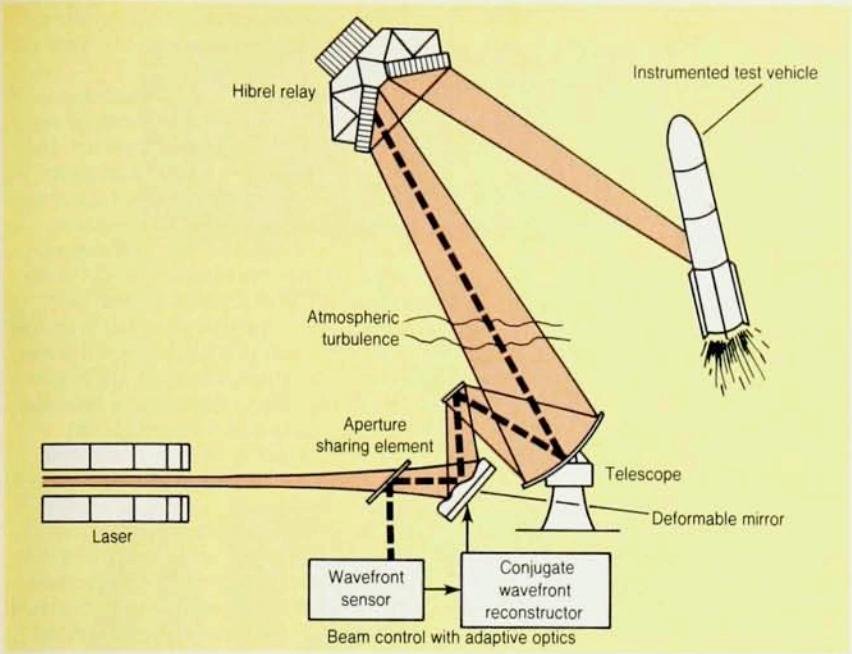

Schematic drawing showing how adaptive optics (pictured in figure on facing page) could be integrated into a ground-based laser system. A downlink signal from the relay mirror, passing through the turbulence, tells the wavefront sensor how to cancel the atmospheric effects. A computer reconstructs the wavefront that will perform the compensation and drives the actuators that deform the rubber mirror segments by the precise amounts required.

explosions would constitute a special threat to space-based sensors, electronics, and optics.

The high energy-to-weight ratio of nuclear explosive devices driving the directed energy beam weapons permits their use as "pop-up" devices. For this reason the X-ray laser, if successfully developed, would constitute a particularly serious threat against space-based assets of a BMD (Sections 3.5 and 9.3).

26. Since a long time will be required to develop and deploy an effective ballistic missile defense, it follows that a considerable time will be available for responses by the offense. Any defense will have to be designed to handle a variety of responses since a specific threat cannot be predicted accurately in advance of deployment.

A thorough understanding of practical responses, such as attacks on the defensive assets, hardening of offensive systems, and rapid deployment of large number of decoys, must be established before conclusions about the technical feasibility and cost-effectiveness of a defensive system can be made. A DEW system designed for today's threats is likely to be inadequate for the threat that it will face when deployed (Section 2.3 and Chapter 9).

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Postscript: Reviewers and authors comment on report

The review committee for the DEW study, headed by George Pake, transmitted the report to the APS Council on 20 April. In his transmittal letter, Pake noted that recent statements from the Strategic Defense Initiative Organization indicated that kinetic-energy weapons, not directed-energy weapons, are being emphasized as a short-term strategy for ballistic missile defense. Under such plans DEWs are largely relegated to discriminating against decoys, he wrote. Although the study dealt with both decoy discrimination and target destruction, it emphasized the latter. The study group had not been charged with examining kinetic-energy weapons components or systems; while the study was under way, SDIO shifted its emphasis.

Pake wrote that three related topics relevant to the APS study group's charge are not treated in the report:

▶ "No evaluation was made of how well the R&D program is being carried out, given its objectives. In view of the classified nature of the program and the broad range of activities undertaken, such an evaluation could not realistically have been made by the study group."

▶ "The cost of a program necessary to achieve any given level of defense capability was not estimated. Not enough is known at present about the hardware to be deployed to make such a cost estimate with any accuracy. In addition, costs would depend on the pace of the program—whether, for instance, several potential solutions to a problem are pursued in parallel—on

progress in important related scientific areas over the next decades, on whether political factors would require early demonstrations or not, and on the level of defense sought. The study group believed that, within the resources and time available to it, the group could not significantly reduce the uncertainties in cost estimates available from other sources. . . . We believe that an extension of existing work could usefully be done by a group of physicists and engineers working with analysts versed in defense cost estimates."

