Laser optics for the defense of Europe and Asia

Robert Gallagher discusses the adaptive optics systems that engineers must develop for laser beam weapons to achieve 'self-induced transparency.'

Europe and Asia require thousands of laser weapons for defense against the Warsaw Pact and its allies. These directed-energy defenses must be able to destroy or disarm nuclear-armed short-range and medium-range ballistic and cruise missiles and artillery shells armed with nuclear warheads. They must be able to shoot down Warsaw Pact aircraft of all types, from supersonic Backfire bombers to helicopter assault vehicles. The bulk of these hostile objects will travel only in the atmosphere. Therefore, a principal task of the Tactical Defense Initiative (TDI), is to solve the remaining, purely engineering problems of delivering kill-intensity laser energies on target, through the densest layers of the atmosphere, near the surface of the earth where atmospheric turbulence is the greatest.[1]

The key to the solution of these engineering problems is application of the concept of "self-induced transparency," originated by Leonardo da Vinci. For high-energy laser weapons, this requires a design that takes advantage of properties of the atmosphere consistent with the transport of beams of laser light to their targets, focused, and without loss of power density. In other words, the beam must work upon the atmosphere, *not against* its own propagation, but for it.

The "optics community" sees the atmosphere only as a *barrier* to light propagation (a somewhat peculiar view given the effective action of light throughout the biosphere). Based on "data" generated by computer simulations of the atmosphere (otherwise known as weather modeling), the opticians rule out the possibility of a practical military solution to laser transmission through it. These theories are the basis for the arguments of anti-SDI Pugwash "scientist" Kosta Tsipis.

Although the Strategic Defense Initiative Organization (SDIO) is influenced by the optics community, Lt. Gen. James Abrahamson's irrepressible optimism tends to obliterate such tendencies. Nonetheless, to gain required funding, General Abrahamson, Defense Secretary Caspar Weinberger, and West German Chancellor Helmut Kohl must contend with a political opposition wielding the arguments of Tsipis and the opticians against the feasibility of the SDI and the Tactical Defense Initiative. Here, we present them with the scientific basis to defeat this opposition.

According to the optics community, the intensity and coherence of high-power laser beams propagating through the atmosphere is destroyed by the following phenomena:

1) Absorption and scattering of light by the molecular constituents of the atmosphere.

2) Thermal blooming: heating of the atmospheric path, as a result of absorption, that produces the spreading of the beam out from its origin. According to the doctrines of the optics community[2] accepted even by some contractors to the SDIO,[3] thermal blooming establishes a maximum beam power that may be transmitted through the atmosphere.[4]

3) Atmospheric turbulence, as observed in the "twinkling," or scintillation of starlight.

There is, in fact, an engineering problem to solve, but it is by no means as devastating to the TDI as Tsipis would have it. The case of atmospheric turbulence is illustrative of this.

At the surface of the earth, the atmosphere encounters a discontinuous boundary, characterized by irregular surface features. The smoother aerodynamic flow of upper regions of the atmosphere breaks up into vortices, upon encountering this surface. This turbulence is characterized by optics theory, to produce spatial and temporal variations in the density of the atmosphere and, consequently, in the index of refraction, and thus the speed of any light traveling through it. As a result, according to contemporary models, portions of a beam emitted from different locations on a source, propagate at different varying speeds, with the result that the coherence and intensity of the beam is destroyed by the turbulence. Add to this, the tremendous additional turbulence that will exist over any battlefield area as a result of explosions, and variations in weather conditions, and the result is a problem that appears to require a considerable engineering deployment to solve.

The atmosphere is a hydrodynamic lens

Existing optical theories, founded on statistical mechanics, rule out the possibility of a solution[5]. These models are based on physical principles inconsistent with nature, and are consequently incompetent. Equally irrelevant are any conclusions regarding the feasibility of endo-atmospheric laser weapon development based on these models, such as those expressed by Tsipis in a December 1981 *Scientific American* article.[6] It should come as no surprise that recent *experimental* results have refuted these models and have demonstrated that a solution to these engineering difficulties is feasible, at least for ranges of military interest in Western Europe and Asia.[7,8] The American optics community has yet to take notice of the significance of these results.

