POSITIONING, *Navigation* AND TIMING

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The risk of insufficient GPS satellites is practically negligible in 2009–2015, the U.S. Air Force says, despite auditor concerns about civil air transport.

Reassurances by the U.S. Air Force in early May — a few days after the U.S. Government Accountability Office (GAO) reported on risks of delayed satellite replenishment in the global positioning system (GPS) — aimed to minimize system-user doubt arising from the report's warning of potential future problems in infrastructure critical to civil aviation. The GAO report essentially questioned whether the Air Force program to replace worn-out GPS satellites will move quickly enough to sustain today's higher-than-required level of positioning, navigation and timing (PNT) services, which air carriers and other aviation operators expect to nearly always be available.[1,2]

"It is uncertain whether the Air Force will be able to acquire new satellites in time to maintain current GPS service without interruption," the report said. "If not, some military operations and some civilian users could be adversely affected. … This would not only have implications for military users but also for the larger community of GPS users, who may be less aware and equipped to deal with gaps in coverage. … It is unclear whether the user community knows enough about the potential problem to do something about it."

Aviation professionals were reminded why precise, stable and reliable PNT services at all times from the nominal GPS constellation — that is, a healthy satellite in each of 24 primary slots making a 12-hour orbit at an altitude of 20,182 km (10,897 nm) — should not be taken for granted while the current upgrade program continues through 2023. Few of the GAO report's findings were disputed by the U.S. Department of Defense (DoD), but the interpretation of forecasts and their significance remained points of disagreement. The findings tend to be magnified by increasing U.S. public awareness of and political sensitivity to the Next

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U.S. Air Force (Photo: Carlton Bailie, United Launch Alliance)

The first GPS block IIF satellite, to the lower right in the illustration, in late 2009 will replace older generations that often operate for twice their design life. Above, a Delta II rocket boosts a GPS block IIR-M satellite into orbit.

Generation Air Transportation System's (NextGen's) dependence on infrastructure enabled by GPS to deliver promised levels of airline safety and efficiency.

By GAO calculations, a two-year delay in the production and launch of the first GPS III–generation satellites in 2014 probably would reduce the current GPS II constellation to fewer than 24 satellites for five years and reduce the probability of providing 24 healthy satellites to less than 95 percent for 12 years. "The delay in GPS III would reduce the probability of maintaining a 21-satellite constellation to between 50 and 80 percent for the period from fiscal year 2018 through fiscal year 2020," the report said. "Moreover, while the probability of maintaining an 18-satellite constellation would remain relatively high, it would still fall below 95 percent for about a year over this period."

Also magnifying the findings was the June 16 Air Force announcement of an extended early orbit checkout procedure for a GPS block IIR-M satellite launched about three months earlier. Ground monitoring stations detected signal distortions, and specialists continued investigating their cause and effects during the checkout. The satellite notably carries a demonstration transmitter for testing the new L5 signal scheduled to be available from every GPS block IIF and subsequent satellite launched from late 2009 onward. The satellite's interface to the transmitter — not the transmitter's underlying technology — appeared to be the source of the problem, the Air Force said, and the satellite was expected to be switched to healthy status for global use around October 2009.

These issues come in the wake of several technical studies about five years ago that have helped the commercial air transport industry prepare for loss of GPS service integrity due to momentary, serious or severe disruptions/outages — ranging from the Air Force temporarily taking a faulty satellite off-line for maintenance to intentional signal jamming. Extensive recommendations have been published on flight crew and air traffic control (ATC) procedures and training; preflight use of publicly accessible GPS outage-prediction/reporting systems, including GPS/wide area augmentation system (WAAS) notices to airmen in the United States; external monitoring and on-board receiver autonomous integrity monitoring; immediate alerts to pilots when navigation anomalies are detected; GPS backup by an inertial reference unit–flight management computer updated by distance measuring equipment; use of raw data from navigation aids on the ground; ATC radar vectors; and redundancy afforded by GPS augmentation systems. Such anticipation prepares flight crews and ATC to assess the relative severity of any GPS service loss and its safety implications, and to act appropriately to protect their operations.[3]

GAO auditors studied the continuing transition from GPS II — in which the final replacements launched in 2009–2013 will have block IIR-M or the newer block IIF levels of technology (Table 1, p. 14) — and GPS III, for which the first satellites will have the block IIIA level of technology. The transition gradually will add several signals that upgrade performance, accuracy and integrity, and provide stronger defenses against jamming of military and civil GPS signals.

