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Effective Military Technology for the 1980s

Richard L. Garwin

Military capability may be increased as much by old as by new technology. However as technological opportunities arise, or as the tasks to be performed change, existing military organization or bureaucracy may be inappropriate to the new means of achieving military capability. Without prescribing changes in the structure of United States military forces or of the bureaucracy by which they are created, this discussion of selected means for enhancing military capability may indicate opportunities for, together with some of the impediments to, their realization. Three of these systems should make major contributions to United States military capability (cruise missile, NAVSTAR, DSTAR); one responds to concerns over strategic vulnerability (silo defense); while one does not seem to hold much promise as a weapon (high-power lasers). In limiting discussion to these five systems, I am able to go into some detail, which I hope will persuade the reader that current arguments over United States military programs simply miss important aspects of military capability. Present programs in large part waste money and effort which could yield superior results in a comparable period. But programs such as these can have greatest potential if they are considered for wide application rather than as a simple replacement for an existing system. Implications for arms control may also go far beyond those attendant on the initially apparent system application, so a broad view is desirable for this reason as well.

Building military capability is hardly advantageous if it leads to the outbreak of nuclear war or to another world war. Explicitly or implicitly, arms control considerations are important. However, the arms control aspects of nonnuclear forces are more complex than those of the strategic forces. Three generally accepted aims of those who want to control strategic arms:
—to reduce the probability of war,
—to reduce the damage if war comes, and
—to reduce the costs of preparation for war,
are also goals of those who want to build tactical military capability. But, additionally, advantage and influence may be derived from that capability. To be able to fight and win nonnuclear wars, with negligible damage to the victor, surely confers political benefit. Strategic nuclear superiority may or may not be useful—to a large extent it is neutralized by an opposing lesser strategic capability which guar-

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antees the power to destroy cities, factories, dams, and general military forces and facilities. But superiority in nonnuclear tactical forces can be important; there are many more dimensions to tactical capability than to strategic.

The discussion of nonnuclear capability (even more than that of strategic) must consider not only the United States and the Soviet Union, and not only America's allies, but other nations and even nonnational capabilities and potential. In advocating additional capabilities for the United States, there is the possibility that others will be more readly persuaded to obtain them. Nations with little present military capability (like Japan) may be more receptive to these innovations, for they have no existing forces to be rendered obsolete. Apparently England had similar concerns (and well-warranted) when it introduced the dreadnought in 1906.

If only two powers are under consideration, as has been predominantly the case on the strategic scene, it is helpful to characterize an individual weapons system in one of the four logical cases as to whether the United States benefits if:

1. the United States has it and its opponent does not,
2. the United States and its opponents both have it,
3. neither the United States nor its opponent has it,
4. the United States doesn't have it and the opponent does.

These cases may be ranked in order of decreasing desirability for the United States (the author's estimate):

—Permissive action links: 2,4,1,3

—Countersilo capability: 3,1,4,2.

The possibilities proliferate if one considers a host of other powers and the sometimes parallel, more often conflicting, interests of the United States and the Soviet Union throughout the world. The relative desirability of the four cases for a given weapons system implies policies about United States research and development, and about arms control and secrecy.

Still, the United States cannot determine its course in building military capability or in evaluating arms control positions without relatively open discussion and analysis of military questions. In the hope of helping to focus this discussion on realities and outcomes rather than on slogans or existing programs, the following disparate systems have been selected for comment in this paper:

—The defense of silos against ICBM attack

—The cruise missile in future United States strategic and tactical forces

—Military and civil applications of NAVSTAR

—Military uses of high-power lasers

—Direct sea-to-air refueling of aircraft (DSTAR).

In each case, the analysis attempts to focus on technical options rather than on the selection among existing Defense Department programs—programs which may have been initiated to advance quite divergent goals.

Defense of Silos Against ICBM Attack

John Steinbruner and Thomas Garwin[1] have analyzed in some detail the environmental hazards (caused by debris from earlier low-altitude bursts) to reentry vehicles participating in a hypothetical attack on the Minuteman force and they have derived severe constraints which must be met for an effective attack. It would be only coincidence if nuclear explosions designed to kill Minuteman silos were the most efficient means of impeding other reentry vehicles, and this section therefore considers several other approaches to the specialized task of defending the Minuteman force against a very high level of destruction in an attack by accurate multiple independently targetable reentry vehicles (MIRVs).

An authoritative explication of the "strategic doctrine" of former Secretary of Defense James R. Schlesinger is to be found in his *Annual Defense Department Report for FY 1976 and FY 197T* of February 5, 1975. That doctrine emphasizes two capabilities—flexible strategic options and hard-target killers. The first is unexceptional, especially insofar as our strategic forces have long been physically capable of carrying out limited flexible options, although perhaps a President has not been confronted with the necessity to propose or endorse specific options. The second—a force of efficient hard-target killers (silo killers)—aroused much opposition. The Secretary emphasized that ". . . we would prefer to see both sides avoid major counterforce capabilities. We do not propose, however, to concede to the Soviets the unilateral advantage in this realm."[2] Since our own silo-killing force was to be housed in those very Minuteman silos which were assumed to be effectively destroyable by the Soviet Union, it was not clear how conversion of Minuteman to a force of silo killers would in itself counter that danger to the Minuteman force, except by the threat of preemptive attack. Indeed, were a force of Soviet silo killers really to materialize, it is likely that the Defense Department would request funds and approval to develop and deploy mobile ICBMs.

In support of his strategic doctrine, the Secretary testified on September 11, 1974 that a particular Soviet attack on ICBM silos with a single 1 megaton (MT)

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[1] John S. Steinbruner and Thomas M. Garwin, "Strategic Vulnerability: The Balance Between Prudence and Paranoia" *International Security*, Vol. 1, No. 1 (Summer 1976).
[2] *Annual Defense Department Report FY 1976 and FY 197T*, p. I 13.

weapon per silo might kill some 800,000 people. Two reports from the Ad Hoc Panel on Nuclear Effects convened by the Office of Technology Assessment at the request of the Senate Foreign Relations Committee (as well as later Defense Department testimony) with more realistic casualty estimates for a militarily effective attack on the ICBM force show fatalities on the order of 3.5 million to 22 million. The reports prepared for the Senate Foreign Relations Committee summarizes the history and the current state of the dialogue on this score, but do not analyze in any detail whether the assumed Soviet forces indeed could cause or even be expected to cause the assumed damage to the Minuteman force.[3] If there were real impediments to such an attack, a glossing over of such difficulties might make this attack more probable. Conversely, if one can show that the assumed force is indeed *incapable* of effective attack on the Minuteman force, that would greatly reduce the chance of its use and might even discourage the building of such an attacking force. The following discussion raises grave doubts about the feasibility of an effective counter-silo attack. It also emphasizes the degree to which we have ignored systems which are capable of preserving the Minuteman force but incapable of defending either softer targets such as cities or unique hard targets such as command centers.

BED-OF-NAILS DEFENSE AGAINST GROUND-BURST FUZING

Consider first the low-drag reentry vehicle (RV) preferred to obtain adequate accuracy in the face of the uncertain direction and velocity of the winds. Assume that the RV contains a 1 MT warhead, that the velocity at atmospheric reentry makes an angle of 22 degrees to the horizontal, and that the RV is desired to detonate at an altitude of 200 meters (m) above the silo. A low-drag RV would still be hypersonic at this altitude.[4] No reasonable self-contained drag or barometric fuze could distinguish between this 97.5 percent penetration of the standard atmosphere and 100 percent penetration of the atmosphere. Even a 1 percent fuzing error, leading to detonation at 98.5 percent penetration (120 meters altitude) would add

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[3] *Analyses of Effects of Limited Nuclear Warfare*, (Committee Print, September 1975), prepared for Subcommittee on Arms Control, International Organizations and Security Agreements of the Committee on Foreign Relations, United States Senate (156 pp.). *Effects of Limited Nuclear Warfare*, Hearing before the Subcommittee on Arms Control, International Agreements and Security Agreements of the Committee on Foreign Relations, United States Senate, September 18, 1975 (61 pp.).

