The UHARS Non-GPS Based Positioning System

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BIOGRAPHY

Desiree Craig is the chief program manager for the 796th Test Support Squadron and the 96th Test Group. The 96th Test Group provides several world-premier test capabilities including the Flight Test Squadron, Holloman High Speed Test Track, the National Radar Cross Section Test Facility, the Survivability and Landing Gear Test Facilities and the Central Inertial and GPS Test Facility. In her current position, she oversees several improvement and modernization (I&M) programs for the 96th Test Group, including the Non-GPS Based Positioning System Phase of the Ultra High Accuracy Reference System program.

Derek Ruff is the systems engineer of the UHARS project for the Department of the Air Force at the 746 Test Squadron. He has over 20 years experience in guidance and navigation test and evaluation. Derek has worked as an analyst, test manager, supervisor and instrumentation, hardware, software and test engineer. He supported the GPS program office for many years advising on GPS user equipment integration.

Dr. Steve Hewitson is a Senior Navigation Engineer at Locata Corporation. He graduated from the University of New South Wales with a PhD in quality control for integrated GNSS/INS in 2006 and has over 10 years of experience developing navigation algorithms and executing geodetic surveys. Steve joined Locata in 2009 and has since been involved with several LocataNet deployments and developed various navigation and quality control algorithms specifically for Locata technology.

Dr Joel Barnes is Director of Navigation at Locata Corporation. He obtained a Doctor of Philosophy in satellite geodesy from the University of Newcastle upon Tyne, UK. Joel has assisted in the research, development and deployment of Locata technology since 2000, and has over 15 years experience in GNSS navigation algorithm development.

John Amt is a Navigation Engineer at Locata Corporation. He graduated from the Air Force Institute of Technology in 2006, with a Masters degree focused on guidance, navigation, and control. He has been working with Locata technology since 2005 at the Advanced Navigation Technology Center. After joining Locata Corporation in 2007, he has focused on developing navigation algorithms and supporting LocataNet installations.

ABSTRACT

The Ultra High Accuracy Reference System (UHARS) is the 746th Test Squadron's next generation reference system, currently under development to meet test and evaluation reference requirements for future navigation and guidance systems. Consisting of a rack mounted, tightly integrated system of navigation sensors/subsystems, data acquisition system, and a post-mission reference trajectory algorithm, UHARS will provide a highly accurate reference solution for airborne and land-based test vehicles in electronic warfare environments where modernized and legacy GPS signals are jammed from friendly or hostile systems. The system will be appropriately sized and constructed for use on-board multiple test-beds including current and future test aircraft and ground vehicles.

Achieving these accurate reference solutions requires a Non-GPS Based Positioning System (NGBPS) subsystem capable of providing sub-meter position accuracy in a GPS-denied (jamming) environment. The NGBPS portion of the UHARS program plans to employ a network of ground transceivers and test vehicle rover receivers, manufactured by the Locata Corporation. The NGBPS uses Locata's standard commercial transceiver and rover devices, but meeting the demanding UHARS accuracy and distance requirements necessitated major improvement of Locata's normal antennas, amplification and navigational software. To this end, the 746th Test Squadron awarded Locata a contract to re-design these components and demonstrate a system delivering longer ranges (both for acquisition and tracking), higher power

transmission levels, new antenna designs for aircraft use, and higher aircraft dynamics than previously envisaged.

The 746th Test Squadron and Locata completed a technical demonstration of this improved capability on October 2011 on White Sands Missile Range. The demonstration (including set-up, flight trials and check-out time) spanned a 3-week period. This paper details the NGBPS demonstration to include the following: technical challenges, conduct details such as flight profiles and ground station set-up, and the results.

NAVIGATING THE TRUTH

The UHARS is the USAF's next generation "truth" reference system, currently under development by the 746th Test Squadron at Holloman Air Force Base, New Mexico. The 746th Test Squadron is the Central Inertial and GPS Test Facility (CIGTF), chartered to provide test and evaluation of DoD guidance, navigation and navigation warfare (NAVWAR) systems for the United States Department of Defense. The UHARS, designed to meet the increasingly accurate reference requirements for future navigation and guidance systems, is expected to provide improved position and velocity accuracies up to 5x better than the current truth system. This current truth is called the CIGTF Reference System (CRS) and has provided reference in support of a plethora of high-accuracy navigation tests over the last decade. It is arguably the most accurate reference system available for testing today, but with forecasted advances in navigation technologies on the immediate horizon, soon CRS will no longer be accurate enough to serve as truth against increasingly precise systems under test.

