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GPS AND THE JOINT FORCE COMMANDER: CRITICAL ASSET, CRITICAL VULNERABILITY

by

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The contents of this paper reflect my own views and are not necessarily endorsed by the Naval War College, the Department of the Navy, or the U.S. Air Force.

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Abstract

GPS AND THE JOINT FORCE COMMANDER:

CRITICAL ASSET, CRITICAL VULNERABILITY

Joint Force Commanders (JFCs) have become over reliant on military and commercial satellite systems for intelligence gathering and dissemination, weather, command, control, communications, and navigation/guidance functions, to name a few. The Global Positioning System (GPS), in particular, is becoming the dominant source for navigation, precision, and timing information in weapon, vehicles, and command and control systems. With the large investment in GPS-dependent systems, there is a tendency to overlook GPS shortcomings and vulnerabilities.

We've reached the point where satellites have become a center of gravity for both military planning and operations. Moreover, the U.S. has not yet weaponized space to protect its assets. The JFC should not rely on GPS as the sole navigational, precision weapons guidance, and timing information in military weapon systems and command and control systems. Over-reliance on GPS produces critical vulnerabilities in the operational concepts of precision engagement, force protection, operational maneuver, and command and control. Although GPS is a critical strength, it can be exploited by an adversary. JFCs must understand not only the capabilities of GPS, but also the weaknesses and vulnerabilities of GPS before employing weapons, equipment, and systems that are GPS-dependent.

GPS and the Joint Force Commander:
Critical Asset, Critical Vulnerability

The commander…finds himself in a constant whirlpool of false and true information…
Carl von Clausewitz

The Joint Force Commander (JFC) should not rely on the Global Positioning System (GPS)* as the sole navigational, precision weapons guidance, and timing information in military weapon systems and command and control systems. JFCs have become over reliant on military and commercial satellite systems for intelligence gathering and dissemination, weather, command, control, and communications, and navigation and guidance functions to name a few. GPS, in particular, is becoming the dominant source of navigation, precision guidance, and timing information used throughout the Department of Defense's (DoD's) aircraft, ships, tanks, precision guided munitions, and command and control systems. This pervasiveness, along with the large investment in GPS and GPS-dependent systems, enforces a tendency to focus only on GPS as a critical operational asset. However, over-reliance on GPS produces critical vulnerabilities in the operational concepts of precision engagement, force protection, operational maneuver, and command and control.

DoD's Increasing Reliance on GPS

Joint Vision 2010/2020 relies heavily on technology to support its operational concepts of precision engagement, dominant maneuver, full dimensional protection, and logistics.[1] Indeed, GPS is perhaps the key technology required to achieve the vision. Admiral William

* See Appendix A for description.

Owens, former Vice Chairman of the Joint Chiefs of Staff, singles out GPS for its profound effect on the operational concept of precision engagement: "…global positioning allows precise, real-time location and targeting of anything tangible."[2] In the aftermath of DESERT STORM, the U.S. Central Command's Army Component Commander (USARCENT), Lt General John Yeosock, declared GPS "indispensable," and called for equipping every tank with a GPS receiver. As of 1995, every U.S. Navy ship and submarine was GPS equipped.[3]

Since the Gulf War, the services have been acquiring GPS-based guidance kits[**] for existing weapons such as AGM-130 Standoff Weapon System, the Standoff Land Attack Missile Expanded Response (SLAM-ER), the Joint Direct Attack Munition (JDAM), and the Tomahawk Land Attack Missile (TLAM). DoD has also integrated this technology into new weapons such as the AGM-154 Joint Standoff Weapon (JSOW) and the Joint Air-to-Surface Standoff Missile (JASSM), to improve accuracy at higher altitudes, greater distances, and in bad weather. Some laser-guided bombs and long-range cruise missiles like SLAM-ER, TLAM, and Conventional Air Launched Cruise Missile (CALCM) either have or will receive GPS guidance systems. The services are also developing new weapons with submunition dispensers that use GPS guidance to attack mobile armor targets. These include the Army Tactical Missile System (ATACMS) and JSOW.[4]