The properties of beam-atmospheric interaction listed by statistical optics—absorption, scattering, turbulence, and thermal blooming—can, over the range to a target, be compared to a highly differentiated electromagnetic lens that changes its characteristics of action, with time. At the physical dimensions of light rays and of the molecular constituents of the atmosphere, the interaction is not percussive and irreversible, as suggested by Tsipis, but electrohydrodynamic. Turbulence, for example, changes the local electrohydrodynamic properties of the atmospheric, and it is such transformations that change the characteristics of light propagation through it.

To achieve self-induced transparency requires:

1) Selection of wavelengths of laser radiation that do *not* perform work upon the molecular constituents of the atmosphere ("absorption");

2) Compensation for atmospheric turbulence.

Even the statistical opticians acknowledge that absorption effects are of little consequence for certain ranges of wavelengths of laser radiation. Today, the optimal laser wavelengths for both atmospheric transmission and destructive impact on target, are ultraviolet. SDIO agrees, and contrary to the statistical opticians' algebraic conclusion that longer wavelength infrared lasers are optimal, it has been proceeding with development of a ground-based ultraviolet krypton-fluoride laser.

In nature, beam propagation is perfect

There exists a phenomenon *in nature*, known as nonlinear Optical Phase Conjugation, that demonstrates, in principle, that beams of laser light can be pre-formed and directed through the lens of the atmosphere to arrive on target with near-perfect coherence and intensity. R. C. Lind and G. J. Dunning of Hughes Research Laboratories directed a coherent dye laser beam through experimentally produced, intense atmospheric turbulence into a preparation of atomic sodium pumped by counterpropagating beams of the same wavelength.[7] "The laser was tuned near the atomic resonance of the sodium D_2 line (589.0 nm) to maximize the four wave mixing conjugate reflectivity," reported *Laser Focus*. Upon arrival at the atomic sodium conjugator, the beam displayed severe aberrations and phase distortion from its original coherent profile, as a result of the instantaneous refractive properties of the lens of the atmosphere. The conjugator then returned the phase conjugate of the beam back through the precise path along which it had propagated from the transmitter. Along this return path, the aberrated beam reformed into one almost perfectly coherent. The time to conjugate the beam (10 ns) and cover the path twice was far less than the time in which the refractive properties of the atmosphere changed. *Laser Focus* reported:

> These data indicate near-diffraction-limited correction capability. In addition, while the aberrated beam shows severe wander and on-axis intensity nulls, the corrected beam stays locked to a particular spatial position.

According to one source,[9] Hughes holds that the technique will work for beam propagation distances up to at least 50 kilometers in the atmosphere.

Optical Phase Conjugation is a property of a spectrum of "non-linear" materials, from tap water to chlorophyll. One form of OPC employs Brillouin scattering, directing a beam of chosen wavelength into a liquid resonant with that wavelength, which action establishes an acoustic wave in the liquid that back-scatters the conjugate of the incident beam, downshifted in frequency by the frequency of the acoustic wave so established. (**Figure 1** shows a schematic view of how the phase conjugate mirror works.)

The task of adaptive optics

In 1984 the Fusion Energy Foundation proposed one use of Optical Phase Conjugation, for a space laser system.[10] In the proposed system, a low-power laser attached to a mirror in orbit, directs its beam down through the atmosphere to a station where the aberrated beam is conjugated, and amplified to high power. The amplified beam then returns to the space mirror coherent, available for attacking ballistic missiles or high-altitude aircraft, but without the need for a high-power laser amplifier in orbit. This proposal is reportedly now under active development by the SDIO.

Since Optical Phase Conjugation requires two passes through the same atmospheric path, it is not clear how it can play the role of a "component" in a system that must directly attack targets in a single pass through the lower, densest portions of the atmosphere.[11]

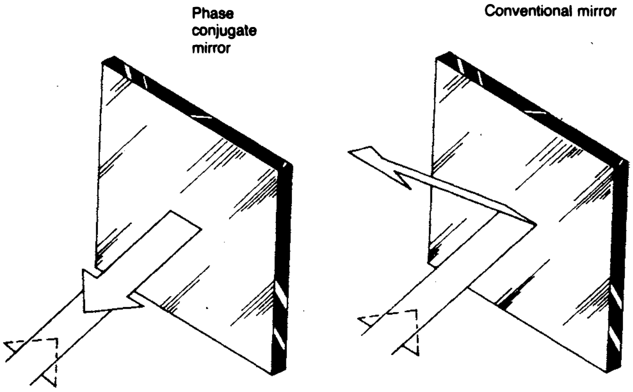
The task of "adaptive optics" is thus to recreate the capabilities of the natural process of Optical Phase Conjugation in engineering hardware that transmits a beam with a single pass through the atmosphere.