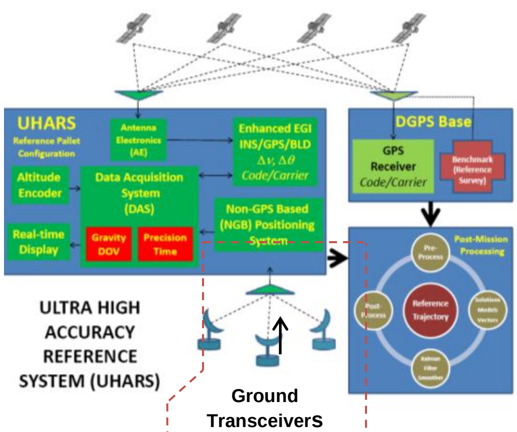

Figure 1: UHARS Architecture

The UHARS subsystem that is the key to achieving these accurate reference solutions is the Non-GPS Based Positioning System (NGBPS), which is capable of providing sub-meter position accuracy in a GPS-denied (jamming) environment (see UHARS Architecture Figure 1 above). The subsystem the 746 Test Squadron chose to supply this capability is a network of ground transceivers and test vehicle rover receivers manufactured by the Locata Corporation, and sold as a commercial-off-the-shelf (COTS) system called a LocataNet™. The ground-based COTS LocataNet has already been adopted for industrial applications in areas where GPS is unreliable – such as machine control in open-cut mining (Additional Resources [1]) – or where GPS is completely unavailable, such as indoors for warehouse automation.

GUIDING PRINCIPLES

Meeting the rigorous 746 Test Squadron UHARS "truth reference" accuracy, range and dynamic requirements necessitated a major upgrade of Locata's existing commercial capability. Therefore, in 2010 the 746th Test Squadron awarded Locata a contract to improve their COTS LocataNet to a level where it could be integrated into the UHARS as the NGBPS component. The enhancements Locata had to demonstrate were:

- Locata receivers must acquire and track NGBPS signals at a minimum range of 30 miles;
- Nanosecond "TimeLoc" time synchronization of the NGBPS network ground transceivers (LocataLites) must be demonstrated at these ranges;
- Demonstrate a capability to transmit Locata signals at higher powers via an external amplifier, while maintaining signal and TimeLoc integrity;
- Design and supply transmitter and receiver antennas that provide adequate coverage (gain) and multipath mitigation under specified aircraft dynamics;
- Ensure adequate Locata receiver tracking loop performance to achieve aircraft flight dynamics;
- Develop tropospheric models that mitigate the large tropospheric errors (delay) experienced by terrestrial signals at long ranges;
- Ensure post-processed position accuracy is <18 cm 3dRMS (when PDOP < 3), at the above ranges.

The ultimate goal of the NGBPS is to achieve a standalone, receiver post-processed measurement accuracy of 10 cm – an extremely demanding specification for a land vehicle, let alone an aircraft traveling at over 550 km/hr in the complete absence of GPS.

TRAVERSING THE TECHNICAL CHALLENGES

Locata carried out initial research and development in late 2010 and passed the NGBPS contract Preliminary Design Review (PDR) requirements in February 2011. To enable a clear demonstration of the enhanced NGBPS flight capabilities for the contracted Critical Design Review (CDR) in June 2011, Locata deployed an experimental 1,500 sq. km wide-area NGBPS system around the Snowy

Mountains Airport near Cooma in New South Wales, Australia.

A number of flight trials were flown in this network before the CDR, proving that the NGBPS performance requirements could be met in the area covered by the 6 sites of the Australian network, and Locata officially passed the CDR on August 19, 2011.

A key milestone following the successful completion of the CDR for this contract, therefore, required Locata to demonstrate their system on the White Sands Missile Range in New Mexico, USA, where the 746th Test Squadron often conducts GPS jamming tests. The demonstration was dubbed the Locata NGBPS Technical Demonstration. Deploying the Tech Demo sounds simple enough in principle; however, the White Sands Missile Range was only available for such a test during the last week of October… a mere four months after the CDR meetings, and due to weather delays, limited aircraft availability and many other issues well outside the team's control, schedule became a major factor. In those short four months, the team, comprised of members from Locata Corporation, 746th Test Squadron, Air Force Institute of Technology (AFIT), Advanced Logistics Corporation and TMC Design Corporation pulled together to plan and execute this critically important test event.