[4] *Atmospheric Reentry*, by John J. Martin (Prentis-Hall Space Technology Series, Fig. 3-4 p. 28). Specifically, an RV with weight-to-drag (W/C_DA) of 1900 pounds per square foot will have velocity 4500 ft/sec at impact with 22° reentry angle. At 90° reentry angle, only 700 psf is required to maintain such a speed to impact.

almost 250 meters displacement to the burst. The alternative—radio-altimeter or radar fuzing—possesses adequate accuracy but would be the height of foolishness given American jamming prowess in general and the particular necessity of the RV to detonate within some hundreds of feet of the silo.

Therefore the silo-attacking offense is driven to the use of a contact (nose) fuze, which presumably works well enough against flat ground. However, should each Minuteman silo be provided with a thicket of steel palings arranged 1 meter apart in east-west rows 600 meters long, with about 150 rows at 5 meters north-south spacing (the palings being a quarter-inch-diameter [0.6 centimeters] steel reinforcing rod 2 meters long, driven 0.6 meters into the ground), it is unlikely that the *fuze* would strike either the ground or one of the palings. Rather, the RV at hypersonic velocity would destroy itself (without nuclear detonation) by contact with one of the palings.

Of course, precursor bursts could be used to attack this "bed of nails" containing some $60,000 worth of steel. But alternative (if less passive) defenses are also possible.

PEBBLE-CURTAIN DEFENSE AGAINST AIRBURST OR GROUNDBURST

Both airburst and groundburst low-drag RVs attacking silos can be countered by a pebble-fan projector—an east-west line 300 meters north of each Minuteman silo and 300 meters long, consisting of propellant emplaced in the ground to project a curtain or fan of pebbles up to 300 meters in the air. Instead of a radar at the silo one could use an upward-looking radar deployed perhaps 3 kilometers forward to detect the RV and to command the firing of the propellant. Ten tons of steel pellets would cost about $2,000 and could be projected by less than 1 ton of propellant. A multi-shot capability to deal with several RVs (or decoys) per silo is readily affordable by deploying several such projectors, which are inherently hard. The radar need have a range of only a kilometer against an RV side-on, where radar cross sections are very large. (Although slim, sharp-pointed RVs reflect little radar energy to a radar they are approaching nose-on, they reflect typically 1,000 to 10,000 times as much energy to a radar looking at them from the side.) The 10 tons of pellets, of 10 grams each, can provide a projected density of 10 pellets per square meter over a protective screen 300-meters square, providing a high probability of dudding or detonating a hypersonic RV.

If the offense abandoned at great expense its force of low-drag RVs and returned to high-drag RVs, it would seriously impair the force's accuracy. An RV of weight-to-drag ratio 400 pounds per square foot which falls at an average 100 meters per second from 6 kilometers takes 60 seconds to do so and would be carried 500 meters down-wind by a 30 kilometer per hour wind. (No one can say with high confidence the magnitude of the winds in the Minuteman fields under attack.) The same 60 second descent and straight-line fall toward the silo, together with the requirement to detonate within 300 meters or so to destroy the hardened silo, makes the high-drag RV an ideal target both for a rapid-fire, self-operating, automatic gun of the type recently deployed by the Army for air defense, and for the more advanced guns being examined by the Navy for defense of ships against homing cruise missiles. Not only are these systems of a reasonable cost for silo defense, but they can be deployed far more rapidly than can a fleet of effective silo-killing missiles and offensive RVs.

Naturally, it is important to determine whether these defensive systems for the Minuteman force are permissible under the 1972 Anti Ballistic Missile (ABM) Treaty. The bed of nails is surely permitted, but the deployment of guns or pebble-fan projectors for the defense of silos against ICBMs appears to be forbidden by the Treaty. The situation is not clear in regard to fuze jamming. In any case, exploration of all these concepts and development of equipment is surely permitted.

The rather unlikely scenario which has Soviet bombers flying over the Minuteman fields and dropping nuclear weapons on one silo after another (and the analogous suggestion that the B-1 can do likewise to the Soviet ICBM silo force after suppressing surface-to-air missile defenses) fails in the face of mobile radar-guided guns. These guns are widely available in both armies and, when deployed next to some of the silos, are admirably suited to destroying aircraft which must fly within a few hundred feet of one silo after another in order to deliver their gravity bombs. Thus, B-1 attack on silos is prevented by machine guns, not by MIG-25s.

The availability of these technologies for the defense of Minuteman silos should emphasize to the Soviet Union the lack of utility of a large investment in reliable, high-yield MIRVs which would be required to effectively attack Minuteman silos. If the Soviet Union was indeed observed to have completed most of a major deployment program with the capability to destroy Minuteman silos, the United States might negotiate a modification in the ABM Treaty which would permit the extensive deployment at Minuteman silos of the specialized systems described here; these would have the capability only of defending silos. Failing quick success in such negotiation, the United States could withdraw from the Treaty under the "supreme national interest" provision and then proceed with deployment.

Such systems, perhaps because of the old-fashioned technology employed or because they are incapable of defending a large spectrum of targets, arouse little interest within the Defense Department. This is surprising in view of the enormous emphasis given by the Secretaries of Defense, among others, since 1969 to the question of Minuteman vulnerability.

The Cruise Missile in Future United States Strategic and Tactical Forces

A "cruise missile" is a pilotless airplane with continuous propulsion from the time of launching to its impact on target. It flies in the atmosphere and is supported by aerodynamic forces. In this way, it differs from a ballistic missile which has propulsion only at the beginning of its flight and which is in free fall thereafter. It differs also from the glide bomb, which uses aerodynamic lift but is unpowered.

Whether one advocates building or constraining United States military forces, the overall merits of cruise missiles must be compared with alternative weapons for the same purposes, in the same time period when cruise missiles could be available.

The central questions to be addressed are:

1. To what extent can the goals of United States military capability be achieved by reliance on cruise missiles?
2. How would the use of tactical and strategic cruise missiles affect costs, vulnerability, and robustness (the degree to which the force is insensitive to level of enemy defenses)?
3. What are the countermeasures against cruise missiles (as compared, for instance, with aircraft)?
4. What do existing Soviet cruise missile forces mean to the United States and to others?
5. To what extent can other nations develop cruise missile capabilities independently?
6. What is the impact of cruise missile transfer to other nations?
7. What are the arms control implications of cruise missiles? How should they be limited in SALT, and how should these limitations be verified?

The answers to these questions should allow one to determine:

1. What should be the overall United States program in cruise missiles?
2. How do present United States defense programs compare with one relying on cruise missiles?

Only a few of these questions can be addressed in the space available here, but the others are included to provide a context for discussion and in the hope of stimulating further analysis, both in and out of government.

Cruise missiles are not new—the V-1 buzz bomb used by Germany against England in World War II was an early cruise missile. It flew at some 300 knots, but at an altitude of a kilometer or more so that it was a good target for antiaircraft fire and for fighters. Azon, Razon, and Tarzon were members of a series of guided bombs use by the United States in the China-Burma-India theater in World War II. After the war, Regulus, Snark, and Mace were American cruise missiles with ranges of hundreds to thousands of miles. Soviet Styx missiles were deployed on Komar and Osa class boats in the 1960s. The Israeli destroyer Elath, for example, was sunk by Egyptian-fired Styx missiles in 1967.