GPS has been so successful that the Congressional Record on 10 November 1993 stated, "After 30 September 2000, funds may not be obligated to modify or procure any DoD aircraft, ship, armored vehicle, or indirect-fire weapon system that is not equipped with a GPS receiver."[5] It is obvious that we will be heavily reliant on this system for military

[**] For example, the GPS guided tail kit attaches to Mark 80 bombs to make 1,000 lb (MK-30) or 2,000 lb (MK-29) smart bombs. The tail kit uses GPS targeting data to guide the bomb with controls that deflect the moveable tailcone fins. These bombs will equip aircraft that do not carry designators for laser-guided bombs, including the B-1, B-2, and B-52.

operations in the future. The U.S. Air Force and Navy each expect to have about 7,000 GPS-equipped platforms in service by 2006, with the U.S. Army deploying about 30,000. By that date, the three services will between them have introduced more than 500,000 weapons using some form of GPS guidance.[6]

According to DoD's after action report to Congress, Operation ALLIED FORCE (the air war over Kosovo in 1998) involved what was undoubtedly the most precise air and missile combat operation in history. In large part, this was made possible through the successful deployment of such weapons as the TLAM, CALCM, JDAM, Joint Standoff Weapon (JSOW), GBU-37 Global Positioning System Aided Munition (GAM), and SLAM, all of which use GPS information for guidance. The desire to avoid collateral damage and the Balkan region's frequently adverse weather resulted in the use of large numbers of these preferred munitions. As a consequence, the DoD is looking at ways to expand the number of platforms that employ precision munitions, given their effectiveness against fixed targets.[7]

GPS as a Critical Asset

Critical strengths are those capabilities considered vital for the accomplishment of a given or assumed military objective.[8] It has been argued that space systems are becoming a critical strength for the operational commander and are potential operational center of gravities (COGs) for major military operations and campaigns. As General Howell M. Estes, III (previous CINC USSPACECOM) explained, "We are presently the world's greatest spacefaring nation. Certainly, space systems provide the infrastructure for our military operations. Because we are rapidly doing away with terrestrial systems and replacing them with on-orbit capability, the U.S. military is dangerously dependent on space support for expeditionary operations. This dependence is also a strength -- it gives us a greater degree of

mobility with unmatched information support. Many believe that this information advantage is so great as to herald a new change in warfare."[9]

GPS provides the JFC capabilities that enhance precision engagement, force protection, operational maneuver, and command and control.

Precision engagement is an emerging joint operational concept in Joint Vision 2010/2020.[10] Precision engagement is a requirement for discriminate and decisive combat power. GPS guided weapons enable the war fighter to deliver weapons to their targets with a high degree of accuracy, resulting in less collateral damage and fewer civilian casualties of war. The use of GPS navigation to guide missiles to their targets has made pinpoint accuracy the norm in U.S. strike operations. Moreover, attacking day or night in any weather, GPS-guided weapons place most targets at risk, denying the enemy sanctuaries created by weather or the use of heavily concentrated defenses.

Today, most modern U.S. theater and tactical missiles are GPS-guided. A missile guidance-and-control system uses GPS to determine its current position and fly towards the GPS coordinates of a designated target, either directly or through a series of pre-programmed waypoints. The guidance-and-control system typically uses position and velocity information from GPS, in conjunction with an inertial navigation system (INS), to control the platform. GPS data corrects the errors from the inertial navigation solution, resulting in increased accuracy. Inertial technology provides position and velocity information during a short period, but has a tendency to drift. GPS and inertial technologies are complementary. GPS provides more accurate information, but may be subject to outages due to either intentional or unintentional interference or satellite blockage. If there is interference, the GPS receiver may not be able to operate, and the inertial navigation system will tend to drift,

resulting in a navigation error.[11] Employment of GPS-guided munitions is significantly different than that of other precision guided munitions. The weapons are "fire and forget" systems; visual contact with the target is not required, nor is illumination with a laser or any other designation device.

Since GPS-guided munitions can correct navigational errors in flight, the war fighter needs fewer rounds to achieve the same or higher probabilities of kill as unguided weapons. Additionally, he can expect GPS-guided munitions accuracy and lethality to reduce the number of launch platforms and the number of soldiers required to counter specific targets.

