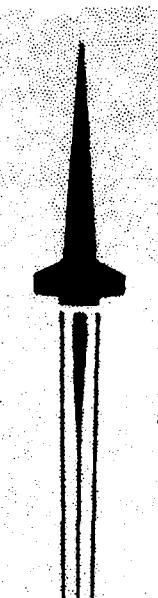
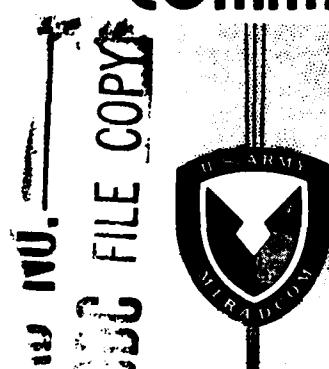


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Redstone Arsenal, Alabama 35809

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TECHNICAL REPORT T-78-16

METHODS FOR PREDICTION OF ATMOSPHERIC
EFFECTS ON LASER GUIDANCE SYSTEMS

J. Q. Lilly
Advanced Sensors Directorate
Technology Laboratory

15 November 1977

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes mathematical models which predict effects of atmospheric turbulence, molecular absorption and scattering, aerosol absorption and scattering, and radiative transport. Turbulence-induced angle-of-arrival fluctuations of a laser target designator are formulated to permit calculation of the fluctuation power spectrum. A numerical procedure employing the fast Fourier transform is used to convert the frequency-dependent power spectrum into the time domain ABSTRACT (Continued) <i>Part 1</i> | | |

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ABSTRACT (Concluded)

giving angular beam wander. A separate computation gives the angular beam-spread due to atmospheric turbulence.

Descriptions of other models to determine molecular line absorption and aerosol absorption and scattering are also given. Models developed during this effort also provide first-order radiative transfer predictions and a multiple scattering model using Monte Carlo predictions. Utilization instructions are included for each of the models.

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I. INTRODUCTION

Laser guidance systems operating in the atmosphere are affected by several phenomena which tend to degrade the transmitted laser beam and result in poorer performance than would be obtainable in vacuum transmission. Of these phenomena, the major contributors to beam degradation are direct attenuation of the beam's energy by absorption, spreading and motion of the beam due to random index-of-refraction variations within the atmosphere, and scattering of the electromagnetic radiation by atmospheric particles.

Direct attenuation of the transmitted energy occurs from molecular absorption by the various constituents in the atmosphere and absorption by aerosol particles present in the atmosphere. Molecular absorption occurs at selected lines or frequencies and varies greatly over fairly narrow frequency intervals. Aerosol absorption, however, remains nearly constant for a given particle over wide ranges in frequency of the transmitted energy. Methods are presented in this report for determining the absorption coefficients for molecules and aerosols.

Index-of-refraction variations in the atmosphere occur from heat transfer processes which produce air temperature inhomogeneity or turbulence. Movement of these random fluctuations in air temperature across the path of a transmitted laser beam caused by wind or beam sluing result in the beam wandering and spreading about its original aim point. Thus, the energy distribution or "spot" produced at a distance downrange of the transmitter does not remain constant, but enlarges and wanders about the "target" area. This turbulence-induced beam "jitter" or wandering adds an additional component to that already produced in the guidance system. This report describes a new analytical method for rapidly predicting spot movement and size as a function of transmitter characteristics, refractive index structure constant, and effective wind speed across the beam.

Air molecules and other particles such as dust, haze, fog, or smoke, which are present in the atmosphere, degrade a laser beam by scattering part of the energy out of the path of the beam. For particles very small relative to the laser wavelength, the angular distribution of the scattered energy can be easily determined. For particle sizes of the same order as the wavelength or larger, however, the theory becomes more complex and extensive calculations are required. Analytical methods suitable for making these calculations are well developed for most particles of interest, but the physical data required are not adequate in many cases. For example, the complex indices-of-refraction and particle size distributions of many aerosols are not well known.

This effort was undertaken to provide methods that could be used to make predictions of the effects of the atmosphere on a terminal homing laser guidance system. Available procedures and methods were

reviewed and those adequate for the present application have been adapted for use. Scientific support was obtained to provide help in developing new procedures and modifying existing models. In particular, the efforts of Dr. D. L. Fried of Optical Sciences Consultants provided the basis for the turbulence beam wander model and the support of W. G. Blattner, D. G. Collins, and M. B. Wells of Radiation Research Associates was obtained to modify their existing Monte Carlo radiation transport model. The molecular and aerosol attenuation models were obtained from Dr. A. Miller of New Mexico State University and Dr. R. B. Gomez at the Army Atmospheric Sciences Laboratory. An additional model for predicting first-order radiation transport for a laser designator system was developed in-house.

Descriptions are presented in the following sections of the models developed for predicting atmospheric effects encountered by a transmitted laser beam, and the Appendix provides utilization instructions. Fortran listings of the in-house developed procedures are included.

II. TURBULENCE-INDUCED BEAM WANDER MODEL

For predicting turbulence-induced wander of the laser transmitter beam the model developed by Fried [1] for calculating the power spectrum of angle-of-arrival fluctuations is used in a numerical procedure employing the fast-Fourier transform (FFT) to convert the frequency dependent power spectrum into the time domain giving the angular jitter of the beam. In this method, the power spectrum defined as the Fourier transform of the angle-of-arrival temporal coherence function is expressed as

$$F_\alpha(f) = 4 \int_0^\infty \cos(2\pi f\tau) C_\alpha(\tau) d\tau ,$$

where $C_\alpha(\tau) = \langle \alpha(t)\alpha(t + \tau) \rangle$ is the temporal coherence function of the angle-of-arrival fluctuations.

In the numerical procedure, the turbulent region between the transmitter and target (Figure 1) is subdivided into N segments of length ΔZ_i and the calculation performed for each segment is

$$F_{\alpha,i} = 1.32(10^{-2}) \left(\frac{\lambda}{D_s} \right)^2 \left(\frac{D_s}{r_{o,i}} \right)^{5/3} f_{o,i}^{-1/3} f^{-2/3} G_\alpha \left(\frac{f}{f_{o,i}} \right) ,$$

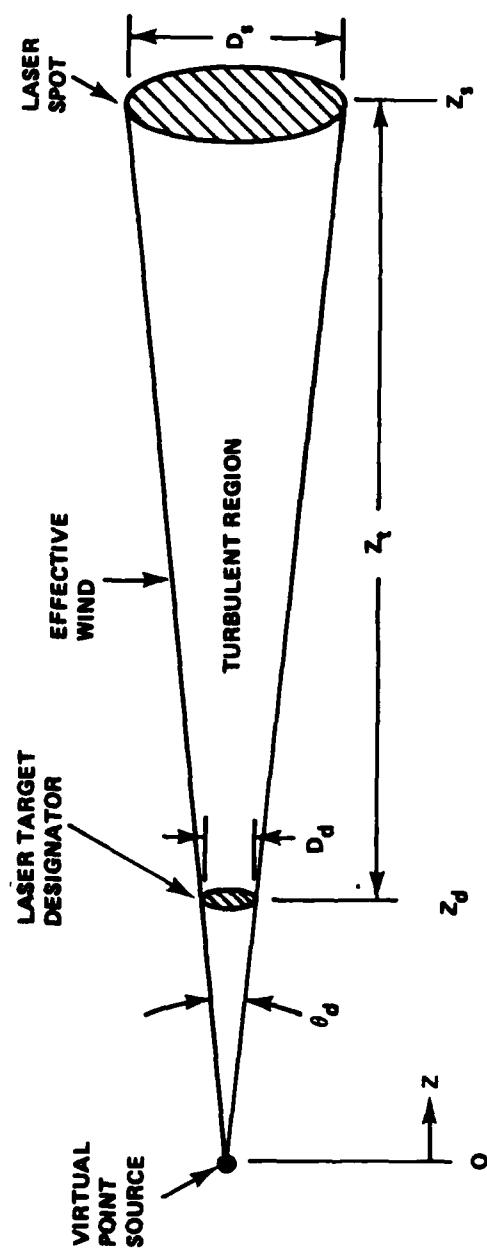


Figure 1. Geometry for turbulence-induced beam wander model.

where

λ = the laser wavelength

D_s = the spot diameter

$r_{o,i}$ = the coherence length of segment i defined by

$$r_{o,i} = \left[16.7 C_{N,i}^2 \left(\frac{\Delta z_i}{\lambda^2} \right) \left(\frac{z_i}{z_s} \right) \right]^{-3/5};$$

$f_{o,i}$ is a reference frequency given by

$$f_{o,i} = \frac{v_{eff,i}}{\pi D_s \left(\frac{z_i}{z_s} \right)}$$

and

$G_\alpha(f/f_{o,i})$ is a function which can be approximated by

$$G_\alpha\left(\frac{f}{f_{o,i}}\right) = \begin{cases} 1 & , \text{ if } 0 \leq f < 0.332 f_{o,i} \\ 1.12 - 0.361\left(\frac{f}{f_{o,i}}\right) & , \text{ if } 0.332 f_{o,i} < f < 3.1 f_{o,i} \\ 0 & , \text{ if } 3.1 f_{o,i} < f \end{cases}.$$

$C_{N,i}^2$ is the refractive index structure constant of segment i and z_i is the distance from the virtual point source to the center of segment i . $v_{eff,i}$ is the effective wind velocity across the beam at segment i and can include the effects of beam sluing by combining with the actual crosswind velocity according to

$$v_{eff,i} = v_{w,i} \pm \dot{\theta}(z_i - z_d) ,$$

where the plus or minus sign is chosen to account for the wind being opposed to or in the same direction as the angular sluing. The power spectrum for frequency f is

$$F_\alpha(f) = \sum_{i=1}^N F_{\alpha,i}(f) .$$

The variance of the power spectrum is the integral over frequency, or

$$\sigma^2 = \sum_{i=0}^M F_\alpha(f_i) \Delta f ,$$

where M is the number of frequency values chosen.

Values obtained for the power spectrum are next combined with a set of random values chosen so as to have zero mean value and unity variance. This gives a random sequence of values having the same variance as the calculated power spectrum. The relation used to form the random sequence is

$$N_r(f_i) = N_{r,i} \sqrt{F_\alpha(f_i)/\Delta t} ,$$

where $N_{r,i}$ is one of the normally distributed random values and Δt is the time interval between values in the time domain chosen so that

$$M \Delta f \Delta t = 1 .$$

A symmetric array of $2M$ values is obtained by folding the $N_r(f_i)$ array to give an equal number of negative frequency values. Fourier transforming the resulting $2M$ array gives an ordered sequence of values representing the time interval $-T \leq 0 \leq T$, where $T = M\Delta t$. The second half of this sequence represents one component of beam jitter. A second set of independent values is obtained in the same manner for the other component of angular jitter to give spot centroid motion at the target.

