VIOLATING THE SANCTUARY

THE DECISION TO ARM SPACE

A Monograph
by

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ABSTRACT

VIOLATING THE SANCTUARY - THE DECISION TO ARM SPACE by Maj Tommy C. Brown, USAF, 50 pages.

This study examines the decision to deploy a space-based kinetic kill vehicle (SBKKV) by examining the validity, feasibility, suitability, and acceptability of such a deployment.

Determining validity entails verifying that a need exists for the type of capability such a weapon might possess. By examining the development of other conventional weapons capabilities, one may define the operational need behind that development. For example, numerous programs are underway to address the long-term need to extend the standoff engagement range of conventional (non-stealthy) aircraft using precision-guided munitions (PGMs). Other initiatives seek to improve the ability to destroy hardened point targets and to conduct Suppression of Enemy Air Defenses (SEAD).

Addressing the feasibility of deploying space-based weapons involves examining the capability of technology to meet the needs of various missions. Initial investigations reveal that relatively "off the shelf" technology could support the development of a SBKKV using hypervelocity impact to destroy terrestrial targets.

Assessing the suitability of space-based weapons requires an examination of how operating from space affects the application of technology to the mission. By the nature of its operating medium, a space-based weapon provides unique capabilities and limitations which require consideration in its design and employment. By comparing missions with these capabilities, one may identify requisite assumptions, qualities, and performance characteristics for a space-based system.

Examining the acceptability of employing space-based weaponry against terrestrial targets requires weighing benefits gained against costs incurred. Definitive estimation of research/development/procurement/life cycle costs is beyond the scope of this study. However, a relative order-of-magnitude examination of the cost of alternative means of mission accomplishment is not. Similarly, an examination of the political ramifications of such employment warrants a separate study unto itself and will be left to the attention of future research efforts.

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INTRODUCTION

Since Sputnik, space has been an arena for political and strategic military struggle. Accordingly, military establishments have developed and exploited space-based capabilities to assist and enhance terrestrial force application. Although international agreements and conventions ostensibly sanctified space for only peaceful uses, constraints upon military involvement in space were often more technological than legal. As technology advanced, so did the ability of space assets to enhance terrestrial force operations with services including communications, navigation, weather, and intelligence. President Reagan's Strategic Defense Initiative (SDI) and subsequent anti-satellite (ASAT) developments heralded a concerted effort to change these technological constraints, and introduce the capability to conduct force projection operations in space. While the events of the last five years have overtaken SDI itself, the resulting technological advances remain.

These same events have also resulted in a radical transformation of the US military into a CONUS-based power projection force. Airpower is a vital element of that power projection capability. However, air defense technology is driving the US Air Force to rely upon stealth and standoff weapons capability to set the conditions for success. The opening hours of the Gulf War saw the integration of both capabilities, using F-117's and Tomahawk Land Attack Missiles (TLAMs) in the initial weapons mix to defeat the Iraqi air defense network.

Compounding this situation, targets themselves are becoming more difficult to kill. In Iraq, 2000-lb laser-guided bombs shattered against well-built bunkers. A special penetrating munition (GBU-28) had to be hastily engineered and built in the US, and rushed into the theater of operations. Weighing 4700 lbs, the GBU-28 required a high-altitude delivery from a F-111 in clear weather over a heavily-defended target, requiring both air superiority and Suppression of Enemy Air Defenses (SEAD).

One potential solution is the development of low observable technologies supporting stealthy aircraft. However, even stealth has its limitations. Counter-stealth technologies do exist, and both the US and Russians are developing them. The day will come when even the B-2, the incarnation of Douhet's invulnerable bomber, cannot go it alone.

Spin-offs from SDI technology offer the potential to position conventional weapons in space to attack hardened, high-value, well-defended terrestrial targets in order to augment the capabilities of terrestrial forces. This study will examine the decision to deploy such weapons in space by examining the validity, feasibility, suitability, and acceptability of such a deployment.

Determining the validity of space based weaponry requires verifying that a need exists for the type of capability such a weapon might possess. By examining the development of other conventional weapons capabilities, one may define the operational need behind that development. For example, numerous programs are underway to address the long-term need to extend the standoff engagement range of conventional (non-stealthy) aircraft using precision-guided munitions (PGMs). Other initiatives seek to improve the ability to destroy hardened point targets and to conduct SEAD.

Addressing the feasibility of deploying space-based weapons involves examining the capability of technology to meet the needs of various missions. Initial investigations reveal that relatively "off the shelf" technology could support the development of a space-based kinetic energy weapon using hypervelocity impact to destroy terrestrial targets. Different missions will levy different requirements upon such a system. Thus this section will also examine the adaptability of a common vehicle to meet a spectrum of mission needs.

Assessing the suitability of space-based weapons requires an examination of how operating from space affects the application of technology to the mission. By the nature of its operating medium, a space-based weapon provides unique capabilities and limitations which require consideration in its design and employment. By comparing missions with these capabilities, one may identify requisite assumptions, qualities, and performance characteristics for a space-based system.

Examining the acceptability of employing space-based weaponry against terrestrial targets requires weighing benefits gained against costs incurred. Definitive estimation of research/development/procurement/life cycle costs is beyond the scope of this study. However, a relative order-of-magnitude examination of the cost of alternative means of mission accomplishment is not. Similarly, an examination of the political ramifications of such employment warrants a separate study unto itself and will be left to the attention of other research efforts.

SECTION 1: VALIDITY

In considering the role a space-based kinetic kill vehicle (SBKKV) might play in enhancing terrestrial forces' capabilities, one should begin by validating the need for any such role. One method to determine this validity is to examine the requirements of operational forces in the field which currently go unmet. These needs reflect the demands levied upon operational forces by the threat environment in which they must operate as well as the targets these forces must prosecute. This study will address both. Implicit validation for those requirements identified in this study lies in the ongoing weapons development programs to redress these needs.

1-1. THREAT

For the 40 years of the Cold War, the most demanding requirements for military hardware lay in coping with Warsaw Pact forces in Central Europe. Present US Air Force structure still reflects the need to penetrate a highly sophisticated and lethal air defense network in order to attack and destroy high payoff targets deep in an enemy's rear areas. Although the end of the Cold War has moved the focus of conflict away from Central Europe, it has not ended the development of increasingly lethal modern air defense systems. Russia, for example, has exported its latest generation surface and airborne air defense systems all around the world. The US Air Force has therefore adapted a three-part strategy to negate the air defender's apparent advantage. The first part of this approach is SEAD, or Suppression of Enemy Air Defenses. The second is stand-off weapons delivery. The third is low observable technology, or "stealth."

1-1a. SEAD

A number of mechanisms exist by which each service may conduct SEAD, both lethal and non-lethal. Each requires careful, detailed, and timely orchestration of a number of capabilities to generate relatively short-lived effects. Through combining lethal and non-lethal means, these suppressive effects can be cumulative over time, resulting in an increasing degree of disruption of air defensive capability. Thus the Gulf War air campaign began with a joint effort to disrupt the integration function of the Iraqi air defense system, then progressed to piecemeal negation and destruction of its isolated parts over time.

Although non-lethal SEAD can employ a variety of means, the ability to conduct lethal SEAD in support of deep air strikes still lies primarily with aircraft. However, the current generation of F-4G Wild Weasel and EA-6 Prowler aircraft is highly specialized, few in number, and aging fast. The USAF is augmenting its fleet with modified F-16 aircraft using High-Speed Anti-Radiation Missiles (HARMs) as a stopgap fix.[1] However, the F-16 with limited signal location and engagement systems is only about 80% as capable as those F-4's being replaced. One long-term fix would employ modified F-15s to locate and destroy air defense radars. However, even this approach will not suffice to negate existing late-generation systems such as the SA-10 and SA-12, which constitute a growing percentage of the world's SAMs. For SEAD against these and future advanced systems, both the USAF and Navy are experimenting with using cueing from space-based systems to engage with stand-off, precision guided weapons.[2]

1-1b. STANDOFF

The rationale behind this trend goes beyond SEAD. Standoff delivery ostensibly allows the delivering aircraft and crew to remain outside the SAM engagement envelope. Autonomous precision munition guidance maximizes weapons effects upon the intended target, while minimizing the number of crews and aircraft exposed to the air defense threat. Additionally, precision guidance allows the aircraft to fly a more survivable delivery profile within the air defender's engagement envelope, if standoff delivery is infeasible. In light of ongoing force level reductions, such maximized effectiveness and force preservation become critical since fewer delivery systems will be available.

One example of this situation lies in the Air Force ground attack fleet and its envisioned employment. As the drawdown continues, the Air Force will shrink to 20 fighter wing equivalents, of which only 13 will be active duty units.[3] Most of these units have already redeployed to bases within the continental US (CONUS), reflecting the reliance upon rapid force projection, rather than forward presence, to respond to contingencies. Smaller numbers of fighters will be hard-pressed to carry out the multitude of missions assigned in any future conflict, particularly multi-role fighters like the F-16. The two major regional contingency (MRC) scenario envisioned by the Defense Department's Bottom Up Review (BUR) simply compounds this situation. Accordingly, the Air Force bomber fleet, once reserved for strategic nuclear deterrence, is being transformed into a force capable of delivering massive conventional strikes from CONUS or secure forward bases. Air Combat Command's (ACC) initial requirements detailed retention of 184 bombers to be able to strike up to 750 targets in the first five days of an MRC, before shifting priority of effort to support a second MRC.[4] However, budget cuts have reduced ACC's bomber fleet to only 107 aircraft, leaving its ability to support the "2-MRC" scenario in doubt. [5] In this environment, any force multiplier such as stand-off and precision munitions is essential to maintain the capabilities of a reduced force structure.

