Time Space Position Information Systems for Flight Test Applications

Applications such as aircraft flight test, missile development, and avionics suites benefit from accurate and plentiful data to verify and validate the platform/system's performance. This data is most useful when it is properly correlated with other contemporaneous test data. This includes ensuring that all data such as from sensors, avionics buses, and video is perfectly in sync with the aircraft's concurrent position and orientation in space. This enhances one's knowledge of what is happening during different maneuvers, allowing engineers to better determine the limits of an airborne platform.

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Time space position information (TSPI) systems deliver this positional data and have been in use for decades. Sensors that gather data such as strain, temperature, and vibrations provide information with a well-defined accuracy that depends on the sensors, wiring, and data acquisition and processing system. TSPI systems, on the other hand, rely on not only the accuracy and precision of the system's internal electromechanical components but also very careful installation and calibration. This white paper looks at different TSPI solutions and discusses requirements and considerations before concluding with thoughts on an optimal system for modern flight test applications.

TSPI solutions

There are two main methods of determining position that aircraft use today; a global positioning system (GPS) and an inertial navigation system (INS). Many people these days regularly navigate using a GPS device, generally integrated into their phones. This system is also useful for commercial aircraft to determine their position with a degree of accuracy that can be more than sufficient for navigation. However, GPS systems generally do not have the accuracy or precision to accurately locate some airborne platforms in applications such as development or operational testing, or missions testing, where the uncertainty of dozens of meters can be an issue.

Commercial GPS receivers have a positional accuracy that vary between meters to sub-meter, due to several factors including the number of simultaneous satellite systems, e.g., GPS, Galileo, GLONASS that are being tracked and if the receiver has a single or multiple (differential) receivers. In addition, the TSPI data is updated at lower rates (5 – 20 Hz), which can be too slow to catch some course change information. For example, a missile traveling at Mach 2 traverses about 780 m/s, equating to a significant possible gap in position information for events such as decoy deployment or end-game scoring.

There are many other sources of error, including:

- The location of the GPS antenna, and multi-path effects on the test platform
- The type of GPS receiver used, e.g., multi-constellation and/or differential GPS (DGPS). Also, if selective availability signals are processed, as in Selective Availability Anti-Spoofing Module (SAASM).
- Atmospheric uncertainty due to charged particles can introduce errors up to a few dozen meters
- Clock errors - even a few nanoseconds could mean a one-meter error
- Ephemeris error, i.e., the difference between theoretical and actual satellite position

An unlucky combination of these errors could result in location data that is too inaccurate to be useful in some test scenarios.

Additionally, GPS receivers do not provide orientation information, such as the pitch, yaw, and roll of a platform, although some models compute a trajectory/velocity albeit at low data update rates. The orientation information along with the trajectory information form the six degrees of freedom (6DOF) data that is critical to help correlate aircraft sensor data with maneuvers to assess an aircraft's performance and operation limits accurately. On the other hand, INS units routinely provide the 6DOF information to help achieve better correlation of measured platform flight test dynamics with the stresses experienced by the platform during these maneuvers.

An INS generally consists of an inertial measurement unit (IMU) which uses accelerometers, gyros, and inclinometers to detect changes, at high sample/update rates, in the forces impacting the test platform and thereby accelerations relative to an initial frame of reference. These have been used as far back as the 1950s when companies such as the Ford Instrument Company produced a ground position indicator for the USAF that weighed in at a then "light" 45 lbs. and would essentially perform dead reckoning calculations based on initial latitude and longitude inputs.

Modern IMU variants are much more sophisticated and compact but still essentially perform the same function. The data from these IMU sensors, e.g., accelerometers, rate sensors or gyros, and inclinometers that measure changes in linear and angular accelerations at high updates rates up to 800Hz, can be used to derive velocities and spatial positions in 6DOF without any additional external inputs. Like GPS, IMU units have several sources of error. A brief overview is given in the following list (a more in-depth explanation of these errors can be found in an analog devices article https://www.analog.com/en/technical-articles/gyro-mechanical-performance.html):

- Drift errors: All sensors drift to some extent over time, both in static and dynamic conditions. These drift errors are generally referred to as Allen variance or deviations.

- Installation error: Incorrect installation and/or measurements of the IMU reference system relative to the aircraft coordinate reference system, referred to as the leverage arms, result in incorrect calculations of the test platform 6DOF data.
- Cross axis sensitivity: There will be some misalignment inside the device's sensors, which will mean a perfectly aligned device externally will need calibration or suffer some error
- Vibrations: Aircraft and missiles can experience a lot of vibration, and these misinterpreted accelerations need to be rejected

Since the IMU units essentially calculate positional and orientation information by calculating differences to a starting reference, errors accumulate and propagate over time and thus shorter durations of flight tests or in-flight recalibrations may be necessary for continued accurate readings. INS units, using a combination of GPS receivers and IMU, provide higher accuracy and at higher update rates, by using the lower update and relatively more accurate GPS receivers to provide the "truth" data on the platform position and the higher update rate IMU data to estimate the platform position and 6DOF data through data fusion/filtering techniques such as Kalman filters.

