The probable design parameters of the nuclear-powered x-ray laser

by Charles B. Stevens

*In Part I of this report (*EIR *Vol 15, No. 44), we undertook a detailed technical analysis of the letters and reports released this past summer, in the wake of the latest controversy surrounding the hydrogen-bomb powered x-ray laser. These documents and that analysis demonstrated that most of what has been publicly presented by others in the way of technical assessments of President Reagan's Strategic Defense Initiative (SDI) program, first announced on March 23, 1983, has been way off the mark.*

Almost all of these so-called "technical" assessments have been off the mark by as much as a factor of one million! And, despite the recent release of an overwhelming amount of previously secret data and assessments, most scientific and technical journals are still publishing distorted reports, to the effect that the x-ray laser does not work.

In any case, what is true is that the nuclear-powered x-ray laser has tremendous firepower potential—one module potentially capable of knocking out the entire ballistic missile fleet of the Soviet Union. In this, the x-ray laser categorically demonstrates the efficacy of Lyndon H. LaRouche, Jr.'s design of the SDI policy. And even so, as Edward Teller emphasizes, the x-ray laser is certainly not the only potential defensive weapon, and is possibly not even the best one.

Yet, it is sadly the case that the West has failed to actually adopt the policy required in regard to SDI. Therefore, the following technical assessments have an ominous ring. Obviously, one module can also knock out the entire U.S. missile fleet. The West has not launched a crash R&D program, according to all public reports, and the Soviets have had at least a seven-year lead on the West in the development of the nuclear-powered x-ray laser.

Here, we present two detailed designs for possible target-acquisition, pointing, and tracking systems for the x-ray laser. These system designs demonstrate that while the x-ray laser anti-missile capability does require further technical developments to be realized as an effective weapon, the advances required are far less than those needed for any other proposed system.

1) Brightness

Given a point source emitting energy, and assuming the energy propagates along radial lines, the brightness, B, of the source in the solid angle θ is simply

$$B = p/Z$$

where P is the power passing through the cone defined by θ.

Just as the angular measure of a circle in a plane may be given either in degrees or in radians (2π radians is always one full circumference), so also a solid angle with apex at the center of a sphere may be given either in θ degrees or in X steradians, where 4π steradians is the full spherical surface.

Consider a sphere is radius R and a cone with apex at the center of the sphere and edge length R. The solid angle defined by the cone, in steradians, is the surface area of the sphere intersected by the cone, call it S, divided by R squared: $X = S/R^2$. A solid angle and apex angle are related but not the same. The apex angle is the plane angle defined by the intersection of the surface of the cone with a plane that passes through the cone's axis (**Figure 1**). If θ is the cone's apex angle, its solid angle is given either as θ degrees or as X steradians, where

$$X = 4 \times \pi \times [\sin(\theta/4)]^2$$

Now consider a 100-watt light bulb. the bulb emits its energy uniformly in all directions (an isotropic radiator); therefore, the solid angle defined by the emitted energy is a cone with an apex angle of 360 degrees. But a cone with a 360-degree, or $2 \times \pi$, apex angle is simply a sphere. Note that the solid angle of a sphere is

$$X = 4 \times \pi \times [\sin(\pi/2)]^2 = 4 \times \pi$$

Assuming the electrical energy used by the bulb is transformed completely into radiant energy (e.g., infrared and visible light), the brightness of the bulb is simply 100 watts divided by $4 \times \pi$.

A laser is not an isotropic radiator, but rather very nearly a unidirectional radiator. A laser's energy is emitted into a very small solid angle or cone. The apex angle of the cone, also known as the divergence angle of the laser, is typically on the order of microradians. (A right angle of 90 degrees has $\pi/2 \times 1{,}000{,}000$ microradians, that is, about 1,570,000 microradians.)

For lasers, the relationship between a solid angle, X, and its apex angle, θ, can be simplified. For small θ, the previous expression for X simplifies to

$$X = (\pi/4) \times \theta^2$$

Thus, if P is the emitted power of a laser within a cone of divergence angle A, then its brightness B is

$$B = 4 \times P/(\pi \times \theta^2)$$

The divergence angle of a perfect laser is limited by the wavelength of the laser light and the diameter of the final aperture (or mirror) of the laser. Asssuming the laser light intesects a circular aperture, the emitted light is diffracted into a circular diffraction pattern. If the pattern is observed a great distance from the aperture, it is called the Fraunhofer diffraction pattern. The pattern is a central disk surrounded by rings of illumination which are progressively fainter for larger diameter rings. The central disk of light is called the Airy disk and contains 84% of the light (or radiated energy).

