One View of the Early Days of Precision Guided Munitions and the Systems in Which They are Embedded

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To compress a vast subject into a brief talk, I will use mostly my own experiences. We can all understand that viewing a scene or a topic through a particular window of time and space provides a very incomplete picture, but I think it is enough to illustrate the evolution of this field, really of putting weapons on targets in a precision and timely fashion. To some extent this unites the dreams of the armorers and the peaceniks—and their fears.

Let's get started.

We are all familiar with the evolution of ballistic and airborne weapons, exemplified by the catapult, the arrow, and the glider. I limit myself to targets on the surface of the Earth, although they may be in motion like cars, trucks, tanks, or ships. Important other classes of targets are aircraft themselves, ships, submarines, satellites, and missiles in flight, outside the scope of this brief discussion.

My involvement in most of these things began in the late 1950s, when I was a consultant to the President's Science Advisory Committee, PSAC, and chaired its Military Aircraft Panel—MAP--among other activities. The MAP was a serious effort, with a two-day meeting every month, and a group of individuals, some of whose names you will recognize:

> Among the MAP members were Terrell Greene from the RAND Corporation, Fred Wolcott from an Army think tank, René Miller from MIT an expert in aeroelasticity, while Al Flax hailed originally from Cornell Aero. There were also Harold M. Agnew, whom you know, Harold W. Lewis—physicist from UC Santa Barbara, and Charles P. Slichter—physicist from the University of Illinois at Champaign/Urbana.

I had spent several weeks in Korea in March-April 1951 with my more senior Chicago colleague, Joseph Mayer, looking for opportunities to develop and apply technology in support of the nascent tactical air command. And in 1953-54 I spent three days a week with Project LAMP LIGHT, at Lincoln Laboratory—an effort to extend the continental air defense to the sea lines of approach of Soviet nuclear-armed bombers.

The general work of MAP was then energized by the real-life example of the Vietnam War, and there was a good deal of synergy between the PSAC MAP and the JASON Summer Study of 1966 that proposed an "air-supported barrier" to North Vietnamese infiltration through Laos. In general, though, the MAP typically had eight one-hour briefings on each of two successive days, meeting in Room 206-208 of what is now the Eisenhower Executive Office Building just west of the White House. We monitored for the President (and served as a technical arm of the Office of Management and Budget) as the DOD and the armed services designed, deployed, and operated aircraft and their weapons. This was an intensely personal and high-stress engagement, meeting with military officers, DOD officials, and defense contractors.

It was clear that most of the investment and operating costs related to the platforms—the aircraft—and much less attention was paid to the overall system. So aircraft generations followed one another with an aim to increase payload, maneuverability, speed, air-to-air effectiveness, and the like, with indifferent or even negative impact on the timely, precise delivery of munitions on target.

The observation drones that are ubiquitous now, even in civilian life, were largely despised by the military. The Army, which stood to benefit most from the development of drones would have a program once in a while, but as soon as it began to bear fruit, the Air Force would take it away and kill it.

During the Vietnam War, the MAP was able to persuade the system to have the DOD and its military commanders make use of the technology that had been deployed by CIA for observation over North Vietnam—unmanned high-speed or low-speed drones that would follow preprogrammed courses and return film and other records for analysis.

There are at least three elements to the improvement of the capability to destroy ground targets, fixed or mobile:

1. Identify and locate the target.
2. Guide or self-guide munitions precisely to the target.
3. Base munitions close enough to the target to enable timely attack.

The MAP, in monitoring a large purchase of aircraft by USAF in the mid '60s, was most interested in a RAND study and field trials in which the performance of jet aircraft in attacking ground targets was assessed as a function of aircraft speed and target visibility. Availability of that study report was intentionally delayed so that it didn't have negative influence on the procurement, because it showed that jet aircraft were essentially ineffective for reconnaissance/strike, and that when the pilot was able to observe a ground target, he could almost never strike it without going around.

I flew in a Grumman A-6 aircraft on simulated bombing runs over Long Island, in which one of the main virtues of the (vacuum-tube) cockpit automation was the ability to return for a second bombing or strafing run after a first strike on the target. The aircraft would do a loop and position itself for a second attack.