The improved accuracy and lethality of GPS-guided deep strike weapons are expected to facilitate the use of advanced tactics, such as nodal targeting. Nodal targeting allows a JFC to attack critical infrastructure targets that cripple an adversary's capability to attack with its forces. Nodal targets could include, for example, command centers, power plants, or logistic choke points such as bridges. Such tactics may reduce unwanted collateral damage and post-war reconstruction hardships.[12]

Force protection can be enhanced and the risk to war fighters reduced. The use of GPS precision weapons allows targets to be struck from safe standoff distances. Weapons, such as the TLAM, which rely on terrain matching guidance systems, have been improved with the addition of GPS receivers. These more capable versions are able to accurately navigate over featureless terrain and bodies of water, and are more effective in night and in adverse weather conditions.[13] TLAMs and long-range standoff weapons have become the "weapon of choice" in applying initial force to prepare the battlefield.

Air Force and Navy requirements models show a strong preference for using precision guided weapons against most targets. The models place a premium on avoiding any aircraft

or aircrew losses or collateral damage. As a result, the models select weapons that are most effective in meeting those objectives. The models tend to select the most accurate and longest standoff weapons, even though these may not have the best target-killing characteristics. For example, the Navy's model selects Tomahawk missiles for many types of targets, even against certain targets where its effectiveness is poor. While the specific situation may dictate the use of a Tomahawk due to target location or threat, other weapon choices could be more effective and less costly, if other factors such as aircraft attrition do not overcome the weapon's cost advantage. This outcome reflects the models' tendency to use standoff weapons versus direct attack weapons (thereby avoiding enemy air defenses and ensuring force protection) and their preference for more accurate weapons.[14]

Operational maneuver can benefit from precise positioning capability. GPS provides increased situational awareness (e.g., knowing one's exact location in relation to other forces and geographic features) and the ability to locate and deconflict maneuvering forces. Accurate position and time information obtained from GPS systems supported complex maneuvers and coordination while maintaining radio silence. During DESERT STORM, coalition forces used GPS to move with confidence over difficult desert terrain, avoiding enemy defenses, assured of resupply, and able to target enemy arms and installations with remarkable precision. Over 5,000 GPS receivers were deployed by U.S. troops that enabled them to determine their location, and successfully navigate across the featureless desert terrain.[15] U.S. forces were able to keep their attack plans flexible virtually up to the moment of attack, since forces using GPS had no need for fixed markers on the ground. For example, the Marines reported that they kept adjusting their breaching point (where they were going to

break through the enemy's front line) as they received fresh intelligence on Iraqi positions, and as the Iraqis moved their forces.

Operational command and control: GPS can aid in battlespace management. Building on the situational awareness achieved with GPS, and the communications technology available today, an integrated combat identification (CID) system can provide the commander with a valuable tool for command and control. The friendly fire casualties during the Gulf War identified the need for the positive and timely identification of hostiles, friends and neutrals. The Joint Combat Identification Office was established to oversee the development of CID solutions. Their top solution was the Tactical Digital Information Link-Link 16 (TADIL-J), a common datalink enabling a single message to convey GPS derived position, platform identification, and weapons control messages. The use of GPS provides a common grid reference for locating the positions of all military assets.[16] Another CID system, the Situational Awareness Beacon with Reply (SABER) system consists of a beacon, a laptop computer, and a small UHF antenna. Any platform integrated into SABER can interrogate a potential target in the battlespace and transmit an "intent to kill" message. SABER would ID the target, ensure weapons radius clearance around it, and authorize weapons release--all within seconds.[17] Such CID systems give a clearer picture of the battlespace, providing the ability to reduce friendly fire incidents, track asset positions, coordinate supporting operations, and aid in search and rescue missions. Increased awareness of ground forces location will allow closer air support for troop movements and amphibious landings.[18]

With GPS, the operational commander has an advantage in mobility and speed in his theater of operations. An adversary without GPS cannot keep up with the pace of battle and

is unable to read the battlespace as effectively and react to coalition operations. An adversary without GPS enabled systems will be less mobile and more sluggish to react.