Sandia National Laboratory demonstrated such a concept, in regard to particle beams, in 1984. A Sandia team led by David J. Johnson ignored the prescriptions of contemporary electrodynamic theory, and developed a specially shaped anode to emit an ion beam, organized to permit a continuous flow of electrons in its path, to focus the beam on target, rather than introduce astigmatism.[12]

The requirements for a laser system for defense of Europe are more stringent. Here, the system must actively correct not just for a static, non-linear lens action by the intervening atmosphere, but for one that changes in time, during the attack on a target, or spatially, over the course of a target's trajectory. Thus, a principal problem of adaptive optics is to develop practical means of *sensing* the distortions, or action of the atmospheric "lens" upon an outgoing beam, so that the beam may be shaped in such a way that the action of the atmosphere, as in the case of Optical Phase Conjugation, is to *focus* it on target. In other words, an adaptive optical system requires some reference for the action of the atmosphere upon a beam, in order to maximize transparency, one that holds up under battlefield conditions.

FIGURE 1

Conventional vs. phase conjugate mirror



When a conventional mirror (right) reflects a beam, the angle of reflection is the complement of the angle of incidence; a diverging beam continues to diverge after reflection. When a phase conjugate mirror (left) reflects a beam, it sends it back in the same direction it came from, and makes a divergent beam convergent, or focused.

The fallacies of optical theory

In arguing against the feasibility of adaptive optical systems, statistical optics dogma rests much of its argument upon an algebraic construct formulated by David L. Fried in 1965, known as the "atmospheric coherence length" of laser light.[2,5,8] Since this notion directs much of the work on laser propagation in the atmosphere, we discuss it here in some detail.

Fried holds positions of note within the optics community. Since 1968, he has been a member of the U.S. Army Science Board, and, at the same time, associate editor of the *Journal of the Optical Society of America*. An objective assessment of his work is required.

"Atmospheric coherence length" is the distance r_0 perpendicular to the beam path, across which the beam is in phase ("phase correlated," see **Figure 2**). Fried defined r_0 as

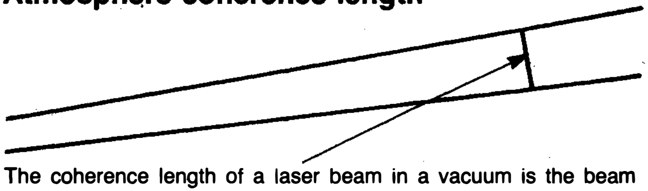
$$1.09\, k^2\, z\, C_n^2/n_0^2)^{-3/5}$$

where k is the optical wave number, z is the range to target, C_n is the "refractive index structure constant," a measure of the degree of turbulence; and n_0 is the index of refraction of the non-turbulent atmosphere.[13]

This formulation states that a beam *must* become increasingly incoherent with distance, or with shorter wavelengths, or with increasing turbulence. It was on the basis of this algebraic construct that the Carter administration emphasized development of the deuterium-fluoride chemical infrared laser. Indeed, in 1981 a spokesman for Itek, Inc., now an SDIO contractor, told *Aviation Week*, "a key parameter in assessing the effect of atmospheric turbulence is 'atmospheric phase coherence length'"[3]. The case of Optical Phase Conjugation demonstrates that this conception is worthless.

FIGURE 2

Atmosphere coherence length



The coherence length of a laser beam in a vacuum is the beam diameter.

First of all, it matters little whether the beam *appears* to be coherent at any point along its path of propagation. What matters is whether the beam is organized, in its propagation, to *arrive* coherent at the target. The work at Hughes Laboratories shows that, practically speaking, we can make the coherence length as long as we wish, as large as the size of the "collecting optics" of the phase conjugator; in other words, potentially infinite![14] Lind and Dunning carried out their experiments with turbulence at the highest end of the spectrum of intensities of turbulence in the atmosphere.

Secondly, Luc R. Bissonnette of the Canadian Defense Research Establishment has shown that the Fried construct underestimates even the *apparent* atmospheric coherence length by a factor of at least 55.