Once one separated the process of location of the target from that of attack on the target, one had the concept that we rather unimaginatively called "bombing by navigation," so that a sufficiently accurate weapon would not even have to observe the target, but could be flown to the "grid point" at which the target was guaranteed to be located, and if the target was moving, an observer could continuously monitor the changing location of the target, to sufficient accuracy, and communicate this through a network or even directly to the munition, as it approached the target.

Before the days of packet-switched networks (e.g., TCP/IP) this would have to be managed by circuit switching and local communication links.

Another approach long bottled up by the Air Force finally saw service in 1972, when Al Flax, a long-time member of the PSAC MAP, had become Assistant Secretary of the Air Force for R&D (and also, Top Secretly, head of the National Reconnaissance Office, NRO). Flax was convinced of the virtue of the laser-guided bomb, a Texas Instrument operational retrofit of any one of the millions of "iron bombs" in the Air Force inventory to a *laser-guided bomb*, which would bring the bomb to within a few meters of the center of the designating laser beam. I recall during the Vietnam War, repeatedly phoning Pentagon officials to urge them to procure more of the LGB guidance kits from Texas Instruments.

Eventually, Air Force Secretary Bob Seamans announced that a single USAF aircraft armed with two laser-guided bombs was able to destroy a span on the Thanh Hoa Bridge, after the United States had lost 41 aircraft in futile attempts to do that with ordinary munitions.

But why was it necessary to have a valuable, vulnerable pilot and a costly aircraft to fly the munition to the neighborhood of the target, from which point it could navigate its way precisely or home on the target itself? These were far from new ideas, but unlike the rapid evolution of technology during WWII, such developments were repressed.

Indeed, USAF and the Strategic Air Command needed a long-range nuclear-armed cruise missile because its aircraft would be vulnerable to Soviet air defenses during a nuclear strike on the Soviet Union, but Air Force doctrine was expressed in the demand for new-generation aircraft rather than improving the overall capability and survivability of the aircraft fleet in both the short and long term. Thus, when an Air Force General told us at a JASON Summer Study (at the Bishop's School in La Jolla) that it was technologically infeasible to develop a nuclear-armed cruise missile of range 2500 km that would fit into the bomb bay of the projected B-1 aircraft, I was able to tell him that the Navy had that very week demonstrated the flight performance of a cruise missile dropped from an A-6 aircraft, although its nominal development and basing was on U.S. nuclear submarines and its role was primarily to carry conventional arms.

Credit for that development goes to Admiral Elmo R. Zumwalt, who had been the liaison officer to the PSAC Naval Warfare Panel—NWP—that I also chaired. Captain "Bud" Zumwalt would sit with us during our two-day monthly meetings, as liaison with the Pentagon and helping to bring briefers from the armed services, the Office of the Secretary of Defense—OSD—and military contractors. He and his corresponding liaison for the Military Aircraft Panel would also arrange field trips for the MAP or the NWP. When Captain Zumwalt was taken from us to head the "brownwater Navy" in Vietnam, and from there selected to lead the U.S. Navy as Chief of Naval Operations—CNO—I wrote him a note of congratulations, to which he replied that he was *"off and running on CAPTOR mines and cruise missiles."*

To avoid resistance by naval aviation, Zumwalt oriented the cruise missile development to basing on U.S. nuclear attack submarines—SSNs, although much of the testing would be carried on by airdrop from naval A-6 attack aircraft.

A snapshot of a global navigation/location system is available from my proposal of 1958 in conjunction with the 10-Nation Conference on Surprise Attack, but that Conference and even preparations for it began in 11/1958, whereas my proposal is dated 07/1958. There is also my post-conference proposal to Mannie Piore, IBM's first Director of Research, that IBM build and operate such a navigation system for the commercial airlines.

Because of the unavailability at that time of mobile computers, I proposed a system in which all the computation was done on the ground, with the tri-laterated position of the aircraft (from radio receivers on high-altitude satellites) communicated via satellite link to the aircraft. A 1974 publication in which I proposed *"A Cruise Missile System for Europe"* (CMSE), among several papers drafted during a 6-month sabbatical from IBM at Harvard, included theater surveillance from phased-array antennas supported by high-altitude helicopters, that not only located moving targets out to 200 km or more from the helicopter, but also the munitions that had been launched into the system and that would be commanded by those same antennas (used as transmitters) to approach and to home in on their targets. Satellite imaging of targets was not described because the CORONA film-return satellite system of the day and its follow-on imaging systems were highly secret at the time and could not be discussed.

