Alpha: the first space-based defense

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Just before Christmas, the Strategic Defense Initiative Organization (SDIO) initiated secret tests of its prototype Alpha chemical laser weapon designed for space-based missile defense at the Capistrano, California TRW laser test range. The tests are being conducted in a simulated space environment carried out under the direction of the New Mexico-based Air Force Weapons Laboratory and are scheduled to be completed by the spring of 1988. Published reports indicate that this multi-megawatt laser system could be flight tested in space by 1990 as part of the Martin Marietta Zenith Star project, which includes the 4-meter-diameter LAMP (Large Advanced Mirror Program)—an adaptive optics, segmented mirror developed by the ITEK Corporation.

What is generally not known, though, is that while a single Alpha laser module would not be capable of intercepting ballistic missiles, continuing technological breakthroughs with multi-element phased array mirrors, phase conjugation firing and coupling systems, and, techniques for distributed phased array coupling of laser modules already promises to provide the means of transforming the firepower of a couple of dozen space-based Alpha laser modules to a level sufficient to destroy thousands of ballistic missiles launched from any geographical location within a few minutes. Such a system could conceivably be deployed within a couple of years, given a crash program to do so.

Even in its first stages of deployment—a handful of lasers in orbit—the system could be utilized to actively discriminate and target warheads in space and thereby immensely improve the capabilities and effectiveness of even the most primitive types of ABM rocket interceptors.

The MIRACL chemical laser

In the mid-1970s, scientists scored major breakthroughs in developing efficient, high-power chemical lasers. In particular, high-power and efficient hydrogen fluoride laser modules were demonstrated. Because of its inherent characteristics the hydrogen fluoride (HF) chemical laser offered the potential of a compact, reliable, and versatile system with many possible military applications. In the late 1970s, the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense initiated a combined program to realize a space-based prototype HF laser and large mirror. The original objective was to develop a system which was publicly presented as a potential anti-satellite interceptor and/or disrupter, but which had a classified mission capability of aiding in the discrimination and targeting of ballistic missile warheads.

The HF laser's operation is essentially quite simple. Hydrogen and fluorine gases are mixed in a high pressure chamber. An electron beam, or other means, is used to spark these highly reactive gases. The resulting hydrogen fluoride molecules are "born" in an excited vibrational state. And this is the essential precondition for laser action at a primary wavelength of 2.7 microns, the wavelength which correlates with HF molecular vibration. The primary energy for running the HF, therefore, comes from the HF chemical reaction itself.

Because these gases can be stored at high pressures, the entire system—and, most significantly, the primary energy source—can be quite compact. The lasing action is quite efficient, so that the potential energy of these easily and compactly stored gases can be readily converted into powerful beams of 2.7 micron light. (Actually, 2.7 microns is in the infrared radiation range. Optical wavelengths, which we can see, have five times shorter wavelengths. The excimer krypton fluoride laser has a wavelength 10 times smaller at about 0.27 microns.)

With the initiation of the Strategic Defense Initiative (SDI) on March 23, 1983, the DARPA chemical laser and LAMP mirror programs were taken over by the SDIO. And on Sept. 6, 1985, the Mid-Infrared Advanced Chemical Laser (MIRACL) successfully destroyed the second stage of a Titan I booster in tests conducted at the High Energy Laser System Test Facility at the White Sands Missile Range in New Mexico.

Actually, by this time the HF laser and LAMP projects had secretly been transformed into a directed energy weapon demonstration project, codenamed Zenith Star. The basic concept was to develop and deploy a space-based laser demonstration capable of being immediately scaled to a power level capable of intercepting a few ballistic missiles. Such a demonstration project had been called for by the Fusion Energy Foundation's director of research, Dr. Uwe Henke v. Parpart, on NBC's "Today" show a few days following President Reagan's March 23 speech.