Practical Flight Test Requirements

As noted earlier, INSs have been around for a long time, and while the large 45 lbs device used on early USAF fighter jets was acceptable then, modern fighter aircraft and munitions have limited space available and try to keep system weight as low as possible. Modern INS use strap-down techniques of accelerometers, rate-sensors, and GPS to compute the TSPI solution to reduce size and weight. While such systems can require a lot of computing power, this has become a minor problem with the advancements in processors in recent years.

In addition to size, weight, and power (SWaP), it is important how a TSPI unit integrates with the rest of the data acquisition system and how data is telemetered to the ground, and/or stored for post-flight access. Both real-time and post-test data are required, and thus, the TSPI unit should be able to provide both. Real-time data, generally the TSPI and trajectory information needs to be formatted for transmission and easily readable by the onboard/ground station software for flight test point clearance and safety reasons. The limited RF downlink bandwidth and real-time processing of data in the ground station, during the flight test, place a premium on the most critical data to be quickly transmitted to the ground for decisions on safety and/or to repeat a test point.

Post-test data analysis, often correlated with external data sources like GPS references and radar data, provide higher fidelity of the flight test data by using the full INS dataset including accelerations and rate sensor measurements that were captured at high update rates. Thus, a TSPI unit used for flight test should be able to locally record a significantly larger amount of IMU data including all the GPS and IMU data, for post-test analysis.

Another consideration is how rugged and robust the unit is. Often in-flight test, electronics are subject to extreme environmental conditions, and thus, any system needs to work reliably across a range of temperatures and mechanical forces. Robustness is also vital as flight test campaigns are typically expensive and under tight timelines. Having to re-fly test points due to equipment not gathering data correctly can quickly throw off schedules and budgets.

Finally, as highlighted when discussing INS readings errors, installation and calibration are critical for accurate readings. Flight test engineers who are used to collecting measurands with great fidelity, may often have the necessary skills to accomplish this, but it would often be beneficial, if not necessary, to have TSPI experts who are familiar with the products to ensure that everything is aligned correctly. The programming software, and the calibration and setup procedures it supports, often play a huge role in ease of use and the correct installation and collection of TSPI data.

The MiTSPI Solution

Curtiss-Wright discovered the unmet need for a compact and accurate TSPI solution and developed the MiTSPI nTTU-2600 in response. The nTTU-2600 is a network tactical TSPI unit with an integrated recorder that is part of the MiTSPI product family. The unit provides user-selectable TSPI information for real-time telemetering via Ethernet and/or IRIG-106 Chapter 4 PCM (Clock and Data) and for simultaneous recording of data as IRIG-106 Chapter 10 for post-flight retrieval and analysis.

The nTTU-2600 comprises sub-systems/functional blocks for both acquisition and recording, as shown in Figure 2.

- MINS-600-1: The miniature INS (MINS) module interfaces with an external GPS antenna to receive the GPS signals and to process them for the “truth” data. In addition, the MINS includes a miniature IMU that also computes the 6DOF data. The MINS combines both the GPS and IMU data to estimate, using Kalman filters and with appropriate translations of the leverage arms data, the test platform’s TSPI and 6DOF data relative to its preferred datum, often the platform’s center of gravity (CoG).
- MREC-601-1: The miniature recorder module is used for recording the TSPI data provided from the MINS-600-1. The industrial-rated CompactFlash Express (CFexpress) memory card, available in 512 GB capacity, is accessible through a sealed, hinged door on the front of the MREC. The MREC is integrated into any MnACQ series data acquisition system via a dedicated high-speed (internal) connector that provides over 1 GB/s recording rate.
- MPPC-600-3: The processor module for the data acquisition system (DAS), performs the necessary overhead functions and processing the TSPI data for real-time telemetry and for recording locally.
- MACQ-600-1: The data acquisition module for the DAS provides the functionality to create IRIG-106 Chap. 4 PCM (Clock and Data) for real-time telemetry output as a RF down-link stream. In addition, the MACQ provides on the ETH ports the real-time multi-cast TSPI output in IRIG TmNS, Chap. 10, and DARv3 formats.
- MPFM-461/MPSM-2005-3: Power filtering and power supply module for the TSPI unit, accepting a MIL-STD-704F 28VDC prime power.

