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Lawrence Livermore Laboratory

FOUR-D PROPAGATION CODE FOR HIGH-ENERGY
LASER BEAMS: A USER'S MANUAL

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August 5, 1976

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Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

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FOREWORD

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FOUR-D PROPAGATION CODE FOR HIGH-ENERGY LASER BEAMS: A USER'S MANUAL

ABSTRACT

This manual describes the use and structure of the June 30, 1976 version of the Four-D propagation code for high energy laser beams. It provides selected sample output from a typical run and from several debug runs. The Four-D code now includes the important noncoplanar scenario feature. Many problems that required excessive computer time can now be meaningfully simulated as steady-state noncoplanar problems with short run times.

I. INTRODUCTION

This manual supplies detailed information about the structure and use of a general-purpose, time-dependent, three-space-dimensional thermal blooming code known as the "Four-D" code. Only material useful to a person making changes to, testing modifications of, or running problems with the Four-D code is in this report. Readers interested in the mathematical models or computational methods used in the Four-D code or in examples of the propagation effects simulated by it should consult our earlier reports ^{1,2}.

The many features of the Four-D code make it a useful tool for evaluating high-energy lasers in specific scenarios, calibrating scaling models, and simulating laboratory-scale experiments that involve laser beam propagation through a gas. This code's time-dependent features permit assessment of the effect of a deadzone (where the wind velocity vanishes) or the on-target intensity of a laser beam and the effect of thermal conductivity on laboratory-scale experiments for continuous-wave (cw) and multipulse lasers. Extensive steady-state features include propagation in the presence of subsonic and supersonic winds and winds that change direction as a function of distance from the laser. Multipulse laser propagation calculations include the effect of t^3 -blooming; thus, corrections for moderate single-pulse blooming need not be made in an ad hoc fashion. The effects of turbulence, multiline absorption, and jitter are also calculated. Table 1 summarizes the properties of the Four-D code.²

A FORTRAN listing and a card deck of the Four-D code are available from the author. The permission of Peter Ulrich of the Naval Research Laboratory or Robert Sepucha of the U. S. Army Missile Command at

Redstone Arsenal, Ala. must be obtained before the listing or card deck can be shipped.

Table 1. Basic outline of current Four-D propagation code.

Variables	<p>x, y, z, t: where x, y are transverse coordinates and z is the axial displacement.</p>
Form of propagation equation	<p>Scalar-wave equation in parabolic approximation:</p> $2ik \frac{\partial \mathcal{E}}{\partial z} = \nabla_T^2 \mathcal{E} + k^2(n^2 - 1)\mathcal{E}$
Method of solving propagation equation	<p>Symmetrized split operator, finite Fourier series, fast Fourier transform (FFT) algorithm:</p> $\mathcal{E}^{n+1} = \exp\left(\frac{i\Delta z \nabla_T^2}{4k}\right) \exp\left(\frac{-i\Delta z \bar{\chi}}{2k}\right) \exp\left(\frac{i\Delta z \nabla_T^2}{4k}\right) \mathcal{E}^n$ $\bar{\chi} = k^2(n^2 - 1)$
Hydrodynamics for steady-state cw problems	<p>Uses exact solution to linear hydrodynamic equations. Fourier method for $M < 1$. Characteristic method for $M > 1$. Solves</p> $v_x \frac{\partial \rho_1}{\partial x} + v_y \frac{\partial \rho_1}{\partial y} + \rho_0 \nabla_T \cdot \vec{v}_1 = 0$ $\rho_0 \left(v_x \frac{\partial \vec{v}_1}{\partial x} + v_y \frac{\partial \vec{v}_1}{\partial y} \right) + \nabla_T p_1 = 0 \text{ , and}$ $\left(v_x \frac{\partial}{\partial x} + v_y \frac{\partial}{\partial y} \right) (p_1 - c_s^2 \rho_1) = (\gamma - 1) \alpha_1$
Transonic slewing	<p>Steady-state calculation valid for all Mach numbers except $M = 1$. Code can be used arbitrarily close to $M = 1$.</p>
Treatment of stagnation zone problems for cw beams	<p>Time-dependent isobaric approximation. Transient succession of steady-state density changes; i.e., solves</p> $\frac{\partial \rho_1}{\partial t} + v_x \frac{\partial \rho_1}{\partial x} = -(\gamma - 1) \alpha c_s^{-2} \alpha_1$

Table 1. Continued.

Nonsteady treatment of multi-pulse density changes

Density changes from previous pulses in train calculated with isobaric approximation using

$$\frac{\partial \rho}{\partial t} + v_x \frac{\partial \rho}{\partial x} = -(\gamma-1) \alpha c_s^{-2} \sum_n \tau I_n(x, y) \delta(t-t_n),$$

where $\tau I_n(x, y)$ is the n^{th} pulse fluence. Density changes resulting from the same pulse calculated using acoustic equations and triangular pulse shape.

Method of calculating density change for individual pulse in train

Takes two-dimensional Fourier transform of

$$-\frac{\sigma \tilde{I} \tau}{2c_s^2} \left\{ 1 - \frac{\sin^2[0.5c_s(k_x^2 + k_y^2)^{1/2} \tau]}{[0.5c_s(k_x^2 + k_y^2)^{1/2} \tau]^2} \right\},$$

where $\tilde{I}$ is Fourier transform of intensity, and τ is the time duration of each pulse (FWHM). Source aperture should be softened when using this provision.

Treatment of steady-state multipulse blooming

Previous pulses in train assumed to be periodic replications of current pulse. Solves

$$\frac{\partial \rho}{\partial t} + v_x \frac{\partial \rho}{\partial x} + v_y \frac{\partial \rho}{\partial y} = -(\gamma-1) \alpha c_s^{-2} \tau I \sum_n \delta(t-t_n).$$

Pulse self blooming treated as in nonsteady-state case.

Treatment of turbulence

Uses phase-screen method of Bradley and Brown with Von Karman spectrum phase screen determined by

$$\Gamma(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} dk_x dk_y \exp[i(k_x x + k_y y)] a(k_x, k_y) \phi_n^{1/2}(k_x, k_y),$$

where a is a complex random variable and ϕ_n is spectral density of refractive index fluctuations.

Table 1. Continued.

Lens transformation and treatment of lens optics

Compensates for a portion of lens phase front with cylindrical Talanov lens transformation. Uses in spherical case

$$\frac{1}{z_f} = \frac{1}{z_T} + \frac{1}{z_L}$$

where z_f is focal length of lens, z_T is focal length compensated for by Talanov transformation, and z_L is focal length of initial phase front.

Treatment of nondiffraction limited beams

Spherical aberration phase determined by

$$\phi_{SA} = \frac{2\pi A}{\sigma^2} (x^2 + y^2)^2$$

or phase screen method of Hogge et al.. Phase determined as in turbulence with

$$\phi_n = \frac{\sigma^2 l_0^2}{2\pi} \exp\left(-\frac{l_0^2 k^2}{12}\right)$$

where l_0 is correlation length and σ^2 phase variance.

Adaptive lens transformation

Removes phase

$$\sum_{i=1}^2 [\alpha_i (x_i - \langle x_i \rangle)^2 + \beta_i (x_i - \langle x_i \rangle)]$$

through lens transformation and deflection of beam. Here $x_1 = x$, $x_2 = y$ averages are intensity weighted, and α_i and β_i are calculated to keep the intensity centroid at mesh center and intensity-weighted rms values of x and y constant with z .

Selection of z -step

Adaptive z -step selection based on limiting gradients in nonlinear contribution to phase and limiting the wind velocity change. Constant z -step over any portion of range also possible.

Table 1. Continued.

Scenario capability	General noncoplanar scenario geometry capability involving moving laser platform, moving target, and arbitrary wind direction. In coplanar case, wind can be function of z and t .
Treatment of multiline effects	<p>Calculates average absorption coefficient based on assumption of identical field distributions for all lines</p> $\bar{\alpha} = \frac{\sum_i \alpha_i f_i \exp(-\alpha_i z)}{\sum_i f_i \exp(-\alpha_i z)}$ <p>where f_i is fraction of energy in line i at $z=0$.</p>
Treatment of beam jitter	<p>Takes convolution of intensity in target plane with Gaussian distribution:</p> $I_{\text{jitter}} = \iint dx' dy' \exp\left\{-\frac{[(x')^2 + (y')^2]}{2\sigma^2}\right\} I(x-x', y-y')$ <p>where σ^2 is variance introduced by jitter.</p>
Code output	Isointensity, isodensity, isophase, and spectrum contours. Intensity averaged over contours. Plots of intensity, phase density, spatial spectrum along specific directions, etc. at specific times. Plots of peak and average intensities vs time.
Numerical capacity when used with CDC 7600 and restricted to internal memory (large and small core)	Spatial mesh, 64x64, 30 sampling times, no restriction on number of axial space increments.
Problem-zoning features	Number of space increments in x and y directions must be equal and expressible as a power of 2.

II. CREATING INPUT FILE AND RUNNING FOUR-D CODE

The generality of the Four-D code is reflected in the number of its input parameters. Table 2 and the comment cards preceding the Four-D code's source deck describe the 102 current input parameters and the names and default values of the corresponding FORTRAN variables. Fortunately, for sea-level atmospheric propagation problems, the default value suffices for over half these parameters. Only the appropriate subset of the smaller list given in Table 3 must be explicitly included in the input file. The Four-D code generally uses cgs units, except that joules have been used as the basic energy unit for fluences, heat capacities, and thermal conductivities; that intensities are in MW/cm^2 ; and that the turbulence strength is in $\text{m}^{-2/3}$.

The Table 3 headings describe the process of specifying a propagation problem for the Four-D code. First, the laser beam and the medium through which it propagates must be specified. Usually, the problem to be solved uniquely defines the values of these parameters. Second, the motion of the propagation medium relative to the laser beam must be specified. And third, the details of how the calculation is to be done must be given.

The motion of the fluid medium relative to the laser beam determines two transverse velocity components that are assumed to vary linearly with distance from the laser; the velocity component parallel to the laser beam is ignored. Fluid velocity is either constant or specified by a scenario that assumes constant speed and straight line motion of laser platform and target. Figure 1 describes the scenario. At time $t=0$, the target is at the point $M(0)$; it moves along the line

Fig. 1. Noncoplanar scenario. The laser is at $L'(t)$, a distance h vertically above the line of motion of the impact point $P(t)$ on the ship.

$M(0)P(\tau_c)$ with speed V_R (code variable VFLRC). At time $t=\tau_c$, it intersects the plane swept out by a vertical line through the center of the laser aperture at the point $P(\tau_c)$. Point P moves with the speed of the laser platform V_T (VFLTR) in the scenario plane defined by the points $P(0)$, $P(\tau_c)$, and $M(0)$; it represents the impact point when the target is aimed at the laser vehicle. If the target is aimed at the laser platform or if the laser platform is stationary, the attack scenario can be specified in the scenario plane by giving the values of D (DTOM), θ_S (THETAS), and l (OFFSET). Otherwise, it must be specified by giving the values of R (RANGE), θ_T (THETAT), and θ_R (THETAR). The former method is used when the impact point is known; the latter is used when target and laser velocity vectors are known. For noncoplanar scenarios, two more parameters are required: h (HL), the distance between the center of the laser aperture (point $L'(0)$) and the line $P(0)P(\tau_c)$, and θ_P (THETAP), the angle between the line $L(0)L'(0)$ and the normal to the scenario plane. The true wind velocity is assumed to be horizontal at an angle θ_W (THETAW) to the direction of motion of the laser platform and to have the speed V_W (VWIND).

Specifying the calculational procedure is often the most complex part of creating an input file because the parameters are not uniquely defined; choosing values for these parameters may require that the user exercise some physical judgment or have previous experience with the Four-D code. For most problems, initial mesh widths (LX and LY) of between five and six times the corresponding $1/e$ radii of the initial Gaussian or truncated Gaussian beam (SIGX and SIGY) work well. For multipulse problems, t^3 -blooming can be included (COEFT3=1.) or turned off (COEFT3=0.). If t^3 -blooming is simulated, it may be necessary to filter the spectrum of the t^3 contribution to the air density to

control aliasing; at Lawrence Livermore Laboratory (LLL), we have used the values FFILT=0.64 and NFILT=4 for this purpose:

Unless the nature of the physical problem being simulated dictates otherwise, it should be run as a steady-state (ISSL=1) problem with a variable lens transformation (ILENS=1) and a variable axial-step size (IVARDZ=1). For steady-state problems, the initial axial-step size should be chosen so the total nonlinear phase change in a single step is between, say, $\pi/10$ and $\pi/100$ and the effective transverse wind velocity changes by less than, say, 20% in any step. For the adaptive lens transformation, ZTF = FOCUS and ZF = 0 are the best choices for these variables; the value of ZTL should be larger than the laser-to-target distance.

The specification of time-dependent runs is more complex. The adaptive lens transformation can no longer be used; so, in addition to the mesh- and step-size parameters, the lens-transformation parameters must be chosen so intensity and spectral density on the mesh boundary start out and remain a small fraction of their respective maximum values at interior mesh points. If possible, the time-step for cw laser beams should be chosen so, at each axial location, gross changes in the intensity profile do not occur in a single time-step³ (except, perhaps, the first time-step). The z-step and time-step must be chosen so the nonlinear phase change at any mesh point in one time-step and in the current z-step is at most a few percent of π . Also, the z-step must be small enough so the distance the heated air moves in one time-step changes by less than about 20% or by less than 20% of the local beam diameter if this is larger; this replaces the steady-state condition of a small fractional change in the effective wind velocity.

Although most steady-state runs can be done with the automatic adaptive lens transformation, time-dependent calculations can only be done with a fixed lens transformation. To set up a fixed lens transformation, the user must choose a mesh width for each z coordinate at which the lens transformation is to be altered and then apply the scaling rule illustrated in Fig. 2 to obtain the parameter z_f'' . To choose $L(R)$, (L_X or L_Y at $z=R$), the user must make a rough, factor-of-two estimate, $\sigma(R)$, of the $1/e$ dimension of the laser intensity profile at $z=R$. In many cases, $L(R)/L(0) = \sigma(R)/\sigma(0)$ can be assumed; although there are bloomed shapes with a broad low-intensity wing for which a much larger $L(R)$ value is required, this rule of thumb is a good starting point if more explicit information about the calculation is unavailable. If no estimate of the dimensions of the bloomed beam is available, try to obtain one by formulating the nearest approximate steady-state calculation and running it on the Four-D code using the adaptive lens transformation.

Occasionally, a time-dependent calculation will have to be computed in segments $z=0$ to R_1 , $z=R_1$ to R_2 , etc. with a different fixed lens transformation in each segment. In the first such region, the parameters z_f' (ZF) and z_f'' (ZTF) are chosen to reproduce the geometric optics focal length, z_f , of the actual laser beam; thus z_f' is determined by the equation $(z_f)^{-1} = (z_f')^{-1} + (z_f'')^{-1}$. At the initial z coordinate of the second and following regions, the lens transformation must be altered without changing the geometric optics focal length of the beam. (The lens transformation is only a computational tool and must not alter the physical problem being calculated.) Thus, the change in lens transformation focal length z_f'' (ZTF) must be compensated

Fig. 2. Scaling triangle for the mesh width $L(z)$ in a region with a constant lens transformation. The two mesh-widths at $z=z_0$ and $z=z_0+R$ determine both the width at any other point, $L(z)$, and the distance z_f'' from $z=z_0$ to the geometric focal point of the mesh point trajectories by the equation $[z_f'' - (z-z_0)]/z_f'' = L(z)/L(z_0)$. (Note that if $L(z_0+R) > L(z_0)$, z_f'' is negative.)

for with an equal and opposite change in the phase of the electric field at each mesh point. This compensating phase is determined by solving

$$[z_f''(z \rightarrow R_i -)]^{-1} = [z_f''(z \rightarrow R_i +)]^{-1} + [z_f']^{-1} ,$$

where $z_f''(z \rightarrow R_i +)$ is determined as described above for a single segment problem and

$$z_f''(z \rightarrow R_i -) = z_f''(z \rightarrow R_{i-1} +) + (R_i - R_{i-1}) .$$

If necessary, this procedure can be applied independently to the x and y dimensions by means of the code variables ZTFX, ZTFY, ZFX, and ZFY.