The Walleye TV-homed glide bomb was accepted into the United States forces in the mid-1960s. The Harpoon anti-shipping missile is now moving into United States naval forces. It is a jet-engine powered, modest range homing missile for launch from aircraft, ships and submarines. The Navy Tomahawk missile is under development for both nuclear and nonnuclear warheads and for launch from submarines, ships, and aircraft. The Air Force is developing the air-launched cruise missile (ALCM) to fit the rotary launcher now used for short-range attack-missiles (SRAMs). The Soviet Union, moreover, now has a stable of air-launched, ship-launched, sub-launched, and anti-shipping cruise missiles.

COMPARISON BETWEEN CRUISE MISSILE AND BALLISTIC MISSILE

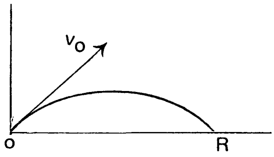
The ballistic missile has great advantages at very short ranges and very long ranges. Examples of short-range ballistic "missiles" are bullets or rocks. Very long-range ballistic "missiles" are satellites which orbit the earth indefinitely without further propulsion. For intermediate ranges, the cruise missile may be much smaller than the ballistic missile of comparable payload, and it may have additional advantages of low-altitude flight, near-invisibility to radar, and accuracy independent of range.

It is simple to calculate the ratio of initial mass to final mass for a ballistic missile and for a cruise missile. This is done in the inset. For the ballistic missile, an initial velocity, v_0, is reached early in the trajectory, which is then a parabola to impact (for the flat-earth approximation). The range of a ballistic missile is thus given in terms of the mass ratio and the specific impulse of the propellant by Equation 1.

For a cruise missile (or an airplane) the relevant parameters are the ratio of lift to drag (which we take here as 7), the velocity, and the specific fuel consumption (SFC). Taking a velocity of 0.8 Mach, and a SFC of 1.2 kilograms of fuel per hour per kilogram of thrust, we find Equation 2 for the fuel expended. The ratio of

Figure 1
Ratio of Initial Mass to Final Mass for Ballistic Missiles and Cruise Missiles

Ballistic Missile



Let g denote the gravitational constant, I_{sp} the specific impulse, M_o and M_f the initial and final masses of the missile, R the range, v_e the exhaust velocity of the fuel, and v_o the initial velocity of the missile. It is known that

$v_o = v_e \ln M_o/M_f$, $v_e = gI_{sp}$, and (for a flat earth) $R = v_o^2/g$.

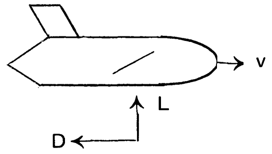
So

$$R = v_o^2/g = g\,I_{sp}^2\,(\ln M_o/M_f)^2. \qquad \text{(Eq. 1)}$$

Let $I_{sp} = 250$ sec, then

$$R = (9.80\ \text{m/sec}^2)\,(250\ \text{sec})^2\,(\ln M_o/M_f)^2 = 620\,(\ln M_o/M_f)^2\ \text{km}.$$

Cruise Missile



Let D and L denote the drag and lift forces on the missile, M_o and M_f the initial and final masses, R the range, SFC the specific fuel consumption (i.e., mass of fuel consumed per unit of time per unit of thrust), and v the (constant) speed. Evidently

$\dot{M} = M_o \cdot \text{SFC}/(L/D)$ and $M_o - M_f = \dot{M}R/v$.

So

$$M_o - M_f = R\,M_o \cdot \text{SFC}/(v \cdot L/D). \qquad \text{(Eq. 2)}$$

Let $L/D = 7$, $\text{SFC} = 1.2\ \text{hr}^{-1}$, and $v = 0.8$ Mach $= 240$ m/sec, then

$$R = \frac{v \cdot L/D}{\text{SFC}}\,\frac{M_o - M_f}{M_o} = 5000\,(1 - M_f/M_o)\ \text{km}.$$

Table 1

Range, km	0	25	100	300	600	1200	3300
Ballistic Missile M_o/M_f	1.00	1.22	1.49	2.00	2.67	4.02	10.0
Cruise Missile M_o/M_f	1.00	1.005	1.02	1.06	1.14	1.32	2.94

initial mass to final mass for ballistic missiles and cruise missiles are shown as the second and third rows of Table 1.

Although ballistic missiles can be used (and are used) for ranges beyond 1,000 kilometers, we see that cruise missiles, even with simple jet engines, can be considerably smaller than ballistic missiles for ranges from 300 to perhaps 5,000 kilometers. Of more importance for tactical cruise missiles, only a small fraction of the initial mass (25 percent) need be added as fuel to extend a cruise missile range from 100 to about 1,000 kilometers.

The versatility of the cruise missile permits and demands a large number of design choices, which determine the utility and cost of the system:

—Type of warhead: nuclear, high explosive, or dispenser.

—Size of warhead: kilograms to tons.

—Mid-course guidance: auto-pilot, radio, terrain following or programmed altitude.

—Terminal guidance or not: autonomous or remote intelligence.

—Design: for a single set of flight conditions (e.g. Mach 0.8 at sea level), or versatile (sea-level to 20,000 meters).

—Basing: land, air, ship, or submarine.

—Launch: air-launch airplane-type takeoff, or zero-length launch.

—Recovery: recoverable or non-recoverable (expendable).

To render the problem finite, I shall define two systems which I think are desirable for the United States inventory, describe their capabilities, possible countermeasures, and their impact on United States force structure. I shall then compare these programs with existing programs.

STRATEGIC CRUISE MISSILE (SCM)

A cruise missile carrying a nuclear warhead weighing perhaps 100 kilograms, and with a design range of 2,700 to 3,600 kilometers could be carried on existing FB-111 and B-52 aircraft. Such a missile could use a combination of self-contained inertial guidance and terrain comparison (TERCOM). The accuracy of the combined system could be much better than 100 meters, although the accuracy of the inertial guidance system alone, depending on the aircraft knowledge of position and velocity at the time of launch, could lead to inaccuracies of several kilometers. But the major influence of the SCM would not be simply as another weapon for the existing bombers or for the B-1. It would be rather to avoid entirely the necessity of developing the B-1 in order to have a survivable, versatile new strategic bomber. The SCM could be carried one hundred to a 747-type aircraft, and fifty to a C-135 or a C-141, to provide as large a survivable striking force as is desired, without the necessity of designing airplanes to penetrate Soviet air defenses at high cost and with rather uncertain results.

If the temptation were avoided to give the SCM the very best accuracy which technology could allow, the missile would be very cheap—essentially the cost of the nuclear warhead and of the inertial guidance package. The aircraft carrying SCM could be based at civilian as well as military airfields, with the SCM warheads under positive control by means of permissive action links (PAL). In my judgment, this is the proper application of strategic cruise missile technology, and the SCM in cargo aircraft (rather than the B-1) should be the successor to the current strategic bomber force—if an aircraft-type successor is indeed needed. There is reason to believe that the existing Navy submarine-launched cruise missile (SLCM) program will lead to a better missile than the present Air Force ALCM program, and it is the SLCM-as-SCM to which I refer here. The article by Archie L. Wood in this issue, *Modernizing the Strategic Bomber Force,* provides detailed argument for the strategic cruise missile as a preferred alternative to the B-1.

The SLCM *per se* is a step backward. Because its range is considerably shorter than that of the Poseidon or the Trident I missile, the submarine must approach its target more closely, thus reducing the ocean area which must be searched to imperil the submarine force. Since the SLCM is designed for torpedo-tube launch, the number of SLCMs which might be carried in a ballistic missile launching submarine, or for that matter in an attack submarine, is limited only by the worst-case imagination of the beholder. Hundreds might be imagined carried in every submarine, and they could also be launched from surface ships, both military and merchant ships.

