2. Aviation & Aerospace

Overview

GPS provides the essential/fundamental infrastructure for real-time navigation of all types of aircraft from drones to commercial and military aircraft. Augmented by space and ground based systems, GPS supports all phases of flight including taxi, takeoff, climb, cruise, descent, approach and landing in all weather conditions. Responding to a wide variety of operational benefits, aircraft fleets have embraced satellite-based navigation. Specifically, every aircraft built from Boeing and Airbus since the late 1990s carries GPS. As an example, the Boeing 777 shown in Fig. 2.1 carries GPS receivers and the position information obtained by those receivers is used by many systems on the aircraft for safety-related functions. These systems include: the flight management system (FMS) for basic navigation, the Enhanced Ground Proximity Warning System (EGPWS) to prevent controlled flight into terrain accidents, and the ATC Transponder to support Automatic Dependent Surveillance-Broadcast (ADS-B) surveillance of the aircraft by Air Traffic Control (ATC), as well as other systems. Virtually all commercial transport aircraft, including business jets, carry GPS.

Fig. 2.1: Flight Deck of the Boeing 777[3]

General Aviation (GA) also makes good use of GPS. GA is the term for all civil aviation operations other than scheduled air services. It also excludes any non-scheduled air transport operations for hire. GA flights range from gliders to corporate business jet flights. The FAA estimates that there are 200,000 aircraft in the U.S., and Garmin Inc. asserts that almost all of them carry GPS of some sort.

Space missions, including human spaceflight and operational satellites, make widespread use of GPS for onboard positioning and timing. The new Low Earth Orbit (LEO) constellations, designed for worldwide internet and weather, will increase this reliance on GPS. Launch vehicles rely on GPS integrated with inertial and other sensors to support all mission phases. GPS measurements from orbiting satellites provide critical data for weather prediction, scientific analysis of global water distribution, and space weather. In addition, space borne GPS enables surveillance of the ground based on so-called synthetic aperture radar. Fig. 2.2 depicts this application, where GPS registers images take along the spacecraft arc. With GPS relative positioning of these images, a very sharp ground image can be formed.

Aviation and aerospace applications require aggressive protection of the GPS spectrum to ensure future use and will benefit substantially from multi-GNSS implementations and modernization/advancements in signals and coverage. Specifically, strong terrestrial radio transmissions in or adjacent to the GPS spectrum constitute a direct threat to the continuity of aviation operations.

[3] Picture courtesy of The Boeing Company

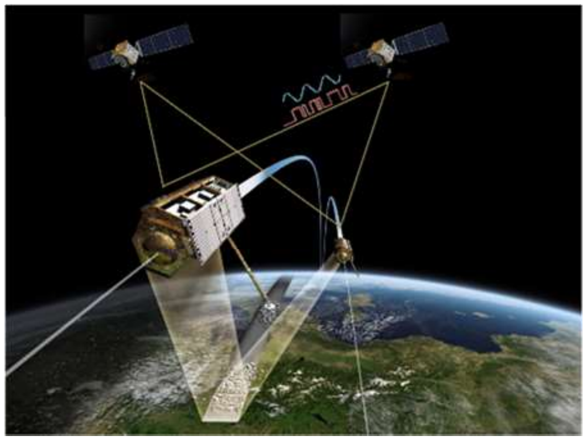

Fig. 2.2: GPS enables space borne imaging of the Earth's surface using synthetic aperture radar[4]

Utilization and Benefits

Current and future aviation and aerospace operations are dependent on reliable, accurate PNT information. GPS with ground and space-based augmentations provides this securely and accurately. Examples include:

- The use of GPS makes the airspace more efficient, provides fuel cost savings and enables adaptation to bad weather
- Aircraft navigation and guidance in all phases of flight including precision approach and landing
- Aircraft surveillance by air traffic controllers increasingly depends on GPS, and improves safety
- GPS is used in terrain awareness and warning systems (TAWS), which has had the single greatest impact to improving U.S. commercial aviation safety in the last 20 years
- Aircraft tracking based on GPS would enhance search and rescue operations globally (e.g. Malaysia Airlines MH370).
- Integration of drones into the national airspace
- Satellite operations including the International Space Station (ISS) and commercial human spaceflight
- Navigation and time for the upcoming large constellations of LEO satellites for communications
- GPS Radio Occultation (GPS-RO) for remote sensing and prediction of atmospheric and space weather
- Integrated GPS with inertial sensors for all phases of reusable launch vehicle flight

Threats

The threats to GPS continue to evolve, increase and proliferate. The availability of systems to interfere with or deny GPS has dramatically increased over the last decade, and the competition for spectrum across a broad range of users places additional pressure on the clear use of the GPS frequencies.