It was a whirlwind of activity as Tech Demo designs were reviewed and revised, components were purchased and tested, and LocataLite ground stations were built. Despite the incredibly tight schedule, and overcoming what sometimes seemed insurmountable events, in early October 2011 the team landed at White Sands with "boots on the ground," ready to work, and began the site erection process. The team had only two weeks to assemble, deploy and perform check-out of 10 sites, with the last week of October reserved for flight testing.

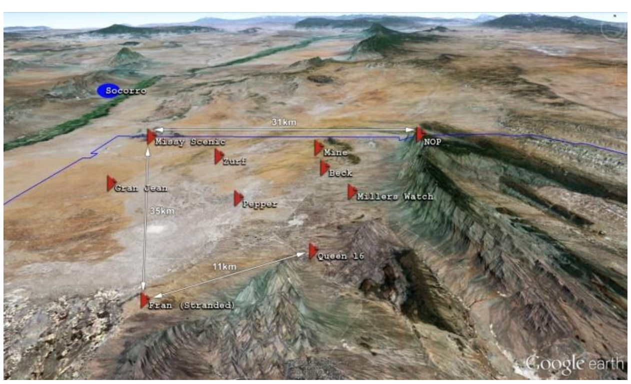

Figure 2 Google Earth Depiction

The Master site was the first one assembled, at a location with significantly higher elevation than the other sites. [See Figure 2 above which is a Google Earth depiction of the 10 NGBPS sites]. After quite a bit of reconnaissance, analysis and negotiation between the 746 Test Squadron, Locata and the Air Force Institute of Technology (AFIT), the exact location for the Master site and one Locata test receiver was selected – at North Oscura Peak (NOP), towards the top north-eastern edge of the Range. (See Figure 3 below of the NOP configuration). This high-elevation site consisted of two transmit antennas, one high-gain dish receive antenna, and one GPS antenna, all mounted on a concrete wall approximately 20 ft high which gave line of sight to all the lower-level locations on the Range. A protective enclosure containing the LocataLite transceiver, meteorological data collection equipment, amplifiers, power converters plus a prime power source rounded out the deployed equipment.

Figure 3 NOP Configuration

Once the "Master" LocataLite was set up and tested, the team was ready to divide and conquer the nine remaining sites slaved to the Master.

Setting up all of the lower elevation sites proved to be a rather arduous and time consuming task. The Tech Demo site spanned an area of approximately 45 miles by 30 miles. Roads on the White Sands Missile Range are few and far between, which necessitated long back-and-forth trips to move from one site to another. Consistent with the UHARS requirement, the standard commercial Locata system has built-in capability for control and monitoring from a remote location using a modem, and this element was used to ease deployment and testing in the Australian experimental wide-area system. However, the time constraints imposed on the Tech Demo simply made it impossible to arrange for the requisite communications approvals on the Range – and consequently the team clocked up many, many miles over the two week period allocated to fielding and checkout. For a system of this size, it quickly becomes apparent to everyone that remote control capabilities are an essential "must-have" feature for real-world deployment!

As the Tech Demo was never meant to be a permanent installation, the 746 Test Squadron required a very portable, field-deployable system which could be easily moved if required, and which could run off either grid or generator power, depending on what was available at suitable geographic sites on the Range. Locata and the 746 Test Squadron therefore specified a Tech Demo NGBPS LocataLite "slave" configuration constructed by TMC Design Corporation which could be manufactured locally, set up by one person if necessary, transported in a pick-up truck – all based on portable antenna masts and a single weather-proof "box" containing all electronics. Each of the nine "slave" sites therefore consisted of two tripods which supported all transmit and receive antennas, and a "box" containing a LocataLite transceiver, meteorological collection equipment, amplifiers, and power converters. The meteorological sensors and probes were grouped onto a separate small mast externally connected to the "box", and power was provided by the most convenient source (either prime power where available, or a gas-powered generator in other locations). (See Figures 4 and 5).

Figure 4 Ground Site Configurations

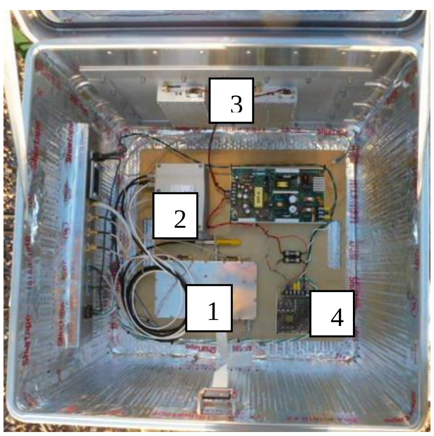

Figure 5 Internal Box Configuration

1. LocataLite 2. Meteorological Sensor
3. Amplifier 4. Power Supply

Because of the logistics and travel times involved, it took eight working days (and sometimes nights!) to configure, set up, and check out the nine "slave" sites. During the two week setup period, the Holloman AFB Range Support Team of the National Geospatial-Intelligence Agency (NGA/SNSH) surveyed two LocataLite transmit antennas per site and the GPS-aided clock antenna at NOP. These 21 surveys were used during the Tech Demo for the real-time code solution and during the post-processing data reduction. They had previously surveyed the GPS reference receiver used by the CRS. The NGBPS accuracy directly relates to these survey accuracies.