The angle subtended by the Airy disk is 2.44 times the wavelength of the light divided by the diameter of the final aperture. But the Airy disk is significantly brighter at its center relative to its edges; 63% of the light is in the central fourth of the disk. Consequently, the "usable" portion of the diffraction pattern is typically defined as the central fourth of the Airy disk. The angle subtended by this area is 1.22 times the wavelength divided by the aperture diameter. Consequently, if W is the wavelength and D the aperture diameter, then the laser's divergence angle, θ, is 1.22W/D, and its brightness is

$$B = 4 \times P/[\pi \times (1.22W/D)^2]$$

Here P is the power (or light) in the central fourth of the Airy disk, which is 53% of the total power emitted by the laser.

Aside

In the above, brightness has been defined using the power passing through a solid angle. For sources which deliver a pulse of energy, rather than a continuous beam, it is often convenient to compute the brightness using the energy passing through the solid angle. In this case, P in the above equations is replaced by E, the energy of the pulse.

2) Flux and fluence

The average power per unit area, for flux, F, of radiant energy a distance R from its source is given by

$$F = B/R^2$$

where B has units of power per steradian. If B has units of energy per steradian, then F is the energy deposited per unit area, or fluence.

3) Nuclear bombs

The yield, or energy release, Y, of a nuclear bomb is usually specified in units of kilotons, abbreviated kt. One kiloton is equivalent to 10^{12} calories or 4.186×10^{12} joules.

When a nuclear bomb explodes, it immediately vaporizes and ionizes itself, converting its components into plasma. A typical plasma velocity for a thermonuclear bomb (hydrogen or fusion bomb) with a high yield-to-weight ratio (about 6kt/kg) would be about 1,000 km/sec, representing about 10% of the total explosive energy (Ref. 3). An object 1 meter from a nuclear weapon would be blown away in roughly 1 microsecond.

Depending on the yield-to-weight ratio of a nuclear bomb, the energy emitted in the first few microseconds after a nuclear explosion is between 50% and 70% x-rays, the higher percentage corresponding to higher yield-to-weight ratios. The rest of the energy at this time is roughly 10-30% kinetic energy of the expanding bomb debris plasma, and 20% thermal energy, prompt gamma rays, and neutrons (Ref. 3).

The largest yield nuclear device that can currently be tested in the United States is 150 kt, due to the Threshold Test Ban Treaty (Ref. 3). The x-ray brightness of such a device is found to be

$$B = (.70)(150\,kt)(4.186 \times 10^{12}\,j/kt)/(4 \times \pi\,SR) = 3.5 \times 10^{13}\,j/SR$$

FIGURE 1
A plane cut through the axis of a cone defines the cone's apex angle

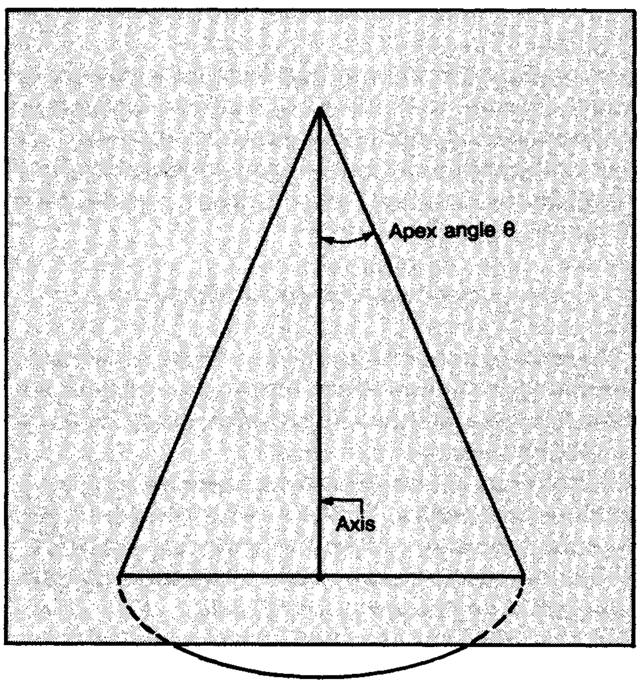
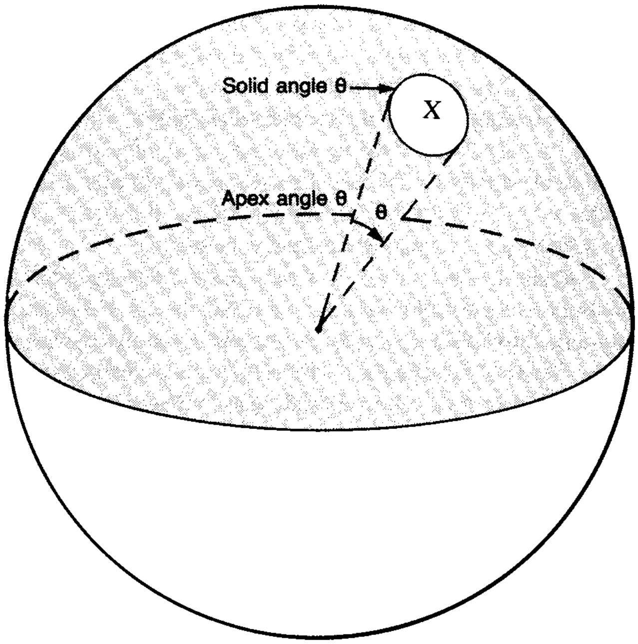