After President Nixon dissolved PSAC in February 1973, I turned more to open publication of the proposals we had made by the MAP within the government.

After the MAP (and JASON) had studied the efficacy of U.S. bombing in Vietnam, I went to the Pentagon to meet with the then USAF Chief of Staff to inform him of RAND Corporation findings that the CEP for half the bombs dropped in Vietnam was 700 ft, and that the other half could not be located. The burden of my discussion was that USAF should urgently support the deployment of what was later named GPS, but that in the meantime, they should choose among the best available non-satellite systems in order to improve their effectiveness. The Chief of Staff was incredulous not only about the recommendations but about the facts.

In addition to the "bombing by navigation," the MAP vigorously promoted homing munitions—on radar signals to destroy radar transmitters, and on the splotch on the ground provided by either a ground-based or air-based laser target designator. The work of the PSAC MAP was communicated in detail to the 1966 JASON Summer Study in Santa Barbara, at which JASON proposed the "air-supported barrier" to North Vietnamese infiltration through Laos into South Vietnam along the Ho Chi Minh Trail. That was to be a real-time implementation of theater surveillance and weapon delivery. Surveillance against trucks in the Laotian tree cover was provided by ground-based sensors delivered by air, transmitting by radio to an orbiting drone aircraft acoustic, magnetic, or seismic signals picked up by the sensors. These transmissions would be relayed by a directional microwave antenna on the drone to a base station at Nakhon Phanom—NKP—in Thailand, and selected and approved target locations on the ground forwarded immediately to loitering strike aircraft that would deliver munitions against those targets in real time—i.e., within a few minutes. These air-delivered sensors consisted of modified U.S. Navy sonobuoys, adapted from their usual role as radio-reporting sensors of submarines.

The computers at NKP implemented the Fast Fourier Transform (FFT) in order to distinguish trucks from other noises, for instance, but USAF dug in its heels and instead relegated this information to the general category of intelligence, used for determining the next-day's air tasking order.

Not until Secretary of Defense Robert McNamara replaced Army General Alfred D. ("Dodd") Starbird by Air Force General Jack Lavelle, did Air Force pay real attention to this source of intelligence. The air-delivered sensors, however, played an important role in breaking the siege of Khe Sanh, where 5,000 Marines had been trapped by some 20,000 North Vietnam forces. Gordon J. F. MacDonald, a leading figure in the JASON study and in some IDA studies of the effectiveness of bombing in North Vietnam, had himself flown by helicopter to Khe Sanh during the siege in order personally to understand and to advance the performance of the sensor system; he was a man of outstanding courage and energy.

Although the MAP saw clearly the benefits and even the precision ultimately available from a GPS-like system (even without atomic clocks on the satellites), many of what are now the most commonly used features of GPS were hardly imagined. We could plan on determining the position of an aircraft within a meter or so, and to be able to direct a GPS-homed munition against a target whose position was established in GPS coordinates, but it was not easy to conceive of having available any significant portion of the Earth's 3-D surface in GPS coordinates, let alone the possibility of accurate digital maps of cities and buildings that are taken for granted in everyday civilian use of smart phones. The ubiquitous communication available from internet-like connectivity was also missing and available only later.

Nevertheless, it was easy to propose GPS for flying and landing aircraft and munitions, because an aircraft runway or target could readily have its position determined stably in GPS coordinates.

In the proposed *Cruise Missile System for Europe*, it was envisioned that the control center could be in the United States, on a ship, or elsewhere, given that even a double transit time of signals in transatlantic cables or via satellite relays could readily be tolerated by such a system.

In fact, although the JASON concept of the air-supported barrier used an unmanned Beechcraft Bonanza aircraft operating high over Vietnam or Laos, the Air Force was never comfortable with that approach and perhaps for good reason always had a pilot flying the relay aircraft. Air Force insisted also on a backup approach, using a large C-121 (later a C-130) aircraft that had not only the VHF-to-microwave relay system, but also some 20 or so onboard workstations, with their operators, to serve as a command center instead of the one on the ground at NKP.