To obtain beam jitter for the target-to-seeker path, the power spectrum of angle-of-arrival fluctuations is determined by a similar procedure except that angle-of-arrival isoplanatism effects must be considered. The complete procedure has been discussed in detail by Fried [2]. Total power spectrum for the two paths becomes

$$F_T(f) = F_\alpha(f) + F_v(f) ,$$

where $F_v(f)$ is the power spectrum associated with the viewing process from the seeker.

The method for target spot size determination proposed by Fried [2] is to make use of his short-exposure resolution theory for the turbulence-induced and diffraction-limited beamspread. The calculation of the effective beamspread becomes

$$\theta_t = \theta_r \Phi\left(\frac{D_d}{r_o}\right) ,$$

where $\theta_r = 1.128 \lambda/r_o$ and the function $\Phi(D_d/r_o)$ is determined by evaluating the integral

$$\begin{aligned} \Phi\left(\frac{D_d}{r_o}\right) &= \left\{ \frac{16}{\pi} \left(\frac{D_d}{r_o}\right)^2 \int_0^1 u du \left[\cos^{-1} u - u(1-u^2)^{1/2} \right] \right. \\ &\quad \times \exp \left[-3.44 \left(\frac{D_d}{r_o}\right)^{5/3} u^{5/3} (1-u^{1/3}) \right] \left. \right\}^{-1/2} , \end{aligned}$$

where r_o is the coherence length for the designator path.

Total angular beamspread is determined by combining with the transmitter optical divergence according to

$$\theta_s = \left(\theta_t^2 + \theta_d^2 \right)^{1/2}$$

and the corrected spot size at the target including turbulence, diffraction, and designator optics becomes

$$D'_s = D_d + \theta_s Z_t .$$

Comparisons of the results of calculations of beamspread made by this method with the methods of others have shown differences in spot size which become quite large under conditions of strong turbulence. Resolution of these differences to determine a preferred method of calculating spot size awaits an experimental validation.

III. MOLECULAR AND AEROSOL ATTENUATION MODELS

Methods for the prediction of molecular and aerosol absorption and scattering developed for other programs were adapted for use in the present effort. Models developed for the Army Atmospheric Sciences Laboratory by Miller et al. [3] and Gomez et al. [4] are particularly applicable to the kinds of problems considered. Brief descriptions of these two models are presented in this section. Input data instructions for making calculations are included in the Appendix.

The molecular absorption and scattering model [3] uses the AFGL (formerly AFCRL) line parameters compilation [5] and computes high resolution molecular absorption, molecular continuum absorption, and Rayleigh scattering coefficients. Property data for the 1962 US Standard Atmosphere are built into the model, or alternate tables of atmosphere data may be user supplied. Line shape options include Lorentzian, generalized Voigt, and collision narrowed line profiles. The output provided by this model are the absorption coefficient, Rayleigh scattering coefficient, and transmittance for the frequency range specified.

Calculations performed by the attenuation model [4] for aerosols are based on standard Mie theory for homogeneous spheres and provide the scattering and absorption coefficients as well as the phase function data necessary for radiative transfer calculations. Input data required are the laser wavelength, index-of-refraction, size distribution, and particle density of the scattering medium. Several size distributions are provided as "built-in" options, or the user may supply size distribution and particle density from measured data. Output from this model may be obtained in punched card form for use as input into radiative transfer models or this model may be used simply as a subroutine in the RT model as in the present application.

IV. RADIATION TRANSPORT MODELS

To predict the effects of radiation absorption and scattering on a laser guidance system, a method to determine the amount of energy reaching the target and receiver is required. Under conditions of only moderate aerosol densities, methods which consider first-order or single scattering effects are usually adequate. Under conditions of very dense aerosols such as heavy fog or smoke in the transmitting region, however, second and higher order scattering effects become important, and more complex procedures are required. Models using both methods of approach to radiation transfer were developed during this effort. An existing Monte Carlo method for performing multiple scattering calculations modified and adapted to the present problem is described in a separate report [6]. The remainder of this section presents a method employing first-order scattering.

The geometry for the model presented here consists of a laser transmitter, an absorbing and scattering medium, the target, and a receiver viewing the target (Figure 2). The target receives energy by direct transmission and by scattering from aerosol particles located in the beam and reflects part of the energy received. Energy reaches the receiver by reflection from the target and by scattering from aerosol particles in the transmitter beam located within its field-of-view. The transmitting range is divided into segments and the procedure is used to calculate the energy scattered from each segment to the target and to the receiver. The target area is divided into annular rings to determine the distribution of scattered and directly transmitted energy.

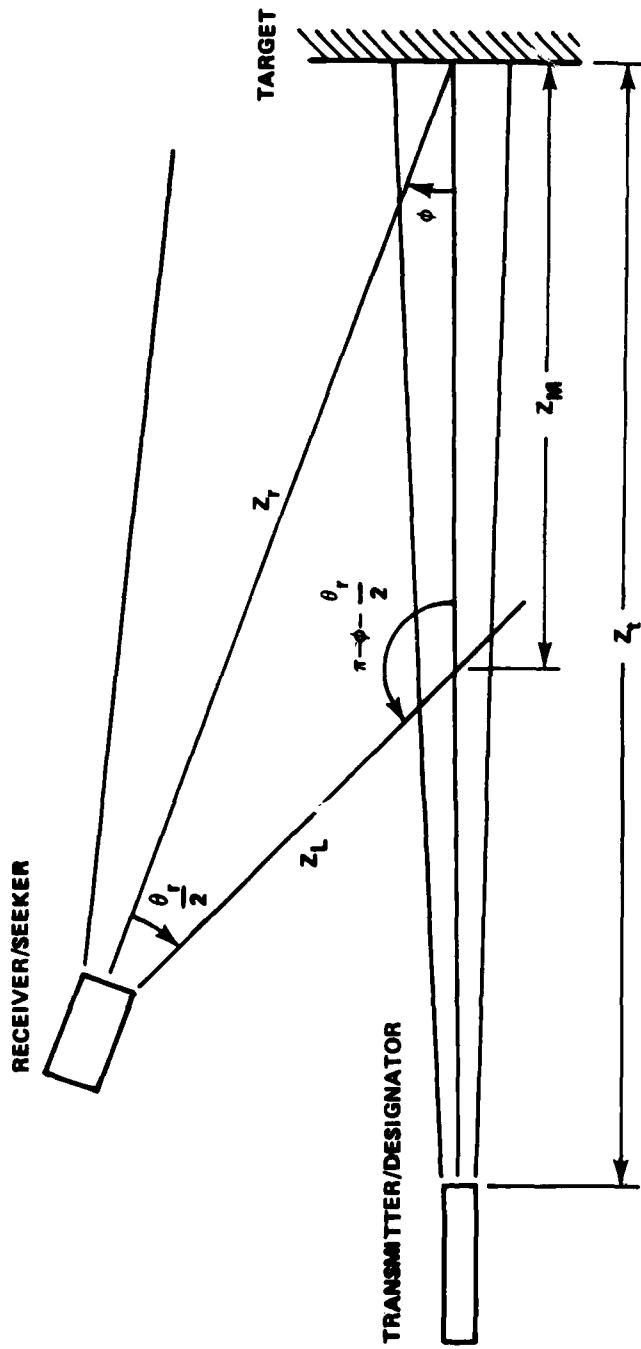


Figure 2. Geometry for first-order radiative transfer model.

The basic relationship used in making the calculations of energy scattered to each area receiving radiation from a segment of length ΔZ becomes

$$P_{s,i} = P_o e^{-\sigma Z_i} (1 - e^{-\sigma \Delta Z}) \omega P(\theta_i) \left(\frac{A_r}{r_i^2} \right) e^{-\sigma r_i} ,$$

where

P_o = the transmitter output power

σ = the total attenuation coefficient due to scattering plus absorption

Z_i = the range to the center of the scattering segment

ω = the albedo or ratio of scattering to total extinction

$P(\theta_i)$ = the normalized phase function at the angle θ_i to the receiving area A_r

r_i = the path distance from the center of the scattering segment to the receiving area and the last term accounts for attenuation along r_i .

The total energy reaching the target area from N segments plus directly transmitted radiation is

$$P_t = P_o e^{-\sigma Z_t} + \sum_{i=1}^N P_{s,i} .$$

The scattered energy is summed over all the annular areas of the target and the sum over N segments gives the total energy scattered to the target (neglecting higher order scattering). For the directly transmitted radiation, a gaussian distribution is assumed and the average intensity is computed for each annular area from scattered and directly transmitted radiation.

Reflected energy from the target (assumed to be a diffusely reflecting surface) that reaches the receiver is computed by the relation

$$P_{r,t} = \rho P_t \frac{\cos \Phi}{\pi} \left(\frac{A_r}{Z_r^2} \right) e^{-\sigma Z_r} ,$$

where

ρ = the target reflectivity

ϕ = the receiver viewing angle to the target normal

A_r = the receiver area

Z_r = the range from the target to receiver.

For a receiver with field-of-view θ_r viewing the target at angle ϕ to the incident beam, the beam length Z_M seen by the receiver is

$$Z_M = \frac{Z_r \sin\left(\frac{\theta_r}{2}\right)}{\sin \gamma} ,$$

where $\gamma = \pi - \phi - \theta_r/2$ and the distance from the receiver to the beam intersection point Z_L is given by

$$Z_L = \frac{Z_r \sin \phi}{\sin \gamma} .$$

The path length Z_M is divided into M segments of length ΔZ_M ; the relation used to determine the energy reaching the receiver from all segments becomes

$$P_{r,s} = \sum_{i=1}^M P_o e^{-\sigma Z_i} \left(1 - e^{-\sigma \Delta Z_M}\right) \omega P(\gamma_i) \left(\frac{A_r}{Z_{L_i}^2}\right) e^{-\sigma Z_{L_i}} ,$$

where γ_i is the angle (counterclockwise) from each segment to the receiver and Z_{L_i} is the distance from the center of each segment to the receiver. The total energy reaching the receiver by reflection and scattering becomes

$$P_r = P_{r,t} + P_{r,s} .$$

In practical cases of interest to the Army, the laser transmitting region consists of a clear atmosphere over most of the path and a smoke cloud or heavy aerosol concentration over the remaining distance. Provision has been made in the model described here by the introduction of

a parameter, Z_{cloud} , giving the distance from the transmitter to the beginning of the aerosol cloud. Then, in performing the computations, if $Z_i < Z_{\text{cloud}}$, no absorption or scattering takes place. When $Z_i \geq Z_{\text{cloud}}$, the computations are performed as previously shown. Similarly, in performing the computation of energy reflected and transmitted to the receiver, no attenuation takes place once the cloud has been exited.