Long versus short wavelength lasers

In space, a laser's firepower is primarily determined by its brightness—its ability to deliver a certain level of power density on target. At a given range, this power density can be measured as the number of watts of light hitting a square meter of the target. In general, existing missiles will be destroyed during their boost phase if a laser beam with a power density of several million watts per square meter irradiates it for more than a second. If the laser beam had a power density 10 times greater, it would destroy the missile booster 10 times faster—within one-tenth of second. In other words, the firepower of the laser—the number of boosters it can kill per minute—is directly proportional to its brightness. (Thin-skinned missile boosters are much softer targets than the warhead re-entry vehicle, which has a thick shield for surviving re-entry into the Earth's atmosphere at high velocities. In general, today's RVs, or warhead and re-entry vehicles, take upward of 100 times more energy density to destroy than boosters. That is, several hundred million watts per square meter delivered over a timespan of one second.)

The firepower of a laser falls off with the square of the distance over which it is fired. That is, the firepower of a laser will decrease hundredfold, if the range over which it shoots is increased from 100 to 1,000 kilometers. A tenfold increase in the range leads to a hundredfold decrease in firepower.

Two other factors generally determine the firepower of lasers: wavelength and diameter of the focusing mirror. All four factors—the total laser power output, the target range, the laser wavelength, and the mirror diameter—can be combined to give a rough determination of the laser's firepower:

$$F = (PDD)/(WWRR)$$

where F is the firepower in watts per square meter, P is the laser power output in watts, D is the mirror diameter in meters, W is the laser wavelength in meters, and R is the distance to the target in meters. As an example, a million-watt output, 2.7 micron (1 micron is one millionth of a meter) HF laser operating with a 4 meter diameter mirror would be able to intercept one missile booster per second at a range of 1,000 kilometers—a million meters:

$$F = \frac{1{,}000{,}000 \times 4 \times 4}{.0000027 \times .0000027 \times 1{,}000{,}000 \times 1{,}000{,}000}$$
$$= 2{,}100{,}000 \text{ watts per square meter}$$

on target. At a range of 10,000 kilometers, the firepower would drop to one missile every 100 seconds. With an 8 meter mirror, the firepower would increase to 4 missiles per second at the 1,000 kilometer range.

It can immediately be seen, that shorter wavelength lasers have a significant firepower advantage over longer wavelength lasers. Keeping everything the same in the first example, a 0.27 micron krypton fluoride (KrF) excimer laser would have 100 times the firepower of the HF chemical laser—a million-watt KrF, 4 meter mirror at a 1,000 kilometer range could kill 100 missile boosters per second.

There are qualitative advantages to shorter wavelength, too. The shorter wavelength lasers generally operate in a pulsed, high-power mode. This, combined with the more efficient coupling of laser light to a target at shorter wavelengths, leads more readily to the more efficient type of shock kill. That is, instead of burning a hole through the missile skin, as is the case with continuous chemical lasers, the shorter wavelength and pulsed KrF could generate a shockwave which would punch a hole through the missile. Furthermore, the shorter shock-action kill and more efficient coupling of the short-wavelength laser is almost impossible to defend against, while in the case of the longer acting, "thermal killing" chemical laser, the missile can be coated with heat-absorbing materials and rotated to disperse the laser's heat over a greater area.

Taking these factors into consideration, it would appear that comparable-power, shorter-wavelength lasers have a firepower potential thousands of times greater than that of long-wavelength chemical lasers.

Target discrimination and location

Despite these apparent, relative drawbacks, the chemical laser program was maintained. While not publicly disclosed, the most likely initial reason for doing so, besides the mature status of HF technology, was the fact that the HF has the ideal wavelength for aiding other types of missile defense in terms of target discrimination and location. Throughout the 1970s and 1980s, advances in microelectronics have revolutionized infrared radiation detection technology—what had previously been termed "heat detectors." Actually, the older, crude "heat detectors" bare little resemblance to the modern microelectronic infrared detector.

By the late 1970s, infrared detection technology had advanced to the point that, under certain circumstances, long wavelength infrared telescopes were capable of distinguishing the signature of a real warhead and a decoy over thousands of miles of space. This was a key step toward reviving "technical" interest in missile defense by the United States.

DARPA had recognized that these infrared detection systems could be vastly improved in performance, in virtually any conceivable circumstance, if the warheads and decoys were illuminated with an infrared laser. And this was one of the major, though secret reasons for originally pursuing the space-based chemical laser concept. The chief point being, that once the real warheads had been distinguished from decoys, a wide variety of systems could be utilized to intercept and destroy the real warheads during the relatively long, 20 minute period that they take to complete their flight through space.