GPS as a Critical Vulnerability

A critical strength can become a critical vulnerability if it lacks adequate protection or support and is therefore open to enemy attack.[19] The degree to which the U.S. has centralized its navigation system in space, and the fact that GPS is pervasive in supporting multiple operational concepts suggest that its loss could be catastrophic. The Navy's Deputy Assistant Secretary for C4I, Electronic Warfare and Space Programs, Mr. Dale Uhler, said, "the Navy is concerned about the continuing reliance on GPS and the difficulties it could cause. The Navy may be putting all of its eggs in one basket and needs to find alternatives to GPS."[20] Although GPS is vital to operational military capability, it is exploitable by an adversary and, thus, is a critical vulnerability in the operational concepts of precision engagement, force protection, operational maneuver and command and control.

Precision engagement - Loss of a GPS signal could mean the inability to use standoff weapons (like the JASSM that can be fired as far away as 200 km from its target) or having to use very expensive smart munitions as "dumb bombs." As such, precision strikes may have to be conducted closer to the target to ensure their accuracy. According to a defense analyst at the Teal Group, "The longer a missile's flight, the more likely a jammer can interfere with the GPS guidance. Shorter-range missiles are less vulnerable."[21]

GPS's relatively weak signal received at the earth's surface can be quite susceptible to enemy jamming. Studies by DoD and the Air Force describe how properly placed jammers can cause a GPS-guided weapon to entirely miss its target. Reports that low power, inexpensive jammers can defeat receivers have elicited great concern over the reliance on

GPS for missile guidance.[22] Fears were fueled in recent years by the emergence of advanced commercially available jammers. During a 1997 Russian air show, for example, a $4,000 jamming transmitter was on display and its manufacturers claimed the device foils the ability of GPS receivers to provide correct geographic coordinates. "The vulnerability of GPS to jamming is pretty well recognized," said Rear Adm. Robert Nutwell, Deputy Assistant Defense Secretary for C3I, Reconnaissance, Surveillance, and Space Systems. "All RF (radio frequency) systems are vulnerable to some degree…GPS probably more so because it is such a weak signal and it is not protected" as are military-unique satellites."[23]

An adversary has enough information on how and when to jam a GPS-dependent system. The Kosovo after action report to Congress indicates the potential vulnerability of these systems to jamming, and stresses the need to look for ways to improve existing and future GPS-dependent systems.[24] One problem facing the engineering community is defining the potential jamming threat so that a cost-effective countermeasure can be developed. Most current missiles don't have an anti-jam capability and, for the ones that do, the degree of anti-jam protection varies from missile to missile.

Precision engagement may become an exercise in failure prone resource management, as the commander must search through his weapon inventory for a system that is not GPS-dependent. On the other hand, relying too much on GPS precision weapons can be costly. During the Kosovo conflict, the U.S. military expended nearly half the GPS precision weapons stockpile. Target planners must take this into consideration and ensure they select the right weapon for the right target and not inflate GPS-guided PGM requirements.

Force protection - Protecting military troops, equipment, and systems from a wide range of threats, is one of the JFC's most important responsibilities. GPS has become a critical

strength and a potential operational center of gravity (COG). As such, doctrine for joint operations instructs the JFC to protect our operational COGs.[25] Threats to satellite systems include jamming, interference, interception, physical attack, as well as ionospheric scintillation and effects from nuclear explosions.

The two greatest risks faced by the U.S. military regarding GPS are the loss of use of the system and enemy use. Loss of use could come from the destruction of a portion of the system or from jamming the signal. The physical destruction of some of the satellites or the ground stations would either partially or totally disable the system. Moreover, anti-satellite (ASAT) and directed energy weapons (e.g., high-energy lasers) are a threat to space-based systems. Military satellites and the military use of commercial satellites make them possible targets of ASATs and other weapons. The Russians have demonstrated previous interest in space weapon (anti-satellite) technologies.[26] GPS satellites fly in low earth orbit (LEO), and LEO satellites are vulnerable to effects from a single high-altitude nuclear burst. Also, LEO satellites are susceptible to destruction from space junk and meteor storms due to their low altitude and high orbital speed.