Appendix. UTILIZATION INSTRUCTIONS

All of the models discussed in this report have been adapted for use on the Army Missile Materiel Readiness Command (MIRCOM) CDC 6600 computer at Redstone Arsenal. This appendix describes briefly the input data required for each of the computer models and contains Fortran listings of the in-house developed models. Instructions for use of the Monte Carlo radiation transport model is presented in a separate report prepared by Radiation Research Associates personnel [7].

1. Turbulence-Induced Beam Wander

Required input data for the turbulence-induced beam wander model consists of run options, laser transmitter characteristics, range and time period, tables of refractive index structure constant, C_N^2 , and windspeed for transmitter and seeker paths, array sizes for frequency, and range segments. The following list contains input data card formats, variables read on each card, and a description of each variable. The CDC 6600 computer program library must be attached for each run.

| <u>Card</u> | <u>Description</u> |
|-------------|---|
| 1 | IOPT, NRUNS Format (2I4) IOPT = 1, calculations for designator path only = 2, calculations for designator and receiver paths NRUNS = Number of cases to be run. A complete set of the remaining data cards are required for each case. |
| 2 | LAMB, DIAM, THET, TDOT, RANG, TIME Format (6E10.4) LAMB = laser wavelength in meters DIAM = diameter of laser designator aperture in meters THET = beamspread angle of laser designator in radians TDOT = angular slew rate of laser designator in radians/second RANG = distance from designator to target in meters TIME = time duration of beam wander calculation in seconds |
| 3 | N, M, N2 Format (3I4) N = Number of segments in designator path M = number of frequencies in power spectrum calculations N2 = Number of segments in seeker to target path. Not needed if IOPT = 1. |

| <u>Card</u> | <u>Description</u> |
|-------------|---|
| 4 | CN(I), I = 1, N Format (7E10.4) CN(I) = values of C_N^2 for laser designator path in (meter) $^{-2/3}$. One value required for each segment. |
| 5 | V1(I), I = 1, N Format (7E10.4) V1(I) = values of crosswind velocity for designator path in meters/second. One value required for each segment. Note: If IOPT = 1, no more cards are needed. If IOPT = 2, the following cards are required. |
| 6 | D1V, R1V Format (2E10.4) D1V = seeker aperture diameter in meters R1V = seeker range to target in meters |
| 7 | CN2(I), I = 1, M Format (7E10.4) CN2(I) = values of C_N^2 for seeker path in (meter) $^{-2/3}$. One value required for each segment. |
| 8 | V2(I), I = 1, M Format (7E10.4) V2(I) = values of crosswind velocity in seeker path in (meter) $^{-2/3}$. One value required for each segment. |

2. Molecular Attenuation Model

The following list presents the data input needed for the molecular absorption model in use at the US Army Missile Research and Development Command (MIRADCOM). This information was extracted from the report by Miller et al. [3] which included additional input information. Spectroscopic data required are obtained from the AFGL tape which must be requested from the MIRCOM tape library for each run. The current serial number of the AFGL data tape used is S08997.

| <u>Card</u> | <u>Description</u> |
|-------------|---|
| 1 | ALTI, ELVTN, DIST, IHR, ICM, IRL, IAL, ID Format (3F5.1, 4I1, 60X, I1) ALTI = initial altitude of path in kilometers ELVTN = angle of elevation in degrees of path from the horizontal |

| <u>Card</u> | <u>Description</u> |
|-------------|--|
| 1 | <p>DIST = distance of path in kilometers IHR = digit 1 to include high resolution molecular line absorption effects, 0 otherwise ICM = digit 1 to include molecular continuum absorption effects, 0 otherwise IRL = digit 1 to include Rayleigh scattering effects, 0 otherwise IAL = not used; leave blank or 0 ID = digit 1 in column 80</p> |
| 2 | <p>V1, V2, CINC, FINC, SETBAK, BOUND, ACY, ID Format (2F12.4, 2F10.4, 2F8.4, E10.3, 9X, I1)</p> <p>V1 = starting frequency in cm^{-1} V2 = end frequency in cm^{-1} CINC = coarse increment in cm^{-1} FINC = fine increment in cm^{-1} SETBAK = wave number interval from line centers at which reversion to FINC should occur BOUND = MAXIMUM half width of integration range ACY = a measure of accuracy desired in terms of <u>magnitude</u> or <u>transmittance</u> (not a %) ID = digit: 2 (in column 80)</p> |
| 3 | <p>NGDN, NADN, ICPN, IPRO, NP, DELV, SLIT, ID Format (5I1, F8.5, F8.4, 58X, I1)</p> <p>NGDN = number of atmospheric model or gas density versus altitude distribution - 0 (zero) for US 1962 Standard Atmosphere - 9 for user supplied atmospheric model NADN = not used; leave blank or 0 ICPN = 0 for continuum calculation only at one wavenumber (the average value of VU and VL will be used ordinarily) - 1 for continuum calculation at every high-resolution wavenumber IPRO = 0 for Lorentzian line profiles - 1 for collisionally-narrowed line profiles - 2 for generalized Voight profile NP = not used; leave blank or 0 DELV = increment in cm^{-1} for frequencies at which transmission results are degraded SLIT = half width of response function (triangular) SLIT = 0.0 prevents convolution by the triangular slit ID = digit; 3 (in column 80)</p> |

| <u>Card</u> | <u>Description</u> |
|-------------------------|--|
| 4 (One per altitude) | ALT(I), P(I), TEMP(I), AIR(I), H2O(I), O3(I), G8(I), G9(I), G10(I), ID Format (F5.1, E10.4, F5.1, E10.4, E9.3, E9.3, 3E10.4, 1X, I1) ALT(I) = altitude in kilometers for ith data set for gases P(I) = pressure in mb at ALT(I) TEMP(I) = temperature in degrees Kelvin at ALT(I) AIR(I) = density of air in g/m ³ at ALT(I) H2O(I) = density of water vapor in g/m ³ at ALT(I) O3(I) = density of ozone in g/m ³ at ALT(I) G8(I), G9(I), G10(I) = densities of additional optional gases in mol/cm ³ at ALT(I) ID ≠ digit 4 (column 80) |
| 5 | DALT(I), DENS(I), ID Format (F5.1, E10.3, 64X I1) DALT(I) = altitude in kilometers for ith data set for aerosols DENS(I) = density of aerosols in particles/cm ³ at DALT(I) ID = digit 5 (column 80) A final type 5 carrying DALT() = 999.0 is required Note: Type 4 and 5 are needed only if the user wishes to insert his own density versus altitude models for (Type 4) gases and/or (Type 5) aerosols. Each type requires one card per altitude. |

3. Aerosol Attenuation Model

Input data required for the aerosol attenuation model have changed somewhat from the format presented by Gomez et al. [4], but the calculations performed remain essentially the same. Additional size distribution options have been built into the model and the input data have been rearranged slightly. This model is used to provide the phase functions and aerosol attenuation coefficients for the First-Order Radiation Transport (FORT) model.

| <u>Card</u> | <u>Description</u> |
|-------------|--|
| 1 | WAVE, DENS Format (2E12.6) WAVE = laser wavelength in micrometers DENS = particle density in particles/cc |

| <u>Card</u> | <u>Description</u> |
|-------------|---|
| 2 | <p>IDSTP, NRADI, NCRDS, IT, MQRTE, MCRTE Format (6I5)</p> <p>IDSTP = 0, 1, ..., 7, size distribution option. See Card Type 3 for details.</p> <p>NRADI = number of different radii in size distribution. If IDSTP = 5, NRADI is used to give number of different ranges in size distribution.</p> <p>NCRDS = 0, for printed output only = 1, for printed and punched output</p> <p>IT = number of terms desired in the phase function expansion.</p> <p>MQRTE, MCRTE normally blank, but can be used to obtain additional printed output.</p> |
| 3 | <p>Data to be input here depend on the value of IDSTP given on Card Type 2.</p> <p>If IDSTP=0 ---- "Arbitrary" distribution F(I), R(I), I=1, NRADI Format (2E20.10), number of input cards required = NRADI F(I) = number of particles of radius R(I)</p> <p>If IDSTP=1 ---- log normal distribution RBAR, SIGMA Format (2E20.10) RBAR = mean radius SIGMA = standard deviation</p> <p>If IDSTP=2 ---- Wynn/Dawes exponential distribution RLO, RHI, CUE, A, B Format (5E12.6) RLO = lower radius of distribution in micrometers RHI = upper radius in micrometers CUE, A, B are constants in distribution</p> <p>If IDSTP=3 ---- Deirmendjian Model C. No input needed; parameters are fixed.</p> <p>If IDSTP=4 ---- Junge distribution RLO, RHI, CUE, A Format (4E10.4) RLO = lower radius in micrometers RHI = upper radius in micrometers CUE, A are constants in distribution</p> <p>If IDSTP=5 ---- Modified gamma distribution RLO, RHI, RC, ALF, GAM, DENS, NRADI Format (6E12.6, I3) Number of cards required equals value of NRADI read in Card Type 2. RLO = lower radius in micrometers RHI = upper radius in micrometers RC = mode radius in micrometers</p> |

| <u>Card</u> | <u>Description</u> |
|-------------|---|
| 3 | <p>ALF, GAM are constants in distribution DENS = particle density in this range NRADI = number of radii in this range</p> <p>If IDSTP=6 ← FOG model VIS Format (E20.10) VIS = visibility in kilometers</p> <p>If IDSTP=7 ← Hoidale dust model VIS Format (E12.6) VIS = visibility in kilometers</p> |
| 4 | <p>EM, CAY, EMM, CONC Format (4F10.6)</p> <p>EM = real part of particle index-of-refraction CAY = magnitude of imaginary part of particle index-of-refraction EMM = index-of-refraction of atmosphere usually 1.0 CONC is not used in this version: internally set to 1.0.</p> |

4. First-Order Radiation Transport (FORT) Model

The aerosol attenuation model described in the previous section is contained as subroutines in the FORT model. Data input for the FORT model consist of the three cards described in the following list of data followed by the input described in the previous section for the aerosol model. A complete Fortran listing is included at the end of this section.

| <u>Card</u> | <u>Description</u> |
|-------------|---|
| 1 | <p>LAMB, DIAM, THET, RANG, POWR, ZCLOUD Format (7E10.4)</p> <p>LAMB = laser wavelength in meters DIAM = transmitter aperture diameter in meters THET = laser beamspread angle in radians RANG = distance from transmitter to target in meters POWR = transmitter output power in meters ZCLOUD = distance from transmitter to aerosol cloud in meters</p> |
| 2 | <p>ZR, PHI, THETR, DR, RHO Format (5E10.4)</p> <p>ZR = range from target to receiver in meters PHI = viewing angle of receiver in radians THETR = field of view of receiver in radians DR = diameter of receiver aperture in meters RHO = reflectivity of target</p> |

| <u>Card</u> | <u>Description</u> |
|-------------|---|
| 3 | NZ, NR, NM Format (3I4) NZ = number of segments in transmitter path NR = number of annular areas on the target NM = number of segments in transmitter path within field-of-view of receiver. |

Card Type 4, etc., for this model begin with Card Type 1 described in previous section of this appendix.

