White Paper – A Case Study of GPS Retransmission Systems for Airborne Applications

GPS SOURCE

GPS LIVE INSIDE

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Introduction

Global Positioning System (GPS) technology is increasingly being applied in many different military applications. The Warfighter uses GPS to enhance situational awareness on the battle field with systems such as Land Warrior, Blue Force Tracker, FalconView, and various electronic mission planning tools loaded on Toughbook or GoBook laptop computers. Tactical radio systems such as the VHF Combat Net Radio or new JTRS software defined radios such as the AN/PRC-117G and AN/PRC-154 Rifleman Radio no longer simply transmit voice information over terrestrial networks. Warfighter positional information, text messages, and other data is also transmitted via their tactical networks. GPS applications for airborne qualified units provide improve situational awareness during transport and guidance to the drop zone in night or inclement weather operations via commercial receivers or military grade SAASM devices. In the case of Joint Precision Airdrop Systems (JPADS), GPS guidance receivers provide navigation and steering commands to guide the payload to the drop zone. GPS enabled asset tracking may provide current position and status of high value assets, such as VIPs, nuclear weapons, etc. In training applications, GPS technology may be used to track the participating assets, scoring the exercise and enabling a far more instructive de-brief.

In all of the examples above, and in many other GPS enabled military applications, it frequently becomes necessary for these GPS receivers to operate in locations where the GPS signals are normally not available. Many times, this environment is the inside of military aircraft such as the C-130 *Hercules*, C-17 *Globemaster III*, V-22 *Osprey*, CASA-212, or CH-47 *Chinook*, in which a Soldier, Airman, Seaman, or Marine must use airborne insertion techniques to deploy humans, supplies, and weapons to the battlefield. This white paper will discuss how GPS Retransmission has been an effective solution to the problem of GPS denied environments for GPS enabled applications supporting airborne operations employed by US Special Forces and Airborne qualified units. It discusses multiple case studies of US Special Operations Forces successfully employing GPS retransmission to improve the efficiency, accuracy, and safety of military free fall (MFF), static line, airborne assault, and aerial re-supply in combat and training environments.

Airborne Operations

There are a number of techniques employed by US and NATO allies today to move assets from aircraft to the battlefield including military free fall, static line, airborne assault, ballistic airdrop, and GPS guided precision airdrop.

Military free fall (MFF) is premier technique employed by elite military units around the world. Identified by the US Army John F. Kennedy Special Warfare Center & School's *Special Operations Forces Military Free-Fall Operations Manual*[1], MFF is defined as:

> MFF parachute operations are used when enemy air defense systems, terrain restrictions, or politically sensitive environments prevent low altitude penetration or when mission needs require a clandestine insertion. MFF parachute infiltrations are conducted using the Ram-Air Parachute System (RAPS), which is a high-performance gliding system. The RAPS is a highly maneuverable parachute that has forward air speeds of 20 to 30 miles per hour (mph). The glide capability of the RAPS provides commanders the means to conduct standoff infiltrations of designated areas without having to physically fly over the target area. This process allows commanders to keep high-value air assets outside the detection and threat ranges of enemy air defense systems or politically sensitive areas.

Military free fall consists of two primary techniques; high altitude low opening (HALO) and high altitude high opening (HAHO). In a typical HAHO exercise, the jumper will egress from the aircraft and deploy the parachute at a high altitude, 10 to 15 seconds after the jump. The jumper will use a compass or, more likely, a GPS enabled navigation device, for guidance while descending under the RAPS for a significant standoff distance. The jumper must use way points, terrain features, and compass to navigate to his desired landing zone, and correct his or her course to account for changes in wind speed and direction. With new GPS aided technology, navigation under canopy can now leverage computer navigation devices, mounted on the soldier's chest or arm. Military free fall techniques are employed by US Special Forces from all three branches of the military, designated as MFF and Airborne capable units.

A second insertion technique utilized by Airborne units is static line parachute insertion. A static line is a cord attached at one end to the aircraft and at the other end to the top of the pilot chute inside the jumper's backpack. The parachutist's fall from the aircraft causes the static line to become taut and then pulls the pilot chute free of the backpack enabling him to descend the ground under non-steerable or steerable canopy. Static line jumps are often executed at low altitudes, infiltrating large numbers of personnel and cargo to support an assault or take a target, such as an airfield. In these applications, the Warfighter uses GPS guided technology to navigate on the ground after landing with tools such as the Garmin Foretrex or laptop based navigation software such as FalconView.

