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## VS.
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**Ultra High-Accuracy Reference System**

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### Air Force Upgrades to a Better Field Reference System for Testing GPS Denial

**BY** Capt. James Kawecki, James Brewer, John Cao and Jason Baldwin

Initial Operational Capability for the Ultra High-Accuracy Reference System has been declared by the U.S. Air Force. Even when GPS is being completely jammed, UHARS provides extremely accurate positioning, navigation and time — more accurate than GPS — over the large area of White Sands Missile Range in New Mexico.

X = Locata transmitter sites at USAF's White Sands Missile Range

# CAN'T DENY THE TRUTH:

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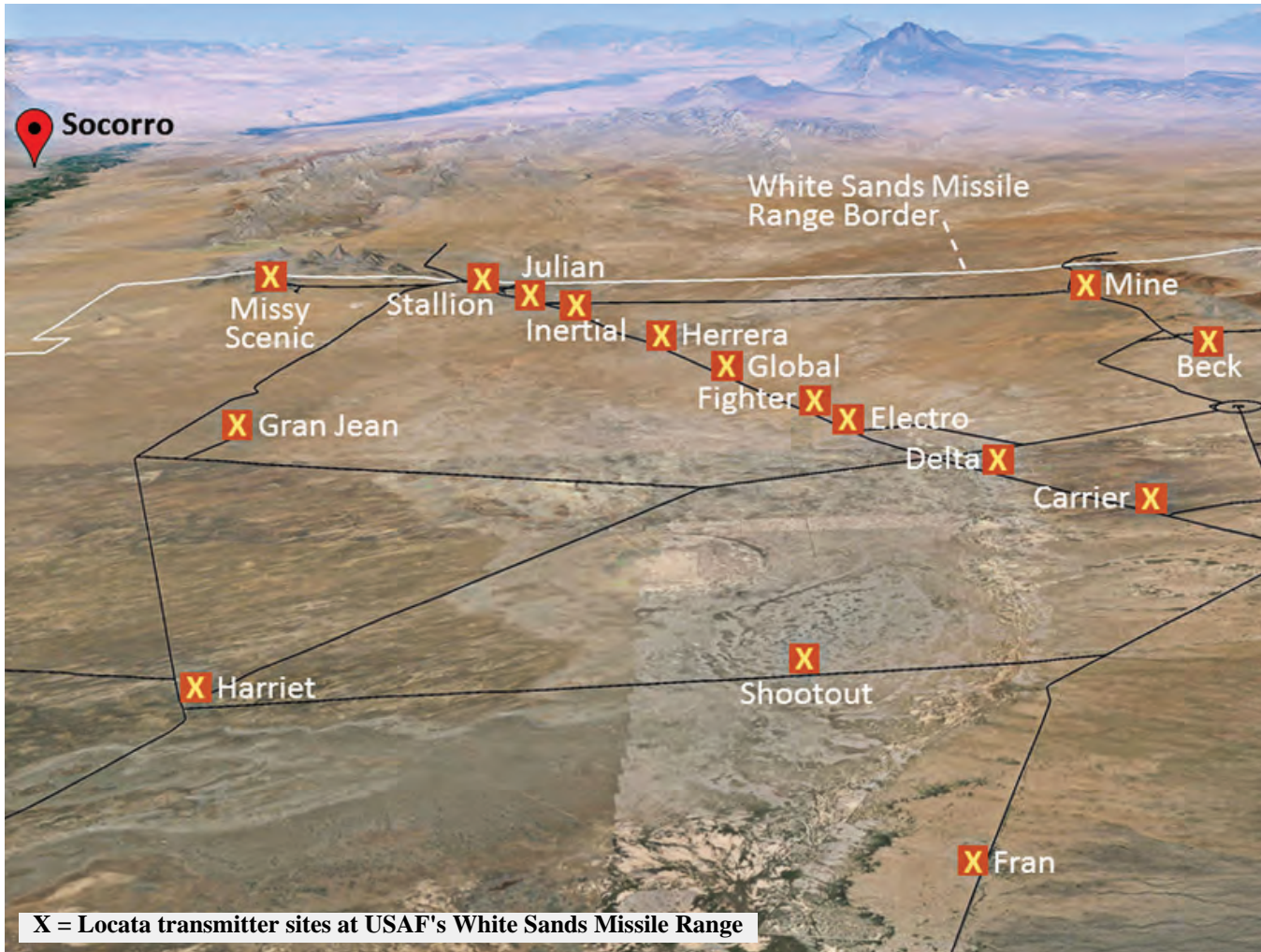
**BY** Capt. James Kawecki, James Brewer, John Cao, 746TH TEST SQUADRON, and Jason Baldwin, TMC DESIGN CORPORATION