▶ "Appendix B describes qualitatively but does not discuss quantitatively the scalability and systems integration issues that arise when separate technical developments are to be merged into a functioning whole—whether for systems testing or operational deployment. A quantitative discussion of these issues is not possible unless the system architecture and hardware are much better defined than at present. As the study group points out, however, such scaling and systems integration issues could well be the most important in determining the effectiveness and reliability of any BMD deployment. No judgment on their resolution can be made at present except to note that such issues will be of unprecedented complexity."

Pake's letter concludes, "the APS study group has had access to classified information and, therefore, the report is written with knowledge that the basic conclusions of the study will not be invalidated by any existing information not available to the public."

As a result of the security review, Pake noted, there are "some small but significant deletions. Considering the vast amount of material contained in the study report, the fraction of material affected by the security review is minuscule. The only significant loss is that some of the countermeasure options available to the offense could not be discussed in detail. However, the number of items so affected are a very small fraction of the total items dealing with this topic."

Once the APS Council had also voiced its approval, a hastily scheduled evening session was held on 22 April during the APS spring meeting. About 200 physicists gathered to hear Kumar Patel, Richard Zare, Thomas Marshall and Bruce Miller summarize the report. Patel noted that from its start to the release of the report, the study took 21 months, "the gestation period of an elephant."

At a press conference the next morning, Patel remarked about the DEW study, "We did not say whether it will work because we don't know what 'it' is and what 'works' means." Zare, commenting on the difficulty of scaling up the known technology of lasers and particle beams, compared the problem to scaling up an automobile by a factor of a thousand. Does that mean you increase the weight, the volume, the speed or what? "You may have to rethink the whole thing." And if you're talking about a laser instead of an automobile, you have to worry about the nonlinear properties of lasers.

It is particularly difficult to predict the progress of technology, the DEW group remarks in chapter 1 of its report. Often very optimistic predictions are made for technologies or schemes at very early stages of development. The report notes: "Whenever orders of magnitude of improvement are necessary in operating parameters, it is likely that many new discoveries and inventions will have to be made. The discrepancy between the present state of the art of DEW and the ultimate requirements is so large that major gaps in technical understanding must be closed before engineering technology verification could become productive."

The report goes on to say that if an immature technology is forced to this verification phase, two undesirable consequences can occur: "First, it tends to freeze technology at levels inadequate for its ultimate goals. And second, it tends to absorb resources which could otherwise be used for research on more promising ideas.

"Past experience with the progression from theoretical concept, via proof of principle, understanding of details, technical development, engineering, to eventual deployment in a very large system, shows that technology typically is frozen several years before deployment, and basic science more than a decade before that. Because of the extensive development needed in many technological areas important to the systems, we judge that the deployment of a substantial DEW component in a BMD system cannot be foreseen before the year 2000."

Meanwhile, chapter 1 continues, during this long development phase and then the deployment period, the offense would also be improving its technology. This introduces an uncertainty that may raise the requirements for lethality and would make survivability more uncertain. "A deployed DEW defensive system may have to face the threat of DEW on the offensive side, in addition to all other conventional threats. If a DEW system is capable of disabling a ballistic missile in the boost or post-boost phase, it is likely that it also meets the lethality requirements against a space platform."

The report has other limitations in scope. Chapter 1 notes the group did not "address the complex issues associated with battle management and C^3I (command, communications, control and intelligence), including testability and reliability of the software." Further, the report doesn't deal with the related issues of arms control and strategic stability, although, the report notes, each of these warrants a separate study. The study group also pointed out that engineering manpower requirements and economic cost are likely to be high and urges that these issues be studied because of their possible impact on the civilian economy, international competitiveness, the armed services and technical manpower.

The DEW study did not receive Federal support, although Presidential Science Adviser George Keyworth had offered to attempt arranging Federal agency support for the study. Instead, funds came from the Carnegie Corporation and the John D. and Catherine MacArthur Foundation, each of which gave $200 000; the APS provided the rest.

Later this year the complete report will be published in *Reviews of Modern Physics*. Meanwhile, a 423-page preprint can be ordered from the APS for rapid delivery. The preprint has all the text and figures but not the finished format of the *RMP* version. For APS members the cost is $50.00 per copy. The member rate for AIP member and affiliated societies, the European Physical Society and the Japanese Physical Society is $100.00 a copy. The nonmember rate is $200.00 each but a 50% discount is available on orders of 10 or more copies. For express mail delivery, those ordering should add $10.00 per copy. Orders should be sent to APS Publications Liaison Office, 500 Sunnyside Boulevard, Woodbury NY 11797.

—GBL □

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