Given sufficiently powerful laser beams, the decoys could even be destroyed or pushed away from the warheads.

Because of these potential applications, the SDIO retained and accelerated the DARPA space-based chemical laser programs. Later on, it was determined to further enhance the program as "demonstration" of directed energy weapon technology. The general goal being to deploy a single prototype within five years. But with the Space Shuttle Chal-

Phase conjugation

Prior to the realization of the laser in 1961, it was generally believed that the science of optics was a closed book. But with the advent of high-power, coherent light sources—that is, lasers—nonlinear optics rapidly emerged as one, if not the leading, frontier of physical science. Today, scientists at Bell Labs are perfecting "soliton" optical transmission techniques, which utilize nonlinear optical interactions to prevent the dissipation of light pulses as they travel through optical fibers, and which could thereby increase optical data transmission over existing lines by many orders of magnitude with no increase in cost.

Theoretically, these same solitons are now being utilized to understand such diverse phenomena as high-temperature superconductors and anti-matter interactions. Phase conjugation is among the most advanced applications of nonlinear optics.

With phase conjugation one can, in effect, reverse time. Imagine an ocean wave as it approaches the shore. The wave can be quite uniform while trasversing the ocean depths, but as it approaches shore, it will form into a breaker and then a plethora of turbulent eddies. What happens to a coherent laser beam when it strikes an optically irregular surface can be thought of in the same way. Phase conjugation permits this turbulent "breaking-up" to be reversed in time and the original wave to be reconstructed out of the turbulent eddies.

In the case of phase-conjugated mirrors this means that any bit of incoming light can be reflected directly back to its source.

Phase conjugation, therefore, makes aiming lasers quite easy. For example, scientists have developed what is called four-wave-mixing phase conjugation systems for aiming lasers. All that's required is that the target be illuminated with a low-power laser beam. This indicator beam can come from any direction, but it will reflect in all directions. A tiny bit of it will therefore bounce toward the phase conjugation system. Left to itself, this reflected light will hit the phase-conjugated mirror and bounce right back toward the target. But if a laser-amplifier is placed between the target and the phase-conjugated mirror, the reflected beam will initiate a large laser pulse toward the target. (It should be noted that since the incoming, low-power beam reflected off the target can be filtered to allow only reflection signatures appropriate to an actual warhead to pass through to the phase-conjugated mirror, the system can act not only as an automatic targeting and fire control mechanism, it can simultaneously act as an automatic decoy discriminator.)

This has immense implications for anti-missile laser weapons. The phase-conjugated mirror and amplifier can fire and aim a defensive laser beam at a speeding missile, maintaining the focus on target despite pockets of turbulence in the atmosphere or irregularities in the trajectory of the missile. (This is due to the fact that relative to the speed of light, the rocket is effectively stationary.) Such procedures are already routinely utilized in laser pellet fusion research.

There are two basic types of phase conjugation systems: 1) The triggering light pulse is at a wavelength unrelated to the laser light pulse that will be generated; 2) The wavelengths are the same.