The Air Force and Navy face similar problems, and are thus developing an entire generation of new standoff weapons, including the Joint Direct Attack Munition (JDAM), Joint Stand-Off Weapon (JSOW), and the Tri-Service Stand-off Attack Missile (TSSAM). Additionally, the Air Force is expanding these technologies in pursuit of an enhanced SEAD weapon, known as the "Shark," capable of striking non-emitting air defense and theater ballistic missile sites. [6] The Navy is also upgrading its Tomahawk Land Attack Missile, as well as its F/A-18 aircraft to offset the capabilities lost with the retirement of its A-6 all weather ground attack aircraft.[7]

1-1c. STEALTH

The Navy's would-be successor to the A-6, the A-11, relied heavily upon another technology developed alongside the Air Force, stealth. Low observable, or "stealth" technology is a generic term applied to a myriad of design, manufacturing, and countermeasures techniques to reduce the signature of a vehicle to radar and infrared detection. The F-117A is the Air Force's first-generation low observable ground attack aircraft. Its reduced radar and infrared signature afforded it almost unprecedented freedom of action in the Gulf War. Its capabilities allowed it to perform a unique type of SEAD, destroying the most heavily defended command and control nodes of the Iraqi air defense system early in the war. The Air Force is relying upon this capability to help preserve the ability of the "non-stealthy" ground attack fleet to function. The B-2 is an advanced low observable platform, capable of conducting conventional or nuclear strikes with relative impunity.

Because of prohibitive development and acquisition costs, these stealthy platforms are few in number. Only 52 F-117s were ever built, with 50 presently remaining in the inventory. Although Congress is still debating the final numbers, only 20 B-2s are currently funded for delivery.[8] Within the environment of a 2-MRC scenario, the nation might not possess enough stealthy assets to carry out all required missions. The two operational squadrons of F-117s were overtasked in the Gulf War to the point that flight safety became questionable.[9] In response, the Air Force is exploring the feasibility of modifying the stealthy air superiority F-22 fighter for ground attack.[10] The US will increasingly rely upon these systems, along with the Navy TLAM, to perform force projection missions in areas of the world too risky for more traditional methods and systems.

No advantage conferred by technology is permanent, however. As painfully discovered by bomber advocates in World War II, countervailing capabilities will inevitably arise to negate any such advantage. The more decisive the advantage, the greater the impetus will be to counter it. Counterstealth technologies already exist, and the US is among those already exploring ways to exploit them. According to former USCINCSPACE, General "Chuck" Horner, "Counterstealth is going to be fundamental to air defense. It can be done, there is no doubt about it."[11]

1-2. TARGETS

In addition to an evolving threat environment, terrestrial forces are faced with the need to successfully engage an evolving target set. With the proliferation of chemical and even nuclear weapons production, the consequences of failing to do so have become intolerable. Every nation with even the most rudimentary delivery capability can potentially play havoc with the regional balance of power and political dynamics. Iraqi SCUDs falling upon Israel nearly unraveled the tenuous fabric of the Gulf War coalition. One chemical warhead could have torn it asunder. The resulting "SCUD Hunt" by coalition Special Forces and aircraft garnered only modest success at significant opportunity cost to an air campaign stripped of resources.[12] The SCUD hunters suffered from the inability to respond quickly enough to mobile threats whose presence and location were known only after launch.

Another trend in target evolution is the increasing degree of protection afforded to key supply sites and command and control nodes by improved bunkers. During the Gulf War, targeteers and intelligence specialists found a number of suspected weapons storage bunkers still intact after being attacked with 2000-lb concrete-penetrating bombs. The bombs had shattered against the bunkers, rather than penetrate before detonation. In a crash weapons procurement program, the Air Force rapidly developed the GBU-28 "Bunker Buster", a 4700-lb laser-guided bomb machined from the barrels of 8-inch artillery guns. Carried by F-111's requiring a high altitude delivery, these weapons could be successfully employed only after air superiority and SEAD had been achieved.[13] Recognizing these limitations, the Air Force Materiel Command is continuing to explore more flexible and capable penetrating munitions, with the goal of successfully prosecuting targets protected by 25 feet or more of reinforced concrete.[14]

1-3. VALIDATION

In examining the current operational climate of prosecuting warfare from the air, certain trends clearly dominate the discussion. In terms of air defense, the threat to Air Force and Navy aviators is high and getting worse as Russia and other nations sell their advanced technologies abroad. The long term plans for SEAD do not adequately address existing threats, much less those on the horizon. Those SEAD assets which will exist are probably too few for a 2-MRC scenario. Stand-off precision weaponry offers aircraft increased survivability and a force multiplier effect, but may be offset by the smaller number of delivery platforms and munitions available. Although stealthy aircraft do not yet suffer from the threat of enhanced air defenses, they may also be too few in number to support multiple theaters of operation.

In addition to being better defended, targets are becoming harder to kill. As evidenced during the Gulf War, mobile targets can prove elusive to locate, much less destroy. However the proliferation of nuclear and chemical weapons technology makes failure to do so potentially disastrous. Even fixed targets may be reinforced to the point that existing munitions may be useless, or require delivery conditions which expose the aircraft to excessive risk from air defenders.

From this analysis, three high payoff requirements emerge for consideration for the application of a space based kinetic kill vehicle capability. These include fixed hardened targets, mobile strategic targets, and enemy air defense assets. Accordingly, the next section will address in broad terms the technological feasibility of applying this capability to satisfy such requirements.

SECTION 2: FEASIBILITY

The feasibility of dropping an object from space to land at or near a specified location on the earth is well established. For decades, satellites have dropped film canisters into prescribed areas for terrestrial recovery. Intercontinental ballistic missiles (ICBM) eject multiple independently targeted re-entry vehicles (MIRVs) in mid-trajectory from space with impact circular error probable (CEP) of under 100 meters.[15] (A circular error probable of 100 meters means the weapon will impact within 100 meters of the target 50% of the time.) At the same time, terrestrial weaponry is beginning to achieve unprecedented autonomy and precision. The fusion of two crucial technologies have enabled an unprecedented combination of autonomy and accuracy. The integration of the Global Positioning System (GPS) with small, reliable Inertial Navigation Systems (INS) enable next generation weapons like the Joint Direct Attack Munition (JDAM), the Joint Standoff Weapon (JSOW), the Tri-Service Standoff Attack Missile (TSSAM), and upgraded Tomahawk Land Attack Missiles (TLAMS) to guide themselves from release to impact at a specified location.

This portion of the study will investigate the feasibility of combining these capabilities. Specifically, it will examine the ability to release a maneuverable re-entry vehicle from a space-borne host satellite, and, using the integrated capabilities of GPS, INS, and possible terminal command guidance, prosecute selected target classes. As previously implied, the target destruction mechanism chosen in this study is the kinetic energy of weapon impact.

2-1. KKV RATIONALE

One of the primary criterion for consideration in designing a space based weapon system is cost effectiveness. The mere deployment of such systems requires a huge investment in expendable launch capability. For example, an average Titan IV launch costs over $250 million. Furthermore, the development of space systems tends to be costly because of the hostility of their operating environment. These adverse conditions, combined with prolonged and continuous operations of satellites, require robustness and redundancy not reflected in terrestrial systems.[16] This requirement for robustness compounds the design complexity (and cost) of technically sophisticated space systems. These considerations, combined with the target requirements outlined earlier serve to narrow the scope of this study to a kinetic energy kill capability.

2-2. KKV MECHANICS

The target destruction mechanism for a SBKKV is virtually identical to that of a bullet or tank sabot round. The energy of the projectile impact upon the target, combined with the resulting energy transfer to the target, generates a number of damage mechanisms. Inflicting maximum damage entails maximizing the kinetic energy of the impacting round. This kinetic energy (KE) is a function of both the projectile mass (M) and its velocity (V), as indicated in the equation below:

$$KE = k \times (1/2\ M \times V^2)$$

The constant k reflects the fact that some energy is lost due to the "real world" response of materials during something less than a purely adiabatic collision.

Velocity limits for a space-based kinetic energy weapon are those imposed by maneuver and thermal design considerations. Such a weapon has a kinetic energy "budget" by virtue of its orbital velocity, paid for by the expensive launch vehicle used to get it there. A typical re-entry speed is around 24,000 feet per second (fps) at 100 NM altitude.[17] Atmospheric friction and vehicle maneuvering during re-entry both "spend" energy from this budget, reducing vehicle velocity. The ability of the vehicle to withstand atmospheric heating (a function of velocity and air density) dictates the maneuver profile required, and thus the velocity at impact.

Another key consideration in defining SBKKV maneuver requirements is the responsiveness required of the system. The enroute time for a maneuvering flight profile is longer than that for a ballistic profile. In both cases, transitioning from an orbital to a ballistic trajectory requires expenditure of fuel to slow a SBKKV to re-entry velocity. The amount of fuel required depends upon the time desired until impact. Shorter time requires more fuel (and thus more expense, given the cost of getting this extra fuel into orbit). If the target does not lie purely downrange of the ballistic trajectory, additional fuel expenditure is necessary to laterally shift the projected impact point.

In contrast to a ballistic projectile, however, a maneuverable KKV can use aerodynamic force, rather than fuel, to affect its trajectory. Some fuel expenditure is still necessary to de-orbit the weapon. However, heavy maneuvering within the atmosphere can bleed off energy and airspeed to shorten SBKKV enroute time without creating intolerable thermal stresses. Additionally, the maneuverable SBKKV can use these same aerodynamic forces to generate cross-range movement to provide more flexible and responsive employment capability. The degree to which a SBKKV can use this capability relies upon the endgame energy requirements and vehicle design.

In addition to retaining sufficient kinetic energy to ensure target destruction, the KKV must have sufficient maneuver potential to defeat area and terminal air defenses. A high-lift SBKKV design provides the highest degree of flexibility in terms of maneuverability, survivability, and responsiveness, but incurs a substantial penalty in terms of vehicle weight (and thus cost). Other designs offer reduced performance, but at reduced weight and complexity.[18]

The point of this explanation of ballistic dynamics is to point out that tradeoffs exist in weapon design between accuracy and lethality. In order to provide a maneuver capability (and thus accuracy and survivability), weapon designers must sacrifice some lethality in terms of impact energy.

While vehicle physics define the upper boundary for kinetic energy, target physics define the lower boundary. For example, hardened targets, such as bunkers require at least 2 - 4 million ft-lbs of kinetic energy at impact to effect a target kill.[19] Underground structures, such as those seen in Iraq, will require even more. With the velocity component of the SBKKV somewhat constrained by its thermal design, the mass component of the kinetic energy equation thus becomes the focus of attention. Figure 2-1 illustrates the tradeoff between velocity and mass for a given kinetic energy requirement.