NON-GPS
POSITIONING SYSTEM,
WHITE SANDS
NORTH RANGE.
X = TRANSMITTER
SITE

# DEFEATING THE JAMMING THREAT

Amid a growing concern about GPS jamming in military areas of operation, testing GPS receivers and antenna systems in a GPS-denied environment has become increasingly important to Department of Defense (DoD) agencies. However, since GPS is often the "gold standard" position, navigation and time information that serves as a truth reference during field and flight testing, conducting tests in an area that has no GPS availability because of intense jamming makes it difficult to compare observed position and navigation data to a valid truth source. Moreover, to evaluate system performance with appropriate statistical significance, the reference system against which test results are measured needs to be significantly more accurate than the system under test. Therefore, when the system under test is GPS itself, this poses an interesting problem.

For more than a decade, the 746th Test Squadron (746 TS), also known as the Central Inertial and GPS Test Facility (CIGTF), has met this requirement by employing its CIGTF Reference System (CRS). The CRS (**FIGURE 1**) is a system of navigation sensors that evaluates combinations of its subsystem measurements in an extended Kalman filter/smoother algorithm to produce an optimal reference trajectory. Delivering sub-meter accuracy in non-GPS-jammed environments and meter-level accuracy in GPS-jammed environments, the CRS is arguably the most accurate reference system in the DoD. However, many future DoD weapons systems are projected to require tighter navigation accuracies in GPS-denied environments, and as these requirements improve, the reference system against which they are evaluated must improve accordingly. To meet these test and evaluation reference requirements in a GPS-denied environment, a new reference system is needed.

The 746 TS embarked on the development of the Ultra High Accuracy Reference System (UHARS), a next generation reference system that meets test and evaluation reference requirements for future navigation and guidance systems. UHARS consists of a rack-mounted, tightly integrated system of improved navigation sensors/subsystems, data acquisition system (DAS) and a new post-mission reference trajectory algorithm. The complete system will provide a significantly more accurate reference solution for future airborne and land-based test vehicles in navigation warfare environments where modernized and legacy GPS signals are jammed from friendly or hostile systems.



**FIGURE 1** CIGTF Reference System (CRS).

After successful completion of the technical demonstration in 2011, in which all of these key technical requirements were demonstrated, the USAF awarded contracts to field the NGBPS.

- Carrier-phase "truth-reference" solution of < 18 cm Three Dimensional Root Mean Square (3dRMS), with a Position Dilution of Precision (PDOP) < 3.0.

- Rover receivers acquiring and tracking Locata signals at a range greater than 30 miles (48 km).

- Accurate and reliable TimeLoc synchronization over the test area, the ability to "cascade" TimeLoc from one LocataLite to another, plus the delivery of nanosecond-level synchronized time on the Range while GPS time is unavailable because of GPS jamming.

- External signal amplification to support the extended signal range requirement while still maintaining nanosecond-level TimeLoc integrity.

- Rover receiver tracking loops perform adequately under flight dynamics.

- Tropospheric measurement and modeling to ameliorate the large tropospheric errors (approximately 300 ppm uncorrected) experienced by terrestrial signals at these ranges.

- Transmit and receive antennas that provide both adequate gain and multipath mitigation for an aircraft flight scenario.