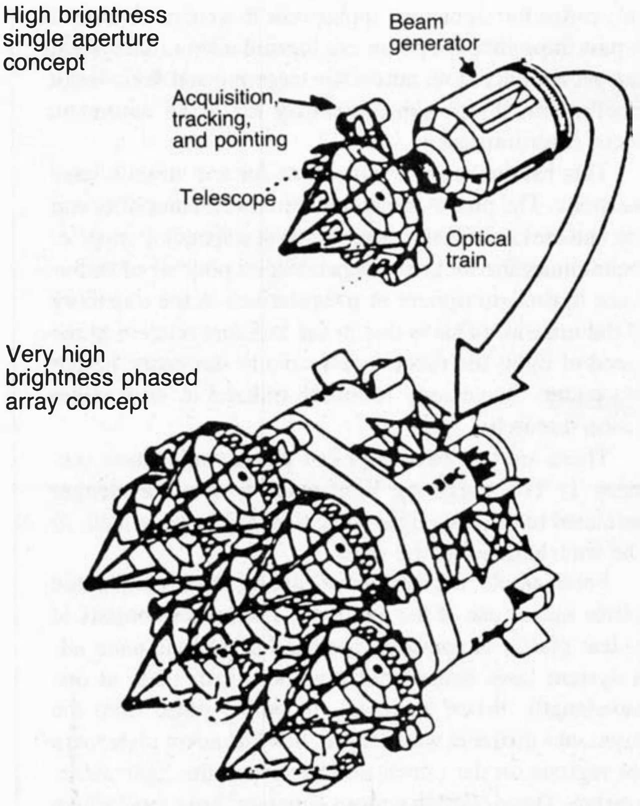
For example, the four-wave-mixing phase-conjugated mirror makes use of the first type. The mirror consists of a clear plastic or specially prepared crystalline material. A system laser beam irradiates the mirror plate at one wavelength. When a second, incoming pulse from the target, at a different wavelength, hits the mirror plate there are regions on the mirror surface where the light waves overlap. These overlap regions generate "hot spots" which change the reflecting properties of the mirror surface so that the incoming target pulse is reflected back toward the target. It is the hot spots, and not any property of the mirror plate itself, which are responsible for this phase conjugation action.

The second type of phase conjugation system can either reflect or pass through the incoming beam. It makes use of a volume of liquid or gas confined in a chamber. As the incoming light pulse passes through the chamber, it nonlinearly transforms the optical properties of the medium. The specific nonlinear effects are called stimulated Brillouin and Raman scattering and usually involve changes in the index of refraction of the medium. These nonlinear changes in the index of refraction throughout the chamber volume can be tailored to match the optical imperfections of the incoming beam. The incoming beam is either reflected or passed through the chamber, but emerges as a perfect optical pulse or as a pulse with characteristics needed to match the measured optical properties of a mirror or for passage through turbulent air.

The second type of phase conjugation can not only be utilized to "clean up" or tailor the outgoing laser pulse, it can also be utilized to compress the pulse so that its power density can be increased many-fold.

FIGURE 1

The space-based laser concept



Source: SDIO

lenger disaster and congressional budget cuts, this target date has been set back by at least two years, to 1990.

Technical breakthroughs transform Alpha

Following four years of coordinated SDI research, major technological breakthroughs have completely revolutionized the potential firepower of space-based chemical lasers.

The primary development in this regard was realized by TRW. TRW carried out major scoping studies on the possibilities of constructing phased array mirrors, which could be made out of relatively small modular components. The basic idea is that a large number of small mirrors could be ganged together to act as one large mirror. The small mirrors could be mass-produced on Earth and more easily transported into space. This would make the system extremely economical. The chief problem with the concept was to design the technology for putting these mirrors together in perfect alignment so that they can act like a single optical surface.

Given the fact that the firepower of a laser beam, that is, its "brightness," is directly proportional to the square of the diameter of the mirror utilized to direct it onto a target, removing the limit on the size of practical optics, deployable in space, TRW had radically transformed the potential firepower of the chemical laser. TRW reported that this single development virtually took the lid off the potential brightness of chemical laser systems.

This Martin Marietta artist's concept depicts a space-based laser demonstration called Zenith Star, that would be conducted as part of the Strategic Defense Initiative program.

A key advance in making this possible was the technology of computer-aided adaptive optics and phase conjugation. Adaptive optics permits the shaping of the mirror surface, usually through the intentional introduction of slight distortions in the mirror surface through mechanical means, in order to match imperfections in the laser beam. Phase conjugation permits the same procedure to be applied to the laser beam. That is, the laser beam, itself, can be transformed through phase conjugation techniques to either become optically perfect, or, as is more generally the case, to have imperfections which match up with the predetermined imperfections of an optical mirror. The imperfections of both can then be designed to cancel each other out and an optically perfect laser beam results. (See box: "Phase Conjugation.")

SDIO reports

While the integrated potentials of these developments have been kept top secret, system elements have been openly reported on in SDIO public reports. For example, **Figure 1** "The space-based laser concept," and **Figure 2,** "The ground-based laser concept," are taken from an April 1987 SDIO report to Congress.