A TACTICAL CRUISE MISSILE

The tactical cruise missile with great potential appears to be one with a range of some 500 nautical miles (900 kilometers) with a warhead of about 500 kilograms of high explosive. Such a missile specialized to fly at Mach 0.8 near sea-level, with mid-course guidance from widely-deployed low-frequency radio navigation aids (LORAN) or from a navigation satellite system (e.g., NAVSTAR), could have a precisely pre-programmed flight route and could manage terrain avoidance by varying its altitude according to a detailed stored program. By LORAN guidance alone, accuracy of 30 to 60 meters is possible; by NAVSTAR, 10 meters. To actually strike a point target, such a missile could be equipped either with an autonomous capability or with a facility to send back a few seconds worth of television so that for the few seconds before impact the cruise missile would be a remote-piloted vehicle (RPV) and could be guided into its target by means of an observer at military headquarters. Since such TV terminal guidance requires only a few seconds of communication, a single active aircraft- or balloon-borne large phased-array communications antenna could handle the time-shared relay of such guidance to thousands of cruise missiles in a theater of operations. To the extent that fighter aircraft (such as the A-7 or A-10) under control of forward air controllers (either ground based or airborne) are used to perform close air support, to suppress short-range artillery, to destroy a tank, and the like, cruise missiles can do a similar job *with the short response time* of approximately one minute. This would be achieved in a war of medium or high intensity by firing cruise missiles into the neighborhood of the opposing force and having them loiter for thirty to forty minutes at low altitude. They would be ready to be called in by the forward air controller either by a change in the target coordinates transmitted to the missile by a radio command link (see the next section, on NAVSTAR) or by homing on a laser designator. For directing either fighter aircraft or cruise missiles, the vulnerability of the airborne forward air controller is a problem; mini-RPVs with TV and laser designators go far toward removing this difficulty.

Such missiles could be launched from military cargo ships (which are far less expensive than aircraft carriers) or from land bases. They would need no fighter escort, rescue aircraft, electronic warfare aircraft, or the like. In all but the most unopposed type of combat, the tactical cruise missile would be a more effective, lower cost and more controllable means of attacking ground targets than are manned aircraft.

This missile should have a production cost on the order of $40,000. It would be provided with a rocket booster to bring it up to design speed from a zero-length launcher. The rocket booster would weigh about 140 kilograms and the overall missile about 1,500 kilograms. It would come in a small packing container, from which it would be launched without preparation. The missile would be self-dudding if its guidance were not effective to impact.

In evaluating the effect on force structure of the availability of such tactical cruise missiles, one is struck by the fact that almost all tactical air capabilities derive from this ground attack role—attack aircraft themselves, the aircraft carrier, fighter escorts, air defense aircraft for the aircraft carrier, and the like. In addition, there is a long logistic tail to support the delivery to the attack aircraft of bombs, defensive munitions, and fuel. Finally, if it takes a 60,000 pound aircraft (and four protective escorts) travelling both ways from base to target to deliver 4,000 pounds of bombs, both the cost of the forces and the amount of peripheral damage are large compared with that associated with the cruise missile alternative. Simply put, building and maintaining a tactical cruise missile force to destroy some prescribed set of ground targets which figure in contingency plans should render both sea-based and land-based tactical airforces non-competitive.

The significance of the tactical cruise missile is much enhanced by the effect of air defenses. Unlike the V-1s of World War II, which flew at speeds on the order of 300 knots, at 1 to 2 kilometers altitude in straight flight, these tactical missiles will fly at 50 to 100 meters altitude, have continuous maneuvering capability built into them, and be difficult to see or to attack either with ground-based or air-based anti-aircraft means. Their speed of 0.8 Mach requires only small wings, and the vulnerable area of a cruise missile is far less than that of a manned aircraft. Thus it is probably an overestimate to take the attrition of a cruise missile as equal to that of a manned aircraft attacking the same target. For the delivery of conventional explosives, manned aircraft have been used extensively at average attrition rates of 0.2 to 0.5 percent per sortie. At one sortie per day, an entire set of 10 percent attrition targets would reduce the capability of an Air Force by a factor of 2.7 in ten days (7.3 in twenty days), whereas the replacement time is on the order of three years. For a force of cruise missiles, 10 percent attrition simply increases the number of cruise missiles required by a corresponding 10 percent. Even a 50 percent attrition rate by highly effective air defenses in the target area would simply double the number of cruise missiles above that required for no defenses at all.

Thus a tactical cruise missile force equivalent to a very large American Air Force operating at one sortie per day per aircraft might correspond to the expenditure of some 10,000 cruise missiles per month, and a war-reserve stock of 30,000 to 50,000 cruise missiles. Cruise missile factories would have to be held in readiness to produce tactical cruise missiles at that expenditure rate, with an allowable warm-up time of three months.

The obsolescence characteristics of such a cruise missile posture differ enormously from those associated with a manned aircraft posture. Aircraft have lives on the order of ten to twenty years, and must be husbanded in wartime. Cruise missiles could have a far lower inventory cost (two billion dollars for 50,000 missiles), and new developments can be incorporated into the factory without the necessity of modernizing the entire stockpile (so long as stockpile missiles have attrition less than 60 or 70 percent per missile).

ARMS CONTROL ASPECTS OF CRUISE MISSILES

Insofar as the cruise missile is a strategic weapon allied with or in competition with strategic bombers, it should be limited in SALT. Otherwise the two sides would have the potential to build unlimited offensive forces, which would not significantly affect security but would ridicule numerical ceilings of the forces limited in SALT. But it seems infeasible to ban the cruise missile entirely in SALT, because shorter-range nonnuclear-armed cruise missiles appear to have such great utility in tactical forces. Furthermore, such a ban between the United States and the Soviet Union would deny these nations access to cruise missiles which are likely to be common elements of the forces of lesser powers. Thus the control of cruise missiles in SALT must be compatible with the continued development and deployment of large numbers of nonnuclear cruise missiles.

There are several difficulties with the enforcement of cruise missile limitations:

1. Testing of the cruise missile is unobtrusive. The in-flight propulsion of a cruise missile is a small turbojet or turbofan engine with a few hundred pounds of thrust (versus 50,000 pounds of thrust for each engine of a 747). For air-launched cruise missiles, no booster rocket is required; for ground- or sea-launched cruise missiles, a solid-fuel rocket will normally boost the missile to flight speed before the engine can take over—this booster may have 10,000 pound thrust for five seconds.

2. Cruise missiles need not be tested at full range to have high confidence that they work at full range. High confidence in performance does not require the fuel tank to be drained continuously in a single test. Furthermore, the flight path in operation or in test need not be straight, and long flight times and long effective ranges may be tested without leaving a region a few hundred miles in extent.

3. There are legitimate military needs for nonnuclear-armed cruise missiles. In fact, some believe that high-explosive-armed cruise missiles with a range of some 1,000 kilometers can replace most United States tactical air forces, both land and sea-based. Short-range tactical cruise missiles, both air-launched and sea-launched, exist in both Soviet and American inventories and have been manufactured recently by other nations (e.g., France and Israel). Very large inventories of such tactical missiles may be required if they are to play a major part in future conflicts.

4. In principle, by appropriate design, a highly useful tactical cruise missile could have its range multiplied by a factor of four or five by the substitution of a turbofan engine for the tactical turbojet, and of fuel (kerosene or high-energy propellant) for most of the high-explosive. In fact, just this dual capability (with only minimal changes in external appearance) characterizes the tactical and strategic versions of the cruise missile being developed under the United States Navy Tomahawk program.