Cyber-attack threats are real and growing. Specifically, technologies are available for intentional Jamming (blocking the GPS signal) and spoofing (providing false signals to GPS receivers). Protecting GPS users is essential. In addition, the ground based reference receivers used by GBAS and SBAS ground stations must also be protected from physical and cyber threats.

In addition, inadvertent radio frequency interference can impact users on the ground, in flight and in space. Other radio services seek to utilize frequencies very close to GPS operating frequencies, placing clear reception of the GPS signal at risk.

The FAA formed a GNSS Intentional Interference and Spoofing Study Team to develop requirements and a set of acceptable techniques to mitigate cyber threats to aviation. They have begun to work with RTCA (Radio Technical Commission for Aeronautics) on the implementation of these techniques.

Recommended Actions

<u>GPS Space Segment</u>:

The Space Segment currently consists of approximately 30 operational satellites with differing configurations, up through GPS Block IIF. These satellites transmit both military and civil signals, supporting military operations in threat environments, and supporting commercial/civil/aviation utilization. GPS Block III is the next generation of satellites, currently in production. The following actions are recommended:

[4] Picture courtesy of Professor Simone D'Amico, Stanford University

- Continue to support the deployment and improvement of four signals for civil users. These four signals are designated L1 C/A, L2C, L5 and L1C
- Implement space service volume signal coverage requirements to support high altitude satellite users
- Ensure stability of satellite clocks to support carrier phase tracking for aircraft navigation integrity and scientific applications
- Manage satellite power to sustain or improve robustness in challenging environments and against threats
- Continue to maintain a constellation of approximately 30 operational satellites whenever possible to ensure maximum availability and continuity of service

GPS Ground Segment:

The ground segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current operational control segment includes a master control station, an alternate master control station, 11 command and control antennas, and 15 monitoring sites. OCX is essential to fully utilizing GPS system capabilities. It provides the following key enhancements:

- The new Kalman filter that is at the heart of the GPS OCX navigation solution will double the accuracy of the signal in space
- GPS OCX will allow control of more satellites, providing better geometry in hard-to-reach areas such as urban canyons and mountainous terrain
- All critical OCX external interfaces will employ digital signatures, protecting information from cyber threats so users can trust it

The following actions are recommended:

- Upgrade Interim Ground Segment to control GPS III satellites and enable monitoring of GPS Civil Signals—required to bridge between current Control Segment and OCX
- Reflect improvements in accuracy of the reported URA data broadcast by the satellites
- Maintain utilization of NGA monitor stations to enhance signal status information and investigate use of other worldwide monitoring capabilities to enhance robustness of signal information
- With multiple satnav systems operating, relying solely on GPS is an anachronism; use of reliably operating foreign satnav systems should be permitted along with GPS, without requirements for licensing
- Add monitoring of other GNSS (e.g. Galileo) signals at GPS monitoring sites to enhance solution integrity for aviation and space users
- Support advancement of civil ground system to support GBAS and SBAS systems such as the FAA's WAAS. For example, continue to prioritize the inclusion of L5 (GPS safety-of-life signal for aviation) in SBAS and GBAS
- Continue/increase U.S. technical and scientific leadership in international GNSS monitoring, data analysis, product generation and dissemination

Aviation and Space Receivers:

The following actions are recommended:

- Improve requirements/capabilities of aviation receivers to enhance, among other things, RAIM, as well as robustness to interference and spoofing
- Resolve both technical and institutional/political issues related to use of non-U.S. GNSS for aviation
- Enhance U.S. competitiveness by reducing export control barriers for space borne GPS receiver manufacturers and technologies that enhance receiver resistance to jamming and spoofing

Summary

- Continued use of a solid GPS is critical for current and future aviation and space operations
- No other system provides comparable coverage, ease of access, reliability and performance
- It is essential to support on-going modernization of Space, Ground and User Segments to ensure leading edge capabilities for U.S. national security and commercial interests
- The Department of Defense (DoD) and Air Force have been excellent stewards of GPS capability and continue to provide additional civil/commercial signals and capability to enhance this global utility