Understanding the primary damage mechanisms of KKV impact is important, since no secondary high explosive effects are present, as with conventional penetrating bombs. In penetrating a target structure, the KKV generates immense quantities of heat, which can spontaneously ignite combustibles within the structure (air, fuel, munitions, etc.). This ignition, along with impact shock waves, will also create some

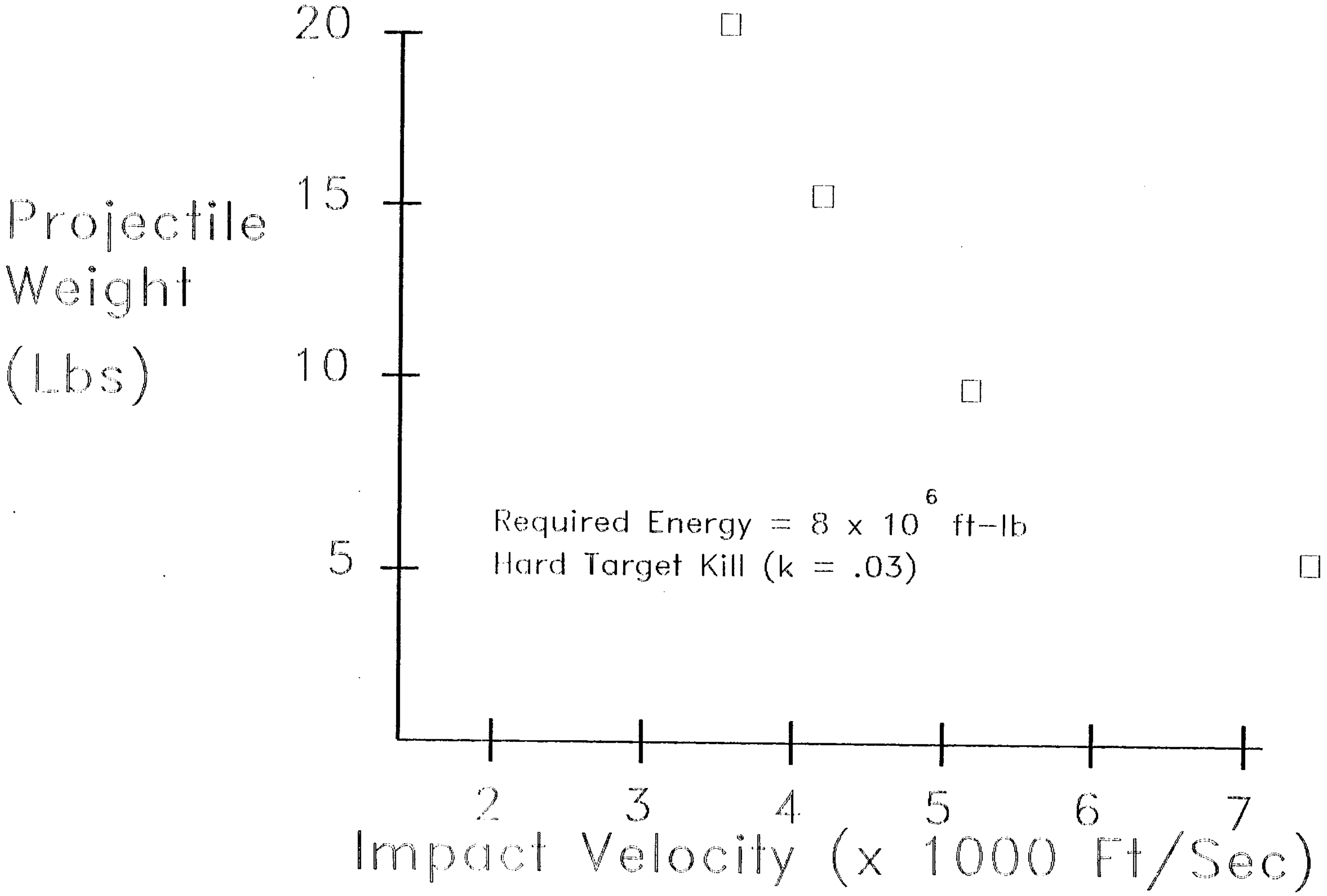

Projectile
Weight
(Lbs)
20
15
10
5
Required Energy = 8 x 10^6 ft-lb
Hard Target Kill (k = .03)
2
3
4
5
6
7
Impact Velocity (x 1000 Ft/Sec)

Figure 2-1

blast and overpressure effects. In addition, the energy transfer from the KKV to the structure will result in other kill mechanisms, such as creating high-velocity spallation within the structure opposite the impact.[20] Thus to some degree, the lethality of KKV impact depends upon some target response. In a compartmented target structure, like a bunker or ship, multiple projectile impacts may be necessary to inflict lethal damage or generate lethal secondary effects. In fact, studies have indicated that up to seven projectile impacts upon such a target may be necessary to inflict such a hard target kill.[21]

If multiple projectiles become necessary to inflict adequate damage upon a target, increasing projectile mass to increase kinetic energy will rapidly reach a point of diminishing return. The penalty of increased projectile mass becomes even more severe when considered in light of achievable projectile accuracy. As mentioned earlier, ICBMs are currently capable of landing within roughly 100 meters of their intended target 50% of the time. With nuclear weapons, this miss distance is acceptable due to the wide radius of lethal munition effects. Kinetic energy weapons, however, require a direct hit in order to be effective. The less accurate the weapon, the more projectiles required to assure target destruction. Determining the number of projectiles vs desired hit probability for a given degree of accuracy requires a few simple calculations. Assuming the projectiles are uniformly distributed throughout a circle of 100 meter radius, the required area coverage is:

$$3.14 \times (100)^2 = 31,416 \text{ square meters}$$

However, given the previous definition of CEP, the weapon will impact within this area only 50% of the time. By some statistical manipulation, one finds the circular error encompassing 95% of weapon impacts is considerably larger, 290 meters. This figure equates to an area coverage of 264,200 square meters. Assuming the target is a bunker 50 x 25 meters results in a target area of 1250 square meters. Dividing the target area by a single projectile's possible impact area results in less than a 0.5% probability of hitting the target. Achieving a 95% chance of hitting the target requires 212 projectiles uniformly spread throughout 264,200 square meters. Thus any increase in mass required to achieve sufficient kinetic energy to kill the target must be multiplied 212 times per KKV. Any such increase will rapidly become prohibitive. With kinetic energy thus constrained by both projectile mass and velocity, attaining a hard target kill begins to appear unlikely.

2-3. KKV GUIDANCE

By increasing the accuracy of the KKV, however, the number of projectiles required to ensure a target hit drops off very rapidly, since area coverage varies with the square of the amount of error. For example, tightening the delivery accuracy to 50 meters CEP reduces the number of projectiles in the previous example to 37. The Global Positioning System satellite constellation can provide three dimensional location anywhere on (or above) the earth within a nominal 10 - 15 meter SEP (spherical error probable) for operators using a military class GPS receiver.

The introduction of GPS into the problem of autonomous guidance offers significant operational advantages in terms of capability, robustness, and security. The GPS system includes a constellation of 24 satellites in semi-synchronous orbits, each broadcasting an extremely accurate time reference, along with a satellite position reference. By receiving time reference signals from multiple satellites, terrestrial receivers compute their relative distance from the satellites, and thus derive earth-relative position. These receivers can also process Doppler shifts in the received signal to determine velocity within .1 meters/second.[22] Equally significant is the consistency of GPS accuracy over time. Inertial navigation systems tend to "drift" due to gyroscopic precession, creating small positional errors which grow arithmetically over time. Typical INS drift rates for aircraft range from 0.8 to 2.0 NM/hour. While periodic positional updates can negate cumulative position errors, they do little to correct the INS drift or its rate of increase. Host platform maneuvering accelerates this drift rate.[23]

Inertial navigation does have an important role to play in autonomous guidance, however. Because of the accuracy limitations of GPS, inertial navigation and guidance systems are better suited to provide rapidly changing information, such as attitude and acceleration information (e.g., rate of change in attitude and velocity). Unlike inertial positional data, these short duration variables are not as sensitive to error over time. With suitable alignment, the INS can also act as a sort of "autopilot" in case of temporary GPS outage. The initial phase of weapon flight is one such instance, in which some time will elapse between weapon launch and initial GPS signal acquisition. For a SBKKV, INS integration helps maintain GPS accuracy despite atmospheric ionization and shock wave effects at hypersonic speeds.[24] Similarly, INS guidance control (vice navigation) during the weapon engagement "endgame" (just prior to impact) will be vital to achieving a "hit." Litton laboratories is already developing an integrated GPS/INS navigation package weighing only seven pounds, to provide guidance for advanced interdiction weapon systems.[25]

This integration of current GPS and INS navigation and guidance will prove extremely capable and widely used by next-generation weapon systems. Yet, initiatives are already underway to further improve the capability and accuracy of autonomous weapons guidance. As illustrated earlier, any increase in accuracy may translate directly into cost savings and increased capability for a SBKKV. One approach to enhance weapon accuracy is the addition of seeker-based terminal guidance.

2-4. KKV SENSORS.

2-4a. SENSOR CONSIDERATIONS

Although the integration of inertial guidance and GPS navigation provides the potential for unprecedented autonomous weapon accuracy, one important limitation exists. Precise guidance to an impact point is useful only if the target is there when the weapon arrives. For fixed, high value targets, such as bunkers, target location may be known with extreme accuracy. In dealing with mobile targets, such may not be the case. Considerable time may pass from initial detection and location until engagement. This passage of time creates ever-increasing window of uncertainty as to the target's anticipated location for any future engagement.

Manned systems can accommodate this uncertainty to some extent, contingent upon the air defense threat. The aircrew comprises an integrated target detection and identification system by virtue of their eyes and minds. However, they rely upon cueing from external sources (such as radar, forward looking infrared, pre-mission briefings, etc.) to focus their high resolution sensors during the search phase of the target engagement.