U.S. policy-makers and the Air Force responded to the resulting public concerns: "The U.S. Air Force launches additional satellites that function as active spares to accommodate periodic satellite maintenance downtime and assure the availability of at least 24 operating satellites," said the Space-based Positioning, Navigation and Timing National Executive Committee, the federal inter-departmental organization that sets national policy for GPS. "As of May 27, 2009, there were 34 satellites in the GPS constellation, with 30 set [by the Air Force as] 'healthy' to users."[4]

Air Force Reassurance

In late May, the Air Force stressed that the timely replenishment issue has received high priority. The Air Force Space Command "acknowledged the potential for an availability gap years ago, and has actively pursued and institutionalized procedures and processes to mitigate the potential gap

GPS Satellite Modernization

Legacy generation, 1989–2002	Current generation, 2005–2012		Future generation, 2014-2023
GPS IIA/IIR satellites	GPS IIR-M satellites	GPS IIF satellites	GPS III satellites
This generation of satellites had broadcast one encrypted signal for military users and one free non-encrypted signal (L1) for civil users.	The last of these eight satellites include IIA and IIR capabilities and, by the end of 2009, will have added to the GPS II constellation: • a second civil signal (L2C); • a second military signal; and, • the ability to increase signal power to improve resistance to jamming.	When launched beginning in late 2009, these 12 satellites will include IIR-M capabilities and add a third civil signal (L5) meeting enhanced requirements for transportation safety-of-life and integrity.	When launched in 2014, these satellites will include IIF capabilities and add: • in Block IIIA, a stronger military signal to improve jamming resistance and a fourth civil signal (L1C) that is interoperable with non-U.S. signals, such as Europe's Galileo satellite constellation; • in block IIIB, near real-time military command and control via cross links; and, • in block IIIC, improved anti-jam performance for military users.

GPS = global positioning system

Note: This table omits corresponding modernization stages of the GPS ground control segment. As of September 2008, the U.S. government had committed to furnishing civil users worldwide a free standard positioning service based on 24 primary slots with signal in space performance measurable as 95 percent or higher probability of 24 healthy satellites, 98 percent or higher probability of 21 healthy satellites and 99.999 percent probability of 20 healthy satellites.

Sources: U.S. Government Accountability Office; U.S. Space-based Positioning, Navigation and Timing National Executive Committee

Table 1

or minimize any impact," the Air Force said.[5] These processes were designed to "extend the life of on-orbit assets and to ensure GPS capability is delivered in a timely manner," according to Lt. Gen. Tom Sheridan, commander of the Space and Missile Systems Center, the acquisitions arm for the space command. "New acquisition approaches, including phased acquisition and prototyping, will reduce risk to constellation sustainment in the future," he said.

The Air Force noted that the seventh of eight block IIR-M GPS satellites was launched in March 2009, and that the space command expects to launch the last of that series in August 2009. Around the same time, early in fiscal year 2010, the space command has scheduled the launch of the first of 12 block IIF satellites.

The Air Force also sought to reassure civilian GPS users that all PNT services would be treated as a critical component of national infrastructure. "I have high confidence we will continue to sustain at least the 24 satellites required to maintain our current performance standard," said Gen. C. Robert Kehler, commander, Air Force Space Command. "The Air Force has been a good GPS steward continually providing 'better than expected' service to our GPS users. At this point, we foresee no significant loss of service in the future, near or far."