The report states:

"The space-based laser [SBL] concept (depicted in Figure 1) envisions self-contained laser battle stations. These battle stations are seen as modular assemblies of laser devices and optical phased arrays that can increase their performance by adding additional modules as the threat grows. The stations would be deployed in orbits to ensure that the required number of weapons can be available to counter ballistic missile launches wherever they occur. Once deployed, such stations could engage ballistic missiles launched from anywhere on the Earth, including sea-launched ballistic missiles and intermediate-range ballistic missiles. The SBL constellation could play other very significant roles. They could destroy post-boost vehicles before all re-entry vehicles are deployed, destroy or identify decoys or penetration aids in the midcourse phase, and defend U.S. satellites. Furthermore, since the beam of some types of space-based lasers could penetrate the atmosphere down to the cloud tops, SBL weapons may be able to provide some capability against aircraft and cruise missiles, and tactical ballistic missiles.

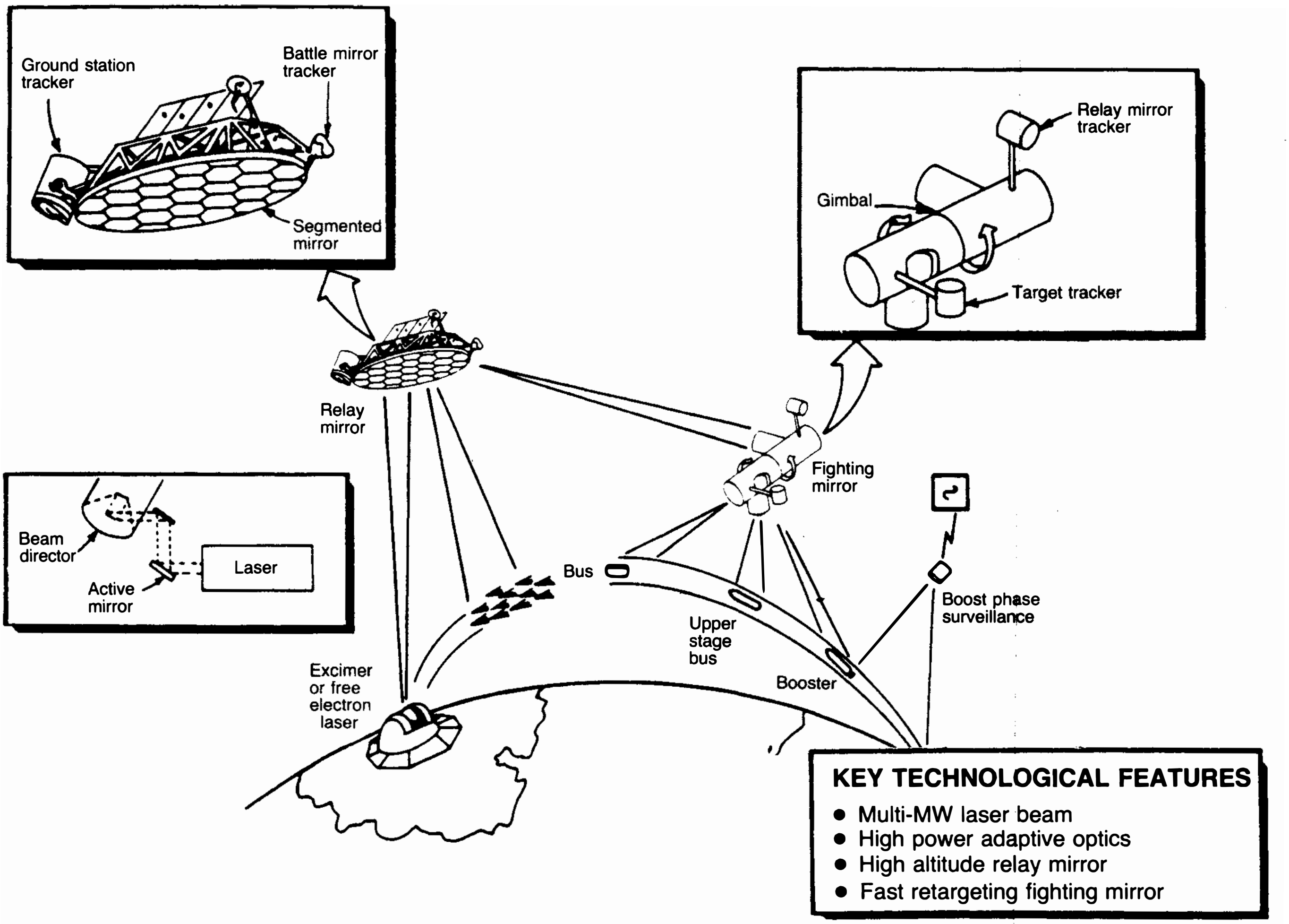
"The primary candidate for the space-based laser concept uses chemical lasers fueled with hydrogen fluoride. Such lasers operate in the infrared at 2.7 micrometer wavelengths. This concept has been under development since the late 1970s. As the first DEW concept identified for ballistic missile defense, it is the most mature. The efforts are well into hardware fabrication for engineering proof-of-principle demonstrations in ground-based tests."