This use of cueing to focus a high resolution endgame sensor is already contributing to the capabilities of next-generation terrestrial weapons systems. Upgrades for the JDAM munition call for the use of both host and weapon sensors in concert, with a number of concepts in development.[26] The accuracy requirement for the final integrated package (GPS, INS, and endgame sensor) is a weapon CEP of only 10 feet.[27] Employment could entail the host aircraft imaging the target with its radar, then passing this image to the munition. For aircraft survivability, this target image could also come from external sources and uploaded before the mission. Upon launch, the weapon uses GPS and INS navigation while imaging the target area with its own sensor. Using the stored target image, or "template," the on-board processor correlates the image it "sees" with one of the specific target. Discarding extraneous image data, the processor identifies the specific target and guides the weapon to impact. Thus, the weapon requires less precision in terms of target location for successful engagement, and is able to differentiate between target and non-target signatures. Next-generation TLAMs will use a similar approach, using an infrared sensor to correlate target and stored template images to identify and home in on the precise target of interest.[28]

One key issue concerning high resolution sensors is the amount of signal and image processing required. This concern is common to all imaging sensors, in that processors must manipulate amounts of data orders of magnitude greater than required of mere "blob trackers" (non-imaging sensors). The processor requirements are proportional to the square of the sensor resolution for a given area. Compounding this requirement is the need to spatially orient the stored target template to match the sensor perspective. For instance, a template may reflect a target perspective as seen from the north at 45 degrees elevation. If the weapon approach differs from these parameters (for example, from the east at 10 degrees elevation) the processor must electronically rotate the template in azimuth and elevation until it finds a match with what it "sees." Moreover, the processor must perform these mathematical contortions extremely quickly (literally "on the fly") in order to provide course corrections to a maneuvering weapon in flight. The net impact is the need for extremely quick yet complex mathematical manipulation of huge amounts of data.

Although processors capable of such high-order, high-speed operations may exist today in desktop workstations and eventually even laptops, such platforms cannot withstand (much less operate in) the extreme environment of terrestrial munitions, let alone space. For example, the typical laptop cannot function at 300 degrees and 20 "G" acceleration. These, among other factors, add still more considerations and constraints to thermal and maneuver capabilities for a space-based KKV. Designing and building hardened, shielded, robust, and reliable processors capable of such operations can add significant cost and complexity to a system designed for one-time use.

These thermal and maneuver considerations also directly impact upon the choice of phenomenology for a SBKKV endgame sensor. For example, aircraft have radomes of radar-transparent material in front of planar or parabolic radar antennas to maintain aerodynamic shape without sacrificing sensor capability. For a SBKKV, this problem of aerodynamic shape compounds that of thermal control, since forward surfaces bear the brunt of re-entry heating (2500 - 3000 degrees F). Materials capable of enduring such high temperatures are not always transparent to a given sensor. Sensor phenomenologies like optical and infrared can use quartz to provide a transparent protective sensor window. However, to be effective, these windows require a heavy and complex active cooling mechanism. Furthermore, neither of these sensors are capable of all-weather operation. Laser radar (LADAR) provides exceptional resolution, but suffers from these same shortcomings.

One sensor technology which meets engagement requirements has already proven itself in space-based remote sensing. Synthetic Aperture Radar (SAR) is a radar imaging technique with a long and proven history, both in space and airborne platforms. In addition to providing all-weather medium resolution imagery, SAR has demonstrated a limited sub-surface detection capability. Shuttle Imaging Radar (SIR) experiments, using low resolution SAR, has detected and mapped subsurface features such as subterranean aquifers and riverbeds and seabed features.[29] Higher resolution could reveal targets invisible to other phenomenologies, to include underground bunkers and weapons storage sites. SAR can also be compatible with SBKKV thermal constraints and ionization effects associated with hypervelocity conditions.

2-4b. SENSOR CUEING

As indicated earlier, an endgame sensor usually relies upon outside cueing to compensate for the lack of a wide area search capability. With some terrestrial weapons, like JDAM, host based sensors (like an aircraft radar) provide both the general target location and target image template. For others, like TLAM, other remote sensors must survey the target area beforehand to provide this data to the weapon. For a SBKKV, either approach appears viable.

A host satellite could provide imagery of a target area to generate the target template for the KKV processor prior to launch. Given the current state of SAR technology, 3-5 meter resolution seems achievable. The US Central Intelligence Agency has been directed to declassify some technologies used to generate high resolution space-based imagery which could further enhance such a host satellite capability, providing resolution down to 1 meter.[30] The key advantage of such a system would be its peacetime utility. Instead of maintaining an expensive weapon system on orbit waiting for an opportunity to use it, a platform capable of surveillance and imagery would be a valuable complement to other strategic and theater intelligence collection assets. Mr. Martin Faga, former head of the National Reconnaissance Office (NRO) has publicly stated that, "There are not enough reconnaissance assets to provide what people want in the way of information." [31]

If host vehicle sensing is undesirable, the Space Warfighter Center at Falcon AFB, CO, has developed a number of initiatives to fuse and broadcast multi-source intelligence in near-real time. Talon Sword is one of these programs which demonstrated last year the feasibility of using this information for in-flight targeting. Follow-on initiatives, like Talon Lance, have expanded upon this capability, integrating other data sources, and employing data dissemination via satellite relays. The intent is to provide targeting data adequate for use in precision guided munitions.[32] Such an approach could support SBKKV employment without the complexity or cost of a host-based sensor capability.

2-5. VEHICLE VALIDATION

Sandia laboratories have tested a ballistically launched maneuvering re-entry vehicle using a conformal SAR antenna.[33] Test results validate the feasibility of a winged biconic vehicle design using autonomous guidance. This design is capable of modest maneuver capability at hypersonic speeds to achieve a small CEP. The SAR resolution is reported to be adequate for target classification. Sandia developed the platform to support Defense Advance Research Projects Agency (DARPA) research for potential strategic and tactical applications similar to those outlined in this study.[34] As illustrated in Figure 2 -2, such a design could provide a departure point for an orbitally-deployed SBKKV.

SECTION 3: SUITABILITY

Just because the development of a SBKKV is technically feasible does not mean such a deployment makes sense. The key to suitability of a space-based solution to operational requirements is the application of that solution in an operational environment. This section will examine the suitability of a SBKKV in this context, beginning with the merits of a space-based solution vs terrestrial weapons. Operating from the space environment affords some unique advantages, but also imposes significant restrictions on tactical employment. The real significance of these advantages and restrictions must ultimately lie with their impact upon the ability to meet the operational requirements as outlined in earlier sections.

3-1. THE CASE FOR SPACE

3-1a. SURVIVABILITY

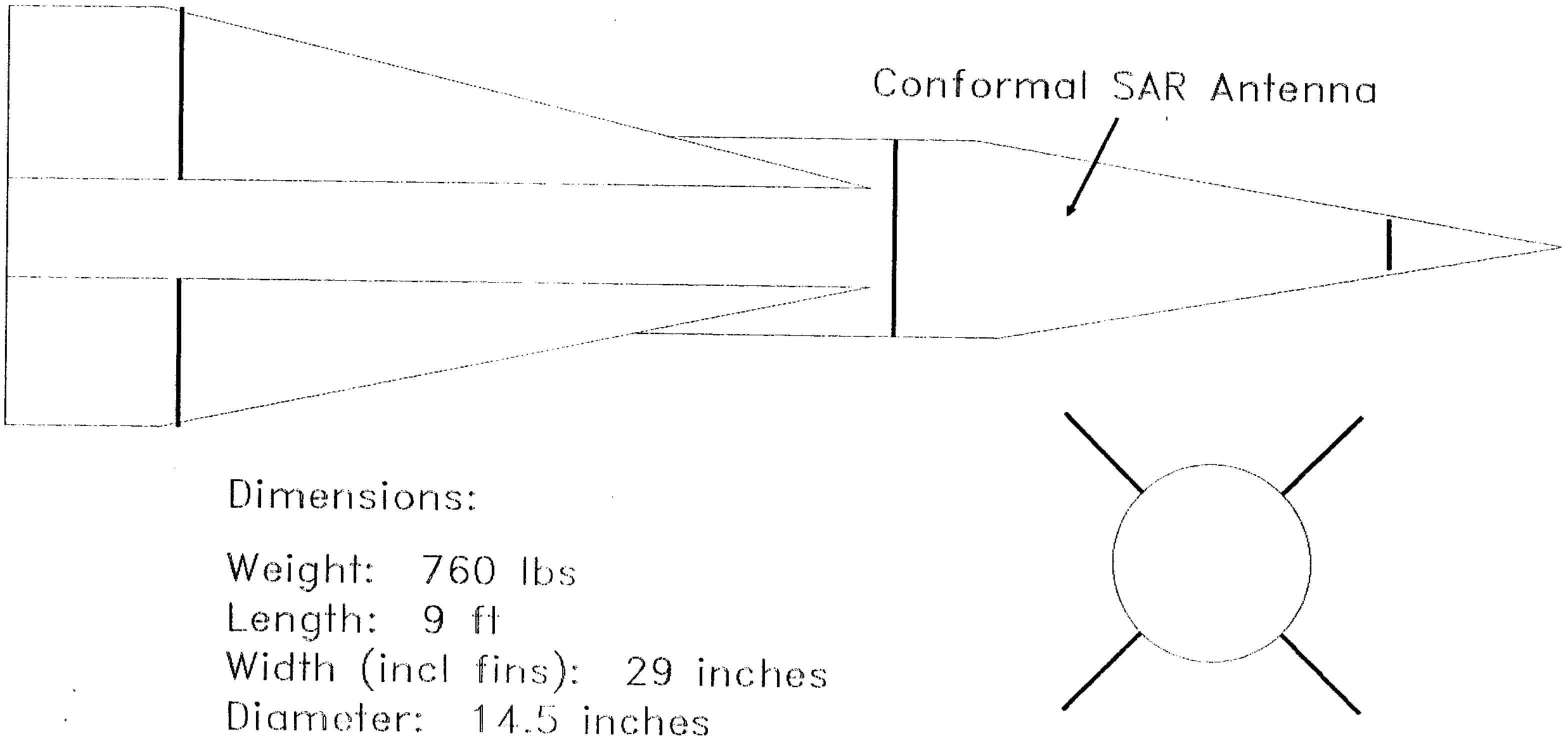
Basing weapons in space offers a number of important advantages over terrestrial systems. Unlike air-breathing vehicles like aircraft and cruise missiles, spacecraft are relatively immune to conventional air defenses. Three important exceptions to this claim warrant further discussion

In the 1980s the former Soviet Union fielded an operational co-orbital anti-satellite (ASAT) system capable of engagement and destruction of low-earth orbiting satellites (below approximately 300 NM). However, such an ASAT engagement required a large, interconnected ground segment dedicated to space surveillance. High-resolution surveillance systems are a requirement for tracking both the ASAT itself and its intended target in order to effect an intercept trajectory. The dissolution of the Soviet Union and ensuing economic problems have disintegrated a significant portion of its space program, including most of its ASAT capability.[35]

The emergence of other space-faring nations raises the possibility of additional ASAT-capable powers. However, none to date show any signs of investing in the type of space surveillance architecture capable of supporting either a co-orbital or direct-ascent ASAT engagement. Furthermore, the cost-effectiveness of such an ASAT capability is uncertain, since any ASAT system will probably cost more to develop and employ than the SBKKV. Further diluting ASAT utility is the fact that any given ASAT engagement merely delays, rather than denies, SBKKV engagement if the SBKKV system employs a dispersed constellation of host satellites.