Similarly, in order to quickly place a team of Soldier's on a target, teams may fast rope or quickly egress a rotorcraft during the mission in locations where the rotorcraft cannot safely land to unload passengers. As in other military operations, GPS guided technology is employed by units capable of performing fast rope techniques to assist in situational awareness and speed the assault mission.

Finally, logistics organizations utilize aerial resupply techniques to insert fuel, water, ammunition, and other supplies to forces operating on the ground. Typically referred to as, "airdrop," this tactic enables a large amount of materiel to be provided in a short period of time without endangering air or ground assets. Airdrop is employed from a wide selection of aircraft, ranging from small tactical aircraft such as a CASA-212 to large cargo aircraft such as a C-130 or C-17. Airdrop has also been supported from rotorcraft such as the CH-53 or CH-47. Today's GPS technology has enabled the US Air Force and USMC to accurately supply these items to ground forces through GPS guided bundles, called Joint Precision Airdrop Systems, or JPADS.

What is GPS Retransmission?

GPS Retransmission, or GPS Repeating, is the art of making the live GPS signal available to handheld or mobile GPS applications at locations where the signal is not otherwise available. Proven applications include the following:

- In the crew compartment of a military vehicle,
- In the cargo compartment of a military aircraft,
- In the garage or hangar bay of a military maintenance facility,
- In the wet well or maintenance deck of a naval ship, or
- In the final assembly stage of a military or heavy equipment manufacturer

In order to repeat a live GPS signal, a GPS retransmission system must be installed to the parent aircraft, vehicle, ship, or facility. This system can be installed in a permanent manner or installed as a mission kit offering flexibility to a wide range of applications.

GPS retransmission has been utilized to benefit all aspects of Airborne operations, ranging from military free fall guidance solutions, such as jTrax or PARANAVSYS, GPS guided JPADS receivers such as FireFly, to Warighter's wearing Garmin Fortrex receivers performing static line jumps or fast rope techniques. The following sections outline the value of GPS retransmission and how it is implemented, as it relates to these Airborne tactics.

Military Aircraft Applications, Benefits, and Added Value

When GPS receivers, or specifically the receiver's antennas, are inside of aircraft (i.e. DAGR or Garmin 60 held by a SOF Soldier inside a C-130) without a Line Of Sight (LOS) view of the GPS satellites, the receivers will not provide navigational or position information. In some cases, loss of the GPS signal will cause receivers to report the last valid position fix, which can lead to erroneous information being dispersed throughout the Warfighter tactical network. The Warfighter may not be aware of this data error, leading to incorrect coordinates being called out for high altitude release point (HARP), time to jump, or other position critical events. Furthermore, a Warfighter tracking his team via FalconView mapping software will not receive updated terrain or positional information from descending Soldiers. This limitation can impact many military GPS applications, even if location data inside of the denied environment is not a requirement.

For example, the receiver's or system's performance may be impacted in the following ways:

- When the receiver deploys from the aircraft, the "time to first fix" (TTFF) can vary significantly based on numerous conditions (worse case TTFF can be over 5 minutes),
- GPS receiver battery life while operating inside of the aircraft is significantly reduced due to the ongoing signal acquisition process,
- Lack of signal availability may preclude verification of system operation prior to deployment,
- Lack of signal availability prohibits jump master or squad leader from understanding real time position prior to jump or JPADS deployment,
- Lack of signal availability prohibits team member from using mapping tool, such as FalconView, to track position of descending Soldiers or aircraft position on moving maps.

With a GPS retransmission system installed in the crew compartment of a military aircraft and providing availability of the GPS signals in the otherwise denied environment, navigation applications benefit in the following ways:

- Enables acquisition and verification of cargo payload receiver's prior to air drop (JPADS),
- The Warfighter can monitor position route, and target location prior to military free fall (MFF) insertion,
- Enables the Warfighter's acquisition and verification of positional data before rapid insertion via helicopter or tilt rotor,
- Reduces time from dismount to initial breach on target location. Further, it ensures accurate fix on target location during dismount,
- Wirelessly enables encrypted SOF communications equipment during transport,
- Enables aircraft modularity from mission to mission

Successful implementation of GPS retransmission systems within military aircraft is evident across a wide range of applications. GPS retransmission provides systems such as DAGR, JTRS radios, FalconView, Garmin Foretrex, Garmin 60, Magellan Triton, Tacticomp, Toughbook or GoBook laptop computers, JPADS Autonomous Guidance Units (AGU), Laser Target Locator Modules (LTLM), AN/PRC-117G radios, or other applications enabled to receive a GPS signal wirelessly. US Army Special Forces and other elite counterterrorism units have employed GPS retransmission during missions requiring military free fall (MFF) and static line insertion techniques which allow each Soldier to receive a live GPS signal to his equipment prior to jump, dramatically improving situational awareness, accuracy, and survivability.