FORTRAN LISTING OF TURBULENCE INDUCED BEAM WANDER MODEL

```

      PROGRAM MAIN(INPUT=65,OUTPUT=65,TAPES=INPUT,TAPE6=OUTPUT)
C   MICOM POINTING JITTER PROGRAM
C   CALCULATES TURBULENCE INDUCED POINTING JITTER AND POWER SPECTRUM
C   FOR LASER TARGET DESIGNATOR AND TERMINAL HOMING SEEKER
C   *****REQUIRED INPUT DATA*****
C   IOPT = 1, CALCULATIONS FOR DESIGNATOR PATH ONLY
C   2, CALCULATIONS FOR DESIGNATOR AND SEEKER PATHS
C   NRUNS = NO. OF CASES TO BE CALCULATED ( SEPARATE SET OF DATA IS
C   REQUIRED FOR EACH CASE)
C   LAMB = LASER WAVELENGTH IN METERS
C   DIAM = LASER TARGET DESIGNATOR APERTURE DIAMETER IN METERS
C   THET = LASER BEAMSPREAD ANGLE IN RADIANS
C   TDOT = LASER BEAM SLUE RATE IN RADIANS/SECOND
C   RANG = PROPAGATION RANGE FROM TARGET DESIGNATOR TO SPOT IN METERS
C   TIME = DURATION OF CALCULATION OR TEST IN SECONDS
C   CN(I) = VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT (CN)**2
C           WITH ONE VALUE FOR EACH SEGMENT OF RANGE FROM LASER
C           DESIGNATOR TO TARGET (IN METERS**(-2/3))
C   V1(I) = SET OF VALUES OF CROSWIND VELOCITY CORRESPONDING TO
C           EACH SEGMENT OF RANGE FROM LASER DESIGNATOR TO TARGET(M/SEC)
C   M = NO. OF FREQUENCIES FOR WHICH POINTING JITTER POWER SPECTRUM
C       IS TO BE CALCULATED
C   N = NO. OF SEGMENTS OF LENGTH DELZ FROM DESIGNATOR TO TARGET
C   DIV = DIAMETER OF SEEKER APERTURE IN METERS
C   RIV = RANGE FROM TARGET TO SEEKER IN METERS
C   CN2(I) = VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT FOR EACH
C           SEGMENT OF RANGE FROM TARGET TO SEEKER (METERS**(-2/3))
C   V2(I) = VALUES OF CROSWIND VELOCITY FOR EACH SEGMENT OF RANGE
C           FROM TARGET TO SEEKER
C   NZ = NO. OF SEGMENTS OF LENGTH DELIV FROM TARGET TO SEEKER
C ****
C   DIMENSION CN(20),V1(20),FO(20),R0(20),FR(1025),PS(1025),V2(20)
C   COMPLEX RAN(2048)
C   COMMON/Z/ FO,R0,LAMB
C   COMMON /XX/ CN2(20),DIV,RIV,N2
C   COMMON /YY/ RAN
C   COMMON /ZZ/ DRO
C   REAL LAMB
C   EXTERNAL DESUB,FALPH
10  FORMAT(7E10.4)
20  FORMAT(3I4)
      READ(5,20) IOPT,NRUNS
      DO 1000 LL = 1,NRUNS
      READ(5,10) LAMB,DIAM,THET,TDOT,RANG,TIME
      READ(5,20) N,M,N2
      READ(5,10) (CN(I),I = 1,N)
      READ(5,10) (V1(I),I = 1,N)
      IF(IOPT .EQ. 1) GO TO 145
      READ(5,10) DIV,RIV
      READ(5,10) (CN2(I),I=1,N2)

```

```

      READ(5,10) (V2(I),I = 1,N2)
10 FORMAT(* CALCULATION OF POWER SPECTRUM AND TURBULENCE INDUCED POI
    INTING JITTER OF A LASER TARGET DESIGNATOR//)
25 FORMAT(* CALCULATION OF POWER SPECTRUM AND TURBULENCE INDUCED POI
    INTING JITTER OF A LASER TARGET DESIGNATOR AND SEEKER//)
30 FORMAT(* LASER WAVELENGTH =*,E10.4,* METERS, DESIG. APERT. DIAM=*
    1,F10.6,* METERS, BEAMSPREAD ANGLE =*,F10.6,* RADIANS*)
40 FORMAT(* SEEKER APERT. DIAM. =*,F10.6,*METERS, RANGE FROM TARGET T
    10 SEEKER =*,F10.2,*METERS*)
50 FORMAT(* BEAM SLUE RATE =*,F10.6,*RAD/SEC, DESIGNATION RANGE =*,F
    110.2,* METERS*)
55 FORMAT(* DURATION OF TEST IS *,F10.4,* SECONDS*)
60 FORMAT(* NO. OF SEGMENTS IN DESIGNATOR PATH =*,I3/)
65 FORMAT(* NO. OF SEGMENTS IN SEEKER PATH = *,I3/)
70 FORMAT(* NO. OF FREQUENCIES FOR WHICH POWER SPECTRUM IS TO BE CAL
    CULATED =*,I4//)
80 FORMAT(* VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT AND WIND S
    1PEED IN DESIGNATOR PATH*)
85 FORMAT(* VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT AND WIND S
    1PEED IN SEEKER PATH*)
90 FORMAT(* SEGMENT NO. = *,I2,* , REF. INDEX STRUCTURE CONST. =*,E12
    1.6,* (METER)2/3 , WIND SPEED =*,F10.4,* METER/SEC*)
100 FORMAT(* VALUES OF FREQUENCY FOR WHICH POWER SPECTRUM CALCULATIO
    NS ARE TO BE MADE*)
110 FORMAT(5F16.6)
115 FORMAT(10E12.4)
120 FORMAT(* FOR FREQUENCY OF *,F10.4,* HERTZ, THE CALCULATED POWER S
    PECTRUM IS *E12.4,* , THE VARIANCE IS*E12.4*)
130 FORMAT(1H0)
140 FORMAT(1H1)
145 CONTINUE
      WRITE(6,140)
      IF(IOPT .EQ. 1) WRITE( 6,25)
      IF(IOPT .EQ. 2) WRITE( 6,30)
      WRITE(6,40) LAMB,DIAM,THET
      IF(IOPT .EQ. 2) WRITE( 6,45) DIV,RIV
      WRITE(6,50) TDOF,RANG
      WRITE(6,55) TIME
      WRITE(6,60) N
      IF(IOPT .EQ. 2) WRITE(6,65) N2
      WRITE(6,70) M
      WRITE(6,80)
      DO 150 I = 1,N
150  WRITE(6,90) I,CN(I),V1(I)
      WRITE(6,130)
      IF(IOPT .EQ. 1) GO TO 156
      WRITE(6,85)
      DO 155 I = 1,N2
155  WRITE(6,90) I,CN2(I),V2(I)
      WRITE(6,130)
C COMPUTATION OF TIME, FREQUENCY AND SPATIAL INCREMENTS
156 CONTINUE
      DELT = TIME/M $DELF = 1./TIME
      DELZ = RANG/FLOAT(N) $DELIV = RIV/FLOAT(N2)

```

```

      MM = M + M $M1 = M + 1 $MM1 = MM + 1 $MM2 = MM + 2
      MSQ = SQRT(FLOAT(MM))
      DO 160 I = 2,M1
      FR(I) = (I - 1)*DELF
160 CONTINUE
      R2 = DIAM/THET
      R = RANG + R2
      D2 = DIAM + THET*RANG
C COMPUTATION OF EFFECTIVE WIND VELOCITY, COHERENCE LENGTH AND
C NORMALIZATION FREQUENCY FOR EACH SEGMENT OF PATH FROM LASER
C DESIGNATOR TO TARGET
      ZI = R2
      Z1 = UELZ/2.
      ROT = 0.0
      DEL = 0.0
      DO 200 I = 1,N
      ZI = ZI + Z1
      Z1 = UELZ
      VEI = V1(I) + TDOT*(ZI - R2)
      RO(I) = (16.7*DELZ*CN(I)*(ZI/R))**1.66667/(LAMB*LAMB))
      FO(I) = VEI /(3.14159*D2*ZI/R)
      RCT = ROT + RO(I)
      DEL = UELZ*CN(I)*(RANG - ZI)/RANG
      RO(I) = RO(I)**(-.6)
200 CONTINUE
      ROT = ROT**(-.6)
C COMPUTATION OF BEAM SPREAD ANGLE DUE TO TURBULENCE AND DIFFRACTION
C COMPUTATION OF SPOT DIAMETER ON TARGET
      DRD = DIAM/ROT
      CALL IGRAT(0.,1,.01,1,DESUB,RDRD)
      RDRO = 1.0/(SQRT(5.092958*(DRD)**2*RDRD))
      THET12 = 1.128*LAMB/ROT*RDRD
      DTHER = SQRT(THET12**2 + THET**2)
      D22= DIAM + DTHER*RANG
      WRITE(6,210) D2,R2,R,DEL,D22
      WRITE(6,240)
      WRITE(6,110) (RO(I),I=1,N)
      WRITE(6,130)
      WRITE(6,245)
      WRITE(6,110) (FO(I),I=1,N)
210 FORMAT(* SPOT DIAM. =*,E12.6,*, R2 =*,F10.4,*, R1+R2 =*,F10.4,*,,
1   DEL = *,E12.6,*, TURB. INDUCED SPOT DIAM. = *E12.6/)
240 FORMAT(* VALUES OF RO(I), I = 1, N*/)
245 FORMAT(* VALUES OF FO(I), I = 1, N*/)
C COMPUTATION OF ANGLE OF ARRIVAL POWER SPECTRUM OF LASER DESIGNATOR
      F2 = 0.
      PS(1) = 0.
      DO 300 J = 2,M1
      F = FR(J)
      F1 = 0.
      CALL SPEC(F,F1,D2,N)
      PS(J) = F1
      IF(IOPT .EQ. 1)PS(J) = F1*(D2/DIAM)**2
      F2 = F2 + PS(J)*DELF