FIGURE 2

A solid angle of θ degrees is an area defined by a cone whose apex angle is θ degrees



If we take a sphere and divide its surface area up into 4 π equal parts (about 12.566 parts), each of these parts represents a solid angle of one steradian. There are 4 π steradians on the surface of any sphere.

The fluence at a range of 1,000 km is

$$F=(3.5\times 10^{13}\text{ j/SR})/[(100\text{ km})(10^5\text{cm/km})]^2=.35\text{ j/cm}^2$$

Note that the nuclear weapon is assumed to be isotropic.

4) Target hardness and kill fluence

The hardness of a target in the context of lasers refers to the power per unit area and energy per unit area that must be deposited on a target to damage it. The term was originally coined to characterize military hardware's ability to operate through the environment caused by a nuclear burst. Because a nuclear burst generates radiation across a wide spectrum, a piece of hardware can be harder to some nuclear effects than to others. Consequently, the hardness of a piece of equipment was always associated with the frequency range at which the equipment was most vulnerable, or conversely, with the nuclear burst generated radiation that was most lethal. With the advent of weapons-grade lasers, specifying the hardness corresponding to specific frequencies of radiation has become more important. Obviously, in the context of x-ray lasers, we are only concerned with x-ray hardness.

The term kill fluence refers to the amount of energy per unit area required to achieve not just damage, but the "sure kill" of a target. Kill fluence is therefore some multiple of the energy hardness of the target, typically a multiple of 10.

Generally speaking, damage inflicted by lasers correlates more closely with the total deposited energy than with the rate of energy deposition or power. To cause damage, the power level need only exceed the rate at which the target can re-radiate or dissipate the absorbed energy. Typically this power level is easy to achieve. This is especially true for pulse lasers such as the x-ray laser.

The preferred kill mechanism for x-ray lasers is generally assumed to be target break-up via impulse, rather than the "frying" of electronics, primarily because it is easier to verify. When the x-ray pulse hits the surface of a target, it is absorbed in a fraction of a millimeter of the target's skin. This volume of matter cannot dissipate the heat before vaporization occurs, resulting in an explosion of the material and the generation of an impulse and shockwave through the target. Roughly speaking, the generated impulse is proportional to the square root of the absorbed energy.

According to Ashton B. Carter (Ref. 1), an impulse of about 10 kilotaps (equivalent to a 0.5 kg hammer head striking a 3 cm radius contact area at 5 m/sec; specific impulse = mass × velocity/strike area; 1 tap = 1 dyne-sec/cm^2 = 1 gm/cm-sec = 0.1 kg/m-sec) is sufficient to destroy a booster in flight. He estimates that an x-ray fluence of 20 kj/cm^2 is adequate to generate such an impulse. The American Physical Society (Ref. 2) uses reasoning similar to, but more detailed than, Carter's and believes an x-ray fluence of 5 kj/cm^2 is sufficient. A booster kill fluence of 10 kj/cm^2 is probably a safe estimate.