Enemy use of GPS could give an innovative adversary similar capabilities for GPS guidance and navigation that U.S. forces employ. GPS frequencies are published and available to the public, and thus to our enemies as well. Third World countries and terrorists could exploit this capability since it doesn't require the resources of a large government.[27] The technology is available to build a GPS-guided medium or long range cruise missile to carry weapons of mass destruction (WMD) payloads (primarily chemical or biological). The threat could also come from simply installing a $700 GPS receiver linked to the autopilot of a small civil aircraft.[28]

WMD cruise missiles are of great concern to the operational commander. In fact, the commanders in chief (CINCs) of the unified geographic commands made cruise missile interception their number two priority (second only to chemical and biological agent detection capability:

> "The second CINC priority is the ability to intercept cruise missiles…These capabilities are particularly relevant for counter proliferation because cruise missiles are an extremely effective delivery system for BW (biological weapon) and certain CW (chemical weapon) attacks."[29]

Finally, the Naval Criminal Investigative Service reported that the GPS operating system software was compromised on 2 March 2001, giving the hacker access to the top secret U.S. computer system codes for guiding ships, missiles, and satellites. While the total impact has not yet been determined, the compromised OS/COMET source code could be used by an adversary or terrorist to disturb computer systems guiding various space programs or it could have been stolen through industrial espionage for commercial advantage.[30]

Operational maneuver - GPS affects the execution of operational maneuver. Nearly every maneuvering unit in the military uses GPS. The potential for widespread effects on navigation without GPS during maneuver is daunting. The ability to maneuver quickly and precisely may be significantly degraded in a GPS-hostile environment: degraded or inoperative navigational systems, reduced capability in combat identification, and degraded readiness in basic navigational skills.

Without GPS, the concept of operational maneuver bogs down, as vehicles of all types resort to back-up navigation, which may or may not have been practiced in training. If GPS is degraded or unavailable, operational forces may not be able to be synchronized properly or maneuver in a coordinated fashion.

Operational command and control - A loss of GPS can degrade theater-wide or operational command and control of forces. Without precise satellite navigation, the JFC's situational awareness can be degraded, and may result in increased friction and a less informed, lengthy decision process necessary to coordinate plans and major operations. The JFC may not know the exact location of his forces in relation to other forces and geographic features. Without a reliable GPS signal, he may not be able to monitor the situation in the theater, observe the movement of his forces, and supervise the actions of his subordinates. A loss of situational awareness also results in a larger increase in voice traffic on combat radio nets that can easily overload the communications bandwidth available.

The main deficiency of GPS for operational command and control is being a centralized system that is vulnerable to the enemy's preemptive attack. Since GPS is used as a source for timing information for many military automated command and control systems, a jammed or lost signal can degrade or even decapitate a JFC from his operational forces. Without command and control capability, it is more difficult for the JFC to sequence and synchronize his forces and assets to accomplish theater objectives.

Command and control procedures can be impacted by the loss of GPS. Over-reliance on GPS as a crutch for basic navigation skills can lead to complacent and unsafe behavior. For example, on 12 September 2000 the crew of LST-1194, Lamoure County, ignored the warning of the Combat Information Center (CIC) during an amphibious assault exercise off the coast of Chile. The ship ran aground and sustained significant hull and running gear damage, flooding in several spaces, and a fuel spill. The accident report cited an over-reliance on GPS as a single source for determining the ship’s position and recommended using all means available to fix the ship’s position. The navigator failed to resolve the

ambiguity between GPS and radar fixes. The bridge watchstanders failed to take into account CIC recommendations and relied on GPS as single source of navigation. The report followed up by saying that overconfidence in GPS created an atmosphere of complacency on the ship resulting in an unsafe crew condition.[31]

Impact on the Joint Force Commander

The growing reliance on GPS as the navigational and positional source for directing missiles and locating aircraft and vehicles, as well as, timing for command and control should be a concern to the operational commander. These critical military capabilities are hanging on a single constellation of satellites. JFCs must understand not only the capabilities of GPS, but also the weaknesses and vulnerabilities of GPS before employing weapons, equipment and systems that are GPS-dependent.