The following description of the detailed operation of the Four-D code applies only to the LLL version. After creating an input file (with the file-editing routine TRIX AC or the card reader) and obtaining a copy of the Four-D code file LHAYES from the photostore's take directory .625700:JOE, type the execute line:

LHAYES box-no. problem-id. input-filename / t v ,

where box-no. is a three-character LLI output distribution box number, problem-id. is a one-to-six character name for the problem, input-filename is the name of the input disk file, and all items on the execute line are space-delimited with no imbedded spaces. The Four-D code creates printer and plot files (problem-id. is imbedded in their names so several runs can be done in parallel) , reads the data for the first propagation path segment, expands its large core memory (LCM) storage space to handle LMAX time points, zeroes the small core memory (SCM) numbered common blocks and all LCM common blocks, and starts running the propagation problem.

Table 2. Input parameters for Four-D code.

Variable	Default value	Description
<u>Material parameters</u>		
CS	3.45E4	Sound speed (cm/sec)
CBL	0.4770	Density refractive coeff (cm ³ /gm)
RHOZ	0.001225	Unperturbed air density (gm/cm ³)
VISCOS	182.7E-6	Viscosity of air in poise
SIGMA	1.E-50	Absorption cross section (cm ⁻¹)
ETA	1.	Refractive index
GAMMAT	1.4	Adiabatic constant or ratio of specific heats
KAPPA	0.	Thermal conductivity of medium in which laser beam is propagating (J/(cm-sec-K)). KAPPA=0 indicates that thermal conductivity is to be neglected. KAPPA = 2.534E-4 for the U. S. extension to the ICAO standard sea-level atmosphere (see <u>Handbook of Chemistry and Physics</u> , 42nd ed., p. 3383).
CP	1.0046	Heat capacity of medium in which laser beam is propagating (J/gm-K)
CNSQ	0.	Coeff for turbulence (m ^{-2/3})
LO	100.	Scale length of turbulence (cm)
IPHS	0	If IPHS is nonzero, a new turbulence phase screen is calculated for each time point.
ISVRN	0	Random-number generator reset number. At the end of each run, the code writes a file with the final value of this number. Reading this value in a subsequent calculation causes the random-number generator to start with the next random number in its sequence rather than repeating its default sequence.
SLOSS	0.	Equivalent absorption coeff for scattering losses (cm ⁻¹). SLOSS contributes to the extinction coeff but not to atmospheric heating.

Table 2. Continued.

Variable	Default value	Description
<u>Multiline absorption parameters</u>		
NLINE	1	Number of rotational lines operating simultaneously. This is the number of absorption coefficients used by the code to model multiline laser beams. All lines are assumed to have the same phase distribution in any x-y plane and to have intensity distributions proportional to total intensity.
FLINE	1. 0. ...	Fraction of total power propagating in the l-th line at the current z is in FLINE(l). You must provide NLINE initial values at z = 0. whose sum must be 1. (no check is made).
ALINE	1.E-50 0. ...	Absorption coefficient for the l-th line is in ALINE(l) (cm^{-1}). You must provide NLINE absorption coefficients.
<u>Laser beam parameters</u>		
IMAX	1.	Maximum beam intensity for input (MW/cm^2)
LAMBDA	10.6E-4	Wavelength (cm)
DTIMP	1.	Pulse duration in multipulse mode. DTIMP is used only to calculate the energy in a given pulse and to estimate the effect of t-cube blooming.
FOCUS	1 (cm).E+45	Focal distance (cm). FOCUS is used to calculate behavior of a Gaussian beam that is focused but does not heat atmosphere.
SIGX	1.	1/e intensity radius along x-axis (cm)
SIGY	1.	1/e intensity radius along y-axis (cm)
WI	0.	An array giving the weights of the intensity as a function of time. For example, WI=1. for every time-point if the beam is cw.
IMP	0	If IMP=1, source is treated as series of delta functions with weights WI(J). If IMP=0, source is treated as continuously varying.

Table 2. Continued.

Variable	Default value	Description
<u>Lens and lens-transformation parameters</u>		
ZF	0.	The part of focal length of lens uncorrected by lens transformation (cm). If ZF=0., the code does not alter the initial phase.
ZTF	0.	The part of focal length compensated for by lens transformation (cm). If ZTF=0., the code does not use the lens transformation. Normally it will be convenient to compensate for only a portion of the true lens focal length using the lens transformation. The remainder of the actual lens strength can be handled with an appropriate value of ZF; i.e., $1/f = (1/ZF) + (1/ZTF)$, where f is the true focal length of the lens. If ZF and ZTF are so related, one can control the size of the beam in the focal plane as desired.
ZTL	0.	Distance over which lens transformation will remain in effect (cm). In most problems, set this to some number larger than the total distance you wish to propagate the laser beam. If you must follow a laser beam through its focal plane, then you will need to set ZTL to some distance that is a fraction of a Rayleigh range short of the focal distance and pick up the beam with a new lens transformation (in a new element) that is a fraction of a Rayleigh range after the focal plane.
ZTFX	nonzero ZTF	Cylindrical lens transformation equivalent of ZTF for z-x plane (cm)
ZTFY	nonzero ZTF	Cylindrical lens transformation equivalent of ZTF for z-y plane (cm)
ZFX	nonzero ZF	Cylindrical lens equivalent of ZF for z-x plane (cm)
ZFY	nonzero ZF	Cylindrical lens equivalent of ZF for z-y plane (cm)

Table 2. Continued.

Variable	Default value	Description
<u>Nondiffraction-limited beam parameters</u>		
AJITTER	0.	Jitter angle (radians). The beam centroid is assumed to have a position that is a Gaussian random variable with the probability distribution : $p(x,y) = \exp[-(x^2+y^2)/(2 \cdot a^2)] / (2 \cdot \pi \cdot a^2)$, where $a = z \cdot \text{AJITTER}$. The calculated air density is unchanged in this simple model of jitter. Our jitter model is roughly equivalent to adding the jitter area to the the bloomed beam area.
IENAV	0	If IENAV is nonzero, each initial time point gets a new random-phase screen. This may be useful in simulating nondiffraction-limited beams due to changes in the laser's active medium.
RPSD	0.	Standard deviation of the random phase for a nondiffraction-limited beam. The random phase is assumed to be a Gaussian random variable with a Gaussian autocorrelation function.
PCL	1.	Random-phase correlation length (cm). $\langle \phi(x,y) \cdot \phi(x_p,y_p) \rangle \equiv \text{RPSD}^2 \cdot \exp[-.5 \cdot ([x-x_p]^2 + [y-y_p]^2) / \text{PCL}^2]$. See C. B. Hogge et al., <u>Appl. Opt.</u> <u>13</u> , 1065 (1974).
AKSA	0.	Number of wavelengths of spherical aberration on initial wavefront at radius SIGX (initial cylindrical symmetry is assumed)
FNOISE	0.	Fraction of total energy that is noise
FSPEC	0.	Fraction of total spectrum encompassed by noise
<u>Aperture parameters</u>		
RRX	1.E+10	Half the x-dimension of a rectangular hard aperture (cm). Initial field values for $\text{abs}(x) > \text{RRX}$ are set to zero.
RRY	1.E+10	Half the y-dimension of a rectangular hard aperture (cm). Initial field values for $\text{abs}(y) > \text{RRY}$ are set to zero.

Table 2. Continued.

Variable	Default value	Description
REX	1.E+10	Half the x-principal axis width of an elliptical hard aperture (cm)
REY	1.E+10	Half the y-principal axis width of an elliptical hard aperture (cm). Initial field values are set to zero when $((x/REX)^2 + (y/REY)^2) > 1$.
NAP	0	When NAP is nonzero, the above hard apertures are replaced by soft apertures. The field is multiplied by $\exp[-.5 * ((x/REX)^2 + (y/REY)^2)^{NAP}]$ for elliptical apertures or by $\exp[-.5 * (x/RRX)^{2 * NAP}] * \exp[-.5 * (y/RRY)^{2 * NAP}]$ for rectangular apertures.
RDONUT	0.	Radius of an opaque circular inner aperture (cm). This obscures the central $\pi * RDONUT^2$ cm ² of the laser beam.
NDONUT	0	If NDONUT is nonzero, the obscured central region is apodized to remove the sharp edge by multiplying the unobscured electric field by $\exp[-([RDONUT-r]/q)^{2 * NDONUT}]$, where $q = 1.1 * REX - RDONUT$. Note that you must enter a reasonable value of REX to use this option.

Scenario parameters

VFLW	0.	Constant wind velocity (cm/sec). Not used in slewing calculations.
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General slewed beam parameters

ISLEW	0	If a problem involving slewing is to be solved, ISLEW must be set to 1 and input values of the velocities of the laser and target must be supplied. If ISLEW=0, an input value of VFLW must be provided.
VFLTR	0.	Velocity of laser platform (transmitter) (cm/sec)
VFLRC	0.	Velocity of target (receiver) (cm/sec)
VWIND	0.	Constant real wind velocity for slewing problems (cm/sec)

Table 2. Continued.

Variable	Default value	Description
THETAW	0.	Direction of real wind (for slewing problems) measured from direction of motion of laser platform (radians)
<u>Parameters for scenarios specified by velocities</u>		
RANGE	0.	Propagation range for a slewing problem (cm). RANGE is not used unless slewing flag is up.
THETAT	3.14159/2.	Angle between propagation direction and direction of motion of laser platform (x-axis) (radians)
THETAR	3.14159	Angle between receiver direction and direction of motion of laser platform (radians). Preset values for THETAT and THETAR correspond to laser and target moving in opposite directions.
<u>Parameters for point of impact that moves with laser</u>		
If DTOM is nonzero, THETAT, THETAR, and RANGE are computed from THETAS, DTOM, and OFFSET (defined below).		
THETAS	0.	Sighting angle from direction of motion of laser platform to target as measured from point of impact (radians)
DTOM	0.	Initial distance from target to point of impact (cm)
OFFSET	0.	Distance from point of impact to laser (cm). This is positive for a bow laser and negative for a stern laser.
<u>Noncoplanar scenario parameters</u>		
HL	0.	Height of center of laser output aperture above that horizontal plane containing point of impact (cm)
THETAP	0.	Angle between plane of attack and horizontal plane (radians). The plane of attack is that plane containing both the line of motion of the target and a line parallel to the velocity of the laser platform. The wind is assumed to be horizontal.

Table 2. Continued.

Variable	Default value	Description
<u>Output selection parameters</u>		
<u>Edit location parameters</u>		
<u>For variable z-step mode of operation</u>		
DZEDIT	1.	Axial distance between edits for variable z-step mode of operation (cm)
NEDITS	1	Number of edits to be taken in current stage
DZSTAGE	1.E+10	If $(NEDITS-1) * DZEDIT$ is less than DZSTAGE and $NEDITS * DZEDIT$ is greater than DZSTAGE, then DZSTAGE is the axial length of the current element (cm). In any case, DZSTAGE must be greater than $(NEDITS-1) * DZEDIT$. This parameter should not be used, it is only provided so that old input decks can be run with edits controlled by location rather than number of steps.
<u>For fixed z-step mode of operation</u>		
NCONT	1	Unused. NCONT is retained for compatibility with old input decks.
NEDIT	1	Number of cycles between edits. Edits occur every $NEDIT * DZ$ cm in the fixed z-step mode of operation.
<u>General output selection parameters</u>		
NC1	1	$X(NC1)$ and $Y(NC1)$ are the minimum coordinates for contour plots in coordinate space.
NC2	NFFT+1	$X(NC2)$ and $Y(NC2)$ are the maximum coordinates for contour plots in coordinate space.
NCK1	1	$XK(NCK1)$ and $YK(NCK1)$ are the minimum coordinates for the spectrum contour plot.
NCK2	NFFT+1	$XK(NCK2)$ and $YK(NCK2)$ are the maximum coordinates for the spectrum contour plot.
NBIN	10	Number of intensities/fluences to be used to calculate area over which an intensity/fluence is exceeded

Table 2. Continued.

Variable	Default value	Description
FIMIN	0.01	Fraction of maximum intensity/fluence associated with first bin
FIMAX	0.91	Fraction of maximum intensity/fluence associated with NBIN-th bin
PFRACT	0.5	Fraction of total power/energy to be included in average intensity/fluence calculation
IGPH	1	If IGPH=1, phase graphics are executed. Otherwise not.
IGSP	1	If IGSP=1, spectrum graphics are executed. Otherwise not.
IGD	1	Set IGD=0 to delete density plots.
ICASE	0	An integer that can be used to classify problem (not required)

Calculation control parameters

LMAX	1	Number of time-points in pulse. If the calculation is for a cw beam, it is assumed that initial intensity is 0.
NELEM	1	Number of elements in propagation path. If propagation calculation requires that the path be broken into a number of different portions each with different data, then NELEM should equal the number of data lists in the data file.
NF	1	Number of integration cycles corresponding to a particular portion of a propagation path

Mesh- and step-size parameters

DT	1.	Time increment (sec)
DZ	1.	Axial space interval (cm)
NFFT	64	Number of mesh points in x- and y-directions. NFFT must be a power of 2 because of use of FFT algorithm.

Table 2. Continued.

Variable	Default value	Description
LX	1.	Length of problem mesh in x-direction (cm)
LY	1.	Length of problem mesh in y-direction (cm)
<u>Variable z-step control parameters</u>		
EPSI	1.E-2	Fraction of maximum intensity below which phase information is to be ignored in estimating variable z-step size
FVDZ	0.1	Estimated change in x-component of phase gradient is held to $FVDZ \cdot \pi / DX$ by variable z-step algorithm
LVDZ	LMAX	Time-point to be used for variable z-step size estimates
DZMIN	1.E+3	Minimum step-size estimate allowed by variable z-step algorithm (cm)
DZMAX	5.E+4	Maximum step-size estimate allowed by variable z-step algorithm (cm). DZMAX should be used to keep the step-to-step change in the wind velocity to an acceptable number.
FDEV	0.005	Fractional deviation between geometric optics and Gaussian beam estimates of beam diameter at end of one z-step. Near a focal point, this code adjusts the z-step to keep the two estimates within this fraction of each other.
EPSV	0.2	Maximum fractional change in wind velocity allowed by variable z-step algorithm
<u>T-cube blooming parameters</u>		
COEFT3	1.0	Weighting factor for average t-cubed blooming over time of a pulse (multipulse case only)
NFILT	1	Filter exponent
FFILT	0.	Filter fraction (sets 1/2 point in k-space). The Fourier transform of the t-cube blooming contribution to the air density is filtered by multiplying by the factor $1./[1. + (q \cdot FFILT^2)^{NFILT}]$, where $q = (kx \cdot dx)^2 + (ky \cdot dy)^2$.

Table 2. Continued.

Variable	Default value	Description
<u>Multipulse steady-state parameters</u>		
NMP	100	Maximum number of identical pulses to be used in a multipulse "steady-state" calculation
NINTRP	1	If NINTRP=1, the air density for multipulse steady-state blooming is calculated using a truncated Fourier series to move the heated air downwind. If NINTRP=0, the downwind motion of the heated air is calculated with a 4-point bilinear interpolation formula.
<u>Miscellaneous problem flags</u>		
ISSL	0	If ISSL = 1, the code will do a steady-state calculation only. Remember, the code also does a steady-state calculation for a time-dependent problem (ISSL=0) if the local wind speed leads to steady-state conditions.
I LENS	0	I LENS = 1 turns on an adaptive lens transformation similar to that used at MIT. This is only good for steady-state calculations.
ITILT	0	ITILT = 1 turns on an automatic adaptive correction for beam deflection that keeps the intensity centroid approximately centered on the computational mesh. This correction for deflection is also done when I LENS = 1 regardless of the value of ITILT. This can only be used for steady-state problems.
IVARDZ	0	If IVARDZ = 1, an adaptive z-step algorithm is used.
IVARVEL	0	If IVARVEL is nonzero, the time-dependence of the transverse component of the effective wind is calculated. Otherwise the t=0 value is used at every time-point in the laser pulse.
IP	1	For IP=1, the complex exponential function is used to put phase changes on the complex electric field. For IP=0, $\exp(ix) = (1+ix*.5)/(1-ix*.5)$ is used instead.

Table 3. Construction of an input deck for Four-D code
(parameters frequently changed).