Another exception to the relative invulnerability of space systems lies with a less subtle, but well established ASAT capability. Detonation of a nuclear weapon in orbit will result in a number of damage mechanisms to spacecraft, ranging from catastrophic failure to gradual performance degradation. The degree and permanence of damage depend upon a number of factors, the two keys being the fragility of satellite design, and proximity to the detonation. Such a use of nuclear weapons in space violates a number of international laws and treaties, and indiscriminately incapacitates friend, foe, and neutrals alike.[36] However, for a pariah nation like Iran or North Korea, the benefits of such an action could outweigh the cost. Suffice it to say that such a nuclear threat exists, but defies a cost-effective counter in terms of vehicle survivability. Any US deterrent or response to such actions lie outside the scope of this study (and that of the DoD).

Sandia Winged Biconic Design



Dimensions:

Weight: 760 lbs
Length: 9 ft
Width (incl fins): 29 inches
Diameter: 14.5 inches

Figure 2-2

The existence of anti-ballistic missile (ABM) systems like the Patriot or Russian SA-12B (Giant) directly impacts upon the survivability of a space-based kinetic kill vehicle enroute to its target. The necessity to cope with this threat to the effectiveness of any SBKKV is one facet of vehicle maneuverability requirements. Studies indicate that a SBKKV must be capable of 10-30 G maneuvers to defeat the ABM threat posed by long range surface to air missiles.[37] The degree to which this requirement dictates SBKKV performance is but one design tradeoff addressed later in this study. For now, suffice it to say that the ABM threat is not an insurmountable design constraint.

Physical survivability is not the only advantage of space-based forces. Both GPS receivers and radar sensors are capable of being electronically jammed, albeit with some difficulty (and risk to the jammer). By virtue of stand-off range and horizon limits, space-based systems are less susceptible to terrestrial GPS jamming.

3-1b. LOW-RISK EMPLOYMENT

This relative invulnerability of space-based weapons translates into reduced risk in their employment. The virtual dearth of space surveillance capability outside that of the US also means employment of a space-based weapon would provide little (if any) warning or signature. Terrestrial assets can possess considerable signatures for active and passive detectors, to include some quite outside operational control. During the execution of Eldorado Canyon, both Maltese and Moroccan radars detected the airborne strike force enroute to Libya, but Malta was unable to warn Libyan air defenses in time. (Morocco did not try.)[38] CNN further demonstrated the operations security (OPSEC) implications of such signatures in the Gulf War, broadcasting live coverage of aircraft taking off to strike targets in Iraq. Iraqi air defense guns could time their barrage fires to coincide with the anticipated arrival time of the jets, based upon this indirect observation. In contrast, employment of a SBKKV could be nearly undetectable. Any of a number of elements of the Air Force's Satellite Control Network (AFSCN) could uplink an encrypted command set to the host satellite to deploy a maneuverable re-entry vehicle from well outside the theater of operations. Even a Patriot-type anti-ballistic missile could prove ineffective, having no warning of initiation, or even direction of attack. In Iraq, Patriot batteries were cued by satellites, providing SCUD launch warning, launch azimuth, and probable impact area. This cueing greatly boosted the Patriot's performance.[39]

The Eldorado Canyon operation contains another factor which illustrates the reduced risk of SBKKV engagement. Upon target egress, an F-111 went down, killing both crewmembers. Had they been captured alive instead, Qaddafi would have had means for retaliation in a public forum. Events in the Middle East and Somalia have demonstrated the enormous impact POWs and hostages can have upon US resolve and strategy. As demonstrated by Gary Powers' U-2 shootdown, and the North Korean seizure of the Pueblo, the disclosure of American presence in covert operations can have important repercussions in the international community as well. While "plausible deniability" may (or may not) be beyond the ken of a space-based system, such an engagement would lack any aircraft or crew to put at risk or be used as pawns in a foreign relations gambit.

3-1c. FORCE PROJECTION

Another advantage enjoyed by space systems over many terrestrial weapons is that of global presence without forward deployment. Like the bomber fleet, a SBKKV could become a player in the Global Reach-Global Power vision of Air Force operations. Reminiscent of the old Strategic Air Command, such a system would always be on alert, ready to respond to tasking. The timeliness of that response could be even faster than that of the CONUS-based bomber force.

In addition to the capability for autonomous force projection, the SBKKV could support other force projection operations, like those of the bombers just mentioned. The support potential for such a system extends beyond the needs of the Air Force. The employment of a SBKKV could also support naval operations against surface ships, which are also discreet, mobile targets. An SBKKV could help negate the proliferation of diesel submarines with the ability to destroy them before they deploy from their home ports. The SEAD a SBKKV could provide for land-based airpower also supports sea-based air strikes, all the more important in light of litorral operations.

3-2. CHALLENGES OF SPACE

Most of the restrictions upon tactical operations prosecuted from space stem from a single source: the nature of orbital mechanics. Because a spacecraft is in orbit, it is capable of access anywhere on the globe, given adequate time. Unfortunately, once the platform is in orbit, terrestrial commanders can do little to affect that response time without incurring prohibitive cost. As indicated previously, because of the magnitude of orbital velocities, significant orbital maneuvering requires immense amounts of fuel (and thus cost) expenditure. Compounding this situation is the inability of a spacecraft to "loiter" over a desired target area. For the most part, spacecraft are on "autopilot," their course and speed dictated by altitude and shape of their orbits.

As a result, for a given SBKKV host satellite, a limited number of short-duration engagement opportunities exist for a given amount of time. For example, a satellite in a 150 NM orbit will pass over the same part of the earth only once per day. Taking only 90 minutes to orbit the earth, even that single pass will be brief. Higher altitude orbits have longer "loiter" time, during which they have access to a given point on the ground, but revisit time (the interval between access times) is longer as well. Satellites in geosynchronous orbits (22,300 NM) have perpetual access to that portion of the globe within satellite field of view, but infinite revisit intervals elsewhere.

These limited engagement windows, in addition to other issues described thus far, place a premium upon SBKKV maneuver capability. If the SBKKV has sufficient cross-range maneuver capability, it can create additional engagement windows during subsequent orbits. For example, a SBKKV host at 150 NM orbit circles the earth every 90 minutes. As shown in Figure 3-1, the rotation of the earth within that time will move a given point on the ground through 22.5 degrees of longitude. Thus, a satellite overflying a point on the equator will be 22.5 degrees west of that point one orbit later. At the equator, this distance translates into 1350 NM. A SBKKV capable of maneuvering cross-range for more than 1350 NM or more will have an additional opportunity to engage a target at that point. In theory, such a maneuver capability would create 3 engagement opportunities (1 orbit before overflight, the orbit of overflight, and 1 orbit after overflight).[40] The Sandia vehicle described in the previous section is incapable of maneuvers on this scale. However, as longitudinal lines converge with increasing latitude, the distance between orbits decreases. Given the cross range maneuver capabil-