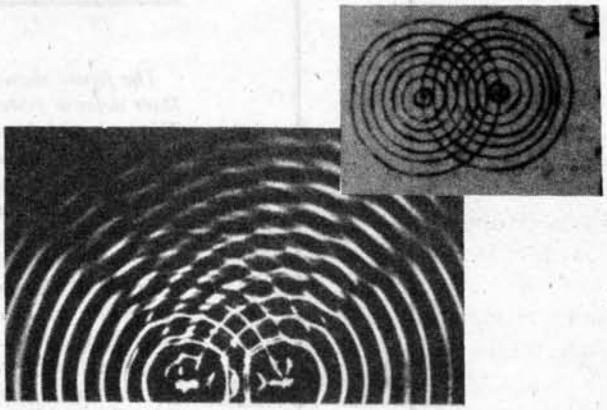
The notion of coherence length is not the only regressive concept dominating optics in the United States and Europe. In addition, the statisticians hold that "an adaptive optics system can only compensate for phase errors that occur at some fraction of the focal plane distance,"[5] i.e., relatively close to the laser transmitter. In other words, turbulence that is farther away from the controlling optics is harder to correct for. The Hughes experiments also refute this claim: in defiance of theory, Optical Phase Conjugation compensated for intense turbulence that occurred along the entire path of the beam.

Leonardo's concept of self-induced transparency

In a now-famous experiment, described by Prof. Enzo Macagno, Leonardo da Vinci placed a flame in front of the mouth of a singer producing a *bel canto* musical tone. The flame remained stable, regardless of the intensity of the voice. Yet the same *bel canto* voice, is capable of inducing resonance in a crystal glass some meters away, so that it shatters. The singer projects waves through the air that "act at a distance," without the transport of matter that would have disturbed the flame. The voice neither disturbs the air, nor is dissipated by it. The *bel canto* song induces "transparency" in the medium of the air, for its own propagation. The complete brilliance of the tone can be heard in the farthest reaches of the opera house, even softly.

In another example of wave action that acts at a distance, Leonardo cited simple sinusoidal water waves:

> If you cast two little stones . . . in water, you will see two separate quantities of circles . . . which growing, come to encounter, one circle intersecting the other, always maintaining for centers the places struck by the stones [see figure]. The reason is that although there is some evidence of movement, the water does not leave its location, because *the opening made in it by the stones closes up again at once* and this motion made by the sudden opening and closing produces a certain shaking, which can be called trembling rather than motion. And to make what I say plainer, take heed of those straws which by their lightness stand on the water; notwithstanding the wave made under them by the coming of the circles, they do not leave their first locations. . . . (Institut de France Ms. A 61r)

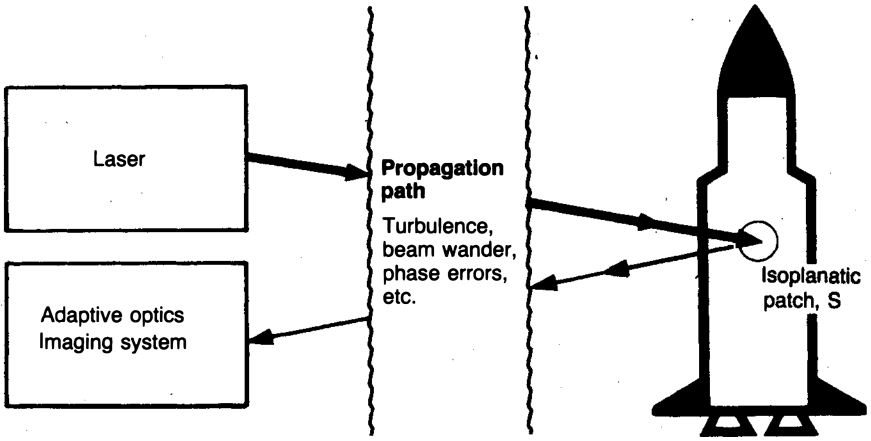


Leonardo's pioneering work on optics is well known. He was the first to understand that the scintillation, or "twinkling" of the stars, was not a property of the stars themselves, but the result of turbulence in the atmosphere. Furthermore, he understood that blue light was the best visible wavelength for self-induced transparency in the atmosphere. This fact, which is obvious to anyone who looks at the blue sky on a clear day, seems to have escaped optical theorists of recent days, who pay little heed to nature. Leonardo hypothesized that the sky is blue because of the absorption of other visible wavelengths by the atmosphere, and reemission and scattering of blue light, by which model the radiation of the sun pumps energy into the atmosphere to produce blue:

> I say that the blueness we see in the atmosphere is not intrinsic color, but is caused by warm vapor evaporated in minute and insensible atoms on which the solar rays fall, rendering them luminous against the infinite darkness of the fiery sphere which lies beyond. . . . (Leicester, Ms. 4a)

FIGURE 3

Statistical optics holds that it is impossible to image, track and destroy a realistic military target through intense atmospheric turbulence.