Variable	Description	
(A) <u>Specify material and laser beam properties</u>		
SIGMA	Absorption coefficient	(cm ⁻¹)
CNSQ	Turbulence strength	(m ^{-2/3})
LO	Turbulence outer scale length	(cm)
LAMBDA	Wavelength	(cm)
FOCUS	Focal length	(cm)
IMAX	Maximum intensity if W1=1.	(MW/cm ²)
SIGX, SIGY	Principal axis 1/e radii of a Gaussian beam	(cm)
W1	Weight factor for intensity	
DTIMP	Pulse length for multipulse case	(sec)
AJITTER	Jitter angle	(radians)
REX, REY	Elliptical aperture principal-axis radii	(cm)
(B) <u>Specify laser beam motion and wind velocity and use one of three scenario schemes</u>		
(i) <u>For unslewed laser beams:</u>		
VFLW	Constant wind speed	(cm/sec)
(ii) <u>For slewed laser beams:</u>		
ISLEW	Slewing flag	
VFLTR	Transmitter (laser) speed	(cm/sec)
VFLRC	Receiver (target) speed	(cm/sec)
VWIND	Real wind speed	(cm/sec)
THETAW	Direction of real wind	(radians)
with either		
RANGE	Laser-to-target distance	(cm)
THETAT	Laser beam angle	(radians)
THETAR	Direction of target motion	(radians)
or		
THETAS	Sighting angle to target	(radians)
DTOM	Distance to target from impact pt	(cm)
OFFSET	Constant laser-to-impact pt distance	(cm)
(iii) <u>For noncoplanar scenarios add:</u>		
HL	Height of laser above scenario plane	(cm)
THETAP	Tilt angle of scenario plane	(radians)

Table 3. Continued.

Variable	Description	
(C) <u>Specify how calculation is to be done</u>		
(i) <u>Specify initial lens transformation</u>		
ZF	Phase-front focal length	(cm)
ZTF	Lens transformation focal length	(cm)
ZTL	Turn lens transformation off at this z	(cm)
(ii) <u>Specify edit locations</u>		
NELEM	Number of propagation path segments	
<u>For variable axial step</u>		
DZEDIT	Distance between edits	(cm)
NEDITS	Number of edits in this path segment	
<u>For fixed axial step</u>		
NEDIT	Number of steps between edits	
DZ	Axial step length	(cm)
NF	Number of steps in this path segment	
(iii) <u>Specify size of calculational mesh</u>		
LMAX	Number of time-points	
DT	Time between time-points	(sec)
DZ	Initial adaptive axial-step length	(cm)
LX, LY	Total mesh widths	(cm)
(iv) <u>Specify problem flags to select type of calculation</u>		
ISSL	Steady-state flag	
ILENS	Adaptive lens transformation flag	
IVARDZ	Adaptive axial-step flag	
IMP	Multipulse flag	
(v) <u>Specify or delete t-cube blooming for multipulse calculations</u>		
COEFT3	T-cube blooming coeff. (1. or 0.)	
NFILT	T-cube blooming spectral-filter exponent	
FFILT	T-cube blooming spectral-filter fraction	

III. OUTPUT FROM TYPICAL RUN

At LLL, the Four-D code generates three output files: a random-number initialization file, a printer file, and a plot file. The random-number initialization file is just a local convenience ⁴. Our printer file contains information primarily intended to help debug the Four-D code and provide a quick look at the more important linear graphs (in table form) before the plot file is available; Table 4 lists its contents. The plot file, after conversion to microfiche, is the primary output media of the Four-D code. Table 5 summarizes the information contained in the plot file. Besides linear graphs and contour plots of the intensity, spectral density, phase, and fluence, the plot file contains various printed diagnostic and summary data (e.g., average intensity in the minimum $1/2$ power ⁵ area, average fluence in the minimum $1/2$ energy ⁵ area, fractional maximum intensity on the mesh boundary, fractional maximum spectral density on the mesh boundary, and locations of the intensity and fluence centroids). Users at installations without a fast turnaround plotting capability should have the above printed information transferred to the printer file.

Figures 3 to 17 are samples of the plot file output for a typical noncoplanar scenario run of the Four-D code.² Figure 3, which is a composite of the three NAMELIST input-deck frames, gives the input parameters for this run. Frames that contain plots similar to these samples are not shown but merely mentioned in the frame captions. Samples of frames 10, 11, 24, and 25 do not appear either since they will be deleted in a future update.

Figure 18 is the timing frame for this run. It contains the execution time; the fractional division of the execution time into central processor unit (CPU), I/O, and system call times; and the octal representation of the last random floating-point number used by the code. The latter can be used in a subsequent run to continue the random-number sequence of this run. (The time-per-cycle line is meaningless since the number of cycles is no longer counted.) The three-minute execution time for the 240 steps of this run is typical for the Four-D code using a 64x64 mesh. The z-step sizes used in this run are probably smaller than necessary for good results, but they are typical of z-step sizes that we have used successfully in stagnation-zone problems.

Table 4. Contents of printer file.

Item	Description
1	Axial position of edit
2	Laser power at this time-point
3	(a) Intensity vs x along central y-mesh line (b) Intensity vs y at x-point with maximum intensity on central y-mesh line (c) Intensity vs mesh diagonal distance
4	(a) Spectral density vs k_x for $k_y=0$ (b) Spectral density vs k_y for $k_x=0$
	1-4 repeated for each time-point
5	Density-edit location and time
6	Density vs distance parallel to wind
	5-6 repeated for each time-point
7	Adaptive lens transformation debug printout if ILENS=1
8	Adaptive z-step debug printout if IVARDZ=1
	7-8 repeated for each step
	1-8 repeated for each edit except the last, which ends with 4 for the last time-point

Table 5. Contents of Plot File.

Frame	Contents
1	List of NAMELIST input deck
2	List of various input and calculated parameters
3	x-component of wind vs axial coordinate
4	y-component of wind vs axial coordinate
5	Wind speed vs axial coordinate
6	Intensity vs x along central y-mesh line
7	Intensity vs y for x-point with maximum intensity on central y-mesh line
8	Intensity vs mesh diagonal length
9	Isointensity contour plot
10	Area with intensity $> I_{test}$ vs I_{test}
11	Area with intensity $> I_{test}$ vs average intensity in that area
12	Table of miscellaneous intensity information including: <ul style="list-style-type: none"> (a) Maximum intensity (b) Average intensity in smallest area that contains PFRACT of total power (c) x-, y-, and r-coordinates of intensity centroid (d) Smallest area that contains PFRACT of total power (e) Table of areas and average intensities associated with intensities greater than a set of test intensities
13	Isospectral-density contour plot for electric field (and ratio of maximum on boundary to maximum in whole mesh)
14	Spectral density vs k_y for $k_x=0$
15	Spectral density vs k_x for $k_y=0$
16	x-component of phase gradient of electric field vs x along central y-mesh line
17	Phase of electric field vs x along central y-mesh line

Table 5. Continued.

Frame	Contents
18	y-component of gradient of phase of electric field vs y for that x at which intensity is largest on central y-mesh line
19	Phase of electric field vs y at that x at which intensity is largest on central y-mesh line
20	Isophase contour plot
Frames 6-20 repeated for each time-point	
21	Fluence vs x along central y-mesh line
22	Fluence vs y along central x-mesh line
23	Isofluence contour plot
24	Area with fluence $> F_{test}$ vs F_{test}
25	Area with fluence $> F_{test}$ vs average fluence in that same area
26	Table of miscellaneous fluence information including: <ul style="list-style-type: none"> (a) Maximum fluence (b) Average fluence in smallest area that contains PFRACT of total energy (c) x-, y-, and r-coordinates of fluence centroid (d) Smallest area that contains PFRACT of total energy (e) Table of areas and average fluences associated with fluences greater than a set of test fluences
27	Maximum intensity vs time
28	Average intensity in PFRACT power area vs time
29	Density vs distance parallel to wind taken through center mesh point
30	Isodensity contour plot

Table 5. Continued.

Frames 29 and 30 are repeated once for each time-point. (30 will be skipped if the contour interval is less than 10^{-14} .)

The whole output sequence 5-30 is repeated for each edit except the last, which ends with 28. A timing frame completes the plot file. Frames 1-4 appear once at the beginning of each propagation path segment; frames 2-4 are plotted only for slewed laser beam calculations.

```

ICASE = 501
LAMBDA = 3.8E-4
IMAX = 2.546E-4
FOCUS = 150809.0182
WI = 15(1.)
IGSP = 1
SIGX = 25.
SIGY = 25.
LX = 180.
LY = 180.
ZTL = 6.E5
ZTF = 150809.0182
SIGMA = 0.07E-5
ISLEW = 1
VFLTR = 1500.
VFLRC = 3.E4
VWIND = 250.
OFFSET = 15600.
DTOM = 150000.0
THETAS = 1.570796326
THETAW = -2.792526803
HL = 1000.
ISSL = 1
DT = 1.
IMP = 0
ILENS = 1
LMAX = 1
DZ = 875.
NELEM = 3
NF = 80
NCONT = 40
NEDIT = 40
END

```

```

DZ = 359.8756185
END

```

```

DZ = 650.2371090
END

```

Fig. 3. NAMELIST input deck, frame 1.

Fig. 4. x-component of transverse wind velocity vs axial coordinate, frame 2. The y-component plot, frame 3, is similar.

Fig. 5. Transverse wind speed vs axial coordinate, frame 4.

INPUT DATA		
CASE NUMBER	501	CBL= 4.7700E-01
NFFT=	64	VFLR= 0.
N2=	0.	ZNULL= 4.3038E+02
GAMMA=	-3.9435E+03	RECEIVER ANGLE= 4.7624E+00
DZ=	6.5024E+02	TRANSMITTER ANGLE= 1.6744E+00
LAMBDA=	3.8000E-04	V-TRANSMITTER= 1.5000E+03
ETA=	1.0000E+00	V-RECEIVER= 3.0000E+04
LX=	6.6355E+01	
LY=	7.1238E+01	
SIGX=	2.5000E+01	
SIGY=	2.5000E+01	
IMAX=	2.5460E-04	
NF=	80	
NEDIT=	40	
ZF=	0.	
ZTF=	0.	
ZTL=	6.0000E+05	
ZT=	9.8790E+04	
AKX=	1.7630E-04	
AKY=	1.5296E-04	
ELEMENT NUMBER=	3	
NE=	3	
SIGMA=	7.0000E-07	
GAIN=	9.9987E-01	
VFL=	3.2313E+02	
VFL0=	0.	
VFL1=	0.	
FVFL1=	0.	
NV=	0	
DT=	1.0000E+00	
DX=	1.0368E+00	
TIME=	1.0000E+00	

Fig. 6. Various input and calculated parameters, frame 5.

Fig. 7. Intensity vs. x for central y-mesh line, frame 6. The plots of intensity vs y, intensity vs mesh diagonal, fluence vs x, and fluence vs y (frames 7, 8, 21, and 22) are similar.

Fig. 8. Isointensity contour plot, frame 9. The isofluence contour plot, frame 23, is similar.

BIN	INTENSITY		
	TEST	AVERAGE	AREA
1	1.40E-05	3.82E-04	1.21E+03
2	1.54E-04	6.47E-04	6.67E+02
3	2.94E-04	7.72E-04	5.16E+02
4	4.34E-04	8.71E-04	4.15E+02
5	5.74E-04	9.59E-04	3.35E+02
6	7.14E-04	1.04E-03	2.67E+02
7	8.54E-04	1.12E-03	2.03E+02
8	9.94E-04	1.19E-03	1.49E+02
9	1.13E-03	1.26E-03	9.46E+01
10	1.27E-03	1.34E-03	4.27E+01

CENTROID X (CM) = 8.1291E-01

CENTROID Y (CM) = 5.5408E-01

CENTROID R (CM) = 9.8378E-01

MAXIMUM INTENSITY (MW/SQCM) = 1.3999E-03

MINIMUM 0.500-POWER AREA (SQCM) = 2.1064E+02

AVERAGE INTENSITY IN MIN. HPA (MW/SQCM) = 1.1074E-03

Fig. 9. Miscellaneous intensity information, frame 12. The table of miscellaneous fluence information, frame 26, is similar.

Fig. 10. Isospectral density contour plot, frame 13.

Fig. 11. Spectral density vs k_y , frame 14. The spectral density vs k_x plot, frame 15, is similar.

Fig. 12 x-component of phase gradient vs x, frame 16. The plot of the y-component of the phase gradient vs y, frame 18, is similar.

Fig. 13. Phase vs x for central y-mesh line, frame 17. The phase vs y plot, frame 19, is similar.

Fig. 14. Isophase contour plot, frame 20.

Fig. 15. Maximum intensity vs time, frame 27. The A marks the actual maximum intensity as calculated by the Four-D code. The V marks the maximum intensity of an infinite Gaussian beam of the same $1/e$ radius as the actual beam (SIGX) propagated in a vacuum, then corrected for the linear absorption and scattering losses of the actual laser beam. The average intensity vs time plot, frame 28, is similar.

Fig. 16. Density vs distance parallel to wind taken through center mesh point, frame 29.

Fig. 17. Isodensity contour plot, frame 30.

16:57:58Z 04/01/76
TIMING INFORMATION
CPU:I/O:SYSTEMS CALLS= 095:04:00
TIME ELAPSED(MINUTES)= 3.0301E+00
TIME TAKEN PER CYCLE(MINUTES)= 3.7876E-02
CYCLES PER MINUTE= 2.6402E+01
RANDOM NUMBER RESET NO. = 1717007777720000011B

Fig. 18. Timing frame.

IV. DESCRIPTION OF FOUR-D CODE

The Four-D code is a large collection of subroutines most of which accomplish a small specific task. The main program handles input for each propagation path segment, file management, assignment of core storage, definition of the initial laser beam, lenses and apertures (which must be at the beginning of a path segment), writing the initial edit for each path segment, and accumulation of timing data. For each path segment, the main program calls subroutine PROPGAT, which moves the beam across the current path segment. Table 6 contains a brief description of the subroutines of the Four-D code. Although the number of subroutines is formidable, the information in Table 6, a basic grasp of the idea behind the lens transformation,¹ and a thorough understanding of subroutines PROPGAT, PHASE, and SSLEW should be sufficient to allow a computer programmer to make the Four-D code operational at another installation.

Table 6. Subroutines of Four-D code.

Subroutine	Function performed	Called by	Externals
ADJUST	Updates lens transformation parameters and removes corresponding quadratic phase from electric field	PROPGAT	LENS
BMAX	Returns maximum value on mesh boundary lines of array 1	EDITS	
CMPLXEX	Computes free propagation Greens's function for current x,y mesh spacing	MAIN DIFF LENSTRN PROPGAT	
CONTOUR	Plots contour plots from array 1	EDITS	
DEDIT	Plots and prints density parallel to wind and plots isodensity contours	PROPGAT	PLOT2 RSCAL
DIFF	Advances electric field one free propagation step	PROPGAT	CMPLXEX
DZEST	Computes suggested length of next z-step (may be shortened because of an edit)	PROPGAT	
EAPRTUR	Simulates an elliptical hard aperture	MAIN	
EDITS	Output of intensity, spectral density, phase, and fluence (by means of FLEDIT) data	MAIN PROPGAT	BMAX CONTOUR FLEDIT PLOT1 PLOT2 POWER PHASEX PHASEXY PHASEY
FIXIT	Erases density in buffer region to control wraparound and computes density from its Fourier transform	PHASE	RFT YXFRM
FLEDIT	Output of fluence and intensity vs time information plus simulation of jitter	EDITS	PLOT1 PLOT2 RFT RSCAL YXFRM

Table 6. Continued.

Subroutine	Function performed	Called by	Externals
GENRATE	Sets certain propagation and plotting constants	MAIN	
INITFLD	Initializes electric field array including random phase (if any) for nondiffraction-limited beams	MAIN	SCREEN
INTENS	Computes intensity array	MAIN PROPGAT	
INVTRAN	Inverse Fourier transforms electric field	MAIN	CPFT
LENS	Adds a quadratic term to phase of electric field	MAIN LENSTRN ADJUST	
LENSTRN	Adjusts x and y coordinates and field amplitude for current lens transformation	PROPGAT LENS	CMPLXEX
MLINE	Computes absorption coeff for next z-step	PROPGAT	
NOISE	Adds a constant amplitude random phase noise term to a fraction of Fourier components of field	MAIN	
PHASE	Computes nonlinear and turbulence phase changes for current z-step	PROPGAT	FIXIT RFT SCREEN SSLEW TSOURCE YXFRM
PHASEX	Computes phase and x-component of phase gradient along central y-mesh line	EDITS	
PHASEXY	Computes phase at each mesh point	EDITS	
PHASEY	Computes phase and y-component of phase gradient for that x-coordinate at which intensity is largest on central y-mesh line	EDITS	

Table 6. Continued.