Orbital Precession Over 270 Minutes

Single Satellite @ 150 NM Altitude

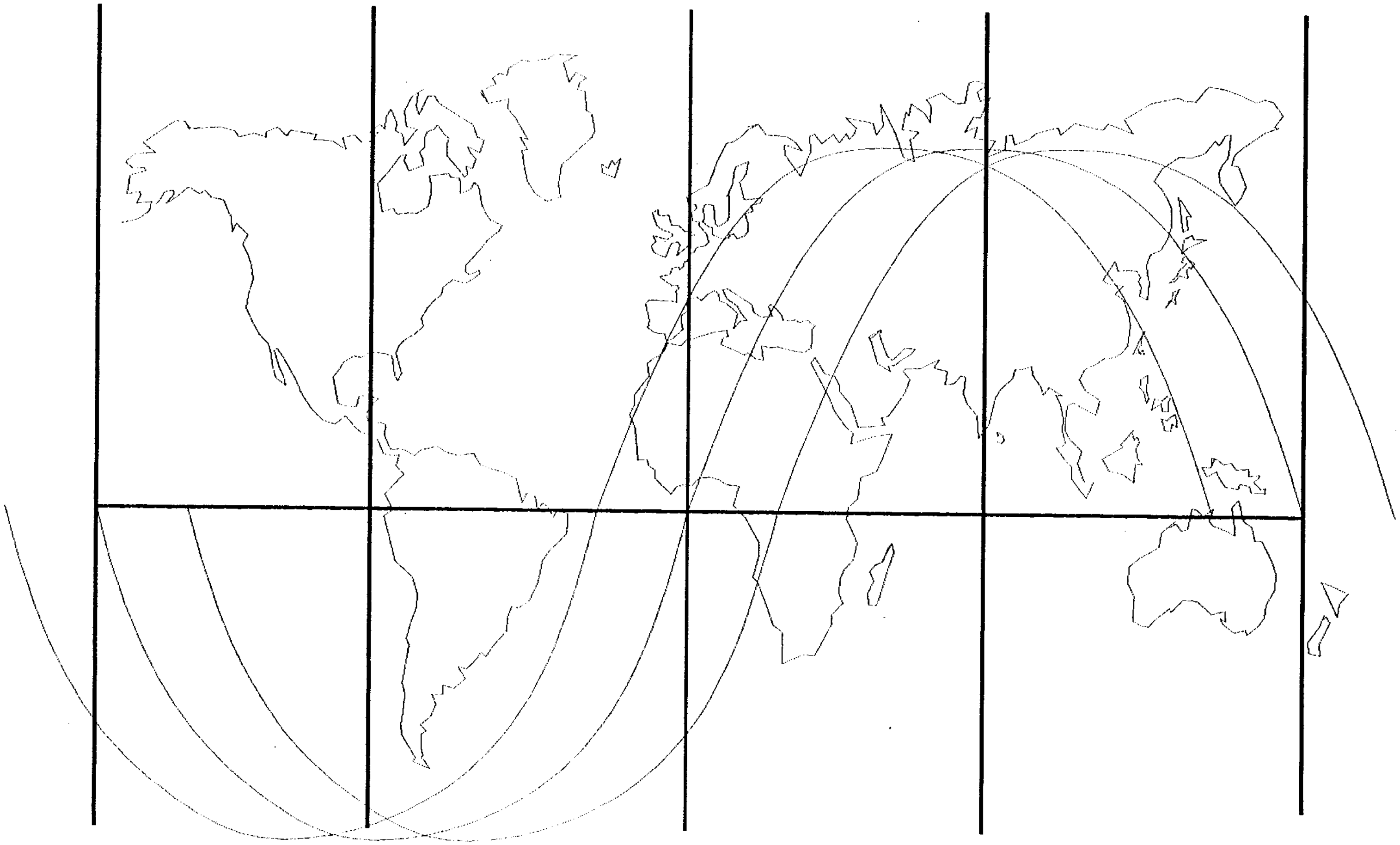


Figure 3-1

ities just discussed, the number of engagement windows will increase with greater target latitude. Even a vehicle with only modest maneuver capability would still have multiple engagement windows at higher latitudes. For example, a target at the north pole would have an engagement opportunity every 90 minutes, because the converging orbits lead to overlap of successive "windows". Likewise, inclining the orbital plane of a SBKKV can create additional engagement windows and enlarge others. Specific calculations of the actual number and size of engagement windows vs orbital inclination requires analysis beyond the scope of this study. However, the degree of inclination should reflect the amount of cross-range maneuver capability of the SBKKV.

Thus far, discussions have concentrated on a single SBKKV platform in orbit. However, a far more robust and responsive system would entail a constellation of multiple SBKKV hosts, spaced and phased to optimize both of these qualities. Here again a trade-off exists between responsiveness and cost effectiveness. The ultimately responsive constellation would consist of a "Brilliant Pebbles" type deployment, with a multitude of single, highly maneuverable SBKKVs on orbit, capable of engaging any spot on earth within minutes. As pointed out previously, maneuverability translates into vehicle weight, and thus cost. The trade-off is one between a more costly SBKKV design which offers fewer, but larger engagement windows, vs a less expensive design providing more but smaller windows.

However, maintaining any system in orbit entails some degree of "overhead" cost in terms of power generation, communications, and other sustaining functions. Duplicating these functions for greater numbers of SBKKVs could involve prohibitive cost. Based upon the requirements and trade-offs defined thus far, a smaller number of more expensive, highly maneuverable SBKKVs would be more cost effective than a greater number of less capable ones. Such a SBKKV would entail a high-lift design similar to Figure 3-2, as opposed to the Sandia winged biconic design.[41] Figure 3-3 illustrates the access potential of a constellation of 4 satellites over 90 minutes.

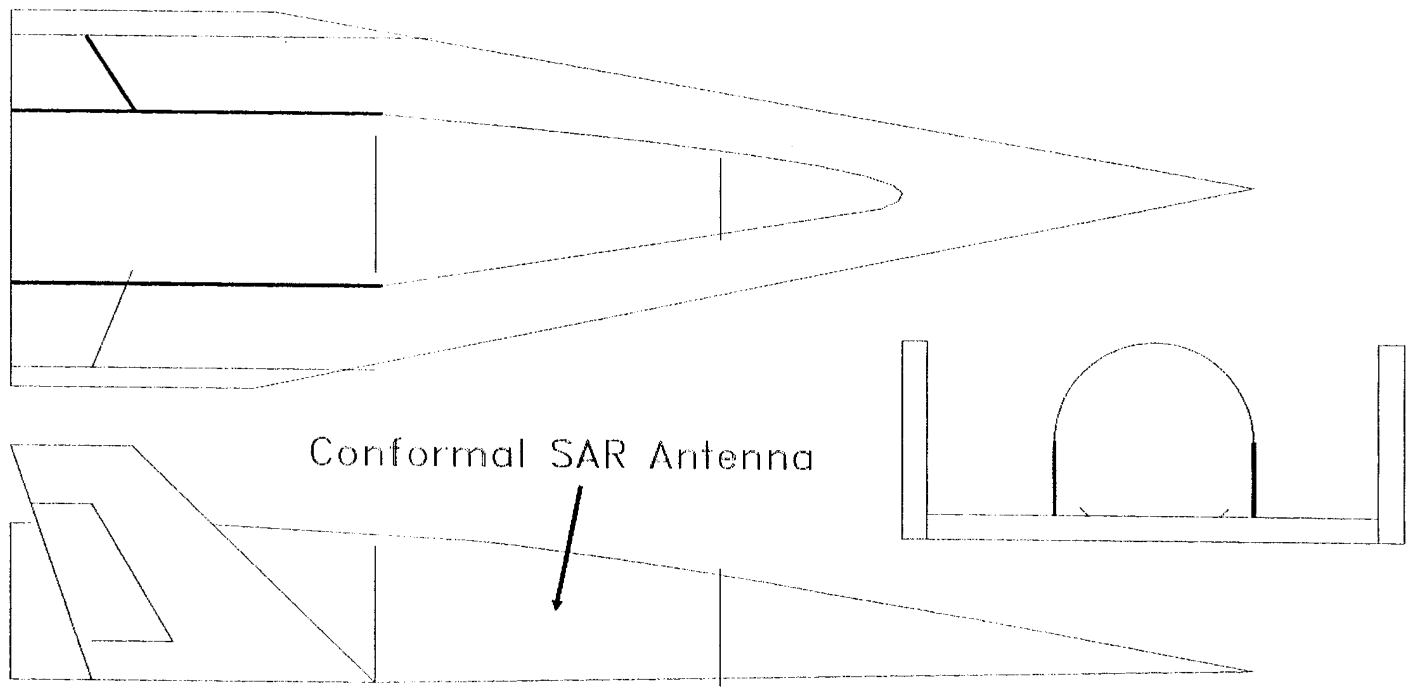
3-3. TARGETS

Each of the target classes identified as requirements will stress the capability of a SBKKV design in different ways. Fixed hardened targets, like bunkers, stress the kinetic energy requirements both in terms of target damage and threat survivability. High value or high payoff targets will be accompanied by heavy defenses. This need for a large kinetic energy "reserve" upon arrival will ultimately limit the cross-range distance achievable by the SBKKV. Compounding this effect is the need for a number of heavy penetrating projectiles to assure a target kill.

Offsetting these stringent requirements somewhat is the relative lack of a requirement for rapid response. Bunkers are not fleeting targets, and thus their engagement is more amenable to prior planning around limited SBKKV engagement windows than are other target classes. Additionally, bunkers comprise relatively large targets, obviating somewhat the need for precise accuracy or terminal guidance sensors.

Mobile strategic targets, like mobile surface-to surface missile launchers, pose nearly the opposite problem. SCUD launchers, for example, are relatively small, soft targets. They lack any real signature until after launching a missile, making their detection, location, and tracking all extremely difficult. Once detected, their mobility places