**Non-GPS Based.** Achieving these accurate reference solutions requires a Non-GPS Based Positioning System (NGBPS) subsystem capable of operating and providing sub-meter position accuracy in a GPS-denied (jamming) environment. The NGBPS portion of the UHARS program employs a network of ground-based LocataLite transceivers and test vehicle receivers (also called rovers). Although the NGBPS uses standard commercial LocataLites and rovers, meeting the demanding UHARS accuracy and distance requirements of better than 18 centimeters accuracy over a 30-mile range in a flight configuration necessitated some additional testing and development of transmit antennas, external signal amplification, navigational software for flight dynamics, as well as the addition of a centralized command and control (C2) capability so the network could be remotely controlled, across the range, from the 746 TS building at Holloman Air Force Base.

## BACKGROUND

The UHARS architecture (**FIGURE 2**) is comprised of three major subsystems which include the Enhanced Embedded GPS/INS (EGI), Locata NGBPS and GPS Antenna with Antenna Electronics (AE). Other key technologies include the DAS, Differential GPS (DGPS) Base Station and Reference Trajectory Algorithm.

The NGBPS rover collects 10.23 MHz chipped code pseudorange and carrier-phase measurements at selectable rates of 1, 5 and 10 Hz. The system uses a patented timing process which tightly synchronizes all LocataLites in the network. With this done, data from the Locata test bed receiver can be processed exactly like survey-grade GPS measurements, but without the need for differential corrections.

Each LocataLite transmits on two spatially diverse signals from two separate antennas at two frequencies within the 2.4-GHz industrial, scientific and medical
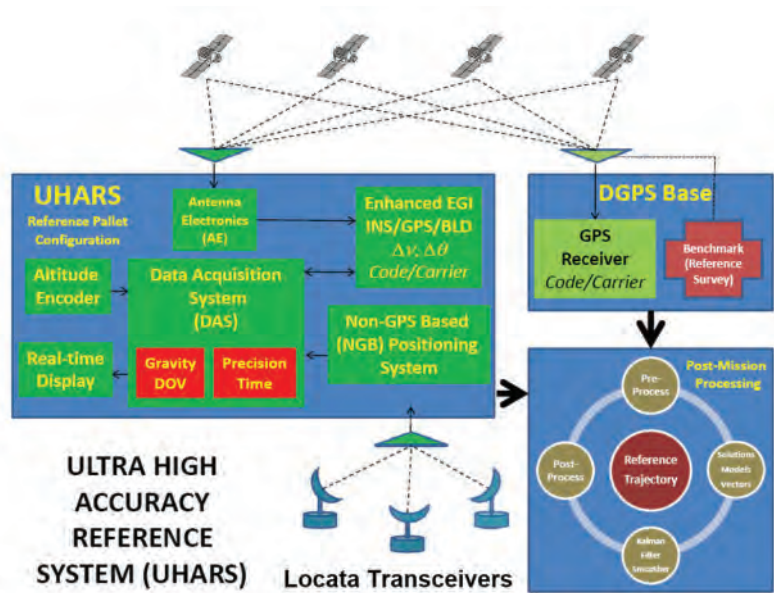


**FIGURE 2** UHARS architecture.

**FIGURE 3** Locata solar aluminum transportable trailer (LSATT).

(ISM) frequency band, 2434.740 MHz and 2462.361 MHz, for a total of four spatially and frequency diverse signals. That signal structure provides precise positioning signals that are both resistant to GPS L1 and L2 jamming and also provide highly accurate positioning.

## OVERVIEW

The deployed system includes 16 Locata Solar Aluminum Transportable Trailers (LSATT) with flexible power options that integrate both shore power (110V AC) and reusable solar power (**FIGURE 3**). The trailer configuration enables easy transportation of major NGBPS components on and off WSMR, allowing for easy reconfiguration of the network or deployment to other test ranges if required.

The NGBPS design currently includes 20 geographically separated deployment sites, 16 of which are populated with LocataLites, over a 20 x 20 mile area on WSMR North Range (see **OPENING FIGURE**). This configuration can be scaled to cover an even larger area when required.