Subroutine	Function performed	Called by	Externals
PLOT1	Computes minimum and maximum ordinate values for plots and advances film frame	EDITS FLEDIT	
PLOT2	Writes flow velocity, power, and convection dwell-time on current film frame	DEDIT EDITS FLEDIT	
PROPGAT	Propagates laser beam across current propagation path segment	MAIN	ADJUST CMLXEX DEDIT DIFF DZE3T EDITS INTENS INVTRAN LENSTRN MLINE PHASE RTILT TRANFRM VFIX
POWER	Computes power of laser beam	EDITS	
RAPRTUR	Simulates a rectangular hard aperture	MAIN	
RFT	Computes a 2N real Fourier transform	FIXIT FLEDIT PHASE SCREEN SSLEW TSOURCE	CPFT
RSCAL	Equalizes scale factor for x and y axes of contour plots	FLEDIT CONTOUR DEDIT	
RTILT	Removes linear phase of field for adaptive lens transformation	PROPGAT	
SCENAR	Computes wind velocity components at current z and time	VFIX	
SCREEN	Computes random part of turbulence and nondiffraction-limited beam phase screens	INITFLD PHASE	CPFT RFT

Table 6. Continued.

Subroutine	Function performed	Called by	Externals
SLEDIT	Plots velocity components vs z	MAIN	
SOLVER	Performs Carlson method integration along characteristics for cw steady-state runs	SSLEW	
SSLEW	Does steady-state density calculation	PHASE	RFT SOLVER TSOURCE YXFRM
TRANFRM	Computes Fourier transform of field array	MAIN PROPGAT	CPFT
TSOURCE	Computes Fourier transform of intensity array for density calculations	PHASE SSLEW	RFT
VFIX	Computes flow velocity, velocity dependent coeffs, and Green's function for isobaric-approx density calculations	MAIN PROPGAT	SCENAR
YXFRM	Computes 2N y-Fourier transform of SCM scratch pad array	FIXIT FLEDIT PHASE SSLEW	CPFT

The assembly language subroutine CPFT performs a one-dimensional fast Fourier transform.

REFERENCES AND FOOTNOTES

1. J. A. Fleck, Jr., J. R. Morris, and M. D. Feit Time-Dependent Propagation of High-Energy Laser Beams through the Atmosphere, Lawrence Livermore Laboratory, Repts. UCRL-51826 (1975) and UCRL-77719 (1976); Appl. Phys. 10, 129 (1976).
2. J. A. Fleck, Jr., J. R. Morris, and M. D. Feit, Time-Dependent Propagation of High-Energy Laser Beams through the Atmosphere: II, Lawrence Livermore Laboratory, Rept. UCRL-52071 (1976).
3. For cw laser beams, the Four-D code assumes that at a given point in space the intensity can be approximated as a piece-wise linear function of time. If the intensity profile changes drastically in one time step, this assumption is invalid, and either a smaller time step should be used or the calculation should be performed in a steady-state approximation.
4. The random number initialization file contains a NAMELIST format input line with the last random number generated by the LLL random number generator RNFL as a 60-bit octal CDC 7600 floating-point number. This same line is also written into the the timing frame of the plot file.
5. The average intensity and fluence are calculated in the minimum f power area where f is the value contained in the input variable PFRACT. The default value of PFRACT is $1/2$.

APPENDIX A: DEBUG TEST CASES

The eight test cases in this appendix all have run times less than 0.3 min on the CDC 7600's at LLL. These cases are not typical runs due to the large z-step size and 32x32 mesh. Although they give qualitatively accurate results, a more correct calculation using a z-step size between 1/5 and 1/10 of the 0.5 km used here and a 64x64 mesh might give significantly different results. These cases are just a cheap-to-run set of debug runs.

Table A1 describes the purpose of each test. Its last column indicates subroutines checked by a given test in a way not covered by tests of a lower test number. I strongly suggest that you start with test number 1 (VACG) for three reasons: it has the shortest run time (0.06 min); it tests a large part of the Four-D code and essentially limits your search for bugs to VFIX, ADJUST, RTILT, DZEST, PHASE, and subroutines called directly or indirectly from PHASE; finally, an analytic solution is known for this case:

$$E(r,z) = \frac{E_0 k a^2}{k a^2 (1-z/f) - i z} \exp \left\{ -\frac{r^2}{2 a^2} \left[\frac{1 - i k a^2 (\{1-z/f\} - z f / \{k a^2\}^2) / f}{(z/k a^2)^2 + (1-z/f)^2} \right] \right\} ,$$

where $k \equiv 2\pi/\lambda$, $\lambda = 3.8 \times 10^{-4}$ cm, $a = 10$ cm, and $f = 3 \times 10^5$ cm. (The above field is the complex conjugate of the result in Appendix B of Aitken, Hayes, and Ulrich, Propagation of High-Energy 10.6-micron Laser Beams through the atmosphere, NRL Rept. 7293 (1971).) The peak intensity at 3 km in test case 1 is about 1.6% lower than the analytical result; this is due to truncation of the initial beam at the 4×10^{-4} fractional intensity points on the x and y axes.

Test 6 (TURB) includes a check of the scenario portion of the Four-D code. At LLL, the pertinent numbers are written on an online teletype; at other installations, this output from subroutine SLEDIT should be diverted to tape 6, the print file. Our values for these numbers are

```

TRANSVERSE WIND SPEED
COMPONENT  XMITTER  RECEIVER
      X    -9.2409E+02  5.9715E+02
      Y      0.         0.
RANGE = 4.8260E+05  THETAT = 9.7705E-01
THETAR = 4.09056E+00

```

The input for this scenario check is

```

VR = VFLTR = 3x104
VT = VFLTR = 1x103
D = DTOM = 5x105
ΦS = THETAS = tan-1(4/3) = 0.9272952180
l = OFFSET = 3x104
VW = VWIND = 500
θW = THETAW = 5π/4

```

The symbols in the first column are defined in section II and Fig. 1.

To get the same results for the turbulence test case, you must use the same random-number sequence. Subroutine RNFL, our random-number generator, uses the linear congruential multiplier algorithm $x_n = \lambda \cdot x_{n-1} \bmod 1$, where

$\lambda = 2^{21}-3$ and the initial value
 $x_0 = 2^{-48} \lambda^2$ if ISVRN = 0
 $= \text{ISVRN}$ (as a 7600 floating-point No.) if ISVRN $\neq$ 0.

The first number generated is x_1 . RNFL uses the CDC 7600 42 floating-point double-precision product command, which produces the low-order 48 bits of the floating-point product (in unnormalized form) with a 12-bit exponent, to compute the random-number sequence. A simple test run of RNFL (to clarify the above) follows:

```

      PROGRAM TESTRNF(TAPE3)
      X = RNFL(B)
      WRITE (59,1002) X,X
      WRITE(59,1000)
1000  FORMAT (" ISVRN = ")
      READ (59,1001) ISVRN
1001  FORMAT( 020)
      CALL LRNFL(ISVRN)
      X = RNFL(B)
      WRITE (59,1002) X,X
1002  FORMAT(" X = ",E21.14,3X,020)
      CALL EXIT
      END
  
```

EXECUTION

```

X = 8.59375201165583E-01    17176700000327777745
ISVRN =
17177215443246662011
X = 5.97186166287336E-01    17174616046123351745
  
```


Table A1. Debug test case purposes.

Test No.	Test ID	Test description	Routines tested
1	VACG	Linear propagation steps (constant wind)	CPFT, TRANFRM, INVTRAN, GENRATE, CMPLXEX, DIFF, LENSTRN, LENS, INITFLD, EDIT, INTENS, POWER, PROPGAT, PHASEX, PHASEY, PHASEXY, BMAX, CONTOUR, PLOT1, PLOT2, MAIN
2	CWSS	CW steady-state density calc (constant wind)	PHASE, VFIX, GENRATE, SSLEW, RFT, DEDIT
3	CWTR	CW isobaric density calc (constant wind)	PHASE, TSOURCE, FIXIT, FLEDIT, VFIX
4	MPTR	Multipulse isobaric transient calc (constant wind)	PHASE, VFIX
5	MPSS	Multipulse steady-state and t^3 blooming calcs	PHASE, VFIX, YXFRM, SSLEW
6	TURB	Turbulence calc and scenario setup	PHASE, GENRATE, SLEDIT, VFIX, SCREEN
7	TSOIN	Supersonic steady-state	VFIX, SSLEW, SOLVER
8	VARZ	Variable z-step variable lens transformation version of test 2	DZEST, ADJUST, RTILT

Test 1 (VACG) checks the vacuum propagation coding.

Input:

LAMBDA	= 3.8E-4
IMAX	= 1.E-4
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 3.E+5
NF	= 1
DT	= 1.
FOCUS	= 3.E+5
ZF	= 12.E+5
ZTF	= 4.E+5
ZTL	= 1.E+7
WI	= 15(1.)
LMAX	= 1
NELEM	= 1
ISSL	= 1
VFLW	= 1000.
NCONT	= 1
NEDIT	= 1
SIGMA	= 1.E-50
COEFT3	= 0.
CNSQ	= 0.
END-RUN	

Selected print file output:

N= 0
Z= 0.

INTENSITY ALONG X-AXIS POWER(W)= 3.1414E+04

IX-AXIS=	1.2341E-08	3.6700E-08	1.0173E-07	2.6283E-07	6.3297E-07	1.4209E-06
IX-AXIS=	2.9729E-06	5.7980E-06	1.0540E-05	1.7859E-05	2.8206E-05	4.1524E-05
IX-AXIS=	5.6978E-05	7.2876E-05	8.6882E-05	9.6545E-05	1.0000E-04	9.6545E-05
IX-AXIS=	8.6882E-05	7.2876E-05	5.6978E-05	4.1524E-05	2.8206E-05	1.7859E-05
IX-AXIS=	1.0540E-05	5.7980E-06	2.9729E-06	1.4209E-06	6.3297E-07	2.6283E-07
IX-AXIS=	1.0173E-07	3.6700E-08				
IY-AXIS=	1.2341E-08	3.6700E-08	1.0173E-07	2.6283E-07	6.3297E-07	1.4209E-06
IY-AXIS=	2.9729E-06	5.7980E-06	1.0540E-05	1.7859E-05	2.8206E-05	4.1524E-05
IY-AXIS=	5.6978E-05	7.2876E-05	8.6882E-05	9.6545E-05	1.0000E-04	9.6545E-05
IY-AXIS=	8.6882E-05	7.2876E-05	5.6978E-05	4.1524E-05	2.8206E-05	1.7859E-05
IY-AXIS=	1.0540E-05	5.7980E-06	2.9729E-06	1.4209E-06	6.3297E-07	2.6283E-07
IY-AXIS=	1.0173E-07	3.6700E-08	1.2341E-08			
ID-AXIS=	1.5230E-12	1.3469E-11	1.0349E-10	6.9081E-10	4.0065E-09	2.0188E-08
ID-AXIS=	8.8383E-08	3.3617E-07	1.1109E-06	3.1895E-06	7.9560E-06	1.7242E-05
ID-AXIS=	3.2465E-05	5.3110E-05	7.5484E-05	9.3210E-05	1.0000E-04	9.3210E-05
ID-AXIS=	7.5484E-05	5.3110E-05	3.2465E-05	1.7242E-05	7.9560E-06	3.1895E-06
ID-AXIS=	1.1109E-06	3.3617E-07	8.8383E-08	2.0188E-08	4.0065E-09	6.9081E-10
ID-AXIS=	1.0349E-10	1.3469E-11	1.5230E-12			
X-SPECTRUM						
FX-AXIS=	3.0091E-13	3.0733E-13	3.2758E-13	3.6499E-13	4.2629E-13	5.2417E-13
FX-AXIS=	6.8280E-13	9.5035E-13	1.4282E-12	2.3845E-12	7.1927E-12	1.2137E-10
FX-AXIS=	2.6230E-09	3.4198E-08	2.2960E-07	7.2021E-07	1.0423E-06	7.2021E-07
FX-AXIS=	2.2960E-07	3.4198E-08	2.6230E-09	1.2137E-10	7.1927E-12	2.3845E-12
FX-AXIS=	1.4282E-12	9.5035E-13	6.8280E-13	5.2417E-13	4.2629E-13	3.6499E-13
FX-AXIS=	3.2758E-13	3.0733E-13	3.0091E-13			
Y-SPECTRUM						
FY-AXIS=	3.0091E-13	3.0733E-13	3.2758E-13	3.6499E-13	4.2629E-13	5.2417E-13
FY-AXIS=	6.8280E-13	9.5035E-13	1.4282E-12	2.3845E-12	7.1927E-12	1.2137E-10
FY-AXIS=	2.6230E-09	3.4198E-08	2.2960E-07	7.2021E-07	1.0423E-06	7.2021E-07
FY-AXIS=	2.2960E-07	3.4198E-08	2.6230E-09	1.2137E-10	7.1927E-12	2.3845E-12
FY-AXIS=	1.4282E-12	9.5035E-13	6.8280E-13	5.2417E-13	4.2629E-13	3.6499E-13
FY-AXIS=	3.2758E-13	3.0733E-13	3.0091E-13			
DENSITY						
DIST // WIND (CM) Z= 1.5000E+05 T(SEC)= 1.0000E+00						
RHO(1)	1.2341E-02	-0.	-1.5591E-58	-1.0566E-57	-4.7444E-57	-1.8276E-56
RHO(7)	-6.4038E-56	-2.0145E-55	-5.6069E-55	-1.3790E-54	-3.0596E-54	-6.2038E-54
RHO(13)	-1.1481E-53	-1.9463E-53	-3.0360E-53	-4.3762E-53	-5.8627E-53	-7.3492E-53
RHO(19)	-8.6894E-53	-9.7791E-53	-1.0577E-52	-1.1105E-52	-1.1419E-52	-1.1587E-52
RHO(25)	-1.1669E-52	-1.1705E-52	-1.1719E-52	-1.1724E-52	-1.1725E-52	-1.1725E-52
RHO(31)	-1.1725E-52	-1.1725E-52	-1.1725E-52			

N= 0
Z= 3.0000E+05

INTENSITY ALONG X-AXIS		POWER(W)= 3.1414E+04				
IX-AXIS=	2.7396E-08	2.2278E-09	6.0630E-10	4.3776E-08	4.0849E-07	1.1243E-06
IX-AXIS=	4.1588E-06	1.3351E-05	3.9447E-05	1.1218E-04	2.7041E-04	5.7018E-04
IX-AXIS=	1.0497E-03	1.6603E-03	2.3087E-03	2.8093E-03	2.9870E-03	2.8093E-03
IX-AXIS=	2.3087E-03	1.6603E-03	1.0497E-03	5.7018E-04	2.7041E-04	1.1218E-04
IX-AXIS=	3.9447E-05	1.3351E-05	4.1588E-06	1.1243E-06	4.0849E-07	4.3776E-08
IX-AXIS=	6.0630E-10	2.2278E-09				
IY-AXIS=	2.7396E-08	2.2278E-09	6.0630E-10	4.3776E-08	4.0849E-07	1.1243E-06
IY-AXIS=	4.1588E-06	1.3351E-05	3.9447E-05	1.1218E-04	2.7041E-04	5.7018E-04
IY-AXIS=	1.0497E-03	1.6603E-03	2.3087E-03	2.8093E-03	2.9870E-03	2.8093E-03
IY-AXIS=	2.3087E-03	1.6603E-03	1.0497E-03	5.7018E-04	2.7041E-04	1.1218E-04
IY-AXIS=	3.9447E-05	1.3351E-05	4.1588E-06	1.1243E-06	4.0849E-07	4.3776E-08
IY-AXIS=	6.0630E-10	2.2278E-09	2.7396E-08			
ID-AXIS=	2.5126E-13	1.6616E-15	1.2307E-16	6.4156E-13	5.5863E-11	4.2316E-10
ID-AXIS=	5.7902E-09	5.9676E-08	5.2095E-07	4.2132E-06	2.4479E-05	1.0884E-04
ID-AXIS=	3.6887E-04	9.2280E-04	1.7843E-03	2.6421E-03	2.9870E-03	2.6421E-03
ID-AXIS=	1.7843E-03	9.2280E-04	3.6887E-04	1.0884E-04	2.4479E-05	4.2132E-06
ID-AXIS=	5.2095E-07	5.9676E-08	5.7902E-09	4.2316E-10	5.5863E-11	6.4156E-13
ID-AXIS=	1.2307E-16	1.6616E-15	2.5126E-13			
X-SPECTRUM						
FX-AXIS=	4.8146E-12	4.9173E-12	5.2413E-12	5.8398E-12	6.8206E-12	8.3867E-12
FX-AXIS=	1.0925E-11	1.5206E-11	2.2852E-11	3.8151E-11	1.1508E-10	1.9420E-09
FX-AXIS=	4.1968E-08	5.4716E-07	3.6736E-06	1.1523E-05	1.6676E-05	1.1523E-05
FX-AXIS=	3.6736E-06	5.4716E-07	4.1968E-08	1.9420E-09	1.1508E-10	3.8151E-11
FX-AXIS=	2.2852E-11	1.5206E-11	1.0925E-11	8.3867E-12	6.8206E-12	5.8398E-12
FX-AXIS=	5.2413E-12	4.9173E-12	4.8146E-12			
Y-SPECTRUM						
FY-AXIS=	4.8146E-12	4.9173E-12	5.2413E-12	5.8398E-12	6.8206E-12	8.3867E-12
FY-AXIS=	1.0925E-11	1.5206E-11	2.2852E-11	3.8151E-11	1.1508E-10	1.9420E-09
FY-AXIS=	4.1968E-08	5.4716E-07	3.6736E-06	1.1523E-05	1.6676E-05	1.1523E-05
FY-AXIS=	3.6736E-06	5.4716E-07	4.1968E-08	1.9420E-09	1.1508E-10	3.8151E-11
FY-AXIS=	2.2852E-11	1.5206E-11	1.0925E-11	8.3867E-12	6.8206E-12	5.8398E-12
FY-AXIS=	5.2413E-12	4.9173E-12	4.8146E-12			

Test 2 (CWSS) checks the cw steady-state coding.