In a "Technical Progress Report," made public, also in April 1987, under the section called "Coupled lasers" it is revealed:

> Brightness levels for BMD [Ballistic Missile Defense] missions may require the mutual coherence, or phasing, of several lasers. The first experimental demonstration of mutually coherent operation of six single-line carbon dioxide lasers, and the first experimental demonstration of mutually coherent operation of two multiline deuterium fluoride chemical lasers recently occurred. . . . An alternative way to preserve high-power laser beam quality as it propagates through the atmosphere makes use of nonlinear optical phenomena such as stimulated Brillouin and Raman scattering. Such approaches may reduce complexity yet improve performance. The research facility for studying such phenomena at significant power levels has been completed at the Capistrano test facility.

FIGURE 2

The ground-based laser concept



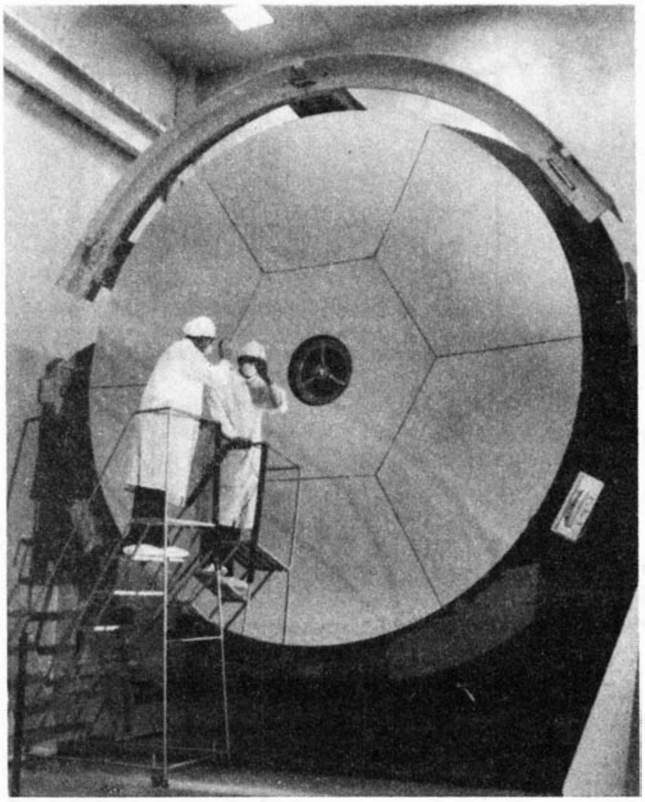
Source: SDIO

Potential architectures

These continuing breakthroughs with optical phased array and phase conjugation systems have not only revolutionized the potential firepower of individual chemical laser systems, but have also completely transformed the possibilities for configuring them into full-scale missile defense. (Also, as noted in the SDIO report to Congress, the system could be utilized for defense against aircraft and low-flying cruise missiles. At the very least the space-based lasers could readily detect these other weapon platforms and pass the information along to other interdiction forces.)