Loss of GPS may increase the fog and friction of war, limit a commander's options for precision strike, or result in the inability to deliver deeper fires from long range standoff weapons. The JFC may need to consider new employment strategies for GPS-guided munitions. For example, GPS-guided cruise missiles fired from a single sea-based platform deliver their weapons to a target area along similar flight paths. Once an enemy detects the first cruise missile, he can defeat the PGM by positioning his jammer near the original flight path to affect any remaining incoming missiles.

Major operations and campaigns may need an anti-jamming phase of operations in order to prepare the battlefield to complement existing electronic warfare (EW) operations. If GPS is degraded or jammed in the area of operations, GPS precision guided munitions may be ineffective against enemy surface-to-air missile (SAM) sites. As a result, additional high-threat suppression of enemy air defense (SEAD) missions may be necessary.

The JFC may need to adjust what to expect from air power in terms of strategic or operational strike operations. He may have to abandon using autonomous GPS precision weapons in politically sensitive strike operations if he can no longer guarantee their accuracy. Using alternative PGMs may require a higher risk operation. Also, gaining air superiority without GPS-guided munitions may take longer, require more aircraft strike missions, or require using less standoff weapons.

The employment characteristics of GPS-dependent weapons also dictate a paradigm shift, concerning accountability. Traditionally, firing units, and aircrew in particular, have been held responsible for where their weapons fall. This has resulted in a mindset of decentralized mission planning. While this planning would normally include specific aim-point selection, it is unlikely that aircrews will themselves be able to mensurate[***] GPS target coordinates. Using GPS-guided weapons will require reliance on a more centralized method of target coordinate production, with the firing unit responsible for verifying coordinate accuracy prior to weapons release. The delivery platform (e.g., aircraft or ship) might only be able to coarsely verify that the actual target position matches the pre-programmed coordinates.[32] The ability of a JFC to rapidly re-task aircraft or weapons in flight may deny "shooters" the time needed to attempt target data confirmation. Thus, as is done with cruise missile employment, the JFC may have to shift targeting accountability from the firing unit to the mission planner[33]

Recommendations

In the near term, JFCs must be aware of precision engagement limitations using GPS-dependent systems. As such, commanders should ensure they seek out and maintain a close

[***] Mensuration is the process of correlating a point on an image with a geo-centric coordinate that GPS uses.

working relationship with the space and communications communities to obtain their functional expertise on the progress of future GPS upgrades that will most certainly impact the satellites' capabilities and potential vulnerabilities.

When planning major operations, JFC staffs should consider that GPS is a potential weakness and develop a force protection plan to ensure safe and reliable operation of the particular GPS ground station[****] in their theater. As an example, RAND's national security study concluded that the GPS master control station at Schriever (formerly Falcon) Air Force Base in Colorado is well protected.[34] If necessary, the stations outside U.S. territory may need additional force protection planning to ensure the reliability of the system.

The services should train their forces that use GPS-dependent systems to be able to operate in a GPS hostile environment, or one in which GPS is not available. Without it, the armed forces could experience an over-reliance on GPS and a degradation of basic navigational skills. The operational commander should insist on training scenarios that stress fundamentals, especially in the area of navigation and weapons employment. They should ensure that soldiers, sailors, and airmen can still get the job done without their GPS receiver. The commander could "pull the plug" on GPS early in war games to learn if there are any effects on his war fighting capability. General Patrick Cordingley, Commander, British Seventh Armored Brigade recalled his reliance on GPS for navigation during the Gulf War:

> "First thing in the morning, and then just after dark, the satellites that provided the signals would go out of range. As a result every morning and evening for about fifteen minutes we would get lost."[35]

The temptation to use the "GPS crutch" will only increase as GPS finds its way into more and more equipment and weapon systems.

[****] See Appendix A for description and the locations of GPS ground stations.

JFCs should consider directing their forces to use alternative systems for sources of navigational aid (NAVAID) in their operations. For example, the commander could require aircrews to keep using terrestrial based navigation systems (e.g., TACAN, VOR, or LORAN) as a backup. Accordingly, naval ships could continue to use their LORAN-C radio-navigation as backup. With regards to precision munitions, the JFC should consider using electro-optical systems and laser-guided munitions (perhaps using UAVs to lase targets when the weather is acceptable) when possible.