The figure shows the adaptive optics problem, as seen by contemporary optics, for a laser defense system attacking a target without a definite area of reflection, or "glint." The laser at left emits a beam which is distorted in its propagation to the target at right. The adaptive optics system receives the reflection of the beam from the target, through a "pinhole" at the imaging system below left, and based on the intensity of the point reflection, adjusts the profile of the outgoing beam, to maximize self-induced transparency through the atmosphere, and lethal energy delivered to the target.

However, according to the opticians, there is no lawful relationship between the intensity of a point reflection and the intensity of the beam at the target, over militarily significant distances, because of random wander of the light, in its course back to the imaging system; as a result, they argue, such adaptive optics systems are not feasible. In general, they state that the maximum area of coherence S of the beam on the target, is considerably less than the minimum area of "random" beam wander; therefore, the reflection from the target could come from anywhere on it, not the chosen focal spot.

In addition, statistical optics holds that, practically speaking, it is impossible to image real, military targets through atmospheric turbulence. It asserts that imaging targets wider than half the atmospheric coherence length, is impossible. According to this theory, light from a point source wanders "randomly" by refraction through the atmosphere,[15] and under intense turbulence the amplitude of this wander is at least greater than $\frac{1}{2} r_0$ (see **Figure 3**). As Pearson et al. write:

> Fried has shown that when two source elements are separated by more than one-half the atmospheric coherence length, they fall outside the isoplanatic patch; that is, they produce phase distortions at the receiver aperture that are essentially uncorrelated at any one instant. A consequence of this fact, is that if one attempts operations with information extracted from both points simultaneously, one obtains a composite phase measure that is incorrect for compensating the path to either of these points or to any other point for that matter. . . .
>
> At all wavelengths, the isoplanatic patch diameter, which we define as $r_0/2$, will almost never be as large as 1 meter (with 4 km paths) . . . referencing [imaging] on truly extended targets (greater than 1 meter) is not allowed by isoplanatic problems.

As an example, for normal (i.e., non-battlefield) atmospheric conditions near the ground, over a range of 4 km, this source estimates that ultraviolet laser light will wander within a cross-sectional area seven times the area of the isoplanatic patch of coherency of the beam. In other words, the beam will never be coherent.

Empirical refutation of these concepts for an adaptive optics system was demonstrated at about the same time as the work at Hughes, by Luc R. Bissonnette of the Canadian Defense Research Establishment. His experiments show that Fried's theory underestimates the size of the isoplanatic patch, the cross-sectional area of coherency of laser light propagating through the atmosphere, by approximately a factor of 2,000, and that the atmospheric coherence length itself is at least over an order of magnitude greater than predicted by Fried's theory. Bissonnette argues that Fried's definition of coherence length is an artificial construct that may hold in certain laboratory set-ups, but does not hold for nature. Light propagation through the atmosphere is always non-linear. In the course of this work, Bissonnette demonstrated the value, as a military system, of one proposed design for an adaptive optical system, known as the Multidither Outgoing Wave (MDOW) system. In order to fully appreciate the controversy evolving out of Bissonnette's work, and its relevance to the development of laser weapons for the defense of Europe, it is necessary to briefly describe this system.

A system that can defend Europe?

An MDOW system consists of a laser, a deformable mirror for pre-shaping the beam, and a sensor. The system senses the intensity of a reflection off a target to determine the transformations required in the outgoing, attacking beam to maximize transparency through the atmosphere, and hence the energy-flux density delivered to the target. But existing optical dogma insists that such a system cannot image a target through the atmosphere, without its having a clearly defined area that produces a "glint" reflection of the outgoing, attacking laser beam. According to theory, if there is no glint, there will be no correlation between the intensity of the beam on target and the intensity measured by the sensor, so that the latter will give no indication of how the beam must be shaped for the atmosphere to focus it, or, according to jargon, for the system to "converge" to maximize beam intensity on target. As Pearson et al. write:

> Multidither systems that have been studied to date require a target highlight or bright feature (a localized region that has a higher reflectivity than surrounding regions—a "glint") for proper operation. . . . Since glint structures are known to evolve, replicate, shift and/or disappear as the target changes aspect angle, the beam may not be stable on a dynamic target [e.g., an artillery shell—RLG], and with featureless targets, standard outgoing wave multidither systems cannot converge.