A wide variety of potential defense system architectures are made possible through the integrated effects of these breakthroughs. And they are not mutually exclusive. In fact, the large number of potential combinations possible, make it extremely difficult for an aggressor to locate the weakest point in the overall defense system. A few examples will elucidate this dilemma for the aggressor.

Prior to the TRW breakthroughs with phased array mirrors and developments with phase conjugation and coupled lasers, it was believed that individual laser battle stations would have to engage missiles over enemy territory during the three- to five-minute boost phase. In order to ensure a sufficient number of laser battle stations are in place over enemy territory during the time when the offensive missiles are being launched, a much larger number would have to be maintained in orbit. Thus, a signficant number of orbiting lasers would not be usable during any given attack. Furthermore, the aggressor could arrange to attack and destroy the few laser battle stations which were most threatening to his missile launch.



The LAMP mirror is an adaptive, segmented mirror currently in final stages of acceptance testing by ITEK Corporation of Lexington, Massachusetts. Here a technician checks the mirror surface after the seventh and final segment is in place on the supporting backplate. The extremely precise figure (shape) and alignment of the mirror's lightweight facesheets are controlled by actuators attached to the rear surfaces. The overall diameter of the fully assembled mirror is four meters.

But with high-flying, large-relay mirrors, like that shown in **Figure 2,** it becomes possible to relay coupled laser beams from one side of the Earth to the other and direct their fire onto missiles originating from any location. Thus, all of the laser battle stations' firepower could be utilized to defeat a launch from any location on Earth. The large-relay mirrors could be deployed in very high, elliptical orbits, which would make it very difficult to attack and destroy them.

In any case, even if they were destroyed, the timespan required for achieving and verifying this would give the defense more early warning time. Even a single minute of increased warning time can vastly increase the prospects for "pop-up" defenses, which are only launched into space upon detection of an attack.

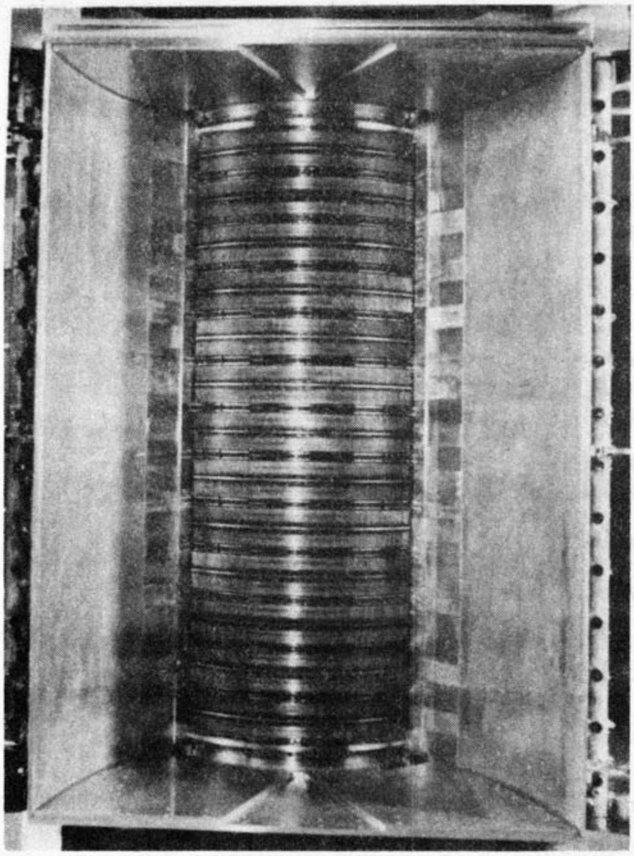
With the recent developments in coupled laser phased arrays, shown in Figure 1, even one pop-up multimodule laser battle station could wipe out the entire Soviet ICBM force during the three- to five-minute boost phase. Such a pop-up defense would also make use of pop-up fighting relay mirrors, shown in Figure 2. Alternatively, large-relay mirrors could be configured to only "open up" and pop down from high elliptical orbits during the time that on-station relay mirrors are being attacked. And finally, pop-up relay mirrors could still be used to re-integrate and reconnect the surviving on-station laser battle stations.