Each site contains permanent monumentation for the two spatially diverse transmit antennas (two monuments per site; 40 total). **FIGURE 4** shows a typical monument site which is equipped with a quadrifilar helix S-band transmit antenna, and one monument also supports the 2.4-GHz receive dish antenna. The monuments and antennas are integrated with an LSATT, UHF-band
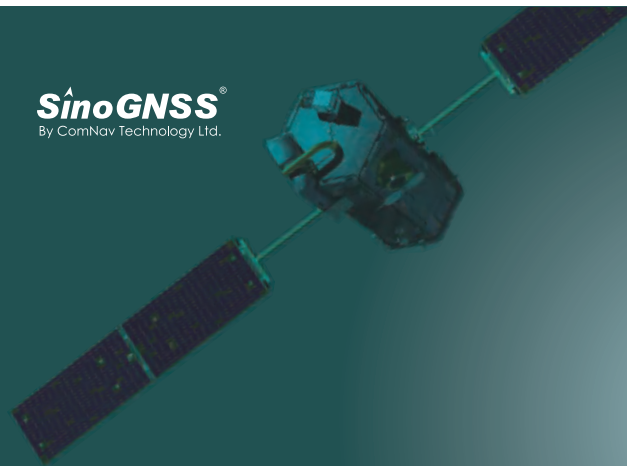
**FIGURE 4** NGBPS transmitter site.



**FIGURE 5** NGBPS C2 repeater station.

(350-360 MHz) wireless architecture for the command and control element, and a meteorological (MET) station made by Vaisala. The MET station measures and collects temperature, pressure and relative humidity data, for calculating tropospheric corrections which are then transmitted as part of the positioning signal generated by a LocataLite for use across the network.

The system is operated, controlled and monitored using either the fixed C2 center located at the 746 TS, Holloman AFB, NM or the mobile C2 Center. The mobile C2 is typically located on the WSMR-North Range to support test events. Two repeater stations (**FIGURE 5**) are installed at WSMR-North Range to enable long distance remote/wireless C2 communications with the NGBPS network.

## SITE ARCHITECTURE

The LSATT includes integrated hardware and software to produce the NGBPS network. The heart of the NGBPS is the LocataLite transceiver, which provides the ranging signals used by the rover to compute position and time information. The same signals are used by each LocataLite for nanosecond-level synchronization across the network. The MET station, mounted on monumentation along with a transmit antenna, collects temperature, pressure and relative humidity data and relays it to the LocataLite for inclusion in the transmitted navigation signal. The LocataLite provides the exciter signal to two Mini-Circuits amplifiers which boost the RF power to around 10 watts for each transmit antenna, providing signal coverage over the large geographical area of WSMR-North Range. The wireless modem relays Locata and MET data to and from the C2 centers using various package compression techniques to ensure data are not lost during transmission. The modem provides 4 watts of power operating in the UHF-Band with a directional high gain antenna.

Situated in the New Mexico desert, the LSATT is also required to operate during extreme weather conditions, necessitating the employment of water-tight containers and temperature reducing mechanisms to protect its commercial subsystems. Accordingly, a filtered fan configuration mitigates elevated temperatures during operation.

Each LSATT also possesses an intelligent low power controller that supports the various communication protocols within the equipment enclosure. A comprehensive and

expandable feature of the controller design enables a centralized methodology for data collection, health and status information and C2 functions. The controller interfaces with the LocataLite transceiver, MET station, amplifiers, and power supply sources. Information is collected and packetized for efficient transmission via the wireless modem. Commands from the fixed or mobile C2 center are received and implemented by the controller. During non-operating periods, the controller reduces power consumption by shutting down non-essential equipment. Likewise, the controller itself enters a stand-by mode until reactivated by the C2 center via the wireless modem. The controller provides a redundant data archive capability and autonomously manages operations in the unlikely event of a wireless communication outage with the C2 Centers. The controller is programmed to shut down after a definable period if C2 communication links cannot be re-established.

The NGBPS design provides pre-, live- and post-mission support through remote wireless C2 operations. This support includes real-time status monitoring and a net-centric architecture for C2 of



**FIGURE 7** USAF C-12J aircraft fitted with Locata antenna.

remote locations. As C2 outages are detected, the wireless network autonomously attempts to self-repair and return the network to an operational state.