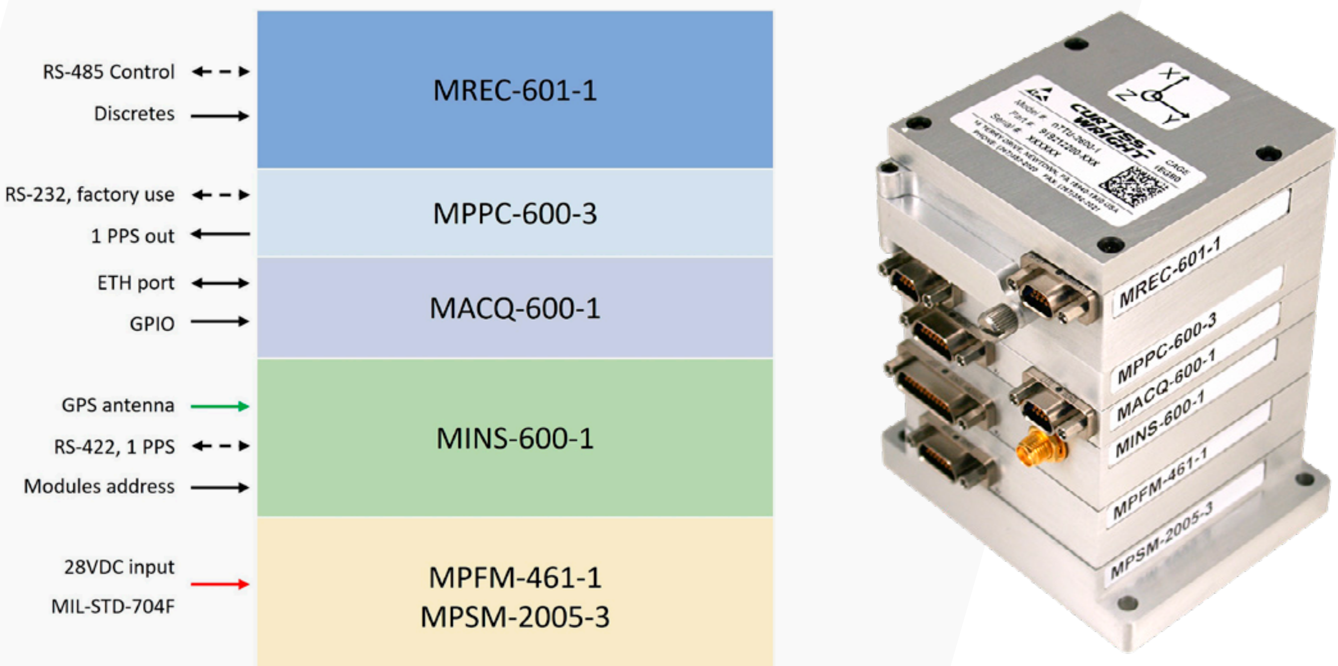

Figure 1: The functional blocks of the MiTSPI nTTU-2600

The nTTU-2600 can transmit real-time serial and Ethernet TSPI data at up to 20 Mbps. However, in almost all cases, the nominal rate is less than 2 Mbps based on the TSPI sensor data rates. The real-time serial and Ethernet multi-cast outputs can be configured to send user-selected navigation (fused) parameters/data such as TSPI in milliseconds or finer, position and position error in ECEF or NED formats, 6DOF data in ECEF or NED formats, accelerations and angular rates in body-frame references, and GPS statistics. Additional IMU data, e.g., delta velocity and delta angles for coning and sculling, quaternions, rotation matrix, and health status and GPS/GNSS data can be locally recorded for post-test analysis.

A calibrated and well-installed nTTU-2600 unit provides the following performance during GPS lock conditions:

- Heading (magnetometer only): 2.0° rms
- Heading (above 5.0 m/s, with GPS lock): <0.1° rms
- Pitch (static): < 0.08° rms
- Pitch (dynamic): <0.03° rms
- Roll (static): <0.08° rms
- Roll (dynamic): <0.03° rms
- Horizontal Position: < 1.0-m, rms (0.01-m with RTK)
- Vertical Position: < 1.5-m, rms (0.01-m with RTK)
- Velocity accuracy: <0.02 m/s
- TSPI update rate: Up to 400 Hz

Curtiss-Wright has a long history of producing rugged systems, and the MiTSPI range has been qualified to the following to ensure reliable performance:

- Operating temperature: -40 to 85°C (storage: -55 to 100°C)
- Random vibration: 15 grms, 20 to 2,000 Hz, 10 minutes
- Acceleration: 25g, indefinite duration, any axis
- Shock: 15g, half-sine, 11 mS, 6 shocks, any axis
- Humidity: 5-95% RH, non-condensing
- Altitude: 0 to 70,000 ft
- EMI : shall meet MIL-STD-461G

Summary

Accurate position and orientation information is a valuable addition to the typical sensor and bus flight test data. Modern, compact solutions utilizing the latest IMU and recording technology can provide the data in a practical form. By ensuring the electronics and package are robust and can integrate easily with existing data acquisition, telemetry, and software solutions, it is possible to deploy a TSPI system alongside flight test instrumentation to enhance the value of the test data.

The flight test data when aligned with contemporaneous TSPI data, provides greater understanding and fidelity to the test platform dynamics and performances during maneuvers, especially if the data is acquired from a small SWaP TSPI like the nTTU-2600 that can be mounted close to the platform center of gravity of fighter aircraft and missile systems.

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Learn More

- MiTSPI nTTU-2600 Product Sheet MiTSPI nTTU-2600 (curtisswrightds.com)
- Flight test applications Flight Test Instrumentation | Flight Test Equipment (curtisswrightds.com)
- Rugged Instrumentation System Solutions for Applications with Limited Space https://www.curtisswrightds.com/infocenter/white-papers/rugged-instrumentation-system-solutions-applications-limited-space.html