GPS Retransmission System Architectures for Aircraft Supporting MFF

GPS retransmission systems, in their simplest form, include at a minimum the following elements:

- Active Antenna (Active meaning the antenna includes an integrated Low Noise Amplifier)
- Interconnecting Coaxial Cable(s)
- Retransmission Amplifier/Signal Conditioner
- Passive Retransmission Antenna
- Power Cable & Power Source

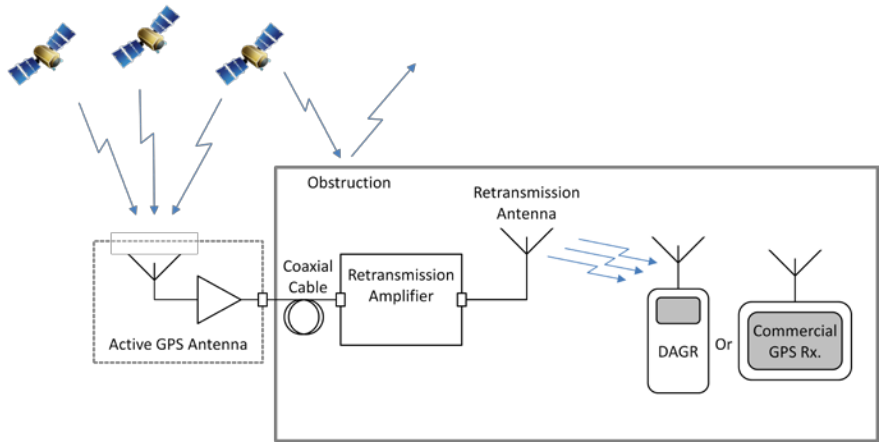

Figure 1. Basic Components of a GPS Retransmission System in US Military Aircraft

In this system (Figure 2), the GPS satellite signals are received by the active receive antenna, amplified, and re-broadcast on the GPS frequency(s) by the retransmission antenna inside the obstruction, or aircraft. Satellite signal delay through the GPS retransmission system is common. GPS receivers will calculate the position of the system's receiving antenna, which is located outside and in view of the LOS signals. This limitation is not critical for the aircraft application described above, because the derived location is close enough to accomplish the intended function. Flexibility in systems architecture can be achieved with the incorporation of additional RF signal distribution hardware, such as a 1x4 splitter or other distribution device, exemplified in figure 3. Or, it can be achieved by adding passive antennas or hardwired connections to equipment within the basic system in figure 2. Power options for any GPS retransmission system include 28V aircraft power or standard BA5590 class Lithium Ion battery. Both power options have been successfully implemented by US Special Forces utilizing GPS retransmission to support airborne missions.