```

```

IF(J .LT. M)GO TO 300
IF(IOPT .EQ. 1)WRITE(6,120)F,PS(J),F2
300 CONTINUE
IF(IOPT .EQ. 1) GO TO 306
C COMPUTATION OF EFFECTIVE WIND VELOCITY, COHERENCE LENGTH AND
C NORMALIZATION FREQUENCY FOR EACH SEGMENT OF PATH FROM
C TARGET TO SEEKER
ZI = 0. $Z1 = DEL1V/2.
DO 220 I = 1,N2
ZI = ZI + Z1
Z1 = DEL1V
VEI = V2(I) + TDOT*(RANG - ZI)
R0(I) = (16.7*DEL1V*CN2(I)*(ZI/R1V)**1.66667/(LAMB*LAMB))**(-.6)
FO(I) = VEI/(3.14159*D1V*ZI/R1V)
220 CONTINUE
WRITE(6,130)
WRITE(6,2400)
WRITE(6,110) (R0(I),I=1,N2)
WRITE(6,130)
WRITE(6,2450)
WRITE(6,110) (FO(I),I=1,N2)
2400 FORMAT(* VALUES OF R0(I), I = 1, N2*/)
2450 FORMAT(* VALUES OF FO(I), I = 1, N2*/)
C COMPUTATION OF TURBULENCE INDUCED POINTING JITTER POWER SPECTRUM
C FROM TARGET SPOT TO LASER SEEKER. COMPUTATION OF TOTAL POWER
C SPECTRUM FROM LASER DESIGNATOR TO SEEKER AND POWER SPECTRUM VARIANCE
CALL THETO(THETA0,FALPH)
WRITE(6,140)
F2 = 0.
DO 305 J = 2,M1
F = FR(J)
F1 = 0.
CALL SPECT(F,F1,DIV,N2)
PS(J) = PS(J) + F1/(1.+(D2/(R1V*THETA0))**2)
PS(J) = PS(J)*(D2/DIV)**2
F2 = F2 + PS(J)*DELF
IF(J .LT. M)GO TO 305
WRITE(6,120) F,PS(J),F2
305 CONTINUE
306 CONTINUE
WRITE(6,310)
WRITE(6,115) (PS(J),J = 1,M1)
WRITE(6,130)
310 FORMAT(* CALCULATED POWER SPECTRUM VS. FREQUENCY*/)
DO 1000 L = 1,2
WRITE(6,140)
WRITE(6,320) L
320 FORMAT(* //////////////////////////////////////////////////////////////////*)
C GENERATION OF RANDOM SEQUENCE HAVING SAME POWER SPECTRUM VARIANCE
C AS INDUCED BY TURBULENCE. ADD SYMMETRIC TERMS FOR NEGATIVE
C FREQUENCIES. COMPUTE MEAN AND VARIANCE OF RANDOM ARRAY
RAN(1) = (0.,0.)
DO 350 I = 2,M1
MMM = MM2 - I

```

```

      RAN(I) = DNRMAL(0.,1.0)*SQRT(PS(I)/DELT)
      RAN(MMM) = RAN(I)
350 CONTINUE
      WRITE(6,130)
C COMPUTE AND WRITE MEAN AND VARIANCE OF RANDOM ARRAY
      WRITE(6,360)
      CALL MEANVAR(1,M)
C FAST FOURIER TRANSFORM RANDOM ARRAY
      CALL FFT(RAN,MM,+1)
      DO 450 I = 1,MM
      RAN(I) = RAN(I)/MSQ
450 CONTINUE
C COMPUTE AND WRITE MEAN AND VARIANCE OF TIME SEQUENCE.
      WRITE(6,480)
      CALL MEANVAR(M1,MM)
      WRITE(6,130)
C WRITE TRANSFORMED ARRAY VALUES CORRESPONDING TO TIME VALUES
C OF POINTING JITTER FOR ONE DIRECTION.
      WRITE(6,130)
      WRITE(6,460) DELT
      WRITE(6,115) (REAL(RAN(I)),I = M1,MM)
1000 CONTINUE
360 FORMAT(* MEAN AND VARIANCE OF RANDOM ARRAY*)
460 FORMAT(* VALUES OF POINTING JITTER AT *,F10.6,* SEC INTERVALS BEG
1 INNING AT T = 0*)
470 FORMAT(* RANDOM VALUES VS. FREQUENCY AT*,F10.4,* HZ INTERVALS*)
480 FORMAT(* MEAN AND VARIANCE OF TIME SEQUENCE*)
END
SUBROUTINE SPECT(F,F1,D2,N)
COMMON/Z/ F0(20),R0(20),LAMB
REAL LAMB
FACT = 1.32E-2*(LAMB/D2)**2
F1 =0.
DO 250 I = 1,N
IF(F .LE..332*F0(I)) G =1.
IF(F .GT..332*F0(I)) G =1.12 - .361*F/F0(I)
IF(F .GE.3.10*F0(I)) G =0.
F1 = F1 + FACT*((D2/R0(I))**5/(F*F*F0(I)))**.33333*G
250 CONTINUE
RETURN
END
SUBROUTINE DESUB(X,Y,NNEQ)
COMMON /ZZ/ DRO
1 Y=X*((ACOS(X)-X*(1.-X**2)**.5)*EXP(-3.44*(DRO*X)**1.6667*(1.-X**0.
13333)))
RETURN
END
SUBROUTINE THETO(THETA0,FALPH)
COMMON /XX/ CN2(20),DIV,R1V,N2
DEL1V = R1V/FLOAT(N2)
C CALCULATE D1INF
D1INF=0. $S1=DEL1V/2. $S =0.
D1V3 = (DIV)**(-.3333)
DO 20 I = 1,N2

```

```

      S = S + S1
      D1INF=DELIV*CN2(1)*((S/R1V)**1.6667) + D1INF
20 S1 = DELIV
      D1INF = 0.5*11.97*D1V3*D1INF
C INITIAL ESTIMATE FOR THETA0
      WRITE(6,35) D1INF
      THETA0 = 1.E-4
25 CONTINUE
      X11=0.  $D1THE=0.  $S = 0.
      S1 = DELIV/2.
      DO 30 I = 1,N2
      S = S + S1
      X11 = THETA0*(R1V-S)/DIV
      D1THE = DELIV*CN2(I)*((S/R1V)**1.6667)*FALPH(X11) + D1THE
30 S1 = DELIV
      D1THE = D1THE*D1V3
      IF(ABS(D1INF-D1THE) .LT. .001) GO TO 40
      THETA0 = THETA0*(1. + .5*(D1INF-D1THE)/D1INF)
      WRITE(6,35) THETA0,D1THE
      GO TO 25
35 FORMAT(2E16.8)
40 CONTINUE
      WRITE(6,35) D1THE
      RETURN
      END
      FUNCTION FALPH(X11)
      DIMENSION A(8)
      DATA (A(I),I=1,8)/1.98714,10.3433,-5.90301,1.83619,-0.301442,
1 2.51509E-2,-9.75229E-4,1.35618E-5/
      IF(X11 .GE. .5623) GO TO 10
      FALPH = 10.66*((X11)**2)
      GO TO 40
10 IF(X11 .GT.31.62) GO TO 20
      FALPH = 0.0
      DO 15 I = 1,8
15 FALPH = A(I)*((X11)**(I-1)) + FALPH
      GO TO 40
20 IF(X11 .GT.1000.) GO TO 30
      FALPH = 7.8*((X11)**.06)
      GO TO 40
30 FALPH = 11.97
40 RETURN
      END
      SUBROUTINE MEANVAR(N1,N2)
      COMPLEX RAN(2048)
      COMMON /YY/ RAN
      REAL MEAN1,MEAN2
      MEAN1=MEAN2=VAR1=VAR2=0.
      DO 400 I = N1,N2
      MEAN1 = REAL(RAN(I)) + MEAN1
      MEAN2 = AIMAG(RAN(I)) + MEAN2
      VAR1 = (REAL(RAN(I)))**2 + VAR1
      VAR2 = (AIMAG(RAN(I)))**2 + VAR2
400 CONTINUE

```

```
MEAN1 = MEAN1/FLOAT(N2 - N1)
MEAN2 = MEAN2/FLOAT(N2 - N1)
VAR1 = VAR1/FLOAT(N2 - N1)
VAR2 = VAR2/FLOAT(N2 - N1)
WRITE(6,700)MEAN1, MEAN2
WRITE(6,800)VAR1,VAR2
RETURN
700 FORMAT(* MEAN OF REAL PART =*,E12.6,*, MEAN OF IMAG PART =*E12.6/)
800 FORMAT(* VAR. OF REAL PART =*,E12.6,*, VAR. OF IMAG PART =*E12.6/)
END
```

FORTRAN LISTING OF FIRST-ORDER RADIATION TRANSPORT MODEL

```

PROGRAM FORT(INPUT=65,OUTPUT=65,TAPE5=INPUT,TAPE6=OUTPUT)
C PROGRAM TO COMPUTE FIRST ORDER RADIATION TRANSPORT FROM A LASER      000110
C TRANSMITTER TO A TARGET AND THE REFLECTED AND SCATTERED RADIATION      000120
C TO A RECEIVER VIEWING THE TARGET                                     000130
C ****REQUIRED INPUT DATA*****                                         000140
C LAMB    = LASER WAVELENGTH IN MICROMETERS                           000150
C DIAM   = TRANSMITTER APERTURE DIAMETER IN METERS                      000160
C THET   = LASER BEAMSPREAD ANGLE IN RADIANS                          000170
C RANG   = PROPAGATION RANGE FRUM TRANSMITTER TO SPOT IN METERS        000180
C PWR    = TRANSMITTER OUTPUT POWER IN WATTS                         000190
C ZCLOUD = DISTANCE FROM TRANSMITTER TO CLOUD IN METERS                 000200
C ZR     = RANGE FROM TARGET TO RECEIVER IN METERS                      000210
C PHI    = VIEWING ANGLE OF RECEIVER IN RADIANS                         000220
C THETR  = FIELD OF VIEW OF RECEIVER IN RADIANS                        000230
C DR     = RECEIVER DIAMETER IN METERS                                 000240
C RHO    = REFLECTIVITY OF TARGET                                      000250
C NZ     = NO. OF SEGMENTS OF LENGTH DELZ FROM TRANSMITTER TO TARGET    000260
C NR     = NUMBER OF ANNULAR AREAS IN THE TARGET SPOT                  000270
C NM     = NUMBER OF SEGMENTS OF TRANSMITTER PATH SEEN BY RECEIVER    000280
C ****                                         000290
C DIMENSION ZN(20),RN(20),P(100),C(100),AREA(20),PWR(20),AINT(20)    000300
C DIMENSION GAM(20),ZL(20)                                              000310
C COMMON/B<2 /          C, ALB00,LLL,LNRD,IT,ITT,NRADI                000320
C REAL LAMB,KEXT                                         000330
10 FORMAT(7E10.4)                                              000340
20 FORMAT(3I4)                                              000350
  READ(5,10) LAMB,DIAM,THET,RANG,PWR,ZCLOUD                    000360
  READ(5,10) ZR,PHI,THETR,DR,RHO                            000370
  READ(5,20) NZ,NR,NM                                         000380
40 FORMAT(* LASER WAVELENGTH =*,F10.4,* MICRON, DESIG. APERT. DIAM=*000390
  1,F10.6,* METERS, BEAMSPREAD ANGLE =*,F10.6,* RADIANS*)           000400
50 FORMAT(* DESIGNATOR RANGE =*,F10.2,* METERS*/,* DESIGNATOR POWER000410
  1 =*,F10.3,* WATTS*/,* DISTANCE TO CLOUD =*,F10.2,* METERS*)       000420
55 FORMAT(* RECEIVER RANGE =*,F10.2,* METERS, REC. FOV =*,F10.5,* R000430
  1ADIANS*/,* RECEIVER VIEWING ANGLE =*,F10.4,* RADIANS, RECEIVER DI000440
  2AM. =*,F10.6,* METERS*/,* TARGET REFLECTIVITY =*,F10.6/)         000450
60 FORMAT(* NO. OF SEGMENTS IN DESIGNATOR PATH =*,I3/* NO. OF ANNUL000460
  1AR ELEMENTS IN SPOT =*,I3/* NO. OF SCATTERING SEGMENTS =*,I3/)  000470
70 FORMAT(8F16.8)                                              000480
115 FORMAT(10E12.4)                                            000490
130 FORMAT(1H0)                                                 000500
140 FORMAT(1H1)                                                 000510
PI=3.1415926535898                                         000520
WRITE(6,140)                                                 000530
WRITE(6,40) LAMB,DIAM,THET                                     000540
WRITE(6,50) RANG,PWR,ZCLOUD                                  000550
WRITE(6,55)ZR,THETR,PHI,DR,RHO                            000560
WRITE(6,60) NZ,NR,NM                                         000570
C COMPUTATION OF SPATIAL INCREMENTS                           000580
C COMPUTATION OF SPOT DIAMETER ON TARGET                     000590
  IT = NR*NZ                                              000600
  IOUT = IT - 2                                           000610
  ZD = DIAM/THET                                         000620