Measures for control of cruise missiles should be examined from several points of view:

1. What can be the impact on the United States, in reality and in appearance,

of the cruise missile deployments *permitted* to the Soviet Union under the candidate agreement?

2. What would be the impact on the United States of Soviet cruise missile deployments undertaken clandestinely in *violation* of the agreement?

Both questions should be addressed for near-future technology before reductions begin for strategic arms, and for more advanced technology in the context of substantial strategic arms reductions.

Candidate agreements must be examined from the point of view of verification. Limitations on development are regarded as unverifiable for ICBMs until they reach the test stage. The same is true for cruise missiles, but, as noted, the test of cruise missiles is not readily observed by unilateral means, unless the agreement specifically restricts cruise missile testing to certain new ranges not previously used for such testing and which can be observed by radar.

The three primary problems with the control of strategic cruise missiles are:

1. The great utility of very similar vehicles with nonnuclear warheads and tactical (non-strategic) applications.
2. The fact that for the nonnuclear armed missiles to be effective they must strike their targets with an accuracy measured in tens of feet—far better than required for effectiveness of a nuclear warhead against even the hardest targets.
3. The horizontal proliferation potential of the delivery vehicles which could be acquired by other nations to improve and modernize their capabilities for conventional warfare, but which would allow the carriage of nuclear weapons when advanced warheads become available.

Because of the long travel time for strategic cruise missiles (to have significant range through normal density air at low altitude where penetration capability is good, cruise missiles must fly at subsonic speed), they cannot be regarded as surprise first-strike weapons. Unopposed, however, they could in principle have the capability to destroy silos hardened to any level. Because of the modest warhead yields available for cruise missiles, the close approach required for silo kills, and the high fratricide potential of a cruise-missile attack on silos, an effective defense of silos against cruise missiles might be obtained by a hardened automatic machine gun mounted near the silo, or by relatively simple homing missiles (in the same way that *silos* could be defended against aircraft dropping nuclear bombs).

Consider the following measures in the implementation of the Vladivostok Accords (SALT II):

1. Ban strategic cruise missiles of intercontinental range (and, as an aid to verification, ban nonnuclear armed cruise missiles of intercontinental range as well); and *limit* air-launched strategic cruise missiles of range between 600 kilo-

meters and 2,700 kilometers by counting as a MIRVed launcher aircraft of a type equipped to fire these strategic cruise missiles.

2. Ban sea-launched strategic cruise missiles and submarine-launched strategic cruise missiles—i.e., nuclear-armed cruise missiles associated with ships or submarines.
3. Ban air-launched cruise missiles of range exceeding 2,700 kilometers.

IMPLICATIONS FOR UNITED STATES DEPLOYMENT (AS PERMITTED)

The deployment of SCMs on our strategic aircraft would (according to the proposal above) reduce the number of MIRVed ICBMs and SLBMs to which we are otherwise entitled under the SALT II Agreement. Thus the tendency would be to use SCMs only on high payload aircraft, so that the loss of a MIRVed missile would be compensated by a substantial number of cruise missiles, rather than simply by a few. This effect would constrain Soviet actions even more strongly.

The ban on ship-based and submarine-based strategic cruise missiles would require the redirection of the Navy SLCM program—that group might well be given the responsibility for the ALCM.

Against soft targets, especially in view of the ABM Treaty and the absence of effective ABM concepts, MIRVed ICBMs seem cheaper and more effective than cruise missiles. The Soviet Union does not yet have the avionics capability to send cruise missiles against hardened targets, and in any case it is not clear that cruise missiles are in any way more effective or less costly than maneuvering reentry vehicles for attack on the Minuteman force. It is difficult to see any significant military benefit to the Soviet Union from cheating on the proposed cruise missile provisions—there are easier ways to abrogate the SALT agreements.

In principle, verification of the cruise missile provisions need not be ironclad, given the small military benefit which would flow from cheating. And it would be unfortunate to claim that cruise missile limitations could be verified with the degree of certainty with which we verify limits on numbers of ICBMs, ABM deployments, etc. The greatest potential for evasion or for building rapid capability after abrogation would arise from the development and testing of a convertible missile, where the same structure and guidance could be refitted with a different engine, fuel tank, and nuclear warhead to be transformed from a short-range tactical missile to a long-range strategic weapon. However, the large number of nuclear warheads required for a force of thousands or tens of thousands of strategic cruise missiles would be of substantial manufacturing cost and drain on the stockpile of special nuclear materials. An ancillary provision could ban such convertible missiles, or subject them to discussion in the Standing Consultative Commission.

THE INTRODUCTION OF CRUISE MISSILES INTO UNITED STATES TACTICAL FORCES

The general tendency in both the United States Tactical Air Force and in the Navy analogue is to approach the tactical cruise missile as a range extension of the glide bomb (e.g., Walleye), with benefits for aircraft survivability. But that tendency puts extra requirements on the cruise missile—aircraft compatibility, size, G-load, necessity to survive hard landings attached to the wing pylon, initialization and guidance by the pilot of a one-man aircraft, and the like. As argued above, the tactical cruise missile should be a replacement for, rather than an adjunct of, the tactical bomber. As such, it should have a range of about 1,000 kilometers, with launch from the ground or from military cargo ships. Guidance should be provided from elsewhere by radio to the missiles, so that the launching site may be kept inexpensive and with low vulnerability. It would make sense also to have the capability to launch the tactical cruise missile from military cargo aircraft (e.g., the C-141) and so to eliminate the necessity of transferring air-transported missiles to ground or ship launchers.

The modern air-launched strategic cruise missile of 2,700 kilometers range should be preferred to penetrating bombers as the airfield-based component of the United States strategic force. Its effectiveness in the face of defenses can more readily be guaranteed. As regards crisis stability and lack of threat to the strategic offensive forces, the cruise missile (like the strategic bomber) is benign. The ground- or ship-launched tactical cruise missile of 900 kilometer range has the potential of replacing tactical air forces for delivery of munitions on surface targets; such a range allows secure, dispersed basing and launch in response to a theater command-and-control system, while providing the ability to concentrate fires in a manner impossible for short-range missiles or artillery. Air defenses which would nullify a high-explosive-armed tactical air force have essentially no effect on a cruise-missile force.

Military and Civil Applications of Navstar

The Defense Department is developing a system of satellites (NAVSTAR) and equipment for military vehicles (manned and unmanned) which will provide positioning information for accuracy better than 10 meters in horizontal and vertical coordinates. Civil aircraft and ships will also be able to use this equipment to obtain instantaneous positioning information to accuracy of about 30 to 60 meters at 0.1 second intervals. The phenomenal accuracy, broad utility and low cost of NAVSTAR could be expected to revolutionize warfare, especially against stationary targets such as bridges, shelters, roads, and the like. This potential effectiveness provides an incentive for the adversary to jam NAVSTAR, to try to use it, or to employ his own similar system. What is the result on balance? Without attempting to answer this ultimate question, we nevertheless raise some points which must enter prominently in any such analysis—points with significance for United States relations with its allies, with commercial users, and even with potential adversaries.

Formerly known as Defense Navigation Satellite System (DNSS) then as Global Positioning System (GPS), NAVSTAR prototype satellites are under development for launch this year and next, with evaluation beginning in 1977. A complete system (if approved) would be scheduled for initial global operation in 1982. The satellites will broadcast on two L-band frequencies, one between 1500 and 1600 megahertz, and the other near 1200 megahertz. Four satellites in view of a user suffice to determine three time differences of arrival which allow a user to determine his position in three dimensions to an accuracy of about 6 meters 50 percent of the time and 9 meters 90 percent of the time. The satellites also transmit information regarding their orbits and the time, enabling a user with a satisfactorily accurate model of the earth to determine his position with respect to any point on earth (e.g., a landing field or a missile target) to similar accuracy. The user equipment is passive (does not radiate signals), could be the size of a book, and is expected to cost initially $30,000. It will be a very short time before the coordinates of all interesting points on earth will be known to accuracies of 3 to 6 meters.