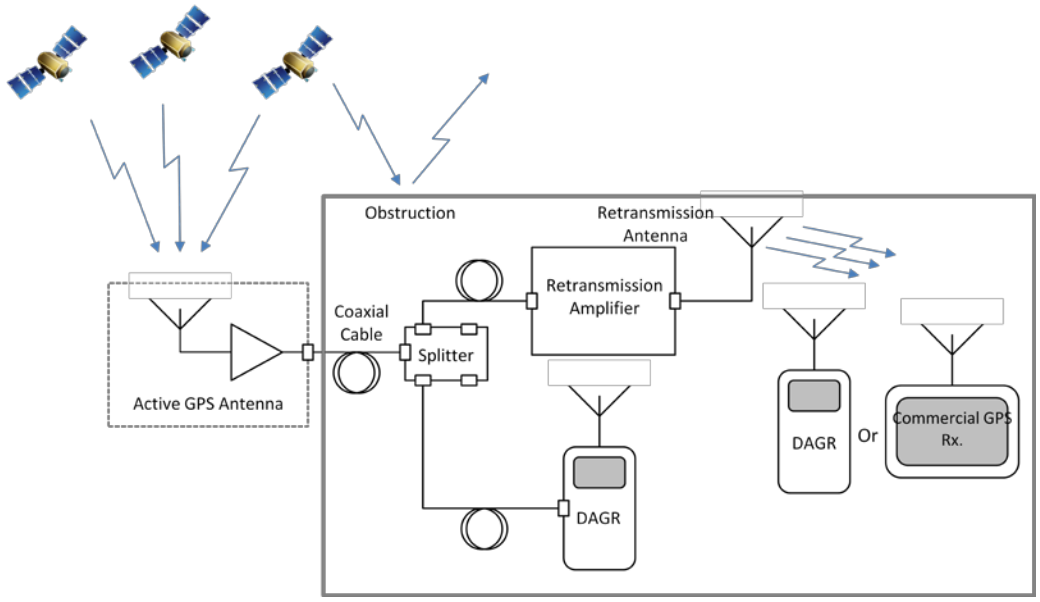

Figure 2. Basic GPS Retransmission System w/ Integrated RF Splitter to Expand System Capabilities

Systems, such as those demonstrated in the previous figures have successfully been implemented aboard aircraft including the C-130, CH-47, MH-47, C-17, CASA-212, C-235, C-23, and other host country aircraft by US Special Forces units. SOF units implemented a GPS retransmission system aboard a US Army CASA-212 aircraft to support MFF training in 2008. Figure 4 demonstrates an integrated amplifier and passive antenna retransmission device installed on the port side of the aircraft interior to provide GPS signal coverage to Soldiers egressing from the rear ramp or rear troop door. In this application, the signal was routed from a windscreen mounted active antenna via RF cable.

Figure 3. GPS Retransmission Device Installed to a US Army CASA-212 Aircraft

To support a desire for roll on/roll off applications by the team performing MFF operations, it is a common need for equipment to be installed quickly and without negative impact to the airframe or existing avionics equipment. For this purpose, the Army utilized a suction cup mounted active GPS antenna to feed a signal to the amplifier and passive antenna inside the aircraft. Shown in figure 5, the active antenna mounts to the aircraft windscreen or eyebrow window above the flight crew, if available. In the case of the CH-47 or CH-46, side bubble windows can also be utilized for installation of the active antenna.

Figure 4. Suction Cup Mounted Active Antenna for Easy Retransmission System Installation

Alternative to the use of a standalone active GPS antenna is the use of the integrated aircraft GPS antenna by tapping into an output RF port native to the airframe, referred to as the GAS-1, antenna electronics unit (AEU), or antenna control unit (ACU). Those aircraft not operating CRPA antenna systems can simply add a splitter into the feed from the aircraft GPS antenna located on the roof. It is critical that system loss be understood for appropriate system application to support MFF GPS receivers.

Advanced systems necessary to provide GPS signal coverage in larger aircraft such as the C-130 or C-17 have also been successfully utilized in both training and combat applications. In these applications, multiple passive antennas are employed within the cargo bay and flight deck of the aircraft to provide 100% GPS signal coverage. GPS Signal coverage on the flight deck is desirable as it provides the capability to the crew to perform mission planning activities in the proximity of the flight crew. In addition, these large systems support precision air drop (JPADS) missions that may support MFF and SOF ground forces.

US Military Airborne Applications for GPS Retransmission

US Special Forces have shown strong interest in the use of GPS retransmission in combat to support a wide range of missions, including air assault, ground assault, military free fall, precision re-supply (JPADS), and communications. GPS retransmission has enabled the Special Operations Warfighter to dramatically improve situational awareness prior to MFF insertion in support of ongoing missions in Afghanistan. As referenced in the USAJFKSWCS *Special Forces Military Free-Fall Operations Manual*, mountainous terrain and difficulty in ground transportation has made MFF a popular force insertion technique for commanders in recent history. For use in MFF deployment, and navigation once on the ground, Warfighter's deploy with SAASM capable receivers, such as DAGR, shown in figure 6, alongside commercial-off-the-shelf receivers such as Garmin's Foretrex 401, Magellan's Triton 500, or GD GoBook laptop computers. Each tool offers value to Special Operations Forces and the individual Warfighter is deploying with one or more GPS enabled devices as global conflicts demonstrate their necessity.

