<td>15.000 DEGREES C</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>TARGET &amp; BACKGROUND</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TARGET LENGTH</td>
<td>5.200 METERS</td>
</tr>
<tr>
<td>TARGET WIDTH</td>
<td>2.700 METERS</td>
</tr>
<tr>
<td>TARGET DELTA T</td>
<td>11.100 DEGREES C</td>
</tr>
<tr>
<td>BACKGROUND TEMPERATURE</td>
<td>12.000 DEGREES C</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>RANGE REQUIREMENTS</th>
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</thead>
<tbody>
<tr>
<td>MIN. REQUIRED RANGE FOR RECUG</td>
<td>1000 METERS</td>
</tr>
<tr>
<td>MAX. REQUIRED RANGE FOR RECUG</td>
<td>10000 METERS</td>
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<tr>
<td>RANGE INCREMENTS FOR RECUG</td>
<td>1000 METERS</td>
</tr>
<tr>
<td>MIN. REQUIRED RANGE FOR DETEC</td>
<td>2000 METERS</td>
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<tr>
<td>MAX. REQUIRED RANGE FOR DETEC</td>
<td>20000 METERS</td>
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### Table DS(d). Input Data

#### TEMPORAL MTF's

<table>
<thead>
<tr>
<th>FREQ. (LOG HERTZ)</th>
<th>0.0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.5</th>
<th>0.7</th>
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<th>1.0</th>
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<tbody>
<tr>
<td>DETECT. ROLL-OFF MTF (X)</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>DETECT. ROLL-OFF MTF (Y)</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<td>BOOST MTF</td>
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#### SPATIAL COMPONENTS MTF's

<table>
<thead>
<tr>
<th>FREQ. (CYC.*/MRAU.)</th>
<th>0.0</th>
<th>1.0</th>
<th>2.0</th>
<th>3.0</th>
<th>3.5</th>
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<tbody>
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<tr>
<td>VIDEICON MTF (X)</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>VIDEICON MTF (Y)</td>
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<td>1.00</td>
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<td>1.00</td>
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</table>

#### NOISE POWER SPECTRUM (VOLTS/SQRT(HZ))

<table>
<thead>
<tr>
<th>FREQ. (LOG HERTZ)</th>
<th>0.0</th>
<th>1.0</th>
<th>2.0</th>
<th>3.0</th>
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<th>4.0</th>
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<th>6.0</th>
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<tbody>
<tr>
<td>POWER (TIMES 10**(-4))</td>
<td>32.00</td>
<td>16.00</td>
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</table>

#### D* OF DETECTOR (CM.*SQRT(HZ) /MATT)

<table>
<thead>
<tr>
<th>WAVELENGTH (MICKONS)</th>
<th>0.00</th>
<th>0.50</th>
<th>0.90</th>
<th>1.50</th>
<th>1.80</th>
<th>1.80</th>
<th>12.00</th>
<th>15.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>D* (TIMES 10**(-3))</td>
<td>0.45</td>
<td>0.52</td>
<td>0.75</td>
<td>0.80</td>
<td>0.83</td>
<td>0.92</td>
<td>1.20</td>
<td>0.90</td>
</tr>
<tr>
<td>DETECTION &amp; RECOGNITION PROBABILITY DENSITY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------</td>
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<td></td>
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<tr>
<td>DETECTION FREQUENCY</td>
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<td>OPTIMISTIC RECOG. FREQ.</td>
<td>37.50</td>
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<td>3.00</td>
<td>2.25</td>
<td>1.50</td>
</tr>
<tr>
<td>CONSERVATIVE RECOG. FREQ.</td>
<td>50.00</td>
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<td>12.00</td>
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<td>6.00</td>
<td>4.00</td>
<td>3.00</td>
<td>2.00</td>
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<td>PROBABILITY</td>
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<td>FREQ</td>
<td>OPTICS</td>
<td>GOBLUR</td>
<td>DETEC</td>
<td>RSPNS</td>
<td>ELECT</td>
<td>BOOST</td>
<td>VICK</td>
<td>LCD</td>
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<td>------</td>
<td>--------</td>
<td>--------</td>
<td>-------</td>
<td>-------</td>
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<td>------</td>
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</table>
Table D6(b). Output Data