The GAO report acknowledged similar views conveyed by the Air Force and the acceptable status so far of GPS III development work. "At present, the GPS IIIA program is on schedule and program officials contend that there is no reason to assume that a delay is likely to occur," the report said. "They point out that the Air Force is implementing an incremental development approach and GPS IIIA, the first increment of GPS III, is not expected to be as technically challenging as other space programs."[6]

Problems keeping on schedule in manufacturing satellites have included changes of contractors and, on the military side, technical difficulties with block IIF, the report said. All satellites since December 2006 have been launched by United Launch Alliance, a joint venture combining the Delta and Atlas rocket programs of Boeing and Lockheed Martin, respectively; capacity to launch satellites was not an issue in the report. Assuming that the IIF program meets the current schedule, however, launch of the first satellite in that series will be three years behind schedule. Another principal concern was that plans for GPS IIIA call for a launch rate three times faster than was used for GPS IIR-M.

Some GPS IIF satellite-production delays were attributable to unsuccessful Air Force contracting reform efforts, technical problems, parts obsolescence and inefficiencies detailed in the report. Another problem cited was adding

requirements — specifically, new military and civil signals, and flexible power capabilities — necessitating satellite design changes after the contractor had begun its work. "Procurement of additional GPS IIF satellites does not appear to be feasible" if significant satellite-replenishment delays actually occur, the report added.

Related concerns were the nine-month delay initiating GPS IIIA satellite acquisition, in May 2008, and reallocation of funding from the GPS IIIA program to other military uses. "GAO's analysis found that [the GPS III] schedule is optimistic, given the program's late start, past trends in space acquisitions and challenges facing the new contractor," the report said.

Unclear Potential Effects

Because civil aviation operations under instrument flight rules generally require augmented GPS signals, solutions to hypothetical GPS coverage gaps already may exist for some operators, depending on the avionics carried and other factors. "For example, many applications using augmentations such as satellite-based augmentation systems (SBAS), which in the United States is [WAAS], have increased tolerance to degraded accuracy and availability when the constellation may be operating at minimum committed levels of availability," the report said. "While a smaller GPS constellation could result in a significant reduction in positioning and navigation accuracy at certain times and locations, these times and locations are usually predictable in near-real time." In other cases, "intercontinental commercial flights use predicted satellite geometry over their planned navigation route, and may have to delay, cancel or reroute flights," the report added. "Because there are currently 31 [now 34] operational GPS satellites of various blocks, the near-term probability of maintaining a constellation of at least 24 operational satellites remains well above 95 percent."

The report encouraged system-user attention to these issues while identification of potential effects on civil aviation continues this year. "The impacts to both military and civil users of a smaller constellation are difficult to precisely predict," the report said. "For example, a nominal 24-satellite constellation with 21 of its satellites broadcasting a healthy standard positioning service signal would continue to satisfy the availability standard for good user-to-constellation geometry articulated in the standard positioning service performance standard. … In general, users with more demanding requirements for precise location solutions will likely be more impacted than other users."

Looking at worst-cases scenarios, GAO auditors were advised by Air Force specialists that another possible step would be to actively manage satellite systems, shutting down some subsystems to prolong the serviceability of others when aging solar-panel arrays no longer can produce adequate electrical power.

Actions So Far

A key GAO recommendation was that the U.S. defense secretary "appoint a single authority to oversee the development of the GPS system, including DoD space, ground control and user equipment assets, to ensure that the program is well executed and resourced and that potential disruptions are minimized." The DoD concurred and explained how this change has been implemented.

The Air Force said in the report that corrective measures have been implemented in the block IIF program: "Using incremental or block development, where the program would follow an evolutionary path toward meeting

U.S. Federal Aviation Administration

In March 2009, the U.S. Air Force tested transmission of the new L5 signal from a GPS block IIR-M satellite, illustrated above. Below, USAF Tech. Sgt. Randall Thomas, right, of the 1st Space Launch Squadron, monitors pre-launch mating of the actual satellite to the Delta II rocket.

U.S. Air Force

needs rather than attempting to satisfy all needs in a single step; using military standards for satellite quality; conducting multiple design reviews, with the contractor being held to military standards and deliverables during each review; exercising more government oversight and interaction with the contractor and spending more time at the contractor's site; and using an improved risk management process, where the government is an integral part of the process."