In the long term, the DoD should consider developing new technologies to complement GPS and to protect current GPS-dependent systems from being jammed. Indeed, the Defense Science Board (DSB) recommends that the three main GPS priorities for the DoD should be "anti-jam, anti-jam, anti-jam."[36] The DSB also recommends that DOD develop more accurate inertial navigation systems that do not rely on a global positioning system as much. The Air Force is evaluating electronic and other countermeasures to develop an anti-jam capability for GPS systems, and it appears a combination of techniques may be needed to ensure reliable and accurate missile guidance. Specially designed antennas and more rapid connection with GPS satellites are among the techniques being considered. So far, the high cost of potential anti-jam devices or more accurate navigational systems has limited their use in precision-guided munitions.[37]

The Defense Mapping Agency is constructing a worldwide geographic database to better support regional CINCs and their digital requirements. This database will provide an ability to focus on developing alternate systems such as Precision Terrain Aided Navigation (PTAN). A PTAN equipped missile would perform continuous terrain contour mapping, and

match the contour with a database stored in the missile's computer. This system gives you precision navigation without GPS.[38]

Conclusion

GPS has revolutionized almost every facet of military operations, from navigation by individual soldiers to weapons guidance. Accordingly, the JFC has become over reliant on GPS as the dominant source for navigation, precision, and timing information in weapon, vehicles, and command and control systems. This dependency on GPS can lull the commander into a false sense of security.

Although GPS is a critical strength, it can be exploited by an adversary. JFCs must understand not only the capabilities of GPS, but also its weaknesses. With the large investment in GPS-dependent systems, there is a tendency to overlook GPS shortcomings and vulnerabilities. Over-reliance on GPS can produce critical vulnerabilities in the operational concepts of precision engagement, force protection, operational maneuver, and command and control.

The battlefield of the future will most likely consists of more GPS-dependent systems to include GPS-guided precision munitions. GPS, as a critical strength, is a potential operational COG for major U.S. military operations and campaigns. We must either protect our operational COG or find alternatives to this system. GPS is not vulnerable because it is in space, but because it is a centralized system that can support the commander at the strategic, operational, and tactical level. Decentralize it (e.g., find a balance between space and terrestrial solutions) and you may reduce its vulnerability.

Appendix A - Global Positioning System (GPS) Description

GPS is a space based worldwide, all-weather, radio positioning network able to supply ground based and airborne users with precise information on position, velocity, and time. The GPS is a $10 billion dollar Department of Defense system. The GPS system consists of three segments: space, control (or ground segment), and users.

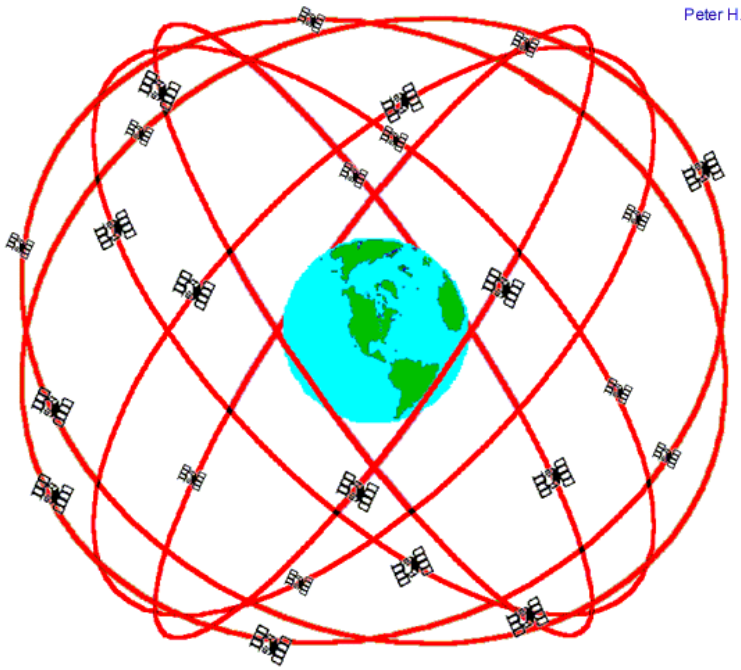
The space segment is a network of 24 primary satellites located in such a way that a minimum of four will always be in view from any point on Earth. The satellites are placed into six orbital planes, eached tipped at 55 degrees to the equator, where they track a twelve hour low Earth orbit (LEO), 10,898 nautical miles above the Earth. The space segment transmits timing pulses and satellite ephemeris data into coded radio signals. The ephemeris data provides sixteen constants that are used to determine the exact location of each satellite. Four extremely accurate atomic clocks are carried on each satellite to provide precise timing measurements. GPS works by determining the time required to receive the radio signal from a satellite. This time delay is used to determine the distance from the satellite to the receiver. Measurements from four or more satellites are used to calculate the position of the receiver. Two different codes are broadcast by GPS; the Precision or P-code and the Coarse/Acquisition or C/A code. The more accurate P-code is available only to users authorized by the U.S. military.