## VERIFICATION AND VALIDATION

After all network and C2 software activities had been completed, TMC Design Corporation conducted a Final System Verification (FSV) on the fully fielded NGBPS system
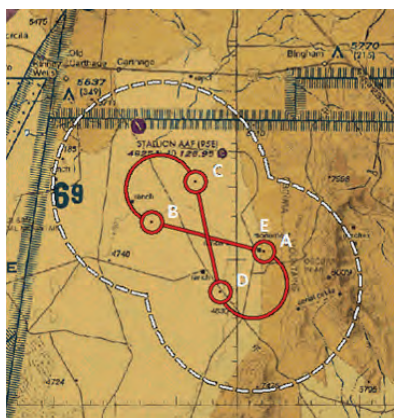


**FIGURE 6** A typical NGBPS clear air flight profile.

on WSMR. The FSV ensured all contractual requirements were adequately met prior to release to the 746 TS for government operations. It included verifying successful communication through the UHF network and ensured that the rover could obtain and process information from each LSATT site in view. Additionally, a mission duration test was performed to ensure the system could operate for the period of a standard mission window without depleting the battery system.

Upon completion of the FSV in September 2014, the 746 TS conducted a series of flight tests to:

- Measure the NGBPS PDOP over the WSMR fielded area.
- Compare the measured PDOP values to the developed PDOP model.
- Evaluate carrier-phase solution with an objective accuracy of <18cm 3dRMS with a PDOP < 3.

Once the squadron's PDOP model was verified, flight profiles were carefully devised to stay within the NGBPS PDOP < 3 envelope (**FIGURE 6**). However, since the 746 TS also sought to evaluate other UHARS components, both individually and as a system, additional flight profiles were flown. When these flight profiles happened to meet NGBPS PDOP criteria, performance was recorded and analyzed. All flight profiles were flown at varying altitudes, aircraft speed and time of day in order to test the NGBPS network performance under a wide range of scenarios.

Although an operational UHARS will ultimately provide an exceptional reference solution in a GPS-denied environment, GPS signals needed to be available during NGBPS validation in order to evaluate the Locata navigation carrier-phase solution against a Differential GPS carrier-phase solution. Thus, all NGBPS validation testing was conducted in clear, unjammed environments. Now that system performance is verified in this NGBPS configuration, it can be used as the primary source of positioning when the GPS signals are denied.

Flight trials were conducted using the USAF C-12J aircraft (**FIGURE 7**) integrated with one quadrifilar helix S-band receive antenna. The NGBPS receiver was integrated in the UHARS flight pallet, and a DAS was connected to the receiver to log specific receiver and health data required for post-test data analysis.

**FIGURE 8** illustrates the top-down view of the predicted PDOP=3 boundaries across the NGBPS network on WSMR. The PDOP volume coverage is shown in 1000 ft. increments (red lines) from 5K to 30K ft. MSL. The green lines are at 10K, 20K and 30K ft. The flight profiles were flown within the PDOP volume footprint to obtain carrier-phase solutions.

## RESULTS

The 746 TS conducted extensive flight tests where the NGBPS system was tested under operationally realistic conditions. Preliminary test results have proven good enough to declare Initial Operational Capability (IOC) for use by the 746 TS's many DoD and Government customers. Not only does the network deliver centimeter-level positioning and navigation, but also nanosecond-level synchronization, which may be useful for military applications requiring precise time transfer in GPS-denied environments. Working in concert with other UHARS components, the LocataNet supports a reference solution which outperforms the CRS in GPS-denied environments.
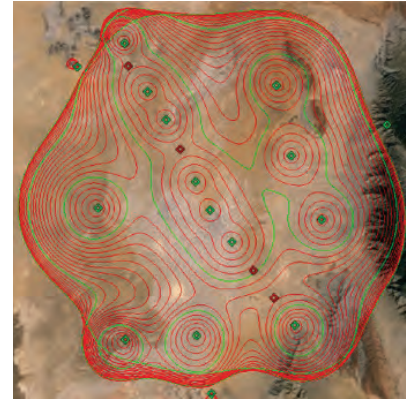


**FIGURE 8** NGBPS PDOP plot.

"Initial testing shows that UHARS delivers accurate independent PNT as good as, or better than, the USAF's current CRS, so it is perfectly able to support current customer requirements," said Jim Brewer, chief scientist of the 746 TS. "However, more data are required to tune the UHARS filter and optimize its accuracy to meet even tighter PNT requirements, which is our objective. When this is achieved, UHARS will deliver truth accuracy for next-generation military capabilities, and we will declare UHARS at Full Operational Capability."