Input:

LAMBDA	= 3.8E-4
IMAX	= 1.E-4
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 5.E+4
NF	= 6
DT	= 1.
FOCUS	= 3.E+5
ZF	= 6.E+5
ZTF	= 6.E+5
ZTL	= 1.E+7
WI	= 15(1.)
LMAX	= 1
NELEM	= 1
ISSL	= 1
VFLW	= 1000.
NCONT	= 1
NEDIT	= 1
SIGMA	= 1.E-6
COEFT3	= 0.
CNSQ	= 0.
END-RUN	

Selected print file output:

N= 0
Z= 0.

INTENSITY ALONG X-AXIS		POWER(W)= 3.1414E+04					
IX-AXIS=	1.2341E-08	3.6700E-08	1.0173E-07	2.6283E-07	6.3297E-07	1.4209E-06	
IX-AXIS=	2.9729E-06	5.7980E-06	1.0540E-05	1.7859E-05	2.8206E-05	4.1524E-05	
IX-AXIS=	5.6978E-05	7.2876E-05	8.6882E-05	9.6545E-05	1.0000E-04	9.6545E-05	
IX-AXIS=	8.6882E-05	7.2876E-05	5.6978E-05	4.1524E-05	2.8206E-05	1.7859E-05	
IX-AXIS=	1.0540E-05	5.7980E-06	2.9729E-06	1.4209E-06	6.3297E-07	2.6283E-07	
IX-AXIS=	1.0173E-07	3.6700E-08					
IY-AXIS=	1.2341E-08	3.6700E-08	1.0173E-07	2.6283E-07	6.3297E-07	1.4209E-06	
IY-AXIS=	2.9729E-06	5.7980E-06	1.0540E-05	1.7859E-05	2.8206E-05	4.1524E-05	
IY-AXIS=	5.6978E-05	7.2876E-05	8.6882E-05	9.6545E-05	1.0000E-04	9.6545E-05	
IY-AXIS=	8.6882E-05	7.2876E-05	5.6978E-05	4.1524E-05	2.8206E-05	1.7859E-05	
IY-AXIS=	1.0540E-05	5.7980E-06	2.9729E-06	1.4209E-06	6.3297E-07	2.6283E-07	
IY-AXIS=	1.0173E-07	3.6700E-08	1.2341E-08				
ID-AXIS=	1.5230E-12	1.3469E-11	1.0349E-10	6.9081E-10	4.0065E-09	2.0188E-08	
ID-AXIS=	8.8383E-08	3.3617E-07	1.1109E-06	3.1895E-06	7.9560E-06	1.7242E-05	
ID-AXIS=	3.2465E-05	5.3110E-05	7.5484E-05	9.3210E-05	1.0000E-04	9.3210E-05	
ID-AXIS=	7.5484E-05	5.3110E-05	3.2465E-05	1.7242E-05	7.9560E-06	3.1895E-06	
ID-AXIS=	1.1109E-06	3.3617E-07	8.8383E-08	2.0188E-08	4.0065E-09	6.9081E-10	
ID-AXIS=	1.0349E-10	1.3469E-11	1.5230E-12				
X-SPECTRUM							
FX-AXIS=	7.3941E-13	7.6613E-13	8.5503E-13	1.0401E-12	1.4213E-12	2.3539E-12	
FX-AXIS=	5.5402E-12	2.1135E-11	1.1357E-10	6.5849E-10	3.4319E-09	1.4451E-08	
FX-AXIS=	4.6307E-08	1.1201E-07	2.1164E-07	3.1200E-07	3.5246E-07	3.1200E-07	
FX-AXIS=	2.1164E-07	1.1201E-07	4.6307E-08	1.4451E-08	3.4319E-09	6.5849E-10	
FX-AXIS=	1.1357E-10	2.1135E-11	5.5402E-12	2.3539E-12	1.4213E-12	1.0401E-12	
FX-AXIS=	8.5503E-13	7.6613E-13	7.3941E-13				
Y-SPECTRUM							
FY-AXIS=	7.3941E-13	7.6613E-13	8.5503E-13	1.0401E-12	1.4213E-12	2.3539E-12	
FY-AXIS=	5.5402E-12	2.1135E-11	1.1357E-10	6.5849E-10	3.4319E-09	1.4451E-08	
FY-AXIS=	4.6307E-08	1.1201E-07	2.1164E-07	3.1200E-07	3.5246E-07	3.1200E-07	
FY-AXIS=	2.1164E-07	1.1201E-07	4.6307E-08	1.4451E-08	3.4319E-09	6.5849E-10	
FY-AXIS=	1.1357E-10	2.1135E-11	5.5402E-12	2.3539E-12	1.4213E-12	1.0401E-12	
FY-AXIS=	8.5503E-13	7.6613E-13	7.3941E-13				
DENSITY		Z= 2.5000E+04 T(SEC)= 1.0000E+00					
RHO(1)	1.2341E-02	-0.	-1.9989E-13	-9.1209E-13	-2.8486E-12	-7.6480E-12	
RHO(7)	-1.8744E-11	-4.2407E-11	-8.9070E-11	-1.7446E-10	-3.1925E-10	-5.4688E-10	
RHO(13)	-8.7878E-10	-1.3275E-09	-1.8900E-09	-2.5441E-09	-3.2493E-09	-3.9546E-09	
RHO(19)	-4.6087E-09	-5.1712E-09	-5.6199E-09	-5.9518E-09	-6.1794E-09	-6.3242E-09	
RHO(25)	-6.4096E-09	-6.4563E-09	-6.4799E-09	-6.4910E-09	-6.4958E-09	-6.4978E-09	
RHO(31)	-6.4985E-09	-6.4987E-09	-6.4987E-09				

N= 0
Z= 5.0000E+04

INTENSITY ALONG X-AXIS		POWER(W)= 2.9882E+04					
IX-AXIS=	1.3085E-09	3.7125E-09	2.3790E-08	1.0197E-07	3.1046E-07	8.0280E-07	
IX-AXIS=	1.9480E-06	4.4030E-06	9.0761E-06	1.7211E-05	3.0055E-05	4.8083E-05	
IX-AXIS=	7.0561E-05	9.4649E-05	1.1599E-04	1.2992E-04	1.3328E-04	1.2564E-04	
IX-AXIS=	1.0915E-04	8.7528E-05	6.4832E-05	4.4254E-05	2.7849E-05	1.6080E-05	
IX-AXIS=	8.5344E-06	4.1649E-06	1.8496E-06	7.6098E-07	2.9515E-07	9.8394E-08	
IX-AXIS=	2.2512E-08	2.3609E-09					
IY-AXIS=	3.7991E-09	2.8644E-09	2.1955E-08	1.0262E-07	3.1247E-07	8.0289E-07	
IY-AXIS=	1.9554E-06	4.4375E-06	9.1724E-06	1.7454E-05	3.0513E-05	4.8648E-05	
IY-AXIS=	7.0859E-05	9.4105E-05	1.1452E-04	1.2840E-04	1.3328E-04	1.2840E-04	
IY-AXIS=	1.1452E-04	9.4105E-05	7.0859E-05	4.8648E-05	3.0513E-05	1.7454E-05	
IY-AXIS=	9.1724E-06	4.4375E-06	1.9554E-06	8.0289E-07	3.1247E-07	1.0262E-07	
IY-AXIS=	2.1954E-08	2.8631E-09	3.7991E-09				
ID-AXIS=	1.0538E-13	6.0040E-14	3.5202E-12	7.6869E-11	7.1224E-10	4.6858E-09	
ID-AXIS=	2.7625E-08	1.4104E-07	5.9530E-07	2.1299E-06	6.4665E-06	1.6526E-05	
ID-AXIS=	3.5768E-05	6.4955E-05	9.8603E-05	1.2497E-04	1.3328E-04	1.2122E-04	
ID-AXIS=	9.4718E-05	6.3438E-05	3.6034E-05	1.7097E-05	6.7682E-06	2.2227E-06	
ID-AXIS=	6.1472E-07	1.4395E-07	2.7952E-08	4.7126E-09	7.1388E-10	7.6986E-11	
ID-AXIS=	3.5229E-12	5.9973E-14	1.0538E-13				
X-SPECTRUM							
FX-AXIS=	7.7603E-13	8.9343E-13	9.8126E-13	1.1586E-12	1.6183E-12	2.6596E-12	
FX-AXIS=	6.0842E-12	2.4755E-11	1.4498E-10	7.9053E-10	3.4931E-09	1.2121E-08	
FX-AXIS=	3.1370E-08	7.8342E-08	1.9881E-07	3.8060E-07	4.7161E-07	3.8060E-07	
FX-AXIS=	1.9881E-07	7.8342E-08	3.1370E-08	1.2121E-08	3.4931E-09	7.9051E-10	
FX-AXIS=	1.4497E-10	2.4754E-11	6.0838E-12	2.6594E-12	1.6182E-12	1.1585E-12	
FX-AXIS=	9.8128E-13	8.9347E-13	7.7603E-13				
Y-SPECTRUM							
FY-AXIS=	6.3384E-13	8.6659E-13	1.0885E-12	1.4415E-12	2.0995E-12	3.6578E-12	
FY-AXIS=	9.0598E-12	3.6220E-11	1.9943E-10	1.1011E-09	5.8508E-09	2.9084E-08	
FY-AXIS=	1.0742E-07	2.6376E-07	4.4418E-07	5.3314E-07	4.7161E-07	3.2911E-07	
FY-AXIS=	1.8960E-07	9.5516E-08	4.2057E-08	1.4798E-08	3.9044E-09	7.7573E-10	
FY-AXIS=	1.2632E-10	2.0965E-11	4.8381E-12	1.7769E-12	9.2813E-13	6.0191E-13	
FY-AXIS=	4.6358E-13	4.5591E-13	6.3384E-13				
DENSITY		Z= 7.5000E+04 T(SEC)= 1.0000E+0C					
RHO(1)	3.7991E-03	-0.	5.7477E-15	-8.6427E-14	-6.1757E-13	-2.5241E-12	
RHO(7)	-7.9290E-12	-2.1593E-11	-5.3494E-11	-1.2137E-10	-2.5274E-10	-4.8470E-10	
RHO(13)	-8.5634E-10	-1.3945E-09	-2.0962E-09	-2.9195E-09	-3.7919E-09	-4.6323E-09	
RHO(19)	-5.3734E-09	-5.9749E-09	-6.4248E-09	-6.7346E-09	-6.9301E-09	-7.0429E-09	
RHO(25)	-7.1021E-09	-7.1303E-09	-7.1425E-09	-7.1473E-09	-7.1491E-09	-7.1495E-09	
RHO(31)	-7.1496E-09	-7.1496E-09	-7.1496E-09				

		DIST //	WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 1.0000E+00		
RHO(	1)		8.1901E-04	-0.	3.9898E-14	3.6747E-14	-6.0321E-14	-5.3598E-13
RHO(	7)		-4.4867E-12	-2.6583E-11	-1.1198E-10	-3.5653E-10	-9.1064E-10	-1.9781E-09
RHO(	13)		-3.5866E-09	-5.2096E-09	-6.1414E-09	-6.3791E-09	-6.4198E-09	-6.4942E-09
RHO(	19)		-6.5721E-09	-6.6129E-09	-6.6229E-09	-6.6255E-09	-6.6261E-09	-6.6261E-09
RHO(	25)		-6.6261E-09	-6.6260E-09	-6.6260E-09	-6.6260E-09	-6.6259E-09	-6.6259E-09
RHO(	31)		-6.6259E-09	-6.6259E-09	-6.6258E-09			

N= 0
Z= 3.0000E+05.

		INTENSITY ALONG X-AXIS	POWER(W)= 2.3272E+04			
IX-AXIS=		8.6521E-09	9.7835E-09	1.7344E-07	1.1855E-06	4.8521E-06
IX-AXIS=		3.4697E-05	7.6277E-05	1.5374E-04	2.5949E-04	3.4608E-04
IX-AXIS=		3.1936E-04	1.9209E-04	6.1654E-05	7.0345E-06	2.1971E-05
IX-AXIS=		9.4113E-06	2.4935E-06	6.0092E-07	1.6792E-08	6.7222E-08
IX-AXIS=		3.9527E-09	1.3395E-09	4.4113E-09	4.7405E-09	3.9325E-09
IX-AXIS=		5.7804E-09	1.0207E-08			5.2684E-09
IY-AXIS=		6.6908E-07	3.5697E-08	1.5391E-06	2.7550E-06	7.9913E-06
IY-AXIS=		3.2454E-05	5.4854E-05	8.7875E-05	1.2861E-04	1.7813E-04
IY-AXIS=		2.7959E-04	3.2001E-04	3.4819E-04	3.6671E-04	3.7311E-04
IY-AXIS=		3.4819E-04	3.2001E-04	2.7959E-04	2.3214E-04	1.7813E-04
IY-AXIS=		8.7875E-05	5.4854E-05	3.2454E-05	1.8201E-05	7.9913E-06
IY-AXIS=		1.5392E-06	3.5702E-08	6.6908E-07		
ID-AXIS=		2.9546E-10	1.4845E-10	3.8995E-09	2.8050E-08	4.4246E-08
ID-AXIS=		6.0425E-07	4.7838E-06	1.9977E-05	5.7557E-05	1.3244E-04
ID-AXIS=		2.7441E-04	2.1499E-04	8.0121E-05	4.9114E-06	2.1971E-05
ID-AXIS=		5.5430E-06	7.7452E-07	1.7662E-07	1.4847E-07	7.7272E-09
ID-AXIS=		3.6126E-09	1.4339E-09	6.2509E-11	2.6288E-11	9.4650E-11
ID-AXIS=		5.1387E-11	3.9623E-11	2.9546E-10		9.2835E-12
		X-SPECTRUM				
FX-AXIS=		2.5785E-13	4.2725E-12	3.1640E-12	6.5187E-12	1.9461E-11
FX-AXIS=		3.1278E-11	2.9785E-11	4.1657E-10	1.2109E-09	8.4995E-10
FX-AXIS=		1.0305E-08	5.0334E-09	2.2748E-08	9.4560E-08	1.4216E-07
FX-AXIS=		2.2748E-08	5.0335E-09	1.0305E-08	2.9462E-09	8.5000E-10
FX-AXIS=		4.1653E-10	2.9784E-11	3.1273E-11	2.0832E-11	1.9455E-11
FX-AXIS=		3.1633E-12	4.2717E-12	2.5785E-13		6.5185E-12
		Y-SPECTRUM				
FY-AXIS=		5.2328E-12	5.7945E-11	1.3570E-10	1.4875E-10	5.4957E-11
FY-AXIS=		3.3129E-09	2.0090E-08	7.3489E-08	2.0751E-07	4.6992E-07
FY-AXIS=		8.7970E-07	7.0538E-07	4.4494E-07	2.5466E-07	1.4216E-07
FY-AXIS=		3.1474E-08	1.2749E-08	5.1270E-09	1.7145E-09	4.5836E-10
FY-AXIS=		4.4070E-11	3.2510E-11	2.2584E-11	1.3556E-11	2.3913E-12
FY-AXIS=		5.5170E-12	4.2718E-12	5.2328E-12		3.2844E-12

Test 3 (CWTR) checks the cw transient coding.