High Lift Vehicle Design



Dimensions:
Weight: 940 lbs
Length: 10.5 ft
Width: 4 ft
Diameter: 18 inches

Figure 3-2

Notional Constellation Coverage

4 Satellites, 1 Orbital Period (90 minutes)

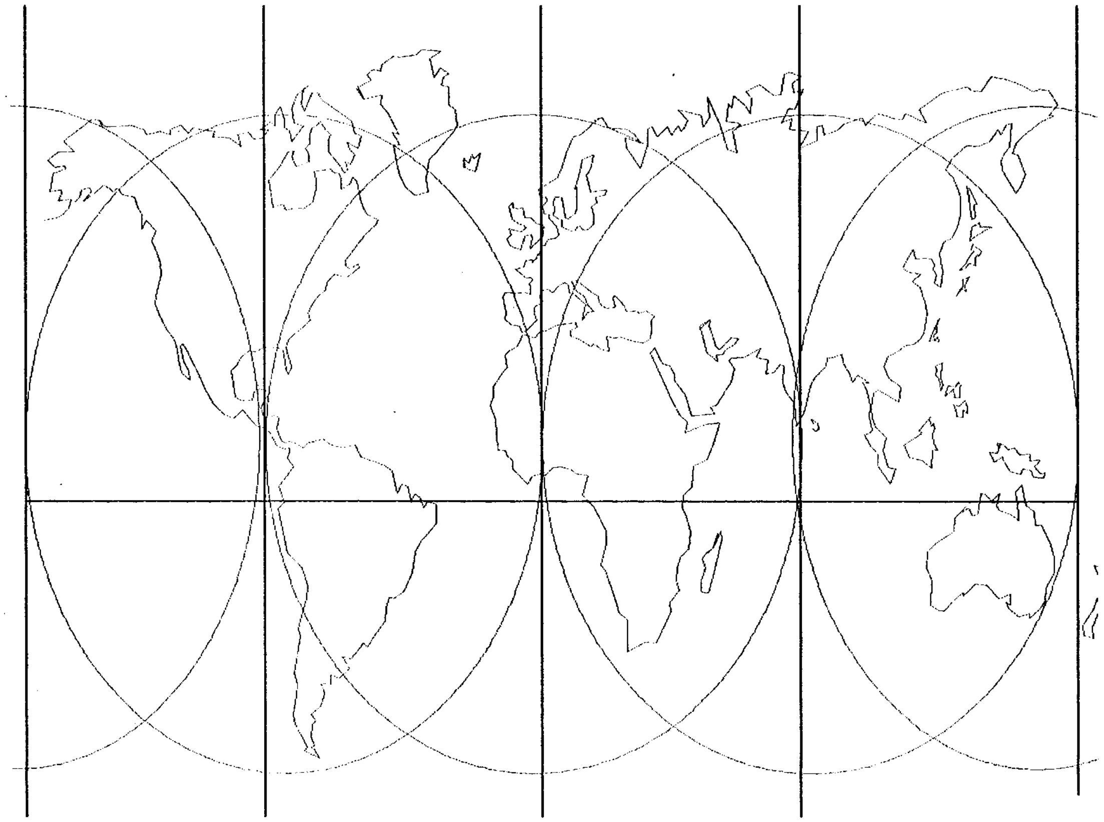


Figure 3-3

NOTIONAL SBKKV FLIGHT PROFILE

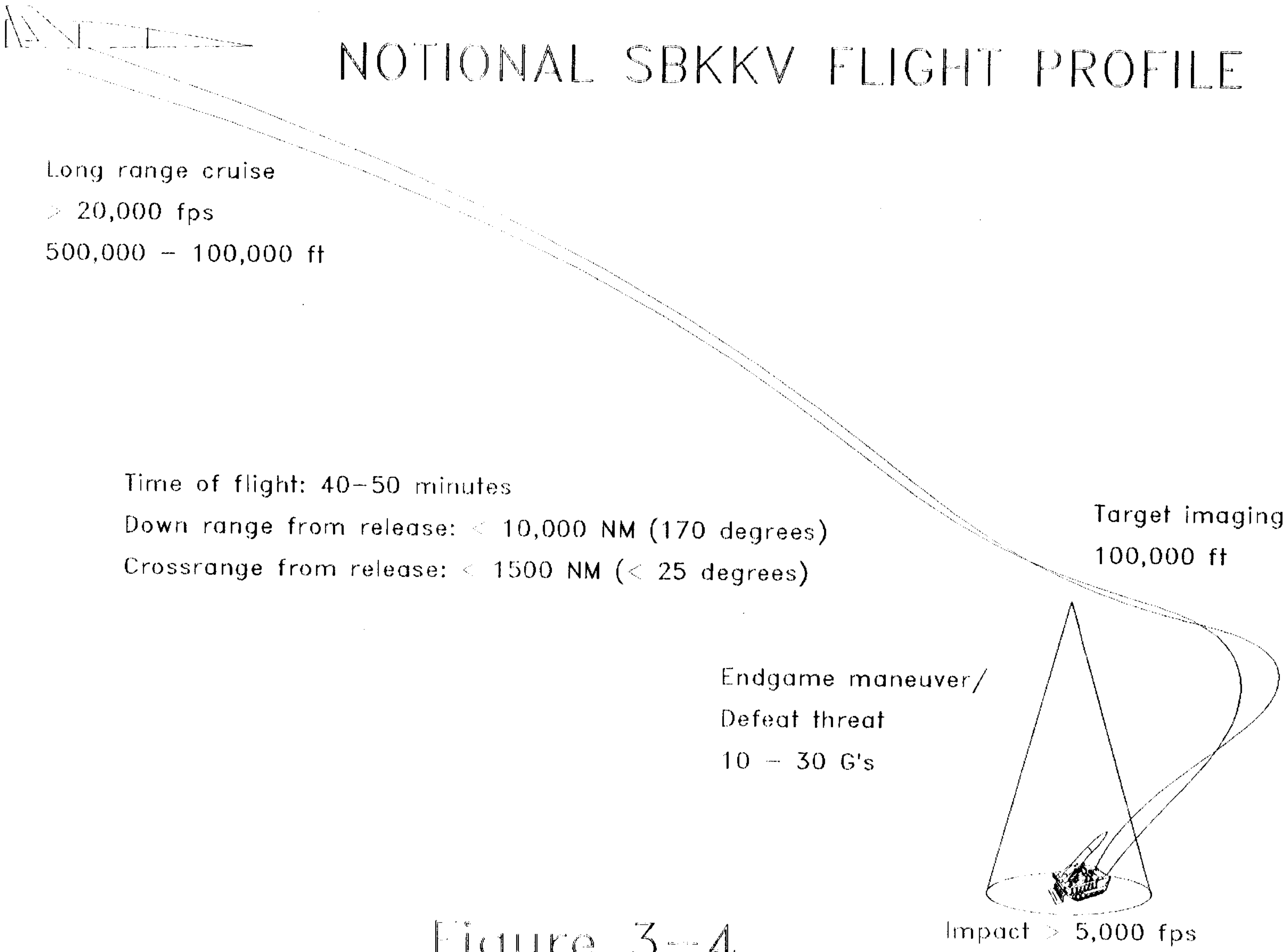


Figure 3–4

a premium on timely response of any engagement system, stressing maneuverability and numbers of SBKKVs to provide for many large engagement windows. Cueing of terminal sensors guidance is also a necessity to ensure target destruction. Defenses near such targets would be negligible, lest a radar signature betray their position.

Suppressing enemy air defenses combines elements of both previous target sets. The SBKKV will require sufficient energy to defeat the threat, but the target itself is relatively soft. A different challenge lies in the nature of the target itself. Latest generation SAM systems, like the Patriot and SA-12, contain multiple, separate components, separated over some area. Obviously, some of these components are more important than others. These vital components, such as the target tacking radar, must constitute priority targets. The issue becomes one of ensuring the destruction of priority components to disable the whole system. For a SBKKV, resolving this issue either requires sufficient munitions effects to cover the entire deployment site, or some mechanism to distinguish the priority target components.

The former solution is not so unrealistic as it may seem. Key components of any air defense system, such as radar and communications antennas, are extremely vulnerable to damage. Missiles themselves contain propellant capable of generating significant secondary effects. Ancillary equipment, like electrical generators, require fuel, which has the same effect. Hypervelocity projectiles as small as 10 grams would suffice to penetrate any armor protection such vehicles would have. A modestly sized warhead could contain thousands of such projectiles, capable of covering a sizable area.

This issue of target discrimination returns to the requirement for cueing a terminal sensor on board the SBKKV, and some of the tradeoffs discussed in the previous section. As previously discussed, sensors capable of the image resolution required to distinguish vehicle types are generally incapable of rapid area search or all-weather operation. On the other hand, phased-array radar antennas associated with modern threats possess distinctive radar cross sections which can dwarf the rest of the vehicle. Another possible distinguishing characteristic will be the analysis of operational deployment patterns of air defense batteries. To operate effectively, many air defense systems must deploy into patterns which betray both the type of system and location of key components. Aircrews routinely use this feature to identify threat systems without relying upon radar emissions.[42] Such patterns can be part of the target template loaded into a munition's processor memory.

The very presence of a SBKKV capable of such engagement can provide the desired suppressive effect on enemy air defenses throughout a theater of operations. Since no terrestrial area is beyond the reach of a SBKKV, any radar (or radio communications) system which emits can be detected, located, and targeted by the Talon Lance architecture. Even if air defenses could prove capable of negating a SBKKV, it must constantly emit to do so, in light of the threat to its survival. Operating in an anti-ballistic mode for survival also degrades other air defense operations. Such emissions also make it vulnerable to engagement by other lethal and non-lethal means, such as next-generation TLAMs armed with sub-munition warheads. Thus, in order to remain survivable, such air defense systems cannot emit. If they cannot emit, they cannot engage terrestrial aircraft, and are effectively suppressed.

In examining the target requirements, the question arises as to whether any SBKKV can successfully prosecute all three target classes. Using previous study proposals as points of departure, the answer is a qualified affirmative. Previous studies relied upon ballistically launched delivery systems, which constrained impact energy, but permitted greater latitude in employment. Consolidating the capabilities, assumptions, and tradeoffs presented thus far yields the following straw man design:

SBKKV: High lift vehicle, 1000-lb class[43]

Maximum cross-range (hard target): 25 degrees (1500 NM)

Maximum down range (notional): 170 degrees (10,000 NM)

Warhead: 25 shaped tungsten rods @ 10 lb each.
Total weight = 250 lbs

Navigation: Integrated GPS/INS

Terminal Guidance: Conformal Synthetic Aperture Radar
(1-3 meter resolution)

CEP: 10 feet (assumed achievable)

Impact velocity/Kinetic energy: 5000 fps/7.5 x 10^6 ft-lbs
(Tradeoff for increased cross-range against soft targets)

The key trade-offs in this design lie with the shared effect of warhead composition and impact velocity against a hardened target. The projectile size provides adequate impact energy, using enough projectiles to provide at least seven hits for the nominal bunker used in previous calculations. As shown in Table 3-1, this warhead (combined with guidance to support a 10 foot CEP), provides a 90% chance of seven or more hits on the bunker with sufficient kinetic energy to destroy the target (assuming an impact coefficient, k, of 0.03).[44] This warhead size also provides a 93% chance of at least one hit on SCUD and SA-12 sized targets.[45]

Figure 3-4 illustrates the atmospheric segment of a notional SBKKV engagement. Target cueing is assumed to be provided via satellite relay from Talon Sword fusion centers either within CONUS or in theater.

Employing a SBKKV in an operational environment thus levies additional constraints upon its design above and beyond the dictates of technological feasibility. However, by building a more robust (and expensive) capability, such a system can meet operational requirements in an operational environment. This design concept can thus meet the test for suitability presented at the beginning of this section.

Probability that # of Hits > X

Assumes 25 projectiles per SBKKV, 10 ft CEP

X	Bunker 25 x 50 ft	SCUD 35 x 10 ft	SA–12 28 x 10 ft
0	.9999	.9622	.9300
1	.9999	.8382	.7440
2	.9995	.6352	.4960
3	.9975	.4142	.2770
4	.9915	.2332	.1310
5	.9775	.1142	.0530
6	.9495	N/C	N/C
7	.9025	N/C	N/C

N/C = Not Computed

Table 3–1

SECTION 4: ACCEPTABILITY

After determining the feasibility and suitability of a space-based solution to operational requirements, the final test is that of acceptability. Two considerations must dominate any discussion of the acceptfability of fielding a SBKKV capability: costs incurred and benefits accrued. Previous sections have outlined the major benefits of developing this type of capability. This section will address some of the cost issues inherent in such employment, both in fiscal and less tangible terms.

4-1. COST VS TERRESTRIAL ALTERNATIVES

As indicated in the introduction of this study, a detailed presentation and analysis of comparative costs is beyond the scope of this effort. However, a cursory examination of some terrestrial weapon systems may prove instructive for providing an "order of magnitude" basis for SBKKV cost comparison.