Despite these and many other challenges, the team had all 10 sites, as well as the aircraft and three "rover" receiver locations, set-up and ready on time for flight trials from the 24^{th} to the 30^{th} of October 2011. One important item of note is that all the ground stations had the ability to collect meteorological data; unfortunately, the specialized version of the meteorological equipment for the aircraft did not arrive in time for the tests, and hence was not fitted to the test aircraft. This was a set-back, as the tropospheric effects of the long ranges encountered in this Tech Demo were of particular interest to the navigation specialists on the Locata NGBPS team that were focused on delivering cm-accurate position solutions. To make up in part for the lack of aircraft-based meteorological data, the USAF arranged to launch weather balloons from the north end of the Range at the start and end of each test, to at least provide some samples of pressure, temperature and humidity conditions aloft. This data allowed Locata to assess meteorological models used to derive tropospheric corrections.

LOCATING THE TRUTH

During the flight trials conducted from October 24^{th} to the 30^{th} 2011 approximately 23 hours of flight data were collected. The flight profiles were designed to test the performance of the Locata NGBPS system against the contract requirements. As a result a number of different flight profiles were flown at varying altitudes, aircraft speed, and time of day in order test the performance of the Locata system under different scenarios. Weather conditions during the flights varied from clear blue skies to heavy wind and rain, hail and snow.

On the aircraft simultaneous data were logged for post-processing from the Locata receiver at a 10Hz measurement rate, and from the existing CRS pallet. The CRS would provide 10Hz post-processed solutions from a high precision GPS receiver and INS data, and act as the "truth" reference. The Locata system used GPS or UTC timing so it would be aligned to the CRS solution. On the ground a high precision GPS reference receiver logged data to allow differential GPS post-processing in the CRS navigation solution. Data from the metrological ground sites were modulated on the Locata signals and logged at the Locata receiver on the aircraft. However, for redundancy, each metrological station also logged data at a 1Hz rate which could be downloaded after each flight sortie.

Following the flight trials the Locata solution and CRS truth solution were post-processed entirely independently by Locata and the 746th Test Squadron respectively. Furthermore, Locata did *not* have any access to the USAF navigation solutions until *after* their final Locata solutions were tendered to the USAF for independent performance analysis. For some preliminary performance analysis Locata was provided with four small (approx one hour) *samples* of CRS truth solution data for comparison purposes. These USAF solution samples would not count towards the final performance analysis undertaken by the 746th Test Squadron.

One of these CRS solution sample periods supplied to Locata was collected during a flight sortie on Sunday, October 30th 2011. The subsequent comparisons of Locata and the USAF truth solution during this sample period is representative of typical Locata performance during the Tech Demo, and is therefore used later in this document to illustrate Locata NGBPS performance against the USAF-furnished positions.

Background: Locata enhancements required for the NGBPS

Locata's COTS systems are in use today for commercial, industrial applications. These COTS applications are well served by the standard Locata system which operates at 2.4 GHz, transmits less than 1 watt in compliance with relevant FCC regulations for that band, has LocataLite transceivers spaced less than 10 km apart, and only has to deal with ground-based vehicle dynamics. When Locata and the 746 Test Squadron signed a contract in 2010 to deliver NGBPS-level capabilities, it was clear that the challenging USAF specification would require Locata to demonstrate that the LocataNet system could deliver new levels of performance in environments Locata had not previously experienced.

Several specific NGBPS enhancements therefore drove Locata's development efforts for this contract:

Enhancement 1: The operational UHARS deployment calls for a NGBPS system which will cover around 2,500 square miles (6,500 sq. km), and the contract specifies that a Locata receiver shall be capable of acquiring a transmitted NGBPS signal at a range of at least 30 miles (48.3 km). Critically, the nanosecond-level TimeLoc synchronization which is essential for Locata network performance must be maintained at these ranges, *even when* the TimeLoc process is sequentially "cascaded" from one slave LocataLite to another slave that is *not* in view of the Master.