<table>
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<tr>
<th>SYSTEM MODULATION FREQ</th>
<th>TRANSFER FUNCTION X MTF</th>
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<tr>
<td>0.20</td>
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Table D6(d). Output Data

DELTA T = 0.111E 02
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WFOV PERFORMANCE

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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. NE\( \Delta \)T
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.
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### Table D7(c). Long Output Data

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Table D7(d). Long Output Data

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- Exact Noise Bandwidth = 0.168E 05
- White Noise Bandwidth = 0.139E 05
- Scan Velocity In Mm/Sec = 0.441E 04
- Det Noise Limited Net = 0.130E 00

159
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Table D7(f). Long Output Data

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Table D7(g). Long Output Data

RECOGNITION PERFORMANCE
TARGET DELTA TEMPERATURE IS 11.12 DEGREES C
TEMPERATURE DEPENDANT PERFORMANCE

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### Table D7(h). Long Output Data

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TARGET DELTA TEMPERATURE IS 11.10 DEGREES C
POWER DEPENDANT PERFORMANCE

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Table D7(i). Long Output Data

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Table D7(c). Long Output Data

Detection based on model target delta temperature is 11.10 degrees C

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Table D7(i). Long Output Data

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</tr>
<tr>
<td>8.00</td>
<td>0.32</td>
</tr>
<tr>
<td>10.00</td>
<td>0.26</td>
</tr>
<tr>
<td>12.00</td>
<td>0.21</td>
</tr>
<tr>
<td>14.00</td>
<td>0.17</td>
</tr>
<tr>
<td>16.00</td>
<td>0.14</td>
</tr>
<tr>
<td>18.00</td>
<td>0.12</td>
</tr>
<tr>
<td>33.00</td>
<td>0.10</td>
</tr>
</tbody>
</table>

| POWER DEPENDENT PERFORMANCE |
| RANGE AT A TRANS |
| X DET P | Y DET P | 45 DET P |
|---|---|---|---|---|---|
| 2.00 | 0.60 | 1.03 | 1.00 | 1.00 |
| 4.00 | 0.31 | 0.96 | 0.96 | 0.97 |
| 6.00 | 0.40 | 0.84 | 0.84 | 0.83 |
| 8.00 | 0.32 | 0.61 | 0.61 | 0.59 |
| 10.00 | 0.26 | 0.43 | 0.43 | 0.41 |
| 12.00 | 0.21 | 0.28 | 0.28 | 0.28 |
| 14.00 | 0.17 | 0.17 | 0.17 | 0.15 |
| 16.00 | 0.14 | 0.10 | 0.10 | 0.09 |
| 18.00 | 0.12 | 0.07 | 0.07 | 0.06 |
| 20.00 | 0.10 | 0.06 | 0.06 | 0.06 |

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for hand calculations of performance. Such calculations may be used to check the pro-
gram 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 perform-
ance 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 \text{NEAT} of
the system.

Table D7(f) contains various predicted system MRT's. Those in the x-direction
\text{(XMRT)} and y-direction \text{(YMRT)} correspond to laboratory measurements. \text{XLMRT}
and \text{YLMRT} are MRT's in the x and y directions adjusted so that the length of a super-
imposed bar pattern will match the target length. These MRT's are used in the calcu-
lation of performance. The 45° MRT is the square root of the sum of the squared x di-
rection 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 cri-
teria based on 4 cycles and 3 cycles, respectively. Note that the short listing displays the
conservative prediction.