The satellite and non-user-related costs for the demonstration system may cost $150 million. A full global system may cost $600 million, with $60 million per year replacement cost. Ten-year *user* costs of present navigation systems for American military forces are $10 to $20 billion (largely maintenance-related). When NAVSTAR is globally deployed, the radio receiver-computer to allow a vehicle to work with NAVSTAR may cost some $5,000.

NAVSTAR satellites in the deployed system can readily be arranged to radiate their desired signals without any possibility of jamming by an enemy, but the user-vehicle receivers are, of course, susceptible to sufficiently intense local jamming within line of sight of a ground transmitter. It can be arranged for the system to have some 60 decibels margin against jamming, so that if a satellite radiates some 20 watts with coverage of an entire earth hemisphere, then a 20-watt jammer (without directional antenna) could jam 1/1000 that diameter, or about 14 kilometers radius. Of course, it is perfectly possible for a jammer to have 1-kilowatt power and to have easily some 15 decibels directivity gain, so that the effective jamming range can be extended to some 550 kilometers (an airborne jammer at 14 kilometers altitude would be required to jam ground-level NAVSTAR receivers at this range; jammers at lower altitude would be shielded by the curvature of the earth). Additional anti-jam margin can be provided by special receiving antennas, at additional cost.

A mature system of satellites would have some redundancy, so that the failure of any one satellite would not degrade service in any area. The failure of two specific satellites would allow continued use of the system to full accuracy by ships, submarines, and other users with accurate prior knowledge of their altitude, if there remained three satellites in view.

Even against intense jamming, certain users could continue to use the system with full accuracy by the use of directional antennas, which could be used to "set a null" on the jammers as well as to enhance the effective area receiving signals from the satellite transmitters. Most aircraft and many missiles could obtain another 20 decibels in jamming margin from the latter effect, and perhaps an additional 10 decibels from the former, thereby reducing the effective radius of the notional jammer from 550 kilometers to about 18 kilometers.

Instead of the L-band adaptive antennas, at lower cost we could provide for a given tactical theater a set of more powerful transmitters mounted on aircraft, on tethered balloons, or on free balloons, which could supply 40 decibels additional margin, either with or without the adaptive antennas.

It would be physically possible for the Soviet Union to launch anti-satellite vehicles, which could reach synchronous orbit in six to eight hours and in principle (either with nuclear weapons or without) destroy individual satellites of a synchronous NAVSTAR constellation. For the planned orbital configuration, less warning would be available. Early demonstration of the ability of our tactical users to work with local transmitters which could take the place of the NAVSTAR satellites should serve to some extent to reduce the perceived benefits to the Soviet Union of building a capability to destroy NAVSTAR (although the geometric configuration of such auxiliary or replacement transmitters would not give accurate altitude data to the users; in that case this datum must be supplied by user-carried altimeters).

The "protected channel," (P-channel) occupying about 10 megahertz of bandwidth and encrypted to deny its use by unauthorized users, is to provide about 9 meters accuracy 90 per cent of the time. In contrast, the "clear channel" (C-channel) would have lower power and about 1 megahertz bandwidth. It would provide three-dimensional positioning to about 60 meters accuracy 90 percent of the time. Even at this accuracy, the world-wide availability of the NAVSTAR clear channel, and its greater accuracy than alternative navigation systems should *dominate* all other systems, and every commercial aircraft and many general aviation vehicles would carry this receiver. Indeed, commercial and military shipping, and many American and foreign military aircraft would also carry this receiver in order to avail themselves of the rapid, reliable, and accurate position fixing which such signals will provide.

Evidently, NAVSTAR will revolutionize navigation, terrain avoidance, weapon delivery, theater command and control. As a world-wide system which can accommodate additional users at zero cost, it raises policy questions which it is important now to ask, even if not to answer. Other questions are raised by another capability which goes naturally with NAVSTAR, namely MONSTAR.

The same satellites which will radiate the NAVSTAR signals to provide position information by time difference of arrival would serve as ideal platforms on which to mount receivers, looking at the earth hemisphere below, and receiving signals from specialized transmitters on vehicles which want their position to be known. Such a cooperative, active, monitoring system (MONSTAR—a term coined for this paper) fills quite a different function from NAVSTAR, but an important one. The required transmitter would cost $500 to $1,000, could have a one-second pulse repetition time, and would serve to locate the position of the transmitter to an accuracy on the order of tens of feet. MONSTAR differs from NAVSTAR in the following ways:

NAVSTAR	MONSTAR
Vehicle receives	Vehicle transmits
Satellite unjammable	Satellite easily jammed
Vehicle equipment $3000-10,000	Vehicle equipment $500-1000
Vehicle learns its position	Control center learns vehicle position
Unlimited number of users	Up to 100,000 simultaneous users

If a MONSTAR were to replace the present Federal Aviation Administration (FAA) air traffic control radar surveillance, it would provide reliable position monitoring and identification down to ground level in all areas of the world and would save perhaps $200 million annually. Together, MONSTAR and NAVSTAR would make possible commercial aircraft operation in all conditions of visibility (including blind taxiing on runways) and would more than double the handling capacity of certain airports now limited to one active runway by navigation and surveillance inaccuracy. Schedule reliability of air travel could be improved; FAA manpower reduced; aviation safety increased; and limitations would be those physical ones of snow on the runway, gusts and hail, and the like.

Furthermore, ships, trucks with valuable cargo (e.g., Energy Research Development Agency or commercial fissile-material shipments) could also carry MONSTAR transmitters and have their positions reported second-by-second to their sponsors. MONSTAR would obviate the use of crash-locating beacons on aircraft, since aircraft positions would be monitored second-by-second until the transmitter ceased transmitting, at which time the aircraft position (including altitude) could be evaluated and emergency forces deployed to the precise site of the crash.

Unlike NAVSTAR, the MONSTAR package is quite readily jammable by antennas anywhere on the earth surface and pointed toward the satellite receiver. On the other hand, MONSTAR could readily locate such jammers to an accuracy better than 100 feet while it is being jammed, whether there is one or more jammers. Furthermore, large commercial aircraft could easily afford to carry a backup surveillance monitoring system which relied on their NAVSTAR receivers, so that the jamming of MONSTAR would not shut down commercial aviation.

POLICY QUESTIONS

Some interesting policy questions raised by NAVSTAR are:

1. What should be the rate of equipping American military and non-government users with NAVSTAR receiver-computers?
2. The entire world will use the NAVSTAR clear channel navigation signals, and the clear channel will provide better bombing accuracy than visual bombing. How shall we protect our own forces from attack by enemy forces using the NAVSTAR clear channel? Shall we deploy clear-channel jammers with all our forces?
3. How shall we protect our friends, or for that matter neutrals? Shall we give all of them jammers or the plans of jammers?
4. Shall we allow our enemies during wartime to use our NAVSTAR clear-channel signal to navigate their aircraft and ships which are not in combat? Should we have contingency plans (either announced or unannounced) to shut off or to spoof the clear channel signal, thereby denying its benefits to our own civil users?
5. Why not let civil aviation, other civil users, and other nations world-wide use the P-channel signal during peacetime? Would it then be a useful diplomatic tool to deny the beneficial use of the P-channel signals to all but American and allied military during times of tension?
6. Is it possible to sell a service for the use of the C-channel and perhaps the P-channel? Will this or some other scheme lead to a useful interdependence among nations, or would it be better simply to deny all but American and allied military the use of the protected channel at all times?