Obviously, such a theory has a dubious military value. We cannot expect the Warsaw Pact to deploy missiles and artillery shells which maximize glint for us, upon which we can focus the impact of Western lasers. Bissonnette wrote in *Applied Optics*:

> There can be many practical instances where the target is featureless and the turbulence-spread beam spot is resolved by the transmitter aperture. This is likely to happen at short to medium ranges, where the MDOW adaptive systems are most advantageous and most suitable for applications.

Bissonnette carried out experiments to test Fried's theory of light propagation in the atmosphere as follows. To image a realistic, "featureless" military target, a target without a glint, Bissonnette measured the intensity of the light reflected off the target through a pinhole aperture, rather than collecting a broad reflection of light, in order to construct a reference whose intensity would correspond to the actual intensity of the outgoing beam at the target. Adjustments in the deformable mirror of his system, to maximize the intensity of light through this aperture, should maximize the intensity of the attacking beam on target.

However, according to Fried's theories of coherence and isoplanaticism, the intensity of light measured through such a pinhole would have an arbitrary relationship to the actual intensity of the beam on target, because of the wander of the light through the atmosphere. Theory requires, that for a system to function, the area of wander must be less than the area of the isoplanatic patch. For two experiments of Bissonnette, theory predicted the values shown in **Figure 4** for coherence length r_0, area of isoplanatic patch S, and area of beam wander, L.[16] According to these theoretical values, there should be no correlation between the light through the pinhole aperture and the beam intensity at the target. However, Bissonnette demonstrated that in both cases, a positive correlation existed, in Experiment 1 with a maximum correlation (i.e., greater than 0.5) of 1.0 and a minimum correlation of 0.65, in Experiment 2 with a maximum of 0.85 and a minimum of 0.6. Figure 4 also shows the recalculated

FIGURE 4

Two experiments in light propagation through turbulence which refuted theoretical predictions of statistical optics

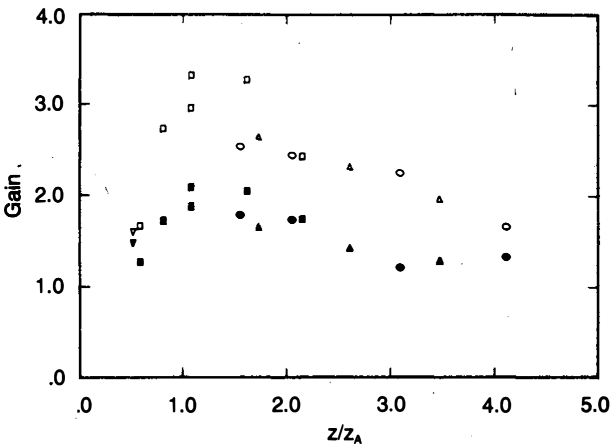
	Experiment 1	Experiment 2
Theoretical values[1]		
Coherence length, r_0	0.144 mm	0.101 mm
Isoplanatic patch, S	0.0651 mm²	0.0321 mm²
Area of beam wander, L	9.24 mm²	61.4 mm²
Ratio L to S	142	1913
Experimental values		
Coherence length, r_e	1.715 mm	4.421 mm
Ratio, experimental to theoretical, r_e/r_0	12	44

[1] Bissonnette, personal communication

The figure shows the complete refutation of statistical optics theories of light propagation through the atmosphere, by two experiments carried out by Canadian scientist Luc Bissonnette. His work demonstrated that the "coherence length" of laser light—the distance perpendicular to the beam, across which it is coherent—is at least 10 to 50 times greater than predicted by the statistical opticians.