In effect, the aggressor must destroy all visible elements of the deployed space-based defense system worldwide within much less than a minute. This is quite a tall order. But pop-up defense potentials make this task even more difficult to carry out with any degree of certainty.

New possibilities

With phased array coupling of laser modules, the net firepower of the system is multiplied by n^2, where n is the number of coupled modules. That is, if one has ten 1-million-watt lasers coupled together, the output is equivalent in firepower to a single 100-million-watt laser. At present, this phased array coupling of lasers envisions that the laser modules are physically linked to each other and are in the same location. Continuing breakthroughs could lead to the possibility of distributed phased arrays like those utilized in radio astronomy to link receiving antennas from one spot on Earth with others.

A far more revolutionary possibility has derived from the work of Dr. David Weston of the British Admiralty Research



The cylindrical gain generator of the Alpha chemical laser is prepared for installation and testing at TRW's Capistrano Test Site. Alpha uses atomic fluorine and hydrogen to form the hydrogen fluoride lasing medium. The device then uses cylindrical mirrors to extract a 2.7 micrometer wavelength high-power laser beam. Alpha is the key component in the concept design for the SDIO's Zenith Star experiment.

Establishment in Dorset, U.K. Weston showed in published papers during 1986 that it is possible to "tune" phased arrays such that the output is coupled according to an n^3 law. While Weston's work was primarily directed toward improving sonar detectors, his theory, in principle, applies equally well to electromagnetic waves. (In the above example, the ten 1-million-watt lasers would then have a coupled output equivalent to a 1-billion-watt laser, according to the n^3 law for "tuned" phased arrays.)

Altogether, these potential new developments could radically increase the firepower of an existing configuration of deployed space-based laser battle stations. For example, a few dozen chemical laser modules could be initially deployed in high elliptical orbits, which are extremely difficult to intercept, in order to provide for targeting and discrimination of real RV warheads. Other systems would be utilized to intercept and destroy the RVs.

At a later point, large mirror arrays and fighting mirrors could be added to the configuration to give it the capacity to intercept missile boosters, using the combined output of many of the laser modules to attack a single missile. And finally, the configuration could be upgraded with the incorporation of distributed phase array coupling techniques to combine the output of many laser modules to generate extremely high power densities on missiles at long firing ranges. This upgrade could be sufficient to increase the combined laser firepower to a level great enough to intercept the 100 times harder RVs.

In fact, at very high irradiation power densities, the longer wavelength infrared lasers could accrue significant advantages over the shorter wavelength lasers. At very high irradiation levels, the longer wavelength infrared laser light tends to generate significant fluxes of high energy electrons and ions. This has proven to be a major drawback for the application of infrared lasers to laser pellet fusion. The high energy ("hot") electrons penetrate to the interior of the fusion fuel pellet and preheat the fuel so that it becomes impossible to efficiently compress the fuel pellet to the high densities needed for laser fusion.

But in the case of warheads, the "hot" electrons' penetration to the interior of the warhead would be most desirable. Such a penetration would disrupt and destroy the essential electronic components of the warhead, preventing it from detonating. This type of "kill" is termed an electronic kill, and it is generally thousands of times more efficient than thermal or shock kills. Electronic kills are also quite efficient against missile boosters, although "hot" electrons would also tend to penetrate and ignite rocket fuel, too, in this case.

The net result is that if very high power densities on target could be achieved by coupling infrared lasers, then the effective firepower of the combined array could be greatly increased over that calculated above. (In other words, the laser energy it takes to destroy a missile could also be greatly decreased.)

In retrospect

The emergence of these "technical" breakthroughs further demonstrates the efficacy of Lyndon LaRouche's 1982 call for a crash SDI program with immediate deployment. The SDI program has actually only led to marginal increases in ballistic missile defense research and its associated technologies. The focusing and combination of these previously existing SDI components has led to useful advances, but much, much more could have been accomplished over the past five years, as the single example of the chemical laser demonstrates.

In fact, the chemical laser program was made into a crash R&D demonstration project. And now it is clear that if this policy had been applied throughout the range of SDI technologies and deployment carried through, instead of simply field testing a single laser module by 1990, an initial defense system could have been put in place by 1990. And this initial deployment could be radically enhanced with continuing R&D advances.