The capabilities required to satisfy the requirements levied upon next generation weapon systems are not inexpensive. A cursory examination of research, development, and acquisition costs for these systems shows budgets of hundreds of millions of dollars. The following figures illustrate the order of magnitude being spent on development of standoff, autonomous precision munitions:

JDAM: $40 million in FY94 R&D[46]
$4 billion procurement ($54,000 apiece)[47]
Block 3 TLAM: $1.4 billion for 1085 missiles = $1.29 million apiece[48]
Block 4 TLAM upgrade: $500 million[49]

TSSAM: $13.9 billion for 7450 missiles = $1.87 million apiece[50]
F-15 Wild Weasel upgrade: $250-750 million[51]

In comparison, a SBKKV itself could probably be built for less than a TLAM, since the weapon portion itself is considerably simpler. For the purposes of comparison, this study will conservatively fix the SBKKV cost at $1 million/copy. However, the issue of support required of the host satellite now resurfaces. Even a simple host bus for SBKKV housing and deployment still requires power, communications, thermal control, radiation shielding, attitude sensing and control, propellant for orbital maintenance, etc. Based upon commercial production figures, such a bus could cost as little as $4000/pound.[52] Assuming the support bus comprises one third of the total satellite weight, a host satellite housing four SBKKVs would cost $8 million (excluding weapon cost). A constellation of four such satellites would thus total $48 million, excluding launch costs.

As indicated early in this study, launch expenses comprise a significant portion of the cost of any space based capability. On average, placing any vehicle in low earth orbit costs from $4000 - $6000/lb.[53] Although the military space commands have pursued a number of initiatives to reduce this figure, none have achieved significant reductions to date. Given the constellation described earlier, total weight to orbit is 24,000 lb, excluding payload assist motors, and other overhead items required for orbital deployment. A Titan 3 launch vehicle is capable of placing this size payload into low earth orbit for as little as $165 million. A Delta 2 vehicle could deploy individual SBKKV satellites for $36 million apiece, totaling $144 million.[54]

The bottom line from these figures is that, excluding research and development costs, acquisition and deployment of a SBKKV capability could cost roughly $12 million per round. On a pure cost comparison, a

SBKKV does not seem to fare well against terrestrial alternatives. However, when one also considers the risk posed to aircraft and aircrews to employ some of these weapons, a different calculus is possible.

All the services are continuing along a trend which sees fewer, more capable, more expensive aircraft dominating the operational inventory. Present generation fighter aircraft cost anywhere from $20 - 50 million, with next generation aircraft, such as the F-22 and B-2 costing even more ($75 - 500 million). Excluding the potential loss of experienced aircrews ($8 - 10 million apiece in training), even a modest risk to such expensive platforms carries the potential for substantial loss in both treasure and capability. If the capability presented by a SBKKV can influence and mitigate this risk, perhaps such an operational context is a more useful framework for cost comparison. This framework is not static, however, as the changing nature of the threat to national interests demonstrate. The SBKKV capability which may not seem cost effective in today's threat may have greater merit in a future threat environment.

4-2. POLITICAL COSTS

Perhaps the first consideration in considering the deployment of weapons in space is one of legality. A common perception exists that a number of legal and treaty prohibitions preclude such a deployment. However, this is not the case. The notion of deploying weapons in the sanctuary of space carries a stigma borne of an idealistic goal of preventing the militarization of space. Shortly after the launch of Sputnik, the United Nations adopted a resolution, stating that "outer space should be used for peaceful purposes only," and the hope of avoiding "the extension of national rivalries into this new field."[55] Such wording overlooked the fact that Sputnik's very presence was an extension of Soviet/US rivalry into this new medium. To this date, the UN still cannot come to a common understanding of "peaceful" use of space."[56]

A more concrete restriction appears in Article 4 of the 1967 Outer Space Treaty, which prohibits deploying "nuclear weapons or any other kinds of weapons of mass destruction" from earth orbit. Equally significant (and still legally binding) are the provisions of the 1972 Anti-Ballistic Missile (ABM) Treaty with the USSR. This treaty prohibits the development, testing, or deployment of ABM systems or components which are sea-based, space-based, or mobile land-based.[57] Although some US administrations have broadly interpreted the specific language to permit some testing of space-based components, the Clinton administration is committed to the narrower interpretation as stated above.[58]

Although the 1979 Moon Agreement places some restrictions on military activities, they are specific to that locale. The US has unilaterally declared a moratorium on testing of Anti-Satellite (ASAT) weapons, placing another restriction on military space activities. However, the UN Institute for Disarmament Research (UNIDIR) has acknowledged the lack of a prohibition against deployment and/or use of conventional weapons in space.[59] Furthermore, if such weapons are directed against terrestrial targets, they do not fall under ABM prohibitions or ASAT moratoria. In short, the deployment and employment of a SBKKV violates no existing legal convention for military operations in space.

This is not to say that deploying such a weapon system would not have significant political baggage. A number of nations are actively seeking to "freeze" the development of space technologies until they can "catch up." The former Soviet Union has introduced a number of initiatives in the UN to negate the technological advantage of the US in space. Overtly continuing to develop an offensive space-based capability may only serve to intensify (and legitimize) such efforts. Another consideration is to what degree the US would cede the "moral high ground" by being the first to deploy weapons in space.

On the other hand, the US is only one of a growing number of space-faring nations. With the demise of the Soviet Union, the US currently enjoys a time of uncontested technological superiority in space. But, as has been discussed, the technology associated with a SBKKV is not overly sophisticated, and is at least as prone to proliferation as nuclear technology. One possible means to prevent multilateral weaponization of space is to develop (but not deploy) a SBKKV capability as a means of deterrence. Such an approach might protect the US technological lead in space without prohibitive fiscal or political cost. Another alternative is to specifically and legally prohibit all space-based weaponry with an expanded protocol to the 1967 Outer Space Treaty. However, such a prohibition could negate much of the current US technological superiority and close future windows of opportunity for militarily exploiting space.

Although the development of a SBKKV is certainly technologically feasible, ensuring the operational utility of such a capability adds considerably to its cost. In the current political and fiscal environment, this cost probably precludes the acceptability of deploying such a capability at this time. However, as indicated earlier, as the world environment changes, so does the calculus of acceptability, requiring the periodic re-evaluation of this policy.

SECTION 5: CONCLUSIONS

This study has examined a number of issues to rationally answer the question of whether of not the US should develop and deploy a space-based kinetic kill capability. The framework for this examination was one of validity, feasibility, suitability, and acceptability. A valid need for the capability such a platform could provide does exist, in terms of hardened point targets, mobile strategic targets, and suppression of enemy air defenses (SEAD). Furthermore, the current state of technology can feasibly support the development of such a system. This study also examined considerations to ensure the suitability of such a system to operational requirements. In particular, the requirement for responsiveness in an operational environment drives the need for a more complex, robust, and expensive vehicle and constellation design. Analysis using these three criteria supports the development of a space-based weapon. However, examining the acceptability of such development raises serious issues. The potential cost of such a system far exceeds that of terrestrial alternatives. Furthermore, while such a deployment does not violate any legal provisions, the potential political cost compounds the situation to make such a system unacceptable. This conclusion is not final, however, and should be revisited within a similar framework as changing circumstances warrant.

APPENDIX: STATISTICS

Sections 2 and 4 rely upon a few statistical calculations for which some explanation is warranted. The first explanation pertains to the derivation stemming from impact CEP. As indicated earlier, a CEP indicates the radius of a circle containing 50% of weapon impacts. Thus if X is a random variable denoting the miss distance for any given impact, the probability of X being less than or equal to the CEP is 50%. One may use this knowledge to find a radius containing 95% of weapon impacts by computing a standardized normal probability function. The advantage of using a standard normal distribution is the existence of tables showing the value of a standardized random variable for any desired probability. The equation for converting any normally distributed variable (X) into a standard normally distributed variable (Z) is:

$$Z_a = (X - \underline{X})/S$$

where X = miss distance

$\underline{X}$ = Mean (average) miss distance

S = Standard deviation of miss distances

Although normally distributed around the target, the impact distances cancel out, thus averaging to zero. (For instance, impacts 20 meters long (+20) and 20 meters short (-20) of the target sum to zero.) Thus $\underline{X}$ is zero. The standard deviation of X is the unknown quantity. Because impacts may be long, short, left, or right of the target, the equation above becomes an inequality, denoting a range of values containing 50% of all impacts. Thus the equation becomes:

$$Z_{.25} \leq (X-\underline{X})/S \leq Z_{.75}$$

From the tables mentioned previously, $Z_{.25} = -0.675$, $Z_{.75} = 0.675$. Substituting these values into the equation above yields a standard deviation for X of 148 ft (since a negative standard deviation has no meaning). Using this value along with Z values corresponding to a 95% confidence interval yields:

$$-1.96 \leq (X - 0)/148 \leq 1.96$$

Thus: $-290 \leq X \leq 290$

A 10 ft CEP assumed in this study (based upon terminal guidance and possibly Differential GPS) yields a 95% confidence interval of ±29 ft.[60] This figure was key to the next statistical calculations associated with the warhead sizing required to achieve an adequate hit probability.

This calculation relied upon the fact that warhead projectile impact was a series of discreet events distributed over an area defined by the CEP indicated previously. This lent itself to analysis using a Poisson probability function as expressed by:

$$\text{Prob}(y = x) = e^{-da}(da)^{x}/x!$$

where y = # hits occurred

x = # of hits desired

e = 2.718...

d = density (number of projectiles per unit area) = 0.0095

a = target area

This equation denotes only the probability for a single case, that of $y = x$. In order to determine the probability that $y \geq x$ (thus assuring target kill), one must sum up all probabilities for $y < x$, then subtract this result from 1. For a vehicle, such as a SCUD, a single hit should suffice to destroy the target. For the conditions stated, the probability of getting at least one hit is 1 - the probability of missing, ($y = 0$). To determine the probability of getting at least 7 hits on a bunker, one must sum all probabilities for $x < 7$, and subtract the result from 1. The result is $1 - \text{Prob}(x = 0, 1, 2, 3, 4, 5, 6) = .9025$.[61]

These calculations assume a conditional probability (rather than independence) between CEP accuracy and hit probability. The rationale for this assumption lies in the fact that the SBKKV warhead effects occupy an area, rather than a point, as do the targets themselves. Thus an impact occurring outside the 95% confidence interval can still affect the target. The net result is a considerably simpler computation which yields a slight overestimation of the Poisson probabilities. This overestimation is less biased than would be the case for an assumption of independent probability functions, and is acceptable for the illustrative purposes of this study.

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