Experiment refutes statistical optics theory

FIGURE 5



The figure shows how the gain of an adaptive optics system—the relative increase in laser energy flux density delivered to a target as a result of its adaptation of a beam for atmospheric propagation—varies over the range to a target, and for different conditions of the medium, for:

1) standard outgoing wave adaptive optics systems relying on a glint from the target for information on atmospheric conditions (data shown with open symbols), and

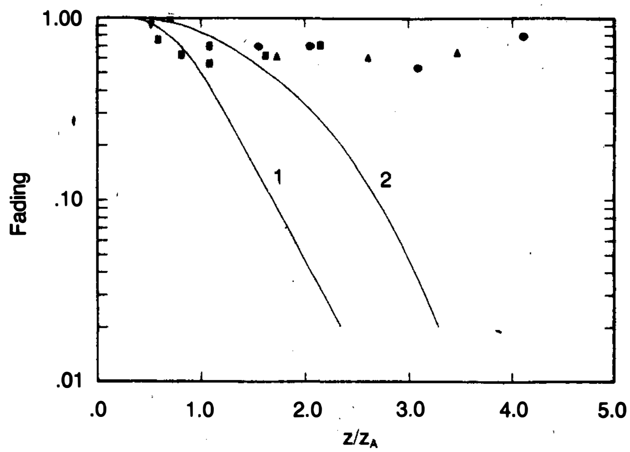
2) a "pinhole" imaging system (solid symbols) tested by Luc Bissonnette.

According to theory, Bissonnette's system should produce no gain. However, experiment showed that his system achieved a gain over 2.0, and continued to exhibit gain at a range four times the amplitude fading distance.

Range to the target is shown in the figure in units of "amplitude fading distance," z_A, the distance over which the intensity of a beam is thought by the theoreticians, to be reduced to 37% of its value.

Source: L. R. Bissonnette, "Outgoing-wave adaptive optics systems: Error sensing method in the case of extended targets in turbulence," Proceedings, Society of Photo-optical Instrumentation Engineers, Vol. 365 (1982), p. 39.

FIGURE 6



The figure shows that two statistical theories of beam propagation predicts dramatic "gain fading," a sharp falloff in gain, or increase in beam intensity on target supplied by an adaptive optics system, with increased range, for a "pinhole"-imaging adaptive-optics system (see curves labeled "1" and "2"). Experimental data (solid symbols) has shown that gain fading is relatively insignificant.

Range shown in units of the amplitude fading distance. (see Figure 4 caption).

Source: L. R. Bissonnette, "Outgoing-wave adaptive optics systems: Error sensing method in the case of extended targets in turbulence," Proceedings, Society of Photo-optical Instrumentation Engineers, Vol. 365 (1982), p. 39.

value of the coherence length on the basis of these results and compares it with that derived from optical theory. It shows that the coherence length found in the experiments is at least 44 times greater than that predicted by theory.

Bissonnette cast these results in terms of maximum effective ranges for imaging targets with his modified MDOW laser system, with reference to the opticians' notion of "amplitude fading distance" z_A, the distance from a source at which the (coherent) amplitude of a beam is 1/e (37%) of its original amplitude. According to theory, the maximum range for imaging for Bissonnette's experimental system would be 0.7 z_A, and that scintillation of a reflection should saturate at $z/z_A = 2$. Bissonnette's system reached its *peak performance* at a range of about 1.6 z_A, or more than twice the theoretical limit. He demonstrated effective ranges of up to 4.1 z_A, the distance at which the beam amplitude—according to theory—would be reduced to $1/e^{4.1}$ (less than 1.8%) of its original amplitude.

He then compared the performance of his pinhole aperture system with an MDOW system supplied with a glint. Again, contrary to theory, which states that a glint is necessary for successful operation of a multidither system, the profile of maximum intensity of the beam on target as a function of distance (measured in terms of the gain of the closed loop system) had the same shape for both systems; the amount of gain was simply lower in the case of the pinhole imaging technique. (See **Figure 5,** reproduced from one of Bissonnette's papers.[17]) Put bluntly, he showed that from the standpoint of experimental results, the theory is "off the wall." **Figure 6,** also from one of Bissonnette's papers,[18] shows this most clearly in a graph of gain fading with distance, in units of the amplitude fading distance. The triangles, squares, and circles are experimental data points from Bissonnette's system; the two continuous curves are theoretical ones based on that of Fried (labeled "1") and another statistician ("2"). (Gain fading measures how the gain in intensity on target, supplied by an optics system, may decline with increasing range to the target.)