One signal is for commercial use, the other for military use only. The military signal (P-code), called the precise prepositioning service (PPS), is an unadulterated signal that is accurate to about 38 feet. Additionally, it can be encrypted. The civil signal (C/A code) is called the standard positioning service (SPS). This signal has a built in error (called selective availability) of approximately 328 feet. This error can be increased by DoD if required.[39]

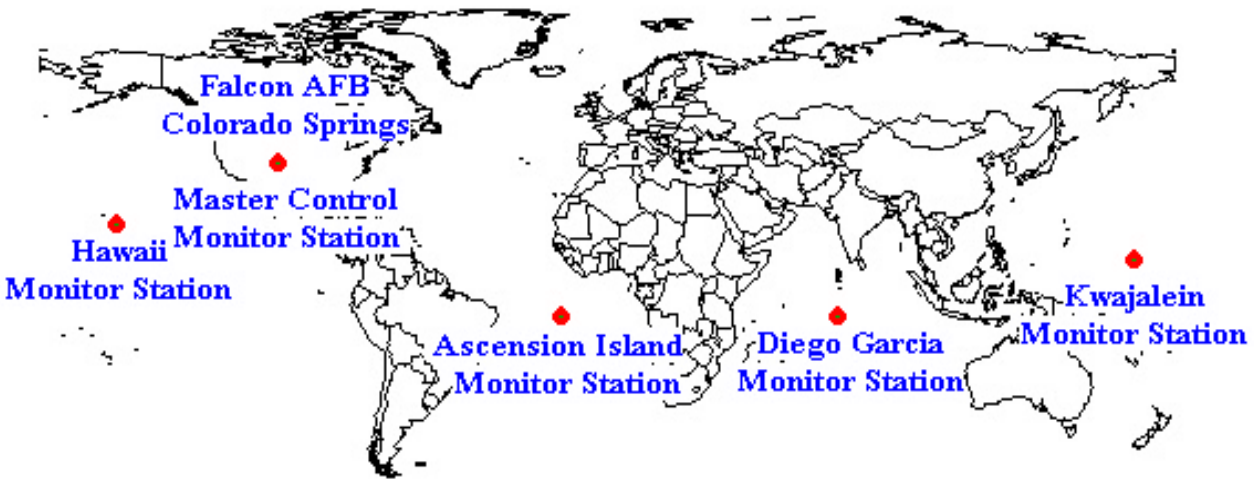
The control segment includes ground stations that monitor the GPS satellites, checking both their operational health and their exact position in space. The master ground station transmits corrections for the satellite's ephemeris constants and clock offsets back to the satellites themselves. The satellites can then incorporate these updates in the signals they send to GPS receivers. There are five monitor stations: Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs. The Master Control Station, which provides the update data, is located at Shriever AFB, Colorado and is operated by the U.S. Air Force Space Command.[40]

The user segment consists of receivers that use the radio signals broadcast by the GPS satellites to calculate accurate position, velocity and timing measurements.

GPS is not the sole navigation system in most weapon platforms. It does, however, greatly improve the capabilities of current inertial navigation systems (INS). In tactical jet aircraft for example, an INS/GPS combination is used. Although the GPS signal is not the only source of navigation information in this system, it is tightly woven into the navigation infrastructure, hence rendering navigation and weapons employment susceptible to GPS signal interruption or manipulation.[41]



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination



Global Positioning System (GPS) Master Control and Monitor Station Network

http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html

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