"UHARS is a rack-mounted, tightly integrated system of improved navigation sensors, a data acquisition system and a new post-mission Kalman filter, all of which need to work together," explained John Cao, technical director of the 746 TS. "It's working very well, but once we completely measure and characterize the individual components and then tune and validate the filter, the complete system will provide a significantly more accurate reference solution for future airborne and land-based test vehicles in navigation warfare environments where modernized and legacy GPS signals are jammed from friendly or hostile systems."

## SUMMARY & CONCLUSIONS

As designed, deployed, and validated, this tailored network provides accurate 3D positioning, completely independent of GPS and while traveling in a dynamic aircraft flight profile. This enables the US government to test, evaluate, and assess capabilities in GPS-denied environments.

Based on successful results of the original technical demonstration at WSMR in a real-world end-to-end environment, the USAF proceeded to the NGBPS production and fielding phase in 2012.

The currently installed network infrastructure on WSMR includes 20 permanent monument sites, 16 LSATT trailers installed in select initial site locations, comprehensive C2 software and solar and battery power for all sites. The system is self-contained, remotely operated and possesses high quality, reliability and safe operation attributes. Its NGBPS capability is now core to the UHARS that is replacing the CRS.

Initial testing shows that UHARS delivers accurate independent PNT as good as, or better than, the USAF's current CRS truth system, and the 746 TS has therefore declared Initial Operational Capability (IOC) for UHARS, making it immediately available to support customers requiring an accurate non-GPS-based solution. Further verification testing will enable the squadron to fine tune the UHARS filter and optimize its accuracy even further to meet even tighter PNT requirements. At that time UHARS Full Operational Capability (FOC) will be declared.

Customers interested in leveraging UHARS into their test programs should contact the 746 TS at (575) 679-2123 or 746ts.info@us.af.mil for scheduling information.

## MANUFACTURERS

LocataLites, Locata rovers and the software/firmware that enables the TimeLoc synchronization technology which creates the LocataNet are manufactured and supplied by Locata Corporation. The S-band transmit antenna was made by Cooper Antennas Ltd.

The 746 TS awarded two separate sole-source contracts for NGBPS. The **Locata Corporation** was contracted to provide production transceivers and rovers, navigation algorithms required for data analysis and subject matter expertise. The **TMC Design Corporation** was contracted to develop the hardware to house and field the Locata network, develop the command and control hardware and software, and then physically field the production hardware at WSMR. ⊕

**CAPT. JAMES KAWECKI** is the analysis flight deputy for the 746 TS, engaged in the planning, documentation and review of all guidance and navigation test efforts for the 746 TS. He provides technical inputs in the continuous improvement of the SPIDER filter for the UHARS program. With 13 years in the Air Force, his experience includes aircraft maintenance, electrical systems engineering, staff positions and advanced sensor analytics for various programs.

**JAMES BREWER** received his doctorate in electrical engineering from the Air Force Institute of Technology. He has evaluated navigation systems for the past 30 years at the 746th Test Squadron, where he currently holds the chief scientist position.

**JOHN CAO** is technical director of the 746 TS, providing technical oversight on the planning, execution and reporting of all guidance and navigation test efforts at the 746 TS. With more than 27 years of Air Force acquisition experience, he supported development and testing of many weapons development programs, including F-16, F-22, Tactical Satellite 3 (TacSat-3), Patriot and other systems.

**JASON BALDWIN is** an information architecture and information systems professional for TMC Design Corporation, providing technical guidance on the planning, documenting and implementing of cybersecurity efforts throughout various Department of Defense (DoD) programs. With more than 18 years of DoD experience, he has supported the development and integration of many systems that include NGBPS, mobile satellite ground terminals, counter-IED devices and other systems.