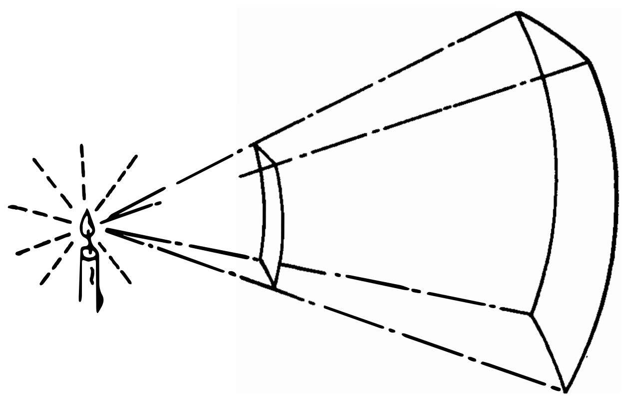
An RV, a so-called "nuclear hardened" target, is specifically designed to withstand the impulse loading that occurs during reentry, as well as the collateral nuclear effects due to nearby exploding RVs. Thus, an RV can probably sustain an impulse of 10 kilotaps without damage. However, an impulse of 100 kilotaps, roughly equivalent to a 1,000 kg automobile (1 m^2 frontal area) hitting a brick wall at 40 km/hr (25 mph), would probably do some damage. Therefore, we presume that a fluence of 100 kj/cm^2 is adequate to damage an RV. Certainly, a sure kill could be obtained if the RV was hit with a fluence of 1,000 kj/cm^2.

5) Nuclear-pumped x-ray laser

The nuclear-pumped x-ray laser enhances the brightness of a nuclear bomb by emitting a portion of the bomb's energy through a much smaller solid angle than the $4\times\pi$ steradian solid angle of the isotropic nuclear explosion. The enhancement in brightness is given by $4\times\pi\times N/X$ where $4\times\pi$ is the solid angle of the nuclear explosion, N is the overall efficiency of converting the nuclear explosion energy into x-ray laser energy, and X is the solid angle containing the emitted x-ray laser energy.

If $N=0.1\%$ and $X=10^{-12}$ steradians, the brightness of an x-ray laser pumped by a 150 kt nuclear bomb would be

FIGURE 3
Luminous flux over unit solid angle



This illustration shows that a spherical (isotropic) distribution of light from a source leads to the intensity falling off as one over the distance squared. that is, the intensity at a two-foot distance from the source will be four times less than the intensity at a distance of one foot.

$$B = (4 \times \pi \times N \times Bbomb)/X$$
$$= (4 \times \pi \, SR)(0.001)(3.5 \times 10^{13} \, j/SR)/(10^{-12} \, SR)$$
$$= 4.4 \times 10^{23} \, j/SR$$

The x-ray laser brightness can be expressed in terms of the yield of its nuclear bomb and its divergence angle by substituting the relevant relationship for Bbomb and X in the above expression. The result is

$$B = (4 \times N \times Y)/(\pi \times \theta^2)$$

For the above example, the x-ray laser fluence at a range of 1,000 km is

$$F = (4.4 \times 10^{23} \, j/SR)/[(1{,}000 \, km)(10^5 \, cm/km)]^2$$
$$= 44{,}000 \, kj/cm^2$$

Note that this fluence level is roughly 44 times greater than the level required for "sure kill" of an RV.

The above numbers for brightness and fluence assume the x-ray laser output is a single beam directed to a single target. But the x-ray laser output beam is most probably formed by combining many individual x-ray beams into a single beam. The brightness and fluence of the x-ray laser output is found by summing the brightnesses and fluences of all the individual beams (we assume the wavefronts of the beams are not in phase). For the case of M individual beams, each with brightness Bbeam, all aimed at the same point, the brightness of the x-ray laser is simply

$$B = 1M \times Bbeam$$

We mention that if all the individual beams could be phased to create a phased array designed to function as a single, coherent radiating aperture, the brightness of the x-ray laser would be $M^2 \times Bbeam$. Since phasing has to be a dynamic, closed-loop process, it does not lend itself to one-shot, pulse lasers such as the x-ray laser. In addition, it is doubtful if the means even exist to sense and manipulate the wavefront of an x-ray laser beam.

Rather than aiming all the individual beams at a single target, it may be possible to aim each individual beam, or groups of individual beams, independently. In this way, a single x-ray laser could kill J targets in parallel, where J is the number of independently aimable beams.

Ashton B. Carter (Ref. 1) postulates the design of an x-ray laser to consist of a cylinder roughly 2 meters in diameter and about 5 meters in length. A nuclear bomb is positioned at the center of the cylinder. The cylinder is formed by placing many thin rods (about 60 microns in diameter) side by side.

Assuming a 50% packing fraction, roughly 100,000 rods are required to form the cylinder.