\section{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 \text{DONE} card after the last card in
Figure D7. When we change this card to an \text{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, how-
ever, 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 \( \Delta T \). 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 \( \Delta T_{AVG} \) 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°C background which may be a true representation of a sky background. To dodge this fault, input 0.00°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 \((\text{IRMAX} - \text{IRMIN})/9\) 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 \((\text{IRDAX} - \text{IRDIN})/9\). 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

\[
\text{RANGE} = \frac{XHTAR \times 1000}{LMTAX \times XCYCLES}
\]

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

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

* I – low water vapor content.
   II – moderate water vapor content.
   III – high water vapor content.
Figure D.1: 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, NEAT, 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 relations:

\[ FNUMB = \frac{FOC}{\text{Diameter of the objective lens (inches)}}. \]

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 handled checked by the user for consistency is

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

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 (\(r_0\)) 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 II, par. A1, MTF, OPTICS, equation (11), and is repeated below for further reference:
\[ H_{\text{BLUR}} = \exp \left( -bf_x^2 \right) \]

where \( f_x \) is the spatial frequency in cycles/milliradian and \( b \) is ABLUR in square mrad. 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:

\[ e^{-1} \]

\[ X \text{ (MRAD)} \]

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

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

• $\text{ABLUR} = \frac{\pi^2}{\alpha}$ from equation (11).

• In this case, $\text{ABLUR} \; \pi^2 w^2$ is the input.

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

\[ \begin{align*}
\text{Given this } w, \quad &e^{-\alpha x^2} = e^{-1} \text{ at } w/2 \text{ or } \alpha = 4/w^2. \\
\text{MTF} \quad &= e^{-\pi^2 f^2 / \alpha} \\
\text{ABLUR} \quad &\approx \pi^2 / \alpha \\
\text{ABLUR} \quad &= \pi^2 \; w^2 / 4 \text{ is the input.}
\end{align*} \]

(c) Another common measurement of spot size is the 50% point of the spread function:
\[
\begin{align*}
\bullet \ e^{-\alpha x^2} &= .50 \text{ at } w/2 \text{ or } \alpha = \frac{-\ln(.50)}{w^2} \\
\bullet \ \text{MTF} &= e^{-\pi^2 r^2 / \alpha} \\
\bullet \ \text{ABLUR} &= \frac{\pi^2}{\alpha} \\
\bullet \ \text{ABLUR} &= \frac{\pi^2 w^2}{-4 \ln(.50)} \text{ is the input.}
\end{align*}
\]

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

\[
\begin{align*}
\bullet \ e^{-\alpha x^2} &= .50 \text{ at } w/2 \text{ or } \alpha = \frac{-4 \ln(.50)}{w^2} \\
\bullet \ \text{MTF} &= e^{-\pi^2 r^2 / \alpha} \\
\bullet \ \text{ABLUR} &= \frac{\pi^2}{\alpha} \\
\bullet \ \text{ABLUR} &= \frac{\pi^2 w^2}{-4 \ln(.50)} \text{ is the input.}
\end{align*}
\]

(e) The user may develop his own techniques.

3.4 \( XLAM 3 - XLAMB \) is the wavelength of diffraction (\( \lambda \)) 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 3.0 or a blank is input as XLAMB, the program sets XLAMB = \((\text{WAVE1+WAVE2})/2.0\) 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 NEAT, 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 (FR) 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

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

where DELTAY is the vertical instantaneous field of view of the detector input on card DETK 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). DELTAY (Δy) is used in MRT calculations, equations (26) and (27), and in the MDT calculation, equation (28). Interactions with other system inputs include:

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

and

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

5.2 XN — XN is the number of active detectors in parallel. XN > 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 > 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:

\[
\text{SRTAD} = \sqrt{\text{width of the detector (mils)} \times \text{height of the detector (mils)}}
\]

SRTAD > 0.0. SRTAD is used in the NEΔT calculation in equations (24) or (25). It interacts with other inputs by

\[
\text{DELTAX} = \text{SRTAD}/\text{FOC}. \quad \text{(for square detectors)}
\]
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 $D^*(\lambda, f_o) = DPEAK \times DDSTAR$.