Some interesting policy questions raised by MONSTAR are:

1. Given the vulnerability of MONSTAR to jamming, would it still be worthwhile to deploy MONSTAR and the cooperative vehicle-surveillance equipment, or is that just asking for trouble and disruption?
2. Would it be possible to obtain international agreements which would provide for the non-jamming of MONSTAR and for the taking of action against jammers precisely located (to twenty or fifty feet accuracy) in real time, extending even to the destruction of jammers on one's own or foreign territory? Would it be helpful to cede the operation of MONSTAR to the United Nations or to some other international body?
3. Given that the benefits of MONSTAR accrue largely to civil users and not to the military who are deploying NAVSTAR, can the United States government manage to aggregate the benefits to pay the relatively small increment for deploying MONSTAR equipment on NAVSTAR satellites?

Modern society, with its complex specialization and distribution systems, is increasingly vulnerable to terrorist or enemy disruption. Must the United States and the rest of the world forego valuable and pervasive civil benefits of a cooperative position-surveillance satellite because of the possibility of disruption by terrorist or foreign action; or is there a combination of unilateral capabilities and international agreements which will make this system more than an attractive nuisance?

Military Applications of High-Power Lasers

The high-powered laser is another technological development the potential significance of which should be evaluated. A military application of a high-power laser is one in which it is the energy of the laser itself which damages a target. Such applications are not to be confused with those of low-power (not damage-producing) lasers (laser-guided bombs and projectiles, laser rangefinder, laser gyroscopes, and the like) which are not discussed here.

An assessment of high-power lasers requires comparison with alternative weapons which could be available in the same time period. The questions to be addressed are:

—Can a definitive evaluation of laser weapons be made now? Is a research and development program warranted toward the acquisition of laser weapons or to hedge against possible advance by others toward laser weapons?

—What should be the response to possibly-exaggerated claims of the promise of laser weapons?

—Are there possible arms control measures which would save money and increase security?

The glass laser and gas laser exemplify high-power lasers available today and in the future. A typical glass laser contains neodymium ions dissolved in glass and emits energy at a wavelength of about 1 micrometer. One efficient gas laser depends for its operation on molecular transitions in carbon dioxide and emits at a wavelength of about 10 micrometers. As an illustration of the ability of a laser to project energy over long distances, consider the following example. After passing through 10 kilometers (about 6 miles) of stable air or vacuum, most of the power from a 30 centimeter (about 1 foot) diameter mirror of a carbon dioxide laser would be concentrated on a circle of 80 centimeters (about 2.6 feet) diameter.[5]

Beyond consideration and design of a laser weapon, however, the planner must consider countermeasures and alternatives. Furthermore, this consideration must be in the same epoch as that when laser weapons might become widely available—perhaps ten years hence.

A rather complete assortment of laser applications can be extracted from the possible combinations of basic options (ground, air, sea, and space) and targets (ballistic missiles, cruise missiles, aircraft, tanks, personnel, satellites, and ships).

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[5] Two chief mechanisms by which lasers damage targets are heat and thermally-induced shock. The laser output energy will normally be redirected at a target by means of a movable mirror. Only at relatively short ranges can the laser beam be focused to a diameter less than that of the output mirror; hence the power density at the output mirror may exceed that at the target. The weapons designer is concerned with his ability to damage targets by energies and pulse lengths which will not (even after many repetitions) damage the output laser mirror itself. The output mirror or output window may absorb very little (in the range of 10^{-4} or 10^{-3}) of the incident light, whereas a common structural material like shiny aluminum may have an absorption coefficient on the order of 10^{-2}. If the purpose of a high-power laser weapon is to melt at a distance a substantial skin of a centimeter thickness of aluminum, and if incipient melting is achieved by causing a 400°C temperature rise, then the required energy per square centimeter absorbed in the target is on the order of 200 calories per cm^2 or about 10^3 joules per cm^2. A gas laser with 30 centimeter diameter output mirror at a distance of 10 kilometers can illuminate an area of about 0.5 m^2, and even black aluminum would require on the order of 5 million joules of laser light to melt it at any spot. It could, however, be substantially weakened by energies only about half this great. On the other hand, if the aluminum is shiny, then laser output energies one hundred times as large would be required for melting such a thick skin. Plastic canopies of aircraft, however, could be melted at much lower power levels, since the absorption is largely in the surface, and the heat is lost only slowly into the interior.

Long-pulse or continuous lasers can be used to cause damage by melting. Short-pulse lasers can also cause damage by bringing the very surface layer into the liquid or gaseous phase. The explosion of the surface layer can exert an impulse on the remainder of the solid material sufficient to cause damage. An absorption of 1 million joules of laser light per square meter could cause a significant impulse of 1000 dyne-second per cm^2, but the propagation of such energies through air in the required 10^{-8} seconds or less is problematical.

The restriction of the laser system to propagation in reasonably clear air means that some of the applications can be eliminated as candidates. Some of the more interesting elements of this basing-target matrix can thus be eliminated as impractical. For example, consider the promise of lasers for ABM, meaning primarily ground-based ABM for defense of the Minuteman force or for city defense. It is clear that even if laser development were eminently successful and if lasers were cheap and reliable, such a defense would be ineffective because the attacker has it within his capacity to explode some nuclear weapons at high altitude. This would raise a great deal of dust at ground level and would thus prevent use of the lasers against subsequent incoming weapons.

Thus, many of the cases are nullified by *incapacity* or countermeasure. In others, alternative weapons simply have greater capability than the laser for comparable investments, and equal or greater maximum capability independent of investment. The short time available to the laser for target kill and the large energies required for such suggest the propulsion of a projectile or of a rocket with the same primary energy source. Indeed, since the laser must rely on non-laser-type acquisition capabilities, this comparison goes beyond the energy source.

At least two possible combinations must be discussed in the context of alternative systems—air-based anti-aircraft capability and shipborne anti-cruise missile defense. The former suffers by comparison with existing semi-active radar-homed missiles like Sparrow. The latter, I believe, is dominated completely by new missile systems which have been tested successfully but which have not yet undergone full-scale development in this application.

A space-based laser ABM faces a much more complex and demanding task and has fewer competitors, but fails as a practical candidate for deployment if only because neither the United States and the Soviet Union would tolerate the other's gradual deployment of such capability. Rather, nuclear-armed interceptors would be used to attack the imagined laser-bearing satellites as they were being readied in orbit over a period of months. Furthermore, of course, both the development, testing, and deployment of satellite-based ABM systems are banned by the ABM Treaty.

In contrast with the enormous potential for application of lasers in the separation of uranium isotopes, for measurements, communications, and designation (as in the terminal guidance of bombs and projectiles), and in fabrication, their use in damage-producing weapons is in general non-competitive with the further evolution of existing weapons—e.g., guided missiles. Some weapon applications for which high-power lasers do seem technically effective are inappropriate because of high development costs which are amortized over a few targets, in contrast with a greater non-laser expenditure per target killed, but with lesser development cost.

Direct Sea-to-Air Refueling of Aircraft (DSTAR)

The topics discussed thus far, with the exception of high-energy lasers, are necessarily selected from a larger set important to future American military capability. They bear no necessary relationship to the present emphases of Defense Department programs, although their elements are largely present if unemphasized. The author has recommended that such current programs as the B-1 bomber and the Trident submarine (and certain advanced tactical aircraft and support programs) should be *replaced* by programs such as those discussed above.