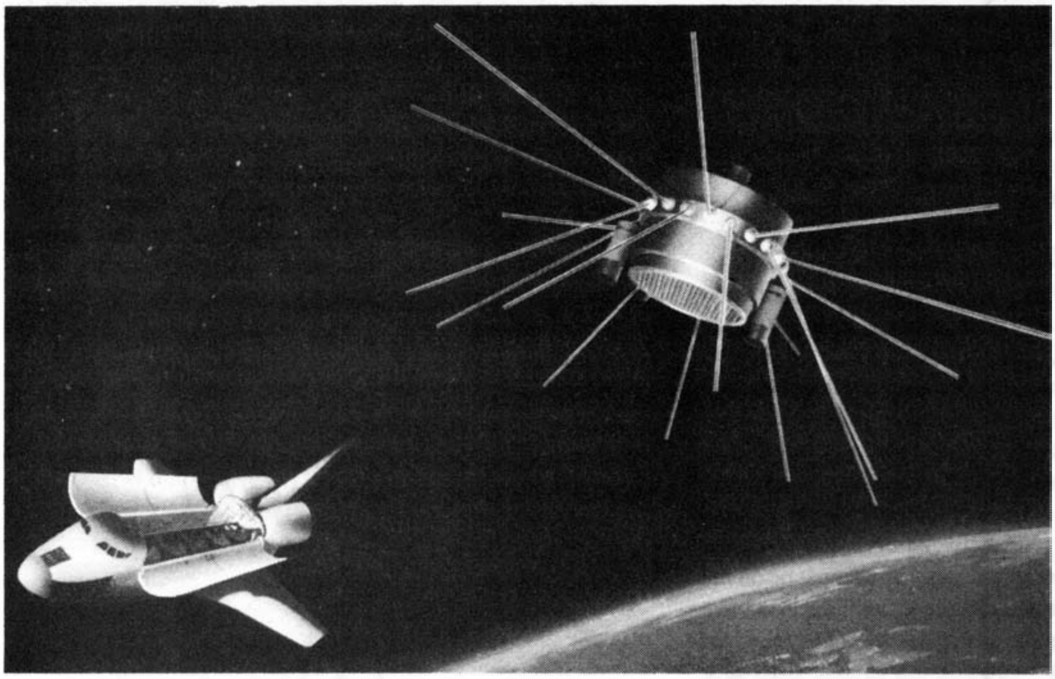
Each individual rod produces an x-ray laser pulse when the nuclear bomb explodes. The lasant material is ionized (converted into a plasma) and pumped by the incoherent x-ray emissions of the bomb.

The lasant material then relaxes, generating a coherent x-ray laser pulse out of one end of the rod. All of this happens in fractions of a microsecond, before the lasant material is blown away by the bomb plasma traveling outward from the center of the cylinder at about 1,000 km/sec.

The energy in each individual x-ray laser pulse is limited by the amount of x-ray energy absorbed by the rod and the efficiency of the lasing process. For the above dimensions of the x-ray laser cylinder, and assuming the nuclear bomb radiates isotropically when it explodes, roughly five-sixths of the bomb's x-rays intersect the cylinder. Assuming these x-rays are uniformly distributed among the rods, but that only half of them are absorbed by the lasant material (recall the 50% packing fraction), roughly five-twelfths of the bomb's x-rays are absorbed by the rods' lasant material. Since there are 100,000 rods, each rod absorbs roughly 0.0004% of the bomb's x-ray emissions.

Knowing the amount of absorbed x-ray energy, the amount of energy in each individual x-ray laser pulse is found by knowing the efficiency of the pumping/lasing process. This is one of the x-ray laser program's many "secrets." However, an efficiency of 2%, comparable to the low-end pumping efficiency of excimer lasers, seems reasonable. This assumption is also used by Ashton B. Carter (Ref. 1).

Based on the above, we find that the energy of the output laser pulse of a single rod is roughly 0.000008% of the energy of the nuclear bomb's x-ray emissions. Since the x-ray emissions represent roughly 70% of the bomb's total explosive energy, roughly 0.000006% of the bomb's total energy ends up in each individual laser pulse. Since there are 100,000



An artist's conception of an x-ray laser module deployed by the Space Shuttle.

individual pulses, i.e., one for each rod, the overall energy conversion efficiency of the x-ray laser is 100,000 times this, or 0.6%. We note that Ashton B. Carter uses a value of 2.5% (Ref. 1).