In early 2009, the USASOC units began utilizing GPS retransmission for a wide range of missions, including military free fall, static line jumps, JPADS resupply, and airborne assault. GPS retransmission kits have enabled these units to better understand heading and position prior to reaching the HARP, in the case of MFF. A live GPS signal provides aircraft jumpmasters the ability to track location, aircraft heading, give accurate time warnings, and exact positioning over the designated release point without relying on the aircraft crew. GPS retransmission allows the units the ability to orient to the drop zone, navigate, and land at the designated drop zone during standoff (HAHO) operations improving safety and survivability. Installed in a C-130, the retransmission system enabled an NCO to track descending soldier's movements via FalconView software installed onto a Toughbook Laptop computer. This improved the commander's vision of the battlefield and allowed more efficient decision making to be made by all parties involved in the operation. The NCO provided feedback on the use of the retransmission system stating, "I have set [the GPS retransmission system] up for teams to use during HAHO operations and the teams said that their GPS systems had maximum bars across the board. The last time I had it connected to a FalconView computer that was tracking their descent from the aircraft. All of this was done at 25,000ft AGL."

Figure 5. Standard GPS Receivers Utilized by US Special Forces

USASOC units have integrated GPS retransmission systems to a wide range of aircraft and ground vehicles to assist them in completing their mission. They have used GPS retransmission aboard the MH-47, CH-47, CASA-212, C-130, and a range of ground vehicles including Stryker, GMV, and MRAP variants. Figure 6 demonstrates a dual passive antenna GPS retransmission system installed to the CH-47 to support unit air assault and MFF missions.

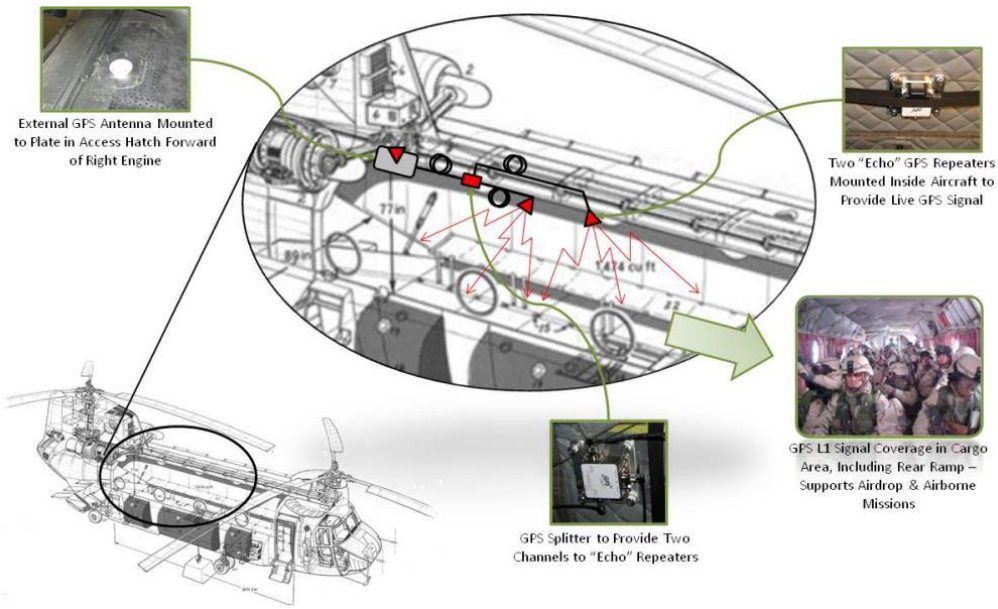

Figure 6. GPS Retransmission System Aboard US Army CH-47

USASFC

In late 2008, subordinate units of the US Army Special Forces Command wrote an Operational Needs Statement[2] (ONS) indicating their requirements for live GPS signals inside aircraft and ground vehicles to support a range of operational needs. These needs included a live signal to support air assault, ground assault, and MFF missions. In March 2009, the organization successfully obtained and implemented a GPS retransmission system for use aboard the CASA-212, CV-22, and MH-47 aircraft. The systems were issued to each reconnaissance team in the company with the remainder issued to communications section. Use of the retransmission system successfully enabled all personnel inside the aircraft to use GPS systems and monitor position and routes prior to MFF operations and aided in ensuring GPS signal lock was achieved for use of the Glideline parachutist's navigation tool. Further, during dismount of Soldier's in ground assault missions from MRAP and GMV vehicles, the Soldier's were oriented to the correct target structure and assault time on the compound was dramatically reduced, resulting in an improvement in survivability.