But modern electronics and control technology, in combination with existing systems, can have other far-reaching impacts on American capabilities. For instance, they can offset the reluctance of allies or neutrals to provide refueling bases for American combat and military cargo aircraft. Briefly, a system can be developed which will permit an aircraft to refuel from a ship at sea in five or ten minutes. An aircraft as small as an F-4 or as large as a C-5 can receive fuel pumped through a hose which links a tanker ship to an aircraft circling at perhaps 1,000 meters distance and 300 meters altitude. A modest 50,000 ton tanker can refuel 500 C-5 flights or 5,000 F-4 sorties, at a cost far below that for providing tanker aircraft on station for air-to-air refueling. This system has been dubbed DSTAR (for "direct sea-to-air refueling") and is described briefly below (and more extensively in Ref. 6).

Even under normal circumstances, consideration of range-payload tradeoffs, vehicle productivity, and general utilization of capital might drive one toward the use of ordinary seaborne tankers for refueling fully-loaded cargo (or even passenger) aircraft. Thus, while the C-5 full payload is 220,000 pounds with a range of 3,000 miles, at 5,500-mile range its payload capacity is reduced to 100,000 pounds. DSTAR could more than double the transport capacity of a fleet of C-5s; its effect on an aircraft designed specifically for DSTAR could be greater.

For supply of American military and allies, it is even more important to be able to refuel enroute. During the "October War" of 1973, Air Force Military Airlift Command (MAC) aircraft did not, and could not, land and refuel at NATO bases

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6. Condensed from Document JSR 75-9, ("DSTAR"—Direct Sea-to-Air Refueling) by R. L. Garwin, June 1976, available from National Technical Information Service, Washington.

while carrying material from the United States to Israel. As is well known, we did use the Azores, without which our effort would have been severely impeded.

Even if allied bases were freely available to the United States, the price that has to be paid for continuing access to these bases might be much reduced if there were a practical alternative to continuing use of the bases.

All in all, I would characterize the need for an at-sea in-flight refueling capability as something between urgent and critical.

In-flight at-sea refueling as described here requires an aircraft to fly in a tight pylon turn centered on a normal tanker vessel of small-to-intermediate size equipped with a small amount of specialized equipment. The aircraft is minimally modified, without a winch on board, and is connected by a hose of substantial diameter to a short mast on the tanker. A nominal "drink" duration of five minutes is quite feasible.

Approximate design considerations lead to DSTAR characteristics for two aircraft types as shown in Table 2.

The data for Table 2 are calculated for aircraft on special autopilot at a bank angle of about 45 degrees and at a speed 20 percent above safe landing speed which, in turn, is 20 percent above stall speed.

An aircraft may prepare for refueling by "snatching" a leader line stretched between two light masts on the ship and entering the refueling orbit. A light servo-controlled winch on the ship would maintain tension on the light line until the aircraft achieved a stable orbit, at which time a heavier servo-winch would take over, maintaining constant tension in the range of 12 tons for a C-5 or 1.4 ton for a fighter aircraft. The refueling hose would then be paid out along the leader line, entering a refueling socket in the aircraft. In five minutes, the aircraft tanks would be filled with fuel, the hose disconnected and withdrawn along the leader line. The aircraft would then fly over the ship once more, allowing the leader line to be

Table 2
DSTAR Parameters for Two Aircraft Types (5-Minute Refueling Time)

Aircraft Type	**Refueling Orbit**		**Hose**				
	Radius	**Altitude**	**Weight**	**Tension**	**Diameter**	**Pressure**	**Air Drag**
C-5	500 m	300 m	6.0 ton	12 ton	10 cm	1500 psi	2 ton*
F-4	500 m	300 m	0.7 ton	1.4 ton	5 cm	1500 psi	1*–0.1**ton

*Cylindrical (un-faired) hose.
**Faired (streamlined) hose; drag coefficient 0.1.

stowed in the winch for immediate reuse. Such a system could also be set up on land to refuel aircraft where no suitable landing field exists.

It appears desirable and feasible to develop immediately such a capability to refuel slightly modified aircraft, of sizes ranging from 50,000 pound fighters to the largest 700,000 pound cargo craft, from tankers underway at sea. Major benefits would accrue to United States military posture and to our position in negotiating access to facilities in allied nations.

Conclusion

The five preceding analytical sketches cover a broad range of application and of technical ripeness. Nevertheless:

—Minuteman pebble-fan defense should be taken seriously *now* as an alternative to continuing cries of Minuteman vulnerability or to hasty action toward abandonment or replacement of Minuteman,

—the tactical cruise missile of 1,000 kilometers range should be evaluated as a *system*, working with theater command and control by radio link directly to the missiles or to a receiver/programmer which loads the cruise missile memory with flight commands at launch. Such evaluations should be used to guide cruise missile development and investment decisions, but also to support much more difficult decisions as to modifications of the structure of the armed forces and as to the further investment in tactical air forces,

—the impact of NAVSTAR on United States and NATO military effectiveness should be evaluated now, to guide development and investment decisions on cruise missiles, guided bombs and projectiles, and on competing systems. This evaluation must take into account realistic possible countermeasures,

—high-power laser development should be evaluated with more attention to utility in wartime than on test ranges, and with even-handed optimism toward future improvement of competing technologies such as guided missiles. The result is likely to be a greater concentration on exploratory development and less on field hardware,

—direct sea-to-air refueling of aircraft (DSTAR) should be demonstrated promptly using automatic flight controls and a tower on land instead of a ship, and the technique should be refined. The increased military capability provided by DSTAR should result in some dozens of small tankers being modified to provide DSTAR capability.

Unconventional or non-single-service applications of technology like those sketched here are not normally elicited even by capability-oriented requests and analyses at the level of the Secretary of Defense. It has been a long time since Systems Analysis under Alain Enthoven first attempted high-level rational planning, e.g. in relation to air lift/sea lift capability. Even there, the bureaucracy provided the Office of the Secretary of Defense (OSD) with the C-5 aircraft as a solution and not with the Fast Deployment Logistic Ship (FDL). The problem is a predominantly due to the bureaucratic and technological imperatives at the working level of the Services, which control the response to a request even from OSD.

We are little better off as regards exploratory development of technology to accomplish important missions. In many cases, the exploratory development is regarded as long-since accomplished and of little interest to technologists who find challenge in new and more powerful technology, rather than in the solution of down-to-earth problems of which they may be only vaguely aware.

Whether approached from the national requirements aspect (via OSD) or from that of technological initiative, solutions such as those described above for the most part are handled awkwardly by the existing bureaucracy. The Navy is not disposed to take an initiative which will result in increased capability for the Tactical Air Force and for the Air Force Military Airlift Command. The Army has little interest in planning efficient means of blowing steel scrap into the air in response to signals from modified highway speed-control radars, when their contractors could be working instead on super-high-performance nuclear-armed interceptor missiles together with phased-array radars at the forefront of the state of the art. The myriad applications of NAVSTAR compete with and will displace many kinds of on-board and ground-based radar and communication systems. The NAVSTAR constituency is yet to be formed; these others exist. It was difficult to obtain $50 million for NAVSTAR a few years ago when the Navy felt that it was $500 million short in its ship building budget. This was irrespective of the fact that money spent on NAVSTAR would improve naval capabilities far more at a given time in the future than would the money spent on ships. To the extent that cruise missiles displace ground-based or carrier-based tactical air, they are unwelcome in those constituencies which see primarily the threat to their case for modernization and expansion of conventional air wings or carrier forces.

Whether OSD takes the initiative or not, it must demand from the Services the analysis of broad service missions, together with alternative technologies and approaches for accomplishing these missions. The cost of organizational change is considerable, but our choice of new or old technology must not be limited by existing organization and bureaucratic structures.