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 NEAT 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 NEAT calculation. If MOM = 0.0, the NEAT for a detector-noise-limited system in equation (24) is computed:

$$NEAT = \frac{4f^2 (\Delta f_n)^5}{\pi A_d^5} r_o \tau_s \sqrt{N} \int_{\Delta \lambda} D^*_\lambda n^*_\lambda d\lambda$$

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

$$NEAT = \frac{4f^2 (\Delta f_n)^5 \sin (\theta/2)}{\pi A_d^5} \tau_s \tau_o f_s \sqrt{N} \int_{\Delta \lambda} D^*_{**} n^*_\lambda d\lambda$$

where $\Delta f_n$ 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 NEAT is calculated by equation (24): however, $\Delta f_n$ 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 $X^P$ on card DROX or $Y^D$ on card DROY is not zero. 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
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^½ is adjusted to 1.0 at frequency F0, 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.
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. NEAT, equation (21), \( S(f) \); in the calculation of \( Q \) in Section III, par. C, MRT, equation (26) and \( Q_0 \) 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 DSTI follow:

5.13 DDSTAR - DDSTAR is a relative spectral curve of the \( D^* (\lambda, f_0) \) which has been normalized to 1.0 at DPEAK.

\[
DDSTAR_\lambda = \frac{D^* (\lambda, f_0)}{DPEAK}
\]

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 NEAT calculations in equations (24), \( D^* \), and (25), \( D^{**} \).

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

![Diagram](image)

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). The electronic MTF ($H_{ELECT}$) is predicted only if
array $X_E$ 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 multiplexer LED. If the system has no multiplexer, 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 $X_K$, $FMAXF$ - $X_K$ is the amplitude of the electronic boost at frequency $FMAXF$. If the system does not have an electronic boost, then $X_K$ and $FMAXF = 0.0$. If a predicted boost MTF is desired as in equation (16), ($H_p$), then $X_K(K) > 0$, $FMAXF(f_{MAX}) > 0$, 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 $X_K = 0.0$ and $FMAXF = 0.0$.

Notes on card $EMTF$ follow:

6.4 $X_E$ - $X_E$ is the MTF of the electronics. $X_E$ is an array of 10 values which correspond to the increasing frequencies of array $FQQ$ on card $FLHZ$. All values of $X_E$ 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 $X_K$ 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 $YTV$. 

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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

\[ H_{\text{CRT}}(f) = \exp(-af^2). \]

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:

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

and

\[ H_N(f_y) = H_{\text{VID}} \cdot H_{\text{LED}} \cdot H_{\text{LOS}} \cdot H_{\text{DISPLAY}} \]

where

- \( H_{\text{ELECT}} \) = electronic MTF
- \( H_B \) = boost MTF
- \( H_{\text{VID}} \) = vidicon MTF
\[ H_{\text{LED}} = \text{LED MTF} \]
\[ H_{\text{LOS}} = \text{stabilization MTF} \]
\[ H_{\text{DISPLAY}} = \text{display MTF}. \]

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, NEAT, 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:

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

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 > 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:

\[
\text{XMAG} = \frac{\text{display size (in.)} \times 100}{\text{viewing distance (in.)} \times \text{VFOV} \times 17.45}
\]

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 calcula-
tion, 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 > 2.0 and WAVE2 < 16.0. Throughout this report,
wavelength is noted by λ and the spectral bandpass, by Δλ.
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 or 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 > 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.

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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), \( \tau_e \), 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:

\[
\text{EYETM} = 0.2 \times \frac{\text{vertical IFOV}_\text{LED}}{\text{vertical IFOV}_\text{DET}}
\]

where the vertical IFOVLED is the input variable YA for an LED display on card DISP and IFOVDET 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, FDCI, 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, FDCI, 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 (V) 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, FDCI 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 FDCI, 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 FQO 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 (H₂O, CO₂, 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

\[
X_L = \frac{1.6}{20.9 \text{DELTAX}}
\]

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 \(10^{-3} \, ^\circ\text{C}\).

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. IAFLAG is the variable used to indicate batch (IAFLAG = 0) or interactive (IAFLAG = 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.
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 in 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 OPTI card. Check Supplement 3 in order to identify the problem.