Other SOF Applications

In early 2010, counter terrorism teams within the US Special Forces community identified a requirement to provide a small area of coverage in the forward cargo area inside a USAF C-17 to enable tactical radios and GPS devices prior to MFF missions in support of operations in Afghanistan. Figure 8 demonstrates the notional intent of the system installed to the aircraft, with the sole purpose of providing situational awareness to the team members prior to military free fall insertion without the burden of a large scale full coverage retransmission system. The team required a thirty-foot diameter area of GPS coverage in the forward portion of the cargo compartment where they located their communications equipment. With the GPS retransmission system in place and retransmitting a live GPS signal, the team was able to make contact with Soldiers on the ground via encrypted voice radio communications. When a positional update was required, members of the team were able to walk into the small "cloud" of GPS signal coverage inside the aircraft to update their GPS devices to better understand time to HARP and current heading. In this case study, GPS retransmission was used to update GPS receivers with position and heading information inside a denied location, but also fixed the precise timing structure of encrypted radio communications equipment for signal hopping to ensure the information was not obtained or jammed by enemy forces.

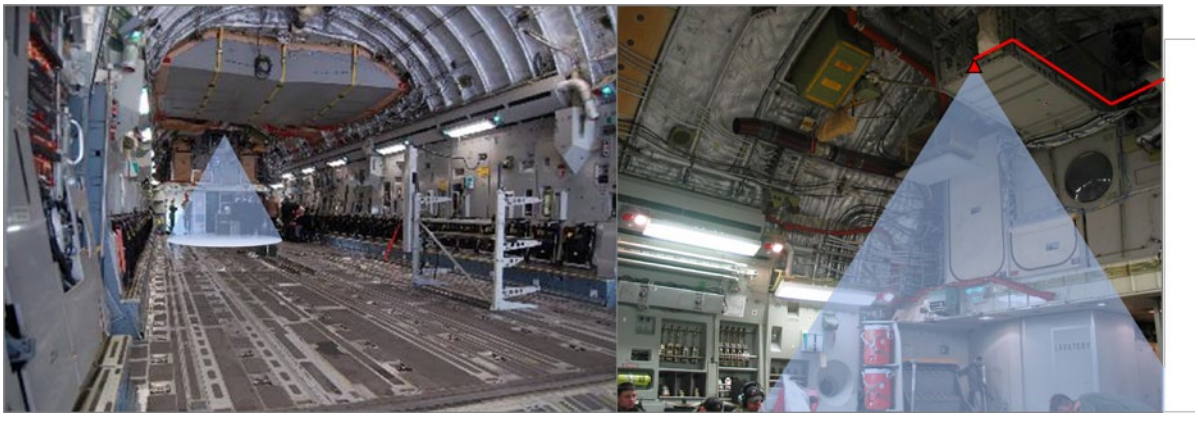

Figure 7. GPS Retransmission System Installed to USAF C-17 to Meet MFF Requirements

In the third quarter 2010, and in response to requests from customer organizations such as USASOC and USASFC, the rotorcraft platform managers pursued an investigation into a permanent GPS retransmission solution for Army rotorcraft to support MFF, air assault, and forward insertion missions. At the time of the release of this white paper, flight certification from the US Army for use of retransmission devices aboard their aircraft had been achieved for a

number of systems. Successful implementation of permanently installed retransmission systems will enable customer infantry units from having to hand carry and install retransmission kits prior to the mission. Further, permanent install solutions provide a more robust, safe, and optimized solution for any aircraft.

US Army Natick Soldier Systems Center PARANAVSYS Program

The Natick Soldier Center is the US Army's one-stop Soldier-support organization. The Soldier Systems Center is responsible for researching, developing, fielding, and managing food, clothing, shelters, airdrop systems, and Soldier support items for the US Army[3]. The Natick Soldier Center has been a key stakeholder in development and implementation of GPS retransmission systems for use aboard US Army and US Air Force aircraft in support of precision air drop (JPADS) and MFF missions for Special Operations Forces. Natick Soldier Center began funding development of key components for use in parachutist navigation devices in 2006, culminating in two systems used by US Army and US Marine Corps Special Forces units in combat and training; PARANAVSYS and Glideline. GPS retransmission is a critical enabling technology for these navigation tools and numerous systems have been evaluated by Natick since 2006. A live GPS signal inside the aircraft enables the navigation system's mission planning tool and enables the user to obtain GPS lock before exiting the aircraft, dramatically improving the accuracy of impacting the pre-determined landing zone, which can be as small as 100 square yards in enemy controlled territory. With input from Natick, and by experience, it has been accepted by the Special Forces community that a GPS retransmission system is key factor in the performance of the parachutist's navigation device, making it a requirement for the MFF program at Natick.