To prevent similar problems in the block IIIA program, the Air Force said in the report that measures would include "re-evaluating the contractor incentive/award fee approach; providing a commitment from the Air Force to fully fund GPS IIIA in Program Objectives Memorandum 2010; funding and executing recommended mitigation measures to address the next-generation operational control segment and the GPS IIIA satellites; combining the existing and new ground control segment levels of effort into a single level of effort, giving the Air Force greater flexibility to manage these efforts; not allowing the program manager to adjust the GPS IIIA program scope to meet increased or accelerated technical specifications, system requirements or system performance; and conducting an independent technology readiness assessment of the contractor design once the preliminary design review is complete."

Mutual Support

Although the United States seeks to remain the leading provider of global navigation satellite services,[7] interoperability with new counterparts under development in Europe and Asia will be important from the standpoint of international relations and redundancy of some signals. "For civil and commercial users, one possible impact of a smaller GPS constellation could be an increased use of other PNT services, including those expected to be offered through Europe's Galileo system by the middle of the next decade," the report said.

However, the U.S. Department of State voiced its own concerns about insufficient U.S. technical experts assigned to activities to promote compatibility and interoperability of PNT systems under cooperative arrangements with Australia's ground-based regional augmentation system and ground-based augmentation system; India's GPS-aided and GEO-augmented navigation (GAGAN); Japan's multi-functional transport satellite–based satellite augmentation system (MSAS) and quasi-zenith satellite system (QZSS); and Russia's global navigation satellite system (GLONASS). The only legally binding executive agreement to date covers joint work with the European Union's Galileo program.[8]

"Without these resources, officials are concerned that it may be difficult to continue to ensure the compatibility and interoperability of [non-U.S.] systems," the report said. "It takes [U.S.] industry 18 to 24 months to develop a market-ready [Galileo] receiver, and the first operational Galileo satellite is scheduled for launch in 2010."

Notes

1. GAO. "Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities." Report to the Subcommittee on National Security and Foreign Affairs, Committee on Oversight and Government Reform, House of Representatives. Report no. GAO-09-325. April 30, 2009.
2. Chaplain, Cristina T. "Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities." Testimony before the Subcommittee on National Security and Foreign Affairs, Committee on Oversight and Government Reform, House of Representatives. GAO. Report no. GAO-09-670T. May 7, 2009.
3. FSF Editorial Staff. "Vulnerabilities Warrant Attention as Satellite-based Navigation Grows." *Flight Safety Digest* Volume 23 (December 2004).
4. U.S. National Executive Committee for Space-based Positioning, Navigation and Timing. "Frequently Asked Questions." <pnt.gov/public/fq.shtml>. June 2009.
5. U.S. Air Force. "AFSPC Exceeds Global Positioning System (GPS) Standard." News release by Air Force Space Command, Peterson Air Force Base, Colorado. Release no. 050509, May 22, 2009. <www.afspc.af.mil/news/story.asp?id=123150739>
6. The incremental approach emphasizes on-schedule performance through strategies that would include postponing work on some block IIIA GPS civil subsystems, including the distress alerting satellite system (DASS) payload, already delayed more than five years. DASS will be used to receive emergency locater beacon signals identifying the precise position of an aircraft, ship, vehicle or person in distress for immediate use by rescue coordination centers worldwide.
7. The Office of Space and Advanced Technology (OES/SAT) of the U.S. Department of State said, "Currently, OES/SAT is coordinating a broad diplomatic effort to encourage acceptance of [GPS] as a worldwide standard for satellite-based navigation." <www.state.gov/g/oes/sat> June 2009.
8. Although not mentioned in the GAO report, China has begun to build — based on its three-satellite COMPASS/Beidou Navigation Test System — a new constellation and ground control segment with global coverage, according to the United Nations International Committee on Global Navigation Satellite Systems <www.unoosa.org/oosa/SAP/gnss/icg/providers-forum.html>.