With the energy output of a single rod in hand, the brightness of the rod's output beam can be computed if we know the divergence angle of the output laser pulse. Ashton B. Carter estimates the divergence angle using a strictly linear, "mechanistic" approach (Ref. 1). The approach can be illustrated as follows. If one puts a "pure color" light bulb (a single-frequency, incoherent, and therefore isotropic radiator) at the capped end of a hollow cylinder, then the light emanating from the opposite, open end of the cylinder becomes more collimated as the length-to-diameter ratio of the cylinder is increased. Eventually, however, a minimum occurs, as further increases in the length-to-diameter ratio yield less collimation, or an increase in the divergence angle of the output beam. This minimum is due to diffraction—the divergence angle of the usable portion of the output beam can never be less than about 1.22 times the wavelength of the light divided by the diameter of the aperture. At the diffraction limit, the following relationship holds:

$$(1.22)(\text{wavelength})/(\text{rod diameter}) = (2)(\text{rod diameter})(\text{rod length})$$

Carter assumes each x-ray laser beam is formed by a cascading of lasant material electrons to lower energy levels. This cascading proceeds down the length of the rod, causing the x-ray laser pulse to be collimated in much the same fashion as the light from the light bulb above. For an x-ray wavelength of 1 nanometer (i.e., a 1.24 KeV x-ray) and a rod length of 5 meters, the above equation yields an "optimum" rod diameter of 60 microns and a minimum achievable (diffraction-limited) divergence.

Carter does not mention, or even consider, a coherence mechanism for the x-ray laser pulse other than its being directed down a long, thin rod. If the lasant plasma behaves in any way like the resonant cavity of more traditional lasers (e.g., chemical lasers, excimer lasers), coherence can be enforced among the individual x-ray photons, and the divergence angle of the x-ray laser pulse then becomes a function solely of the size of the aperture emitting the pulse. The larger the aperture, the smaller the divergence angle. Clearly, the divergence angle can be made less than Carter's upper limit of 20 microradians in this case.

It may also be possible to create a "plasma lens" to focus the x-rays. Just like any form of radiation, x-rays can be refracted, and therefore focused, by passing them through two mediums for which the speed of light is different in each. Since light travels at different speeds through different plasmas, a plasma lens could be formed when the material forming the x-ray laser is ionized. The divergence angle of each individual x-ray laser beam would then be limited only by the upper limit on the effective diameter of the lens.

If we assume the x-ray laser pulse produced by a single rod has a divergence angle of 1.0 microradians, and the rod is pumped by a 150 kt nuclear bomb, but converts only 0.000001% of the bomb's energy into an x-ray laser pulse, then the brightness of the rod's laser beam is

$$\text{Bbeam} = (Y \times \text{Nbeam})/(\pi/4 \times \theta^2)(150\text{ kt})(4.186 \times 10^{12}\text{ j/kt})(10^{-7}) = (\pi/4\text{ SR/rad}^2)(10^{-6}\text{ rad})^2 = 7.99 \times 10^{18}\text{ j/SR}$$

The fluence delivered by the rod at a range of 1,000 km is

$$\begin{aligned} F_{beam} &= B_{beam}/R^2 \\ &= 7.99 \times 10^{18}\ \text{j/SR})/[(1{,}000\ \text{km})(10^5\ \text{cm/km})]^2 \\ &= .799\ \text{kj/cm}^2 = 799\ \text{j/cm}^2 \end{aligned}$$

6) X-ray laser targeting and pointing

Even if the fluence delivered by an x-ray laser is sufficient to destroy a target, a kill cannot be achieved if the targeting and pointing accuracy and the spot size of the laser beam is insufficient to hit the target. Consider an x-ray laser with a 1 microradian divergence angle attempting to irradiate a target 1,000 km away. The spot size of the beam at the target is roughly 1 meter in diameter. If the projected area of the target is also roughly 1 meter in diameter, then the targeting error (i.e., the relative position error between the x-ray laser and the target) and pointing error of the x-ray laser must be on the order of 0.1 microradian or better if the x-ray laser is to have a high probability of hitting the target.

An active state-of-the-art surveillance system such as a microwave radar can determine the range to distant objects to within centimeters, and their angular location (cross-range) to within a milliradian (e.g., the divergence angle of a radar with a 1 cm wavelength and a 10 m dish is on the order of 1 milliradian). The cross-range accuracy of a single radar does not meet our needs. But an active tracking system of properly placed ground (or space-based) radars could, since triangulation can locate an object to the same degree of accuracy as the range accuracy. In other words, the location of a target relative to an x-ray laser can be known to within centimeters using a triangulation approach. At a range to target of 1,000 km, this translates into a $(10^{-2}\ \text{m})/(10^6\ \text{m})$ or 0.01 microradian targeting error. Phased-array systems with this level of performance are already in routine use.