Figure 8. PARANAVSYS Systems by Rockwell Collins (Left) and Glideline by Nanohmics (Right)

US Air Force C-17 *Globemaster III* High Altitude Airdrop Program

In 2007, the USAF and Boeing Integrated Defense Systems identified a requirement for a permanent install GPS retransmission system to meet the need for high altitude precision aerial delivery capabilities in Afghanistan. GPS Source was contracted to design, build, and qualify this system to meet the needs of US Air Force C-17 crews supporting deployment of US special operations forces and resupplying the ground force in Afghanistan and Iraq. In April 2010, Boeing and GPS Source successfully completed the qualification test plan and all required flight tests and received air worthiness certification from the US Air Force for the permanent install GPS retransmission system. This system provides 100% signal coverage for the cargo compartment and flight deck of the C-17, enabling precision air drop and military free fall missions by Special Operations Forces. The system offers Built-in-Test (BIT), Fault Isolation, output power control, and oscillation detection capabilities, offering the safest solution on the market for GPS retransmission.

Current GPS Retransmission Systems Supporting Airborne Operations

GPS Source offers a line of GPS retransmission kits targeted to the needs of Airborne operator for MFF, static line, airborne assault and JPADS missions in which a live GPS signal inside an aircraft or vehicle is key to mission success. The GLI-Cobra, Figure 11, offers the Warfighter all equipment necessary to repeat a live GPS signal in any aircraft or ground vehicle, including airframes as large as the C-17 and C-130, to ground vehicles as small as a GMV or Toyota Hilux. The GLI-Cobra is a self contained GPS retransmission kit which includes all hardware for installation and troubleshooting, including mounting plates, straps, active antenna, passive antennas, RF cables, power cables, User's Manual, and GLI-GLI-ECHO II device. The kit can be powered from a BA5590 battery or 28V vehicle/aircraft power.

Figure 10. GLI-Cobra GPS Retransmission Kit by GPS Source

GLI-ECHO II, the industry's first "*smart repeater*," is the key component included in GPS Source retransmission kits. Designed to be small and lightweight, GLI-ECHO II offers the ability for the operator to install a single solution across a wide range of platforms, both air and ground. The GLI-ECHO II offers four key safety features, including: Manual & Automatic Output Power Control, Automatic Oscillation Detection, Fault Isolation, and Built-In-Test Capabilities. Output power control is important in negating antenna gain variability and variations in output power that can result from variations in antenna systems aboard aircraft or variations in ambient temperatures. Furthermore, the ability to manually set the output power offers a single solution for a diverse range of host aircraft or vehicle platforms. The GLI-ECHO II set to Level 1, for example, allows for operation inside a GMV, HMMWV, or M-ATV while Level 14 enables operations inside a C-17 aircraft. Oscillation detection alleviates oscillation events resulting from poor or improper installations. It can remedy high output power levels from repeat antennas. This ensures the appropriate level of output power is emitted for the application. Plus jamming due to oscillation, does not prohibit use of L1 or L2 enabled GPS devices on the battlefield. Finally, BIT and fault isolation capabilities are important functions of meeting mission readiness. A digital readout not only provides output power and brightness levels, but also provides fault codes for use in troubleshooting issues. These features are all important in ensuring a *safe* and *functional* GPS retransmission system, enabling the Warfighter during MFF, assault, resupply (JPADS), or patrol missions.

Figure 9. GLI-ECHO II from GPS Source

Sources

1. *Special Forces Military Free-Fall Operations Manual*. April 2005. United States Army John F. Kennedy Special Warfare Center & School. Ft. Bragg, NC.
2. *Operational Needs Statement for 3rd Battalion, 7th Special Forces Group.* March 2009. Captain Jamie Clark, Detachment Commander. Ft. Bragg, N.C.
3. www.army.com/Natick. US Army Natick Soldier Center Website.

GPS Source Contact Information

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