Input:

LAMBDA	= 3.8E-4
IMAX	= 1.E-2
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 5.E+4
NF	= 6
DT	= .01
FOCUS	= 3.E+5
ZF	= 6.E+5
ZTF	= 6.E+5
ZTL	= 1.E+7
WI	= 15(1.)
LMAX	= 2
NELEM	= 1
IMP	= 1
ISSL	= 0
VFLW	= 1000.
NCONT	= 1
NEDIT	= 1
SIGMA	= 1.E-6
COEFT3	= 0.
CNSQ	= 0.
DTIMP	= 1.E-4
END-RUN	

Selected print file output:

		DIST	WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 1.0000E-02		
RHO(	1)	5.4401E-05	1.0039E-12	1.1446E-12	9.7521E-13	1.1430E-12	9.1671E-13	
RHO(	7)	9.6801E-13	6.8288E-14	-3.0081E-12	-2.4779E-11	-1.0847E-10	-3.7680E-10	
RHO(	13)	-1.1103E-09	-2.5341E-09	-4.2888E-09	-5.5834E-09	-6.0256E-09	-5.9358E-09	
RHO(	19)	-5.6672E-09	-5.2310E-09	-4.6046E-09	-3.7999E-09	-2.9032E-09	-2.0630E-09	
RHO(	25)	-1.3943E-09	-9.2074E-10	-5.9388E-10	-3.5921E-10	-1.9533E-10	-9.2189E-11	
RHO(	31)	-3.6445E-11	-1.1627E-11	-2.7811E-12				

		DIST	WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 2.0000E-02		
RHO(	1)	5.4401E-05	-2.9791E-13	-4.0111E-13	-3.9082E-13	-7.1689E-13	-9.6257E-13	
RHO(	7)	-3.4503E-12	-1.7040E-11	-7.4666E-11	-2.5258E-10	-6.6017E-10	-1.4769E-09	
RHO(	13)	-2.8435E-09	-4.3805E-09	-5.3582E-09	-5.6693E-09	-5.8338E-09	-6.1052E-09	
RHO(	19)	-6.4808E-09	-6.9096E-09	-7.3574E-09	-7.8496E-09	-8.3497E-09	-8.7514E-09	
RHO(	25)	-8.8921E-09	-8.6880E-09	-8.1977E-09	-7.5272E-09	-6.7237E-09	-5.8109E-09	
RHO(	31)	-4.8185E-09	-3.7965E-09	-2.8185E-09				

N= 0
Z= 3.0000E+05

		INTENSITY ALONG X-AXIS		POWER(W)= 2.3272E+04			
IX-AXIS=	4.8136E-09	2.5180E-09	2.0955E-08	6.5950E-09	3.9005E-08	4.8593E-07	
IX-AXIS=	2.4016E-06	6.9914E-06	1.9018E-05	5.2142E-05	1.3020E-04	2.6862E-04	
IX-AXIS=	4.3376E-04	5.3855E-04	5.2669E-04	4.2677E-04	2.8834E-04	1.6483E-04	
IX-AXIS=	1.1156E-04	1.0154E-04	7.4614E-05	4.3033E-05	2.3130E-05	1.0524E-05	
IX-AXIS=	4.2322E-06	1.7216E-06	5.8419E-07	1.4247E-07	3.9476E-08	1.4052E-08	
IX-AXIS=	7.8140E-09	2.2158E-10					
IY-AXIS=	1.4599E-08	5.0588E-09	9.1017E-09	2.0208E-08	9.2364E-08	6.2457E-07	
IY-AXIS=	2.2416E-06	6.0227E-06	1.4472E-05	3.1977E-05	6.8229E-05	1.3336E-04	
IY-AXIS=	2.2673E-04	3.3662E-04	4.3859E-04	5.1213E-04	5.3855E-04	5.1213E-04	
IY-AXIS=	4.3859E-04	3.3662E-04	2.2673E-04	1.3336E-04	6.8229E-05	3.1977E-05	
IY-AXIS=	1.4472E-05	6.0227E-06	2.2416E-06	6.2457E-07	9.2364E-08	2.0208E-08	
IY-AXIS=	9.1017E-09	5.0588E-09	1.4599E-08				
ID-AXIS=	6.0942E-12	2.6630E-12	7.3717E-12	1.2102E-10	8.8961E-10	3.7567E-09	
ID-AXIS=	6.2338E-09	2.4492E-08	4.3276E-07	3.1683E-06	1.4233E-05	5.2090E-05	
ID-AXIS=	1.6068E-04	3.3662E-04	4.4243E-04	4.0818E-04	2.8834E-04	1.6342E-04	
ID-AXIS=	1.1444E-04	6.9918E-05	3.2441E-05	1.1321E-05	3.1814E-06	7.9085E-07	
ID-AXIS=	1.4500E-07	2.7179E-08	4.1935E-09	3.6789E-10	5.1541E-11	5.9303E-12	
ID-AXIS=	2.2136E-12	1.2851E-12	6.0942E-12				
X-SPECTRUM							
FX-AXIS=	6.2042E-12	5.2732E-12	1.3268E-12	4.8635E-12	3.2400E-11	3.9096E-11	
FX-AXIS=	1.9891E-11	2.1234E-11	4.1903E-11	9.6331E-10	5.6782E-09	1.9551E-08	
FX-AXIS=	4.1106E-08	1.0465E-07	3.2667E-07	6.7807E-07	8.6705E-07	6.7807E-07	
FX-AXIS=	3.2667E-07	1.0465E-07	4.1106E-08	1.9551E-08	5.6782E-09	9.6331E-10	
FX-AXIS=	4.1903E-11	2.1234E-11	1.9891E-11	3.9096E-11	3.2400E-11	4.8635E-12	
FX-AXIS=	1.3268E-12	5.2732E-12	6.2042E-12				

	Y-SPECTRUM					
FY-AXIS=	4.9929E-12	3.8379E-12	1.4184E-11	4.2174E-11	3.0460E-11	8.8762E-11
FY-AXIS=	4.2590E-11	1.0853E-10	2.0945E-09	1.2599E-08	4.9211E-08	1.7275E-07
FY-AXIS=	5.3011E-07	1.1850E-06	1.7179E-06	1.5830E-06	3.6705E-07	2.1624E-07
FY-AXIS=	4.5693E-09	1.7198E-08	1.8288E-08	3.2954E-09	3.4005E-11	4.1707E-11
FY-AXIS=	8.3051E-11	2.9323E-11	1.8903E-11	1.4195E-11	6.9320E-12	1.7538E-12
FY-AXIS=	1.3737E-13	2.5639E-12	4.9929E-12			

N= 0
Z= 3.0000E+05

	INTENSITY ALONG X-AXIS		POWER(W)= 2.3272E+04			
IX-AXIS=	1.9406E-08	1.0459E-08	9.5394E-08	8.1266E-07	3.4165E-06	1.1227E-05
IX-AXIS=	2.6970E-05	5.6770E-05	1.1751E-04	2.1407E-04	3.1376E-04	3.7230E-04
IX-AXIS=	3.5874E-04	2.6543E-04	1.3047E-04	2.4320E-05	4.1257E-06	2.6206E-05
IX-AXIS=	2.0148E-05	9.2348E-06	4.4595E-06	1.5346E-06	1.3955E-06	5.6347E-07
IX-AXIS=	2.3389E-07	1.2921E-07	7.5290E-08	4.8222E-09	1.0385E-08	1.2580E-08
IX-AXIS=	4.4579E-09	2.0143E-08				
IY-AXIS=	2.9928E-07	1.4590E-08	4.3340E-07	9.3988E-07	3.0822E-06	8.4634E-06
IY-AXIS=	1.7505E-05	3.2396E-05	5.6643E-05	9.1050E-05	1.3708E-04	1.9345E-04
IY-AXIS=	2.5015E-04	3.0057E-04	3.3914E-04	3.6345E-04	3.7230E-04	3.6345E-04
IY-AXIS=	3.3914E-04	3.0057E-04	2.5015E-04	1.9345E-04	1.3708E-04	9.1050E-05
IY-AXIS=	5.6643E-05	3.2396E-05	1.7505E-05	8.4634E-06	3.0822E-06	9.3988E-07
IY-AXIS=	4.3340E-07	1.4590E-08	2.9928E-07			
ID-AXIS=	2.6304E-10	6.1534E-11	1.8605E-09	1.6882E-08	3.9166E-08	3.3427E-08
ID-AXIS=	2.6295E-07	2.5689E-06	1.2148E-05	3.8368E-05	3.5942E-05	1.9345E-04
ID-AXIS=	2.7468E-04	2.6668E-04	1.5043E-04	2.8366E-05	4.1257E-06	1.8605E-05
ID-AXIS=	1.2594E-05	6.8083E-06	3.1151E-06	2.8452E-06	1.1835E-06	6.8090E-07
ID-AXIS=	2.4243E-07	7.5913E-08	2.2040E-08	5.9729E-09	1.1242E-09	1.9845E-10
ID-AXIS=	5.5952E-11	6.8918E-11	2.6304E-10			
	X-SPECTRUM					
FX-AXIS=	3.3797E-12	1.0244E-12	1.4354E-12	2.8418E-11	3.9720E-11	2.8431E-11
FX-AXIS=	2.4517E-11	2.3525E-10	1.6557E-09	4.7241E-09	3.1469E-09	9.9217E-09
FX-AXIS=	2.0479E-08	8.0750E-09	2.3720E-08	1.2866E-07	2.0275E-07	1.2866E-07
FX-AXIS=	2.3720E-08	8.0750E-09	2.0479E-08	9.9217E-09	3.1469E-09	4.7241E-09
FX-AXIS=	1.6557E-09	2.3525E-10	2.4517E-11	2.8431E-11	3.9720E-11	2.8418E-11
FX-AXIS=	1.4354E-12	1.0244E-12	3.3797E-12			
	Y-SPECTRUM					
FY-AXIS=	3.1436E-12	4.2014E-11	1.4789E-10	2.3004E-10	1.9391E-10	6.4058E-11
FY-AXIS=	8.3474E-10	9.6051E-09	4.2288E-08	1.1638E-07	2.8395E-07	6.4705E-07
FY-AXIS=	1.0424E-06	1.0151E-06	6.3658E-07	3.5801E-07	2.0275E-07	8.9583E-08
FY-AXIS=	3.2083E-08	1.5065E-08	4.9867E-09	1.5180E-09	3.0737E-10	1.3017E-10
FY-AXIS=	5.4451E-11	3.8099E-11	3.1147E-11	1.4099E-11	3.0676E-12	3.7704E-12
FY-AXIS=	6.2739E-12	1.5738E-12	3.1436E-12			

Test 4 (MPTR) checks the multipulse transient coding.

Input:

LAMBDA	= 3.8E-4
IMAX	= 1.E-2
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 5.E+4
NF	= 6
DT	= .01
FOCUS	= 3.E+5
ZF	= 6.E+5
ZTF	= 6.E+5
ZTL	= 1.E+7
WI	= 15(1.)
LMAX	= 2
NELEM	= 1
IMP	= 1
ISSL	= 0
VFLW	= 1000.
NCONT	= 1
NEDIT	= 1
SIGMA	= 1.E-6
COEFT3	= 0.
CNSQ	= 0.
DTIMP	= 1.E-4
END-RUN	

Selected print file output:

		DIST	WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 1.0000E-02		
RHO(	1)	3.2506E-05	-0.	-0.	-0.	-0.	-0.	-0.
RHO(	7)	-0.	-0.	-0.	-0.	-0.	-0.	-0.
RHO(	13)	-0.	-0.	-0.	-0.	-0.	-0.	-0.
RHO(	19)	-0.	-0.	-0.	-0.	-0.	-0.	-0.
RHO(	25)	-0.	-0.	-0.	-0.	-0.	-0.	-0.
RHO(	31)	-0.	-0.	-0.	-0.	-0.	-0.	-0.

		DIST	WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 2.0000E-02		
RHO(	1)	3.2506E-05	5.2940E-23	-2.1176E-22	-7.9409E-23	-1.8529E-22	-0.	
RHO(	7)	-1.0588E-22	-5.2940E-23	5.2940E-23	-0.	-1.7298E-14	-1.0144E-13	
RHO(	13)	-5.1912E-14	-1.0672E-13	-7.8433E-14	-1.0356E-13	-1.5687E-13	-7.6455E-14	
RHO(	19)	-2.9867E-13	-2.4670E-13	-7.2423E-12	-1.3289E-10	-1.3628E-09	-8.0080E-09	
RHO(	25)	-2.8046E-08	-5.9341E-08	-7.3224E-08	-5.1127E-08	-2.0207E-08	-4.5819E-09	
RHO(	31)	-5.5393E-10	-3.3490E-11	-1.1981E-12				

N= 0
Z= 3.0000E+05

		INTENSITY ALONG X-AXIS		POWER(W)= 2.3272E+04			
IX-AXIS=	3.8268E-07	3.0486E-07	3.8967E-07	3.1221E-07	4.1397E-07	3.3317E-07	
IX-AXIS=	4.7324E-07	3.8392E-07	4.7535E-07	2.4674E-09	2.3209E-05	3.0248E-04	
IX-AXIS=	2.9943E-03	2.0110E-02	7.7626E-02	1.7141E-01	2.2234E-01	1.7141E-01	
IX-AXIS=	7.7626E-02	2.0110E-02	2.9943E-03	3.0248E-04	2.3209E-05	2.4674E-09	
IX-AXIS=	4.7535E-07	3.8392E-07	4.7324E-07	3.3317E-07	4.1397E-07	3.1221E-07	
IX-AXIS=	3.8967E-07	3.0486E-07					
IY-AXIS=	3.8268E-07	3.0486E-07	3.8967E-07	3.1221E-07	4.1397E-07	3.3317E-07	
IY-AXIS=	4.7324E-07	3.8392E-07	4.7535E-07	2.4674E-09	2.3209E-05	3.0248E-04	
IY-AXIS=	2.9943E-03	2.0110E-02	7.7626E-02	1.7141E-01	2.2234E-01	1.7141E-01	
IY-AXIS=	7.7626E-02	2.0110E-02	2.9943E-03	3.0248E-04	2.3209E-05	2.4674E-09	
IY-AXIS=	4.7535E-07	3.8392E-07	4.7324E-07	3.3317E-07	4.1397E-07	3.1221E-07	
IY-AXIS=	3.8967E-07	3.0486E-07					
ID-AXIS=	6.5865E-13	4.1801E-13	6.8292E-13	4.3840E-13	7.7078E-13	4.9924E-13	
ID-AXIS=	1.0073E-12	6.6293E-13	1.0163E-12	2.7381E-17	2.4227E-09	4.1152E-07	
ID-AXIS=	4.0326E-05	1.8189E-03	2.7102E-02	1.3215E-01	2.2234E-01	1.3215E-01	
ID-AXIS=	2.7102E-02	1.8189E-03	4.0326E-05	4.1152E-07	2.4227E-09	2.7381E-17	
ID-AXIS=	1.0163E-12	6.6293E-13	1.0073E-12	4.9924E-13	7.7078E-13	4.3840E-13	
ID-AXIS=	6.8292E-13	4.1801E-13	6.5865E-13				

		X-SPECTRUM				
FX-AXIS=	2.1911E-10	2.2703E-10	2.5337E-10	3.0822E-10	4.2117E-10	6.9753E-10
FX-AXIS=	1.6417E-09	6.2629E-09	3.3655E-08	1.9513E-07	1.0170E-06	4.2823E-06
FX-AXIS=	1.3722E-05	3.3192E-05	6.2714E-05	9.2454E-05	1.0444E-04	9.2454E-05
FX-AXIS=	6.2714E-05	3.3192E-05	1.3722E-05	4.2823E-06	1.0170E-06	1.9513E-07
FX-AXIS=	3.3655E-08	6.2629E-09	1.6417E-09	6.9753E-10	4.2117E-10	3.0822E-10
FX-AXIS=	2.5337E-10	2.2703E-10	2.1911E-10			

	Y-SPECTRUM					
FY-AXIS=	2.1911E-10	2.2703E-10	2.5337E-10	3.0822E-10	4.2117E-10	6.9753E-10
FY-AXIS=	1.6417E-09	6.2629E-09	3.3655E-08	1.9513E-07	1.0170E-06	4.2823E-06
FY-AXIS=	1.3722E-05	3.3192E-05	6.2714E-05	9.2454E-05	1.0444E-04	9.2454E-05
FY-AXIS=	6.2714E-05	3.3192E-05	1.3722E-05	4.2823E-06	1.0170E-06	1.9513E-07
FY-AXIS=	3.3655E-08	6.2629E-09	1.6417E-09	6.9753E-10	4.2117E-10	3.0822E-10
FY-AXIS=	2.5337E-10	2.2703E-10	2.1911E-10			