Pearson et al. argue that the maximum range of an MDOW system is 1.6 kilometers.[2]. Bissonnette has shown that they underestimate the maximum effective range by at least a factor of 6, resulting in a range of at least 10 kilometers. This is the difference between a system that is militarily significant and one that is not. The Bissonnette system appears able to attack targets that rise over the horizon (only 15 km away) at ballistic velocities. Based on the physical principles discussed above, it appears certain that further extension of the feasible ranges will be demonstrated.

This writer offered some of the optical authorities whose theories are refuted by Bissonnette, a chance to publish comment on his work together with this report. All of them refused to do so. Not one disputed Bissonnette's results. Their only comments were as follows:

"I don't think the atmosphere is non-linear at these power levels" (milliwatts).

"I always have a problem with someone who argues in simple physical terms."

"The scientific issues in propagation through atmospheric turbulence are already solved."

And finally:

"This work is trash."

Notes

1. "European Air Defense Initiative: a crash program for beam defense," *EIR*, Vol. 12, No. 20, May 21, 1985, pp. 46-53.
2. F. G. Gebhardt, "High Power Laser Propagation," *Applied Optics*, June 1976, Vol. 15, No. 6, p. 1,479.
3. Itek, Corp. representative quoted in *Aviation Week*, Aug. 24, 1981, p. 62.
4. The notion that there exists a "power density" barrier in laser propagation through the atmosphere, is similar to the now-refuted belief that there existed a "sound barrier" to aircraft as they approached the speed of sound. As Uwe Parpart-Henke has documented, appropriate shaping of supersonic aircraft induces transparency, for their movement through the atmosphere beyond the speed of sound, and even pushes the alleged "barrier," the speed at which drag increases, from seven-tenths of the speed of sound to beyond Mach 2, as well as reduces the maximum amount of drag. See *Open the Age of Reason*: Proceedings of the Krafft Ehricke Memorial Conference, June 15-16, 1985.
5. James E. Pearson, R. H. Freeman, and H. C. Reynolds, "Adaptive Optical Techniques for Wave Front Correction," in *Applied Optics & Optical Engineering*, Vol. 7. R. Shannon and J. Wyant, eds., Academic Press, New York, 1979.
6. K. Tsipis, "Laser Weapons," *Scientific American*, December 1981.
7. "Real-time Compensation of Atmospheric Turbulence by Nonlinear Phase Conjugation Demonstrated," *Laser Focus*, September 1983.
8. L. R. Bissonnette, "Adaptive Optical System Referencing in the case of resolved targets illuminated through turbulence," *Applied Optics*, Vol. 21, No. 22, Nov. 15, 1982, p. 3998. Also, "Outgoing-wave adaptive optics systems: Error sensing method in the case of extended targets in turbulence," *Proceedings*, Society of Photo-optical Instrumentation Engineers, Vol. 365 (1982).
9. "Adaptive Optics," *Science Digest*, May 1984.
10. "At the Forefront of Laser Technology: Optical Phase Conjugation," *EIR*, Vol. 11, No. 24, June 19, 1984, pp. 12-14.
11. One possibility might be to irradiate a target and then conjugate and amplify a coherent reflection. However, it is questionable whether the power levels of such a reflection off an arbitrary target would be large enough, and whether it would be possible to isolate that portion of the reflected beam that was coherent at the target.
12. D. J. Johnson et al., "Electron and ion kinetics and anode plasma formation in two applied B field ion diodes," *J. Appl. Phys.*, **57**(3), 1 Feb. 1985; and "Time-resolved proton focus of a high-power ion diode," *J. Appl. Phys.*, **58**(1), 1 July 1985.
13. Or in the language of Pearson et al., "the atmospheric coherence length [is] the distance perpendicular to the beam path over which [refractive] index fluctuations are phase correlated."
14.

Hughes experiment, statistical optics estimates r_0 at less than 1 cm! *See* Reference 2.

15. J. Strohbehn (ed.), *Laser Propagation Through the Atmosphere*. New York: Springer-Verlag, 1978. "The phase fluctuations arise directly from the fact that the refractive index is a random function of space and time, which from the simple relation v = c/n [where c is the velocity of light and n is the refractive index of the atmosphere] produces a random velocity in the propagating wave."
16. Bissonnette, personal communication.
17. Figure 8, paper in SPIE proceedings, cited above.
18. Figure 9, paper in SPIE proceedings, cited above.