Before the CDR, Locata's analysis concluded that the NGBPS acquisition ranges required the transmitter RF power for each signal be increased from the standard COTS level of 100 milliwatts up to a new level of 10 watts to the antenna. Tests proved that transmitting 10 watts enables acquisition and tracking out to more than 50 km, and maintains received signal levels at -100 dBm, or better. A number of external amplifiers were tested over a period of months, and a suitable candidate was chosen for the Tech Demo deployment. Figure 6 shows a plot of measured data for received power versus tracking distance, using two test aircraft antennas, and recorded during the CDR wide-area trials.

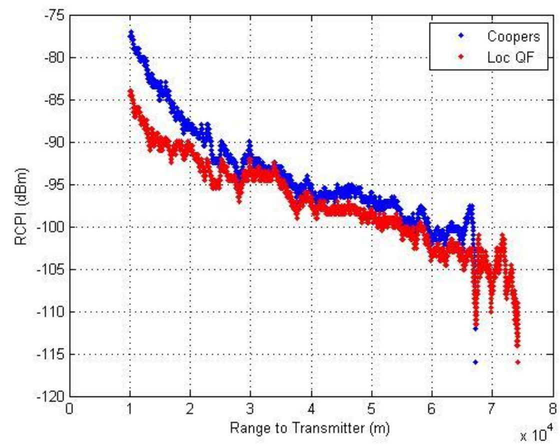

Figure 6 : Tracking Range to a LocataLite transmitting 10 watts per signal

Enhancement 2: In the past, Locata COTS networks provided positioning to ground-based users, transmitting signals from either a patch antenna pointing from the perimeter into the area of interest, or from a monopole antenna radiating equally in all directions from a LocataLite within the area of interest.

However, neither of these antennas provides an optimal radiation pattern for NGBPS signals to be used by aircraft overhead. A monopole antenna, when oriented to provide the necessary omni-directional pattern horizontally, suffers a null in its radiation pattern to its zenith. Aircraft above the LocataLite will suffer signal drop-out, and the consequent loss of that site for the geometry required for accurate positioning. This is particularly troublesome if a 3-D solution is required, since the LocataLites near (or under) the aircraft provide the primary signal components for vertical positioning. Alternatively, a patch antenna, when oriented upwards, provides good signal strengths for overhead users. However, because of its flat geometry, it does not provide good gain to the sides, and will therefore severely limit the operational range of a Locata network.

Reconciling these conflicting requirements led to an intensive search for a better aviation antenna for Locata and NGBPS uses.

After months of testing it was decided that a quadrifilar helix antenna design would best deliver the required

NGBPS system performance. This led to Locata's in-house fabrication and prototyping of several quadrifilar helix antennas specifically for testing under NGBPS conditions. Once an optimal design was determined, Locata worked with a very capable and respected antenna manufacturer, Cooper Antennas Ltd of Marlow in Buckinghamshire (UK), to produce an aircraft-certified version of this quadrifilar helix antenna. The Cooper antennas were used in Locata's Australian tests with excellent results, thereby confirming Locata's research and analysis. The Cooper-Locata production antenna also gave excellent performance throughout the Tech Demo, and these antennas can be seen in Figure 7.

Figure 7 Antenna Mounted on C-12J

Enhancement 3: Prior to the NGBPS flight trials, all Locata COTS systems had been used to position ground-based vehicles such as cars, trucks and rill rigs. For the NGBPS, however, the system must function under aircraft operating dynamics, including banking, angular and linear accelerations, airspeeds up to 300 knots (560 km/hr), and altitudes up to 30,000 ft above sea level. Prior to the Tech Demo at White Sands, Locata did not have access to an aircraft which could match these performance requirements so all dynamics testing was simulated, using a bench-test setup to analyze Locata's tracking loops, and a hardware-in-the-loop scenario. The transmitter Direct Digital Synthesis (DDS) of a LocataLite was commanded to replicate the appropriate frequency plus Doppler shifts that would be seen by a receiver on board an aircraft engaged in the specified dynamics. The receiver portion of the LocataLite transceiver (which is identical to a Locata roving receiver) then tracked this signal, verifying Locata's tracking loop development and performance. This simulation demonstrated that Locata's receiver tracking loops could handle the specified aircraft dynamics, and this was borne out with real-world aircraft dynamics tracked during the Tech Demo at White Sands.