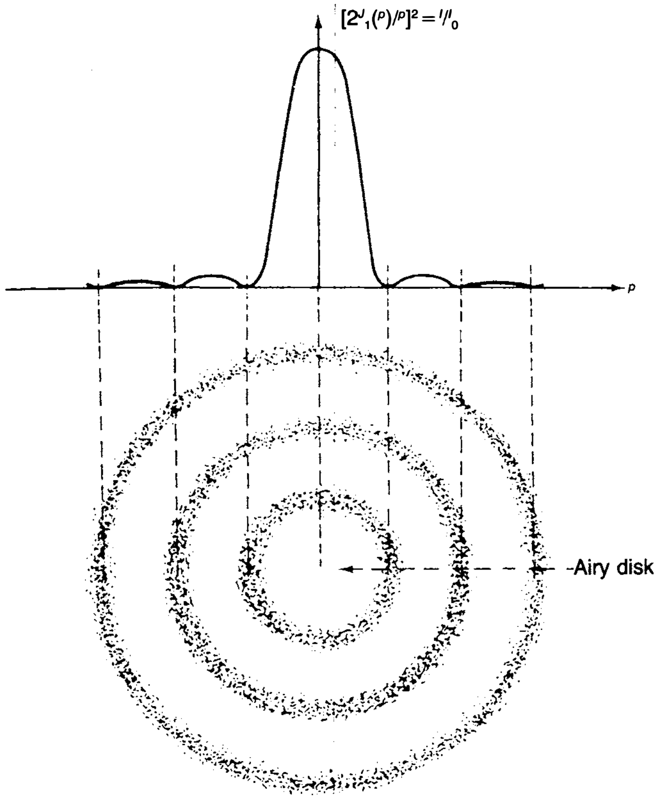
The principal contributors to pointing error depend on whether an "open-loop" or "closed-loop" system is employed. An open-loop system would require the x-ray laser to know its own orientation and the relative orientation of each of its aimable beam sources to within 0.1 microradian of error. The major error contributors in such a system are principally three: attitude control system accuracy, mechanical vibrations or jitter, and alignment and boresighting errors. The first impacts the orientation of the x-ray laser as a whole; the latter two impact the orientation of each aimable beam sources relative to the x-ray laser structure.

The principal component of attitude control systems is the gyro. Gyros with accuracies of 0.001 microradians/sec are just within the current state of the art. Ten years of further development are expected to bring a factor of 10 improvement. Thus, if a 1993 x-ray laser fires within 500 seconds of the time its attitude control system is initialized (or "updated"), the orientation of the x-ray laser can be known to within roughly 0.1 microradian, which meets our requirements.

If the x-ray laser is "popped up" to its firing location by a ground or submarine launched missile, and its attitude control system is initialized at launch, then the x-ray laser has 500 seconds (8.33 minutes) to fly to its firing location. Since a typical strategic missile can reach an altitude of 1,000 km and travel downrange roughly 1,500 km in 500 sec, the x-ray laser could be launched from the United States and have plenty of time to reach locations from which to fire at Soviet RVs headed toward the United States. Basing the x-ray laser on submarines or NATO countries in the northern latitudes

FIGURE 4

The Fraunhofer diffraction pattern and the distribution as calculated by Airy



When a coherent light beam passes through an optical aperture—some physical boundary which limits the diameter of the coherent light beam—then the beam is diffracted so that its cross section expands as the beam passes through space. If we take this aperture to be circular, the light beam will fill an infinite cone. But besides spreading out, the aperture diffraction causes the intensity of light within the beam to be distributed into rings. (These rings are seen in the plane which cuts the beam and forms a circle.) This ring distribution of intensity is called the Fraunhofer diffraction pattern. Airy calculated the distribution function across the circular cross section of the beam. The rings are shown in the lower portion of the figure. The Airy distribution is shown in the upper portion.

would probably also permit the x-ray laser to fire on Soviet ICBMs in both their boost phase and RV deployment phase of flight.