```

```

ZC = ZD + ZCLOUD          000630
ZT = RANG + ZD          000640
DT = DIAM + THET*RANG    000650
ZI = ZC                  000660
DELZ = (ZT - ZC)/FLOAT(NZ) 000670
DELR = DT/FLOAT(NR)      000680
Z1 = DELZ/2.              000690
DO 200 I = 1,NZ          000700
ZI = ZI + Z1              000710
Z1 = DELZ                000720
ZN(I) = ZI                000730
200 CONTINUE               000740
      WRITE(6,210) DT,ZD,ZT          000750
210 FORMAT(* SPOT DIAM. =*,E12.6,* , ZD =*,F10.4,* , ZT = *,F10.4/) 000760
      WRITE(6,215)
      WRITE(6,70) (ZN(I),I = 1,NZ)        000770
215 FORMAT(* VALUES OF (ZN(I),I = 1,NZ) *) 000780
C COMPUTATION OF RADIUS TO ANNULAR ELEMENTS ON TARGET 000800
C COMPUTATION OF AREA OF ANNULAR ELEMENTS ON TARGET 000810
      RI = 0.                      000820
      AI = 0.                      000830
      R1 = DELR/2.                 000840
      DO 220 I = 1,NR             000850
      PWR(I) = 0.                  000860
      A1 = PI*((DELR*FLOAT(I))**2) 000870
      AREA(I) = A1 - AI           000880
      AI = A1                     000890
      RI = RI + R1                000900
      R1 = DELR                   000910
      RN(I) = RI                  000920
220 CONTINUE               000930
      WRITE(6,130)                 000940
      WRITE(6,225)
225 FORMAT(* VALUES OF ((RN(I),AREA(I)), I = 1,NR) *) 000950
      WRITE(6,70) ((RN(I),AREA(I)),I = 1,NR)        000960
      DO 230 J = 1,NZ             000970
      DO 230 I = 1,NR             000980
      ANG = ATAN(RN(I)/(ZT - ZN(J))) 000990
      L = NR*(J - 1) + I         001000
230 C(L) = COS(ANG)          001020
      KKK = 1                     001030
      CALL AGAUSS(P,KEXT,KKK)
      WRITE(6,130)                 001050
      WRITE(6,235)
C 235 FORMAT(* VALUES OF ((C(I), P(I)), I = 1,IR) *) 001060
C 235 FORMAT(* VALUES OF ((C(I), P(I)), I = 1,IR) *) 001070
C 235 FORMAT(* VALUES OF ((C(I), P(I)), I = 1,IR) *) 001080
C 235 FORMAT(* VALUES OF ((C(I), P(I)), I = 1,IR) *) 001090
      WRITE(6,70) (C(I),P(I),C(I+1),P(I+1),C(I+2),P(I+2),C(I+3),P(I+3), 001090
      II=1,IOUT,4)
      DO 240 J = 1,NZ             001100
      ZTZN = ZT - ZN(J)           001110
      POWFAC = PWR*EXP(-KEXT*(ZN(J)-ZC))*(1.-EXP(-KEXT*DELZ)) 001120
      1*EXP(-KEXT*ZTZN)*ALBDD 001130
      DO 240 I = 1,NR             001140
      L = NR*(J - 1) + I         001150
      PWR(J) = PWR(J) + POWFAC*P(L)*AREA(I)/(ZTZN**2 + RN(I)**2) 001160

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```

240 CONTINUE
    WRITE(6,130)
    WRITE(6,245)
245 FORMAT(* POWER AND AVERAGE INTENSITY IN ANNULAR AREAS *)
    TPOW = 0.0
    POWER = PWR*EXP(-KEXT*(RANG - ZCLOUD))
    DO 250 I = 1,NR
        TPOW = TPOW + PWR(I)
        AINT(I) = PWR(I)/AREA(I)
250 CONTINUE
    WRITE(6,70) ((PWR(I),AINT(I)),I=1,NR)
    WRITE(6,130)
    WRITE(6,255) POWER,TPOW
255 FORMAT(* DIRECT POWER TO TARGET =*,F16.8,* WATTS*,*, SCATTERED
1 POWER TO TARGET =*F16.8,* WATTS*)
    DO 260 I = 1,NR
        AINT(I) = AINT(I) + 2.*POWER/(PI*DT*DT)*EXP(-2.*RN(I)*RN(I)/(DT*DT))
    1)
260 CONTINUE
    WRITE(6,265)
    WRITE(6,70) (AINT(I),I=1,NR)
265 FORMAT(* TOTAL INTENSITY = DIRECT + SCATTERED VS. RN(I)*)
    WRITE(6,130)
    THETR2 = THETR/2.
    GAMA = PI - THETR2 - PHI
    AR = PI*DR*DR/4.
    ZM = ZR*SIN(THETR2)/SIN(GAMA)
    IF(ZM .GT. RANG) ZM = RANG
    ZS = RANG - ZM
    IF(ZS .LT. ZCLOUD) ZS = ZCLOUD
    IT = NM
    IOUT = IT - 3
    IF(IOUT .LT. 1) IOUT = 1
    DELZ = (RANG - ZS)/FLOAT(NM)
    WRITE(6,267) GAMA,ZM,ZS
267 FORMAT(* GAMA =*,F10.5,*, ZM =*,F10.3,*, ZS =*,F10.3/)
    ZI = ZS
    ZI = DELZ/2.
    DO 270 I = 1,NM
        ZI = ZI + ZI
        ZI = DELZ
        ZN(I) = ZI
        ZL(I) = SQRT(ZR**2 +(RANG-ZN(I))**2 - 2.*ZR*(RANG-ZN(I))*COS(PHI))
        TETAR = ASIN((RANG - ZN(I))*SIN(PHI)/ZL(I))
        GAM(I) = PI - TETAR - PHI
        C(I) = COS(GAM(I))
270 CONTINUE
    WRITE(6,275)
275 FORMAT(* VALUES OF ((ZN(I),ZL(I)),I = 1,NM)*,/)
    WRITE(6,70) ((ZN(I),ZL(I)),I=1,NM)
    WRITE(6,130)
    KKK = 2
    CALL AGAUSS(P,KEXT,KKK)
    PWRSR = 0.0

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DO 280 J = 1,NM                                001710
ZLJ = ZL(J)                                     001720
IF(ZCLOUD .GT. .001 .AND. ZR*COS(PHI) .GT. (RANG-ZCLOUD)) 001730
1ZLJ = (ZN(J) - ZCLOUD)/COS(PHI - GAM(J))      001740
PWRSR = PWRSR + PWR*EXP(-KEXT*(ZN(J)-ZC))*((1.-EXP(-KEXT*DELZ))* 001750
1ALBDO*P(J)*AR/(ZL(J)**2)*EXP(-KEXT*(ZLJ))    001760
280 CONTINUE                                     001770
ZRCL = ZR                                       001780
IF(ZCLOUD .GT. .001 .AND. ZR*COS(PHI) .GT. (RANG-ZCLOUD)) 001790
1ZRCL = (RANG - ZCLOUD)/COS(PHI)                001800
PWRTR = (POWER + TPOW)*RHO*COS(PHI)*AR/(ZR*ZR*PI)*EXP(-KEXT*ZRCL) 001810
WRITE(6,285) PWRSR,PWRTR                      001820
WRITE(6,130)                                     001830
285 FORMAT(* POWER SCATTERED FROM BEAM TO RECEIVER =*,E16.8,* WATTS*/001840
1,* POWER REFLECTED FROM TARGET TO RECEIVER =*,E16.8,* WATTS*/) 001850
END                                              001860
SUBROUTINE AGAUSS(PSUM,UTSUM,KKK)
DIMENSION F( 500),R( 500),FSUMI(10),C(100),P(100),PSUM(100) 001880
COMMON/BK2 /          C, ALBDO,LLL,NCRDS,IT,ITT,NRADI 001890
1 FORMAT(6I5,49X,I1)                                001900
2 FORMAT(4F10.6)                                   001910
3 FORMAT(24X,2(E20.10))                           001920
4 FORMAT(2E20.10)                                 001930
5 FORMAT(6E12.6,I3)                               001940
6 FORMAT(4E10.4)                                 001950
7 FORMAT(1H ,100H*****AEROSOL DISTRIBUTION TYPE IS UNDEFINED*****001960
*EXECUTION CONTINUING ASSUMING NO AEROSOL MATERIAL) 001970
8 FORMAT(1H ,4I1H DISTRIBUTION WAVELENGTH REFRACTIVE,13X,12HC E001980
*XTINCTION,13X,12HC SCATTERING,16X,5HALBDO/1H ,6X,4HTYPE,6X,9H(MICRO001990
*ONS),8X,5HINDEX,16X,12H(SQ MICRONS),13X,12H(SQ MICRONS)/1H ,I9,4X 002000
*,F11.4,F10.4,2H(I,F7.4,2H),3E25.14)           002010
9 FORMAT(1H0,4(5H MU,8X,17HPHASE FUNCTION )/1H ) 002020
10 FORMAT(1H ,4(F13.9,E17.10))                  002030
11 FORMAT(1H0,65X,14HPHASE FUNCTION/1H )         002040
12 FORMAT(1H ,5X,1HL,20X,16HL-TH COEFFICIENT,23X,14HRMS DEVIATION/1H002050
* )                                         002060
13 FORMAT(1H ,8H MU ,4(30H ORIGINAL EXPANDED )/1H ) 002070
14 FORMAT(1H ,F8.5,8E15.8)                        002080
15 FORMAT(1H ,////24H AEROSOL PARAMETERS ARE )   002090
16 FORMAT(1H+,24X,6HRBAR= ,E20.10,15X,7HSIGMA= ,E20.10/) 002100
17 FORMAT(1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,5HCUE= ,E10.4,1X,002110
*3HA= ,E10.4,1X,3HB= ,E10.4/)                 002120
18 FORMAT(1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,5HCUE= ,E10.4,1X,002130
*3HA= ,E10.4,1X,4HVIS= ,E10.4/)               002140
19 FORMAT(1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,4HRC= ,E10.4,1X,5002150
*HALF= ,E10.4,1X,5HGAM= ,E10.4,7H NRADI=,I3,4H J2=,I3/) 002160
20 FORMAT(1H+,24X,3HA= ,F4.1,1X,7HNRADI= ,I4,1X,5HGAM= ,F4.1,1X,5HVIS002170
*= ,E20.10/)                                    002180
21 FORMAT(1H+,24X,40H RADIUS (MICRONS) RELATIVE DENSITY /) 002190
22 FORMAT(* INDX=*,I3,* M= *,F10.6,* K = -*,F10.6,*I. EMM=*,F8.6,* 002200
*CONCENTRATION = *,F 10.6 )                   002210
23 FORMAT(* THIS IS A MIXED CASE---SUBSEQUENT REFRACTIVE INDEX PRINT-002220
*OUTS ARE NOT GENERALLY VALID*)                002230
24 FORMAT(1H ,24X,* MIE SIZE PARAMETER RANGE

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*,F8.4/) 002250
25 FORMAT(2(F15.5,5X),3(E20.6,5X)) 002260
26 FORMAT(1H ,//4X,16HRADIUS (MICRONS),4X,14HSIZE PARAMETER,13X,7HQ (002270
  *EXT),17X,7HQ (SCA), 19X,9HQ (RADAR)) 002280
27 FORMAT(/* NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = *,E14.7/) 002290
28 FORMAT(/* K(EXT) = *,E13.7,* K(SCA) = *,E13.7,* K(RAD) = *,E13.7002300
  */) 002310
29 FORMAT(/* WAVENUMBER = *,E15.7,* CM-1*,5X,*DENSITY = *,E15.7, *PAR002320
  *TICLES PER CM-3*/) 002330
C 002340
C END PRELIMINARIES 002350
C 002360
IF(KKK .GT. 1) GO TO 52 002370
READ(5,5)WAVE,DFNS 002380
IF(DENS.EQ.0.0)DENS=1.0 002390
GNU=1.0E+04/WAVE 002400
NRANGE=1 002410
READ(5,1)IDSTP,NRADI,NCRDS 002420
IF(IDSTP.EQ.5)NRANGE=NRADI 002430
ITMM=IT-1 002440
PI=3.1415926535898 002450
WRITE(6,15) 002460
IF(IDSTP.NE.0)GO TO(34,36,38,40,43,47,40,51),IDSTP 002470
READ(5,4)(F(J),R(J),J=1,NRADI) 002480
WRITE(6,21) 002490
WRITE(6,3)(R(J),F(J),J=1,NRADI) 002500
FSUM=0.0 002510
DO 33 J=1,NRADI 002520
FSUM=FSUM+F(J) 002530
GO TO 49 002540
34 READ(5,4)RBAR,SIGMA 002550
WRITE(6,16)RBAR,SIGMA 002560
RHI=RBAR* EXP(3.0*SIGMA) 002570
RLD=RBAR* EXP(-3.0*SIGMA) 002580
RADS= FLOAT(NRADI-1) 002590
DELRD=(RHI-RLD)/RADS 002600
FSUM=0.0 002610
DEN=2.0*SIGMA*SIGMA 002620
DO 35 J=1,NRADI 002630
RJ=J-1 002640
R(J)=RLD+RJ*DELRD 002650
GNUM=A LOG(R(J)/RBAR) 002660
F(J)= EXP(-GNUM*GNUM/DEN)*RBAR/R(J) 002670
35 FSUM=FSUM+F(J) 002680
GO TO 49 002690
36 READ(5,5)RLO,PHI,CUE,A,B 002700
WRITE(6,17)RLO,RHI,CUE,A,B 002710
RADS= FLOAT(NRADI-1) 002720
DELRD=(RHI-RLD)/RADS 002730
FSUM=0.0 002740
DO 37 J=1,NRADI 002750
RJ=J-1 002760
R(J)=RLD+RJ*DELRD 002770
F(J)=CUE*A* EXP(-A*R(J))+ (1.0 -CUE)*B* EXP(-B*R(J)) 002780

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37 FSUM=FSUM+F(J)          002790
   GO TO 49                 002800
38 FSUM=0.0                 002810
   DENS=1.378E+04            002820
   DELRD=0.02                002830
   DO 39 J=1,NRADI           002840
   RJ=J-1                   002850
   R(J)=0.02     +RJ*DELRD  002860
   IF(J.LT.5)F(J)=450.2      002870
   IF(J.GE.5)F(J)=2.251      *DELRD*R(J)**(-4.0) 002880
39 FSUM=FSUM+F(J)          002890
   GO TO 49                 002900
40 IF(IDSTP.EQ.4)  GO TO 41 002910
   READ(5,5) VIS             002920
   RLO=0.1                  002930
   RHI=15.0                 002940
   CUE=30.0                 002950
   A=4.0                    002960
   NRADI=300                002970
   DENS=1.1     *10.0    **(+5.0 -ALOG10(VIS)) 002980
41 IF(IDSTP.EQ.4)  READ(5,6) RLO,RHI,CUE,A
   WRITE(6,18)RLO,RHI,CUE,A,VIS 002990
   FSUM=0.0                 003000
   RADS= FLOAT(NRADI-1)       003010
   DELRD=(RHI-RLO)/RADS     003020
   DO42 J=1,NRADI           003030