Enhancement 4: For the NGBPS flight trials the requirement to track signals up to 30 miles means that tropospheric delay is the major error source for measurements used in the navigation solution. Using standard atmospheric parameters the unmodelled tropospheric delay is approximately 280 parts per million (ppm), which equates to approximately 13.5 meters of error over 30 miles. Therefore in order to meet the position accuracy of less than 18 cm 3dRMS (when PDOP < 3), a key component was developing methodologies to mitigate the effects of tropospheric error.

Locata has developed new tropospheric models that make use of metrological stations measuring temperature, pressure and relative humidity at the ground-based LocataLite sites and data on the aircraft. The remaining "residual" tropospheric error is then estimated in the navigation Kalman Filter solution. For the NGBPS trial at White Sands the meteorological equipment for the aircraft did not arrive in time for the tests. The launching of weather balloons at the start and end of each test assisted Locata in refining post-processed models to estimate aircraft meteorological data from the ground based metrological sites. The analysis conducted so far indicates that the modeling alone, with data input from metrological sites, is able to mitigate the tropospheric effects to within a few part per million. The following "residual" tropospheric estimation in the navigation solution then accounts for the remaining correlated portion of the tropospheric error.

AND THE TRUTH IS….

By October 23, 2011 the Locata NGBPS Tech Demo network of 10 LocataLites and 2 Locata ground-based receivers had been deployed across the designated test area at the northern end of the White Sands Missile Range. Importantly, a Cooper-Locata antenna and Locata receiver had by then been installed in the 746 Test Squadron's C-12J aircraft, alongside the established GPS and inertial reference sensors normally used to provide CRS truth data for post-processed position solutions. All systems were confirmed ready for the aircraft to fly defined flight profiles, and the USAF flew a total of eight flights over seven consecutive days from October 24th to October 30th inclusive. Predefined profiles were flown each day to record data for testing and to evaluate network performance. Flight times were staggered over various periods of each day to ensure data was collected in as many different diurnal, weather and tropospheric conditions as possible. The weather during that week was relatively benign, except for a fierce storm (lightning, hail, snow up at the NOP site) in the middle of the night of Wednesday, October 26th. Astonishingly, the 746 test pilots still calmly flew their profiles in that intense weather, while those of us on the ground watched in amazement, and shook our heads in disbelief at the professionalism and sheer guts on display. Test pilots are certainly in a league of their own!

The Locata receiver installed in the C-12J electronics rack had internal memory, backed up by disk storage on a notebook computer, to record measurement data while in flight for later, off-line analysis. Other collected data included logs from the LocataLite transmitters, weather data collected at each transmitter site and by weather balloons, plus positioning data collected by the USAF from their own current CRS on the aircraft.

Locata's nanosecond-accurate TimeLoc worked flawlessly over the entire Range for the full duration of the Tech Demo. For the actual flight tests each day, LocataLite sites were authorized to transmit only during the test times approved by Range management. Because of the way TimeLoc is managed in a network, Locata could control transmission of signals over the *entire* NGBPS network by simply turning the Master LocataLite on or off. A slave LocataLite will not transmit if it does not receive a TimeLoc reference signal, so turning on the Master LocataLite commenced the TimeLoc process, and subsequent LocataLite signal transmission, throughout the whole network. Upon receiving the Master signal, other LocataLites generally required only 30 seconds to a minute to TimeLoc to the nanosecond level. Due to real-world line of visibility constraints, the NGBPS has the capability to "cascade" the TimeLoc reference function through a first slave to reach a second slave which is unable to see the Master. Locata successfully demonstrated this capability during tests on October 28th. Throughout the Tech Demo, the entire 800 sq. mile (2,000 sq. km) network achieved nanosecond accurate TimeLoc within several minutes of the Master being activated, and remained rock-solid (even during the severe weather) until turned off at the end of each test.

Sample results – Flight Test October 30, 2011

At the time of writing in early April 2012, the Locata data had been fully analyzed and Locata-derived position solutions for the entire period of the Tech Demo had been supplied to the USAF. The USAF, however, had not yet had sufficient time to complete their analysis of the entire data set, and independently compare and corroborate Locata's performance against their USAF-derived truth reference positions. Nevertheless, enough data has now been analyzed to give the NGBPS team confidence about the measured performance over that Tech Demo period. A representative data set from Sunday, October 30, 2011 (local time 10:09:18 – 10:47:30) is published here, as a typical example of the observed performance. The flight profile for this example data consists of three "race track" circuits at a flying height of approximately 25,000 feet above sea level, and with an approximate aircraft speed of 195 knots.