N= 0
Z= 3.0000E+05

	INTENSITY ALONG X-AXIS		POWER(W)= 2.3272E+04			
IX-AXIS=	1.6387E-06	8.9042E-07	6.4798E-06	9.8693E-07	1.5079E-05	5.4756E-05
IX-AXIS=	5.5372E-05	3.1781E-04	1.0985E-03	3.1166E-03	8.2056E-03	1.9980E-02
IX-AXIS=	4.6196E-02	8.6622E-02	1.2000E-01	1.3273E-01	1.1059E-01	6.3736E-02
IX-AXIS=	2.5609E-02	7.7557E-03	1.7327E-03	4.0961E-04	9.6811E-05	1.1769E-05
IX-AXIS=	1.3336E-05	1.8753E-06	4.3248E-06	2.9388E-06	2.2877E-06	2.2972E-06
IX-AXIS=	2.9966E-07	1.2486E-06				
IY-AXIS=	8.5140E-07	1.1627E-06	8.9028E-06	3.2545E-05	8.7084E-05	1.3666E-04
IY-AXIS=	2.7307E-04	6.8228E-04	1.5014E-03	2.5173E-03	3.4851E-03	4.6188E-03
IY-AXIS=	6.4134E-03	1.4413E-02	4.5636E-02	1.0130E-01	1.3273E-01	1.0130E-01
IY-AXIS=	4.5636E-02	1.4413E-02	6.4134E-03	4.6188E-03	3.4851E-03	2.5173E-03
IY-AXIS=	1.5014E-03	6.8228E-04	2.7307E-04	1.3666E-04	8.7084E-05	3.2545E-05
IY-AXIS=	8.9028E-06	1.1627E-06	8.5140E-07			
ID-AXIS=	6.8764E-07	5.4546E-07	3.3175E-07	2.2450E-07	1.7606E-07	5.0323E-07
ID-AXIS=	1.0921E-06	6.0908E-06	2.2370E-05	1.6457E-04	9.5125E-04	3.3647E-03
ID-AXIS=	1.0378E-02	2.7812E-02	5.5556E-02	1.0130E-01	1.1059E-01	4.4468E-02
ID-AXIS=	5.5393E-03	6.6999E-04	5.7895E-05	6.0788E-06	9.2737E-06	7.6520E-07
ID-AXIS=	7.0030E-06	1.5778E-05	2.0888E-05	2.2536E-05	1.6794E-05	8.4978E-06
ID-AXIS=	1.8600E-06	4.9990E-07	6.8764E-07			
	X-SPECTRUM					
FX-AXIS=	7.6926E-09	3.2750E-09	2.8694E-09	2.4188E-09	2.6498E-09	1.3034E-08
FX-AXIS=	4.4485E-08	9.3991E-08	4.0083E-08	1.2761E-07	1.1381E-06	2.8589E-06
FX-AXIS=	7.4771E-06	1.8790E-05	3.8192E-05	6.2672E-05	7.4338E-05	6.2672E-05
FX-AXIS=	3.8192E-05	1.8790E-05	7.4771E-06	2.8589E-06	1.1381E-06	1.2761E-07
FX-AXIS=	4.0083E-08	9.3991E-08	4.4485E-08	1.3034E-08	2.6498E-09	2.4188E-09
FX-AXIS=	2.8694E-09	3.2750E-09	7.6926E-09			
	Y-SPECTRUM					
FY-AXIS=	3.4705E-10	5.3821E-11	8.0884E-09	9.9871E-09	5.7696E-09	2.4795E-09
FY-AXIS=	1.2548E-08	2.5315E-07	1.9999E-06	7.9130E-06	2.2687E-05	4.9142E-05
FY-AXIS=	7.8826E-05	9.6929E-05	9.6130E-05	8.5894E-05	7.4338E-05	6.1817E-05
FY-AXIS=	4.4528E-05	2.7524E-05	1.3232E-05	4.6183E-06	1.1266E-06	1.8911E-07
FY-AXIS=	3.0871E-08	3.9626E-09	7.1340E-09	4.5337E-09	3.6930E-09	6.0908E-09
FY-AXIS=	1.6648E-09	2.0334E-10	3.4705E-10			

Test 5 (MPSS) tests the multipulse steady-state coding.

Input:

LAMBDA	= 3.8E-4
IMAX	= 1.E-2
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 5.E+4
NF	= 6
DT	= .01
FOCUS	= 3.E+5
ZF	= 6.E+5
ZTF	= 6.E+5
ZTL	= 1.E+7
WI	= 15(1.)
LMAX	= 1
NELEM	= 1
IMP	= 1
ISSL	= 1
VFLW	= 1000.
NCONT	= 1
NEDIT	= 1
SIGMA	= 1.E-6
COEFT3	= 1.
CNSQ	= 0.
DTIMP	= 1.E-4
END-RUN	

Selected print file output:

	DIST	WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 1.0000E-02			
RHO(1)	7.0330E-03	2.2319E-11	5.8754E-11	3.1922E-11	4.8224E-11	4.4367E-11		
RHO(7)	7.7792E-11	1.9816E-10	3.1329E-10	3.4828E-10	2.3398E-10	5.8577E-10		
RHO(13)	-2.7753E-10	-2.9142E-09	-2.3751E-09	-5.1228E-10	-9.5092E-10	-3.8881E-09		
RHO(19)	-4.3883E-09	-3.1925E-09	-3.9048E-09	-5.8290E-09	-1.2279E-08	-2.0178E-08		
RHO(25)	-1.9416E-08	-1.5569E-08	-1.5676E-08	-1.9009E-08	-1.5559E-08	-9.4368E-08		
RHO(31)	-6.6304E-09	-7.2476E-09	-1.4085E-08					

N= 0
Z= 3.0000E+05

	INTENSITY ALONG X-AXIS	POWER(W)= 2.3272E+04				
IX-AXIS=	3.0233E-03	7.6200E-05	2.3463E-05	1.6544E-05	1.4531E-04	7.7436E-04
IX-AXIS=	1.9616E-03	3.2649E-03	5.0439E-03	1.0149E-02	1.8583E-02	2.4080E-02
IX-AXIS=	2.3243E-02	2.5815E-02	4.9993E-02	7.3246E-02	6.5569E-02	2.3953E-02
IX-AXIS=	1.0705E-02	1.0945E-02	1.2562E-02	6.4631E-03	3.9428E-03	1.7537E-03
IX-AXIS=	6.8058E-04	2.3124E-04	1.1885E-04	1.5183E-05	3.3943E-06	4.2272E-07
IX-AXIS=	1.7859E-06	1.3362E-05				
IY-AXIS=	6.3794E-05	1.6394E-05	3.1762E-05	9.7350E-05	2.0332E-04	3.0147E-04
IY-AXIS=	5.3812E-04	8.4268E-04	1.2136E-03	1.8871E-03	2.9091E-03	6.2529E-03
IY-AXIS=	1.1598E-02	2.0295E-02	4.3621E-02	6.6264E-02	7.3246E-02	6.5854E-02
IY-AXIS=	4.3514E-02	2.0841E-02	1.1860E-02	6.2355E-03	2.9169E-03	1.9042E-03
IY-AXIS=	1.2134E-03	8.3921E-04	5.3678E-04	3.0075E-04	2.0294E-04	9.7374E-05
IY-AXIS=	3.1814E-05	1.6387E-05	6.3794E-05			
ID-AXIS=	5.1964E-07	1.7240E-07	1.3074E-06	6.4176E-06	1.4342E-05	2.0903E-05
ID-AXIS=	2.9782E-05	2.0501E-04	7.5699E-04	1.8804E-03	4.5191E-03	1.1968E-02
ID-AXIS=	1.7568E-02	2.0959E-02	2.7027E-02	6.6264E-02	6.5569E-02	2.4727E-02
ID-AXIS=	1.5403E-02	6.3009E-03	1.5811E-03	2.4320E-04	1.6460E-04	9.7054E-05
ID-AXIS=	2.7539E-05	1.7210E-05	6.4919E-06	1.9412E-07	9.3745E-07	1.2009E-06
ID-AXIS=	2.0300E-07	6.5981E-07	5.1964E-07			
X-SPECTRUM						
FX-AXIS=	1.5878E-08	3.4214E-09	1.1888E-08	2.6800E-08	3.4883E-08	1.5486E-08
FX-AXIS=	6.2168E-08	1.4532E-07	2.1509E-07	2.9999E-07	1.8996E-07	2.0639E-07
FX-AXIS=	1.3902E-06	9.3764E-06	3.3187E-05	6.8989E-05	8.6774E-05	6.8981E-05
FX-AXIS=	3.3178E-05	9.3713E-06	1.3889E-06	2.0622E-07	1.8936E-07	2.9864E-07
FX-AXIS=	2.1371E-07	1.4415E-07	6.1543E-08	1.5366E-08	3.4717E-08	2.6565E-08
FX-AXIS=	1.1776E-08	3.3996E-09	1.5878E-08			
Y-SPECTRUM						
FY-AXIS=	5.9002E-08	1.0051E-07	3.5796E-07	3.2960E-07	2.0194E-07	1.6562E-07
FY-AXIS=	2.0778E-07	2.5396E-06	6.0049E-06	7.5131E-06	9.6001E-06	2.4833E-05
FY-AXIS=	5.4111E-05	8.2408E-05	9.4985E-05	9.5585E-05	8.6774E-05	6.9772E-05
FY-AXIS=	4.8321E-05	2.8524E-05	1.3183E-05	3.7545E-06	1.9523E-07	1.0859E-06
FY-AXIS=	2.5618E-06	1.4822E-06	5.3615E-07	5.6103E-08	4.7803E-08	8.1386E-09
FY-AXIS=	3.1131E-09	6.4717E-09	5.9002E-08			

Test 6 (TURB) checks the phase screen simulation of turbulence.

Input:

LAMBDA	= 3.8E-4
IMAX	= 1.E-4
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 5.E+4
NF	= 6
DT	= 1.
FOCUS	= 3.E+5
ZF	= 12.E+5
ZTF	= 4.E+5
ZTL	= 1.E+7
WI	= 15(1.)
LMAX	= 1
NELEM	= 1
ISSL	= 1
VFLW	= 1000.
NCONT	= 1
NEDIT	= 1
SIGMA	= 1.E-50
COEFT3	= 0.
LO	= 100.
CNSQ	= 5.E-14
ISLEW	= 1
DTOM	= 5.E5
OFF3ET	= .3E5
THETAS	= .9272952180
VFLTR	= 1000.
VFLRC	= .3E5
VWIND	= 500.
THETAW	= 3.926990818
END-RUN	

Selected print file output:

	DIST	// WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 1.0000E+00			
RHO(1)	1	1.4186E+00	-5.2622E-51	-5.2621E-51	-5.2619E-51	-5.2611E-51	-5.2601E-51	
RHO(7)	7	-5.2594E-51	-5.2589E-51	-5.2576E-51	-5.2538E-51	-5.2443E-51	-5.2060E-51	
RHO(13)	13	-5.0806E-51	-4.7852E-51	-4.2475E-51	-3.4568E-51	-2.5123E-51	-1.6050E-51	
RHO(19)	19	-8.8774E-52	-4.1592E-52	-1.6538E-52	-5.5944E-53	-1.5653E-53	-4.7871E-54	
RHO(25)	25	-3.0571E-54	-2.4855E-54	-2.0807E-54	-1.4233E-54	-7.3857E-55	-4.8318E-55	
RHO(31)	31	-2.1982E-55	-1.0825E-55	-0.				

N= 0
Z= 3.0000E+05

	INTENSITY ALONG X-AXIS	POWER(W)= 3.1414E+04				
IX-AXIS=	1.0505E-06	3.9480E-06	3.0718E-06	2.5119E-07	2.5526E-06	4.3054E-06
IX-AXIS=	7.2816E-07	1.1183E-05	2.1661E-05	7.9723E-05	2.4633E-04	5.5715E-04
IX-AXIS=	1.0944E-03	1.8012E-03	2.4598E-03	2.7944E-03	2.9118E-03	2.5557E-03
IX-AXIS=	1.9939E-03	1.3705E-03	8.6364E-04	4.7115E-04	2.0889E-04	8.7707E-05
IX-AXIS=	4.8199E-05	2.1817E-05	1.0406E-05	2.0640E-06	1.0380E-06	1.6969E-06
IX-AXIS=	3.7398E-06	7.1922E-07				
IY-AXIS=	2.3008E-06	8.4202E-06	5.6839E-06	5.0641E-06	3.0542E-05	4.8378E-05
IY-AXIS=	6.1752E-05	1.2524E-04	2.3393E-04	3.8575E-04	6.3623E-04	9.1380E-04
IY-AXIS=	1.4272E-03	2.0983E-03	2.4820E-03	2.7624E-03	2.9118E-03	2.4306E-03
IY-AXIS=	1.6702E-03	1.0859E-03	5.9066E-04	1.6984E-04	5.4083E-05	8.5623E-06
IY-AXIS=	4.3261E-06	1.0593E-05	5.1245E-06	2.4588E-06	4.8774E-06	8.6142E-07
IY-AXIS=	1.5238E-06	2.7944E-07	2.3008E-06			
ID-AXIS=	1.1902E-06	6.8440E-08	3.2645E-06	4.0559E-06	3.9426E-06	7.8148E-06
ID-AXIS=	9.1978E-06	8.0636E-06	3.1170E-05	5.8137E-05	1.3068E-04	2.7732E-04
ID-AXIS=	7.1537E-04	1.3912E-03	2.2061E-03	2.7103E-03	2.9118E-03	2.2412E-03
ID-AXIS=	1.1674E-03	5.2038E-04	1.3759E-04	9.4698E-06	1.9921E-06	1.1387E-06
ID-AXIS=	2.0394E-06	1.2934E-08	9.6159E-07	1.2284E-06	7.4155E-07	3.2374E-07
ID-AXIS=	3.4857E-06	1.4370E-06	1.1902E-06			
X-SPECTRUM						
FX-AXIS=	1.4665E-10	3.4903E-10	2.2372E-10	6.6756E-10	8.9933E-10	1.6070E-10
FX-AXIS=	1.2976E-09	5.2074E-09	6.0147E-09	4.6149E-09	2.4401E-09	4.7007E-09
FX-AXIS=	8.7926E-08	1.4769E-06	7.1948E-06	1.3215E-05	1.2057E-05	6.2401E-06
FX-AXIS=	2.7565E-06	9.8039E-07	2.6052E-07	6.0405E-08	2.1532E-09	3.6989E-09
FX-AXIS=	1.0194E-08	1.0008E-08	2.5641E-10	1.9225E-11	3.0196E-10	9.3006E-11
FX-AXIS=	9.1748E-11	1.4209E-10	1.4665E-10			
Y-SPECTRUM						
FY-AXIS=	7.3308E-10	1.8786E-10	2.1544E-10	3.4988E-10	1.0176E-10	8.7859E-10
FY-AXIS=	6.9293E-10	1.4792E-09	1.7150E-09	1.5180E-10	3.2436E-10	2.2626E-09
FY-AXIS=	1.3320E-07	1.1439E-06	4.1696E-06	8.6790E-06	1.2057E-05	8.9232E-06
FY-AXIS=	3.1783E-06	3.9528E-07	3.0377E-09	2.2481E-08	1.7070E-08	1.0860E-08
FY-AXIS=	5.9069E-11	9.3045E-11	8.7887E-10	9.7615E-11	1.7425E-11	1.9909E-10
FY-AXIS=	2.0705E-10	8.1508E-11	7.3308E-10			

Test 7 (TSON) checks the transonic slewing coding.

Input:

LAMBDA	= 3.8E-4
IMAX	= 5.E-4
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 5.E+4
NF	= 6
DT	= 1.
FOCUS	= 3.E+5
ZF	= 12.E+5
ZTF	= 4.E+5
ZTL	= 1.E+7
WI	= 15(1.)
LMAX	= 1
NELEM	= 1
ISSL	= 1
RANGE	= 3.E+5
NCONT	= 1
NEDIT	= 1
SIGMA	= 1.E-6
COEFT3	= 0.
LO	= 100.
CNSQ	= 0.
ISLEW	= 1
THETAR	= 0.
THETAT	= 1.570796327
VFLTR	= 3.E4
VFLRC	= .69E5
END-RUN	

Selected print file output:

	DIST	WIND (CM)	DENSITY	Z= 2.7500E+05	T(SEC)= 1.0000E+00		
RHO(1)	3.3635E-02	-1.7672E-09	-1.7521E-09	-1.7305E-09	-1.6996E-09	-1.6556E-09	
RHO(7)	-1.5938E-09	-1.5081E-09	-1.3922E-09	-1.2399E-09	-1.0476E-09	-8.1743E-10	
RHO(13)	-5.6139E-10	-3.0405E-10	-7.9980E-11	7.7470E-11	1.5227E-10	1.5500E-10	
RHO(19)	1.1642E-10	6.9355E-11	3.3495E-11	1.3171E-11	4.1669E-12	1.0362E-12	
RHO(25)	2.0236E-13	3.8813E-14	1.3558E-14	6.0567E-15	2.0770E-15	9.6621E-16	
RHO(31)	1.0529E-15	6.9359E-16	-0.				