   RJ=J-1                   003040
   R(J)=RLO+RJ*DELRD        003050
   F(J)=CUE*R(J)**(-A)      003060
   IF(IDSTP.EQ.7.AND.J.LE.3) F(J)=1.0E+05 003070
42 FSUM=FSUM+F(J)          003080
   GO TO 49                 003090
43 JZ=0                     003100
   FSUM=0.0                 003110
   DO 45 ISZ=1,NRANGE        003120
   READ(5,5)RLO,RHI,RC,ALF,GAM,DENS,NRADI 003130
   WRITE(6,19)RLO,RHI,RC,ALF,GAM,NRADI,JZ 003140
   FSUMI(ISZ)=0.0            003150
   DELRD=(RHI-RLO)/ FLOAT(NRADI-1) 003160
   B=ALF/(GAM*RC**GAM)       003170
   DO 44 J=1,NRADI           003180
   RJ(J+JZ)=RLO+DELRD* FLOAT(J-1) 003190
   IF(J.EQ.1)XMN=2.0          *PI*R(J+JZ)/(WAVE) 003200
   IF(J.EQ.NRADI)XMX=2.0      *PI*R(J+JZ)/(WAVE) 003210
   F(J+JZ)=( EXP(-B*R(J+JZ)**GAM)*R(J+JZ)**ALF)*DELRD 003220
44 FSUMI(ISZ)=FSUMI(ISZ)+F(J+JZ) 003230
   DELRD=DELRD*2.0          *PI/(WAVE) 003240
   WRITE(6,24)XMN,DELRD,XMX 003250
45 JZ=NRADI+JZ              003260
   DO 46 JN=1,NRANGE          003270
46 FSUM=FSUM+FSUMI(JN)      003280
   NRADI=JZ                  003290
   GO TO 49                 003300
47 READ(5,4) VIS             003310
                                003320

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FSUM=0.0          003330
DELLR=0.02        003340
A=500.            003350
NRADI=280         003360
GAM=3.0           003370
WRITE(6,20)A,NRADI,GAM,VIS      003380
PWR=-2.0          *GAM/3.0       003390
R(1)= (VIS-0.04   )/0.31       003400
F(1)=A*R(1)**PWR      003410
DO48 I=2,NRADI     003420
EXPO=ALOG(R(I-1))+DELLR      003430
R(I)= EXP(EXPO)      003440
F(I)=A*R(I)**PWR      003450
48 FSUM=FSUM+F(I)      003460
49 DO 50 J=1,NRADI     003470
50 F(J)=F(J)/FSUM      003480
WRITE(6,27)FSUM      003490
GO TO 52             003500
51 WRITE(6,7)          003510
GO TO 61             003520
52 QTSUM=0.0           003530
QSUM=0.0              003540
QRSUM=0.0              003550
DO 53 J=1,IT          003560
53 PSUM(J)=0.0          003570
IF(KKK .GT. 1) GO TO 100      003580
C READ(5,1)NINDX      003600
C DO 57 NK=1,NINDX      003610
READ(5,2)EM,CAY,EMM,CONC
CONC = 1.0
WRITE(6,22)NK,EM,CAY,EMM,CONC
CAY=CAY/EM
IF(MQRTE.EQ.12345)WRITE(6,26)
100 CONTINUE
DO 56 L=1,NRADI
ALPHA=2.0          *PI*EMM *R(L)/WAVE      003670
CALL FMIEG2(EM,CAY,ALPHA,WT,QS,QR,P,MQRTE,KKK)
IF(MQRTE.EQ.12345)WRITE(6,25)R(L),ALPHA,WT,QS,QR
DO 54 J=1,IT
PSUM(J)=PSUM(J)+P(J)*F(L)*CONC      003690
003690
003690
003700
003710
003720
003730
003740
003750
003760
003770
003780
003790
003800
003810
003820
003830
003840
003850
54 CONTINUE
55 QT SUM=QT SUM+R(L)*R(L)*WT*F(L)*CONC
QR SUM=QR SUM+R(L)*R(L)*QR*F(L)*CONC
56 QS SUM=QS SUM+R(L)*R(L)*QS*F(L)*CONC
57 CONTINUE
QT SUM=QT SUM*PI
QR SUM=QR SUM*PI
QS SUM=QS SUM*PI
ALBDO=QS SUM/QT SUM
CAYNG=-CAY
PFACT= WAVE*WAVE/(PI*QT SUM*EMM*EMM)
DO58 J=1,IT
58 PSUM(J)= PSUM(J)*PFACT/(4.*PI*ALBDO)
IF(NINDX.GE.2)WRITE(6,23)

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      WRITE(6,8)IDSTP,WAVE,EM ,CAYNG,QTSUM,QSSUM,ALBDD          003860
      QTSUM=QTSUM*DENS*1.0E-06                                003870
      QSSUM=QSSUM*DENS*1.0E-06                                003880
      QRSUM=QRSUM*DENS*1.0E-06                                003890
      WRITE(6,28)QTSUM,QSSUM,QRSUM                            003900
      WRITE(6,29)GNU,DENS                                     003910
      WRITE(6,9)                                              003920
      WRITE(6,10)((C(J),PSUM(J)),J=1,IT)                      003930
      C   IF (IOUT.LT.1)GO TO 61                               003940
      C   DO 59 J=1,IOUT,4                                    003950
      C   WRITE(6,10)C(J),PSUM(J),C(J+1),PSUM(J+1),C(J+2),PSUM(J+2),C(J+3), 003960
      C   *PSUM(J+3)                                         003970
      59 CONTINUE                                           003980
      RETURN                                               003990
      61 STOP                                                004000
      END                                                 004010
      SUBROUTINE FMIEG2(EM,CAY,ALPHA,SGT,SGS,SGR,P,MCRTE,KKK) 004020
      DIMENSION C(100),EYE1(100),EYE2(100),P(100)            004030
      DIMENSION REAN(250),REBN(250),FAN(250),FBN(250)        004040
      COMMON/BK2 /           C, ALBDD,LLLL,NCRDS,IT,ITT,NRADI 004050
      PIE=3.1415926535898                                 004060
      EN=1.                                                 004070
      S=1.                                                 004080
      ISWI=1                                              004090
      SUMT=0.                                             004100
      SUMS=0.                                             004110
      SUMRR=0.                                            004120
      SUMRI=0.                                            004130
      SUMS1=0.                                            004140
      SUMS2=0.                                            004150
      C MIE SERIES CUTOFF CRITERION                         004160
      FACT=1.2                                             004170
      IF(ALPHA.GT.51.0)FACT=1.0      +2.26    *ALPHA**(-.613) 004180
      A=EM*ALPHA                                         004190
      B=A*CAY                                           004200
      GAMMA=EM*CAY                                       004210
      SINA= SIN(A)                                       004220
      COSA= COS(A)                                       004230
      COSHB=( EXP(B)+ EXP(-B))/2.                        004240
      SINHB=( EXP(B)- EXP(-B))/2.                        004250
      AB=A*B*B                                         004260
      RNLI=SINA*COSH B                                  004270
      SNL1=-COSA*SINHB                                 004280
      TNL1= SIN(ALPHA)                                 004290
      UNL1= COS(ALPHA)                                 004300
      C THESE ARE THE BESSSEL FUNCTONS OF N=1 ORDER       004310
      RN=(RNLI*A-SNL1*B)/AB-COSA*COSH B                004320
      SN=(RNLI*B+SNL1*A)/AB-SINA*SINHB                 004330
      TN=TNL1/ALPHA-UNL1                                004340
      UN=UNL1/ALPHA+TNL1                                004350
      GO TO 2                                           004360
      1 TWONL1=2.0    *EN-1.                           004370
      STEP7=TWONL1/AB                                   004380
      STEP8=TWONL1/ALPHA                             004390

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C THESE ARE THE RECURRENCE RELATIONS FOR THE UNPRIMED FUNCTIONS AND... 004400
RN=STEP7*(A*RN1-B*SN1)-RN2                                         004410
SN=STEP7*(B*RN1+A*SN1)-SN2                                         004420
TN=STEP8*TN1-TN2                                                       004430
UN=STEP8*UN1-UN2                                                       004440
004450
C ...FOR THE PRIMED FUNCTIONS                                         004460
2 RPN=RN1-EN*(A*RN-B*SN)/AB                                         004470
SPN=SN1-EN*(B*RN+A*SN)/AB                                         004480
TPN=-EN*TN/ALPHA+TN1                                               004490
UPN=-EN*UN/ALPHA+UN1                                               004500
004510
C REFERENCE LIGHT SCATTERING... BY VAN DE HULST                      004520
C P123 FOR AN AND BN
N=EN                                                               004530
EK SN=RN*TPN-EM*RPN*TN-GAMMA*SPN*TN                               004540
CAPN=SN*TPN-EM*SPN*TN+GAMMA*RPN*TN                               004550
EPSN=RN*TPN-SN*UPN+EM*(SPN*UN-RPN*TN)-GAMMA*(RPN*UN+SPN*TN)    004560
PHIN=RN*UPN+SN*TPN-EM*(RPN*UN+SPN*TN)-GAMMA*(SPN*UN-RPN*TN)    004570
EK SPN=RPN*TN-EM*RPN-(GAMMA*SN*TPN)                                004580
CAPPN=SPN*TN-EM*SN*TPN+GAMMA*RN*TPN                               004590
EPSPN=RPN*TN-SPN*UN-EM*(RN*TPN-SN*UPN)-GAMMA*(RN*UPN+SN*TPN)    004600
PHIPN=RPN*UN+SPN*TN-EM*(RN*UPN+SN*TPN)+GAMMA*(RN*TPN-SN*UPN)    004610
W=EKSN/PHIN
004620
C THESE KEEP THE ANOS AND BNOS CLOSE TO 1, SINCE THE NUMERATORS AND
C DENOMINATORS ARE INDIVIDUALLY LARGE                                 004630
X=CAPN/EPSN                                                       004640
Y=CAPN/PHIN                                                       004650
Z=EK SN/EPSN                                                       004660
DENOM=EPSN/PHIN+PHIN/EPSN                                         004670
WP=EKSPN/PHIPN                                                    004680
XP=CAPPN/EPSN                                                     004690
YP=CAPPN/PHIPN                                                    004700
ZP=EKSPN/EPSN                                                     004710
DENMP=EPSPN/PHIPN+PHIPN/EPSPN                                       004720
REAN(N)=(WP+XP)/DENMP                                              004730
REBN(N)=(W+X)/DENOM                                                004740
FAN(N)=(YP-ZP)/DENMP                                              004750
FBN(N)=(Y-Z)/DENOM                                                004760
IF(MCRTE.EQ.67890) WRITE(6,19) REAN(N), FAN(N), REBN(N), FBN(N)    004770
19 FORMAT(1X,4(E20.10,10X))
S=-S                                                               004780
TONP1=2.0 *EN+1.                                                   004790
004800
C SEE P127
SUMT=SUMT+TONP1*(REAN(N)+REBN(N))                                     004810
SUMS=SUMS+TONP1*(REAN(N)*REAN(N)+FAN(N)*FAN(N)+REBN(N)*REBN(N)+FB 004820
1N(N)*FBN(N))                                                       004830
SUMRR=SUMRR+TONP1*S*(REAN(N)-REBN(N))                                004840
SUMRI=SUMRI+TONP1*S*(FAN(N)-FBN(N))                                004850
IF(EN.EQ.1.0)GO TO 6                                                 004860
EK=EN-1.                                                               004870
004880
SUMS1=SUMS1+EK*(EK+2.      )*(RAN*REAN(N)+RBN*REBN(N)+PAN*FAN(N)+PBN) 004890
**FBN(N))/EN
SUMS2=SUMS2+(2.0      *EN-1.      )*(RAN*RBN+PAN*PBN)/(EN*EK)        004900
004910
6 RAN=REAN(N)
RBN=REBN(N)
004920
004930