Acquisition and Tracking Performance

Locata examined their receiver logs to determine when the receiver acquired the first signal with each flight, and the maximum range at which the receiver tracked a signal. From Locata's analysis of the full data set over the period of the Tech Demo, it is known that the average range for acquisition of the first signal from the network was 48.8 miles (78.5 km). For this October 30 example, Figure 8 shows the tracking status of the first signal acquired, with green indicating when the signal is tracked and red when it is not tracked. Figure 8 shows that, once the LocataNet started transmitting, the first signal was acquired in 73 seconds at a range of 38.6 miles (62.2 kilometers). On October 30 the maximum range at which the receiver tracked a signal was 40.9 miles (65.8 kilometers), which is well above the 30 mile tracking requirements of the USAF.

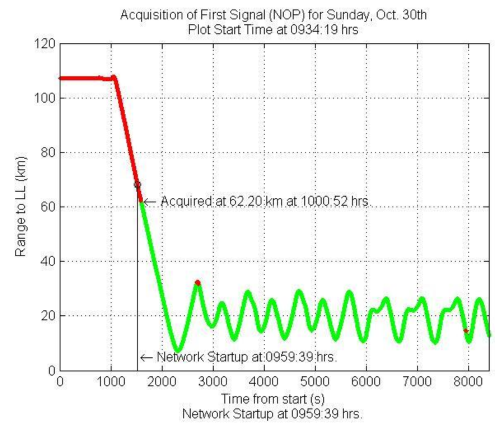

Figure 8, First signal acquisition, Sunday, October 30

Positioning Results

Flight Characteristics

Figure 9 shows the racetrack pattern at 25,000 feet for three circuits at approximately 195 knots for the example data on the October 30. The USAF solution ("Ref") is shown in blue and the Locata code solution shown in red, together with the positions of the 10 LocataLite sites indicated by an *. Against the USAF reference solution the code solution performance of the Locata NGBPS is shown in Figure 9 (below) with an overall 3dRMS difference of 0.25 meters.

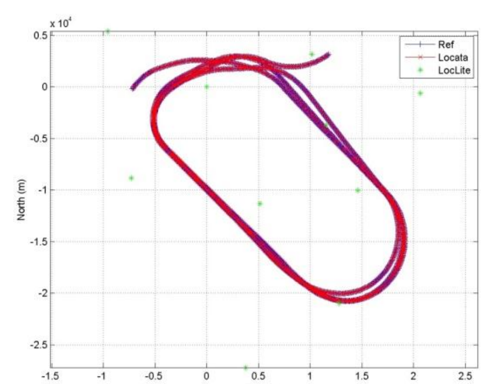

Figure 9 Aircraft racetrack profile at 25,000 feet on 30 October

The aircraft roll, pitch, heading, velocity and altitude is given in Figures 10 and 11, as provided by the USAF reference solution. Importantly the attitude information allowed the USAF solution to be lever-arm corrected to the Locata receiver's antenna.

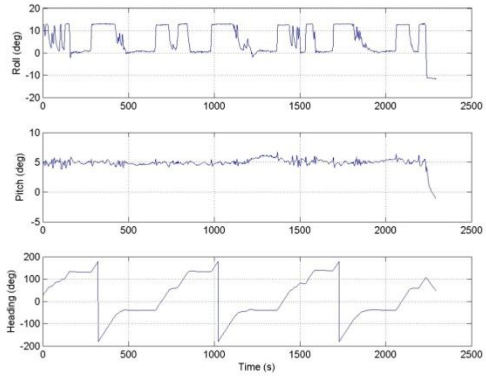

Figure 10 Aircraft roll, pitch and heading for racetrack profile at 25,000 feet on October 30

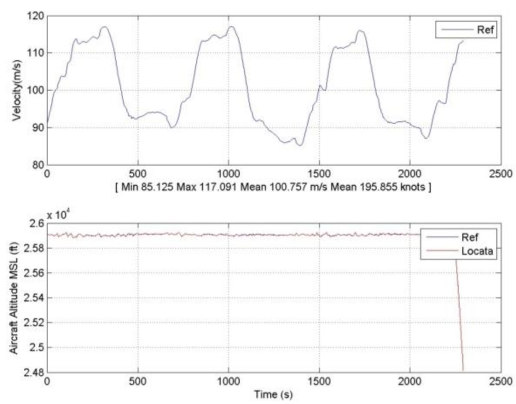

Figure 11 Aircraft velocity and altitude for racetrack profile at 25,000 feet on October 30.