N= 0
Z= 3.0000E+05

	INTENSITY ALONG X-AXIS	POWER(W)= 1.1636E+05			
IX-AXIS=	1.7823E-07	5.6860E-07	8.4877E-07	7.6407E-07	1.5112E-06
IX-AXIS=	9.7150E-06	2.4820E-05	6.1683E-05	1.6742E-04	4.3861E-04
IX-AXIS=	2.2582E-03	4.1112E-03	6.4995E-03	8.8950E-03	1.0510E-02
IX-AXIS=	9.8238E-03	7.7275E-03	5.3642E-03	3.2363E-03	1.7297E-03
IX-AXIS=	3.5587E-04	1.4614E-04	5.6735E-05	2.0264E-05	7.5728E-06
IX-AXIS=	7.8569E-07	2.6020E-07			
IY-AXIS=	3.1489E-06	2.2870E-06	2.1562E-06	8.3697E-06	2.0768E-05
IY-AXIS=	6.1508E-05	1.1508E-04	2.3709E-04	5.3639E-04	1.1600E-03
IY-AXIS=	4.0594E-03	6.2579E-03	8.5249E-03	1.0270E-02	1.0887E-02
IY-AXIS=	8.5262E-03	6.2447E-03	4.0598E-03	2.3028E-03	1.1598E-03
IY-AXIS=	2.3698E-04	1.1332E-04	6.1411E-05	3.4399E-05	2.0775E-05
IY-AXIS=	2.1629E-06	2.3909E-06	3.1489E-06		
ID-AXIS=	7.7657E-09	1.2684E-10	3.9771E-09	8.3400E-09	6.2058E-08
ID-AXIS=	1.3992E-06	4.2923E-06	8.5707E-06	5.8091E-06	6.4302E-06
ID-AXIS=	6.6362E-04	2.1695E-03	4.9669E-03	8.3639E-03	1.0510E-02
ID-AXIS=	7.7327E-03	4.5374E-03	2.1496E-03	8.2184E-04	2.7127E-04
ID-AXIS=	2.4306E-05	6.9801E-06	1.9559E-06	6.0774E-07	2.3899E-07
ID-AXIS=	1.7891E-08	1.3406E-08	7.7657E-09		
	X-SPECTRUM				
FX-AXIS=	5.8252E-12	3.3061E-12	5.5844E-12	1.4629E-11	2.2891E-11
FX-AXIS=	3.1348E-11	9.0614E-11	5.5493E-10	1.3876E-09	3.9430E-09
FX-AXIS=	1.4860E-07	9.5433E-07	9.4648E-06	3.7581E-05	5.7534E-05
FX-AXIS=	9.4736E-06	9.5256E-07	1.4628E-07	2.5085E-08	3.8371E-09
FX-AXIS=	3.7995E-10	2.6849E-11	2.1523E-11	2.1544E-11	1.3010E-11
FX-AXIS=	8.2248E-12	6.5902E-12	5.8252E-12		
	Y-SPECTRUM				
FY-AXIS=	4.6411E-11	3.2505E-11	2.9406E-11	2.1712E-11	3.3438E-11
FY-AXIS=	3.2472E-11	4.0224E-11	3.8343E-11	2.0255E-10	4.0497E-10
FY-AXIS=	2.9982E-07	2.5854E-06	1.2280E-05	3.4773E-05	5.7534E-05
FY-AXIS=	2.3863E-05	5.0547E-06	4.8239E-07	2.5579E-08	9.9686E-10
FY-AXIS=	1.3793E-10	1.1853E-10	7.7922E-11	6.2329E-11	4.3075E-11
FY-AXIS=	4.8340E-11	5.4940E-11	4.6411E-11		

Test 8 (VARZ) checks the variable
z-step and lens transformation coding.

Input:

LAMBDA	= 3.8E-4
IMAX	= 1.E-4
SIGX	= 10.
SIGY	= 10.
LX	= 60.
LY	= 60.
NFFT	= 32
DZ	= 500.
IVARDZ	= 1
NEDITS	= 6
DZEDIT	= .5E+5
ILENS	= 1
ZTF	= 3.E+5
ZTL	= 1.E+7
DT	= 1.
FOCUS.	= 3.E+5
WI	= 15(1.)
LMAX	= 1
NELEM	= 1
ISSL	= 1
VFLW	= 1000.
SIGMA	= 1.E-6
END-RUN	

Selected print file output:

79-

		DENSITY		Z= 2.5000E+02		T(SEC)= 1.0000E+00			
DIST // WIND (CM)									
RHO(	1)	1.2341E-02	-0.	-4.0579E-13	-1.5198E-12	-4.3037E-12	-1.0734E-11		
RHO(	7)	-2.4538E-11	-5.2143E-11	-1.0361E-10	-1.9313E-10	-3.3837E-10	-5.5827E-10		
RHO(	13)	-8.6895E-10	-1.2785E-09	-1.7825E-09	-2.3611E-09	-2.9811E-09	-3.6011E-09		
RHO(	19)	-4.1798E-09	-4.6837E-09	-5.0933E-09	-5.4040E-09	-5.6239E-09	-5.7691E-09		
RHO(	25)	-5.8586E-09	-5.9101E-09	-5.9377E-09	-5.9515E-09	-5.9580E-09	-5.9607E-09		
RHO(	31)	-5.9619E-09	-5.9623E-09	-5.9624E-09					
SX =	1.091E-03 SXX =	4.985E+01 SYY =	4.985E+01 SDPX =	3.298E-04 SXDPX=	7.883E-05 SYDPY=	-2.102E-03			
ZFX =	-1.046E+10 ZFY =	3.921E+08 ZTFX =	2.997E+05 ZTFY =	2.997E+05					
DZS =	1.000E+03 DZP =	0.	DZC =	5.000E+02 DDPHI =	1.682E-03				
DZL =	1.0636E+05								
SX =	1.073E-03 SXX =	4.961E+01 SYY =	4.961E+01 SDPX =	9.962E-04 SXDPX=	8.454E-05 SYDPY=	-4.315E-03			
ZFX =	-9.702E+09 ZFY =	1.901E+08 ZTFX =	2.990E+05 ZTFY =	2.992E+05					
DZS =	1.200E+03 DZP =	5.000E+02 DZC =	1.000E+03 DDPHI =	3.454E-03					
DZL =	1.0592E+05								
SX =	1.002E-03 SXX =	4.924E+01 SYY =	4.924E+01 SDPX =	1.805E-03 SXDPX=	4.077E-05 SYDPY=	-5.277E-03			
ZFX =	-1.997E+10 ZFY =	1.543E+08 ZTFX =	2.979E+05 ZTFY =	2.986E+05					
DZS =	1.440E+03 DZP =	1.000E+03 DZC =	1.200E+03 DDPHI =	4.224E-03					
DZL =	1.0528E+05								
SX =	8.527E-04 SXX =	4.881E+01 SYY =	4.881E+01 SDPX =	2.784E-03 SXDPX=	4.607E-05 SYDPY=	-6.356E-03			
ZFX =	-1.752E+10 ZFY =	1.270E+08 ZTFX =	2.966E+05 ZTFY =	2.979E+05					
DZS =	1.728E+03 DZP =	1.200E+03 DZC =	1.440E+03 DDPHI =	5.088E-03					
DZL =	1.0452E+05								
SX =	5.794E-04 SXX =	4.829E+01 SYY =	4.829E+01 SDPX =	3.976E-03 SXDPX=	5.199E-05 SYDPY=	-7.660E-03			
ZFX =	-1.536E+10 ZFY =	1.042E+08 ZTFX =	2.950E+05 ZTFY =	2.970E+05					
DZS =	2.074E+03 DZP =	1.440E+03 DZC =	1.728E+03 DDPHI =	6.132E-03					
DZL =	1.0360E+05								
SX =	1.152E-04 SXX =	4.767E+01 SYY =	4.768E+01 SDPX =	5.431E-03 SXDPX=	5.715E-05 SYDPY=	-9.242E-03			
ZFX =	-1.379E+10 ZFY =	8.530E+07 ZTFX =	2.931E+05 ZTFY =	2.959E+05					
DZS =	2.488E+03 DZP =	1.728E+03 DZC =	2.074E+03 DDPHI =	7.398E-03					
DZL =	1.0251E+05								
SX =	-6.403E-04 SXX =	4.693E+01 SYY =	4.695E+01 SDPX =	7.210E-03 SXDPX=	6.013E-05 SYDPY=	-1.116E-02			
ZFX =	-1.290E+10 ZFY =	6.954E+07 ZTFX =	2.908E+05 ZTFY =	2.947E+05					
DZS =	2.986E+03 DZP =	2.074E+03 DZC =	2.488E+03 DDPHI =	8.936E-03					
DZL =	1.0120E+05								
DIST // WIND (CM)		DENSITY		Z= 2.6532E+05		T(SEC)= 1.0000E+00			
RHO(	1)	2.0912E-04	-0.	-6.5922E-13	-2.3684E-12	-8.9024E-12	-2.6311E-11		
RHO(	7)	-6.1201E-11	-1.2126E-10	-2.1784E-10	-3.7546E-10	-6.4283E-10	-1.0726E-09		
RHO(	13)	-1.6853E-09	-2.4692E-09	-3.3737E-09	-4.2919E-09	-5.1066E-09	-5.7322E-09		
RHO(	19)	-6.1292E-09	-6.3266E-09	-6.4033E-09	-6.4365E-09	-6.4700E-09	-6.5165E-09		
RHO(	25)	-6.5699E-09	-6.6206E-09	-6.6635E-09	-6.6945E-09	-6.7129E-09	-6.7229E-09		
RHO(	31)	-6.7286E-09	-6.7325E-09	-6.7350E-09					

SX = 9.401E-02 SXX = 4.411E+00 SY = 1.742E+01 SDPX = 2.076E-01 SXDPX = -2.365E-01 SYDPY = -3.562E-01
 ZFX = 3.085E+05 ZFY = 8.086E+05 ZTFX = 3.814E+05 ZTFY = -4.342E+05
 DZS = 3.201E+04 DZP = 2.299E+04 DZC = 3.065E+04 DDPHI = 2.463E-01
 DZL = 3.2005E+04
 SX = -1.833E-01 SXX = 4.717E+00 SY = 2.073E+01 SDPX = 2.530E-01 SXCPX = -1.604E-01 SYDPY = -1.907E-01
 ZFX = 4.864E+05 ZFY = 1.798E+06 ZTFX = -1.638E+06 ZTFY = -3.075E+05
 DZS = 3.627E+04 DZP = 3.065E+04 DZC = 1.935E+04 DDPHI = 1.316E-01
 DZL = 3.6270E+04

N= 0
 Z= 3.0000E+05

INTENSITY ALONG X-AXIS POWER(W)= 2.3272E+04
 IX-AXIS= 1.0276E-06 1.6370E-06 3.6253E-06 6.3333E-06 1.0340E-05 1.7917E-05
 IX-AXIS= 3.5424E-05 6.0636E-05 9.8606E-05 1.3985E-04 1.8713E-04 2.3093E-04
 IX-AXIS= 2.8390E-04 3.3072E-04 3.7305E-04 3.8761E-04 3.6842E-04 3.2236E-04
 IX-AXIS= 2.5142E-04 1.6610E-04 9.0159E-05 3.7027E-05 9.5632E-06 6.9774E-06
 IX-AXIS= 1.9639E-05 2.5942E-05 2.6062E-05 1.6332E-05 1.0172E-05 4.2699E-06
 IX-AXIS= 2.0038E-06 1.3813E-06
 IY-AXIS= 6.0714E-09 6.2102E-09 1.3542E-08 5.4305E-08 2.3351E-07 9.1953E-07
 IY-AXIS= 3.1829E-06 9.4231E-06 2.3625E-05 5.1597E-05 9.6972E-05 1.5797E-04
 IY-AXIS= 2.2587E-04 2.8992E-04 3.4122E-04 3.7530E-04 3.8761E-04 3.7532E-04
 IY-AXIS= 3.4125E-04 2.8996E-04 2.2591E-04 1.5801E-04 9.7001E-05 5.1617E-05
 IY-AXIS= 2.3637E-05 9.4283E-06 3.1849E-06 9.2022E-07 2.3370E-07 5.4343E-08
 IY-AXIS= 1.3552E-08 6.2166E-09 6.0714E-09
 ID-AXIS= 7.1111E-10 5.9110E-10 2.9152E-09 5.7951E-09 3.5615E-09 6.3041E-09
 ID-AXIS= 7.4178E-09 2.5883E-07 2.2527E-06 9.0499E-06 2.6661E-05 6.0409E-05
 ID-AXIS= 1.2919E-04 2.2597E-04 3.2117E-04 3.7530E-04 3.6842E-04 3.1658E-04
 ID-AXIS= 2.5238E-04 2.0499E-04 1.6841E-04 1.2422E-04 8.5732E-05 5.0885E-05
 ID-AXIS= 2.5311E-05 1.0269E-05 3.3720E-06 9.0816E-07 2.0812E-07 3.6497E-08
 ID-AXIS= 4.2967E-09 1.0949E-09 7.1111E-10
 X-SPECTRUM
 FX-AXIS= 8.4992E-13 4.2302E-13 5.3145E-13 7.2241E-13 7.2845E-13 3.0706E-14
 FX-AXIS= 2.6120E-12 3.6770E-12 9.9991E-11 5.6508E-10 9.4782E-10 9.4991E-10
 FX-AXIS= 1.0756E-08 8.8244E-08 8.0131E-08 3.9927E-06 1.1573E-05 3.9952E-06
 FX-AXIS= 8.0217E-08 8.8267E-08 1.0766E-08 9.4972E-10 9.4799E-10 5.6525E-10
 FX-AXIS= 1.0003E-10 3.6913E-12 2.6038E-12 3.1282E-14 7.2905E-13 7.2245E-13
 FX-AXIS= 5.3121E-13 4.2315E-13 8.4992E-13
 Y-SPECTRUM
 FY-AXIS= 1.1984E-10 1.7570E-11 1.5868E-10 2.4284E-13 1.2177E-10 7.0721E-11
 FY-AXIS= 7.0480E-11 1.3197E-11 2.1022E-11 2.7278E-10 1.5117E-10 2.8089E-11
 FY-AXIS= 3.0866E-10 1.4032E-09 7.2471E-09 1.2350E-06 1.1573E-05 5.1509E-06
 FY-AXIS= 5.5548E-07 6.7057E-08 2.0958E-08 5.9337E-09 4.1948E-09 4.9581E-10
 FY-AXIS= 2.1173E-11 1.5964E-10 3.2849E-11 9.5345E-11 4.2728E-11 2.8957E-11
 FY-AXIS= 7.1120E-11 1.2939E-12 1.1984E-10

APPENDIX B: FLOW CHARTS

I have included flow charts (Figs. B1 to B5) of the main program and subroutines PROPGAT, PHASE, and SSLEW because learning the function of these routines is a key to understanding the structure of the Four-D code. Most of the remaining subroutines can be easily understood from their FORTRAN listings. Detailed understanding of the output subroutines DEDIT, EDITS, FLEDIT, and SLEDIT requires knowledge of LLL plotting subroutines. Users at other installations should start with the information in section III and Appendix A of this report and rewrite these four output subroutines using their own plotting subroutines. Brief descriptions of LLL plotting subroutines are in LTSS-304, ORDERLIB Subroutine Library, which can be obtained from the LLL Technical Information Department or from the author. The flow chart of VFIX appears here because of its logical complexity.

The numbers in the circular connector symbols in these flow charts are statement numbers from the FORTRAN coding; the alphabetic symbols are flow chart symbols.

Fig. B1. Main program.

Fig. B2. Subroutine PHASE.

Fig. B3. Subroutine PROPGAT.

Fig. B4. Subroutine SSLEW.

Fig. B5. Subroutine VFIX.

Fig. B5. Continued.

Fig. B5. Continued.

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