```

```

PAN=FAN(N)                                004940
PBN=FBN(N)                                004950
TERMN= ABS( REAN(N) )+ ABS( FAN(N) )+ ABS( REBN(N) )+ ABS( FBN(N) ) 004960
IF( TERMN.GE.1.0E-9.AND.EN.LT.8.0      +FACT*ALPHA)GO TO 4 004970
GO TO(3,5),ISWI 004980
3 ISWI=2 004990
4 EN=EN+1. 005000
RNL2=RNL1 005010
SNL2=SNL1 005020
TNL2=TNL1 005030
UNL2=UNL1 005040
RNL1=RN 005050
SNL1=SN 005060
TNL1=TN 005070
UNL1=UN 005080
GO TO 1 005090
5 ALF2=ALPHA*ALPHA 005100
C QEXT=SGT      QSCAT=SGS      QABS=SGA      QRADAR=SGR      AVE      COS(0)=SGM005110
C           QPR=SGMP(SEE P128) 005120
C           SGT=2.0      *SUMT/ALF2 005130
C           SGS=2.0      *SUMS/ALF2 005140
C           SGA=SGT-SGS 005150
C           SGR=(SUMRR*SUMRR+SUMR(*SUMR))/ALF2 005160
C           SGMAS=2.0      *(SUMS1+SUMS2)/SUMS 005170
C           SGMP=SGT-SGMAS*SGS 005180
DO 98 K=1,IT 005190
COST=C(K) 005200
SINT= SQRT(1.0      -COST*COST) 005210
PINL1=0. 005220
RHNL1=0. 005230
PIN=1. 005240
RHN=0. 005250
TAUN=COST 005260
SUMI1R=0. 005270
SUMI1I=0. 005280
SUMI2R=0. 005290
SUMI2I=0. 005300
C SUMMATION OF MIE SERIES 005310
DO 97 L=1,N 005320
EN= FLOAT(L) 005330
TWONL1=2.0      *EN-1. 005340
ENNPI=EN*(EN+1.) 005350
ENL1=EN-1. 005360
IF(L.EQ.1)GO TO 10 005370
PIN=(TWONL1*COST*PINL1-EN*PINL2)/ENL1 005380
RHN=TWONL1*PINL1+RHNL2 005390
TAUN=PIN*COST-SINT*SINT*RHN 005400
10 TONPI=2.0      *EN+1. 005410
SUMI1R=SUMI1R+TONPI*(REAN(L)*PIN+REBN(L)*TAUN)/ENNPI 005420
SUMI1I=SUMI1I+TONPI*(FAN(L)*PIN+FBN(L)*TAUN)/ENNPI 005430
SUMI2R=SUMI2R+TONPI*(REBN(L)*PIN+REAN(L)*TAUN)/ENNPI 005440
SUMI2I=SUMI2I+TONPI*(FBN(L)*PIN+FAN(L)*TAUN)/ENNPI 005450
PINL2=PINL1 005460
PINL1=PIN 005470

```

| | |
|---|--------|
| RHNL2=RHNL1 | 005480 |
| 97 RHNL1=RHN | 005490 |
| 11 EYE1(K)= (SUMI1R*SUMI1R+SUMI1I*SUMI1I) | 005500 |
| EYE2(K)= (SUMI2R*SUMI2R+SUMI2I*SUMI2I) | 005510 |
| P(K)= (EYE1(K)+EYE2(K))/2.0 | 005520 |
| 98 CONTINUE | 005530 |
| RETURN | 005540 |

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