Locata Carrier Solution Performance

The Locata 10Hz carrier solution was post-processed entirely independently of the USAF reference solution using a forward and reverse Extended Kalman Filter (EKF), incorporating tropospheric corrections derived from available metrological data to solve for position, velocity, acceleration, "residual" tropospheric scale factor and signal ambiguities using geometry change. Figure 12 shows the number of signals tracked by the receiver and used in the EKF solution along with the total number of LocataLite sites available (note that *each* LocataLite is designed to transmit four ranging signals simultaneously). All 10 LocataLite sites were used for the entire period and 35-36 signals were used in the EKF solution. In terms of position dilution of precision (PDOP), Figure 13 shows the PDOP as well as component DOPs in east, north and vertical. The maximum PDOP for the flight profile is approximately 3, while the worst component dilution of precision is approximately 2.7 in the vertical component.

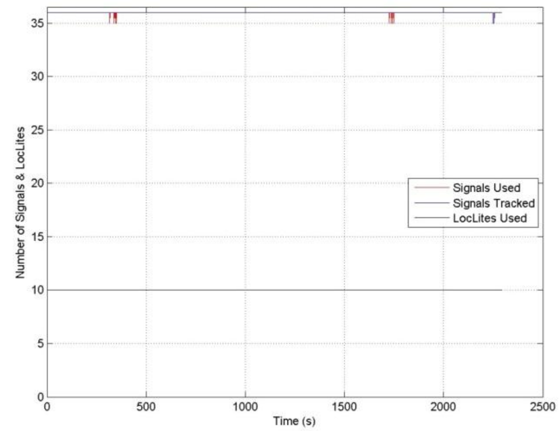

Figure 12 Number of signals tracked by the Locata receiver and used in the EKF navigation solution and total number of LocataLite sites available for the racetrack profile at 25,000 feet on October 30

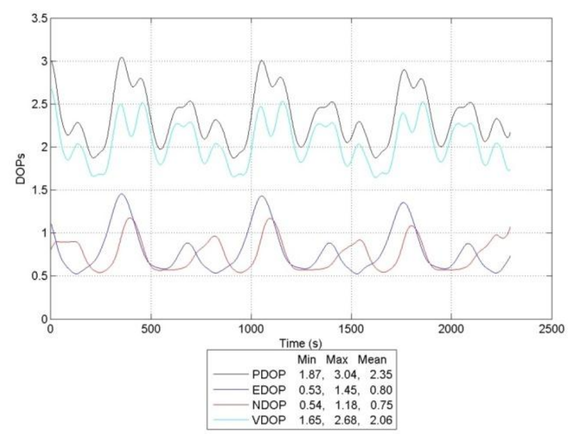

Figure 13 Dilution of precision for the racetrack profile at 25,000 feet on October 30.

Figure 14 shows the difference in east, north and vertical between the USAF reference solution and the Locata carrier solution, and Table 1 contains the respective RMS statistics. The RMS values in the east and north components are 0.06m, whilst the RMS in height is just over twice that of the horizontal at 0.15 m. These values correlate with the larger DOP in the vertical component than the horizontal components. The overall and 3D positioning accuracy meets the requirement set out by the USAF with an RMS of 0.17m.

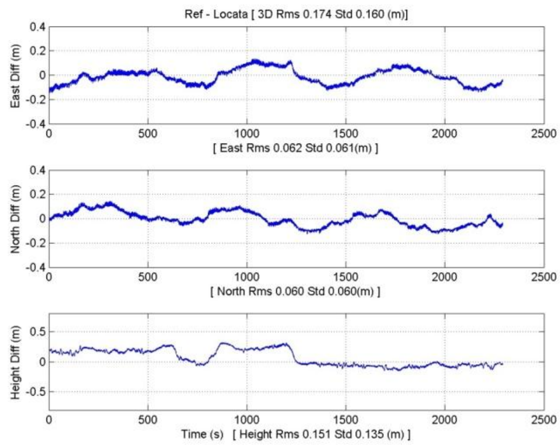

Figure 14 Difference between USAF and Locata carrier solution for the racetrack profile at 25,000 feet on 30 October.

Locata Solution Performance against USAF Solution		
	Code Solution RMS (meters)	Carrier Solution RMS (meters)
East	0.070	0.062
North	0.105	0.060
Height	0.210	0.151
3D	0.245	0.174

Table 1 Locata code and carrier solution RMS values against USAF solution.

CONCLUSION

In the end, Locata successfully demonstrated that their COTS LocataNet technology met or exceeded the UHARS specifications on White Sands Missile Range. The team is currently in the midst of contract negations. However, the 746th Test Squadron expects to complete Full Operation Capability milestones by September 2014 with their "gold standard" system in place.

ACKNOWLEDGEMENTS

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