Secretary of Defense McNamara had been briefed at the end of the 1966 JASON Summer Study and, rather than creating the recommended 30-person military-civilian review group to study the proposal further, commanded its immediate implementation as a Secret project codenamed DCPG (Defense Communication Planning Group). The effort was based at the Naval Observatory in Washington, and I and Henry Kendall and Hal Lewis, as I recall, served on its Advisory Panel, together with a number of other government and non-government members. I recall urging a fellow DCPG Advisory Panel member, former head of Systems Analysis in OSD, to buy a few thousand laser-guided bombs, but he said that they wouldn't be able to do that, because they had already defined the three million tons of bombs that were to be procured in the coming year.

Although Air Force had delayed the initial use of the LGB probably by more than a year, they were used highly effectively in the Vietnam conflict, to the extent that 40,000 LGB were employed. The delay was caused, at least in part, by the Air Force doctrinal insistence on a "fire and forget" weapon, to be launched from the aircraft that observed target, which could immediately decamp in order to be less vulnerable to enemy fire. USAF was far less interested in supplying munitions on targets designated by ground observers (especially Army ground observers) or from helicopters or observation aircraft.

Even now, with the very public (if often unacknowledged) use of laser-guided missiles fired from Predators or other drone aircraft, the (remote) observer keeps the cross-hairs of the designator on the target until the munition strikes.

Other approaches were also used, such as Walleye, which was truly a fire and forget weapon, so that it would lock on to the target via its own TV imager while on the wing of the aircraft, and would then be launched against it, maintaining a lock on that TV image, as it enlarged with the approach of the weapon.

What is new and enormously important since the 1970 era is the global communication network that enables Predator imagery to be transmitted instantaneously via satellite link to control centers in the United States where military operators observe, often for hours or days at a time, the potential targets for the weapons. There is, also, a great deal of steady surveillance from multiple high-definition TV imagers on drones, orbiting a city or an area of operations and likewise downlinked either to a base in the area or back home.

While the GPS system, as configured and improved for military use to the present time, has features that render it less vulnerable to jamming and deception, it can be and is jammed and its use denied in small areas of the battlefield. Commercial GPS jammers are an article of commerce, so that many of the GPS-guided munitions launched by the United States have GPS denied as they approach targets protected by jammers. This hardly affects the accuracy of impact, however, because almost all such munitions now carry an onboard inertial navigation system—INS—sufficiently accurate to maintain final approach on the designated target even if GPS is not available. With "bombing by navigation" one can identify the target visually, so that a weapon, when delivered, will have impact accuracy of a few meters.

Systems are sufficiently flexible that not only the point of impact, but also the direction and even the precise time can be specified in some cases, so that a weapon can be directed through a window, down a chimney, or along a tunnel, to explode inside. Thus, when the strike is to take place (perhaps because of some communications activity indicating that the building is being occupied by military forces) dense cloud or camouflage will no longer prevent effective strike.

But these systems have not had to withstand the test of large-scale combat against a capable adversary, for which we can be grateful. It is not clear the extent to which the necessary communication links can be jammed, the orbiting drone aircraft destroyed, or the systems otherwise diminished in capability.

For targets that are moving, there is usually continuous designation, so that the target vehicle or vessel can be attacked either by a device that homes on the designating spot—e.g., a laser-guided bomb—or the designator can be equipped with a precise laser ranging device and angle encoder, so that once set up, the "designator" can be used as an input to the system, providing accurate GPS coordinates vs. time for the moving target. Thus, the munition itself does not need to have visibility of the target during its flight.

From the beginning, incidentally, I always proposed a requirement that the weapon be capable of being dudded or diverted—in case a target vehicle at the time of arrival of the weapon is in a marketplace, under a tunnel, or the like. Similar dudding or diversion would be useful in case of interference with the targeting cycle, so that a weapon that is prevented from striking the target does not cause undesired damage.

At the end of course, warfare advances, and not always to our advantage. During the Iraq War, the opposition introduced the Improvised Explosive Device—IED, controlled by increasingly effective and countermeasures-resistant fuzing and arming systems, to destroy U.S. and Iraqi government vehicles on the roadways.

Poorly trained suicide pilots brought down the World Trade Center towers, and individuals with explosive suicide vests have transformed modern society.

According to Winston Churchill, "No matter how enmeshed a commander becomes in his plans, it is occasionally necessary to take the enemy into consideration."