If the pointing mechanism for each beam of the x-ray laser is vibrating excessively, then at the instant of x-ray laser firing, a beam may be pointing away from its target. This will not happen, however, if the jitter is kept under 0.1 microradians. Designed about a decade ago, the U.S. Air Force's Teal Ruby Experiment, an IR (infrared) surveillance system designed to track aircraft from space using an open-loop pointing system, achieved a jitter requirement of about 1.5 microradians. This was measured on the ground, as the Teal Ruby Experiment has never flown. By 1993, fifteen years after Teal Ruby was designed, new materials and new technologies such as magnetic bearings should bring a jitter requirement of 0.1 microradian within the state of the art.

Even if the orientation of the x-ray laser outer structure is accurately known, a laser beam can still miss its target if it is not pointed where the x-ray laser pointing system believes it to be pointed. The problem is similar to the relationship between the muzzle of a gun and the gun's sights. If the two are not aligned, no matter how well the gun is aimed, the bullet will always miss its target. This type of pointing error is termed an alignment and boresighting error. Many sophisticated techniques are available for making sure all of an x-ray laser's pointing components are properly aligned after production. But can this alignment be maintained immediately after the detonation of the x-ray laser's nuclear bomb? What of structural deformations caused by unexpected thermal gradients and blast effects? Only adequate amounts of empirical testing can determine if a 0.1 microradian boresighting requirement can be met in the face of such an extreme environment. However, based on the Teal Ruby Experiment referred to above, it is doubtful such a stringent boresighting requirement can be met with an open-loop pointing system. The overall pointing accuracy of Teal Ruby was limited to about 500 microradians, primarily due to structural deformations caused by uncompensated thermal effects.

A closed-loop pointing and tracking system is probably required to achieve the x-ray laser's pointing requirements. Such a system would employ some means to send a signal from the x-ray laser to each of its targets and then back again to the x-ray laser. A low-power, wide-angle laser would be ideal for this. The low-power laser would illuminate several targets at once or in succession. The reflected light would be "received" or tracked by "receiver optics." Each x-ray laser beam source would be moved until it was aligned with the reflected light from its target. The x-ray laser would then be ready to fire. Assuming perfect alignment and no jitter, pointing accuracies of better than 0.1 microradian can be achieved with this technique (e.g., an UV (ultraviolet) laser of wavelength 0.1 micron and 1 m diameter receiver optics can provide angular pointing to an accuracy of 0.1 microradians). A closed-loop pointing and tracking system still requires an open-loop pointing system to point its low-power laser in the direction of the targets. However, the attitude control system of the open-loop system need only be good enough to put the low-power, wide-angle laser light on the targets. Consequently, the accuracy requirements of the x-ray laser attitude control system can be greatly reduced. Use of a closed-loop system also relaxes the alignment requirement between the attitude control system and each aimable beam source. Very precise alignment between each aimable beam source and the "receiver optics" must still be maintained, however. By having each x-ray beam source and the tracking system share a portion of the tracking system's optical train, active compensation techniques within the pointing and tracking system's control loop can be used to maintain alignment. The system would automatically compensate for structural deformations due to thermal effects. But can the alignment be maintained within 0.1 microradians? The Star Lab Experiment of the Strategic Defense Initiative Organization (SDIO) may provide the answer.

Star Lab is a space-based, closed-loop, laser pointing and tracking system experiment to be flown on a Shuttle in 1991. Lockheed is the prime contractor. The system will attempt to track a booster with a low-power laser over a range of 1,000 km. Since the diameter of a booster is on the order of 1 m, it seems probable that Star Lab must achieve a pointing accuracy of 0.1 microradians or better if it is to be a success. Obviously, if Star Lab is successful, major hurdles en route to the development of an x-ray laser pointing system will have been passed.

Perhaps the major disadvantage of a closed-loop laser pointing and tracking system is the fact that it must be able to deal with countermeasures. For example, if the pointing system employed a UV laser, hundreds of cheap UV reflectors (which may be transparent to microwaves to avoid detection by radar, e.g., glass prisms) could be deployed in the vicinity of the targets to create confusion. Corner reflectors could be mounted on the targets to enhance the return signal and blind the receiver optics. While a discrimination scheme could be used to counter this, it would significantly increase the complexity of the x-ray laser pointing system. Of course, given the tremendous firepower of the x-ray laser, targeting and firing at the reflectors may not be a major disadvantage—a comparison of the numbers involved is required to settle this question. Note that in the open-loop pointing scheme, the discrimination job is handled by the external tracking system, allowing the x-ray laser pointing system to be as simple as possible.

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